RCA Engineer

Vol 18 | No. 6
April | May
1973

Automotive electronics

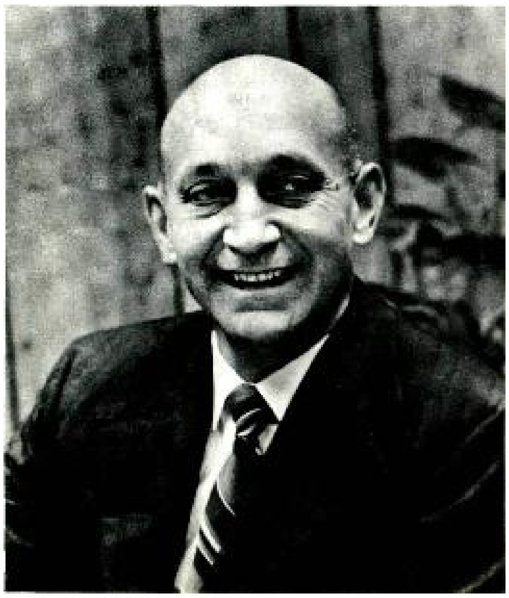
During the past several years, product design and applications engineers in the solid-state field have been devoting extensive effort to the unique requirements of automotive electronics. Solid state devices have been used for many years in automotive entertainment electronics equipment from the a.m. radio through the rather complex a.m.-fm stereo radio with tape deck.

The applications horizons today, however, are much broader for automotive electronics. Within the next three years, solid-state electronics will play an important role in response to various federal safety and pollution requirements. Included among these are "lap and shoulder belt protection system with ignition-system and belt warning", effective in August 1973, emission control via the "clean air act amendments" of 1970 with progressively tightening specifications through 1976 model years, and adaptive braking required for certain classes of vehicles effective in September 1974.

Included among the devices from the solid-state industry are sensors for temperature, pressure, and air and fuel flow, complex linear integrated circuits to amplify and condition signals from these low level sensors, COS/MOS IC's to drive activators as a function of the sensor inputs. We can realistically expect to sell up to 31 million of these devices in the automotive market in 1973.

A price-sensitive market such as the automotive industry demands the utmost skill in effective engineering. In automotive applications we have a combination of the most difficult engineering compromises required. Low cost, hostile temperature environment, severe power supply transients, and near space-age reliability together impose a most severe test for the solid-state industry.

Some of the papers in this issue address this problem. Before the automotive industry totally accepts the solid-state industry as a responsible participant, extensive additional effort in product design and reliability is required for full participation in the fastest growing segment of solid-state electronics.



B.V. Vonderschmitt

Bernard V. Vonderschmitt
Vice President and General Manager
Solid State Division
Somerville, New Jersey

Our cover

. . . is a kaleidoscopic look at the transportation industry. Interspersed throughout this montage of tickets, maps, and travel cards are photos of actual RCA products, described in this issue. On the front cover (clockwise from far left) are a Doppler radar described by Presser and Johnson (p.62); a device used in transistorized ignition systems described by Vara and Bennett (p. 50); and a Tactec terminal covered by Mitchell (p. 16). On the back cover are an airborne radar described by Lucchi (p. 28) and part of a microwave signalling system described by Kaplan and Schiff (p. 42). **Cover design;** J P. Dunn.

Vol. 18, No. 6
April/May
1973

RCA Engineer

A technical journal published by
RCA Research and Engineering
Cherry Hill, N.J.

RCA Engineer articles are indexed annually in the April-May Issue and in the *Index to RCA Technical Papers*.

• To disseminate to RCA engineers technical information of professional value • To publish in an appropriate manner important technical developments at RCA, and the role of the engineer • To serve as a medium of interchange of technical information between various groups at RCA • To create a community of engineering interest within the company by stressing the interrelated nature of all technical contributions • To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field • To provide a convenient means by which the RCA engineer may review his professional work before associates and engineering management • To announce outstanding and unusual achievements of RCA engineers in a manner most likely to enhance their prestige and professional status.

Contents

Theme — transportation

editorial input

electronics on the move

Despite the obvious drawbacks of the automobile, any examination of electronics in the transportation industry must start with this dominant mode of transportation. Most projections show the automotive electronics market to rival the massive communication and computer markets by 1980. Stanford Research Institute, for example, estimates that the present $300 million automotive electronic market will multiply more than five times by 1980. An Arthur D. Little study estimates that the U.S. consumption of automotive electronics averaged $35 per car in 1971, and that this should double by 1976, and reach $100 per car by 1980. Based on these figures, and the estimated number of domestically manufactured cars, the total automotive electronics market may top $1.3 billion by 1980.

The products themselves range from entertainment packages to performance and safety enhancements; several that are on the horizon for the near future are mentioned by Bernie Vonderschmitt in his "inside cover message".

Optimism over this burgeoning market, however, must be tempered by a clear understanding of the automotive industry — its limitations, methods, motives, and structure.

Parts are not accepted until proven under actual driving conditions and over great lengths of time. Vendors are not accepted until they can demonstrate their ability to manufacture reliable products at automobile-production-line rates. Therefore, electronic components will not be "snapped up" by automobile manufacturers to replace proven electromechanical or mechanical parts. As in the medical field, anything new must first provide a clear advantage, *and* it must fit into the production, market, and service patterns of the industry.

Meyers (p.3) provides a good insight into automotive industry thinking in his review of electronic ignition systems: the main impetus for the switch to electronic ignition was not the improvement in performance offered but the tightening of emission standards and service requirements.

But, despite the auto industry's conservative — and highly successful — business philosophy, RCA has made good market penetration. One of the Solid State Division's most successful automotive products has been, and should continue to be the power transistor (see Bennett and Vara, p. 50).

RCA is also making further penetration in the established mobile communications market with the new Tactec radio (see Mitchell, p. 16) and with several solid-state components for mobile radio (see Kamnitsis, Maximow, and O'Moleski, p. 66).

A look to a possible future role for automotive electronics is provided by Dr. Clorfeine (p. 7) who proposes a wide-ranging driver-alert-and-inhibition system as a basis for further planning and discussion.

Some of the devices and systems that may eventually find their way into electronically controlled driving are described by Kaplan and Schiff (p. 42), Shefer and Klensch (p. 54), Johnson and Presser (p. 62) and Schiff and Staras (p. 72).

Switching from the automotive scene to the shipping industry, Mr. Jellinek (p. 37) proposes a system for identifying and controlling harbor traffic — a problem that bears on pollution control as well as maritime safety and efficiency.

In airborne electronics, RCA has, over the past decade, established a solid product base in the commercial avionics field; Lucchi (p. 28) surveys the frequency spectrums used by present airborne communication and navigation systems and discusses some of the problems of designing equipment within these spectrums. Of course, one of the most persistent problems plaguing air travel has been the mid-air collision; J.L. Parsons describes one proposed system — SECANT — which is a cooperative, transponding collision-avoidance system, designed to be compatible with the entire aviation community.

Within the next ten years, synchronous satellites will play a dominant role in air and sea navigation by providing communication, navigation, and surveillance services for civilian ships and aircraft (see Miller, p. 32).

RCA has been a strong contributor to the electronic communication revolution which has brought peoples of the world closer together by allowing them to deliver their voices and pictures to one another practically instantaneously. It is interesting to speculate what might happen when the same creative genius is fully applied to the problems of transporting the people themselves, their goods, and their services throughout the world — safely and efficiently.

The papers in this issue are proof that the thinking processes have started.

— J.C.P.

Future issues

The next issue, the eighteenth anniversary of the *RCA Engineer*, will contain representative papers from most areas of RCA. Some of the topics to be covered are:

Linear integrated circuits
Ultrasonic holography
Spacecraft dynamics
Binary PSK modems
Miniature color tv cameras
Electroless plating
Four-channel sound
Computer security management
Unmanned spacecraft design
Popcorn noise in Op Amps
Computer terminals

Discussions of the following themes are planned for future issues:

Global communication
Broadband information systems
SelectaVision systems
Communications, command, control
RCA, Ltd. engineering
Consumer electronics

The Engineer and the Corporation

Electronic ignition comes of age

R. S. Myers

In the last ten years, automobile ignition systems have become more reliable and less costly. However, the primary reasons these systems have been adopted in recent years are the tightening of emission standards and increased service requirements. This paper examines the automotive industry's attitudes toward such systems and compares them with the prevailing attitudes in the electronics industry.

ELECTRONIC IGNITION systems have been available for more than a decade; their advantages are well known. The use of a transistor between the points and the ignition coil eliminates arcing and burning of the points and increases point life. Once point life is not a problem, the coil current and, hence, the spark energy can be raised for better fuel consumption and smoother engine running. In addition, if the coil inductance is lowered and more current used, the spark energy can be improved, perhaps 3:1 at 3,000 r/min. The more elaborate capacitive discharge ignition can make further improvement; it can reduce the current consumption, improve performance at high engine speed still further, and fire fouled plugs by virtue of its faster-rising output voltage

Many small and some large firms in the electronics industry have designed, marketed, and sold limited quantities of such systems; most hoped to ultimately sell theirs to the automobile manufacturers. Numerous individuals built and installed their own systems, and reported fewer tune-ups, better gas mileage, smoother running engines, and more power. However, although the automobile manufacturers designed some circuits themselves[1] and offered them for very limited specialty uses, they did not begin to offer electronic ignition systems to any great extent until very recently.

There are several very valid reasons for this apparent lag between availability and application, and they are the subject of this paper. The reasons are simple, but, because they stem from fundamentally different operating philosophies, they will not be obvious to an electronics oriented person, as the reader of this magazine is assumed to be. The reader is asked, then, to think automotive and not electronics. This is difficult because automotive and electronics manufacturing are so completely different; it will be beneficial, then, to an understanding of the story of the development of the electronic ignition, to examine and compare these differences.

Industry differences

Table I summarizes and compares the differences between the automotive and electronics industries. Perhaps the most striking difference highlighted by Table I is that of how each industry views standard and custom parts. The electronics industry is built on the concept of assembling standard parts—parts designed and made for general sales and used in many types of equipment by numerous companies. Major electronics equipment, such as computers, tv's, radios, test equipment, etc. are assemblies of standard switches, meters, relays, semiconductors, and standard resistors of standard values — all available from catalogues. Those few parts that must be custom made, such as the chassis, printed-circuit boards, and some hardware, are minimized because they are relatively expensive and require capital for tooling.

In a diametrically opposite practice, automobiles are built primarily from custom parts. Such parts as engines, seats, body panels, windows, brakes, tire rims, distributors, carburetors, etc. are custom made and available from only one supplier; even parts of the electrical system are custom made.

A few of the approximately 4,000 parts in a car are standard; these are generally

Richard Myers, Applications Engineering, Solid State Division, Somerville, N.J., received the BSEE from Drexel University in 1962. He joined RCA as a co-op student in 1958. He has been a transistor applications engineer for the past ten years, and has contributed substantially to the success of practical automotive electronic-ignition systems. Presently, he is responsible for applications engineering on high-voltage power transistors for industrial markets.

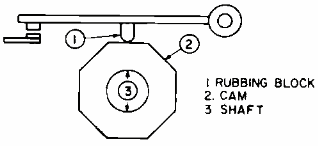
Reprint RE-18-6-31 (ST-6133)
Final manuscript received March 13, 1973.

parts that must be replaced as they wear out. The automobile manufacturer usually obtains even these parts from a single manufacturer.

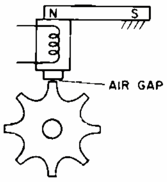
The automotive industry's products, then, are built around custom parts, while the electronics industry's are built around standard parts; it is only natural, therefore, that their problems and operating methods must be different.

The operating methods of the automotive industry are directed toward solving the two primary problems associated with custom parts: unproven manufacturability and unproven reliability. Manufacturability — actual parts costs, tolerances, on-time delivery of parts manufactured in great volume — can only be proven by actual experience. Therefore, those parts and vendors used in the past have a great advantage over any new parts or vendor. New vendors who have no guarantee of a sale cannot afford to invest the capital required to make a competitive automotive part nor to make sufficient quantities of the part to demonstrate the ability to deliver. The importance of reliability is understandable when one realizes the enormous costs of an error. Consider the expense of automobile recalls compared with the relatively minor changes which cause them.

Reliability of the parts used in the varied environments found in an automobile is best proven by actual use on many cars. The laboratory testing method has a poor record for predicting automotive reliability. Therefore, again, those parts and vendors used in the past have an overwhelming advantage over any new design or any new vendor. In both instances—manufacturability and reliability—there is confidence in the established vendor. His problems are known and can be worked out. A new vendor represents many unknowns and potentially large problems.



(a) POINTS



(b) MAGNETIC PICKUP

Fig. 1 — (a) Standard ignition timing system, (b) magnetic pickup timing system.

This single-vendor situation has a profound influence on the purpose and content of the specifications used by the automobile manufacturer. Often the specification merely describes the part which is known to work. It becomes a restrictive document which defines a certain part which can only be made a certain way. It may not define the actual operating requirements and it may call for specifications that are not actually needed. Again, it is too expensive to find out what parts specification is needed for field reliability. In some cases, the specification is simply a list of specifications that the established vendor can meet.

The specifications written for an ignition system or its parts are not the minimum requirements for performance, for those vary from engine to engine. Instead, they are specifications that have evolved through fifty or more years of using that system. For this reason, when the electronics industry pressed the automotive industry for an electronics-industry type of ignition specification, none was available. Some were written, but they showed little agreement, and ranged from overly simplified to overly demanding. All included, as an ultimate measure of reliability, tests on many cars in actual field use. This has led some vendors who do not understand the problems of the auto industry as discussed above to assert that Detroit doesn't really know what they want or need. It may be true that they don't know the minimum performance specification, but automotive manufacturers surely know what they want.

Table I — Comparison of auto and electronics industries.

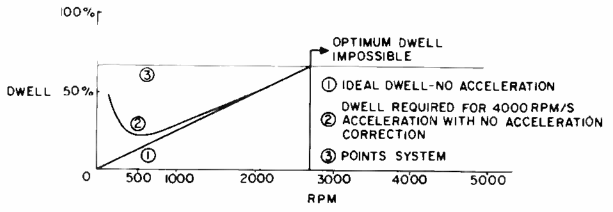
Auto industry	Electronics industry
• Custom parts (>75%) (engines, radiators, seats, etc.) 1) No previous production experience on custom parts 2) Costs of parts are estimates until manufacturer is in production 3) Only a few vendors make custom parts 4) Custom parts are sold to only one customer	• Standard parts (>75%) (resistors, semiconductors, capacitors, etc.) 1) Proven parts 2) Cost and production tolerances well-known 3) Parts available from many vendors 4) Standard parts sold to many customers
• Standard parts offer little advantage	• Custom parts are avoided
• Few very large manufacturers	• Many small companies
• High capital requirements (very high cost of entry) 1) Single production line – tight schedules 2) No production shutdown allowed	• Low capital (garage operations common) 1) Batch manufacturing processes 2) Inventory at given steps in manufacture allows temporary production stoppage
• No inventory (critical delivery schedules)	• Inventories
• Must-work designs (adjustments avoided)	• Tested and tuned performance (*e.g.* color tv has more than 20 factory picture adjustments)

In summary, the automotive manufacturer saw little wrong with the present ignition system and only a slight performance improvement with the more expensive electronic ignition. Further, the electronic ignition was unproven. Its improved specifications were not significant; only an extensive field trial would demonstrate any performance advantages. And if any reliability problem developed, its solution would be expensive. Therefore, viewed as a new part to do an old job, the electronic ignition was quite correctly rejected by the automotive manufacturers.

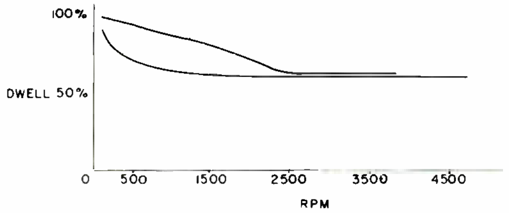
Electronic ignition becomes more attractive

The emission standards and service restrictions imposed on the automotive industry have made electronic ignition systems more attractive. An improvement in nearly any part of the engine will help to meet the emission requirements, and even if the contribution of the electronic ignition to the total improvement of the performance of the automobile is considered small, it is now desirable. Those areas in which the present system is deficient and in which the electronic system is superior are explained below.

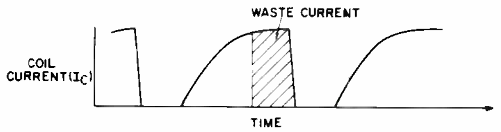
The points (contacts) in the ignition system produce ignition timing errors in three ways, as shown in Fig. 1a: 1) wear of the rubbing block, 2) variations in the cam profile, and 3) shaft eccentricity. Cam and shaft eccentricity change the timing of each cylinder relative to the



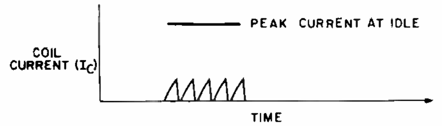
(a) comparison of dwell percentages *vs.* r/min.



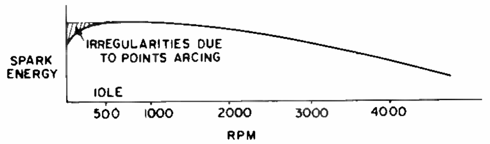
(e) two practical dwell curves.



(b) engine idling at 500 r/min.



(c) engine at 5000 r/min (same scale as Fig. 2b)



(d) spark energy as a function of r/min for a constant-percent dwell system.

Fig. 2 — Ignition system dwell waveforms.

others. The elimination of these points of wear in the ignition-point system is also helpful in meeting the emissions tests for 50,000 miles without engine service. These three problems are solved by using a magnetic pickup, Fig. 1b, instead of points. But a magnetic pickup produces only a small signal, which necessitates amplification and, hence, an electronic ignition.

In summary, the automotive industry is using the electronic ignition, but not for the reasons given over the last ten years—not more output, not higher speed, not more fuel economy, etc.; they are using the electronic ignition to obtain performance not previously required—more accurate spark timing and the elimination of the need for periodic adjustment of the timing.

Legal restrictions prohibit the description of circuits in use by particular manufacturers; however, a general discussion of the four principal characteristics of inductive ignition systems is appropriate. These characteristics include dwell, battery-voltage compensation, high-voltage limiting, and obtaining output-transistor base drive.

Dwell

Dwell is the portion of the operating cycle in which the ignition coil is being charged, and is expressed in either percent (as in this paper), in degrees of crankshaft rotation (100% dwell = 90° for 8 cylinders; 100% dwell = 120° for 6 cylinders, etc.), or in milliseconds (the amount varies with r/min). Breaker points produce constant-percentage dwells independent of r/min, as shown in curve 3 of Fig. 2a. This is not the optimum dwell; it is excessive at low r/min and wastes current as shown in Fig. 2b. At high r/min, Fig. 2c, the dwell is more correct. Fig. 2d shows spark energy as a function of r/min for a constant-percent dwell system. The minimum dwell is shown in curve 1 of Fig. 2a. This dwell would minimize the battery current consumption. A magnetic pickup does not allow the use of a simple circuit to compensate for acceleration. One solution adds extra dwell; this approach produces curve 2 of Fig. 2a.

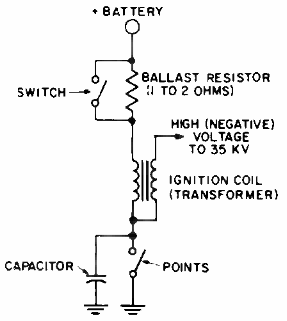
These functions are important because a magnetic pickup can only produce a 50% dwell unless electronic circuits are added. The resultant dwell function will be a compromise with circuit economics. Two simple, practical, dwell curves are shown in Fig. 2e.

Battery-voltage compensation

Some method must be used to compensate for battery-voltage variation. Just when the best spark is needed—during starting—a low battery voltage exists. When starting, the plugs and the air are cold, the cylinder pressure is up, and the fuel mixture is poorly controlled, so a

Typical ignition-coil parameters

Turns ratio	100:1
Secondary	25,000 turns #41
Primary	250 turns #22
Primary inductance	6 to 10 mH
Primary resistance	about 1.5 ohms
Secondary inductance	40 H
Secondary resistance	10 kilohms



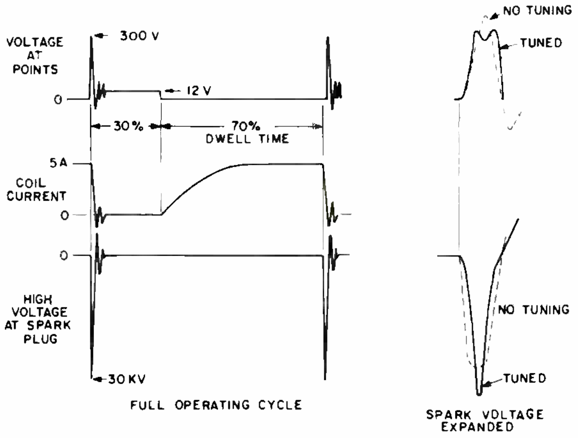


Fig. 3 — Operation of a basic ignition circuit. A low engine speed and a disconnected spark plug are assumed for clarity. The high voltage is generated when the points located in the distributor open. The capacitor reduces arcing by decreasing the rate of voltage rise at the points. It also "third-harmonic" tunes the coil and raises the peak output voltage. The switch shown may be built into the ignition switch, the starter, or the starter relay.

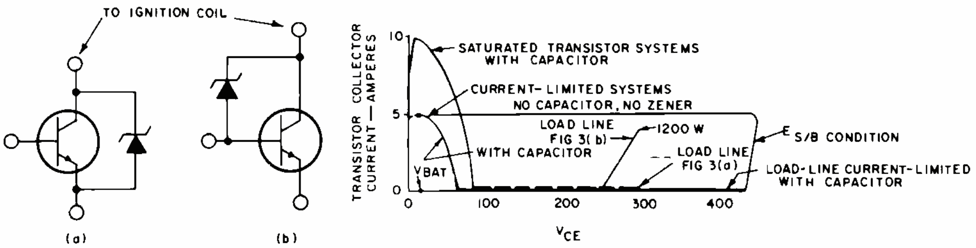


Fig. 4 — Methods of eliminating the need for a 1,000-V transistor in the transistor ignition system.

good spark is needed. The battery voltage drops as much as 60% because of the high current drain in the starter motor. Conventionally, this loss in battery voltage is compensated for by shorting a ballast resistor in the ignition, as shown in Fig. 3. However, when used with an electronic ignition, this method causes excessive transistor currents when the battery is fully charged, or worse if a booster battery (24 V) is applied by a service truck. The latter is a worst-case condition for the transistor; the collector currents can approach 20 A.

An electronic ignition system can be made to compensate for battery-voltage variations if the output transistor is made to operate as a current limiter. However, not only is it difficult to cool a transistor operating in the active-region in the hostile environment under the engine hood, but such operation limits the number of suitable mounting locations. Also important is the fact that a system so operated produces less spark energy than the point system when the battery is fresh, and this might adversely affect starting capability when the engine is hot.

High-voltage limiting

High-voltage limiting is concerned with the method used to protect the output transistor from excessively high voltages. All of the systems being used or considered by the automotive manufacturers use the standard 100-to-1 turns-ratio coil, and require the transistor to operate at approximately 300 V. Either a disconnected spark plug or a cold start with a good battery can raise the transistor's voltage to 800 or 1,000 V. There are four ways to eliminate the need for a 1,000-V transistor. The coil current can be limited by the output transistor, as described above, in which case a 400- or 500-V transistor would be adequate. The second way is to use a zener clamp from the transistor's collector to its emitter to absorb the energy, as shown in Fig. 4a; however, the required 10-W zener is expensive. The third way to protect the transistor is to use the transistor to amplify the zener output. The zener is a 0.5-W unit placed across the transistor's collector and base, as shown in Fig. 4b. The transistor must dissipate high peak powers (900 W) in short pulses. The fourth way is to use a 300-V transistor that can absorb the energy in a voltage-breakdown mode. This approach would be the most expensive with the present state of the art.

Each of the methods discussed requires different output transistor capabilities.

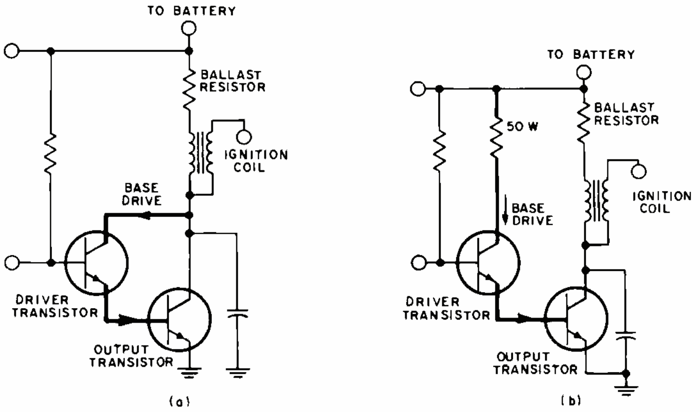


Fig. 5 — Methods of obtaining base-drive.

An example of the worst-case load lines are shown in Fig. 4c. Current limiting requires high power-dissipation capability, particularly when the engine stalls. When no capacitor is used, a severe second-breakdown condition exists. In saturated transistor-switch systems with collector-emitter zeners, the transistor requirements are minimized. Despite the high pulse-power loads needed for the collector-base zener approach, this system is the least expensive.

Obtaining base drive

The final difference among inductive, electronic-ignition systems is the source of base drive for the power transistor. Cost-effective, high-voltage power transistors require more than one ampere of base drive for the starting condition (a battery voltage of 6 V and a collector current of 3 to 5 A); two methods exist for obtaining this current. In the first, a Darlington transistor is used, as shown in Fig. 5a, which means that the base drive of the output transistor passes through the coil. This arrangement minimizes the current requirement but increases $V_{CE(sat)}$, and a lower resistance, more expensive coil is needed. In the second approach, as shown in Fig. 5b, the base drive comes from the battery through a separate power resistor. This yields a better $V_{CE(sat)}$, but requires up to 3A more battery current, a 50-W resistor, and extra wiring.

Conclusion

Electronic ignition systems have come of age for the primary reason that new emission and service restrictions have developed a need to eliminate the breaker points found in the present systems. Electronic ignition designs have matured in the last decade, and the automobile's electrical system, especially its transients, are now better understood. More reliable semiconductors at lower prices are now available. But most important, automotive manufacturers have learned how electronics people operate, and, as explained in this article, the electronics companies have learned how to satisfy the automotive manufacturers.

Reference

1. U.S. Patent 2955248, B. H. Short, October 4, 1960, assigned to General Motors indicates how long the electronic ignition has been actively considered.

Driver alert and inhibition — a new systems approach to motor-vehicle traffic safety

Dr. A. S Clorfeine

A broad-ranging sociotechnological system for dealing with the critical problem of motor-vehicle accidents is described. The system attempts to assist and influence the driver toward bringing about a safe and orderly flow of traffic. In view of its concept, the system is termed *Driver Alert and Inhibition* (DAI). A description of system components, operation, evaluation, and phasing-in is given. Interrogation—a means for continually testing for possible system malfunction-is also described. Although DAI is only conceptual at present, it is hoped that enough interest will be generated to stimulate discussion and experiments leading to eventual adoption in some form of an operating system.

Dr. A. S. Clorfeine, Communications Research Laboratory, RCA Laboratories, Princeton, N.J., received the BSEE (magna cum laude) from the College of the City of New York in 1959. Upon graduation, he received the "Engineering Alumni of the City College Award in Electrical Engineering". He obtained the MS and Phd in electrical engineering from the Carnegie Institute of Technology (now Carnegie-Mellon University). Specific technical projects and accomplishments in which he has been involved include the first demonstrations of parametric amplification and millimeter-wave frequency conversion in superconductors and the concept of self-pumped parametric amplification in semiconductor diodes, the development of a comprehensive theory for the anomalous (TRAPATT) mode of oscillation, the establishment of a set of oscillator design rules, the attainment of record TRAPATT L-band and S-band pulsed powers, and the development of cost-saving pulsing methods and lumped-element TRAPATT circuits. His work with superconductors resulted in an "Industrial Research-100" award. He has shared in two RCA Laboratories Achievement Awards and has over twenty-five technical publications. Dr. Clorfeine is a member of Eta Kappa Nu, Tau Beta Pi, Sigma Xi, and the IEEE, serving on the tunnel-diode device standards sub-committee for the IEEE.

MOTOR-VEHICLE traffic accidents currently account for, each year, more than fifty-thousand fatalities, two-million disabling injuries, and a monetary loss to society in excess of twelve-billion dollars.[1] The causes of these mishaps are numerous, complex, and not well understood, involving driver actions, vehicle malfunction, and/or road conditions. The question of causality in motor-vehicle accidents is discussed in the next section. Despite the questionable state of knowledge in this area, most observers agree that the correction of improper driving practices would prevent the great majority of accidents.

Specifically, effective control of 1) speed too great for the prevailing conditions, 2) following too closely ("tailgating"), and 3) inattention would result annually in the prevention of approximately fifteen-thousand fatalities, six-hundred-thousand disabling injuries, and a financial loss to society of nearly five billion dollars. The system proposed appears capable of effectively controlling driver actions in these three areas thereby realizing the potential savings indicated above. In view of the concept by which the system attempts to reduce accidents, it is termed Driver Alert and Inhibition (DAI)

Technology has long been a pervasive force in beneficially influencing individual behavior as pointed out by Schwitzgebel.[2] Driver behavior influence (in a much more limited way than we propose here) is in wide use today. The use of stop-signs, posted speed-limits, and traffic summonses is directed toward controlling the behavior of a driver with the objective of bringing about a safe and orderly flow of traffic. Electronic behavior-control (or action influence) is manifest in the use of traffic signals and police radars. All of these means are directed toward (a) *informing* the driver of his expected behavior and/or (b) *deterring* him from deviating from such behavior. These means of action influence, while certainly helpful in promoting traffic safety, are only partially effective for several reasons. First, because of inattentiveness, the driver may be unaware that at a given moment he is driving in violation, for example, of the speed limit. Secondly, because of a common tendency not to recognize personal vulnerability, he may be satisfied that *his* driving at a given moment is not unsafe. Finally, since a driver is aware that the great majority of traffic offenses surely go undetected, he may be willing to assume the small risk of detection.

In DAI, the concept of action influence is greatly strengthened and the above shortcomings are overcome. The already existing action-influence mechanisms of (a) informing the driver of his expected behavior and (b) deterring him from deviating from this behavior are supplemented by additional features. These are (c) alerting the driver to the fact that he is driving in a manner which has been determined to be technically unsafe every time such driving occurs, and (d) strongly and continuously inhibiting him from continuing every time such driving persists (of course, an acceptable inhibition, in addition to being effective, must not be characterized by overriding side effects of a legal, moral, or safety nature). One inhibition mode, described in detail later, involves violation recording. A simplified version of violation recording has already been used with trucks and buses.

It is important to emphasize the semantic distinction that we make here, for the sake of discussion, between deterrence and inhibition. Deterrence stems from the driver's knowledge that a small percentage of the time a particular driving behavior leads to an accident or a summons. Inhibition results from the

---

Reprint RE-18-6-22
Final manuscript received November 28, 1972.

driver's cognizance that such behavior will lead to undesirable consequences every time it occurs. Whereas many drivers may ignor deterrences, surely, very few will drive unsafely in the face of a properly chosen inhibition mode.

While some of the elements of the system have been proposed before individually (e.g., on-car radar to control intervehicle separation and transmitter-receiver systems to control speed) it is felt that DAI, as a package, offers much that is new in the way of a practical, flexible, enforceable, and effective system. The driver is an integral part of DAI; the system might be characterized as one which is semi-automatic in nature, taking advantage of driver capabilities to greatly enhance system reliability and efficacy.

DAI, of course, should be considered in a comparative light with other traffic safety concepts. Fully automatic highway systems have been proposed on a number of occasions.[3] Such systems would likely be characterized by an improved measure of safety. Problems and costs, however, would be immense and, additionally, operation presumably would be restricted to limited-access highways. By contrast, the major portion of DAI is sufficiently simple so that it could be implemented in the near future; also, eventual use is envisioned for all roads.

A more limited automatic system currently under consideration involves the use of automatic braking.[4] In such a system, brakes are applied when information (with the aid, for example, of on-car radar) indicates a relative vehicle velocity which is too large for the prevailing intervehicle separation.

Automatic braking has a relatively limited (though, by no means, insignificant) safety value in that a) it too is generally proposed only for use on limited-access highways; b) it is useful for preventing a class of accidents which is smaller than that for DAI; c) because of "clutter", may be "fooled" into positive action by a target which actually presents no danger and, therefore, must be provided with a manual override, enabling the would-be tailgater to defeat his system; and d) conceivably, a car may be needlessly and suddenly braked in high-speed traffic possibly causing an accident if the driver does not override in time. Automatic braking is discussed again in this paper as part of the considerations for "counteracting tailgating and inattentiveness."

By contrast, DAI is relevant to a greater range of accident situations, has no manual override, and for the most part, is appropriate for use on all roads and entirely clutter-free (that aspect which is not entirely clutter-free is "clutter-tolerant") However, DAI is compatible with automatic braking in that the two systems can coexist in the same vehicle.

At this point it may be useful to emphasize what this paper does and does not try to do. Any proposed accident avoidance system, perhaps, should be judged on a number of factors — primarily whether or not it is likely to be (a) technically effective, (b) sufficiently reliable, (c) of acceptable cost, and (d) socially acceptable. Since DAI is in the proposal stage, our present objective is primarily to stimulate discussion. Thus, we make no pretense at proving all the points discussed in the paper. For example, any such system, in its early stages of use, is likely to be more expensive than anyone would like and would pose reliability problems. The latter, however, are more often than not, soluble. Reliability can usually be increased at the expense of cost and even if one does not fully accept the cost-effectiveness arguments of appendix B, neither is one likely, at this point, to convincingly argue that the cost would be prohibitive in view of the immense monetary (and humane) savings possible.

This paper makes no attempt at being complete — such would be premature in the early proposal stage of a complex system. Nor does it attempt to satisfy everybody (or anybody) on all major points. Such an expectation on the writer's part would be arrogant — especially considering that the area of automobile safety is one in which so many hold such strong opinions. It is hoped that the spirit in which the reader approaches DAI is simply one of determining for himself whether the concepts proposed here merit public discussion, and, possibly, further investigation, modification, and refinement.

On the causes of motor-vehicle accidents

A very large number of motor vehicle accidents are caused by drivers under the influence of alcohol. Also, many accidents have more than one necessary ingredient. For example, in an accident involving a drinking driver who was speeding, prevention of either the driving while drinking or the speeding would likely have prevented the accident. Alternatively, speeding is a major cause of accidents among alcohol-influenced drivers just as it is among other drivers. The contention that perhaps about half the traffic fatalities are caused by drivers who had been drinking is not disputed here; nonetheless, this contention does not invalidate accident statistics which ignore alcohol and categorize according to driving actions. Thus, even if it is impossible to prevent drivers from drinking, it is possible to prevent many accidents and lessen the severity of others by controlling driving actions. It is, of course, likely that the driving behavior of an alcohol-influenced driver is more difficult to control than that of his non-drinking counterpart; nevertheless, in most cases the driver who has been drinking is generally not beyond reach. According to a recent analysis,[5] 95% of drinking drivers were listed as "under the influence of intoxicants" compared to only 5% who were listed as "intoxicated". Hence, most of these drivers are still subject to control by a properly chosen set of alert and inhibition modes, as discussed later in this paper.

Primarily, because of the priorities and circumstances prevailing in the immediate aftermath of a motor-vehicle accident, statistics relating to the causes of these mishaps are generally suspect. Nevertheless, they represent at least an approximate basis for demonstrating the expected effect of eliminating a specific type of unsafe driving behavior.

It is generally accepted that operating a motor-vehicle at a speed too great for conditions is a leading factor in traffic mishaps — especially those which result in fatalities (later in the paper the concept of speed "too great for conditions" is discussed). The theoretical basis that implicates speeding is clear — at excessive speeds, avoidance maneuvering times become shorter, stopping distances greater, collision forces higher, probability of losing control higher, probability of tire failure higher, etc. Also, speeding by part of the vehicle population results in a non-uniform traffic flow which, in itself, is regarded as a safety liability.

According to statistics compiled by the National Safety Council,[1] speed too fast for conditions was responsible in 1969 for 15,600 fatalities (one-third of motor-vehicle occupant deaths), and 410,000 disabling injuries. The total number of accidents attributed to this cause was 2,350,000. This latter figure is consistent percentage-wise with a more detailed study of accidents in 1969 on the New York Thruway.[5] Yet other statistics[6] for 1969 hold speeding responsible for 18,700 deaths. The lower estimate is used in this paper.[1] Some would contend that accident reports tend too frequently to indict speeding as the principle causative factor. On the other hand, it can be argued that the above figures may actually be conservative. The basis for this contention is an examination of other accident causality categories (e.g., pedestrian deaths, failure to yield right of way, driving left of center, improper overtaking) which are listed independently of speed too fast for conditions. In many accidents covered by these categories, excessive speed is likely to have been a necessary, though not the primary ingredient, as regards the cause or aggravation of these mishaps. Thus, any tendency to indict speeding too often as a principal cause is likely offset by the disregarding of the role of speeding in other accident categories. Hence, it does not seem unjustified to accept the raw statistics on principal causes as approximations to the potential savings if speed too great for conditions were eliminated.

Tailgating appears to be a minor cause of fatal accidents though it weighs heavily in mishaps involving property damage. Statistics[1] for 1969 indicate that this practice accounted for 500 fatalities, 230,000 injuries and 1,850,000 total accidents. The National Safety Council does not isolate "inattention" as a separate category; however, a previous report[7] for turnpike accidents indicated inattention as the principal circumstance in 14, 16, and 19% of the fatal, injury-producing, and total accidents, respectively. Inattention is likely not as severe a problem on roads other than turnpikes; however, it is clearly a formidable factor (for the general estimates below, one half the turnpike rates are used).

In summary, then, three factors — 1) speed too great for prevailing conditions, 2) tailgating, and 3) inattention — are collectively responsible each year for approximately twenty-thousand fatalities, eight-hundred-thousand disabling injuries, and six-million accidents. Item 1 alone is the principal cause in about 40% of the above total of accidents, half the injuries, and three quarters of the fatalities. It is likely that the system described in the ensuing sections is capable of eliminating nearly all accidents in the above three groups. Even a 75% effectiveness of DAI would result in the avoidance of 15,000 fatalities, 600,000 injuries, and more than four-million accidents each year.

Components and operation of DAI

This section is concerned with that part of DAI which addresses itself to the elimination (or severe reduction) of speed too great for the prevailing conditions. It is important to emphasize the flexibility implied in the term *speed too great for the prevailing conditions.* Speed limits which are to be most effective in eliminating a class of accidents without being unduly restrictive of traffic flow should be adaptive to the prevailing conditions (note that such a system, to the extent that it promotes uniform speeds on a given road, is likely to increase traffic flow). Conditions that determine a safe speed include (a) the type of road, (b) road-surface conditions as influenced by the weather, (c) localized road problems resulting from construction, etc., (d) visibility as influenced by the weather, (e) visibility at night vs. that during the day, (f) the type of vehicle, and (g) the prevailing traffic density. Note that, under low-traffic and otherwise ideal conditions, some presently existing limits can actually be raised.

In full operation, the system will consist of central control boards, a network of stationary units at various locations along all roads, and a receiver unit on each vehicle. Each road unit is to consist of a traffic counter and a transmitter (possibly with antenna wires imbedded in the road). Road units are posted at each point where the speed limit changes (in pairs, on two-way roads). The transmitters are to be of very short range with a total of, perhaps, sixteen different outputs available. Each output signifies a different speed limit. Thus, the sixteen different outputs can represent limits from 5 mi/hr to 80 mi/hr in 5-mi/hr increments. If necessary, road units can be mounted atop poles to keep them relatively immune to vandalism. Modest power requirements may permit the use of solar cells (and storage batteries) as power sources for the road units obviating the installation of power cables.

Each motor vehicle is to be equipped with a DAI receiving unit, a black box representation of which is shown in Fig. 1. The function of each box will become clear shortly. The receiver unit cannot be deactivated by the driver. The optimum specific means of performing each black box function can be determined only when a development program is undertaken; this topic is not pursued here. Let it suffice to point out that all operations called for are within the capabilities of present technology and are not likely to require hardware of high sophistication.

As an example of system operation, consider Fig. 2. Car A, traveling north is about to leave a zone where the speed limit has been set at a central control board to the 50 mi/hr. It is to enter a 35-mi/hr zone. A speed limit sign, of course,

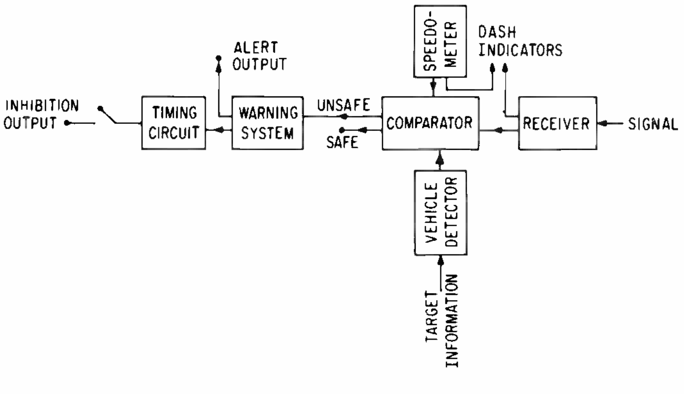


Fig. 1 — DAI receiving unit.

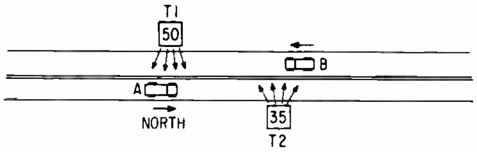


Fig. 2 — Example of system operation to establish speed limits.

informs driver A of this change. His receiver unit was previously set for 50 mi/hr by the last transmitter encountered. As driver A approaches the zone boundary, his receiver may (depending on the particular antenna layout) experience a signal from transmitter T1 which is intended for oppositely moving traffic. In any case, on the other side of the zone boundary, A receives a signal from T2 setting the new limit of 35 mi/hr. This limit is displayed on the driver's dashboard along with his speedometer reading, as indicated in Fig. 1. Driver B, traveling south, will have his unit automatically reset to his new limit of 50 mi/hr.

With the flexibility (or versatility) of DAI one or more central control boards in each state can receive weather and road condition reports from local police departments. These reports can be used to set the base (low traffic density) limits on all roads. Each transmitter can have, perhaps, three base outputs corresponding to driving conditions which are (a) normal, (b) moderately hazardous, and (c) very hazardous. When it is judged that driving conditions in a given section are very hazardous, the resetting of a single switch at the control board reduces all turnpike base speed limits from, say, 70 mi/hr to 40-mi/hr limits, on 50-mi/hr roads to 30 mi/hr, etc.

A separate schedule of base speeds can be switched in at dusk. Traffic counters can be used to automatically actuate a lower speed limit schedule at individual road-units in the event of high traffic densities. Override switches at each road unit can actuate special settings as required, for example, by local construction. Receivers for trucks and buses can be identical to those for automobiles except for the comparators which "interpret", for example, a 70-mi/hr automobile speed limit as a 60-mi/hr limit, with corresponding reductions for other limits. In this manner, an effective, flexible, ever-changing speed map tailored to the specific traffic, road, vehicle, and weather conditions can be drawn.

DAI mode descriptions

An objective of DAI is to continuously enforce adherence to a driving code that has been determined to be consistent with traffic safety. The system does so by (a) immediately detecting significant deviations from this code, (b) instantly alerting the driver to all such deviations, and (c) in the event that corrective action is not taken, strongly inhibiting the driver from continuing such behavior.

When the DAI comparator (Fig. 1) registers an output indicating speed too great for prevailing conditions (i.e., the limit communicated to the vehicle by the last-encountered transmitter), the alert mode is immediately activated. In practice, it might be preferable for the alert mode to be activated when the limit is exceeded by 5 mi/hr. Speed schedules would take this tolerance characteristic into account. Also, a short delay time might be included prior to alert-mode activation when a vehicle crosses from one zone to another of lower speed limit. The question now arises as to the specific nature of the alert mode and whether or not it also should be designed to annoy as well as alert, for it may be argued that unless the response is also irritating, the driver will often ignore it. On the other hand, there will be situations (during passing, for example) where brief excursions above the set limit will occur. Since such excursions are inevitable and generally not inconsistent with safety, should they not be immune from invoking an annoying response?

In the answer to this dilemma lies a key feature of DAI—the dual-mode response. The alert mode is designed to be non-annoying, and therefore the system is tolerant to the type of situation mentioned above. On the other hand, the driver cannot ignore the alert mode; respect for the alert signal in DAI stems from the driver knowing that unless he ceases speeding in a prescribed time (e.g., 20 seconds) the system will switch to its inhibition mode. Thus, when faced with the certainty of the impending activation of the inhibition mode, the driver will heed the alert signal. (His alternative of speeding to a value significantly above the limit, sharply braking to avoid the inhibition mode, speeding again, etc., will surely not be a viable one.) Consequently, the dual-mode characteristic of DAI manifests the required tolerance without breeding defiance. An alert signal that informs without irritating can take the form, for example, of a gentle audio output or a visual display on the dashboard, or both.

The design of the inhibition mode is a subject meriting much investigation. The criteria which govern the choice of such a mode are the following:

1) It must be highly effective; the great majority of drivers must be dissuaded by the impending activation of the inhibition mode from sustaining improper driving behavior, once alerted, and most of the remaining drivers should be sufficiently inhibited from continuing once the inhibition mode is activated.
2) The inhibition mode must not be characterized by overriding side-effects of a legal, moral, or safety nature.
3) The technical characteristics of the inhibition mode should be such that the mode resists simple defeat by vehicle owners.

The inhibition mode proposed appears to be consistent with the above three conditions. If proper vehicle operation is not restored during the course of the alert interval (e.g., 20 seconds), a violation is noted by a counter in a tamperproof locked box. Continued ignoring of the alert signal results in additional violations being recorded for each such interval of time. The motor-vehicle code would prohibit operation of a vehicle with more than a specified number (e.g., three) of recorded (i.e., "un-cleared") violations. A vehicle with excess violations could be detected in a number of ways—e.g., via an rf signal transmitted from within the locked box (continuously or in response to an interrogation) or eventually, at the time of periodic inspection. Thus, the owner of a vehicle with, say, three recorded violations, would be forced to have his recorder cleared at an inspection station (for which there may or may not be a nominal service charge).

There would appear to be no need to impose fines or restrict driving privileges based on these violations and, indeed, such a procedure might well raise a variety of objections. The strong inhibiting nature of this mode stems from the need for the owner to spend time traveling to and from, and waiting at, an inspection or violation station to clear his recorder. It should be obvious to every would-be violator that time lost through this procedure will offset time saved by speeding. Thus, it is likely that the great majority of potential speeders would heed the alert signal.

Problems associated with the above-described inhibition mode would seem to be minor. It is possible, of course, for a vehicle's system to become defective and inaccurately record a violation, placing what might seem an unfair burden on the owner (though, with proper design, the incidence of malfunctioning should be quite low). Such, however, differs in no basic way from the burden imposed by a defective headlight or muffler. It is the owner's responsibility to maintain his vehicle in proper operating condition and to bear whatever nuisances and expense this entails.

Secondly, consider a violation during a period in which the car is rented or on loan. The situation may be equated to that in which a parking violation is charged. With DAI matters are simpler, in fact, since the owner can readily note the new violation total upon return of the vehicle. Presumably, a car-rental agency might charge a lessee for direct or indirect expenses associated with any violations tabulated during the rental period.

Though it is felt that the inhibition mode described here is most effective and least problematic, possible alternatives are discussed in appendix A. The inhibition modes described are proposed for use individually though, of course, use of more than one would provide reinforced inhibition. The choice of the optimum mode is a subject requiring additional thought, design, and testing. What seems evident, however, is that at least one inhibition output can be found that would greatly discourage virtually any driver from sustaining improper driving behavior.

Interrogator for detecting inoperative systems

DAI is a system that sets standards of proper driving behavior and, further, detects, alerts to, and inhibits deviations from such behavior. It is, of course, to be expected that some drivers will seek ways to overcome the restrictions imposed upon them by DAI. Tampering with the system in an effort to defeat it will likely be a practice indulged in by only a small percentage of vehicle owners provided, of course, the legal penalties for driving with an improperly operating system are in effect and mechanical design is such that effective tampering would be difficult and time-consuming. In this case, the would-be law-breaker would have to carefully deactivate his system after his vehicle's periodic inspection, hope that his tampering or system malfunctioning would not be detected thereafter, and carefully reverse the procedure prior to the next inspection. While these considerations should be sufficient to dissuade the great majority from tampering, it would be very advantageous to have a means of discouraging or detecting most of the remainder. The means described below does this and serves the additional purpose of continually checking for and detecting possible system failure of an accidental nature.

The essence of tamperproofing DAI lies in a) the locked box, and b) the interrogation concept. The locked box is a safe that contains virtually all the hardware of DAI and that can be opened only at an inspection station. Certain access ports to the locked box, however, must be made available and these, to some extent, will be vulnerable to tampering. These access ports provide power for the electronic components within the box (presumably from the vehicle's electrical power system) and electronic information from the antenna. Also, depending upon the specific system design, ports might have to be provided for a speedometer cable and an inhibition-mode output. Note that several of the inhibition modes (e.g., recording of violations) may be housed within the black box. The resultant relative freedom from tampering should be considered a factor in the choice of an inhibition mode. As regards the other inhibition modes, detection within the locked box of tampering external to it is usually possible, though likely with some difficulty. As regards velocity information, the tampering problem can be eliminated by the use of a speed-indicator housed totally within the locked box. Such indicators are technically feasible in the form of accurate, simple, true ground-speed Doppler radars of potentially very low cost.

Thus, we are left with possible problems concerning the power and antenna ports. Placement of electrical terminals can be such that disconnecting power or antenna terminals (especially in a reversible non-obvious manner) can be quite difficult. Short-circuiting or otherwise impeding antenna reception in a non-obvious manner can be discouraged by effective antenna placement. Obvious, willful tampering is, of course, to be discouraged by heavy penalties. Nevertheless, it would be quite useful to provide a means for further discouraging tampering. *Interrogation* provides such a means for coping with an remaining vulnerability.

Interrogation, in the early stages of the program, can be of a semi-automatic nature progressing to a more fully automatic system as DAI becomes universally adopted. In either case, its role is to provide a simple, rapid, and frequent means of detecting a system that is not functioning. It seems safe to assume that because of 1) periodic inspection, 2) legal restrictions, 3) effective mechanical design, and 4) an effective interrogation system which is now to be described, that the percentage of inoperative systems at any given time will be quite small. If the mere presence of an inoperative system in the vicinity of a stationary or moving police car or check point would result in certain detection, then the mean free (i.e., undetected) time of an inoperative system would be quite small. Such detection can be accomplished if each police check point is equipped with a transmitter that "interrogates" vehicles in its proximity. The interrogation signal is picked up by the vehicle's receiver which activates a warning device (*e.g.*, a light on the body of the vehicle.) The light remains *on* only as long as the signal is received. Thus, if the power or antenna has been disconnected, the light will not turn *on* when the vehicle has been interrogated. The post-detection procedure might include stopping the vehicle or merely noting the license number and mailing a notice; it may entail fining the driver or simply ordering the owner to appear at an inspection station, which, of course, involves significant personal inconvenience. In any case, interrogation affords detection with a short mean free time and should provide the additional discouragement for would-be tamperers, if needed.

The concept of interrogation can be utilized to deal with another potential problem, if necessary. In principal, the would-be-speeder could build (or have built for him) a transmitter with which he could set his own speed limit. It is, of course, unlikely that more than a very few would spend the requisite time, effort, and/or money and assume the risk of illegally operating such a transmitter (*e.g.* , use of equipment as a countermeasure for police radars appears not to be a significant problem). However, the simple measure of replacing the vehicle's interrogator responder light by a light pattern, with the colors and/or positions indicating the stored speed limit would make detection a simple matter. Note that instead of a light or light pattern the system can utilize an rf signal which is transmitted from within the black box upon interrogation (making use of the antenna already provided). The signal, in addition to verifying that the system is operating, can have additional information such as the stored speed and a possible excess in stored violations.

More automatic forms of interrogation can be considered, especially when DAI becomes universally deployed, so that it is feasible to require it on out-of-state cars also. For example, vehicle detectors and automatic interrogators can be placed in road beds at various points, one in each lane. The density of such interrogators can be quite low; however, their effective placement at critical locations can insure that it is exceedingly difficult for a vehicle to escape interrogation for any reasonable length of travel. Each vehicle, when interrogated, would be expected to respond (*e.g.*, by means of an rf signal). Failure to do so can result, for example, in a signal to the officer overlooking the check point or, alternatively, in the automatic photographing of the offending vehicle and its license plate.

Testing and phasing-in of DAI

Prior to major deployment of DAI, it will be necessary to demonstrate its efficacy in a modest-scale test. It is, perhaps, impossible to devise a flawless test, *i.e.*, one that accurately simulates a full range of driving situations in which the fatality, injury, and accident rates would indeed be valid on a macrocosmic scale. However, the test described below should provide results that are reasonably indicative of the degree to which DAI meets expectations.

In such a test, the cooperation of a state interested in establishing the system would be enlisted. DAI transmitters are to be constructed on the toll roads of this state and a rather large number of vehicles (*e.g.*, 100,000) are to be equipped with receivers. Vehicle owners who are invited to join the test are chosen with a reasonable distribution of ages, etc.; encouragement to join may take the form, for example, of government or insurance company subsidies toward the cost of insurance and toll-free transportation. At entering toll booths, records are kept as to the fraction of vehicles enrolled in the test. Notations as to DAI enrolees are made for all vehicles involved in accidents. From these records, involvement rates for equipped and unequipped vehicles can be compared and the efficacy of DAI evaluated.

Costs for the equipment required in the test (which may be in the order of twenty-million dollars, not including research and development) might be borne by several of the interested parties which include federal and state governments, insurance companies, and industrial concerns which may market the equipment.

If and when the preliminary testing of DAI shows it to be effective, plans for its deployment must be made. Such deployment can take place in stages. For example, once a state adopts DAI, it can construct transmitters first on its limited-access roads, where presumably speed limits are higher than elsewhere. In the second phase of the program, transmitters set for the maximum state limit (except for the limited-access roads) can be placed at the entrance to all roads leading into the state. Thereafter, transmitters should be added in a manner so that the higher limits are electronically-enforced first. Thus, situations in which the driver must proceed, for example, at 25 mi/hr because there is no transmitter for the next higher-limit zone will be avoided.

System additions for counteracting tailgating and inattentiveness

Rear-end collisions resulting from tailgating or inattention are a major cause of motor-vehicle accidents. In this section three systems—automatic braking, simple warning, and subsystem of DAI—all of which deal with this problem are described and compared.

Each system comprises three parts:

A vehicle detector (most systems presently under consideration employ a simple on-car radar) which determines distance and closing velocity with respect to a target — generally the vehicle immediately preceding the equipped vehicle in question;

A comparator which compares the information provided by the vehicle detector and a speedometer with internally stored safe limits; [These limits have been discussed in articles concerning automatic braking and will not be considered here.] and

A response mode which is activated when the comparator output indicates that these safe limits have been violated.

The three systems being considered differ solely in their response modes. We shall discuss the response of each system both to a legitimate danger signal and to a false signal, *i.e.*, clutter.

Automatic braking

When an automatic braking system receives an indication that the speed of the equipped vehicle is too great for the intervehicle separation and relative vehicle velocity, the brakes are automatically applied (such action may be combined with automatic throttle control).

An apparent advantage of automatic braking is the elimination of the driver's reaction time. In principle, this would permit smaller intervehicle separations in heavy traffic. However, since the system can never be totally error free, it should not permit the encouragement of driving habits that totally rely on the system to avoid accidents. Thus, the system design should not take advantage of the no-reaction-time feature.

There are a number of problems associated with automatic braking which are now discussed. The first is one previously alluded to, *viz*. clutter. There is little doubt that research will result in a considerable reduction in the incidence of clutter. In the remainder of this paper, almost all signals will be assumed to be legitimate targets. It is probable, however, that the clutter problem will never be entirely eliminated and even an occasional response which may activate the brakes needlessly in high-speed traffic is likely to be considered unacceptable. A manual-override option, of course, must be provided with automatic braking so that the driver can reverse a clutter-induced braking action; however, significant braking may have occurred prior to this countermeasure. Thus, an automatic braking system is particularly *clutter-intolerant*, responding to clutter in a way that is, at the very least, annoying and, at worst, catastrophic. We shall see that DAI is, by contrast, clutter-tolerant.

A second problem with automatic braking is that since the system responds without the consent of the driver, it may reach an incorrect decision even while tracking a legitimate target, *i.e.*, one which is not classified as clutter. Two such examples are discussed in appendix C. The possibility of serious consequences from both clutter and faulty automatic decisions are eliminated in the following two systems since initial vehicle responses are determined by the driver.

Simple warning system

The simplest type of response mode, to be activated when the comparator indicates too high a closing speed, is a warning in the form, for example, of a buzzer and/or a visual output. The question now arises as to whether the warning should also be made highly irritating to the driver. If the warning is not made highly irritating then the would-be tailgater may simply ignore it. On the other hand, if it is irritating and the response is spurious (*i.e.*, in the case of clutter), then the driver will justifiably complain about being annoyed without cause. *Thus, there is no single response which can handle both legitimate targets and spurious ones equitably.*

DAI

To accommodate the added function of protecting against rear-end collisions, the basic DAI vehicle system (Fig. 1) must be altered by the addition of a vehicle detector and a modification of the comparator. These changes are shown in Fig. 3. Note that the comparator output now registers an output of "safe" or "unsafe", the latter indicating either speed too fast for conditions or an intervehicle separation which is too small.

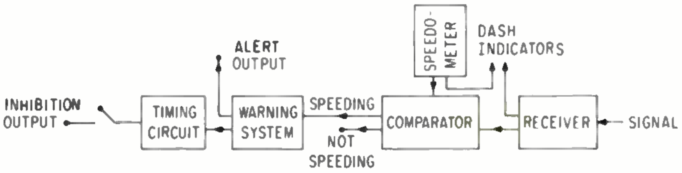


Fig. 3 — DAI system modification to counteract tailgating.

The clutter-tolerance feature of DAI stems from two factors — 1) the short duration of the clutter, and 2) the dual-mode nature of the response. Consider, for example, clutter from a stationary target. If a vehicle traveling at 50 mi/h begins tracking a stationary object at 300 ft, it will reach that target in only 4s, and the alert mode will be deactivated. One can not completely generalize regarding spurious responses from moving vehicles; however, it seems safe to say that the great majority of these will not result in a comparator output of "unsafe" which will endure long enough to activate the inhibition mode. Hence, the result of a very occasional spurious signal is merely several seconds of a totally innocuous alert response. The spurious nature of the response will be quite clear to the driver and surely he will not find a rare, brief, non-irritating response unacceptable; thus, DAI is considered clutter-tolerant. This feature is not realized at the sacrifice of effectiveness, however. Too small an inter-vehicle separation is a result of either inattention or a disposition to tailgate. As regards the former, the driver's immediate response to the alert mode will be corrective in nature (unless he notes that there is not legitimate target, *i.e.*, unless, as will be the case for a very small percentage of signals, the response is clutter-induced). Thus, the alert mode will indeed serve the purpose of aborting inattention.

Consider now the effect of the system on the tailgater who either occasionally or regularly would prefer to follow at a distance which the comparator regards as unsafe. The immediate response to his action is the alert mode which brings with it the knowledge that the inhibition mode is about to be activated. To avoid the inhibition mode, the driver has a choice of tailgating, braking, tailgating, braking, etc., or simply increasing his following distance to a safe value. Surely he may be expected to adopt the latter policy so that tailgating as well as inattention will be largely eliminated as a cause of motor-vehicle accidents.

As part of the overall DAI system, the rear-end collision avoidance concept discussed here can be made yet more versatile by taking advantage of the roadside transmitters. For example, safe following distances should be increased in the case of poor road conditions. Such changes can be effected by including, for example, alternate sets of characteristics in the comparator corresponding to "moderately hazardous" or "very hazardous" road conditions which could be switched in by a signal from the roadside transmitter concurrent with the switching in of the reduced speed limits. Also, it may be possible to utilize roadside transmitters to combat a most difficult type of clutter which is discussed with reference to Fig. 4. Because of road curvature, equipped vehicle A tracks vehicle B in the adjacent lane, instead of vehicle C. This needn't be a serious problem for DAI since it is unlikely that the unfortunate combination of specific road curvature and relative vehicle speed would persist for the entire duration of the alert mode and even if time were running short, driver A, by virtue of a momentary acceleration could break contact with B (note that in an automatic braking system initial radar contact with C could result in brake application possibly risking a collision with vehicle D).

Even though the result of such clutter should not be serious in DAI, its significant reduction would be welcomed and might be effected by a signal from the transmitter at the beginning of a particularly troublesome curve. The signal could, of course, temporarily shut off the collision-avoidance portion of DAI (note that the speed-control portion is not susceptible to clutter). Better yet (though cost and effectiveness considerations require examination), the signal could instruct the vehicle's radar antenna to tilt an amount related to the average curvature of a fairly constant

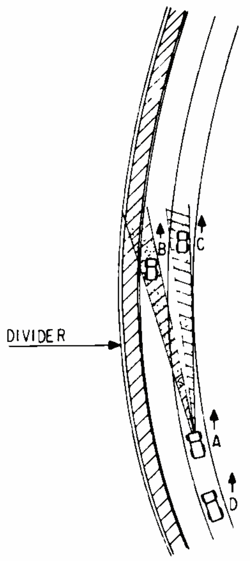


Fig. 4 — Severe "clutter" problem illustrated.

curvature section so that vehicle A is much more likely to track C than B.

Thus, a relatively modest addition to the basic DAI hardware can be expected to result in a large reduction of accidents resulting from driver inattention and tailgating. Further, it appears to offer a number of advantages when compared to other suggested systems. In particular, it is expected to exhibit clutter tolerance, driver control in tight situations, acceptability to the driver, and versatility.

Summary and concluding remarks

The broad-ranging sociotechnological system described in this paper attempts to assist and influence the driver toward bringing about a safe and orderly flow of traffic. Justification for attempts to control driver actions rests with the fact that driving is a public rather than private activity and government has long considered that it has a right and, indeed, an obligation to control such actions.

While causality in motor-vehicle accidents is a most controversial issue, enough is known to indict as a major cause unsafe driver actions in general. Specific types of unsafe driver actions which are amenable to electronic influence have been identified. Driver Alert and Inhibition (DAI) appears to have the potential of virtually eliminating accidents resulting from these types of actions.

1) Accepting, transmitting, and receiving flexible standards for proper driving behavior based on the prevailing conditions,
2) Immediately detecting any significant deviation from such behavior,
3) Instantly alerting the driver to all such deviations, and
4) In the event that corrective action is not quickly taken, strongly inhibiting the driver from continuing such behavior.

A description of system components, operation, evaluation, and phasing-in has been given. Interrogation—a means for continually testing for possible system malfunction has also been described.

The advantages of DAI over other accident-avoidance systems such as automatic braking include its wider scope and lack of deleterious side-effects. It is tentatively estimated that full deployment of DAI would result in the avoidance each year of 15,000 fatalities, 600,000 injuries, over four million accidents, and accident-associated costs of nearly five-billion dollars. By virtue of the latter figure alone, DAI should more than pay for itself, which fact will be manifest to the individual vehicle owner by virtue of significant insurance premium reductions. Of special interest, perhaps, to the electronics components and systems industries is that deployment of DAI would result in a new multibillion-dollar annual market and employment opportunities for many thousands. Finally, although research and development are required to determine the optimum choice of specific procedures and components, DAI requires no new basic technology—*i.e.*, implementation can proceed on the basis of devices and subsystems that exist today.

Acknowledgment

The contributions of V.L. Dalal to some of the ideas on counteracting tailgating and driver inattentiveness are very much appreciated. In addition, the author gratefully acknowledge exceedingly helpful discussions with numerous colleagues during the course of this work.

References

1. "Accident Facts." 1970 Edition, National Safety Council, Chicago, Illinois.
2. Schwitzgebel, Robert L., "Behavior Instrumentation and Social Technology," *American Psychologist*, Vol. 25 (June 1970) pp. 491-499.
3. See, for example, Plotkin, S. C., "Automation of the Highways, an Overview," *IEEE Trans. on Vehicular* Technology, Vol VT-18, No. 2 (1969).
4. See, for example, Harokopus, W. P., "Application of Radar to Automobile Control and Sensing," *IEEE* International Microwave Symposium, Washington, D.C. (May 1971).
5. Analysis of Traffic Accidents, New York State Thruway Authority, 1969.
6. "The Travelers 1970 Book of Street, Highways, and Interstate Accident Facts." The Travelers Insurance Company, Hartford, Connecticut.
7. "Accident Facts," 1963 Edition, National Safety Council, Chicago, Illinois.

Appendix A — Possible alternative inhibition modes

As previously stated, the inhibition mode seems likely to be effective and not significantly problematic. Here, however, we briefly describe possible alternative inhibition modes. While they are, perhaps, more open to one objection or another, they are listed, since we can not conclude with definitiveness, prior to a thorough investigation which mode will operate most satisfactorily.

Reinforcement of the violation-recorder mode

While the inhibition mode described in the paper is felt to be of a sufficiently inhibitory nature, its effect would be yet enhanced by (a) the assessment of a penalty charge (*e.g.*, $5.00) for each violation (though the legality of this procedure might be open to question) and (b) making available the violation records to insurance companies for determining a vehicle's insurance rates.

Irritating buzzer in the passenger compartment

Each time improper driving behavior is sustained beyond the alert interval, an annoying buzzer is activated to inhibit the continuance of such driver action.

Activation of a horn external to the passenger compartment

In this mode, each instance of post-alert-period improper driving activates a loud horn (and perhaps also flashing lights). One could, in principal, use the same horn with which the vehicle is conventionally equipped; however, from a countermeasure point of view it would be advantageous to locate the horn within the locked box. Inhibition in this mode stems from (a) the annoyance feature, (b) the uneasiness and embarrassment associated with having one's violation broadcast so blatantly, and (c) the increased probability of alerting a law enforcement officer to the violation. These inhibitions in combination, while perhaps not as effective as those for the violation recorder, are likely to be sufficient to result in the desired abortion of improper driving behavior during the alert period in the great majority of cases.

Automatic enforcement of lower speed limit or other performance retardation

The premise upon which the mode to be described is based is that potential speeders would be particularly inhibited from speeding by the knowledge that such action would result in the application of even greater speeding restraints. Thus, for example, speeding beyond the alert period might result in the switching in for perhaps one minute, of a speed governor which holds the vehicle speed to 10 mi/hr *below* the prevailing limit. Actual activation of this mode is likely to be quite infrequent and, in any case, the beneficial inhibiting effect should easily offset the temporary and small negative effect on the uniformity of traffic flow.

Safety considerations might make it more prudent to have an additional delay associated with this mode. Thus, for example, a signal will inform the driver who has not heeded the alert that in 30 seconds his speed will be so controlled. In any case, the would-be speeder will be severely inhibited by the knowledge that he must "pay for" each period of excess speed by an even longer period of diminished speed. (Governors which would place an ultimate single limitation on the speed of all vehicles—*e.g.*, 85 mi/hr—have been proposed for consideration. While helpful, they would be of rather limited benefit).

It may be possible to inhibit improper driving behavior by presenting, as the consequence, a reduced vehicle mobility or performance (with or without the time delay discussed above) by means other than with the use of a speed governor. For example, it might be possible, by switching in a properly designed electrical load in the ignition coil circuit, to retard vehicle performance to the point where it would be annoying (though not incapacitating) to the potential speeder. This type of inhibition mode is certainly more speculative and would require careful investigation.

Appendix B — Cost effectiveness of DAI

Since no attempt has been made to delve within the "black boxes" which comprise the hardware of DAI, it will not be possible to estimate the system cost with even a fair degree of accuracy. Also, statistics relating to accident costs are not sufficiently detailed to permit an accurate estimate of potential savings resulting from accidents avoided. Nevertheless, we shall attempt to demonstrate that DAI is more than likely cost effective, *i.e.*, that even disregarding the value of lives saved and the avoidance of pain and suffering associated with injuries, the annual savings in direct costs to society will be greater than the corresponding costs of DAI. First consideration should be given to the portion of DAI designed to deal with speed too great for prevailing conditions.

The National Safety Council has stated[1] that the costs to the United States associated with motor vehicle accidents in 1969 were $12.2 billion. This number is actually conservative since, while it does include the costs of property damage, injuries, and insurance administration, it excludes costs of certain public agency activities such as police, fire and courts, damages awarded in excess of direct cost, indirect costs to employers, etc.

As we discussed earlier, speed too great for prevailing conditions is a major causitive factor in various types of accidents. Two factors leading to probable errors in these statistics were postulated. Since these factors tend to cancel one another, it appears that these statistics are, in fact, a reasonable basis for continuing toward rough estimates.

Assuming it were possible to eliminate speed too fast for conditions entirely, one quarter of all accident costs would be avoided. This fraction is approximately midway between those for fatal accidents and total accidents and is justified by the fact that, on the average, accidents involving speeding are obviously more serious and costly than accidents in general. The use of DAI with a powerful inhibition mode should greatly discourage virtually any driver from speeding. Assuming a 75% effectiveness, its universal use would save $0.75 \times \frac{1}{4} \times \$12.2$ billion = 2.3 billion.

The annual costs of DAI are those related to vehicle equipment (Fig. 1) road equipment, and system administration. Using present annual sales as a guide, approximately ten-million new vehicles must be equipped each year, and if each receiver unit were to cost, say, $75, then the total cost involved would be $0.75 billion. Even with repair and maintenance costs, this figure should be kept to a value of order $1.0 billion. A fully deployed system might include six-million road transmitters. Considering an annual allotment of $100 per unit for maintenance and electricity, total yearly road-unit costs are about $0.6 billion which, when added to the vehicle equipment total, gives $1.6 billion. This permits an additional $0.7 billion for expenses associated with maintaining central control equipment and system administration without exceeding the $2.3 billion savings estimate.

Consider now the cost-effectiveness of the collision-avoidance addition to DAI. Statistics indicate an additional savings of $2.6 billion for this type of mishap resulting in a total accident cost avoidance of $4.9 billion. If the required modifications to DAI cost an additional $50 per vehicle, the total annual system cost would rise only $0.5 billion.

While the numbers used here are certainly open to question, we have, starting with a very conservative estimate of the cost to society of motor vehicle accidents, attempted to demonstrated that DAI is cost effective, i.e., that even disregarding the value of lives saved and pain and suffering avoided the material savings to society from DAI more than cover the cost of the program.

Appendix C — Examples of incorrect decisions in automatic braking systems

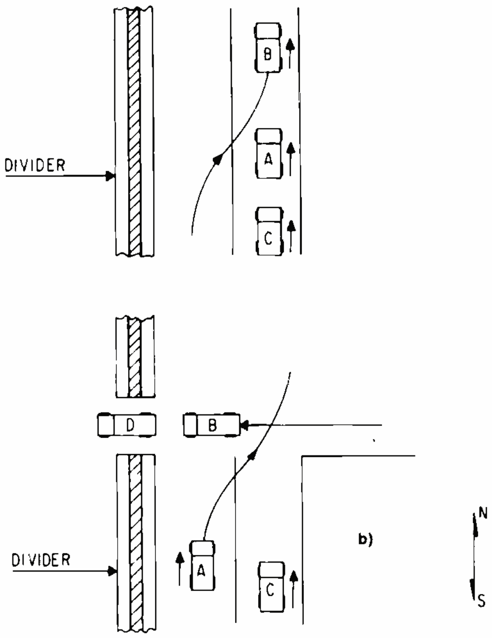


Fig. 5 — Situations where incorrect decisions can cause collisions if automatic braking system is used.

Consider Fig. 5a. Driver B has unwisely cut in front of vehicle A thereby activating the automatic brakes of the latter. Vehicle C (unequipped or with inoperative equipment), which had been following too closely, collides with A. In the absence of automatic braking, driver A, cognizant of C, could have braked lightly or not at all, accepting the temporary discomfort of having to follow B too closely, but avoiding a collision with C.

In Fig. 5B, driver B has carelessly entered the main road; finding that since D has stopped, he must do likewise. The brakes of vehicle A are automatically engaged, but room is insufficient to avoid a collision — with either B or C. In the absence of automatic braking, vehicle A could have accelerated while switching lanes, thereby avoiding a collision.

Thus, while most automatic application of brakes will surely be such as to minimize the possibility of a collision, situations can occur where such application is contraindicated and may lead to consequences which are grave.

Mobile Communications and the Transportation Industry

G. J. Mitchell

A rapid rise in population world-wide, coupled with the associated transportation and communication needs of the populace, is a challenge to technology. In this paper, future funding by the Government for engineering and research, market considerations, frequency allocations, types of service, and reviews of the applications of RCA's communications equipment are given. It is predicted that ongoing and future research will solve many current and future transportation system problems related to automatic vehicle location and monitoring.

URBAN AMERICA'S population will double in the next 40 years, growing as much in that time as all of American urban growth since the landing of the Pilgrims. In that short period, satisfying the needs of both the poor and older cities, and the newer satellite cities, for efficient and rapid transportation of all types, is essential to their economic development.

Government funding

The Federal government, recognizing the need for urban mass transportation, has passed several acts that enable huge sums of money to be spent on both research and development of new transportation systems as well as improvement and refurbishment of existing ones. The Secretary of HUD (Housing and Urban Development) was directed in 1966 by Section 6B of the Urban Mass Transportation Act (UMTA) of 1964 as amended... "To undertake a project to study and prepare a program of research, development and demonstrations of new systems of urban transportation that will carry people and goods within metropolitan areas speedily, safely and without polluting the air... in a manner that will contribute to sound city planning."

An estimated 900 million dollars will be distributed by this agency in fiscal year 1973; 90 million dollars of this total is available for demonstration type projects. Recipients of these funds include CTA (Chicago Transit Authority), BART (Bay Area Rapid Transit), SEPTA (South East Philadelphia Transit Authority) and the Massachusetts Bay Area Transit Authority.

Reprint RE-18-6-9
Final manuscript received February 22, 1973.

Industry Profile

With the generally rapid expansion of mass transportation affecting airlines and railroads for both passenger and freight movement, taxis for passenger movement, motor carriers for trucking and auto, for emergency uses, there exists a significant need for two-way radio communications. These needs are manifested in the form of vehicular, personal/portable, fixed station and ancillary type equipments manufactured by the Commercial Communications Systems Division located at Meadow Lands, Pennsylvania.

The FCC authorizes the various transportation industries to operate radio systems according to rules and regulations defined under FCC Rules, Part 93. Table I shows the frequency assignments available, on a private basis, under this service. The purpose of these rules and regulations is to describe the conditions under which parts of the radio spectrum may be employed for radio communications and control facilities in certain land transportation operations.

Table I — Channels available in various frequency bands by type of service

Service	25-50 MHz	148-174 *MHz*	450-512* *MHz*
Motor Carrier	59	46	22
Railroad	--	91	17
Taxi	--	26	12
Auto Emergency	--	15	4

Table II — Total transportation communications market - 1793.

Category	*$ Millions*	*% of Total Land Mobile Comm. Market*
Motor Carrier	17.1	3.4
Railroad	14.8	2.9
Buses	3.2	.7
Taxis	19.3	3.9
Auto Emergency	7.9	1.6
Airline Airports	1.3	.3
Marine Use of Land Equipment	.8	.2

Channels in 470-512 MHz portion of the band shown in Table I is available only in the top ten major metropolitan areas. In addition to these allocations, there are approximately two-hundred 450-MHz band channels available for licensing on a shared secondary user basis with Public Safety, Government, etc.

The total transportation industry mobile communication market (mobiles, portable, base station, and ancillary equipment) is estimated at $64.4 million dollars for 1973. This represents 13% of the total industry market for this type equipment. Table II is a breakdown of this amount by user category.

George J. Mitchell, Manager, Product Administration, Commercial Communications Systems Division, Meadow Lands, Pa., received the BSEE from University of Pittsburgh in 1962. Mr. Mitchell was employed by Motorola, Inc., for three years where he designed special two-way radio systems. Subsequently, he joined RCA in 1965 as a Systems Engineer. In 1967, Mr. Mitchell transferred to the Mobile Proposal Administration as Manager. In 1969, Mr. Mitchell was promoted to Manager of Product Planning. In 1973, Mr. Mitchell was promoted to Manager, Product Administration, responsible for Product Planning, Systems Engineering, Mobile Proposal Administration and Mobile Contract Administration.

The top ten motor carriers increased their total revenues by 18% in 1971 over 1970. A similar growth occurred in 1972. Taxi industry statistics list 185,000 vehicles in service at the end of 1970. There are 50 major railroads, the majority of them not adequately equipped with communications, purchasing approximately 7,500 radios per year presently. In the food distribution industry alone there were 4800 fleets (a fleet defined as ten or more vehicles) in 1971. For the construction industry there were over 12,000 fleets in the same year.

Typical System Installation

Over the past several years, RCA has installed several large communication systems in a variety of transportation applications. Of special interest is the New York City Transit Authority in which over 4700 buses have been equipped with mobile radios. This represents the largest single sale of mobile equipment in the industry to date. The Southern California Rapid Transit system installation marked the first application of digital signalling in a vehicular communication system. Other large system applications include the Long Island Railroad and the Tampa Airport Transit systems. These are but a few of the numerous RCA Land Mobile Communications Systems presently in operation.

Mobile and station equipment line

RCA has observed a marked increase in mobile communication equipment sales in the recent past. Many systems have been straight base/mobile applications, using local or remote control central points. The trend is towards more sophistication with specialized systems using interesting variations of controls and modes of operation. These systems require product designs which are flexible enough to accommodate both the ordinary and the extraordinary applications.

RCA has a broad variety of mobile and base equipment with many options and accessories available to perform other functions not normally provided as standard equipment. The Series 500 radio (Fig. 1) is a trunk mounted unit available in the 150-MHz and 450-MHz bands. It is all-solid-state except for the transmitter

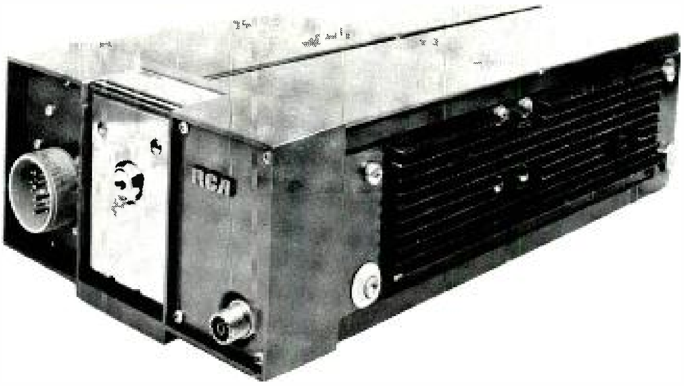


Fig. 1 — Series 500 all-solid-state radio.

Fig. 2 — Series 700 all-solid-state radio for trunk mounting.

Fig. 3 — Series 700 all-solid-state radio for automobile dash mounting.

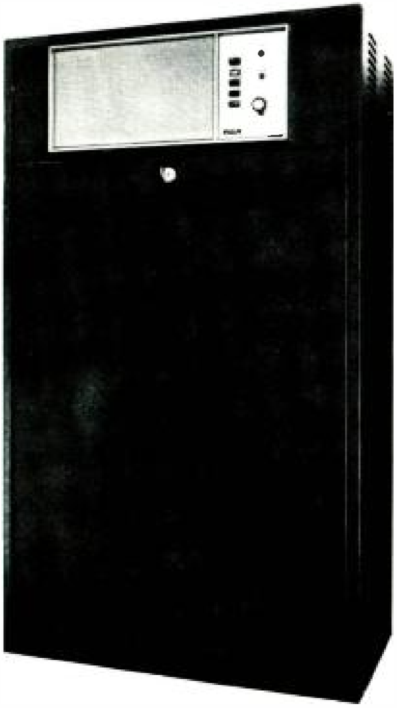


Fig. 4 — Series 500 base-station central communications equipment.

final stage. It is available in power output versions ranging from 40 to 110 watts. The Series 700 trunk mount (Fig. 2) is an all-solid-state radio available in all three frequency bands with power output options ranging from 25 to 55 watts for systems not requiring extended range coverage requirements. It is also available for desk-top mounting . . . and in a dash-mounted configuration (Fig. 3).

The Series 1000 radio is similar to the Series 700 but offers higher power output (with all-solid-state components) for greater talk-back range. It is of interest to note that all three product lines have mobile installations that are interchangeable as far as control units and control cables are concerned.

Fixed station equipment is available in companion frequency ranges to the mobile 500, 700 and 1000 product designs. Fig. 4 shows a Series 500 base station housed in a 38-inch cabinet with local control operation. Remote control operation via phone lines and dc signalling is also available. Higher power output versions are housed in larger size cabinets.

Data communication equipment

RCA "Voice-Plus" communications combines both voice and data messages into a single compatible two-way radio system (Fig. 5). This system enables virtually all routine intelligence to be transmitted by simply pressing a button. Data messages are encoded by 600-Hz tone modulation at a rate of 150 baud. The code format is an eight-digit asynchronous, two-out-of-five system. The total time required for messages transmittal is less than one second.

The Dial Cab Taxi system in New York City illustrates customer benefits that can be achieved utilizing Mobile Data Communications equipment. Problems that were resolved by employing the Voice Plus system centered around 1) overloaded radio channels 2) the desire to have a fair and efficient dispatch system 3) and, the desire to provide taxi drivers a means of signalling for help (silent alarm system).

RCA Voice Plus data equipment installed in the New York City system resolves all three problems as illustrated by the following example: A customer "calls in" requesting that a cab be dispatched for his use. The dispatcher, by means of mobile radio voice communications, indicates that a fare is available in a certain geographic location. When this information is received, those cabs desiring to obtain the fare, due to their proximity to it, depress a "bid button" in their vehicle. The "bid button" sends out a short, 1/2 second data burst which is decoded at the dispatcher's position. The decoded message is displayed and logged by means of the Voice Plus dispatcher equipment. Any number of cabs may respond to a particular fare by depressing their "bid button". All are logged on the paper tape together with a time stamp indicating when their bid was received. After all cabs bidding for that particular fare have been logged in, the dispatcher punches a time card for the fare (Fig. 6 shows the dispatching equipment). The cab having the last identification digit closest to the time stamp indication is given the fare. Data in this case provides a roulette type of dispatching and eliminates the possibility of favoritism on the part of the dispatcher, as all bids are automatically logged.

Fig. 5 — Voice plus two-way radio system for cab installations.

Fig. 6 — Voice plus dispatching equipment.

In addition, it greatly reduces channel congestion as the bidding period is far less than can be accomplished when voice communications are required to do the same job.

There are occasions when an attempt to rob or harm the taxi driver occurs wherein the driver would like to be able to use his radio for requesting assistance; data communications make this possible. A foot-operated alarm button allows the taxi driver to request assistance simply by its momentary activation. The alarm message is automatically transmitted to the dispatcher, at which time an audible alarm is sounded. The line printer logs the alarm in red, showing the identification of the taxi and the time at which the Alarm was reported. This silent alarm system provides centralized reporting, wherein the dispatcher can request aid for the particular taxi having a problem.

Some of the benefits of Mobile Data Communications are readily apparent in the Dial Cab System. Automation (automatic logging), greatly reduced channel congestion, silent alarm signalling, and overall improved system efficiency are readily illustrated in this short example.

Portable equipment

The transportation industry is escalating its use of personal communications rapidly. The recently introduced RCA TACTEC portable radio (Fig. 7) will find considerable application for operational security and increased supervisional control of personnel.

The application of new technology (beam lead passivated standard and custom IC's, and thick-film hybrid packaging) has resulted in a small, reliable, and maintainable high-performance unit. This degree of reliability permits the human-engineering conscious transportation industry to expand greater effectiveness to the person on foot. Bus companies can obtain a smoother traffic flow and keep transportation running on schedule with the balanced loading, using street corner bus dispatchers.

The recent rash of plane hijackings has made the airlines extremely security conscious. In addition to new search procedures, added portable radios are needed to coordinate all security personnel with airlines people, including baggage handlers. By using RCA TACTEC (totally advanced communications technology) portable radios, the airlines ground support personnel can work quickly and efficiently with the additional supervisional control and coordination in situations involving passenger information, air freight flow, security and emergency repairs.

On the horizon

There are numerous new and promising systems on the horizon; some of these can be illustrated as follows:

1) *A passenger demand activated bus system* by either phone or two-way radio complete with computer logging and dispatching of calls, origins, destinations, passenger count and vehicle location.
2) *Exclusive right-of-way personal transit* automatically routed over network guideways serving low-to-medium population density areas of a metropolis.
3) *Dual-mode vehicle systems* in which small vehicles can be individually driven and converted from street travel to travel on automatic guideway networks.
4) *Automated dual mode bus*, a large vehicle system which would combine the high-speed capacity of a rail system operating on its own private right of way with the flexibility and adaptability of a city bus.
5) Pallet or ferry systems, an alternative to dual-mode vehicle systems in the use of pallets to carry (or ferry) conventional automobiles, minibuses or freight automatically on high speed guideways.
6) *Fast intra-urban transit lines* automatically controlled vehicles capable of operating either independently or coupling into trains, serving metropolitan area travel needs between major urban modes.

Fig. 7 — Tactec series of personal, portable, two-way communications package.

Although these new concepts for intra-urban transportation require breakthroughs in technology, design and development, they exist today and for tomorrow's transportation system whether it be the mass transit including railroads, interstate bus lines, airlines, taxis or subways. The need for effective communications between the operations room and the vehicle is evident in all instances.

Conclusions

Transportation system managers are turning more and more to two-way communications, both vehicular and personal, to improve their operational methods. RCA, through its Commercial Communications Systems Division, is aiding this industry by providing innovative equipment and systems designs which meet users groups needs.

Much research is presently going on, both in and out of RCA, into a practical method of automatic vehicle location and monitoring. The maturation and reduction to practice of this research is certain to open up a communications market in this industry which far exceeds its present status.

Acknowledgments

Credit is extended to Harold Addison, Joe Hillman, Andrew Missenda, Walter Painter and Bill Stewig for their assistance in the preparation of this paper.

SECANT: a solution to the problem of mid-air collisions

J. L. Parsons

SECANT is a system for the Separation and Control of Aircraft using Non-synchronous Techniques. This cooperative, transponding collision-avoidance system, designed to be compatible within the entire aviation community, is capable of accommodating the dense air traffic anticipated for the 1980s and beyond. It makes available to the pilot evasion or escape maneuvers in any direction — vertical, horizontal, or a combination. SECANT helps the pilot to avoid mid-air collisions by transmitting probes and receiving replies within a 1-microsecond pulse up to 1000 pulses/s on 24 different frequencies. Various discriminants are used to eliminate undesired signals, and the false alarm rate is zero. The capabilities of each of the following modular equipments are discussed: remitter, proximity warning indicator, vertical escape collision avoidance system, vicinity traffic finder, collision-avoidance system, and traffic-monitoring system. The correlator, which transmits a randomly selected frequency probe and, when a corresponding frequency probe is received, retransmits an appropriate reply, is described. The theory of operation is presented, and development plans are outlined.

J. L. Parsons, Mgr., Aviation Program Operations, EASD Aviation Equipment Department, Van Nuys, Cal., received his BS degree in electrical engineering from LaSalle College. Since joining RCA in 1953, Mr. Parsons has held various assignments in engineering design and development areas involving tactical radar and associated display systems. He assisted in the development of an analog diode switch for the TALOS tactical displays, conducted a development program for electronically controlling the coefficients of the Fourier Series for high-speed symbol generation, and developed the basic logic for the BMEWS tactical monitoring display system. Following these programs, Mr. Parsons was responsible for the development and fabrication of the high-resolution kinescope television recorder for the Ranger moon probe system that was used to produce the first TV pictures from the moon. Prior to his present appointment in Aviation Equipment Department where he is responsible for product management of RCA's line of navigation and communications equipment, Mr. Parsons was successively Manager, Display Engineering; Manager, Military Aviation Products and Systems; and SECANT Program Manager. In the SECANT program, he was responsible for system concept, development, and design; new business and marketing; and coordination and liaison within RCA and with external customer organizations. Mr. Parsons is a charter member of the Society for Information Display and is a member of IEEE, the Institute of Navigation, and the Army Aviation Association of America.

SECANT is a cooperative transponding system developed by RCA, as a solution to the aviation industry's most pressing air safety problem; mid-air collisions. From the very beginning RCA's system design was based on the following specific requirements. RCA believes emphatically that certain requirements must be met by anv collision avoidance system before it can be adopted as an international standard.

Collision avoidance system requirements

RCA has established criteria for the SECANT system in the form of the following set of six minimum requirements:

1) An aircraft collision avoidance system should be compatible within the total aviation community. General aviation should participate fully, along with the commercial and military sectors. RCA believes further that, as a condition of entering air space where there is a possibility of a collision, every aircraft should at least carry an equipment that will enable more sophisticated collision avoidance equipment to detect its presence. Thus, in its simplest form, such equipment must be inexpensive to buy or perhaps should be available on a rental basis.

2) The system must accommodate the dense air traffic expected over terminal areas by the 1980's and beyond. There can be only one standard collision avoidance system, with each aircraft carrying the equipment which makes it a participant. It is economically impractical to carry several types of equipment to perform the same function in different geographical locations. If a system only satisfies today's problems, it would be certainly ill advised to install that system now, and accept it as the standard. A system not geared to future growth in air traffic would be worse than no system at all because it would impart a false security.

3) The system must be highly reliable and have a near-zero false alarm rate. False alarms can quickly destroy the pilot's confidence in the system...and to the degree that he may disregard a warning signal at the very moment when the pilot most needs to be alerted. In the development of any collision avoidance system, the advantages of early warning times must be traded off against the disadvantages created by false alarms or pre-mature warnings. The earlier the warning, the more likely and frequent the false alarms, to the point where the system would be creating more problems than it was conceptually designed to solve. The key to this balance between early warning times and a zero false alarm rate is in the threat discrimination performed by the system. RCA's SECANT system, because of its more precise and accurate measurement capabilities, provides a better and more sophisticated analysis of threat situations.

4) The anti-collision system must be complementary to the normal air traffic control system (ATC) and its procedures; it should not force significant changes in air traffic control methods; and, if possible, it should reduce the overall ATC problems that now exist. To accomplish this, the

---

Reprint RE-18-6-4
Final manuscript received February 25, 1973.

system should provide a means for the communication of the data being gathered relative to the threatened aircraft encounter into the ATC system on the ground. An airborne system should be capable of providing more accurate data in regard to the actual threat situations than that being gathered by ground based radar installations.

5) As a basic criterion, RCA believes that a true collision avoidance system must make available to the pilot possible evasion or escape maneuvers — in any direction, vertical or horizontal. This is one of the cornerstones in the SECANT system concepts. Ideally, the system should prevent the development of situations in which the pilot is required to make abrupt changes in course. It should give him ample warning, in time to make controlled maneuvers, with maximum safety and comfort for his passengers.

6) All aircraft, including those minimally equipped, should have systems which are completely operational without any reliance on external signals, which at times during a flight could be unavailable. One area where signals might not be available is over the oceans.

In addition to these minimum requirements, RCA believes that an anti-collision system should have other important characteristics: All versions of the system, from the simplest to the most sophisticated, should be included in the same signal structure and frequencies. Additionally, RCA believes that a growth capability to "preventive flying" should be inherent in the system design. This suggests that an airline pilot, intending to change course, should be able to consult a visual traffic display to avoid getting into trouble on the new course.

The SECANT concept

SECANT is a cooperative transponding system which operates at L-band. SECANT performs the collision avoidance function by transmitting probes and receiving replies with a 1-microsecond pulse, at a rate up to 1000 pulses per second, on 24 different frequencies. Various discriminants are used to eliminate the undesired signals or "fruit": different frequencies and probe spacings are allocated as a function of altitude of the flight of the aircraft; the fields above and below the aircraft are probed separately; analog thresholds are established, based on the range required for the collision avoidance function, which discriminate against signals coming from aircraft too far away to be involved.

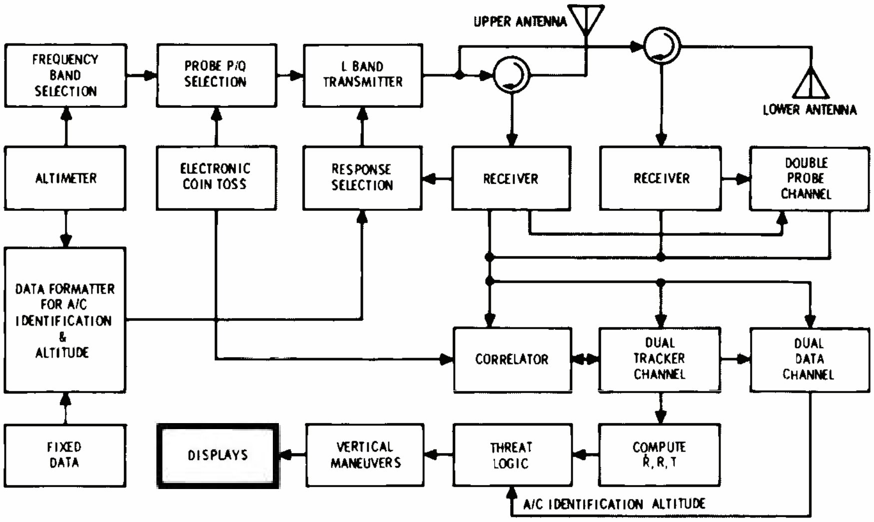


Fig. 1 — Block diagram showing the key correlation process.

The most important techniques used in the system are the correlation techniques performed by the correlator (Fig. 1). The correlator processes those signals that remain after other forms of signal discrimination have been performed and extracts true replies (replies to your aircraft's interrogation) from the remaining undesired replies or "fruit." Having separated true replies and identified the presence of a potential threat, a tracker is assigned and accurate measurements are taken on slant range and closure rate. The system performs the mathematical operation of dividing range by closure rate; it thus defines the time-to-closure or *TAU*. While this is taking place, the system is exchanging digital data between the aircraft. This data contains such things as aircraft identity, altitude, heading, airspeed, and indications of intended course change. In the full collision avoidance system, SECANT is measuring bearing during this same tracking period. SECANT uses this measurement of bearing to compute miss-distance for purposes of an enhanced threat discrimination and to provide information for the capability of horizontal as well as vertical escape maneuvers.

From the outset, SECANT has been designed as an anti-collision system in which all aircraft would participate. To further this goal of universal participation, RCA has worked toward developing a modular family of reliable and mutually compatible equipments with equipment modules geared to the needs and financial means of the various members of the aviation community. For the light plane owner, SECANT will provide a remitter at a price which makes it economically feasible for the full participation of all general aviation. It is important here to note that the findings of the U. S. National Transportation Safety Board showed that 98% of the mid-air collisions in the decade of 1959 to 1969 involved a general aviation aircraft.

Like the time frequency system, SECANT is a cooperative system; but, unlike time frequency, SECANT is a non-synchronous transponding system and as such does not require time synchronization references broadcast from satellites, from other aircraft, or from ground stations. Time synchronization reference stations are not required in the SECANT system. The frequency accuracies required within the SECANT system, one part in 10^6, are well within the state of the art.

The word "non-synchronous" is critical here, since it describes a remarkable advance in communications technology. In SECANT, extremely large numbers of communicating equipments, all using the same frequencies and basic message structure and all transmitting at will without any pre-arranged order or sequence, can accomplish the transfer of quantities of information from each one to all of the others, without the slightest confusion or interference, and with each source unambiguously identified.

Heretofore, any such data interchange among a large number of participants required synchronization so that each transmitted in turn and then listened for messages from the others; any other approach would have resulted in crippling mutual interference. SECANT has eliminated this problem and with it all the paraphernalia associated with synchronization: costly precision or precisely resynchronizable clocks within each equipment, even more costly atomic clocks spread throughout the system as primary standards to maintain the system's time base, complex queueing schemes, and the like.

The SECANT system uses low transmitter power. In almost all cases, solid-state output stages provide for the highest possible reliability.

The full collision avoidance system differs in yet another way from other systems—it computes and utilizes an additional threat discriminator: miss-distance, the separation distance between the aircraft at their closest point of approach. This additional threat discriminator helps to further minimize false alarms and allows earlier, and thus more gradual, disengagement in either the vertical or horizontal plane.

The SECANT system includes optional provisions to send information on air-to-air encounters to ATC ground control centers with what RCA terms the "hot line." This provides accurate information of the encounter to the air traffic control center which, if desirable, could then participate in the disengagement and thus achieve more coordination. The SECANT concepts are adaptable to many other applications such as air-to-air stationkeeping, terrain hazard markers, instrument landing systems, and search and rescue locator beacons.

The additional threat discriminations performed by the full SECANT system to discriminate against false alarms mean that longer escape times can be employed. SECANT is designed to provide between 45 and 60 seconds escape time, counting from the particular time in which escape maneuvers are initiated. Other systems do not issue their escape commands until approximately 25 seconds before contact.

The SECANT system design involves two fundamental aspects. The first is the system technique, as described above, for locating and gathering data on an intruder; the second aspect deals with the operational choices of threat definition and the selection of escape maneuvers to be employed. SECANT and other collision avoidance systems differ in a fundamental and mutually exclusive manner with regard to the first aspect, electronic system technique. However, in the operational area, the full SECANT system differences are ones of augmentation and enhancement rather than opposition. These enhancements are being treated as a separate area for discussion, development, and evaluation. When and if they are required, they can be added as an evolutionary development. All systems are completely compatible.

Certain SECANT fundamental characteristics were built in engineering experimental systems and successfully flight tested in 1971 by the developing company. U. S. Navy tests also started in 1971 and were completed in February of 1972. There are currently under development three engineering experimental models of a system, not utilizing bearing, that will provide the complete operational capability defined in the Airline Industry Document ANTC-117. This system has been termed VECAS (vertical escape collision avoidance system) and is a member of the SECANT family of modular systems. These models are expected to be flight tested during the summer of 1973 in order to evaluate SECANT as a candidate for an international standard airborne CAS.

With this understanding, the SECANT modular systems can be divided into two groups. The first group is within the operational requirements of the ANTC-117 document and includes a remitter, proximity warning indicator (PWI), a vertical escape collision avoidance system (VECAS), and a simplified more economical version of VECAS known as VECAS-GA intended for general aviation use. The second group of systems, compatible with the first, extends the system capability beyond the requirements of ANTC-117 by adding bearing. This group includes a vicinity traffic finder which uses sector bearing only, a collision avoidance system, and a future system termed the traffic monitoring system. These latter two systems use bearing to provide an additional threat discriminant, miss distance calculation; and to provide for horizontal, vertical, or combination maneuvers.

The modular system

The SECANT system is a modular one. All of the family of equipments, from the simplest to the most sophisticated, include a remitter. The remitter makes possible the operations between all types of aircraft from the smallest general aviation aircraft to the highest performing civil or military jet. The capabilities of the SECANT system for each of the modular equipments are as follows. The remitter alone is a unit which can be used as a ground-based hazard marker or it can be used in an aircraft to make that aircraft electronically visible to any aircraft carrying a more sophisticated SECANT equipment; for example, the PWI, VECAS, VECAS-GA, VTF, or CAS. The pilot in the remitter-equipped aircraft has no indication that he is being threatened, so it is up to the more completely equipped aircraft to make the evasive maneuver. The remitter is the cheapest and least sophisticated member of the SECANT family of equipments, but it provides the lowest cost unit for general aviation aircraft to participate in the SECANT system.

The next level of sophistication is the proximity warning indicator (PWI). This equipment provides the pilot with an alarm when an intruder penetrates a pill box shaped shield surrounding his aircraft. The pilot has the ability to adjust the radius of this shield by a simple adjustment on his PWI unit and it, for example, could be varied from 0.2 nautical miles on out to 4.0 nautical miles. He would adjust the range depending on whether he is traveling enroute or in terminal traffic. It is expected that general aviation and military aircraft will utilize this equipment.

The vertical escape collision avoidance system (VECAS) is the next level of sophistication. The system gathers accurate range and closure rate information, determines the *TAU* state of the intruder, receives data including altitude, processes the information, determines the appropriate pilot commands in accordance with ANTC-117, and appropriately displays the commands to the pilot. This equipment will be suitable for business aircraft, air carriers, and certain military aircraft.

A less sophisticated and more economical version of VECAS, known as VECAS-GA, is intended for the light to medium class aircraft of general aviation. VECAS-GA is a complete collision avoidance system in that it detects all intruders, evaluates all threatening encounters and issues escape commands to the pilot in accordance with the ANTC-117 document but does so via a simpler and less costly display type indicator designed especially for general aviation use.

The vicinity traffic finder (VTF) is the first level of equipment sophistication that includes bearing measurement. It assists the pilot in visually acquiring the threat. The system gathers accurate range and closure rate information, computes *TAU*, receives data including altitude, and measures bearing to within ±15 degrees. All of this data is then processed for threat discrimination. VTF has sufficient information to appropriately display to a pilot the time to closure, the intruder's relative altitude, and at what relative angle within ±15 degrees he could expect to visually sight the intruder. The pilot then initiates his own evasive maneuver after having visually acquired the intruder. This equipment will be suitable for business aircraft, air carriers, and the military.

The next level of equipment is the complete SECANT collision avoidance system (CAS). This system gathers the same information as that of the Vicinity Traffic Finder but it has added additional data computation. It computes miss distance which provides an additional significant criterion for determining, to a high probability, whether or not a threatening encounter will occur. The information gathered, including bearing measurement, also is used to call upon a particular combination of stored vertical and horizontal escape maneuvers and to issue those instructions to the pilot. The use of the additional threat discriminant provides for the early determination of the need for evasive action. The system will provide a warning as early as 60 seconds. This system has enough information to advise ATC ground control centers with detailed and accurate data on the threatening aircraft encounter, along with intentional change of course of any aircraft. This information could be sent to the ATC ground system via a separate hot-line channel. This equipment will be suitable for air carriers and high performance military aircraft.

The highest level of sophistication planned will be incorporated in a future optional configuration called the traffic monitoring system (TMS) which will assist in preventing the development of a threatening encounter. This SECANT system will gather enough information on each intruder so that, with some additional data processing, potential threats as well as immediate threats could be identified. This information could be displayed on a Plan Position Indicator display within the cockpit. The pilot then could recognize that there is a hazardous traffic nearby. The larger air carriers and sophisticated large military aircraft could utilize this equipment.

The SECANT family of collision avoidance systems is a modular one. The remitter is a transceiver only which does not issue probes, but does reply to incoming probes of proper altitude code. In the PWI, the transceiver has the ability to issue its own probes, and has a means of separating incoming replies that are intended for other aircraft from those replying to its own interrogations. The correlator performs this signal separation function. The correlation is performed within a pre-determined listening time following the interrogating pulses. When the replies are within the range of interest, a threat indicator is lighted to warn the pilot. To form the VECAS, the capability of range tracking is added. After having detected a target, a tracker (similar to those in radars) is assigned, range on each reply to the interrogations is measured, and the results are integrated over a period of time. This integration provides an accurate measurement of range and range closure rate. The system then computes time to closure *TAU* by dividing range by closure rate. During the tracking operation, the target aircraft sends data to the interrogating aircraft. This data contains aircraft number, altitude, etc. The gathered information (range, closure rate, *TAU*, and altitude) is then processed against ANTC-117 threat logic and pilot commands are generated and displayed.

The vicinity traffic finder uses a triad antenna located on top and bottom of the aircraft. During the time of tracking, the electrical phase difference between pairs of elements is measured for each arriving reply pulse. The electrical phase measurement being made is integrated over a series of pulses and then converted from an electrical phase angle into a relative angle between aircraft. The accuracy of the measurement is expected to be ±5 degrees but with a precision of ±0.3 degrees. That information can then be used to determine the actual relative direction of the intruder aircraft within the ±15 degrees that is considered adequate for a pilot to visually acquire the aircraft. The pilot can then have displayed to him the range, time of closure, relative altitude, and relative bearing of all aircraft determined to be threats.

The collision avoidance system is formed by adding additional data processing and by adding escape maneuver logic and escape commands to the display. The additional data processing is used to further evaluate an intruder that is determined to be threatening from the altitude, range, and *TAU* criteria. Using the bearing measurements, range, and closure rate data, closest point of approach or miss distance is calculated and then compared to the value of miss distance established as the criteria for a threat. If the intruder is determined to be a threat, the escape maneuver logic determines the optimum escape maneuver: either vertical, or horizontal, or a combination. The system then issues the escape commands through an appropriate display to the pilot. All information gathered in the collision avoidance system, and the results of the data processing, can be expanded to determine if non-threatening targets should be treated as hazards. Targets which are non-threatening but hazardous can be displayed to the pilot for ready reference to help guide him in the operation of his aircraft. This would assist him in preventing the creation of a threatening encounter.

Principles of operation

SECANT is a cooperative transponder system in which each aircraft probes its environment at up to 1,000 pulses per second. Transponders are hardly new, but SECANT's differs from all predecessors by encoding every question in a unique form that evokes a unique response, so that each aircraft can tell which of the many thousands of replies that may fill the air at any instant are answers to its own interrogation. Further, each interrogation from a given airplane differs from the one that preceded it in a random, but carefully remembered manner, so that no two aircraft can end up using the same code words.

Each SECANT-equipped aircraft selects a set of frequencies depending on its altitude, see Fig. 2. Having selected the appropriate frequency set, the aircraft then makes a selection of one of two frequencies for probing. Each probe transmission must be and is an independent decision on which frequency is used. The decision to send either a "P" frequency probe or a "Q" frequency probe is done in a statistically random manner. Therefore, over a reasonable period of time, an equal number of decisions are made for P, as for Q, by each aircraft within the system. There is an associated set of frequencies used to reply to each probe frequency. Each aircraft in SECANT listens for a particular set of incoming probe frequencies on its lower antenna and a different set on its upper antennas. It must reply in kind to the frequencies received; for example, if a P-type probe frequency is received, the reply must be made with a P-type reply frequency; if a Q-type probe frequency is received, the reply must be made with a Q-type reply frequency. Since there are an equal number of P and Q frequencies being generated as probes, it therefore follows that there will be an equal number of P and Q frequencies produced as replies. If a snapshot of the signals present at any given instant were taken, regardless of the density of traffic, there would be an equal number of both P and Q probes and P and Q replies. If a (+1) value were assigned to all P-type replies and a (−1) value to all Q-type replies, and the P and Q replies were integrated in an up-down counter over a series of pulse times, the plus count and minus count would balance and there would be a statistical annihilation of signals which would produce a near-zero net count over the integration time period. As described later the SECANT correlator provides a means of introducing a bias into this statistical process such that reply signals to the interrogating aircraft's probes integrate in a positive manner, while the signal exchange taking place between other aircraft annihilate each other. Detection of a target is accomplished by determing if positive integration of signals has occured.

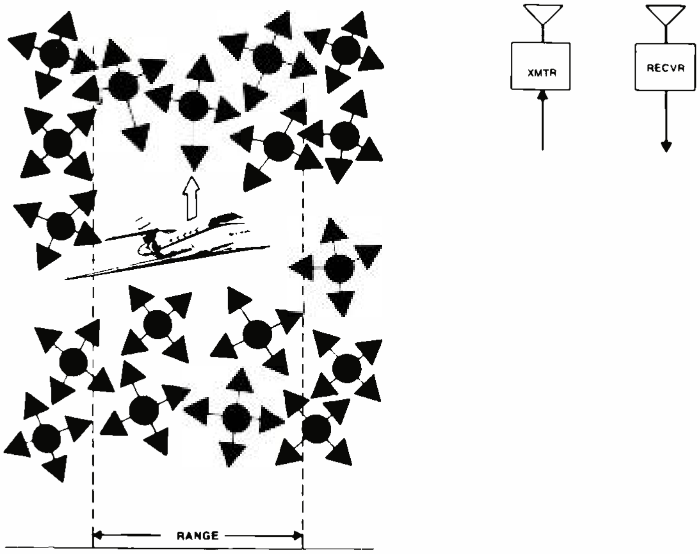


Fig. 3 — Representation of basic inputs to the aircraft without the application of SECANT discriminants.

As an example of how the SECANT system would perform, assume a general aviation aircraft flying below 10,000 feet (Fig. 3); in this example, dots represent other aircraft and arrowheads represent the multitude of signals, both probes and replies, taking place between all these aircraft. The situation depicted corresponds to each aircraft having a transmitter that is sending probes and a receiver that is listening to all the pulses present. Two antennas are used, one mounted in forward top area and the second in the forward lower area of the aircraft. The SECANT system uses a number of techniques to eliminate the undesired signals and to extract those signals that are meant to reply to your probes. Since this aircraft is flying below 10,000 feet, a particular set of 12 frequencies is used for the collision avoidance function.

The first technique used by SECANT to reduce the number of targets to be interrogated simultaneously is called altitude probe coding. Altitude layers (Fig. 4) 500 feet thick below 10,000 feet and 1000 feet thick above 10,000 feet are assigned distinct codes. Each aircraft answers only those probes that represent its own altitude and rejects all other codes. Each aircraft probes not only its own altitude layer but also altitude layers above and below. The altitudes layers of interest can extend to 3300 feet when climbing or descending. This technique is also a powerful discriminant against fruit in the reply channel as each aircraft answers only a portion of all of the probes.

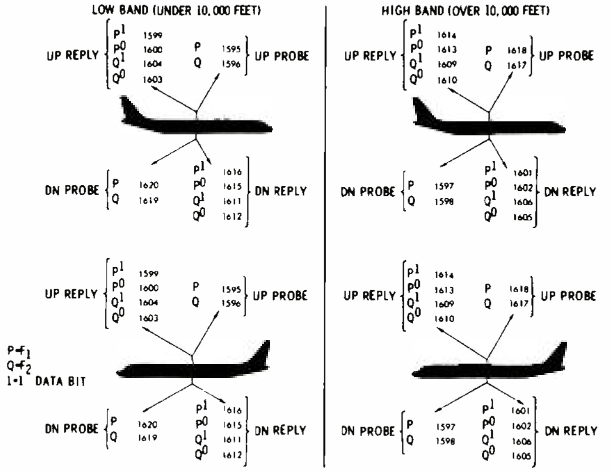


Fig. 2 — Sketch showing SECANT frequency application in up-field and down-field space.

As the next discriminant, SECANT uses a different set of six frequencies above the line of flight than is used below the line of flight, see Fig. 4. The SECANT system always listens on both the top and bottom antenna simultaneously; however, in probing operations, it probes first in the field above and then in the field below, alternating until it finds a target of interest. In addition to choosing a different set of frequencies for interrogating above and below the line of flight, each interrogating pulse is randomly jumped in time, up to a quarter of the repetition time, to provide a pulse jitter which prevents an accidental time phasing of signals between aircraft. The use of different frequencies above and below the aircraft provides about 30% reduction of other-aircraft signals and altitude coding of the probe signals allows the aircraft at one altitude to be interrogated without aircraft at other altitudes answering on the same probe.

The next technique employed by SECANT to eliminate undesired signals is to purposely set the power budget within the transmitter system in conjunction with an analog threshold circuit in the receiver system, so that signals which are too far away to be of interest for the collision avoidance function are eliminated, see Fig. 5. For example, below 10,000 feet, SECANT uses 25 watts of transmitter power, and the analog threshold is appropriately set so that aircraft beyond 7.5 miles will not have sufficient signal to cross the threshold and, therefore, will not be correlated. Thus, all aircraft beyond a 7.5 nautical mile range will have been eliminated through a power budget and an analog threshold technique.

The next technique that is used is the heart of the system design: the correlator Each SECANT-equipped aircraft follows two rules: (1) transmit a randomly selected P or Q type frequency probe; and (2) when a P or Q type frequency probe is received, re-transmit a P or Q type frequency reply, see Fig. 6. The aircraft issuing the probe pulse knows whether it issued a P or a Q. The receiver circuits separate the incoming P and Q frequencies as they are received and direct the signals in an appropriate fashion to an up-down digital counter, see Fig. 7. During each probe time, the pulses can be routed such that one type causes an up count and the other type causes a down

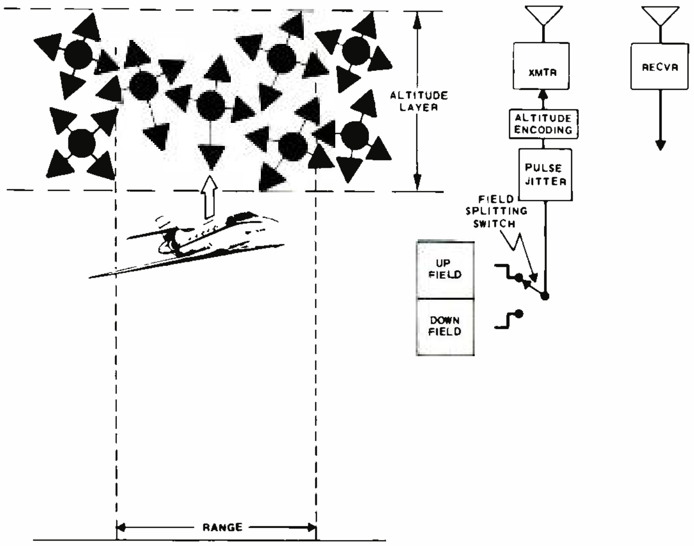


Fig. 4 — SECANT signal separation as a result of up-field and down-field discrimination.

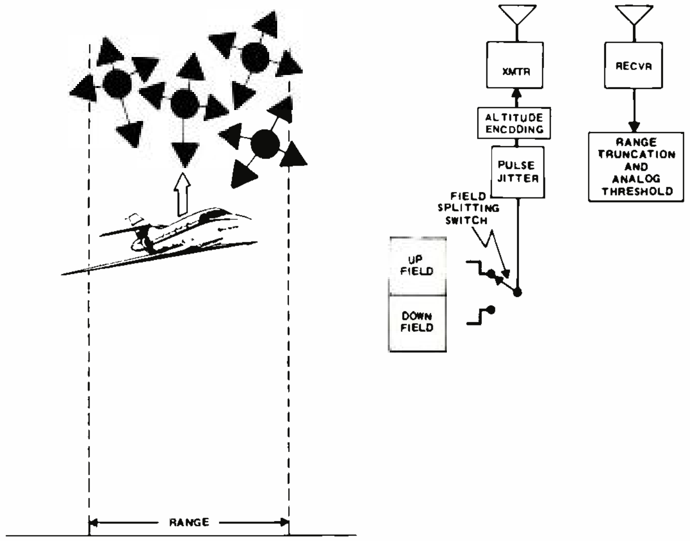


Fig. 5 — SECANT signal seperation as a result of range truncation and analog threshold discrimination.

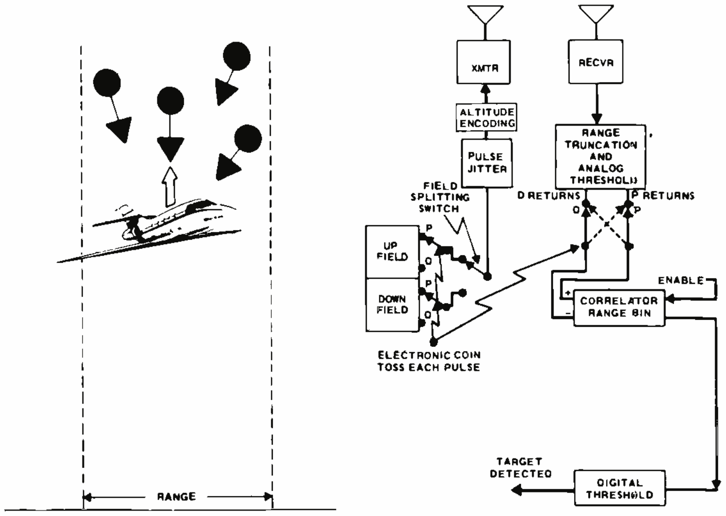


Fig. 6 — SECANT signal seperation as a result of correlator range bin and digital threshold discrimination.

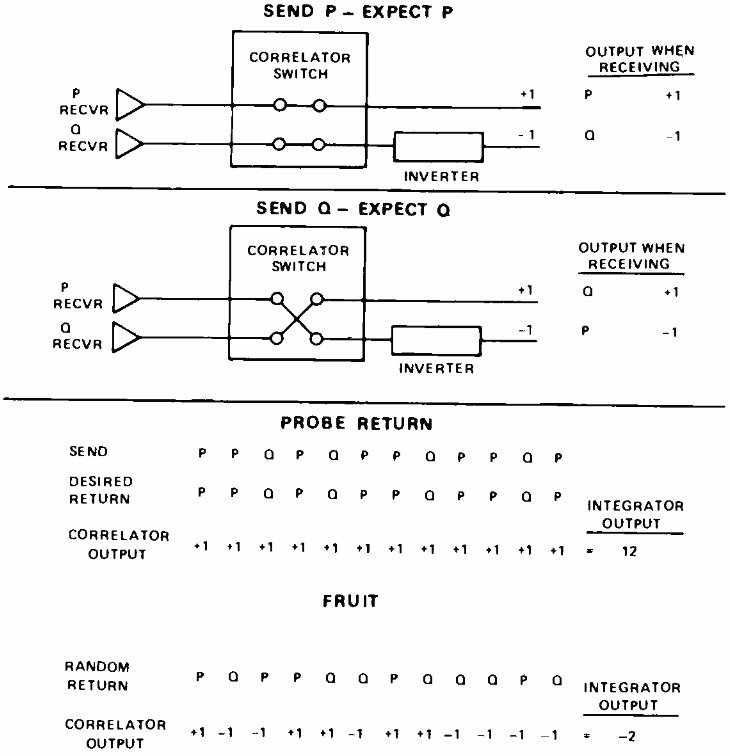


Fig. 7 — The correlator function.

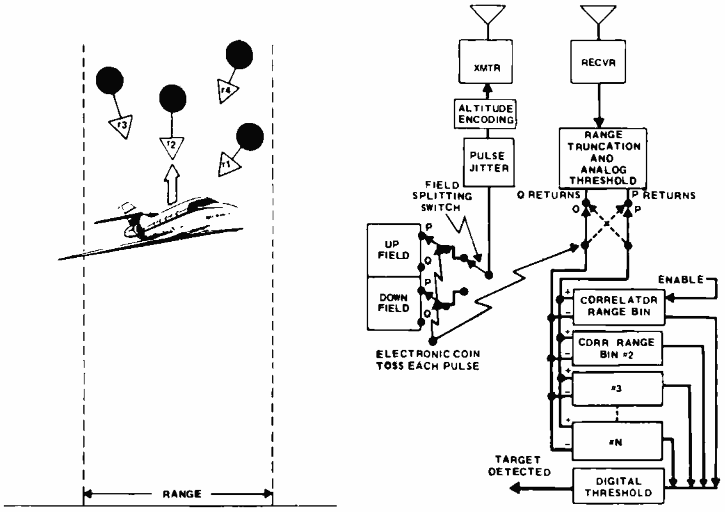


Fig. 8 — SECANT signal seperation as a result of sequential range bin discrimination.

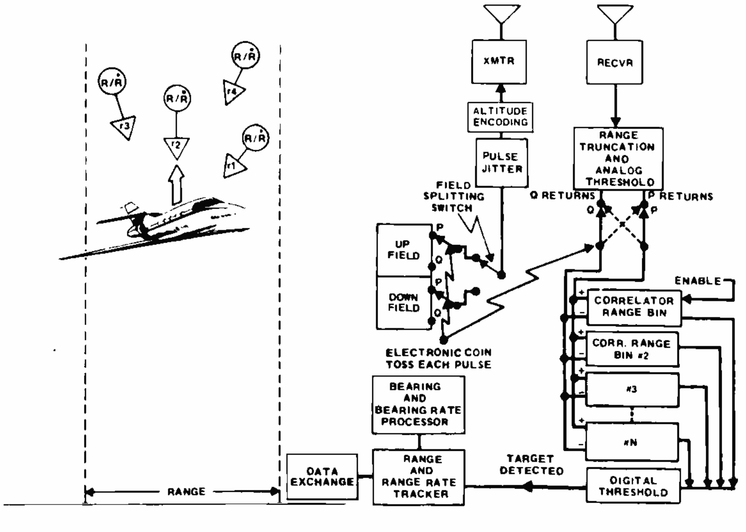


Fig. 9 — SECANT signal seperation as a result of tracker assignment.

count. Since the equipment knows whether it transmitted a P or a Q, it also knows that a returning reply will come in on a corresponding channel; that is, if a P probe was selected, a reply from the target aircraft will be on the P channel. Other aircraft could also have been interrogating with P frequencies, so that there may be other P reply frequencies present which are not intended for the interrogating aircraft. There will also be Q reply frequencies present which are of no interest. The desired and undesired P frequencies are sent to the plus side and counted as (+1) each; the undesired Q frequencies are sent to the minus side and counted as (−1) each. On the next pulse, if a Q is selected, the switch is changed so that incoming Q replies are now counted as (+1) and incoming P replies are counted as (−1). During this period of time, if another aircraft is replying, it must be replying on a Q channel and this Q reply will now be counted as a (+1) as was the P reply in the previous example. In this way, the replying aircraft will continue to have a (+1) value assigned to its replies. Replies not intended for the interrogating aircraft will cause self-annihilation within the up-down counter. The true replies integrate in a positive manner and the results of this integration can then be compared after a period of time to a fixed number used as a digital threshold. If the results exceed that threshold, the SECANT system declares that there is an aircraft-of-interest present and replying to the probes.

The detection of a target is sufficient for the PWI version of SECANT. In the PWI system, a single correlator is used to cover the entire range of interest. The pilot determines the range by setting his range shield to between 0.2 nautical miles to 4.0 nautical miles.

However, if more information is desired on the encounter (such as is needed in the VECAS, VTF, CAS, and TMS systems) then more correlators (range bins) and a tracker must be added. To assign the tracker, more accurate information is needed about the location of the target. This is obtained by using a multiple series of range bins which will be sequentially enabled as a function of time after each interrogation pulse, see Fig. 8. These correlation range bins are designed to look at a 1-microsecond time slot (or a 503-foot range band) radially away from the aircraft. When one of these correlators finds an intruder, it is not only detected but its position is known to within a 500-foot range band. A tracker is then assigned to that particular range band and locks up precisely on the center of the target, staying with the target for as long as 700 pulse times, see Fig. 9. This length of sampling time provides a statistical reduction of random errors (as created by noise, for example), and precisely determines the range and closure rate. The aircraft that is replying is also sending a digital data message by sending a logical one or a logical zero by selecting one of two frequencies for either P-type or Q-type replies. During the time the tracker is assigned, the digital data bits being transmitted are detected by noting the frequency of each return pulse. Additionally, the electrical phase of arrival of each pulse is being measured, summed, and integrated. Thus, at the end of the tracking time, range, closure rate, and bearing have been measured and the data message has been received. With this information, the data processing computes the determination of a threat, the selection of an escape maneuver, and the selection of the necessary pilot commands.

The SECANT tracker actually has three modes of operation: a test-track mode, a half-track mode, and a long-track mode. Upon initial correlation of the target, the SECANT system assigns the tracker in a test-track mode. In this mode, range and closure rate are measured. The target is rejected if it has a sufficiently large *TAU*; if not, the tracker initiates the half-track mode. In this mode, range and closure rate data is then refined and altitude data is exchanged. This range, closure rate, and altitude data is used to determine if the target is of any further interest. If the target is not of further interest (either because it is not co-altitude, or it is too far away in range, or it is opening in range), the track is then broken and a search is made for the next target. If the target is co-altitude and has a time of closure of less than 60 seconds, the system stays with the target for an additional length of time. The test-track, first half-track, and second half-track time are each 400 milliseconds long. The additional data gathered during the last 400 milliseconds includes a more accurate determination of range and closure rate and a complete statement of data including aircraft identity.

Conclusion

In summary, then, the SECANT operational sequence accepts all replies to the probing aircraft and rejects undesired signals through various means such as frequency selections, signal strength, correlation methods, and range determination, see Fig. 10. Having rejected the undesired signals and having determined that a target is present, the tracker is assigned. Range, range rate, and bearing are measured; data is exchanged; and computation of miss distance is then made. If the target is a threat, action is then initiated within the system to provide data to the air traffic control center (that is, to initiate transmission of data through a hot line channel), if that channel has been implemented. At an appropriate time, escape maneuver instructions are then provided to the pilot. In the full SECANT system, either the vertical or horizontal or combination maneuvers can be provided.

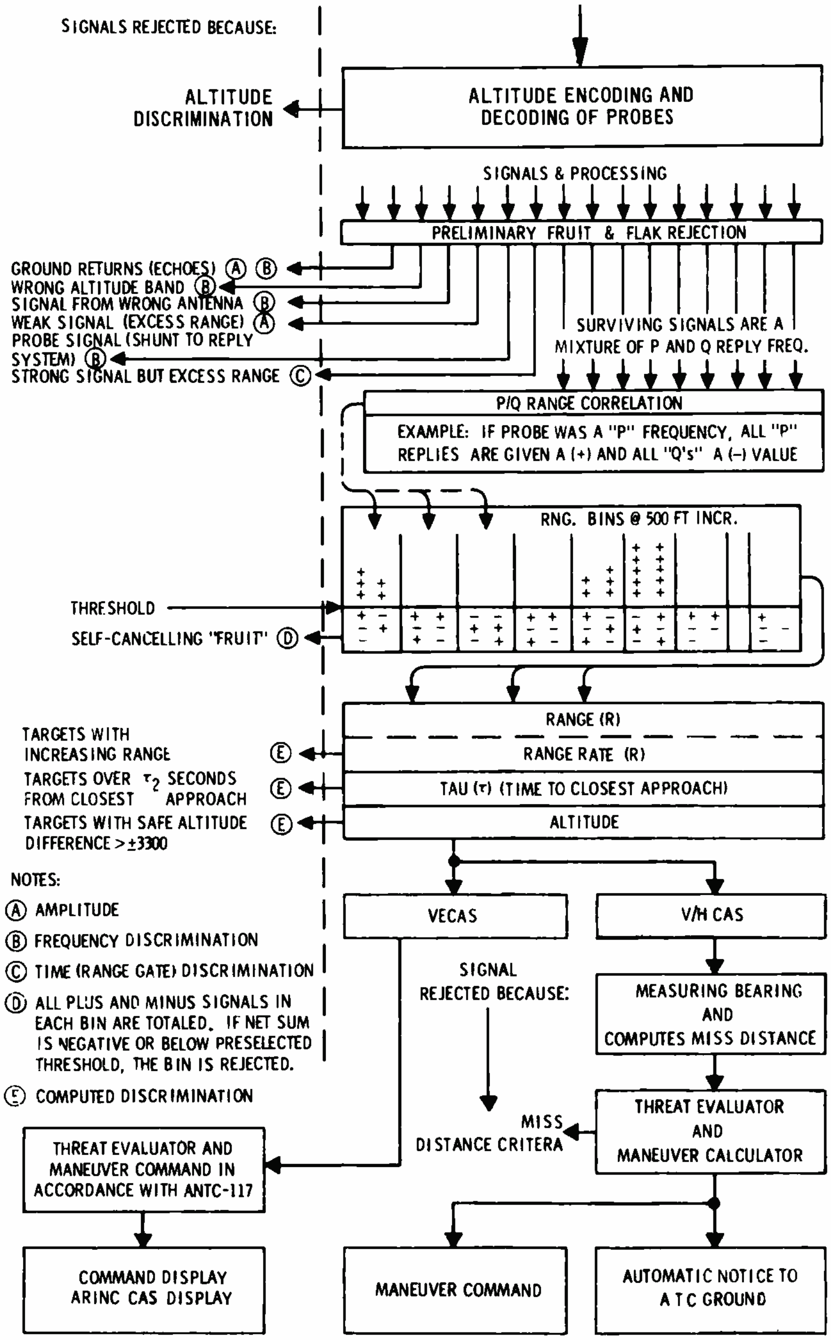


Fig. 10 — The SECANT operational sequence.

Frequency spectrum of commercial airborne avionics

G.A. Lucchi

Avionics employs a substantial portion of the available frequency spectrum—a condition that directly affects the designer of RCA commercial aviation equipment. In this paper, the author reviews and discusses the various RCA aviation equipment designs and their assigned operating frequencies.

THE AIRBORNE navigation and communication equipment used by both general aviation and the airlines operates throughout most of the practical radio-frequency spectrum, and as new and higher frequencies become practically available, aviation will find applications for them.

Choice of frequency

It has been empirically verified that very low frequencies generate strong ground waves that travel through the ground and propagate at relatively long distances under water. As the frequency is increased, the radiated radio-frequency energy is radiated in space and reflected from the heaviside (ionosphere) layer, and above 30 MHz (depending on time of day and year) the r-f energy is no longer reflected. It travels into space. For this reason, long-range communication is not possible at high frequencies (except for forward-scatter techniques), and satellites are needed for this line-of-sight communication. It is not the purpose of this paper to delve into the attenuation of radio waves by vapor (including rain), which generally increases as the frequency is increased, but it must be considered when choosing a frequency for providing a specific application.

Reprint RE-18-6-7
Final manuscript received October 13, 1972

G.A. Lucchi, Mgr., Engineering, Aviation Equipment Engineering, EASD, Van Nuys, Cal., received his BSEE degree from the University of California at Berkeley and completed MSEE graduate studies at UCLA. Since joining RCA in 1955, he has participated in the development of the BOMARC target seeker radar, BMEWS surveillance radar, air traffic control transponders, distance measuring equipments, and weather radars. Before joining RCA, Mr. Lucchi was with the CAA (now FAA) for eight years. As project engineer on the ATC transponder efforts, he was responsible for the development of a special evaluation equipment under contract with the FAA which has been used to evaluate the present ATCRBS, resulting in the present system configuration. Following this effort, the AVQ-60, AVQ-65, and the present AVQ-95 ATC transponders were developed under his guidance. He spearheaded the development of distance measuring equipments which resulted in the development of the AVQ-70 airline DME, the AVQ-75 general aviation DME, and the new solid-state AVQ-85 DME. Mr. Lucchi represented RCA in the RTCA and the AEEC transponder DME activities. During recent years, he has made significant contributions to weather radar technology which resulted in the development and production of the AVQ-47, AVQ-21, and AVQ-30 weather radar systems. Mr. Lucchi has been awarded six patents in the ATC Transponder and TACAN fields. A registered professional electrical engineer in the State of California, he holds both amateur and commercial radiotelephone and radiotelegraph licenses. He is a member of Eta Kappa Nu and AIAA, and a Senior member of IEEE.

Another consideration for the choice of radio frequencies is the physical size of the antenna required; at lower frequencies an antenna one mile long is not unusual, but certainly not on an airplane. At higher frequencies, where it is desirable to provide a very narrow beam (as with radar), care must be taken to choose the frequency which results in:

1) A minimum of attenuation due to vapor,
2) A reasonably-sized antenna (especially in airborne applications) and,
3) Use of the lowest possible frequency.

A list of the most used frequencies in avionics, with a brief background statement on the function of each, is set forth in this paper in the order of ascending frequencies. A number of frequencies used in military and civil avionics applications are not discussed in this paper.

Omega: 10.2 kHz, 11 kHz, 33 kHz, 13.6 kHz

Omega is a long-range, low-frequency hyperbolic worldwide navigational system. The ground stations transmit accurately time-controlled phase signals referenced to a worldwide atomic clock. When the implementation is completed, it is expected that mobile users will always be within range of at least three of the planned eight worldwide ground stations. Owing to the low frequency and 10-kW transmitter power of Omega, submarines will be able to navigate by it while submerged.

Loran: 90 kHz to 110 kHz

Loran is a low-frequency long-range hyperbolic worldwide navigational system using pulse and phase-measuring techniques and two ground stations. It is used by some overseas airlines to obtain position fixes as backup to dead-reckoning or to doppler and/or inertial navigational systems.

Automatic direction finder: 200 kHz to 1.7 MHz

Owing to the widespread use of beacons and AM broadcast stations, the ADF continues to be used extensively for navigational purposes. The 200-kHz band extends through the AM broadcast band and generally to 1.7 MHz. A ferrite-loop antenna and relatively simple electronics permit the avionics equipment to determine the direction of the transmitter from the aircraft, thus permitting theta/theta type navigation.

Loran A: 1800 kHz to 2000 kHz

Loran A is a pulse-type hyperbolic navigational system. It was developed during World War II and is generally a part of the Loran C receiver. It is used as a backup navigational aid by overseas operators.

H-F communications: 1.5 MHz to 30 MHz

The h-f band is shared with many other long-range communications services. Specific portions of this frequency spectrum are allocated to airborne users. Amplitude-modulation telephone, morse-code telegraphy, and single-sideband suppressed — carrier techniques are generally employed. Radiated r-f power of up to 1 kW is commonly used, and the equipment bandwidth of ±3 kHz is standard.

Marker beacon: 75±0.4 MHz

The marker beacon is part of the instrument landing system (ILS). It generates a vertical fan signal modulated at audio frequencies, depending on the distance of the marker from the approach to the runway. As the aircraft flies over the marker, the pilot is able to determine the distance to touchdown.

ILS localizer system: 108.1 MHz to 111.9 MHz

Listed above is the frequency range of the localizer (lateral guidance) portion of the ILS; the frequency now includes odd tenths only, and is due to expand to include odd tenths plus 50 kHz. By comparing the amplitudes of two subcarrier modulations of 90 and 150 Hz, the aircraft receiver senses the overlap of equal amplitude and guides the pilot to the runway center line.

ILS Glideslope: 329.3 MHz to 335.0 MHz

Listed above is the frequency range of the glideslope (vertical guidance) portion of the ILS; the spacing is now 300 kHz and is due to expand to 150 kHz spacing. By comparing the amplitudes of two subcarrier modulations of 90 and 150 Hz, the glideslope receiver senses the overlap area of equal amplitude and guides the pilot on a glide path to intercept the runway.

VHF omnidirectional range: 108.00 MHz to 117.95 MHz

By means of amplitude modulation from one set of antennas and frequency modulation from another antenna, it is possible for airborne navigational receivers to determine direction from the ground VOR station. This is a primary airborne line-of-sight bearing navigational device.

VHF communications: 118.00 MHz to 135.95 MHz

Most radio telephone air traffic control communication by non-government aviation is made by means of amplitude-modulated vhf. Airborne equipments generally develop between 2 and 50 W of rf power on the frequencies ranging from 118.00 MHz to 135.00 MHz. Coverage of up to 200 miles is provided, depending on the altitude of the aircraft. The 118.00MHz to 135.95MHz band is due to be expanded to 25 kHz spacing.

Emergency locator transmitter: 121.5 MHz and 243 MHz

The emergency locator transmitter, operating on 121.5 MHz and 243 MHz, is becoming mandatory. Most current designs generate between 1 and 2 watts and the transmitter is activated manually or by hard-ground impact.

Two-way public air-ground communications

Frequencies within the band 454.675 MHz to 460 MHz are available for radiotelephone communication between aircraft and the public telephone system on the ground. The power used is generally 10 W with signle-sideband modulation. Some low-level radar altimeters continue to operate in the 420 MHz to 460 MHz band.

Air traffic control radar beacon: 962 MHz to 1213 MHz

Tactical air navigation/distance

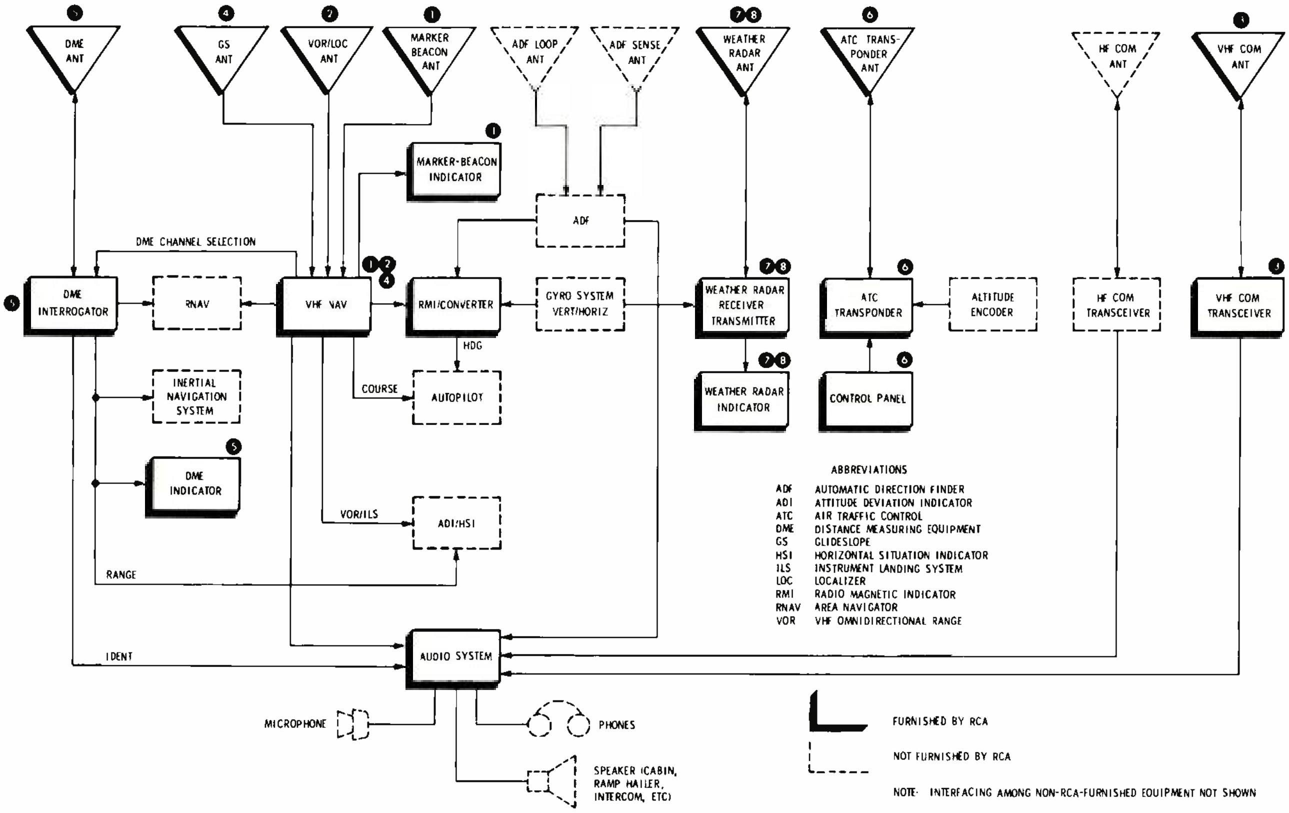


Fig. 1 — Block diagram showing the RCA aviation equipment used aboard aircraft.

measuring equipment (TACAN/DME) airborne interrogators transmit pulse codes which are received and retransmitted by a ground-station transponder. Range circuits in the airborne equipment measure the roundtrip time of the signals, then calculate distance for display to the pilot.

The air traffic control radar beacon system (ATCRBS) operates on 1030 MHz and 1090MHz. The airborne equipment receives interrogation from ground-based interrogators (the secondary surveillance radar system) and responds with selected coded-pulse replies for identification and aircraft location purposes along with altitude data.

This navigational device is mandatory for air-carrier aircraft and for all aircraft operating in specified airspace. The FAA is improving the ATCRBS system to sharpen azimuth resolution and to provide for discrete-address interrogation. Combined with automatic altitude reporting, this refined system may provide collision-avoidance information.

Collision avoidance: 1592.5 MHz to 1622.5 MHz

The U.S. Federal Aviation Administration has announced that the final collision avoidance concept will not be adopted until evaluation of three contending designs is complete. The time-frequency concept, recently evaluated by the FAA and some airlines, uses an atomic clock reference to assign accurate time slots to participating aircraft for transmittal of identification, altitude, etc. The SECANT non-synchronous concept is under development by RCA. Honeywell is working on a third system. All of these systems are cooperative types.

Low-level altimeters: 4.2 GHz to 4.4 GHz

Low-level altimeters (radar altimeters) use the frequency range listed above to derive altitude information. Circuits measure the phase of the return signal following transmission by a low-powered airborne radar altimeter transmitter. Accuracies to within a few feet at altitudes up to 2500 ft. are obtained. Some equipments employ higher-power pulse techniques to measure altitude. Low-level altimeters are required for aircraft proposing to meet at least Category II landing visibility minimums.

Low-frequency weather and ground-mapping radar: 5-GHz band

Some airlines prefer a relatively low radar frequency for weather detection (actually for the measure of rainfall rate). The lower frequencies are less subject to attenuation than the high frequencies, and thus permit deeper observation into storms to seek out the more intense cells. Disadvantages of the lower frequency as compared to the more popular 9.3 GHz frequency radar for an equivalent installation size are: 1) larger waveguide components, 2) lower antenna gain, 3) greater antenna beam width, and 4) decreased azimuth resolution.

Commercial weather and ground-mapping radar: 9.3 GHz to 9.5 GHz

Most airborne weather radars produced for commercial use are in the 9.3 to 9.4 GHz frequency range, formerly called X-band. New designations of frequency bands were introduced by NATO in 1972. The randomly assigned letters like X-band, K-band, etc., will doubtless be used less and less in the future. Because of the relatively narrow beam width, about 3° with a 30 in. paraboloidal reflector, a special radiator (or spoiler) is needed to fan out the beam for practical coverage when ground-mapping.

Doppler ground speed and drift angle measuring equipment: 13.25 GHz 13.40 GHz

Relatively low-power cw energy is radiated from three stabilized antennas aimed at various angles at the ground. The returned frequencies, which contain the doppler components, are separated and evaluated by a computer to measure and display the drift and ground-speed information which results. This equipment is generally used by overseas carriers.

Airborne weather and ground-mapping radar: 15.4 MHz to 15.7 MHz

A number of equipments in this relatively high-frequency radar band have been produced for general aviation use. Because of its potentially high-resolution capabilities, it is finding use in helicopters. Its principal drawback is high attenuation in vapor and thus limited usefulness in weather detection and observation.

Frequencies under consideration

Other frequencies under consideration for application to aviation are:

a) 1543.5 to 1558.5 MHz: Satellite-to-aircraft
b) 1645.0 to 1660.0 MHz: Aircraft-to-satellite
c) 5.125 to 5.250 GHz: Earth-to-satellite
d) 5.125 to 5.250 GHz: Satellite-to-earth

A new instrument landing system making use of three frequency bands is now under development. One band, 5.0 GHz to 5.12 GHz, is reserved for distance measuring equipment used to provide the pilot or computer with distance to touchdown. A second frequency band, 5.13 GHz to 5.25 GHz, will provide elevation and lateral guidance information. The third frequency band, 15.4 GHz to 15.7 GHz, will be used to furnish the final altitude and flare-out information.

Current RCA equipment and operating frequencies

The RCA Aviation Equipment Department has designed and currently produces airborne equipment operating in the following frequency bands:

1) 75 MHz — Marker-Beacon Receiver
2) 108.00 to 117.95 MHz — VOR/Localizer Navigation Receiver
3) 118.00 to 135.95 MHz — VHF Communications Transceiver
4) 329.3 to 335.0 MHz — Glideslope Receiver
5) 962 to 1213 MHz — Distance Measuring Equipment
6) 1030 to 1090 MHz — ATC Transponder
7) 5400 MHz — Weather Radar
8) 9300 to 9400 — Weather Radar

In Fig. 1 block diagram, the interface of RCA-produced avionics aboard the aircraft is shown. Numbers just outside the blocks key those equipments with transmitters and/or receivers to the preceding list of frequencies. For the purposes of clarity, interconnecting lines between non-RCA-furnished equipments are not shown.

Selection of the vhf navigation frequency automatically tunes the distance measuring equipment to the associated DME or tactical air navigation channel. The DME furnishes: 1) range information to the area navigator, 2) updating information to the inertial navigation system, and 3) range information to the DME indicator which not only displays distance to station but derives and displays time-to-station and ground-speed values. The DME (or distance portion of a TACAN ground station) transmits a Morse-code identity signal which is fed to the audio system.

The audio system balances and amplifies the audio outputs of all the avionics aboard the aircraft that produce audio signals for flight-crew use.

The vhf navigation system consists of three receivers. It receives all of the components of the ILS localizer, glideslope, and marker-beacons besides the VOR navigation signals. It also contains converters that drive the indicators and flags of the attitude deviation and heading situation indicators, as well as any repeaters used at other crew stations. It additionally provides bearing information to the autopilot and area navigator.

The radio-magnetic-indicator converter receives VOR, ADF, and directional-gyro compass signals, and from this information provides a related display of ground station and compass information. The RMI also can provide heading information to the autopilot. The weather radar interfaces with the aircraft gyro system in order to stabilize the antenna. The radar indicator displays the water in storm cells and, depending on antenna attitude or configuration, also displays terrain, ships, islands, etc.

The ATC transponder is largely a self-contained system. It usually interfaces only with an altitude digitizer and encoder that enables the transponder to transmit the aircraft altitude relative to mean sea level when so interrogated by the secondary surveillance radar system.

The interface of the hf and vhf communications systems is self-evident from the diagram.

Antenna problems

In general, one of the most difficult (and not yet fully resolved) problems in the airborne installation is that of designing a practical antenna. For example, long trailing wires have been used at low frequencies (not practical at Mach 1 speeds), and long blades, etc., have been employed at higher frequencies. Such antennas are not received with enthusiasm by airframe designers. Flush-mounted antennas are employed in the 75 MHz to the 2 GHz navigation and communications frequencies, even though less than desired coverage results. Generally, the penalty is the need to generate more rf power from the transmitter and greater sensitivity for the receiver, both costly compromises.

Conclusion

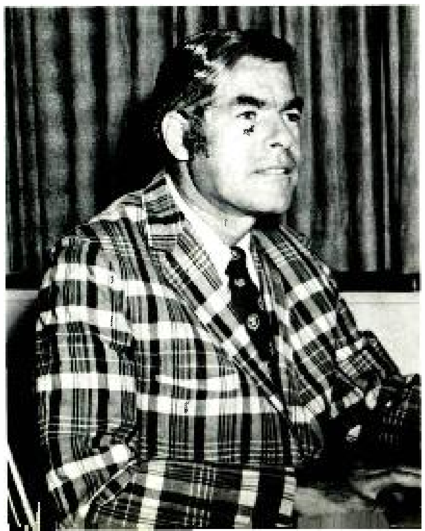
It is obvious that the avionics equipment utilizes a great portion of the available frequency spectrum, and designers must maintain a broad range of skill in the various rf disciplines. In the immediate future, it is expected that more use of frequencies in the 35 GHz range will find its way into radar developments. Some developments have been pursued in the infrared region, and lasers have already been used on the moon to map its surface contours.

Satellite systems for civilian vehicle traffic control

B. P. Miller

The possible use of satellite systems for vehicle traffic control by non-military users is reviewed by the author. User requirements are reviewed and evaluated. Air traffic control over oceans, ship communications, continental aircraft systems, and land vehicle systems are discussed. The trends for satellite systems development are summarized and it is predicted that the mix of present programs will rapidly change.

B. P. Miller, Manager, Special Programs, Astro-Electronics Division, Princeton, N.J., received the BS in Aeronautical Engineering from Pennsylvania State University in 1950, and did post-graduate work in Aeronautical Engineering at the U.S. Air Force Institute of Technology in 1953 and 1954 and at Princeton University from 1957 to 1959. Mr. Miller is a graduate of the Cornell University Executive Development Program. From 1950 to 1953, as a Captain in the USAF, he was assigned to the Aircraft Laboratory, Wright Air Development Division. He then taught Fluid Dynamics and Thermodynamics at the U.S. Naval Academy. In 1956, he was appointed Head of the Thermodynamics group of the Academy's Department of Marine Engineering. He joined the RCA Special Systems and Development Department in Princeton in 1957, and transferred to the Astro-Electronics Division in 1958. There, on Project JANUS, he performed trajectory and orbital analyses and ascertained propulsion-system requirements. From 1959 through 1961, he was Project Engineer on a series of studies examining military applications of space systems. In 1961, Mr. Miller participated in the series of studies that eventually led to the RCA Ranger Project. With the organization of the RCA Ranger Project, he was appointed Group Leader, Mechanical Systems, and in 1963 was made Ranger Project Manager. Mr. Miller received one of the coveted NASA Public Service Awards in October 1964 for work on the six-camera television system used aboard the successful Ranger 7, 8, and 9 spacecraft. In 1967, Mr. Miller was appointed Manager of the RCA Earth Resources Satellite Program; related to this, he received, in 1971, an Industrial Research IR 100 award for his work on the 2-inch return beam vidicon camera and laser beam image reproducer. Mr. Miller is an Associate Fellow of the American Institute of Aeronautics and Astronautics, a member of the AIAA Space Systems Technical Committee, and is a Registered Aeronautical Engineer. He has served as Chairman of the Princeton Section of the AIAA, and as Associate Editor of the *Journal of Spacecraft and Rockets*. Mr Miller has published numerous papers on spacecraft systems, television, and television recording and display technology.



DURING THE NEXT DECADE satellite systems will be developed to provide vehicle traffic control services for non-military users. These systems will initially provide communications, navigation, and surveillance services for civilian aircraft and ships, and could eventually be extended to provide traffic control for certain land vehicles.

Satellite systems

The common characteristic of these systems will be the use of a synchronous satellite to transfer data between moving vehicles and fixed locations.

User requirements and competing systems

The three functions of a vehicle traffic control system are:

1) Navigation: X, Y, Z determination of position on board the vehicle.
2) Communications: Code, Telex, and Voice, and
3) Surveillance: Vehicle status data - and X, Y, Z determination of position of vehicles from a fixed location

While navigation can be accomplished with only passive equipment in the vehicle, as in the TRANSIT system,[1] the communications and surveillance functions require both receipt and transmission by the vehicle. Fig. 1 is a conceptual arrangement of the elements of a generalized traffic control system and identifies the system elements.

The network of Fig. 2 illustrates some of the possible paths for the development of satellite systems for vehicle traffic control. Since the problems of aircraft traffic control over land and the oceans are significantly different, both continental and oceanic systems are considered to be possible developments for aircraft. The several branches shown in Fig. 2 represent possible growth paths for the systems to exploit technology to fill user needs. Experiments in vehicle traffic control with the NASA/ATS satellites are worthy of note as having demonstrated the feasibility of satellite systems, but are not shown as the experiments were of limited duration and scope. As will be described subsequently, vehicle surveillance in the form of independent determination of vehicle location and the telemetering of vehicle status may be important in some systems. For example, in a traffic control system, it may be just as important for a central control facility to know the position of all vehicles at a given instant as it is for the vehicle operator to have knowledge of his own position for vehicle navigation. Similarly, it may be just as important for vehicle status to be telemetered to the vehicle destination in order to minimize vehicle downtime for maintenance purposes as it is to display vehicle status to the operator for safety reasons.

Reprint RE-18-6-9
Final manuscript received February 22, 1973

Glossary

TRANSIT	Navy Navigation Satellite System
LORAN	Low Frequency Long Range Radio Aid to Vavigation
ATS	NASA Advanced Technology Satellite
OMEGA	VLF Radio Navigation System
CONUS	Continental U.S.
VORTAC	Visual Omni Range and Distance Measuring Facility
DOT	U.S. Department of Transportation
AMTRAK	National Railroad Passenger Corp.
ESRO	European Space Research Organization

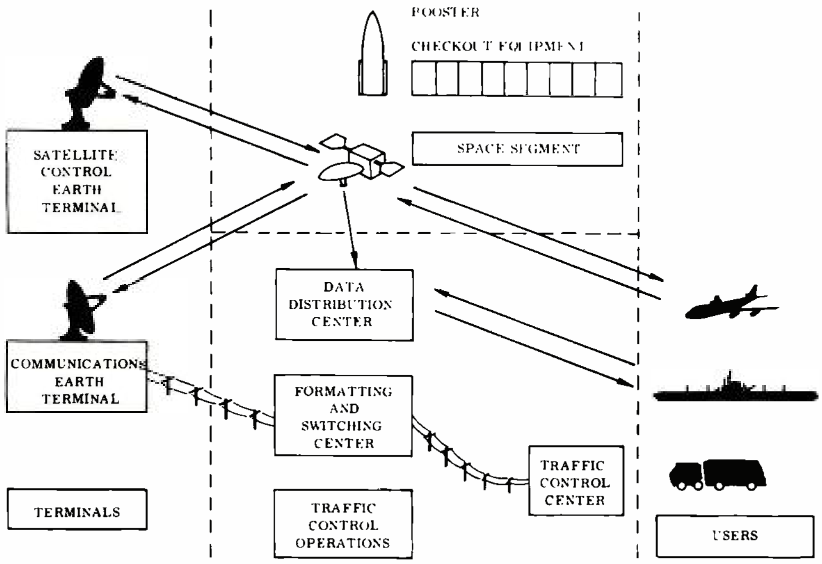


Fig. 1 — Conceptual arrangement of a generalized traffic control system.

Systems are developed to meet user requirements. Thus, the development of systems for vehicle traffic control implies the existence of both the user requirements and the necessary technology. In the case where existing systems partially satisfy, or can be modified to satisfy user requirements, satellite systems must compete on the basis of factors such as cost, capability, and growth. An appraisal of user requirements for traffic control services is shown in Fig. 3. Included in this figure is a listing of present systems which provide these services, and identification of needs not adequately filled by the present systems. This illustration (Fig. 3) is useful in evaluating the limitations of present systems, and in determining the potential role of satellites in providing services that are not provided or are inadequately provided by present systems.

A summary presentation of the technical feasibility, need, and economic justification of improved traffic control systems is shown in Fig. 4. As indicated by the study, the technical and economic feasibility of land vehicle systems has yet to be demonstrated. On the other hand, requirements have been established for land, air, and sea vehicle systems. Improvements in air and sea systems appear to be economically justifiable, while the land vehicle area requires further study.

Aircraft traffic control over the oceans

At the present, trans-Atlantic aircraft carry both vhf and hf communications; vhf is limited to a range of about 200 mi. at 30,000 ft. altitude. High frequency will propagate over the horizon and is used for the greater part of the flight over the ocean. However, hf has limited traffic capacity and is often unreliable because of ionospheric disturbances. At the present time, position surveillance of aircraft over the ocean is unreliable because of the variabilities of the hf link. With improvement of the communications link between aircraft and ground control it will be possible to maintain position surveillance using either onboard navaids (such as inertial guidance) or satellite interrogation/transponder systems. The accurate surveillance of vehicles will enable more efficient use of the airspace over oceans and more optimum routing of the aircraft.[2] With the provision of a surveillance data link it will also be possible to telemeter aircraft status data to effect a more rapid maintenance turnaround at the destination. It is difficult to provide substantial improvements in communications for aircraft over the ocean or to provide surveillance by upgrading existing hf communication links. The number of channels available is limited by frequency allocations and the link reliability is strongly a function of the assigned frequency. Thus, for communications and surveillance of over the ocean aircraft flights, a satellite system can provide needed services with little or no competition from existing systems. Moreover, as shown in Ref. 3, although navigation by satellite is not the primary motivation for an over the oceans system, a satellite system can provide substantial improvements over both LORAN and inertial systems.

Ship/open-seas systems

Ship communications on the open seas are also limited by the vagaries of hf transmission and the number of available channels. Current statistics show that there is a mean delay of about six hours before a ship-to-shore message reaches its addressee.

Ref. 3, further indicates an increasing requirement for maritime communications with increasing automation and

USE	TECHNICAL FEASIBILITY	NEED	ECONOMIC JUSTIFICATION	BEST ACCOMPLISHED BY
SEA				
MERCHANT SHIPS				
HIGH SEAS	▭	▭	▭	S
CONFLUENCE AREAS	▭	▭	▭	S
HARBORS		▭		O
COMMERCIAL FISHING	▭	▭	▥	S
OCEANOGRAPHIC AND OFF-SHORE OIL	▭	▭	▭	S
UNMANNED SENSORS	▭	▭	▥	S
SEARCH AND RESCUE	▭	▭	▭	S
PLEASURE CRAFT	▭	▨	▥	S
AIR				
TRAFFIC CONTROL	▭	▭	▭	S
EN ROUTE NAVIGATION	▭	▭	▥	S
COLLISION AVOIDANCE		▭		O
SEARCH AND RESCUE	▭	▭	▭	S
BALLOON SENSORS	▭	▭	▥	S
LAND				
VEHICLE LOCATOR	▧	▭		O

KEY
▭ FEASIBLE
▧ NOT FEASIBLE
▭ NEEDED NOW
▨ NEEDED AT END OF PERIOD
▭ JUSTIFIED ON OWN
▥ JUSTIFIED IF OTHER PRINCIPAL USER
S SATELLITE
O OTHER SYSTEMS

FROM: NATIONAL ACADEMY OF SCIENCES SATELLITE STUDY (PANEL 11), 1969, "USEFUL APPLICATIONS OF EARTH-ORIENTED SATELLITES - NAVIGATION AND TRAFFIC CONTROL"

Fig. 2 — Possible network paths of satellite systems for traffic control.

USER	LOCATION	SERVICE			NEED
		COMMUNICATION	SURVEILLANCE	NAVIGATION	
AIRCRAFT	OCEANIC	HF	NONE	INERTIAL LORAN OMEGA	IMPROVED COMMUNICATIONS SURVEILLANCE
	CONTINENTAL	VHF UHF	RADAR BEACON	VORTAC LORAN	IMPROVED SURVEILLANCE AND COMMUNICATIONS
SHIP	OPEN SEAS	HF	NONE	TRANSIT CELESTIAL LORAN OMEGA	IMPROVED COMMUNICATIONS SURVEILLANCE
	CONFLUENCE	VHF	RADAR	HF/DF	TRAFFIC CONTROL
LAND VEHICLE	URBAN/REGIONAL	UHF	NONE	NOT REQUIRED	POSITION LOCATION
	INTERSTATE	NONE	NONE	NOT REQUIRED	STUDY REQUIRED TO ESTABLISH NEEDS

Fig. 3 — Appraisal of user needs for traffic control.

modernization of the maritime fleet. For example, with increasing ship automation, the number of crew and the ability for in-route maintenance will be reduced. In this case it may be desirable to utilize a communication link to telemeter ship status data to minimize maintenance turnaround time at the destination. The same study also states the desirability of a centralized maritime system for search, rescue, weather routing, and position location surveillance.

An analysis of navigation methods used by merchant ships in the open seas of the North Atlantic (Ref. 3) indicates that 50% of the navigation fixes were based on dead reckoning and celestial sightings, and 30% of the sightings based on LORAN A. The remaining 20% of the sightings employed various other electronic techniques. A further study of maritime mobile satellite service requirements stated that "the maritime community has a vital need for increased voice and data communications, but no critical need for new radio determination services." Although presently available navigation techniques, including radio techniques such as LORAN and Omega, appear to be adequate for most marine users, certain specialized users such as the large tankers, ore, and bulk carriers and fishing fleets could benefit from the improved accuracy of satellite navigation. Studies of ship design and utilization have shown the following trends:

1) Large tankers and bulk carriers — 527 new tankers were on order at the end of 1969 averaging 106,000 DWT. The largest of these was 400,000 DWT, with designs in existence for 500,000 DWT ships.
2) Increased use of bulk carriers and containerized vessels will cause cargo handling to approach tankers in turnaround time.
3) More fleet type fishing with new regions in the Indian Ocean and Southwest Pacific being opened up.

It is likely that the combined trends toward larger cargo carriers, fleet type fishing, and automation will increase both the demand for improved communications and navigation accuracy.

It is of interest to note that the number of civilian users of the TRANSIT satellite navigation system will probably exceed the number of military users by the end of 1972. Based upon current estimates, about 450 translocation receivers are now in use with about 50% of these in civilian applications. The number of civilian applications of the TRANSIT receivers is increasing at a faster rate than the military applications. However, the expense of receiving equipment and associated computers currently limits further expansion of the user community.[4]

In general, the ship/open-seas communications problem is similar to the over-the-oceans aircraft communications problem. Upgrading the existing hf communications facilities to meet the user needs is difficult because of the frequency allocation problems and atmospheric interference effects. Thus, it would appear that satellite systems for open-seas ship-to-shore communications will receive little competition from upgraded hf systems. The vlf Omega system now in development has the potential of satisfying both marine and aircraft requirements for improved navigation. Only a fully operational Omega or satellite system has the potential of meeting both civil air and marine navigation requirements on a worldwide basis. However, further evaluation will be required before extensive civil application can be defined for either system.

No general requirement for navigation systems by means of satellites currently exists. The first requirement of a satellite system for civil air and maritime purposes is expected to be for communications and secondarily for navigation and surveillance on an international basis.[4]

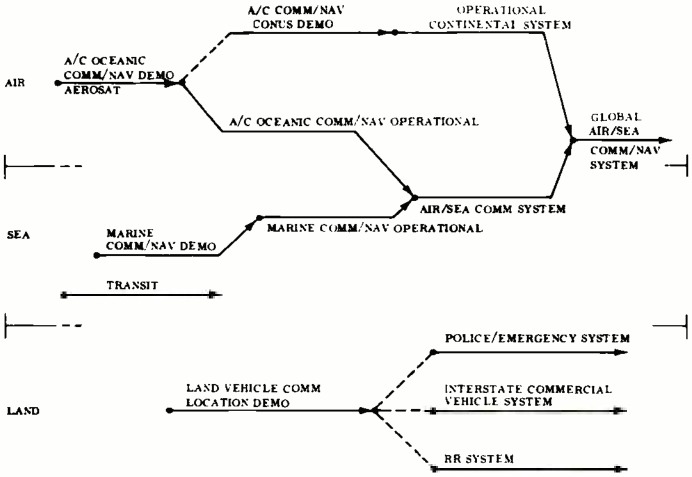


Fig. 4 — Summary of justification of improved traffic control.

USER	LOCATION	SERVICE			COMMENTS
		COMMUNICATION	SURVEILLANCE	NAVIGATION	
AIRCRAFT	OCEANIC	HIGH	MEDIUM	LOW	EXPERIMENTAL SYSTEM PLANNED (AEROSAT) NAV NEEDS ECONOMIC JUSTIFICATION
	CONTINENTAL	LOW	MEDIUM	LOW	COMPETING SYSTEM COULD PREVAIL
SHIP	OPEN SEAS	HIGH	MEDIUM	LOW	NAV NEEDS ECONOMIC JUSTIFICATION
	CONFLUENCE	LOW	LOW	LOW	COMPETING SYSTEM CAN MEET NEEDS
LAND VEHICLE	URBAN/REGIONAL	LOW	LOW	LOW	LAND SYSTEM EXPERIMENTS
	INTERSTATE	LOW	LOW	LOW	REQUIREMENTS DO NOT EXIST

Fig. 5 — Summary of probable evolution of satellite services.

While the demand for improved marine-navigation services is not clear, it is apparent that some form of demand is operating, as an increasing number of commercial users are buying TRANSIT system receivers.

Aircraft continental systems

Navigation within CONUS at present is based upon VORTAC. This dependency will continue unless a new system shows a major cost advantage. Because of the extensive use of VORTAC by airborne users and its economy, it has become a national and international standard. Eventual replacement of the VORTAC system is a possibility, and the FAA plans R&D in this direction in the 1975-80 time period. Considering that the VORTAC system will be well entrenched by that time, a new system will have to exhibit significant advantages to overcome the existing user investment in VORTAC.

Under the direction of DOT, studies have been performed on alternative Fourth Generation Air Traffic Control System concepts to meet the future air traffic demand forecasts for CONUS. The two competing concepts studied were satellite based and ground based. Although the economic studies showed a cost advantage of approximately $400,000,000 for the ground based system, it must be noted that the costs of the satellite based system were increased by the inclusion of a non-intergrated, independent LORAN type system. Moreover, the satellite based system did not consider cost savings that could result from the space shuttle program. The study concluded that both systems concepts were technically and operationally feasible, and recommended continued study of both system concepts before rejecting either.

Land vehicle systems

The subject of land vehicle traffic control appears to be largely unexplored in comparison to aircraft and ship systems. The relative lack of investigation in land vehicle systems may be attributed to:

1) Existing land vehicle systems such as police and urban bus systems are regional in nature, and until recently national agencies did not exist to focus the use of technology on these regional problems, and
2) National land transportation sytems such as AMTRAK, national bus companies, and long haul trucking companies do not appear to have well defined communication or surveillance needs, or their needs are met by existing land wire systems.

An apparent need does exist for automatic vehicle location in urban areas. A vehicle monitoring system of this sort could be used to provide instantaneous location, communication, and status information to a central location for police and fire vehicles, or for the routing and control of busses in an urban mass transit system. In response to a request for proposals from the DOT, RCA proposed an Electronic Sign Post location technique for shared voice and data transmission between vehicles and base stations. Automatic vehicle location would be provided by a dense array of sign posts placed throughout a city. The sign posts will be arranged along zonal boundaries so that any vehicle crossing the boundary must pass through the electronic fence. The sign post transmitters will emit a digitally coded message identifying the zone which is received and stored in the vehicle. The vehicle is then interrogated by the base station, and the location information is transmitted between pauses in speech transmission on the speech channel.

While a well defined need does appear to exist to improve location and communication with vehicles in the urban environment, it does not appear to present an opportunity for the application of satellite technology. This conclusion is supported by the National Academy of Sciences Satellite Study (Panel 11), which indicates the need for improved land vehicle location, and that satellite systems are not suitable for this purpose.[5]

Time trends for system development

The previous analysis of user requirements and competing systems has highlighted the need for improved communication and surveillance services for both aircraft and ships in ocean areas. A secondary requirement for improved navigation capabilities for both aircraft and ships in oceanic areas has also been identified.

A summary of the probability of the development of satellite services for civil vehicle traffic control is shown in Fig. 5. Based upon user needs and the growth capabilities of existing systems, it is concluded that satellite systems for surveillance and communication with over-the ocean aircraft and ships on the open seas have the highest probability of immediate development.

In order to investigate the nature of the market for satellites, ground terminals, and user equipment, it is necessary to forecast the time trends of system development. The speculative nature of this forecasting should be understood, as it is apparent that political, economic, and technical factors could influence the development of these systems to follow paths other than those outlined. Fig. 6

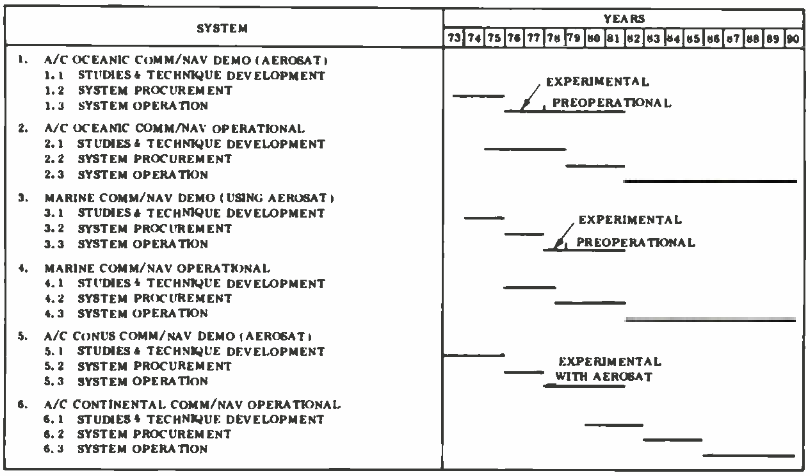


Fig. 6 — A possible path of systems development.

illustrates one possible path of development toward the operational systems described earlier. At this time, it appears as if the point of departure for the development of operating systems for marine and aircraft traffic control will be the Aeronautical Satellite Program. This system, as jointly defined by ESRO and FAA, is intended to provide experimental and pre-operational experience with a synchronous satellite system for air traffic control over the Atlantic and Pacific oceans.[6] While it was intended that the procurement of this system begin in 1972, it is likely that the procurement will be delayed to 1973 by political and economic factors concerning the ownership and lease or buy arrangements for the system.

Additionally, it is possible that renegotiation of the agreement between the U.S. and ESRO will lead to a reduced system with coverage only over the Atlantic, and the Pacific system may await similar agreement between the U.S. and Pacific nations. With these delays, it is probable that an Atlantic AeroSat system will be launched during 1975, and the system will be available for experimentation and pre-operational use in the 1975-80 period. Since the maritime frequencies are immediately adjacent to the AeroSat aircraft frequencies, it is likely that the AeroSat concept will be expanded to include a maritime experiment. Moreover, since the satellite operation will not be affected by the boundary between the continental land mass and the oceans, it will be possible to use the AeroSat to conduct experiments in the use of satellite systems for continental air traffic control. Thus, it appears that the AeroSat is the keystone of further development in the use of satellites for vehicle traffic control, and the development of operational systems will proceed on the basis of the experimental and pre-operational experience gain with AeroSat. Based on the foregoing assumptions, it is probable that the development of a marine and over-the-ocean aircraft traffic control system will begin after several years of experimentation and pre-operational experience with AeroSat, and that an operational system will be in use by approximately 1980. Considering the need for further competitive evaluation with land-based systems, the development of a satellite-based CONUS air traffic control system is considered to occur in the mid-to-late 1980's, and is at best problematical until further evaluation is completed. It is of interest to note that all of the systems considered use synchronous (or geostationary) satellites.

Conclusion

By its very nature, an analysis that aims to predict system development trends over a two - decade period is both highly speculative and perishable. The mix of programs and their time phasing is subject to change. Additionally, advancing technology and experimental experience could accelerate or retard the forecasted developments. However, notwithstanding the uncertain environment, it may be concluded that satellites will play a dominant role in the future of traffic control of ships and over-the-ocean aircraft. On the other hand, it is unlikely that satellites will play a role in land vehicle traffic control in the foreseeable future, and a satellite based CONUS air traffic system is considered to have a low probability of development at the present time.

Two factors are seen as being of major importance in obtaining user acceptance of a satellite based traffic control system. The first is to gain user confidence by demonstrating intended system continuity from experiment through operation. Additionally, while several of the studies referenced in this paper have explored the economic justification of satellite based systems, a true benefit/cost analysis has yet to be performed with the full involvement and participation of the users. The importance of this step in obtaining user support should not be overlooked. In the course of this analysis several questions have been opened but not answered. It is important to summarize them at this time as the ultimate answers could affect the conclusions drawn. The impact of the development of military traffic control systems cannot be fully assessed at this time. The impact of the space shuttle has not been considered as both the demonstration and operational systems could be developed before the shuttle achieves operational maturity. In the event that the development of the operational system is delayed, the advent of the space shuttle could impact the nature of the satellite. Political factors such as the choice of a government operation as opposed to a commercial venture for the system, or lease or buy of the satellite and user equipment, or combining or separating aircraft and marine services into a single satellite are as yet indeterminate and could delay or change the nature of the systems to be developed.

References

1. Board, J. E., "The New Celestial Navigation - Inexpensive Position Fixes by Satellite," RCA Engineer (Feb. - Mar. 1972).
2. Leverinton, D., "An Appraisal of an Aeronautical Satellite System, Part 1," JBIS Vol. 24 (May 1971).
3. "The Use of Satellites for Maritime Purposes," *Eurospace Memoranda No.* 8, (July 1971).
4. DOT *National Plan for Navigation*, AD-706905, (1970).
5. "Useful Applications of Earth Oriented Satellites," *National Academy of Sciences*, (1969).
6. "AeroSat, Request for Proposal - Specification Draft No. 2," (Oct 1, 1971), Federal Aviation Administration, Washington, D. C.

Harbor traffic ranging, identification, and communication (HATRIC)

E. Jellinek

A new navigation aid system having the high accuracy needed in narrow waterways is being developed under the USCG River and Harbor Aid to Navigation System (RIHANS) program. A key feature of the RCA approach is that it not only satisfies the RIHANS requirements for ship self-position fixing relative to fixed reference stations but also can easily be expanded to provide functions needed by the associated Vessel Traffic System. These additional functions permit the reference stations to obtain position fixes on all equipped ships, to identify them, and to have two-way digital message communication with them. This expanded system is called HATRIC, for Harbor Traffic Ranging, Identification, and Communication. The author emphasizes that the assertions contained herein are the opinions of the writer and are not to be construed as official or reflecting the views of the Commandant or the U.S. Coast Guard at large.

THUCYDIDES, the Greek historian, in 461 B.C., said: "a collision at sea can ruin your entire day." Today, this saying may more correctly be, "A collision in a harbor can ruin the harbor", since cargoes often include pollutants or fire and explosion hazards. In the congested waterways of harbors and rivers, collisions and groundings have become more prevalent as traffic density and ship size continues to increase.

Traffic and collisions to increase

Between 1966 and 1970, the world gross tonnages increased from 171.1 to 227.5 million. Larger and larger ships are being built each year; more and more supertankers are being placed into service. Today, tankships of 300,000 dead weight tons (DWT) are sailing the seas and 500,000 DWT versions are on the drawing boards. The tankships are not the only types of vessels that are growing in size. The containerships, the Lash and Seabee ships, the liquified natural gas ships, and the integrated tug and barge units, are all larger vessels than their predecessors.

Increases in size and speed of new ships have, in many cases, reduced their maneuverability. For example, the supertankers' stopping distances are measured in miles instead of yards. The effective safety margins of vessels confronting each other in restricted waters have been reduced because of the increased size and limited maneuverability of these vessels.

Reprint RE-18-6-8
Final manuscript received February 21, 1973

Within the past 5 years, the number of collisions occurring in United States waters or involving U.S. registered vessels increased from 922 in 1966 to 1093 in 1970. Most of these occurred on navigable inland waters, accounting for 735 in 1966 and 821 in 1970. Groundings, which are as dangerous as collisions, outnumber them by three to one.

In 1970, nearly 200 billion ton-miles of freight were transported along United States inland and costal waterways, an increase of about 58 percent over 1960. A conservative estimate is that there will be at least a 50 percent increase in water transportation traffic over the next 10 years. The main part of barge cargoes is comprised of raw materials. Approximately 41 percent of these cargoes consists of petroleum and its products. Another 4 percent consists of other chemicals. It is forecast that the consumption of energy in the United States, requiring 30-million barrels of petroleum per day in 1970, will double by 1985.

Need for collision avoidance systems

These statistics and forecasts substantiate a continuing sharp upward trend in the quantity of hazardous and dangerous cargoes, particularly petroleum products, transported over the inland and coastal waters of the United States. Means for reducing the risk of collisions and groundings have been studied by many agencies, including the National Transportation Safety Board.[1] The general recommendation has been to give the Coast Guard the responsibility for directing traffic in harbor areas. Also recommended was the development of a harbor collision avoidance system which would include the following functions:

a) Accurate position determination.
b) Vessel identification.
c) Surveillance.
d) Rapid data processing and prediction.
e) Communications.
f) Decision making.

The last four of these functions are available in various forms, but the first two require new development. For safe navigation in bad weather, a position fix accuracy of 1/4 channel width is necessary. For a typical channel of 400-ft width, an accuracy of 50 ft would be needed which no available system provides. Automatic identification of vessels correlated with their position is

Ernest Jellinek, Staff Systems Manager, Navigation and Traffic Control, Government Plans & Systems Development, Camden, New Jersey, received the BEE in 1941 from the Polytechnic Institute of Brooklyn where he also held a Teaching Fellowship until 1942. From 1942 to 1955 Mr. Jellinek was with the General Electric Co. as first Technical Representative to the U.S. Navy on shipboard radar during World War II, and later in the development of photoelectric control systems for industrial applications. From 1955 to 1958 he was Chief Engineer, Fireye Division of the Electronics Corporation of America where he was responsible for research, development, and production engineering of infra-red systems for detecting and suppressing fires and explosions in engine nacelles, fuel tanks, and armament bays of military aircraft. He joined the RCA Communication Systems Division in 1958 as Project Engineer on Time Division Data Link and was responsible for system integration of the radio command guidance system used by SAGE to launch and guide BOMARC air defense missiles. He later led programs to develop integrated communication and navigation systems for advanced aircraft such as TFX (now F-111), AMSA (now B-1), and AWACS. In 1968 Mr. Jellinek joined the Systems Development group (formerly known as SEER) where he has been responsible for advanced systems development in the areas of navigation and traffic control for aircraft and ships. He is presently Technical Director for the SECANT, RIHANS, and HATRIC programs He is a Senior Member of IEEE, a member of the Institute of Navigation and of the American Institute of Aeronautics and Astronautics, and a Licensed Professional Engineer (N.Y.).

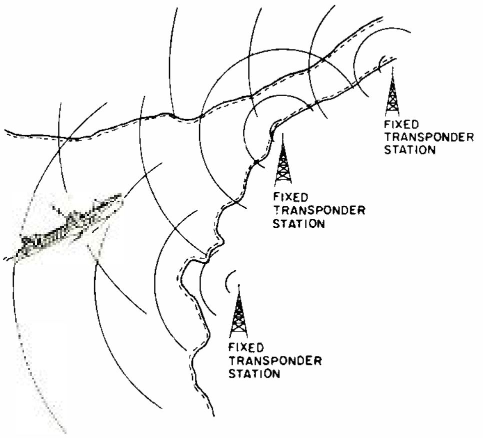


Fig. 1 — The RCA RIHANS/HATRIC concept.

also unavailable. This function is needed to close the loop between surveillance and communication. Vessels, determined by radar to be conflicting, must be correctly identified to insure that avoidance maneuvers are communicated to the correct vessel.

To have these capabilities, when developed, a ship would have to carry two new equipments: 1) a precision radio navigation equipment, and 2) an identification transponder. Two new shore facilities would also be needed: 1) precision radio navigation aids, and 2) identification interrogator and position correlator.

Government approach to the problem

To implement a collision avoidance system, the Government has taken a number of steps. For example, in July 1972, Congress passed the Ports and Waterways Safety Act, giving responsibility to the Coast Guard for developing and implementing means for increasing harbor safety. R&D is presently underway by the Coast Guard on two major systems that support the collision avoidance objective:

1) A vessel traffic system (VTS) provides a means for surveillance of ships and two-way communication for status and control purposes. The approach uses radar, computer and an information display but lacks an automatic means for ship identification and correlation with position. An R&D testbed has been set up by the Coast Guard in San Francisco harbor using individually purchased elements integrated into a system by the Applied Physics Laboratory.

2) A river and harbor aid to navigation system (RIHANS) provides an all-weather means for ship self-position location; with it, the ship can maintain an assigned channel position to avoid collision and grounding. A position accuracy of 50-ft radius (95% probability) is required. The Coast Guard plans a four-phase program for development of this system. RCA is one of three companies under contract for the first phase (from July 1972 to April 1973). In this phase, the system concept originally proposed is to be refined so as to predict the equipment and deployment configuration, accuracy, and costs. Eventually, one contractor will be selected for system implementation.

RCA's RIHANS system concept

RCA's system concept not only satisfies the RIHANS navigation requirements but combines the surveillance and identification functions into a single system and thereby minimizes the cost of the total system.

The RCA concept was developed for the RIHANS program with recognition that the cost of the newly needed systems could limit acceptance. It was also recognized that navigation and surveillance were basically identical functions. In navigation, a ship identifies shore stations and gets a fix on them. In surveillance, the roles are reversed. Therefore, the approach was taken to satisfy both the navigation and the surveillance requirements by providing the same functions on both ship and shore, using the same signals and equipment. The results provides identical coverage areas and accuracy for both functions at the least cost in equipment and spectrum utilization. RCA named the combined system HATRIC, an acronym for harbor traffic ranging, identification and communication system. HATRIC accomplishes these three goals:

1) Provides all of the position location, identification, and communication functions needed to increase harbor safety.
2) Performs these functions for ship to shore, shore to ship, and ship to ship purposes.
3) Minimizes the equipment cost.

The RCA RIHANS/HATRIC concept (Fig. 1) uses interrogator-transponders on ships and shore stations to determine distance lines of position (LOP's). The ship's position is defined by the intersection of circular LOP's from two shore stations. Because there is no requirement for synchronization among stations or orthoganal baselines, there is great flexibility in their deployment. In general they are deployed on the same side of a waterway to avoid ambiguity. This is ideal for long narrow waterways where every station can be paired with each of the two adjacent stations for a fix.

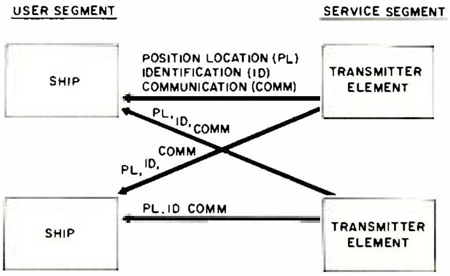


Fig. 2 — RIHANS information flow.

For a RIHANS position fix, a ship obtains a distance line of position (LOP) to each of two known shore stations, called transmitter elements (TE) of the service segment. As shown in Fig. 2, the signals from each TE also furnish its identification and any general communication such as navaid status.

HATRIC functions satisfied

The additional HATRIC functions are achieved from the same transmitter elements and ship equipments by simply adding the reverse flow of the same signals (see Fig. 3). Thus a fix on a ship is obtained by two TE's each obtaining a distance LOP to the ship plus its identification. Communication messages from the ship are also contained in the signals. For greatest ease of operation the messages are restricted to information that can be automatically generated by instruments or easily inserted manually, and could include:

1) Automatically generated
    Ship Underway/Anchored/Docked
    Speed
    Heading
    Position
    Rudder position
2) Manually inserted
    Intend to get underway/anchor/dock
    Intend to turn starboard/port
    Estimated time ___
    Next check point ___
    Request voice contact on channel ___

General system operation

The transmitter element forwards the distance LOP, identification, and communication from each ship in real time to the vessel traffic center. There, the identity, position, and status of all vessels may be displayed. The vessel traffic center can also forward messages to any or all ships via one or more TE's. The messages can be general information for all ships, such as weather, traffic, navigational aid status, or specific information for a particular ship such as collision avoidance instructions.

The system is designed to operate continuously in both directions without saturating in the traffic densities projected for the future. Each ship continuously interrogates two TE's 75 times per second. On each received reply a range measurement is made and these are integrated to provide an accurate position fix every three seconds. Each received reply also contains a data bit of a digital message and these are decoded to provide communication at 75 bits per second. The same parameters also apply to the interrogation of ships by the TE's.

Interrogator/transponder

The interrogator/transponder functions of RIHANS are shown in Fig. 4. The user equipment transmits on frequency F1 and receives on F2. The service segment receives on F1 and transmits on F2. The frequencies selected are each 12.5 MHz wide at the lower edge of the 2900 to 3100 MHz S-band allocated to Radio-navigation/Radiolocation. Each ininterrogation is a pair of short pulses (0.1) usec each) which have selectable spacings for coding. The user selects two of six available codes to indicate the stations he wishes to interrogate. In Fig. 4 the selection of codes A and B by the user and the assignment of code A to the service segment TE is indicated. The user equipment alternates interrogation on code A and code B at 75 per second each. Different timing and codes are used for the interrogations to the two stations to avoid the interference that would occur when the ship is equidistant from the two stations.

For each code A interrogation received by the code A TE, the transponder sends a reply-pulse pair which serves as both a ranging pulse and one data bit of a digital message. The data bit is coded as a zero or one by different spacings between pulses. The TE built-in message register circulates continuously at 75 bits per second to superimpose its message on the replies. During each 1/75 second interval the same bit is sent as the reply to each interrogation received. When the reply pulse pair is received by the user, a range measurement is made and the data bit is decoded and stored. A sequence of 225 range measurements are integrated to provide a high-accuracy LOP, and at the same time a message is formed from the data bits contained in the sequence.

Reference points and fixes

The process is also performed at the same time on the alternating replies received from the code B TE. From the LOP's and the known latitude/longitude coordinates of the TE an accurate latitude/longitude position fix is made. The 50-ft accuracy requirement dictates that the fix be given in tenths of a second which, of course, is not usable to the navigator because it is not readable on conventional nautical charts.

A more useful approach has been developed for displaying the fix to the navigator. The channel center-line can be considered to be defined by a series of line segments as in Fig. 5a. The junction of each line segment is taken as a reference point and is identified by number and location on the chart, just like a channel buoy. In some cases the reference point is co-located with a buoy and in many cases the point is imaginary.

At any time, the vessel can be considered to be between a particular pair of reference points, "from", the one it has passed and, "to", the one toward which it is heading. These points define a coordinate system with the "to" point as the origin and line connecting them as the negative portion of the Y axis as in Fig. 5b. The position fix determined by the equipment is then displayed in terms of yards to starboard of the line and yards to go to draw abeam of the "to" reference point, as in 5c. Coordinates of the reference points are stored in a read-only memory on a plug-in board and automatically fed to the computer according to the ship's position and direction.

Surveillance operation

For surveillance, the same ranging, identification, and communication functions are provided in the reverse direction by adding to the RIHANS functions of Fig. 4, the functions shown by the dashed lines of Fig. 6. No additional receivers, transmitters, or frequency assignments are required. The service segment transmitter element simply sends interrogation pulse pairs (shown as code C) on F2 along with its normal replies. The user detects each code C pulse pair received and transmits a reply pulse pair on F1, superimposing one bit from its message register. From the reply pulse pairs received by the service segment, the range to the user is determined and the data bit is extracted. At the end of the three second integration interval, the accurate LOP and the ship's message including its identity are obtained and forwarded to the Vessel Traffic Center. The range tracker and message extractor handle one ship at a

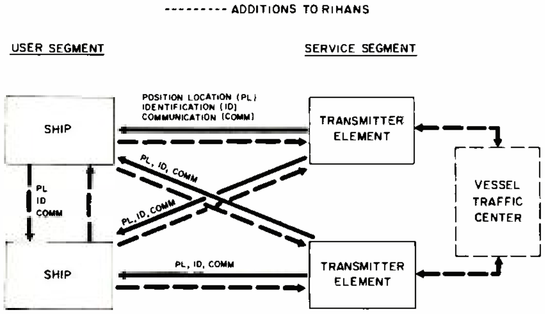


Fig. 3 — HATRIC information flow.

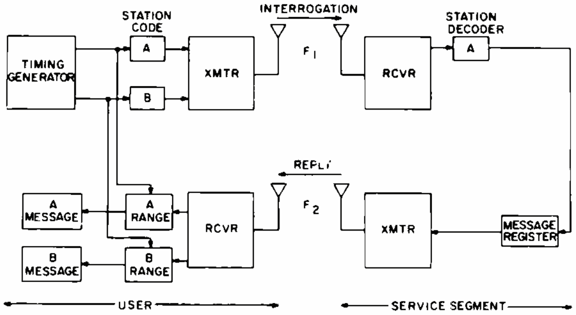


Fig. 4 — RIHANS interrogator/transponder functions for position fixing.

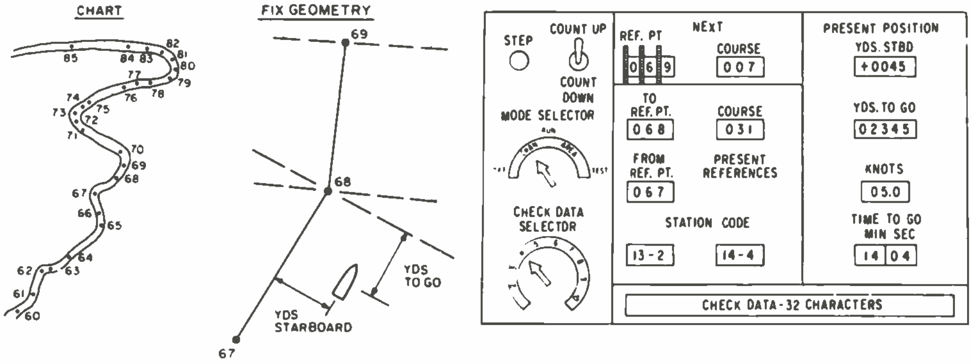


Fig. 5 — (a, left) channel centerline references points on chart; (b, center) channel position fix geometry; (c, right) shipboard controls and displays for position fixing.

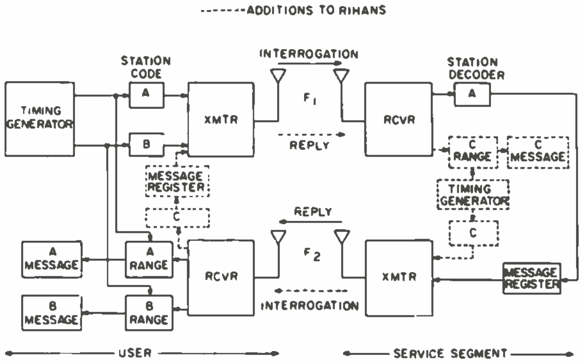


Fig. 6 — HATRIC functions added to RIHANS equipment.

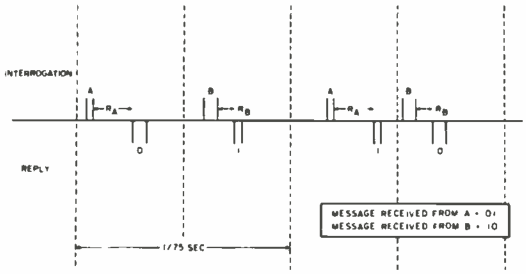


Fig. 7 — Signal format of user interrogation and reply.

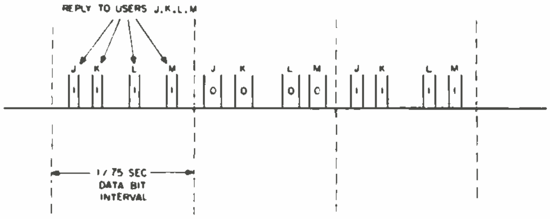


Fig. 8 — Signal format of transponder replies.

time and are cycled among all of the ships that reply to the stations's interrogations. Several trackers are provided wherever needed to minimize the overall cycle time.

Signal characteristics, problems and solutions

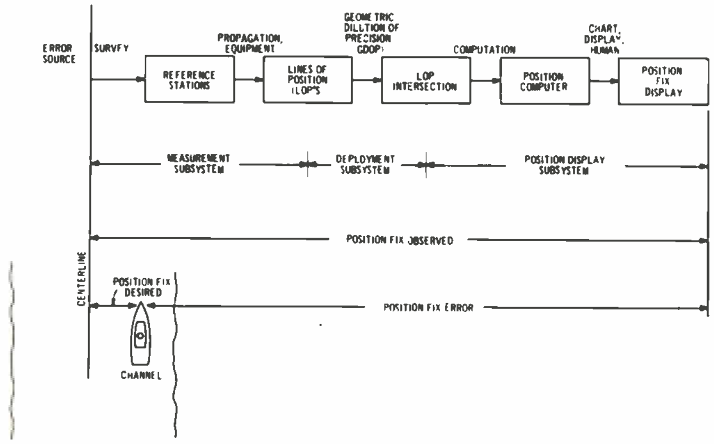
The key to the success of this concept is the use of a unique signal structure. The signal structure usually used in transponding systems has four basic characteristics that could cause problems in this type of service:

1) Saturation — The system is unable to serve the required number of users because the transponder spends so much time replying to interrogations that there is a high probability of not replying to another interrogation. This is especially a problem in a high accuracy system where many range samples are required to reduce errors.
2) Synchronous garble — Two repliers who are close in range can not be separately distinguished because their signals overlap.
3) Mutual interference — Interrogations by other interrogators and replies by other transponders overlap each other and interfere with their proper reception.
4) Multipath interference — The overwater path generally produces reflections of the desired signal which overlap it and interfere with its proper reception.

A commonly proposed approach for preventing synchronous garble is to use discretely addressed interrogation and a timing of the interrogations so that the replies will not overlap. However, this form of discrete addressing has two major drawbacks. First, it would require every interrogator to determine and keep track of the identification of all transponders involved and then sequence interrogation address codes in each interrogation. Second, the message length required to provide sufficient number of discrete addresses would permit severe system degradation by multipath interference, mutual interference, and saturation.

The HATRIC signal structure overcomes these problems. The probability of synchronous garble is first minimized by keeping transmissions very short. Instead of sending an entire message in a burst, only one bit of the message is sent at a time. The message is spread out in time with far more time between pulse-pair repetitions than occupied by a pulse pair (40,000:1).

With the very small ratio of the pulse width to the repetition interval, the probability of blocking or mutual



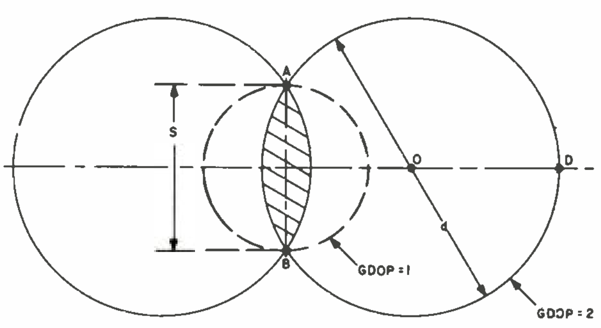


Fig. 9 — Error sources in channel position fixing.
Fig. 10 — Accuracy contour produced by sites A and B.

interference is kept very low. When it does occur, however, only a single bit of a message or a single range sample is lost instead of the entire message or range measurement. Simple error detection and correction techniques and range integration readily eliminate these effects.

Only a limited form of discrete addressing (6 different codes) is then needed to resolve the rare garbles that occur when range differences are less than a pulse width. Being so few, the codes do not require extensive bookkeeping and can easily be cycled through when desired, as the actual identity of the transponder will be provided by its reply signals.

The signal format and timing are shown in Fig. 7. The user interrogation format shown above the line in Fig. 7 shows one code A pulse and one code B pulse sent during each 1/75 sec interval. They are time hopped randomly so that each user can separately distinguish the replies to his own interrogations. At the transmitter element of the service segment, the replies to users J, K, L, and M are shown in Fig. 8. A reply is sent at the time each interrogation is received. The data bit sent is the same to all repliers during each 1/75 second data bit interval. The replies received by the user from stations A and B are shown below the line in Fig. 7. From the replies, the range samples and the message bits are extracted as shown in the tabulation.

Position fixing accuracy

To achieve the very-high position fixing accuracy required, all sources of error must be held within bounds. Fig. 9 shows the steps involved in making a position fix and the sources of error in each step. The steps can be grouped into the three subsystems of the overall system:

1) Measurement subsystem — The means by which an LOP is generated and measured.
2) Deployment subsystem — The way that reference stations are deployed to produce suitable LOP's in the service area.
3) Position display subsystem — The means of converting the measured LOP's into the position fix observed by the navigator.

The allocation of the allowable 50-ft position radius among these subsystem is as follows:

Measurement	σ = 9.7 ft rms
Deployment	R σ = 5 *
Measurement/Deployment	R = 48.5 ft *
Position Display	R = 9.5 ft *
Total RSS	R = 50.0 ft *

*(95% probability)

From Burt[2], R/σ is the factor that converts the ranging error into the circular error radius. The deployment value of 5 is equivalent to a geometric dilution of precision (GDOP) of 1.88 at 95% probability.

To meet the 9.7-ft rms limitation allocated to the Measurement Subsystem a 12.5-MHz bandwidth pulse ranging system is used with leading edge tracking and integration of 225 range samples.

To meet the permissible error allocated to the Deployment Sub-system the shore stations are deployed in such a way that the intersection angle between lines drawn from the user to the reference stations is greater than 32°. The permissable coverage area is shown within the large circles of Fig. 10, except for the shaded area. The diameter, d, of the large circle is equal to almost twice the baseline distance, S. In most cases the stations A and B would be deployed along the shoreline so that one of the ambiguous circles would be eliminated and also so that the loss of the shaded area is insignificant.

Conclusions

Systems are needed to reduce the risk of collisions and groundings in congested waterways.

The RCA approach for meeting the Coast Guard requirements for the RIHANS position fixing system provides the highest accuracy and greatest flexibility of any approach. Up to now this capability of an active ranging system was considered to be subject to saturation. This limitation is removed by a unique large capacity random access waveform.

The RCA HATRIC approach provides accurate navigation for the Coast Guard River and Harbor Aid to Navigation System (RIHANS) and also can provide additional capability for surveillance, identification, and communication. These additional functions will eventually be needed for the vessel traffic system and this approach will minimize the cost of the total system by providing them in one new system instead of two.

The unique signal structure permits this capability to be achieved with high position fixing accuracy, and freedom from degradation by saturation, synchronous garble, mutual interference and multipath interference.

References

1. "Collisions within the Navigable Waters of the United States — Considerations of Alternative Preventative Measures Adopted Feb. 2, 1972", *Report Number NTSB-MSS-72-1 National Transportation Safety Board*, Wash., D.C.
2. Burt, W. A. *et al.* "Mathmatical Considerations Pertaining to the Accuracy of Position Location and Navigation Systems — Part C", *Stanford Research Institute Report AD-629609* (April 1966).

An X-band signpost system for automatic location and tracking of vehicles

G. S. Kaplan | Dr. L. Schiff

RCA Laboratories has developed a technique for tracking the motion of a randomly moving vehicle with the aid of electronic signposts deployed throughout a heavily builtup urban area. Signpost emplacement, data rates, mutual interference between signpost elements and other system parameters are described. The results of specific field tests in the City of Philadelphia performed under contract to DOT are highlighted and a comparison with other vehicle location techniques is made.

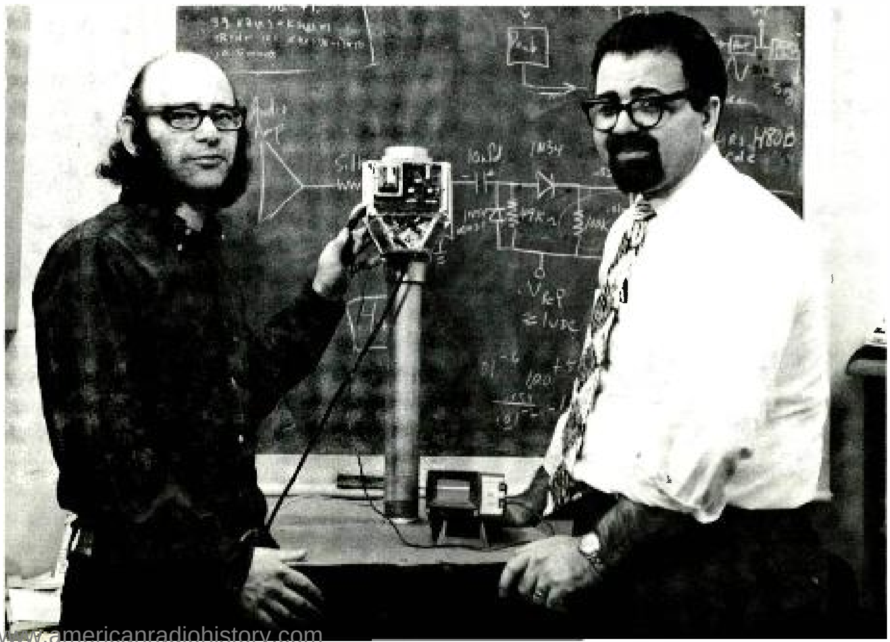
AUTOMATIC VEHICLE LOCATION AND TRACKING is becoming an important requirement in the command and control of fleets of vehicles, particularly in large cities. The police would like to know continuously the deployment of all their vehicles to speed up their response to reported incidents. Bus companies must know the arrival time of their vehicles at certain checkpoints for maintaining and modifying schedules. Truckers who have vehicle tracking equipment aboard their trucks would have another useful tool to control hi-jacking, since hi-jacked vehicles could then be tracked through city streets and police vehicles dispatched to intercept them.

Reprint RE-18-6-6
Final manuscript received December 12, 1972.

Gerald S. Kaplan, Communications Research Laboratory, RCA Laboratories, Princeton, N.J., received the BSEE from the City College of New York in 1962 and the MSEE from Princeton University in 1964. In June 1962, he joined the Technical Staff of RCA Laboratories. Since 1963, he has been associated with the Communications Research Laboratory where he has investigated various problems in electromagnetic and communication theory. Some recent projects included acquisition and analysis of X-band 1-GHz propagation data in urban environments, effects of atmospheric phenomena, including rain, on satellite-to-earth X-band communication links, and the study of point-to-point microwave and millimeter wave communication systems. Mr. Kaplan was a major contributor to the design of an electronic signpost Automatic Vehicle Monitoring (AVM) system for locating and tracking motor vehicles in urban areas. This AVM system has recently been tested in the City of Philadelphia (under a contract from the Department of Transportation). Mr. Kaplan is a member of Eta Kappa Nu and Tau Beta Pi.

Dr. Leonard Schiff, Communications Research Laboratory, RCA Laboratories, Princeton, N.J., received the BEE from the City College of New York in 1960, the MSEE from New York University in 1962, and the PhD from Polytechnic Institute of Brooklyn, N.Y., in 1968. From 1960-1966, he was employed by Bell Telephone Laboratories, where he worked on electronic switching systems. In 1967, he joined RCA Laboratories. He has been concerned with data transmission systems and various types of vehicle location systems. He has also worked on various system aspects of mobile radio, especially techniques for making these systems more spectrally efficient and more efficient in their traffic carry capacity. He has authored a number of technical papers in these areas. Dr. Schiff is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

Authors Kaplan (left) and Schiff.



A consideration of alternatives

There are several different principles that could be utilized as basis for an automatic vehicle location and tracking system: pulse ranging, phase ranging, signpost, and dead-reckoning. A preliminary study was made of all of these. It was recognized that for some applications, accuracies of 500 ft or better would be required while for other applications accuracies of one-half to one mile would be adequate. It was also recognized that system costs broke down into two major catergories; costs associated with fixed installations outside the vehicle and costs associated with vehicle equipment. Therefore, the preferred system from the cost point of view could be quite different depending on whether a relatively small number or an extremely large number of cars are in the system.

In investigating all these variables it was decided to drop a detailed study of pulse ranging systems for essentially two reasons: 1) the bandwidth required to accommodate the narrow pulses is quite large and spectrum congestion in large cities is a serious problem; and 2) high-power, wideband pulse transmitters (and wideband receivers also) for each car appeared to be fairly expensive and could involve a large increase in cost over and above the two-way radio that a vehicle is expected to have.

Phase ranging at first seemed to have many desirable characteristics. By modulating an existing two-way radio with an audio tone (3 kHz, say), it appears possible to implement a phase ranging system at modest cost. However, a detailed analysis [1,2,3] indicates that multipath in a heavily built up area (such as the loop in Chicago or the canyons of Wall Street in New York) is so severe that accuracy may not be adequate for many cases.

For the above and other reasons, RCA Laboratories has undertaken the development of an X-band signpost vehicle location and tracking system. The signpost system is almost certainly the simplest and cheapest for fixed route system (such as buses). On high-speed busways, presently under study for surface mass transit systems, electronic signposts coupled with odometer readings between signposts offer the possibility of extremely accurate vehicle tracking suitable for merge control and collision avoidance.

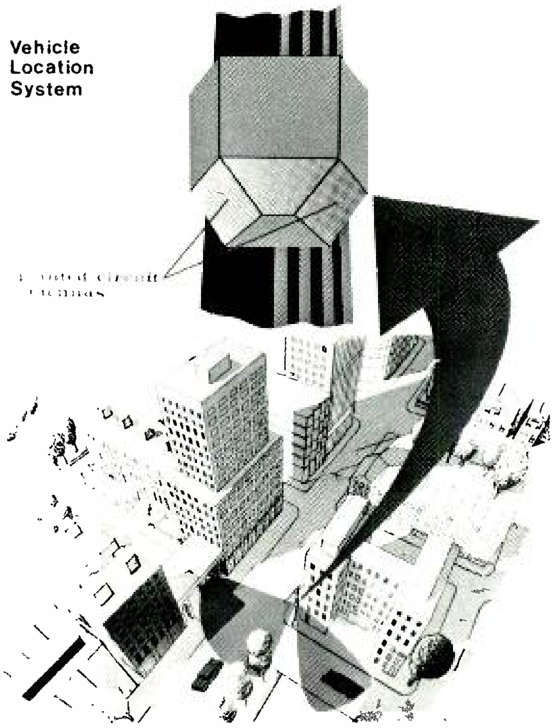


Fig. 1 — Street installation of signpost transmitter.

Furthermore, signposts can be deployed with different spacings in different parts of a city to obtain variable accuracy. In some sections of the city, signposts may be wanted on every street corner, while in other sections accuracies of five or even ten blocks may be adequate. Thus, a given area may be divided into many sub areas or cells of variable size and shape and the signposts deployed along the boundaries of these cells in such a way that no vehicle may enter or leave a cell without passing a signpost. As mentioned, signposts require an initial high capital investment but incur little additional cost as the number of vehicles in the system increase. Other systems, such as pulse ranging, involve a more modest cost for initial installation but require substantial increase in costs as the number of vehicles in the system increase. Finally, the X-band signpost vehicle locator system puts little burden on the congested portion of the radio spectrum.

The X-band signpost system

There are two basic approaches to a signpost sytem: 1) the signposts serve as receivers and pick up the vehicle identification signals as the vehicles pass the signpost. Each signpost then adds its own location identification and transmits these two signals to the control center; and 2) the signpost serves as a transmitter which transmits its location information to properly equipped vehicles which pass the signpost. These vehicles must then be interrogated on the two-way radio in the vehicle to relay its location information to the control center.

The first approach requires all the signposts to be connected to the control center by telephone lines or radio links, either of which could be quite expensive. Also, the probability of mutual interference of the vehicle identification signals could be fairly serious at crowded intersections in rush hour traffic since there is then the possibility of many vehicles simultaneously transmitting their identification to signposts. For these reasons, RCA has adopted the second system in which the signpost element is a short-range X-band transmitter.

As shown in Fig. 1, the X-band signpost transmitters are mounted on street-lighting poles so that all vehicles driving along the street must pass within range of the transmitter. Although one box is mounted on the pole, two different messages are transmitted. These messages, one for each side of the transmitter, do not interfere with each other because of

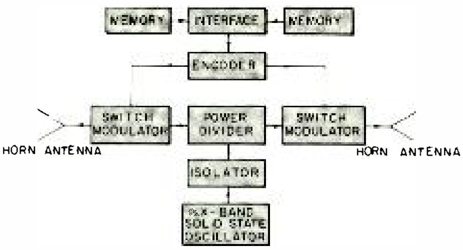


Fig. 2 — Block diagram of transmitter.

the antenna front-to-back ratio, and also because they are transmitted in time sequence and not simultaneously. Information is sent by amplitude modulation of the X-band carrier with one of two tones (AM/FSK). For simplicity, economy, and reliability, direct detection at the receiver front end is used, eliminating the need for an X-band local oscillator and mixer. After removal of the X-band carrier by direct detection, the resulting FSK signal is amplified and demodulated through a conventional bandpass filter, envelope detector, and comparator "chain". The received signal is also subjected to both signal strength and parity checks. Those messages which fail either the parity or signal strength checks are rejected in the the receiver. This insures that weak signals (or noise alone) will be ignored and only reliable messages based on strong signals will be received and accepted for storage.

An analysis[4] of the system indicates that excellent system performance can be obtained for threshold-to-noise values of 10 to 12 dB and S/N values of 14 to 16 dB when the vehicle is within the reception range.

A block diagram of the earliest transmitter design is shown in Fig. 2; photos of that transmitter are shown in Fig. 3. In this design, an avalanche diode source operating at X-band produces approximately 120 mW of cw power. The output of the oscillator goes into an isolator and is split into two equal parts by the power divider. Reflective-type diode switches are inserted between the power divider outputs and the 10-dB gain vertically polarized horn antennas. By proper biasing of the diode switches, AM modulation of the X-band carrier radiated by one antenna is obtained. While one antenna is radiating a message, the other antenna is not. The information is sent by AM modulation of the carrier with an FSK signal (10 kHz for mark and 12 kHz for space) at 100 bits/s. As presently implemented, a message consists of 10 bits although expansion to a larger number of bits is easily achieved. A single logic card suffices to derive all timing, encoding, and modulation signals.

A block diagram of the first receiver is shown in Fig. 4 and photos of the receiver are shown in Fig. 5. A monopole over a ground plane is used as an omnidirectional receiving antenna. The output signal of the antenna is fed into a tunnel diode detector and the resulting FSK signal is passed through a high-gain amplifier and then decoded by the bandpass filters, envelope detectors, and a comparator. With the threshold and parity checks mentioned earlier, the receiver's sensitivity is set as approximately -61 dBm. For input signals above the level, messages are received with extremely low error rates; below that level, messages are rejected by the threshold. In the demonstration receiver, the decoded message is shown on a seven-segment numerical display (Fig. 6). In an operational system, the data channel on the vehicle's two-way radio would be used to relay the information from the vehicle to the control center.

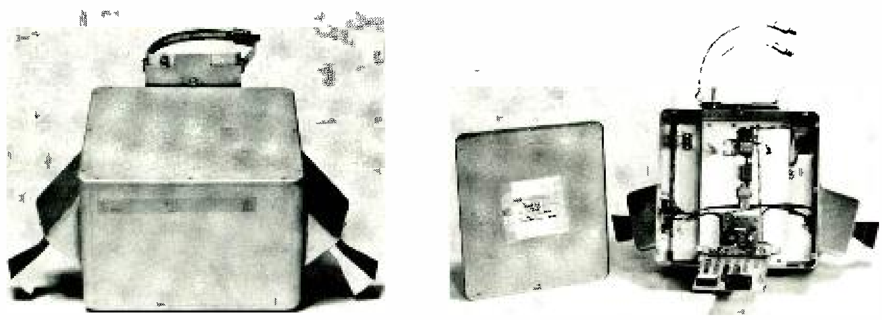


Fig. 3 — Two views of vehicle location transmitter.

It should be emphasized that the above equipment was constructed for demonstration of the system concept and does not represent anything close to a final design. For large-scale production, the actual implementation of the signpost equipment would be radically different from the equipment pictured earlier. Through use of microwave integrated circuitry, custom logic circuits of the COS/MOS type, and other techniques which prove advantageous in mass production, substantial reductions in size, weight, and most important, cost are possible. As one step further towards an actual system implementation, an advanced design of the signpost transmitter was constructed. A sketch of the transmitter (shown mounted on a pole) is shown in Fig. 1. This transmitter utilizes microwave integrated circuitry, conventional COS/MOS logic circuits, and a flat printed circuit antenna. A photograph of the microwave integrated circuit module is shown in Fig. 7.

The module shown contains all the microwave components needed for the transmitter. A transferred electron oscillator (TEO) operating in a microstrip cavity serves as the power source. Temperature compensation is used to keep the frequency fixed to within ± 20 MHz and the power constant to within 2 mW over a temperature range of −50 to +75°C. The oscillator, power divider, and PIN diode modulators are fabricated on a 15-mil alumina substrate, and the isolator is fabricated on a ferrite substrate.

Conventional COS/MOS circuits on a single card of a size approximately 3.5 × 5 in. have been used to obtain all logic and control signals. In large-scale production, the logic functions will be derived from a single, standard twenty-four-pin package. The antenna, shown in Fig. 8, consists of a printed circuit pattern

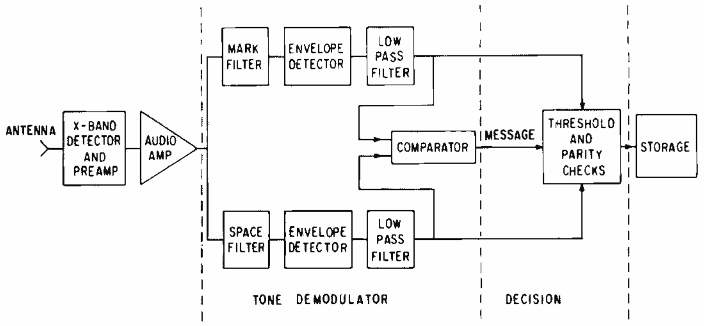


Fig. 4 — Block diagram of receiver.

placed on both sides of a fiberglass board. The unit shown contains a four-element array of dipoles and has a gain of approximately 11 dB. Use of the printed circuit technique for antenna construction results in a compact and inexpensive design.

A cost estimate of each of the various components and subsystems in the transmitter and receiver has been undertaken. Preliminary estimates indicate a transmitter cost in the neighborhood of $100 and a receiver cost well under that figure once large production quantities (in the 50,000 to 100,000 range) are achieved. For much smaller quantities (in the 3,000 range), the transmitter should cost less than $250. Again, these are preliminary figures which are certainly subject to revision as more information is acquired.

Two-way radio system

The street network of X-band signposts and X-band receivers on the equipped vehicles serve ultimately to deposit the designated number of a signpost beam in a register in the vehicle. The purpose of the two-way radio system is to relay this information and additional information, such as the status of the mobile unit, from the car to the central monitor. It is assumed that any user of an automatic vehicle monitoring (AVM) system would need two-way voice capability so that the two-way radio system must provide voice service as well. While there are several possible configurations, depending on system requirements, a scheme exists in which the two-way radio on the car can provide both data and voice communications with only one transmitter and receiver and still retain the inexpensive half duplex mode of operation. The scheme requires a multi-channel receiver with one more channel than would be provided for voice service alone. It must be emphasized that the particular example described below satisfies a relatively fast polling rate (update rates of once per minute or once every 15 s). Such techniques are typically needed to meet AVM requirements for public safety vehicles.

On the other hand, requirements for buses would likely be less stringent and even less so for taxis or trucks. All these different requirements would manifest themselves in differently designed systems than the one described. Further, not only the user requirements but also his existing equipment enters the picture. In the example below, we have assumed that his existing units can readily be modified to be able to turn on in the order of 10 ms (which is true for modern transistorized equipment). Equipment that could not be so modified would lend itself to a far different communications system.

The number of extra channels (over and above the voice channels) needed for the whole system is determined by the polling rate desired. The configuration to be described is such that one mobile radio channel can handle 800 polls per minute. As an example, suppose one wanted to service a fleet of 1000 vehicles with an AVM service in which 80% were polled once per minute and 20% were polled four times a minute. Hence, for the whole system, two conventional mobile radio channels are needed for data in addition to the voice channels. Any one vehicle, however, has access to only one data

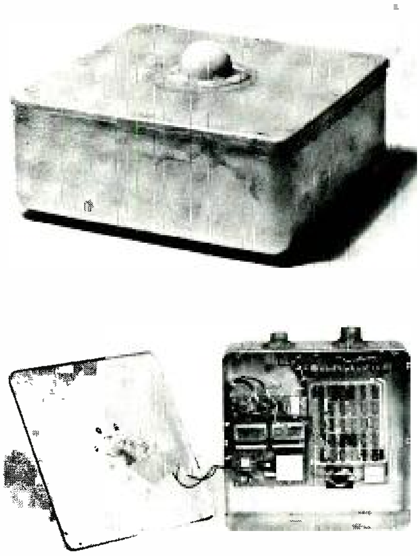


Fig. 5 — Two views of vehicle location receiver.

Fig. 6 — Display used for vehicle location system.

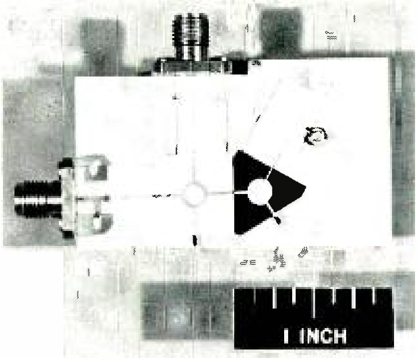


Fig. 7 — Microwave circuit transmitter module.

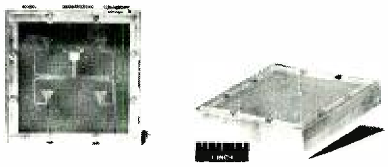


Fig. 8 — Printed circuit antenna.

channel. Each vehicle's unit is normally tuned to its own data channel. The data channel not only allows for polling but also acts as a command and control channel for the vehicle's radio. The most important command is the one that causes the unit to switch from the normal data channel to another channel for voice communication.

There are six classes of messages that are sent from the central monitor to vehicles over the data channel:

Type 1 —normal polls
Type 2 — invitations for voice service requests or alarms
Type 3 — invitations for alarms only
Type 4 —command to switch to voice channel
Type 5 — acknowledge request for voice service
Type 6 —acknowledge alarm

The first three types are termed scheduled and the last three, unscheduled transmissions. The implication of these terms is that for each data channel, the central monitor has the equivalent of a list of 870 scheduled messages to send. Of these, 800 are of Type 1. Some of the entries on the list can be repeats, *e.g.*, vehicles polled four times as often have four entries on the list at equal spacings. Of the remaining 70 entries, 60 are Type 2 and 10 are Type 3. Messages are sent once every 65 ms (the smallest time that still allows sufficient guard times between replies). If there were no unscheduled messages, it would therefore take almost one minute (56.5 s) to go through the whole list and complete one cycle. The 60 Type 2 entries and 10 Type 3 entries are so spaced on the list that they come up about once every second and once every six seconds, respectively. The purpose of these messages is to ascertain which vehicles want voice service and which are in an "alarm" state (*i.e.*, have operated their "silent alarm" button) without having to wait up to a minute before they are polled by a Type 1 message.

When a vehicle operator wants voice service, he goes "off-hook" or presses a designated button on his unit. The unit then waits for a Type 2 message. Upon receipt, it transmits back a message indicating its identity and indicating a desire for voice service. The unit then returns to its normal state, *i.e.*, receive mode on the data channel. Of course, other units might on some rare occasions respond in the same time slot and the messages would thereby have mutilated one another. The mobile operator will ultimately note this by not receiving an acknowledge (message Type 5) and can reactivate his request by pushing the voice request button again. It should be noted that when a response to a Type 2 message is received at the central monitor it does no more than inform the proper dispatcher. Activating voice service is at the discretion of and under the control of the dispatcher.

Because of their need for immediate action, alarms are treated differently. First of all whenever an alarm is activated, the unit will keep sending an alarm signal in response to a Type 2 or 3 message until turned off by the receipt of a Type 6 message. The alarm can get in on the "fast access" time slot that comes up about every second although on this slot they have competition from units requesting voice. They are also provided a "slow access" time slot, devoted to alarm use, that comes up about every 6 seconds. To guard against the rare case in which two units have activated their alarms within the same 6-second interval, (and have not gotten in on the Type 2 response) the alarm can get in on the regular poll (Type 1) as well. But in this case there can be a delay of up to one minute.

As mentioned above, if no mobile unit operator or dispatcher wanted voice service and no alarms were activated, a cycle would be completed in 56.5 s with the sending of 870 scheduled messages. If any of these conditions are not met, the central monitor will, in effect, generate a list of unscheduled messages. Whenever such a list size is greater than zero, the transmission of the scheduled messages ceases until all unscheduled messages on the list are transmitted out (also at the rate of once every 65 ms). Now, of course, every time an alarm response or a request for voice response is received, an unscheduled message is generated (Type 6 or 5, respectively). Also, whenever a dispatcher "commands" a mobile unit to switch to a voice channel an unscheduled message is generated (Type 4). It is important to realize that the dispatcher may do this *either* because he wants to speak to the man in the vehicle *or* because the man in the vehicle wants to talk to him (*i.e.*, the mobile operator, by requesting voice service, caused his unit to respond to a Type 2 message and the central monitor displayed the request to the proper dispatcher who now answers the request). When the dispatcher wishes to terminate the voice conversation, he causes the central monitor to send out (on the voice channel) a data signal that switches the vehicle unit back to the data channel.

An important computation is the average cycle time. This computation also serves as a review of the overall two-way radio system. Assume that any one data channel handles 500 vehicles (with 20% polled 4 times as often as the rest). Assuming 0.004 erlangs voice traffic per car, this means 2 erlangs voice traffic for the 500 cars. If one assumes a 15-s average conversation time, this implies 8 voice requests/min and (with a 50-50 split) 4/min initiated at dispatcher request and 4 at a vehicle operator request. With this in mind, (and assuming no alarms) an average of about 4 of the 60 Type 2 messages/cycle are answered. This means that an average of 4 unscheduled Type 5 messages/cycle will be generated per cycle to acknowledge them. In addition, since the dispatchers will ultimately respond to these requests, these 4 requests/cycle will cause an average of 4 Type 4 messages/cycle. Therefore, not counting dispatcher initiated calls, 878 messages are sent per cycle. Since there are an average of 4 dispatcher initiated calls/minute, the total number of messages/cycle is 882. The average time to send the data messages of all types (at the rate of one/65 ms) is 0.96 min. At peak periods the cycle time is increased only slightly since the scheduled messages dominate the system.

Philadelphia field tests

To verify the appropriateness of the signpost system parameters, such as radiated power, antenna gain and pattern, and data rate, extensive testing was performed, both in the laboratory and under actual field (urban and suburban) conditions. Shown in Fig. 9 is a map of a portion of the City of Philadelphia in which a number of transmitters were installed and tested under contractual support from the U.S. Department of Transportation. Also shown on the map are the lamppost locations where the transmitters were mounted and an indication of the antenna pattern orientation. This particular area in Philadelphia was

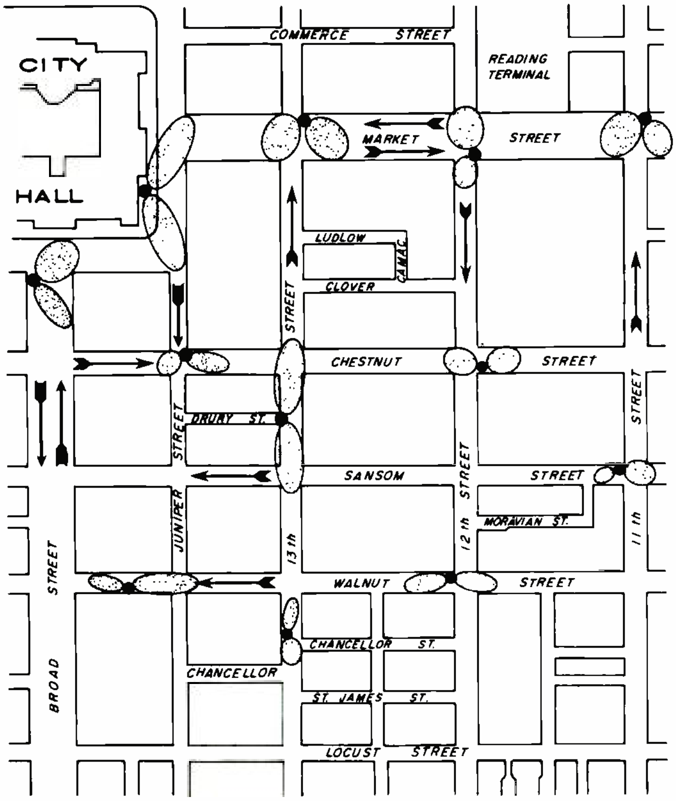


Fig. 9 — City of Philadelphia test area.

selected because it encompassed a number of different topological features including tall buildings, low buildings, wide streets (such as Broad and Market) and narrow streets (Juniper and Drury), unusual-shaped intersections (such as City Hall Plaza), and even unusual-shaped intersections. In addition, as expected in most urban centers, a great deal of traffic, including automotive, bus, and truck was encountered. The effect of all this traffic, and both stationary and moving objects on the received X-band signal was of great interest during these tests.

One of the prime goals of the Philadelphia field test was to demonstrate that it was possible to simultaneously satisfy two conflicting requirements. These were that good signal coverage was needed to insure that the vehicle driving past the transmitter receives the correct messages, but yet the signal should not propagate far beyond its intended range and cause interference between adjacent transmitter units. The interference question was of particular concern during this installation, since adjacent transmitters were, in some cases, less than 350 ft apart. The dual requirements of both good coverage, but no interference were satisfied by utilizing the advantages of X-band frequencies. These included the use of gain in the transmitting antenna to aid in confining the signal to the desired coverage areas. At short wavelengths, it is possible to achieve gain in the antennas and still have a physically small antenna. In addition, propagation at X-band is essentially confined to line-of-sight and even within line-of-sight in urban areas, the signal strength usually decays faster than for free-space propagation. In previous tests with a single transmitter in Trenton, New Jersey, the use of two different antenna orientations allowed complete coverage with no interference. The difference between these orientations was in the depression angle of the transmitting antennas. For most situations, a steep depression angle of approximatley 45° was used. At a few locations, when more range was needed (Broad Street, City Hall Plaza, and dual coverage from Drury Street) the antenna depression angle was decreased to 30°.

The actual field test included driving a vehicle throughout the test area while traversing a "random" route and noting the message stored in the receiver. Many test runs through the area were made over a period of several days and included diverse traffic and weather conditions. Performance was excellent as evidenced by proper coverage and lack of interference between the closely spaced transmitters. The results of these tests demonstrated that an AVM signpost system, operating at microwave frequencies, is operationally feasible.

Conclusions

The X-band signpost vehicle location and tracking system demonstrated within the City of Philadelphia has shown that, even for closely spaced signpost transmitters, mutual interference does not occur when antenna gain and orientation are properly used to limit propagation range. The signpost system allows for variable resolution in different parts of the service area. Use of integrated-circuit technology, coupled with mass production, is expected to lead to an equipment cost of under (or less than) $100 per signpost. The direction detection vehicle receiver is expected to cost even less. Thus, the cost characteristic of this system is: relatively high initial cost but little additional cost as the number of vehicles in the system grows.

Acknowledgment

Grateful acknowledgment is extended to the Urban Mass Transit Administration, Department of Transportation with whose support, under Control No. UT-10023, some of the work reported here has been done; to J. Rosen of RCA Laboratories who designed and fabricated the rf portion of the X-band transmitter and the printed-circuit antenna; and to A. Ritzie of RCA Laboratories who was involved in the assembly and testing of the transmitter and receiver and also assisted during the field tests which determined many of the system parameters.

References

1. Staras, H. and Honickman, S. N., "The Accuracy of Vehicle Location by Trilateration in a Dense Urban Environment," *IEEE Trans. Vehicular Technology*, VT-21, No. 2 (Feb. 1972).
2. Turin, G. L., *et al.* "A Statistical Model of Urban Multipath Propagation," *IEEE Trans. Vehicular Technology*, VT-21, No. 2 (Feb. 1972).
3. Turin, G. L., *et al.* "Simulation of Urban Vehicle Monitoring Systems," *IEEE Trans. Vehicular Technology*, VT-21, No. 2 (Feb. 1972).
4. Kaplan, G. S., "Analysis of an Electronic Fence Element for a Vehicle Location System," *IEEE Trans. on Vehicular Technology*, VT-20, No. 2 (May 1971).

For outstanding corporate effort leading to an innovative video-by-telephone system.

Alfonse Acampora, Denis P. Dorsey, John T. Frankle, Samuel N. Friedman, William D. Houghton, and Lewis B. Spann

Acampora
Dorsey
Frankle

Friedman
Houghton
Spann

Messrs. Acampora, Frankle, Friedman, and Spann of RCA Global Communications, Inc., New York and Messrs. Dorsey and Houghton of RCA Laboratories, Princeton, N.J., led a large corporate-wide effort in the successful introduction of Videovoice — the only currently available system for transmission of video information over voice-grade circuits which is compatible with existing telephone lines and switching equipment. The basic task called for a generation of a system's concept followed by the design and development of the necessary equipments for implementation. The system is fully compatible with standard video equipment both at the transmit and receive terminals.

In addition to the development of the frame-freeze unit and scan-rate conversion at RCA Laboratories and the systems work by RCA Global Communications, significant program contributions were made by Electronic Components, RCA Service Company, and Government Communications Systems.

For outstanding achievement in the development of a highly innovative magnetic tape video player-recorder.

H. Ray Warren

Warren

Mr. Warren of Consumer Electronics, Indianapolis, Ind., has been the primary force in the development of a magnetic tape video player-recorder that is innovative in broad conception and detail. The design overcomes the principal problems in performance, cost, reliability and ease of operation which have until now prevented the introduction of this type of instrument in the consumer mass market. Mr. Warren provided the technical foundation as well as the determined leadership, motivation, and organizational accuity so essential to the success of a development of this kind.

The 1973 David Sarnoff Awards for Outstanding Technical Achievement

RCA's highest technical honors, the annual David Sarnoff Awards for Outstanding Technical Achievement, have been announced for 1973. Each award consists of a gold medal and a bronze replica, a framed citation, and a cash prize.

Awards for individual accomplishment were established in 1956 to commemorate the fiftieth anniversary in radio, television and electronics of David Sarnoff; awards for team performance were initiated in 1961. All engineering and research activities of RCA Divisions and subsidiary companies are eligible for the Awards. Chief Engineers and/or Laboratory Directors in each location present nominations annually. Final selections are made by a committee of RCA executives, of which the Executive Vice President, Research and Engineering, serves as chairman.

Cullen
Herzog
Mueller
Scott

Barbin
Barkow
Evans
Gross

Haslau
Hughes
Masterton
Thompson

For outstanding team research leading to a new class of integrated semiconductor arrays.

Glenn W. Cullen, Gerald B. Herzog, Charles W. Mueller, and Joseph H. Scott, Jr.

Drs. Cullen and Mueller and Messrs. Herzog and Scott of RCA Laboratories, Princeton, N.J., have conducted research on material preparation, device fabrication, and circuit application leading to a new class of integrated semiconductor arrays. The silicon-on-sapphire (SOS) approach developed by this team is now recognized as the way to solve many of the problems encountered in applying COS/MOS to large volume applications. Circuits made with SOS can also operate at higher voltages without the latchup problem presently plaguing the COS/MOS product line. This is especially important for the automotive field. The work has been widely acclaimed by leaders in the semiconductor field and RCA is recognized as the pioneer in this new technology. The Air Force recognizes RCA as being in the best position to produce commercial products with this technology. NASA has recognized the importance of this research by a citation and award to members of the team for outstanding effort.

For outstanding technical achievements in color picture tube systems.

Robert L. Barbin, William H. Barkow, John Evans, Jr., Josef Gross, Horst E. Haslau, Richard H. Hughes, Walter D. Masterton, and Ira F. Thompson.

Messrs. Barbin, Evans, Hughes, and Masterton of Electronic Components, Lancaster, Pa; Mr. Barkow and Dr. Gross of Electronic Components' Materials and Display Devices Laboratory at the David Sarnoff Research Center, Princeton, N.J.; and Messrs. Haslau and Thompson, of Consumer Electronics, Indianapolis, Ind., have made unique and outstanding contributions to RCA's worldwide television business by inventing and developing the RCA large-screen, narrow-neck 110° system.

The novel design of the 26-in. picture tube and precision-static-toroid deflecting yoke advanced the state of the art to provide high performance and lower cost due to the intrinsic simplicity of the system germane to RCA's penetration of the European market. The RCA system provides improved product uniformity and reliability when compared to the more complex competitive European hybrid Mark-I and the solid-state Mark-II wide-neck 110° systems.

In 1972 Scranton produced 135,000 A67-150X picture tubes against a forecast for 120,000 and 20,000 tubes were produced by Videocolor at Anagni. Increasing quantities are forecast for 1973 with 240,000 for Scranton, 220,000 at Videocolor plus additional quantities by TCTL, SEL and Sylvania. It is anticipated the European narrow-neck 110° system will be further developed and optimized in the Super Matrix 19V size by 1974 and possibly 25V size by 1975.

The RCA narrow-neck saddle deflecting yoke system has also been adopted by several Japanese licensees and TAA and has gained wide acceptance in Japan during 1972. It is anticipated the Japanese will adopt the PST deflecting yoke during 1973 to achieve the additional performance and economy advantage. RCA's Patent License income should be enhanced during the next decade by this development.

Thirty-one engineers at six locations made outstanding and unique contributions to the development of the 110° narrow-neck system. The engineers cited by this award advanced the technical state of the art by making invention(s) which made the RCA large-screen, narrow-neck 110° system successful.

Power transistors in automotive applications

W. P. Bennett | J. S. Vara

Electronics is destined to be a major factor in the success of transportation systems of the future from the standpoint of reliability, as well as environmental and user-convenience considerations. The automobile, especially, will expand its use of solid-state devices such as the transistor and integrated circuits. This paper discusses many present and future applications, functions performed by transistors, reliability, and considers the status of present and impending uses of solid-state devices.

THE GENERAL USE of electronic systems in automobiles has been projected for several years. Although most of these projections have been overly optimistic, they do represent a trend which, accelerated by safety and pollution legislation, is becoming a reality in 1973[1,2,3]

In most electronic equipment, the need to provide muscle in the form of linear amplifiers, voltages regulators, or power-switching devices requires the use of power transistors. The electronic equipment in an automobile is no exception: the transistor radio in the mid 1960's, the Chrysler transistorized voltage regulator in 1969, and Chrysler's use of the electronic ignition in their entire line in 1973 are but a few examples.

RCA's automotive transistor line

To assure that electronic equipment meets automotive requirements, special consideration must be given to electrical as well as environmental characteristics. A cost-effective design which provides high reliability must be implemented. RCA has developed a broad line of power transistors in both hermetic and plastic packages for automotive applications; a survey of these transistors is given in Table I. Table II shows the estimated use of power transistors in domestic automotive systems for the years 1971 through 1975.

Categories of applications

Power transistors are used in automobiles in entertainment, performance, durability, safety, pollution control, driveability, and comfort systems. In many cases, systems overlap. For example, the electronic ignition system enhances performance, provides greater durability (maintenance-free operation), and also is a key element of the emission-control system. The radio and tape player constitute the entertainment package. The transistorized voltage regulator provides durability and enhances performance by maintaining the battery in peak form through its life. The seatbelt interlock is strictly a safety feature. Adaptive or antiskid braking systems not only provide safety but enhance driveability.

Injected-fuel systems not only control emissions but also enhance performance.[4] A major element of emission controls for 1973 and beyond will be exhaust-gas recirculation systems. the more advanced of these will employ transistor-controlled solenoid actuators.[5] Electronically operated transmission systems will reduce emissions and improve driveability. Speed-control, anti-slip, and anti-wheel-lock systems all improve driveability. Electronically actuated air-conditioner-clutch drives and electric fan-motor drives are part of the comfort package.

Present applications

Automotive applications in which power transistors are widely used today include

---

Reprint RE-18-6-12
Final manuscript received February 27, 1973.

Wilfred P. Bennett was graduated from Michigan State University in 1944 with a BSEE with high honors. He has done graduate work in physics at Franklin and Marshall College, Lancaster, Pa. Mr. Bennett has been employed continuously since 1944 by RCA in the design and application of power devices, and has been substantially involved at some time with every major power device, solid and vacuum. Mr. Bennett is currently Engineering Leader, Automotive Electronics, within the Power Transistor Application Engineering Department of the RCA Solid State Division. Mr. Bennett is a registered Professional Engineer in both New Jersey and Pennsylvania, and is the author of many technical papers.

John S. Vara, Power Transistor Applications Engineering, RCA Solid State Division, received the BSEE in 1965 from Fairleigh Dickinson University, Teaneck, New Jersey. He worked for Tung-Sol Electric in Rectifier and Transistor Applications prior to joining RCA in 1966 as an Applications Engineer for Power Transistors. He is currently active in the characterization and application of power transistors for the automotive and consumer markets. Mr Vara received the RCA Electronic Components and Devices 1968 Engineering Team Achievement Award for Power Transistor Engineering.

audio output devices in radios (class-A and class-B, n-p-n/p-n-p complementary-symmetry amplifiers); tape-player motor-speed regulators; clutch controls for air-conditioner compressors; motor-speed controls for air-moving blowers in air-conditioners; voltage regulators controlling field current in alternators; and electronic ignition systems. In all of these applications, except for the radios, in which the use of power transistors has reached saturation, there will be a substantial increase in the use of electronic systems employing power transistors in the relatively near future. This increased use will occur as more of the automobile manufactureres follow the current leaders in adopting electronic systems for use in their product lines on a 100-percent basis.

Future applications

Other systems that employ power transistors and that will be coming into use with the 1974 model year, largely because of legislative mandates, include seat-belt interlock systems for passenger cars; adaptive, anti-skid braking systems for large trucks; and solenoid actuators in exhaust-gas recirculation systems. In the 1975 model year and beyond, systems will include actuators for electronically controlled transmissions and anti-skid braking systems for passenger cars, smaller trucks, and light-service vehicles.

Speed-control, anti-slip (max-traction), and anti-wheel-lock systems will probably be initially available as options in 1974-1976 models, and may well become standard items on the automobiles of most manufacturers during the late 1970's. Transistorized fuel-injection and fuel-metering systems will no doubt be used in limited numbers in 1974 or 1975 model cars and trucks; however, the use of these systems will grow in the following years.

Functions performed by transistors

With the exception of the radio, in which the power transistor is employed as an audio amplifier to drive the speaker coil, most of the work performed by power transistors involves current switching, usually to inductive loads; for example, to the solenoid of a relay, or, in motor-control or voltage-regulator service, to the inductive winding in a motor or alternator. In some applications, such as seat-belt interlock and turn indicators, current is switched to an incandescent lamp which requires a high "in-rush" of current from "turn-on" until the lamp filament reaches the proper operating temperature.

In the inductive ignition system, the transistor replaces the traditional breaker points in switching the current to the primary of the ignition coil, which typically has an inductance of 5 to 10 millihenries.[6] Figs. 1 through 5 show typical simplified circuits for the principal transistor applications (voltage regulator, radio, ignition system, tape-player motor regulator, anti-skid solenoid driver).

Table I — RCA power transistors for automotive applications.

Application	*Transistor type*	*On-state current/ voltage req.*			*Sustaining voltage*	*Typical energy requirements*				*Typical RCA family type*
						I_s/b			E_s/b (mJ)	
		I_c (*A*)	V_{CE} (*V*)	h_{FE}	(*V*)	V_{CE} (*V*)	I_C (*A*)	time	(mJ)	
Radio										
Class - A	n-p-n	1	15	20	35	—	—	—	180	2N5298
Class - B	n-p-n	1.5	1	35	30	40	7	10ms	—	2N5298 or 2N6292
true-comp.	p-n-p	1.5	1	35	30	—	—	—	—	2N6107
Voltage regulator										
Standard	n-p-n	3	1	15	30	—	—	—	70	2N5298,2N5496 or 2N6290
	p-n-p	3	1	15	30	—	—	—	70	2N6107
	n-p-n	5	1	25	45	—	—	—	180	2N6103
Heavy duty	n-p-n Darlington	5	1.5	1000	90	—	—	—	180	2N6388
	p-n-p Darlington	5	1.5	1000	90	—	—	—	180	TA8203
Ignition										
Driver	n-p-n	3	1	15	30	—	—	—	—	2N5298 or 2N6292
Output	n-p-n	3	1	4	300	300	8	50μs	—	2N5840
	n-p-n	5	1.5	5	400	400	10	25μs	—	TA8847
	n-p-n Darlington	5	1.5	100	400	400	10	25μs	—	TA8847/2N3585 or TA8766
Seat-belt interlock	n-p-n Darlington	0.6	1.5	1200	80	40	1.6	5ms	50	TA8790
	n-p-n	0.6	1	20	80	40	1.6	5ms	50	2N6292
	p-n-p	1.2	0.5	6	40	—	—	—		2N6107
Anti-skid solenoid driver	n-p-n	3.5	1	12	45	—	—	—	—	2N5496
Tape player motor regulator	n-p-n	1	2	25	40	—	—	—	—	2N5298
Air-conditioner valve control	n-p-n	0.4	4	50	40	—	—	—	—	2N5298

Table II — Estimated power-transistor usage in millions of units in domestic automotive systems.

Year	*Usage (millions)*
1971	30
1972	40
1973	95
1974	145
1975	160

The automobile environment

The environment in the automobile,[7,8] especially in the engine compartment, is demanding, but not excessively so for properly characterized and rated power transistors; the passenger-compartment environment is more favorable than that under the hood. Table III shows a comparison of conditions in both compartments. Some of the conditions mentioned in the table require some amplification.

Most systems must function at battery supply voltages as low as 5 or 6 volts, but must survive supply voltages as high as 24 volts for short periods of time; for example, during booster start conditions (road service). In addition to the wide range of dc battery supply voltages, there are numerous transient conditions to which the electrical systems may be exposed. Depending on the particular electrical systems involved, exponentially decaying positive voltage transients, peaking as high as 120 volts with 45-millisecond time constants, may be experienced during load-dump conditions when the battery becomes disconnected.

Survival of the various electronic systems is also expected when battery polarity is

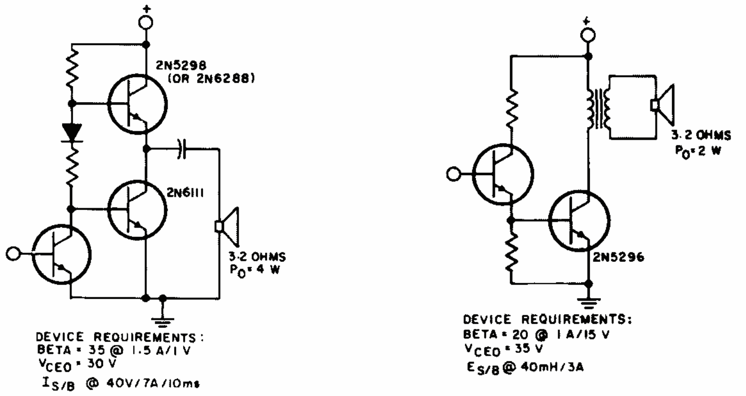


Fig. 1 — Radio circuits: (a) class AB output; (b) class B output.

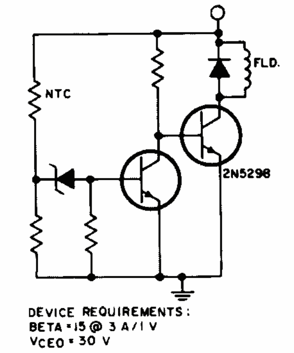


Fig. 2 — Voltage regulator.

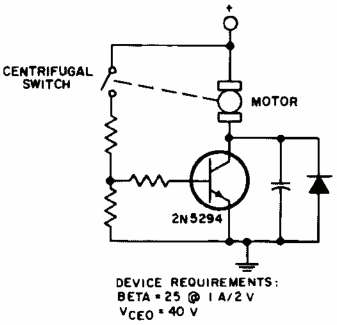


Fig. 3 — Tape-player motor regulator.

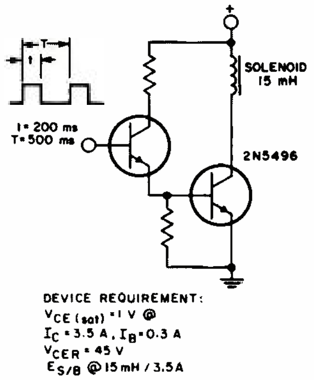


Fig. 4 — Adaptive braking (anti-skid) solenoid driver.

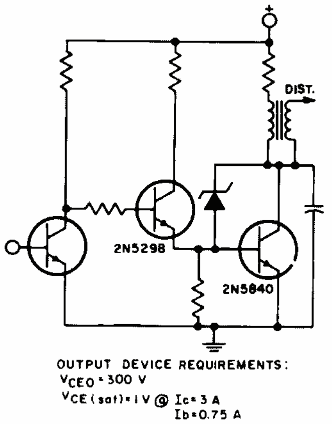


Fig. 5 — Electronic ignition.

inadvertently reversed. Negative peak transients reaching 80 volts (with 30-millisecond time constants) are typical of the worst-case conditions which electrical systems and components are required to survive. These conditions could result from field decay, should the battery be disconnected from the alternator field, or from voltage spikes produced by the ignition coil and applied to the various systems if the battery is disconnected or becomes open circuited.

The mechanical shock and vibration conditions experienced do not significantly affect transistor performance; however, the method used to mount the transistors in the system can introduce conditions deterimental to that performance. If excessive forces are employed in securing the transistor to the mounting structure, permanent deformation, with resultant internal damage to the transistor, can occur. On the other hand, if transistor headers are only loosely secured to mounting structures that also serve as heat-removal elements, excessive heating of the transistor can occur. However, the degree of process control required to properly secure the transistor assembly is trivial when compared to that required to mount the transistor pellet on its substrate. In the engine compartment, where conditions are most severe, the transistors are usually mounted with other components and the entire circuit encapsulated in a protective potting compound.[3]

Thus, the two most critical environmental parameters are temperature extremes and the extremes of the electrical environment expressed in terms of overvoltage and voltage transients, both forward and reverse.

Reliability assurance

Reliability is the most desired characteristic in any automotive electronic system, since we all fear the failure of any automotive component, particularly when it causes the automobile to function improperly or fail at a critical time. But personal inconvenience is no longer the sole criteria for evaluating reliability. In the automotive field, warrantees against defects for increasingly extended periods of time or mileage are in vogue, and reliability is measured directly in terms of warranty claim costs to the automobile manufacturer. Reliability and the first costs in achieving it are constantly being evaluated against failure rates and warranty repair costs. Thus, it is necessary not only to provide power-transistor products which experience low failure rates, but also to provide rating information which the sytem manufacturer can use to design his system within the specified worst-case failure-rate limits of the selected components. The principal criteria of transistor operation are thermal-fatigue ratings, safe-operating-area curves,[10] and/or specifications in both forward and reverse emitter-base-bias modes.

It is the repeated thermal-cycle stress, resulting from the intermittent nature of automotive service, compounded by the large ambient temperature extremes which make the automobile environment so hostile to the power transistor. The complete power transistor with its leads and protective package is a physical structure and, like all physical structures, its component parts experience constant mechanical stress when subjected to repeated thermal cycles. The greater the change in temperature during each cycle, the greater will be the stress. Like the materials used in most physical structures, the materials in transistors will ultimately fail when subjected to a sufficiently high number of repetitive mechanical-stress cycles, even though the stress level during one cycle is less than the yield strength of the materials involved. The transistor designer who employs materials and processes which provide high-strength structures and who designs the structures to minimize mechanical stress resulting from temperature change will be a successful designer of products for use in automotive applications. Likewise, the automotive equipment designer who selects power-transistor types which carry thermal-fatigue rating specifications and who utilizes these ratings in his design effort will know that thermal fatigue failures will not plague his future.

A typical thermal-fatigue rating chart for a popular power transistor is shown in Fig. 6. The credible transistor manufacturer will not only assure that the design capability of his product matches or exceeds the thermal-fatigue ratings he publishes, but he will also perform various, accelerated, real-time, control tests on the product on a continuing basis to monitor process ontrol. Only in this way can he assure that the product capability is maintained.

The severe voltage transients experienced in the automotive environment dictate that the transistor designs selected must possess the requisite peak energy-handling capabilities and that adequate testing be performed to guarantee these capabilities. High-energy pulses may be experienced in either the turned-on (forward bias) or the turned-off (reverse bias) state of the transistor.

For many applications, it is adequate to stipulate tests at specific voltages and currents, and pulse duration at a specific energy (an I_s/b test verifying the absence of forward-bias second breakdown and/or an E_s/b test verifying the absence of reverse bias second breakdown). The tests may be accomplished by switching the transistor off and forcing it to absorb, in the avalanche condition, the energy stored in a series inductor at a specific current level. In some applications, notably in ignition systems, it may be desirable to test each transistor in a circuit that simulates a worst-case ignition condition. The circuit would deliver the energy pulse to the transistor as it would be experienced in the application.

A study of the data on field failures of transistors in typical automotive systems reveals that a large fraction (often approaching 50%) of the transistor failures occur within the first thousand miles of service, and when a piece of electronic equipment has survived beyond the 5,000-mile point, it will probably last for the life of the automobile.[3] Thus, an all-out attack on this "infant mortality" problem is in order.

The problem of infant mortality in electron devices is not new. High-cost, high-reliability types have been produced for the military and aerospace systems for some time. An integral part of all high-reliability product processing has been an extended power burn-in and/or an extended stress testing of the product to screen out that portion of the population which would be subject to premature failure. In the automotive industry a screen test which can be performed on a product at a very high production rate and at a very nominal cost is needed. The beneficial effects of a screen test, its economic worth, and the fact that it produces no deleterious side effects on the product must all be thoroughly proven. The RCA Power Transistor Group has such screening processes now under evaluation in the pilot phase.

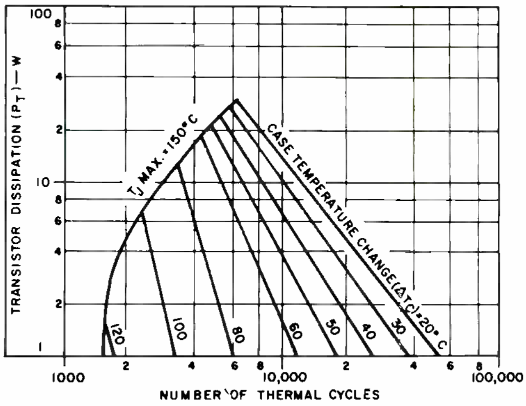


Fig. 6 — Thermal-cycling rating chart lor the type 2N5298 transistor.

Table III — Comparison of conditions in automobile passenger and engine compartments.

Environmental parameter	*Passenger compartment*	*Engine compartment*
Chemical	100% relative humidity	100% relative humidity plus grease, oil, water, anti-freeze, solvent fuels, salt spray.
Temperature		
Operating	−30°C to +85°C	−40°C to +125°C
Temperature cycling	5000 cycles from 15°C to 75°C to 15°C for typical 50,000 miles service.	5000 cycles from 15°C to 95°C to 15°C for typical 50,000 miles service
Thermal shock		10°C water spray quench from 125°C
Electrical	Short-term battery voltage ranging from 5 to 24 volts Transients: to + 120 V with 45 ms time constant, to − 80 V with 30 ms time constan Reversed battery polarity	

Conclusion

It is clear that power transistors will play a major part in the expanding automotive electronics market. The trend to develop cost-effective, high-reliability devices to reduce warranty costs will accelerate. To meet this challenge, the RCA Solid State Division visualizes the extended use of Darlingtons, which can be driven directly from integrated circuits. Less expensive packages resulting from better device passivation techniques and packages that perform multiple functions will become a reality. The net result of this effort will be an automobile that not only meets safety and environmental requirements, but does so economically with no sacrifice of dependability.

References

1. Mason, John F., "The Electronic Car Gets a Green Light in Detroit". *Electronic Design*, Vol. 19 No. 10 (May 13, 1971) p. 22-28.
2. Beardsley, Charles W., "A Slow Slow Start in a Cold Market". *IEEE Spectrum*, Vol. 9 No. 9 (Sept. 1972) p. 22-29.
3. Balan, L., VanHalteren, C.J., Weier, R.M., "Performance of Electronics in the Automobile to Date at Chrysler", Society of Automotive Engineers, paper No. 730131.
4. Rachel, I.L., "Electronic Fuel Injection — A Fuel Management Method Employing Optimal Electronic Contouring", 1972 Wescon Technical papers (Sept. 1972).
5. "Emission Control Devices Complicate Engine Design", *Product Engineering*, Vol. 93 No. 9 (Sept. 1972) p. 28-29.
6. Myers, R. S., "Electronic ignition comes of age", *this issue*.
7. Walsh, W.J., "Environmental Problems of Vehicular Electronics", *1972 Wescon Technical papers* (Sept. 1972) p. 19, 21.
8. Andrews, Gilman B., "Control of the Automotive Electrical Environment," Society of Automotive Engineers, paper No. 730045.
9. Lang, G.A., Fehder, B.J., Williams, W.D., "Thermal Fatigue in Silicon Power Transistors," *IEEE Transactions on Electron Devices*, (Sept. 1970) p. 787-793.
10. Turner, C.R., "C.R. Turner Speaks out on Second Breakdown", *EDN/EEE*, Vol. 15 no. 7 (July 1967).

Harmonic radar for automobile collision avoidance

Dr. J. Shefer and R. J. Klensch

An experimental automobile radar has been demonstrated which is designed to avoid rear end collisions on highways. A completely passive reflector, mounted on the back of vehicles, returns the second harmonic of the frequency transmitted from the trailing vehicle. The radar is immune to clutter since its receiver is tuned to the second harmonic frequency only. It is also immune to blinding by cars traveling in the opposite direction, as well as to other interference problems inherent in a "dense" environment.

In 1970, there were 12.3-million collisions involving two or more vehicles. Of this number, 3.8 million, or close to one third, were rear end collisions.[1] These collisions resulted in a "societal cost" that has been estimated at close to $10 billion. Noting that a rather simple geometrical relationship exists in rear end collisions, *viz*, two vehicles aligned with the road and in a head-to-tail orientation, it appears that a radar alerting or braking system can be effectively employed in preventing or moderating many of these collisions.

System considerations

RCA Laboratories has developed a radar system that will aid the driver in maintaining a safe distance from the car in front by constantly monitoring the distance and the closing rate, as well as his own ground speed. The driver would be warned by sound or light signals whenever the combination of these parameters indicates that the separation between his car and the car in front becomes unsafe. As a further step in the system's development, the brakes would at the same time be activated automatically. Throttle activation can eventually be added for completely automated headway control.

A viable radar for cars on highways must first be immune to clutter, which includes reflections from the roadway, trees, highway signs, overpasses, bridges, and similar highway fixtures. The seriousness of clutter can be assessed when it is recognized that the radar cross section of an overhead sign can be 30 dB larger than the radar cross section of the back of a small car. Other car radar systems try to cope with this problem by excluding any returns from objects that are stationary with respect to the ground. That kind of processing does eliminate clutter from stationary objects; unfortunately, it also eliminates the return from a car standing in one's own lane. This is a serious deficiency, especially since a majority of all rear end collisions occur at a time when the car in front has completely stopped. When we add to the picture a large number of other cars carrying the same kind of radar and traveling in both directions of a highway, a whole new family of mutual interference problems arise. These can be characterized as blinding, masking, and cross-talk types of interference. They can cause false alarms or mask true alarms in conventional radar systems. But in the harmonic radar system, they have been completely eliminated. Minimizing the incidence of false alarms is of prime importance if automobile radar systems are ever to become a reality. When false alarms occur more often then at a very low threshold rate, users are likely to lose faith in the system and either override it or shut it off completely.

The harmonic radar concept

The radar receiver shown in Fig. 1 is tuned to the second harmonic of the transmitted frequency. The car in front is equipped with a special reflector that returns efficiently the second harmonic only. (In extensive testing so far, we have not found any natural objects that will produce a detectable second harmonic frequency.) Thus clutter is eliminated because the sources of clutter, — signs, overpasses, — do not produce radar echoes at the second harmonic, and blinding is eliminated because all radar receivers respond only to signals at the second harmonic of the transmitted frequency.

Authors Shefer (left) and Klensch.

Richard J. Klensch, Communications Research Laboratory, RCA Laboratories, Princeton, New Jersey, received the BSEE degree from the University of Illinois in 1951. He did graduate work in the Electrical Engineering Department of Princeton University from 1952 to 1958. Mr. Klensch joined RCA Laboratories as a research engineer in 1952, to work with high-resolution radar and infrared detection devices. From 1954 to 1956, he served in the army as a radar instructor; returning to the RCA Laboratories in 1956. Subsequently, he did research in the areas of microwave scanning antennas, time division multiplex systems, digital and analogue communications, and color television. In 1961, he participated in research leading to an advanced Naval Communications System, continuing this effort until 1966. From 1966 until 1971, he did research in new electronic halftone generation techniques and CRT display systems. Since late 1971, Mr. Klensch has been investigating traffic safety control and microwave detection systems. He is a member of Sigma Xi and a senior member of the IEEE.

Dr. Joshua Shefer, Communications Research Laboratory, RCA Laboratories, Princeton, New Jersey, received the BS and Ingenieur (EE) degrees from the Technion Israel Institute of Technology, Haifa, Israel in 1949, and the PhD from London University, London, England, in 1955. In 1956, he joined the Electronics Research Laboratories of the Israeli Ministry of Defense, where he headed the Microwave R&D Division. During that time, he also lectured at the Technion on microwave theory and techniques. From 1960 to 1962, after completing a two-year appointment as Scientific Attache at the Israeli Embassy in London, he joined the Gordon McKay Laboratory, Harvard University, Cambridge, Mass., as Research Fellow, working on antenna problems and, specifically, surface waves in periodic structures. During that period, he also acted as Research Consultant to the Foxboro Company in Massachusetts on applied electromagnetic problems. In 1962, he joined Bell Telephone Laboratories, Whippany, N.J., where he worked on problems relating to horn antennas, overmoded waveguides, propagation on open guiding structures, and atmospheric fading. In 1967, he joined the RCA Laboratories, where he is presently active in the utilizaiton of new microwave solid state devices in communiction systems as well as highway safety applications. His work included propagation tests at 900 MHz and 10 GHz in an urban environment; development of a microwave vehicle locator system; and the design and testing of a harmonic radar for vehicle collision avoidance. Dr. Shefer is a member of Sigma Xi and a senior member of the IEEE.

Reprint RE-18-6-11
Final manuscript received January 22, 1973.

Blinding interference

Car A in Fig. 2 is traveling behind car E, with its conventional radar measuring distance to car E. Clearly car D, going in the opposite direction, will deliver an enormously large signal to car A's receiver, compared with the reflection from car E. Quantitatively, the blinding signal can be 50 dB or 60 dB higher than the echo being looked for. This blinding transmission will therefore be seen from a large distance ahead and may cause a false alarm, as well as saturate the receiver of car A. The sidelobes from cars B and C may have the same effect. In the harmonic radar system, on the other hand, the receiver of car A will reject all signals other than the second harmonic of its transmitted frequency.

Cross-talk interference

Fig. 3 indicates another kind of interference, inherent in conventional radar, which may be called cross-talk interference. Car C in Fig. 3a may receive a false alarm even though it is in no danger of running into car B. With a harmonic radar, as in Fig. 3b, the return signal is shaped into a well-defined beam, covering the width of one lane only.

In the situation on a curve, as in Fig. 4a, quite evidently we do not need a third car to produce a false alarm. The skin of car B will respond to the transmission from a fundamental radar and may cause a false alarm at car A. Fig. 4b shows that with a well-defined narrow beam reflected from car B, if any reflection occurs at all, the possibility of a false alarm is drastically reduced.

Masking interference

Fig. 5, illustrates yet another problem inherent in a conventional radar which uses the car's body as the reflector. Radar cross sections of rears of cars can vary tremendously: the back of a trailer truck may have a radar cross section several hundred times larger than a small sedan. The effect is then the masking of the desired return from a close vehicle by a larger vehicle much further down the road. With the harmonic radar, all radar cross sections of reflectors are the same, unless designed otherwise. If all reflectors are mounted at a standard height, only the nearest reflector can be seen while all others will be blocked.

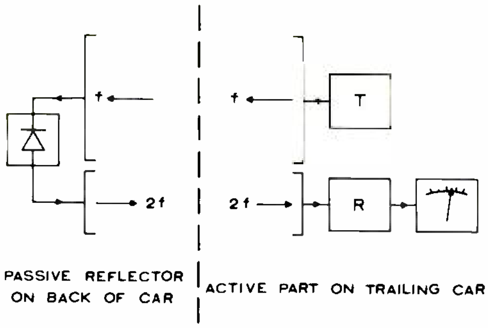


Fig. 1 — Harmonic radar configuration.

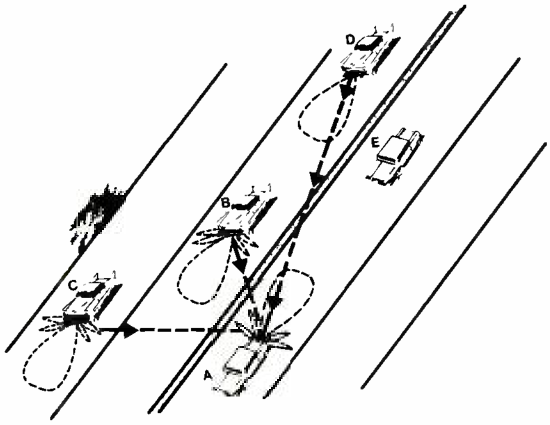


Fig. 2 — Blinding by oncoming vehicles.

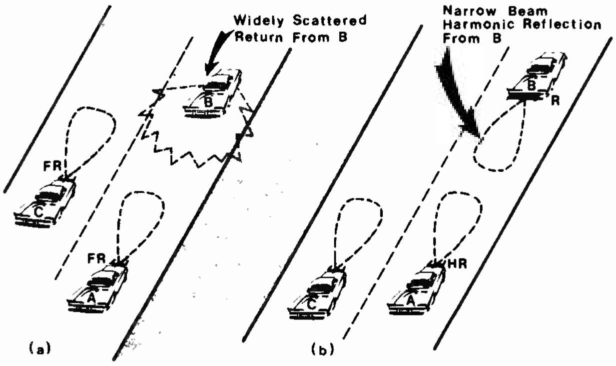


Fig. 3 — Conventional *vs* harmonic radar: "cross talk" from adjacent lanes.

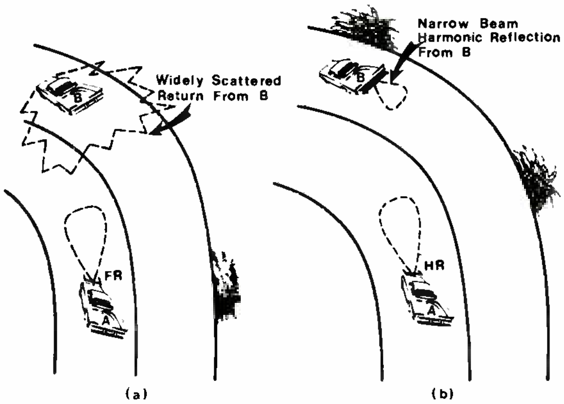


Fig. 4 — Conventional *vs* harmonic radar: road curves.

Fig. 5 — Conventional *vs* harmonic radar: masking.

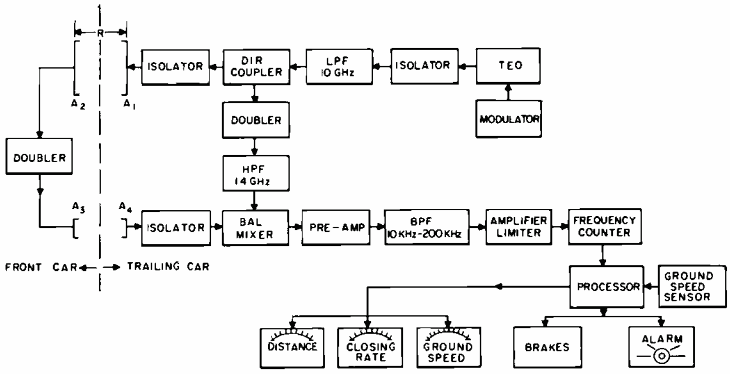


Fig. 6 — Block diagram of experimental collision avoidance radar system.

The radar system described in this paper is unique in its ability to eliminate false targets and clutter, in its immunity to blinding by radars of similarly equipped vehicles, and in its potential of providing automatic braking for specifically "tagged" objects, such as known off-highway collision hazards or wrong-way entrances to one-way streets and highway access ramps.

When in general use, it also has the potential for safely providing higher traffic packing densities without running the risks of massive pileups.

Although it is a cooperative system in that all vehicles must carry the harmonic reflector, the reflector is completely passive, quite inexpensive in mass production, and can easily be retrofitted on existing vehicles. The cooperation required is not more burdensome than the requirement for red tail light assemblies; and the purpose is the same — to aid in preventing collisions.

The radar uses solid state components throughout, and is easily adaptable to integration and printed circuit techniques. It uses a frequency spectrum region that is still not crowded and, with a power density over the antenna aperture of 0.15 mW/cm^2, it does not constitute a radiation hazard even in the immediate vicinity of the radar.

General description of harmonic radar system

The harmonic radar system is shown in the block diagram of Fig. 6. A varactor tuned transferred electron oscillator (TEO) generates cw power at X-band, which is linearily frequency modulated with a total frequency excursion of ΔF, at a rate of f_m, as shown in Fig. 7. The frequency-swept power is radiated from antenna A_1 mounted on the front of the trailing car. It impinges on a similar antenna A_2 which is a part of the harmonic reflector mounted on the back of the front car. The completely passive doubler generates the second harmonic frequency of the power incident on antenna A_2 and radiates it back to the trailing car via antenna A_3. This frequency is in Ku-band. The receiving antenna A_4 delivers the received power, which is at the second harmonic frequency, to the mixer, where it is mixed with a sample of the doubled frequency of the transmitter power. After mixing, we obtain the beat frequency, given by $f_b = \tau\,(df/dt)$ where τ is the round trip time delay equal to $2R/c$ and R is the distance between cars. With triangular modulation as used in this system, $df/dt = 4\,(\Delta F \times f_m)$

Since the time delay is proportional to the distance to the front car, the beat frequency is a linear measure of distance also. After suitable filtering and amplification, a counter circuit develops a voltage which is proportional to the distance between the vehicles. Another step in the processing circuitry derives a voltage which is proportional to the first derivative of the range, *i.e.*, the closing rate. To make a proper decision for a "safe distance," a third piece of information is needed, namely, the ground speed of the vehicle. This is derived from an independent microwave doppler speed sensor. The processor combines the three measurements (range, closing rate, and speed) in a pre-determined fashion, depending on the criteria chosen for "safe distance", which are, of course dependent on weather and road conditions. When a dangerous driving situation is detected, an audible warning is sounded and a warning light is flashed. In our experimental unit, the brakes are applied at the same time, whenever the system is switched to the automatic braking mode. The range, closing rate, and ground speed are also displayed on three panel meters mounted on the dashborad, strictly for experimental purposes. In an operational system, it is not expected that these measured quantities would be displayed.

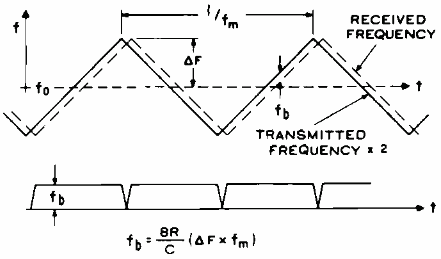


Fig. 7 — Modulation scheme of harmonic radar.

Detailed system description

Modulation parameters

As shown in Fig. 7, the beat frequency, f_b, is given by

$$f_b = 8R(\Delta F \times f_m)/c \qquad (1)$$

where R is range to target, ΔF is total frequency excursion at X-band, and f_m is sweep rate and is independent of the center frequency chosen. The choice of parameters ΔF and f_m is closely related to the presence of a "step error" in distance measurements with frequency modulated radar[2]. Since the waveform of f_b is periodic in f_m, the average measured frequency, f_b, must always be an exact multiple of f_m. The step error ΔR thus introduced is equal to

$$\Delta R = c/8\Delta F \qquad (2)$$

To minimize this basic "granularity" in distance readings, ΔF must be chosen as large as possible. In practice, bandwidth limitations in the doubler and mixing circuits, as well as regulations requiring the efficient use of frequency spectrum, do not allow ΔF to exceed a few tens of MHz. In the experimental system, a good compromise has been found to be ΔF equal to 25 MHz, giving a step error of ΔR = 1.5m. This step error can be tolerated in a distance measurement for collision avoidance where the relative

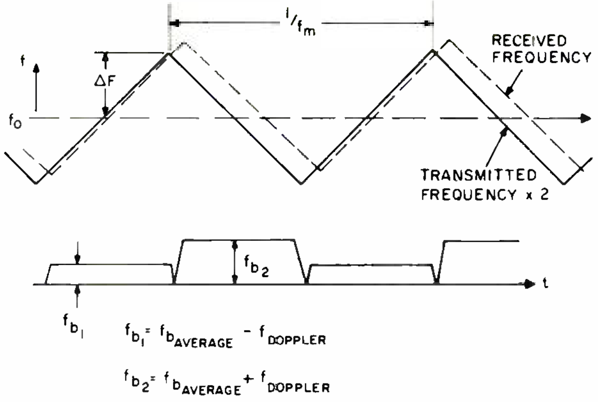


Fig. 8 — Doppler shifts with moving vehicles (approaching).

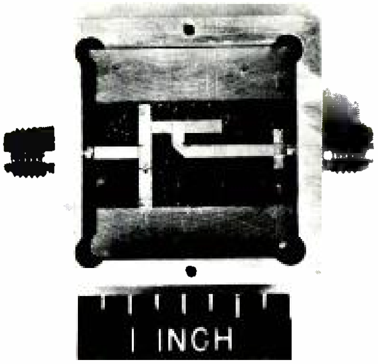


Fig. 9 — Frequency doubler microstrip circuit.

motion of the two vehicles tends to have an error smoothing effect.

Once ΔR has been chosen and ΔF has been determined, eq. 1 can be re-stated together with eq. 2 to read

$$f_b = (R/\Delta R)\, f_m \qquad (3)$$

If a system is to operate over a range of R_{min} to R_{max}, the required bandwidth, B, is given by

$$\begin{aligned} B &= f_{bmax} - f_{bmin} \\ &= (R_{max} - R_{min}) f_m/\Delta R \qquad (4) \end{aligned}$$

Eq. 4 would indicate a choice of modulation rate f_m as low as possible.

The low limits for a choice at f_m are contingent on the following:

a) The noise present at the mixer signal port can be represented as proportional to $1 + f_k/f$, where the second term indicates flicker noise of a $1/f$ frequency dependence, and f_k is the frequency of the "corner" in the noise versus frequency curve. The total noise in the system bandwidth is

$$N \propto \int_{f_{bmin}}^{f_{bmax}} (1 + f_k/f)\, df \qquad (5)$$

or

$$\propto [(R_{max} - R_{min}) f_m/\Delta R + f_k \ln(R_{max}/R_{min})]$$

The first term represents "white noise" in a bandwidth B as indicated in eq. 4. The second term represents the $1/f$ noise contribution and is seen to be independent of f_m. However, as very low frequencies are approached (<1 kHz), flicker noise increases faster than $1/f$, and the second term in eq. 5 does decrease with f_m.

b) Local oscillator (transmitter sample delivered to LO port of mixer) noise increases closer to the carrier. An imperfectly balanced mixer will down-convert these noise components into the band of beat frequencies f_{bmin} to f_{bmax}. This noise depends on (loaded) cavity Q factor and is hard to predict.[3,4] According to recent measurements, TEO noise shows a $1/f$ behavior with a "corner" frequency at ~ 100 kHz. The comments made in paragraph (a) will apply here as well.

c) The rate at which information must be updated also imposes a lower limit on f_m. Range measurements must be averaged over a number of periods of $1/f_m$, for reasons stated below. If range data is to be updated at a minimum rate of 10 Hz, a minimum for f_m would be ~ 100 Hz.

As a reasonable compromise, the modulation rate of the collision avoidance radar has been chosen to be f_m equal to 3 kHz. The range of audio frequencies is then f_{bmin} = 10 kHz to f_{bmax} = 200 kHz for a range variation of 5 m to 100 m. The range vs. frequency slope is 2 kHz/m.

Doppler shifts

As seen in Fig. 8, relative movement between vehicles will have the effect of shifting the beat frequency by an amount equal to the doppler frequency. It will be a positive shift in one half of the modulation cycle and an equal but negative shift in the other half. The *average* beat frequency, *i.e.*, the zero crossing rate averaged over many cycles, will be the same as for a stationary car at the same distance. The range reading is therefore independent of motion. An up-down counter switched in synchronism with f_m could detect the closing rate. In the present system, however, the closing rate is derived by differentiation of R.

Frequency doubler

The success of the harmonic radar concept was critically dependent on developing an efficient, passive harmonic reflector, *i.e.*, finding a solid state device which in a suitable designed circuit will generate the second harmonic with the required efficiency. In the car radar application it was felt strongly that the reflector must be completely passive, with no wiring to the car's electrical system. It was evidently the best way to assure reliable operation and inexpensive installation.

Preliminary computations showed a need for relatively high doubling efficiencies for a low-input, non-biased, device. With antennas roughly the size of a license plate and a radiated power of 0.1 W at X-band, the power delivered to the doubler, under free-space propagation conditions, is roughly 10^{-5} W at 100 m. A conversion efficiency of at least 1% is then needed to provide an acceptable S/N at the receiver. It turned out that silicon Schottky barrier diodes, when mounted in a suitable microstrip circuit as shown in Fig. 9, can perform with adequate efficiency. A 0.8-mil-diameter diode chip is seen connected across a gap, located for

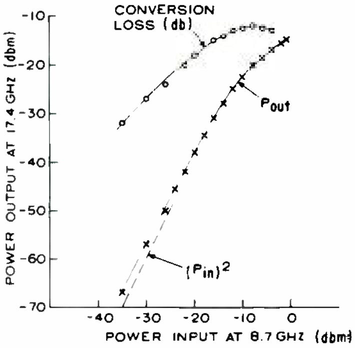


Fig. 10 — Harmonic generation efficiency of frequency doubler.

best impedance match, in a $\lambda/2$ (fundamental) resonator. Input at X-band is coupled at a voltage maximum point of the fundamental frequency, output is coupled at a voltage maximum point of the second harmonic, with a $\lambda/4$ open section coupled to the output line to reflect the fundamental frequency back into the circuit. Fig. 10 shows the conversion efficiency of the doubler circuit. As one would expect, at the lower levels the power output at the second harmonic varies as the square of the power input at the fundamental, following a law of

$$P_{out} = KP_{in}^2 \qquad (6)$$

with K equal to 2500 W^{-1}. The bandwidth of the doubler is approximately 75 MHz, centered within the Ku-band in the experimental unit.

A similar doubler circuit is used to provide a sample of double frequency transmitter power to the local oscillator port of the mixer, but this circuit is operating at high power levels. A 50-mW input at X-band yields a conversion efficiency of 10% over a 200-MHz band.

Antennas

The choice of antennas and the rf frequency are closely related. For reasonable traffic lane discrimination, a maximum horizontal beamwidth of 5° requires a horizontal aperture width of 10 wavelengths. To achieve this aperture in a 12-in. physical size (approximately license plate size) necessarily places us somewhere in X-band. A $10\lambda \times 10\lambda$ aperture with 50% efficiency has a gain of 28 dB, which makes transmitter power requirements quite reasonable, as will be shown below. Also, solid state power sources at X-band frequencies are readily available, and spectrum space at X-band is still under-utilized.

An existing printed antenna design, developed at Missile and Surface Radar Division at Moorestown and used for the "back-pack radar", was found quite suitable for our system. The antenna has an aperture of 13 ×7-½ in., a gain of 26 dB at 9 GHz, and a 10% bandwidth. It consists of 128 fan-shaped dipoles printed on both sides of a 1/32-in.-thick polyethylene sheet, phased into a 50Ω input through a succession of quarter-wave balanced transmission lines. An 18-GHz antenna has been produced by scaling up in frequency from the X-band design, with similar electrical characteristics. The antenna pair is shown in Fig. 11 with protective covers (fiberglas) removed.

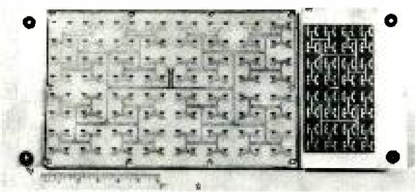


Fig. 11 — Harmonic reflector (with protective cover removed).

By using a polarization of the Ku-band antenna at 90° to the polarization of the X-band antenna, we get additional rejection of spurious second harmonic power generated at the source and received either directly from an oncoming vehicle or reflected from nontagged objects. This is in addition to second-harmonic filtering at the low-pass filter and isolators in the transmitter circuit. Total rejection of spurious second harmonic amounts to 150 dB, reducing it to well below receiver noise level.

Range equation

Assuming free-space propagation conditions, effective antenna apertures of A_f and A_{2f} for the X-band and Ku-band antennas, respectively, a target at distance R will present to the receiver a signal power of

$$P_r = (4K)\ P_o^2 A_f^4 A_{2f}^2/\lambda^6\ R^6 \qquad (7)$$

where P_o is the transmitter power at the fundamental wavelength λ and K is the doubler coefficient when operating in its square law region where P_{out} equals $K(P_{in})^2$.

This range equation is typical for a harmonic radar system and has several unusual features: the received power is proportional to the square of the transmitted power, to the fourth power of the fundamental antenna aperture, and is inversely proportional to the sixth power of distance. It is obviously more advantageous, relative to conventional radar systems, to increase the source power, and, for a given total aperture, to allocate the larger area to the fundamental antenna. In our radar, this aperture ratio is 4:1, giving the same gain to the two antennas. The very steep decrease of signal strength with distance has an advantage in that interference effects caused by out-of-range targets will be greatly reduced.

The signal strength at the receiver is modified by ground reflections. In the presence of a reflecting ground, power will reach the reflector via a ground reflection as well as the direct path. The reflection coefficient can generally be expressed as[5]

$$r = |r|e^{i\phi} \qquad (8)$$

with $0 \leqslant |r| \leqslant 1$ and ϕ complex, depending on the property of the ground, the polarization, and the angle of incidence. For the car radar, angles of incidence are between 5° and 0.5°. At such small angles, the reflection coefficients converge to be identical for horizontal and vertical polarization, and the value of ϕ in eq. 8 is close to π. The magnitude of r has been found to be 0.7 0.8 for dry asphalt at X-band, with similar values to be expected at K_u-band. As a result of the ground-reflected component adding in or out of phase, the range equation 7 has to be modified. Assuming the ideal case (not far from reality) where r is equal to -1,

$$P_r' = P_r\,[64\sin^4(2\pi h_1 h_2/\lambda R) \times \sin^2(4\pi h_1 h_2/\lambda R)]$$

where h_1, h_2 are heights above ground of the active radar and passive reflector antennas, respectively, and λ is the fundamental wavelength. As R changes, we expect a series of reinforcements and partial cancellations of signal strength. A partial cancellation will occur wherever $R = 4h_1h_2/n\lambda$), where n = 1,2,3,... and for the values $h_1 = h_2 = 0.52$ m of the experimental radar, a signal minimum is expected at $R_{n=1}$ equals 32 m and $R_{n=2}$ equal to 16 m, with more below R_{min}.

For distances where $R > 10h_1h_2/\lambda$, the trigonometric functions in eq. 9 can be

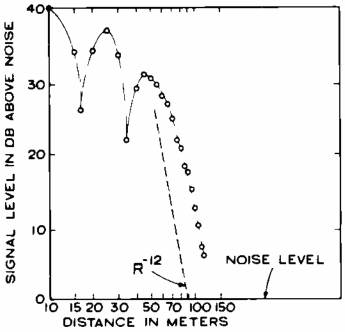


Fig. 12 — Signal strength *vs* distance. (antenna height is 21 in. above road surface.)

replaced by their arguments, resulting in a received signal of

$$P_r'' \propto P_o^2 A_f^4 A_{2f}^2 (h_1 h_2)^6 / (\lambda R)^{12} \qquad (10)$$

indicating a drop-off with distance as steep as R^{-12}

Measured signal strength as a function of distance is shown in Fig. 12 for the experimental radar over dry asphalt.

Signal and noise

At the maximum design distance, R_{max} equal to 100 m, the received signal P_{min} must exceed the total noise power P_N in the system bandwidth $B = f_{bmax} - f_{bmin}$ by a factor of S/N, thus

$$P_{min} = (S/N) P_N \qquad (11)$$

The following contributions to P_N can be identified:

Thermal (Johnson) noise which is essentially "white" in B: A mixer with noise figure (NF) will introduce

$$P_{N1} = kTB(NF) \qquad (12)$$

Local oscillator noise: Local oscillator noise is generated by beat products of the TEO noise spectrum in a band B off-carrier. For the TEO used in the experimental radar, a spectral noise density K_{TEO} of -125 dB below carrier in a 100-Hz bandwidth at 100 kHz away from carrier has been measured. ($K_{TEO} = 0.3 \times 10^{-14}/\mathrm{Hz}$). It varies with frequency as $1/f$, with the "corner" at f_k equal to 100 kHz.

This noise is reduced by the mixer balance factor, (MB). For a local oscillator power level P_L it is given by

$$P_{N2} = P_L/(MB) \int_{f_{bmin}}^{f_{bmax}} \tfrac{1}{2} K_{TEO} (1 + f_k/f)\, df$$

$$= \left(\frac{P_L}{MB}\right) \left[\frac{K_{TEO}}{2} \left(B + f_k \frac{R_{max}}{R_{min}}\right)\right] \qquad (13)$$

and with R_{max}/R_{min} equal to 20, P_L equal to 1 mW and B equal to 2×10^5 Hz, the contribution of local oscillator noise is equal to

$$P_{N2} = 0.75/(MB) \times 10^{-12}\mathrm{W} \qquad (14)$$

The contribution of P_{N1} as referred to the mixer output port, for a mixer noise figure of 10, is given by $P_{N1} = 0.8 \times 10^{-14} W$.

A mixer balance factor (MB) of more than 20 dB is therefore required to make $P_{N2} < P_{N1}$.

Detected amplitude modulation of the local oscillator: The source of this amplitude modulation is the dependence of TEO output power on frequency, which is swept over a range ΔF. The (imperfectly) balanced mixer reduces but does not eliminate this amplitude modulation. Its fundamental frequency is f_m equal to 3 kHz, and clearly third and higher harmonics cannot be filtered out, being in the 10-to 200-kHz range of f_b. The magnitude depends on the TEO diode in use and on mixer balance, which in turn depends on the particular pair of mixer diodes. However, with a minimum mixer balance of 20 dB and a TEO power variation of 0.1 dB maximum over ΔF, this source of noise seems to be of minor importance.

Mixer sensitivity and balance: The mixer sensitivity and balance are strongly dependent on frequency. This is partly caused by the fact that the isolation between the rf ports is rather poor (~ 6 dB), causing multiple reflections of the local oscillator power and its harmonics at the imperfectly matched isolator, antenna, and high-pass filter (see Fig. 6). When swept over a range of frequencies ΔF, a noise signal at f_m is generated at the i.f. output port, the harmonics of which enter the video band, f_{bmin} to f_{bmax}, of the system. The magnitude of this noise signal varies with the mixer diodes in use and the choice of center frequency. With careful matching of components and adjustment of cable lengths it can be somewhat reduced, but in practice it has been found to be by far the dominant noise source, exceeding the first two contributions (P_{N1} and P_{N2} above) by 10 to 20 dB. Therefore, the current design is not operating at its theoretical Johnson noise limit regarding signal-to-noise ratios, and consequently its maximum range of 100 m is somewhat below a theoretical noise limited system.

Improvement in the future can be achieved by using a balanced mixer design which has better isolation and is less prone to generating spurious signals at f_m and its harmonics. One could also attempt matched filtering in the video amplifier chain to more nearly match the amplitude *vs* range characteristic of the radar system. It is also obvious that the full bandwidth, f_{bmin} to f_{bmax}, is not needed since at any given time a signal at $f_b(R)$ exists which requires a bandwidth of order f_m only. Should increased range become necessary, a more sophisticated (and more complex) design may be used, incorporating a tracking, narrow-band filter.

In the present design, a signal of P_{min} equal to -80 dBm is required at the receiver input for a 10 dB overall S/N ratio.

Video circuits and signal processing

Following pre-amplification and the 10-kHz HPF is a high-level amplifier/clipper which clips signals about 2 or 3 dB above the background level. The processor consists of a one-shot circuit that is triggered by the clipped input signal. The duration of the one-shot "on" time is as long as possible, consistent with the maximum input signal frequency of 200 kHz. (Making the time as long as possible gives as much noise immunity as possible since this particular one-shot cannot be retriggered during its "on" time.) If the output of the one-shot is integrated then a voltage proportional to its range is obtained. Likewise, if the one-shot is made to drive a meter movement, the deflection will be proportional to range. Such a meter has been connected and calibrated to read 100 meters at full scale.

In a collision avoidance system more than just the range to the car in front is needed. Some velocity data must be used in conjunction with the range so that a decision can be made to slow down or continue. One convenient way to obtain velocity is from a doppler speed sensor, described elsewhere in this issue of the *RCA Engineer*. By integrating the output pulse train of the doppler unit a voltage proportional to velocity is developed, which is displayed on a second meter, calibrated in miles-per-hour with a full scale of 100 mi/h. Combining the two signals (range and velocity) in a variable threshold device, it is possible to sound an alarm whenever the vehicle gets too close to the car in front for the speed being maintained. One car length for each 10 mi/h of velocity is an example for a typical alarm setting, which may be arbitrarily set to any desired value.

There exists one other useful bit of information in determining the presence of a hazard. It is the closing velocity between the two vehicles in question. Knowing the closing velocity as well as the range between vehicles and one's own velocity, it is possible to further optimize the condition for giving the danger signal. In the experimental radar, the alarm is sounded and the brakes are applied when

$$R \leqslant (k_1 v + k_2\, dR/dt) \qquad (15)$$

where R is the distance between vehicles; v is the velocity of the following vehicle; dR/dt is the closing velocity between the two vehicles; k_1 is a factor, as mentioned earlier, such as one car length per 10 mi/h or 0.5 m/mi/h: and k_2 is a factor, determined by trial and error to be in the region between 1 to 3 m/mi/h.

If the closing velocity, dR/dt were not available, eq. (15) would reduce to $R \leqslant k_1 v$ for the alarm to be given. The constant k_1 would have to be made large enough to allow a safe stop for the situation of a car closing on a parked car. However, for the condition of two moving vehicles (one following the other) the system would then appear to be overconservative. By adding the dR/dt factor, the system recognizes closing velocity and thereby allows k_1 to be made smaller. (The assumption being that the car in front cannot come to a sudden stop but must decelerate. This deceleration would appear as an increase in closing velocity and would cause the following car to also decelerate and both cars would then stop safely.)

It should be noted that provisions can easily be made for the driver to reset, by the flick of a switch, constants k_1 and k_2 in accordance with prevailing weather and road conditions.

The closing rate, dR/dt, can be derived either by differentiating the range voltage, R, or by obtaining the doppler shift directly from the video signal. As can be seen from Fig. 8, if a switched up-down counter is used, synchronous with the triangular modulation, f_m, a count proportional to the doppler shift can be obtained.

The first of these methods was used in the experimental model, using a capacitor-driven operational amplifier with resistive negative feedback. A third meter, calibrated in mi/h, displays the negative (receding) or positive (approaching) closing rates, and the alarm circuit utilizes dR/dt according to eq. 15.

Automatic collision avoidance braking

The automatic braking system in the experimental radar is fairly rudimentary at the moment in that once the alarm is given, the brake pedal is automatically depressed by a force that increases linearly with time up to maximum pressure, until the alarm is removed. The force is then removed linearly with time. Developing the force necessary to apply the brakes was accomplished by using a vacuum-operated piston. Fig. 13 shows this mechanism as it is mounted to pull the brake pedal. The piston pulls the pedal via a spring in series with a flexible cable that goes through the firewall and connects to the brake pedal. This allows the driver to override or augment the braking if necessary. The valve that allows the engine's vacuum system to evacuate the chamber of the piston is driven by electrical signals derived from the signal processor when an alarm is given.

A proportional braking system is currently under consideration. In that system, the brakes will be applied according to the severity of the danger situation; the pedal force P will then be

$$P = k_P\,[k_1 v + k_2\,(dR/dt) - R] \qquad (16)$$

where k_p is a constant, adjusted to the car's braking and accelerating dynamics, and has the dimensions of force/meter.

Summary and conclusions

Experimental Tests

The experimental system uses an RCA transferred electron oscillator power source. Antennas are modified and scaled versions of the RCA hand-held radar. An efficient doubler circuit in microstrip was developed at RCA Laboratories, as well as the various video circuits for amplification, filtering and other processing. Other rf components were purchased as standard catalog items.

The components of the experimental system are shown in Fig. 14, including the doppler speed sensor and the active radar power supply which operates from the 12-volt car battery. The maximum power drain is 20 W. The reflector is completely passive and needs no power whatever.

The experimental setup on the test vehicles is shown in Figs. 15, 16, and 17. Although the size of either the active radar or the passive reflector is presently slightly larger than that of a license plate,

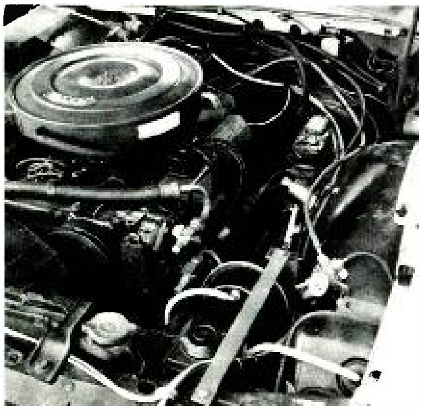


Fig. 13 — View of engine compartment, showing collision avoidance brake activator and vacuum valves.

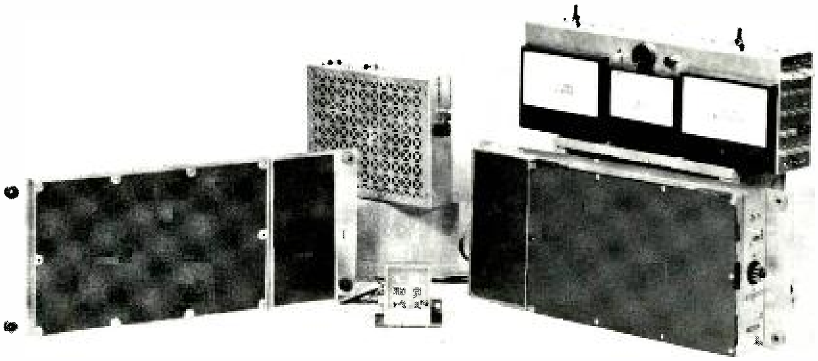


Fig. 14 — Collision avoidance radar components.

Fig. 15 — Active part of experimental radar.

Fig. 16 — Processing and display unit inside vehicle.

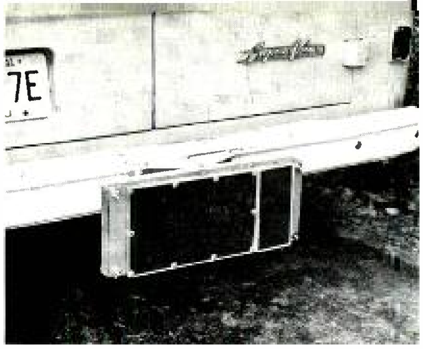


Fig. 17 — Passive reflector mounted on back of vehicle.

scaling to higher frequencies would decrease the size to that of a license plate. The registration numbers can then be imprinted on the protective antenna covers (fiberglas) and the units can be mounted in the space reserved for license plates. Alternatively, the active radar can be mounted behind a plastic grille.

The experimental collision avoidance radar has been extensively tested on RCA Laboratories' grounds and adjoining highways. (For some tests, an airstrip belonging to Princeton University was used so as not to endanger others.) Although not specifically ruggedized for highway use, the sytem has not failed because of vibrations or adverse climatic conditions. It was not affected by rain appreciably, nor was the performance noticeably degraded by applying a layer of mud and road dirt to the antenna covers.

The distance measurements were quite repeatable and of adequate accuracy. Fig. 18 shows measurements of distance readings on the display meter *vs* actual distances. The remaining errors can be reduced as needed, by using a more linear meter movement. (The display accuracy is of course of no importance in the collision avoidance radar).

Modes of operation

Several different modes for utilizing the collision avoidance radar can be discerned. In a semi-automatic mode, the radar will sound and flash an alarm whenever warranted; the taking of action will be left to the driver, who may choose to slow down, change lanes, or ignore the warning for any reason.

In another mode of operation, the brakes can be applied automatically, either immediately at the instant the alarm is sounded, or perhaps with delayed action, giving the driver a chance to act first. If the driver fails to act, the system will provide a last minute "panic" stop that will at least moderate the collision impact.

In yet another mode, the collision avoidance radar can be integrated with a cruise control system, providing completely "foot off" operation.

It is also possible to "tag" specifically identified collision hazards located on or off the highway, such as bridge abutments, construction barriers or trees. A reflector mounted on such an obstacle will stop a car approaching it within a predetermined angle, but will not influence a car traveling in a safe lane.

Reflectors can also be placed at wrong-way entrances to one-way streets or highway exit ramps to prevent inadvertent entry.

Cost and cost effectiveness

The system lends itself very well to integration using printed circuit techniques throughout. The passive reflector, which in general use will have to be mounted by law on the back of every vehicle (similar to requirements of red tail lights), can be produced inexpensively on one printed circuit board, at $5 to $10 perhaps, in large quantities. The active radar is more complex, but not more than a.m./fm radios currently used in automobiles.

To make the radar "cost effective", its cost must be less than the damage involved in the rear end collisions which have been prevented through its use, on the average. We have mentioned an estimate of $10 billion in "societal cost" per year due to rear end collisions. This comes to $100 per car per year, which amounts to a substantial sum over a vehicle's lifetime. A radar with a capability of preventing or moderating even a fraction of the rear end collision damage might become quite an attractive proposition.

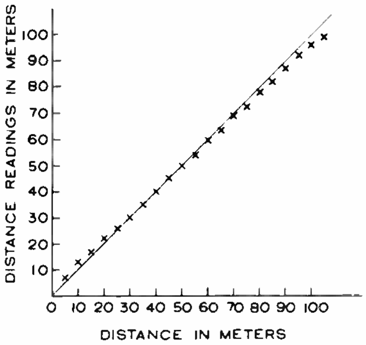


Fig. 18 — Accuracy of distance measurements.

Acknowledgments

The harmonic radar effort has drawn on the talents and skills of diverse RCA groups. The authors are grateful to Harold Staras, who held the whole project together and provided ideas and encouragement at every turn; to L. Schiff for many fruitful discussions; to W. C. Wilkinson, O.M. Woodward and Z.L. White of MSRD who designed and constructed the antennas; to L.S. Napoli, J. J. Hughes and J. Rosen who developed the microstrip doubler circuit, to H. C. Johnson and A. Presser who designed and tested the TEO and local oscillator doubler; and to R. Burgen and T. Nolan who helped build and road test the system.

References

1. "Accident Facts", published by National Safety Council, Chicago, Ill., 1971 Edition.
2. Luck, D.G.C., *Frequency Modulated Radar*, McGraw-Hill (1949).
3. Narayan, S.Y., and Sterzer, F., "Transferred Electron Amplifiers and Oscillators", *IEEE Trans. on Microwave Theory and Techniques* (November 1970)
4. Ohtomo, M., "Experimental Evaluation of Noise Parameters in Gunn and Avalanche Oscillators", *IEEE Trans. on Microwave Therory and Techniques* (July 1972).
5. Kerr, D.E., Ed. "Propagation of Short Radio Waves." *MIT Radiation Laboratory Series*, Chap. 5.

Automotive Doppler radar speed sensor

H.C. Johnson | A. Presser

This paper describes a Doppler ground-speed radar developed at the Microwave Technology Center, RCA Laboratories, to provide accurate velocity data for speedometer and anti-skid brake applications.

THE DOPPLER EFFECT was discovered more than a century ago. The Doppler frequency is defined as the change in the observed frequency of a frequency source that is in relative motion to the observer. The application of this effect to electromagnetic sources of frequency for purposes of velocity measurement has been thoroughly investigated during the last few decades.[1] These efforts have led to a large number of different Doppler-radar speed-detection and navigation systems.

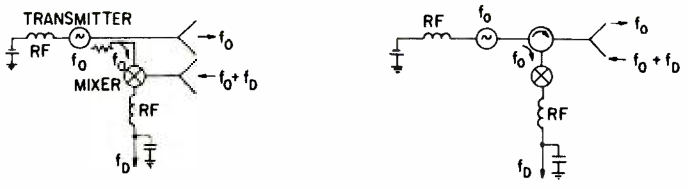
The automotive industry is now considering the application of Doppler radars in active safety equipment on automobiles and trucks. One such application is in anti-skid brake systems that avoid vehicle swerve caused by wheel lock. Legislation is now in effect to require all large trucks manufactured after 1974 to include anti-skid brake systems. A few automobile manufacturers presently offer such systems as an optional extra.[2] These systems use sophisticated logic circuits that estimate the true ground speed and vehicle deceleration during braking based on individual wheel speeds. This process is relatively complex and inaccurate. A braking system that uses a Doppler radar to continuously measure the true ground speed offers an accurate comparison between ground speed and wheel speed—and thus quicker, more accurate brake control can be achieved.

Reprint RE-18-6-27
Final manuscript received January 18, 1973.

Henry C. Johnson, Microwave Technology Center, RCA Laboratories, Princeton, N.J. attended Johns Hopkins University and received the BS from Drexel University. He joined the RCA Electron Tube Division in Harrison, N.J., in 1956 working on pencil tube design. In 1959, he transferred to the Microwave Technology Center at the RCA Laboratories in Princeton, New Jersey, where he has made significant contributions in the fields of optical modulators and detectors, transistor oscillators, FM linearizing circuits and integrated linear amplifiers. He has recently been involved in the development of transferred electron oscillators, and collision avoidance and Doppler radar systems. Mr. Johnson has disclosed inventions in these fields, and has contributed approximately 20 papers and presentations to many technical journals and conferences.

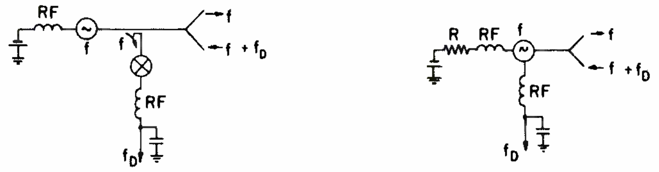
Adolph Presser, Microwave Technology Center, RCA Laboratories, Princeton, N.J. received the BEE in 1950 from the Institute of Technology, Vienna, Austria, and the MEE in 1961 from the Polytechnic Institute of Brooklyn. From 1950 to 1952, he was a production engineer for the Schrack A.G. in Vienna, and was a development engineer for the Allied Control Co. in New York from 1954 to 1959. In 1959, Mr. Presser joined the RCA Microwave Technology Center at the David Sarnoff Research Center as a member of the technical staff. As a member of the Microwave Circuits Technology section he has been engaged in the development of various solid state microwave devices. His work includes the design and development of parametric amplifiers, tunnel diode amplifiers, tunnel diode frequency converters, and tunnel diode oscillators. In 1965, his field of interest widened towards microwave integrated circuitry. He was instrumental in the design and development of telemetry transmitters, high-power transistor amplifiers, power sources for ECM systems, and more recently, of linear transistor power amplifiers and Doppler radar modules. Mr. Presser received an Outstanding Performance Award of RCA Electronic Components in 1964 and an RCA Laboratories Achievement Award in 1965. He is the author of many technical papers in the field of solid-state components and is a member of the IEEE.

Authors Presser (left) and Johnson with a model of the speedsensor.



a) isolated mixer.

b) circulator-coupled mixer.



c) loosely-coupled mixer.

d) self-mixing oscillator.

Fig. 1 — Doppler radar circuits.

Operating principles

Doppler radars require a frequency source and a reflector that are in relative motion to each other. In the specific ground-speed application, the source is mounted on the vehicle with the antenna beam having some acute angle θ in relation to the reflector — the road surface. The beam lies in a common vertical plane with the vehicle's velocity vector. Part of the transmitted signal is diffusely reflected from the road surface back to the receiving antenna. If the vehicle is moving with velocity V, the reflected signal is shifted by the Doppler effect. The doppler frequency f_D is given by:

$$f_D = 2V \cos \theta / \lambda$$

where λ is the wavelength of the transmitted signal. The Doppler frequency is extracted by a mixing process between the reflected signal and a sample of the rf source. The Doppler is in the low audio-frequency range for an X-band source at normal automobile velocities. The audio output has to be further processed for useful purposes. In this application, it is amplified, clipped, and used to trigger a pulse generator. The output pulses can be fed directly to an anti-skid sysem, while the integrated pulses provide an analog velocity readout.

Design considerations

The basic elements of a simple Doppler radar circuit are an rf power source, a transmitting and receiving antenna, and a receiver as shown in Fig. 1a. The transmitted signal is reflected and Doppler shifted from a moving target, enters the receiving antenna, and is fed to the mixer of the receiver to extract the Doppler frequency. A sampled portion of the transmitted signal provides the local oscillator power for the mixer. This basic radar circuit can take many forms depending upon the application and desired accuracy/cost tradeoffs.

One possible circuit simplification is to eliminate one of the two antennas and the directional coupler, using a circulator as shown in Fig. 1b. This reduces the sensitivity of the radar because of the finite isolation and loss of the circulator between transmitter and receiver. One further simplification is to omit the circulator and replace it with a loosely coupled mixer shown in Fig. 1c. This reduces the isolation between transmitter and receiver even further and limits the radar sensitivity to a larger degree. The ultimate simplification is brought about, as shown in Fig. 1d, using the active element of the Doppler radar in a self-mixing mode. Isolation between transmitter and receiver is at a minimum, and in addition, isolation between the Doppler output and the dc supply is lost. An isolation resistor R prevents bypassing of the Doppler signal through the low-impedance power supply.

The choice of a radar circuit depends upon the particular application. The radar cost increases with circuit complexity. The lowest cost self-mixing circuit is useful in applications in which a qualitative speed indication is sufficient and dc source fluctuations are absent. Automotive electrical sources are fixed (12-V battery system) and contain alternator spikes, ignition noise, and other interfering disturbances that cause large voltage fluctuations. Although a voltage regulator can minimize these variations, the large voltage drop across the required isolation resistor generally reduces the available radar supply voltage below a useful level. The loosely coupled mixer arrangement (Fig. 1c) is a better choice although slightly more expensive. Speed measurement accuracies of approximately 4% are possible with this circuit type. High sensitivity and accuracy applications warrant an even higher cost circulator-coupled radar circuit.

Other important considerations in the radar design are the choice of the active solid-state device for the oscillator and the circuit structure. For X-band applications, the device selection narrows to a transferred-electron (TE) diode or an IMPATT diode. Even though IMPATT diodes are presently less expensive than transferred-electron diodes, this cost advantage is offset by the high-voltage requirement and the general noisiness of the IMPATT diode. To generate the high voltage from a 12-volt battery, dc to dc converters are required. Recent advances in the development of TE devices have reduced the efficiency margin IMPATT oscillators enjoyed over TE oscillators. Typical efficiencies of 7 to 9% are now possible through the use of an integrally-plated gold heat-sink[1] that reduces the thermal resistance between the active region of the device and the heat sink.

For cost effectiveness, circuit structures are usually made compatible with the type of antenna used. Waveguide struc-

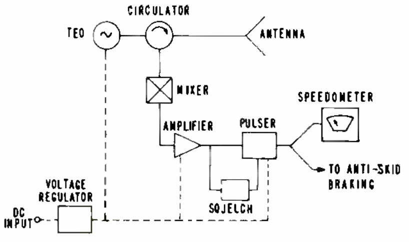


Fig. 2 — Block diagram of Doppler radar module.

tures are appropriate with waveguide horn or slot antennas and microstrip structures with printed-circuit antennas.

Doppler radar-module design

The above design considerations and experimentation with various radar circuits point to the use of a circulator-coupled unit for automotive velocity measurements. Such a unit permits the achievement of speed resolutions of ±1% over a variety of road-surface materials and conditions. A block diagram of the circulator-coupled radar module is shown in Fig. 2. Microstrip circuits for the oscillator, circulator, mixer, and antennas provide a rugged configuration that is relatively simple to fabricate. Low-cost, thermally stable, low-loss copper-clad polyolefin substrates are used in the microstrip component construction.

The oscillator consists of a coupled-line microstrip resonator that is loaded by the TE diode. The diodes were supplied by the Solid State Technology Center of RCA Electronic Components, Harrison, New Jersey. A cylindrical dielectric resonator, make of single crystal rutile, is coupled to the microstrip resonator which increases the effective Q of the resonator system.[4]

The metallized ferrite disk of the microstrip circulator is mounted through a hole in the rf circuit board. The circulator magnet is located under the ferrite disk.

The antenna is a printed-circuit array of four dipoles etched on a metallized polyolefin substrate (see Fig. 3). It is a modified version of a larger antenna developed originally for a hand-held radar by RCA Government and Commercial Systems in Moorestown, New Jersey. The antenna has a gain of 13 dB and side lobes 12 dB below the beam peak.

The design of the dc and processing circuitry is geared towards an automotive speed indicator that provides uniform pulses with a repetition rate proportional to speed. Commercial anti-skid systems are designed to accept velocity information in pulse form. The low-frequency circuits include a voltage regulator, audio amplifier, squelch, and a linear-frequency pulser as shown in Fig. 2. The amplified audio signal drives the pulse generator that produces a series of current pulses at a repetition rate equal to the frequency of the audio input. The pulse train is averaged in a current meter that is calibrated in (mi/h). The pulses are also available at a separate output for the anti-skid brake system. A squelch circuit prevents pulse generation when the velocity is zero and no signal is present. Thus, false speed readings due to noise at zero velocity are eliminated. The complete dc circuitry contributes less than ±0.3% inaccuracy to the velocity measurements over the temperature range from -40 to +75°C.

The dc and processing circuits are constructed on separate printed circuit boards. One circuit board contains the voltage regulator and audio amplifier and the other board, the linear-frequency counter and squelch circuits. The rf, dc, and processing circuit boards are mounted in a single dual-compartment housing. The front section of the housing contains the rf and antenna assembly and the rear section, the dc and processing circuits. The assembled radar module (front and rear) is shown in Figs. 3 and 4, respectively. The protective antenna radome is removed to expose the microstrip antenna. With the radome in place, the units is completely sealed against moisture.

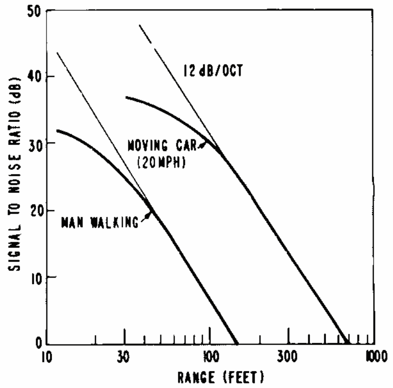


Fig. 5 — Sensitivity performance of Doppler speed sensors.

Radar performance

Direct measurement of the rf power from the Doppler module is not possible since the generated power is directly fed to the printed antenna. A test setup that permits measurement of radiated power is calibrated and used as follows. A known radiated power from a printed antenna of the same construction as used in the module is calibrated against a waveguide horn antenna spaced a fixed distance from the printed antenna. The power output of the module can then be estimated when measured with the calibrated horn in the same geometric arrangement. The power output at room temperature of a typical unit is 15 mW at 10.3 GHz, the frequency deviation is 0.5 MHz/°C, and the power output variation is less than 2.5db over the temperature range of −20 to +50°C.

There are many ways to measure the sensitivity of the module. The simplest is to look at a continuously moving target in the laboratory and observe the output of the Doppler return at the output of the

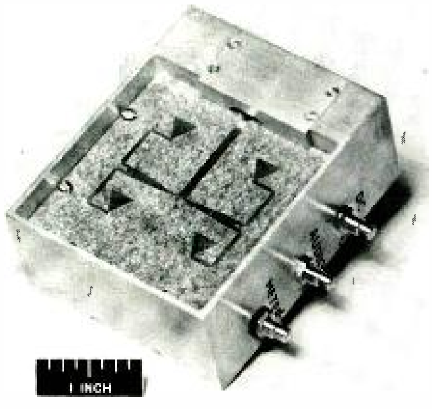


Fig. 3 — Front of Doppler speed sensor

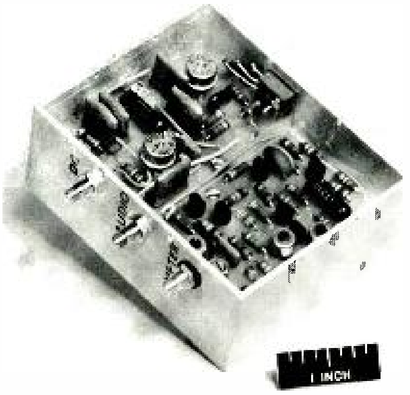


Fig. 4 — Interior (rear) of Doppler speed sensor.

audio amplifier. The moving target, in this case, is a rotating serrated aluminum disk protruding into a slot in an X-band waveguide. One end of the waveguide is terminated in a matched load and the other open to the radar signal. A waveguide variable attenuator is placed before the rotating disk. The attenuator is compared for different units to determine their relative sensitivity. The data is not presented here since it is strictly qualitative with respect to absolute sensitivity.

A more quantitative measurement is made by observing a moving target of known cross section at a given range. The signal-to-noise ratio as a function of range was measured for a walking man and moving automobile. For distant targets, the observed sensitivity follows the theoretical 12 dB/octave falloff, and for nearby targets, this falloff reduces mainly because of saturation of the audio amplifier. Typical results obtained with this method are plotted in Fig. 5.

Road tests

For road tests, the radar is mounted on an automobile 12 in. from the ground with an incident-beam angle of 45°. The module is powered from the auto's electrical system and the audio output, pulse output, and speed readings are recorded. The ground-speed reference is obtained from a fifth-wheel speedometer.

The return signal from a road surface is a summation of many returns from discrete scatterers of the surface, each return having a different amplitude and phase. A typical resultant Doppler radar mounted on an automobile traveling at 50 mi/h is shown in the scope trace in Fig. 6. The audio signal is unclipped in this photograph to show the amplitude modulation. The upper trace shows the pulse output from the processing circuit. The Doppler radar speed readout compared to the fifth-wheel speed is plotted in Fig. 7 for asphalt and smooth concrete road surfaces. The readout accuracies are a function of the return-signal amplitudes. The relative amplitudes from different road surfaces are listed in decreasing order.

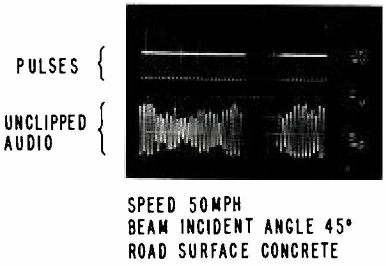


Fig. 6 — Audio and pulse output traces.

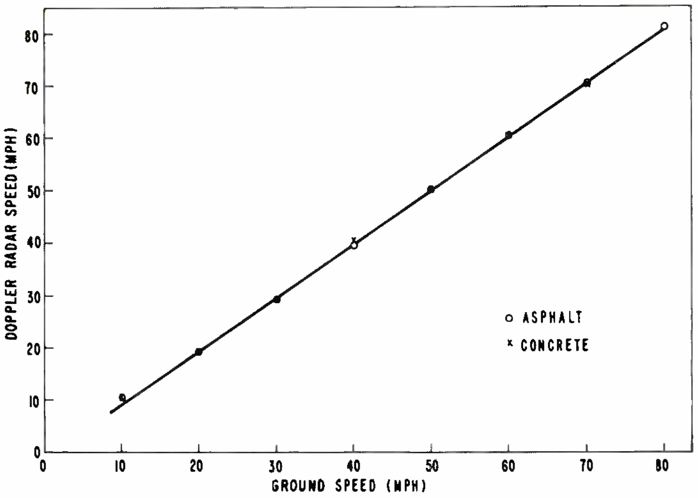


Fig. 7 — Doppler radar *vs.* fifth-wheel speed.

Gravel
Rough ashpalt
Packed snow (1 in.)
Smooth asphalt
Old concrete
New (smooth) concrete

Once calibrated, these radars generally have demonstrated inaccuracies of about 1% or less on any of above dry surfaces for speeds of from 20 to 70 mi/h. Preliminary road tests made on very smooth, wet surfaces, however, have shown a decrease in accuracy, especially during heavy rain. A possible cause for this problem is a reduction of signal return from the wet surface combined with significant back scatter from spray and wheel splash. Further road tests under different weather conditions including deep snow, slush, and ice are in preparation.

Conclusions

The use of a Doppler radar to measure a vehicle's true ground speed can greatly simplify anti-skid brake systems. The radar output can also be used to drive a speedometer and with the addition of a pulse counter, an odometer. Discussions with automobile and heavy truck equipment manufacturers indicate that inaccuracies of 2 or 3% are permissible for typical automotive speed measurement and brake-control applications. The Doppler ground-speed radar described has shown excellent performance on normal dry surfaces with inaccuracies approximately 1%. Several radar units are presently being prepared for intensive environmental testing under worst-case weather and road conditions.

Acknowledgments

The authors are indebted to J. Rosen of the Communications Research Laboratory for the printed-circuit antenna design and valuable technical discussions. The authors also wish to thank L. Mackey and E. Mykietyn for their skillful circuit assembly, evaluation and final packaging of the Doppler radars.

Building blocks for mobile radio design

C. Kamnitsis

B. Maximow

M. O'Molesky

This paper describes a 15-W module, the RCA-R47M15, a high-power broadband amplifier module designed for uhf mobile applications, that can raise a 100-mW input to the 15-W level. Also described is a 30-W uhf transistor, the RCA-40970, that can be used in an add-on amplifier with the R47M10 (10-W module) to form a 30-W chain capable of raising a 100-mW input to 30 W output.

CONCURRENT with the present state of the art, the most economical amplifier chain for 12.5-V uhf mobile applications employs the modular approach up to the 15-W level and an add-on amplifier using a discrete device to raise the output to higher power levels. Block diagrams of the 15-W module and of the 30-W chain are shown in Fig. 1.

R47M15, 15-W module

The R47M15, 15-W module is specifically designed to cover the 440- to 470-MHz band, although it can be used over a wider range (the RCA Dev. No. TA8423 is designed to cover the 390- to 440-MHz band). Fig. 2 shows the performance of the R47M15 module under various conditions over the frequency range of 420 to 470 MHz; Fig. 3 shows TA8423 performance in the range of 390 to 440 MHz. The minimum guaranteed gain is 20 dB at 12.5 V at the nominal output power of 15 W. The typical performance indicated in Fig. 2 was obtained with an input power of 100 mW. The output power level can be controlled by the voltage imposed on the first stage (gain-control pin); Fig. 4 shows the effect of gain control on module performance. Regulation of the gain reduces the total dissipation and consequently the heat generated by the module. The regulated variable voltage for the gain-control function is easily provided. The nominal collector current of the stage to be regulated is 200 mA; this current increases to about 240 mA. The current requirements of the final stages approach 3.5 A at the 15-V level when the gain control is not used; this condition makes it difficult to regulate the supply. However, because the output level can be controlled from the predriver stage, the circuit designer is allowed greater flexibility; the output leveling that can and should be in-

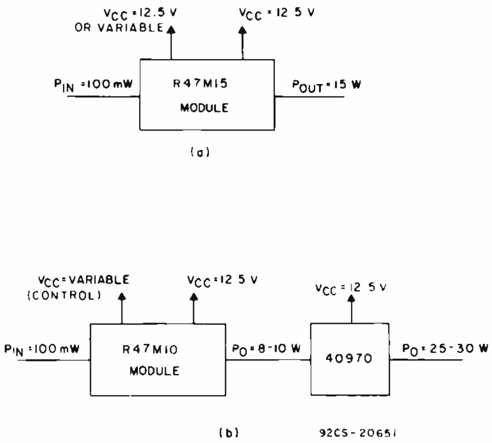


Fig. 1 — (a) 15-watt module; (b) 30-watt transmitter chain.

Mark O'Molesky, Power Device Design, Solid State Division, Somerville, N.J. graduated from Newark College of Engineering in 1968 with the BSEE. He joined Raytheon Company, Missile Systems Division, as a Systems Engineer, and worked on uhf, power-transistor oscillators in broadband applications. In 1970, he joined the RCA Solid State Division as an Applications Engineer; he is presently a Member, Technical Staff. His initial work with RCA involved the development of L-band, low-noise devices. He then moved into the commercial, mobile, power area where he is now working on the development of high-power (50 to 100W) vhf and uhf devices. Mr. O'Molesky has authored several papers on mobile device applications and has submitted patent disclosures on integral thermal-and power-balancing networks for high-power transistor structures.

Boris Maximow, RF Module Applications, Solid State Division, Somerville, N. J., received the BSEE from Newark College of Engineering in 1961. In addition, he has taken several graduate courses in electronics and mathematics. Upon graduation, Mr. Maximow assumed the duties of an applications engineer in the Tube Division of Tung-Sol Electric Company From 1965 to 1966 he was a project engineer with Theta Instrument Corporation working with analog-to-digital converters. Mr Maximow joined RCA in 1966 as an applications engineer in the Industrial Applications Department. He was engaged in the design and development of broadband amplifiers in CATV, aircraft communications band, and the 225-MHz to 400-MHz military-communications band. His design activities extended into the L-band, including the radiosonde. Mr. Maximow has published several papers on high-power broadband transistor operation

Authors O'Molesky (left) and Maximow.

Reprint RE-18-6-29 (ST-6099)
Final manuscript received March 12, 1973

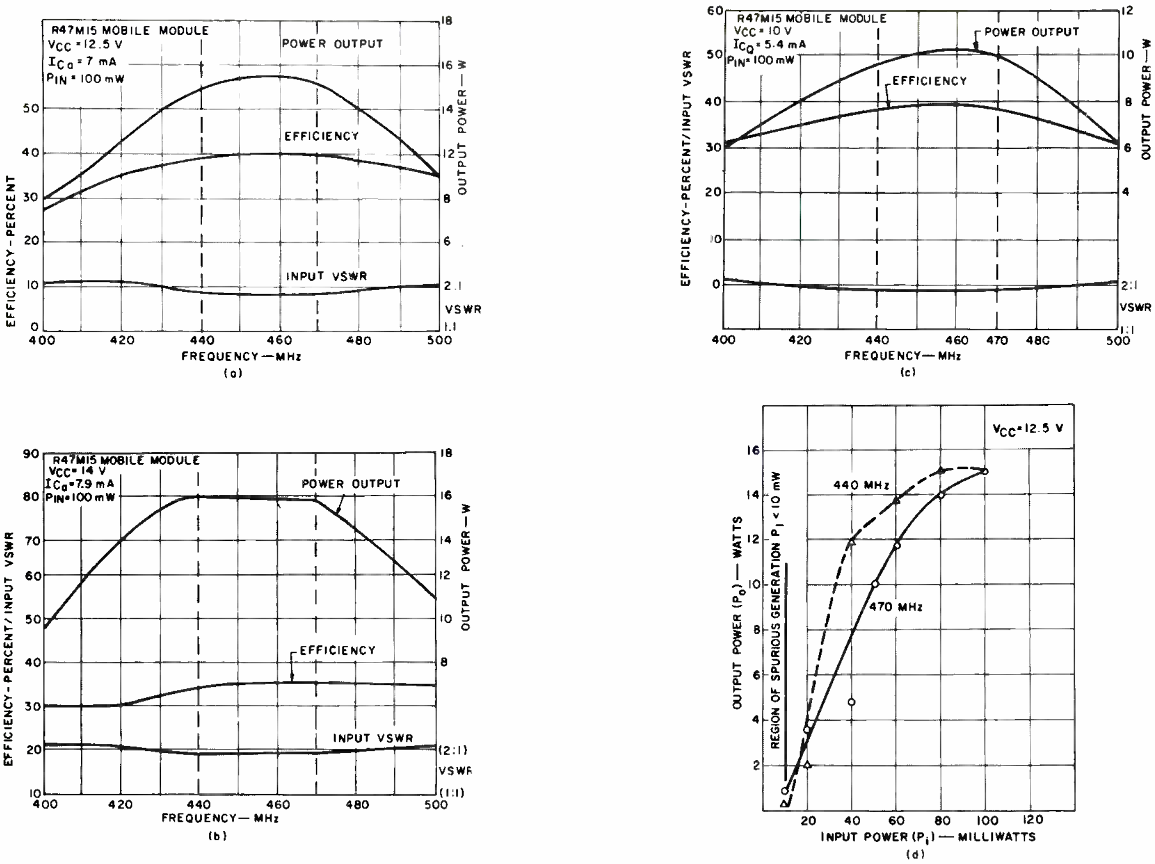


Fig. 2 — Typical R47M15 module performance.

C. Kamnitsis, Ldr., RF Module Applications, Solid State Division, Somerville, N. J., received the BSEE from Monmouth College in 1966. Upon graduation he joined the RCA Solid State Division where he worked on the research and development of broadband power amplifiers and state-of-the-art, thin-film, microwave integrated circuits. Mr. Kamnitsis has done extensive design work in the area of rf modules for military and commercial applications. He has authored seven technical papers and has two patents.

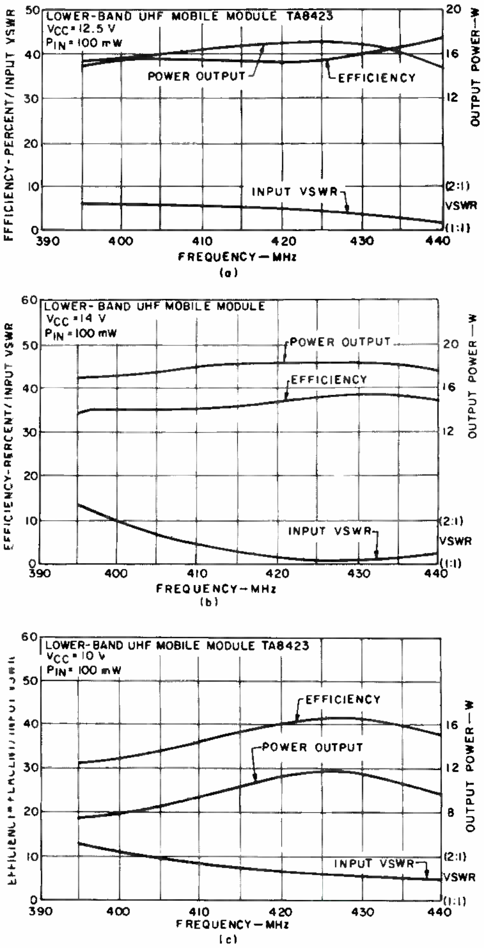


Fig. 3 — Typical RCA Dev. No. TA8423 module performance.

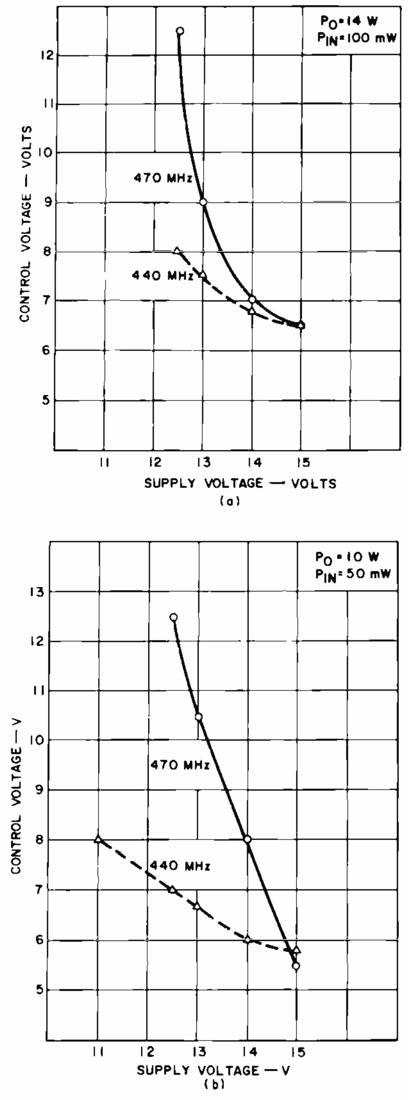


Fig. 4 — Typical effects of gain control on R47M15 module performance.

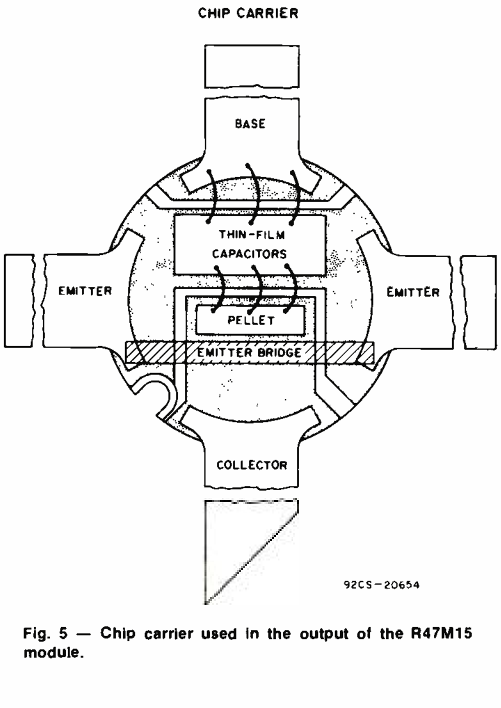


Fig. 5 — Chip carrier used in the output of the R47M15 module.

corporated in the transmitter design takes the emphasis off the need to regulate the supply voltage on the final stages.

Oscillations and the generation of spurious responses are normally understood under the general term *instability.* The performance of the R47M15 module was checked under varying operating conditions, such as drive variation and supply-voltage variation. No instability was detected in the R47M15 module under drive variation between 10 and 200 mW with a supply voltage of 12.5 V. This range of variation is plotted in Fig. 2d as a function of input power. Variation of the supply voltage between 0 and 15.5 V with a drive of 100 mW also produced no detectable instability. When the control voltage alone was varied with a constant final-stage supply voltage of 12.5 V and a constant drive of 100 mW, spurious responses began to appear at control voltages below 6 V in some modules. The second harmonic in the output was measured from −25 to −40 dB, depending upon frequency. The input vswr was measured near 1.8:1 on the R47M15 over the frequency range of 400 to 500 MHz; the maximum input vswr for the TA8423 was 1.6:1 under a normal V_{CC} of 12.5V and an input power of 60 mW. The modules have been load-pulled at V_{cc} of 14V, an output power of 17W, and a frequency of 470 MHz with an output vswr of ∞:1, all phase.

Module construction and assembly

The modules are fabricated by using thin-film microstrip circuitry on high-quality alumina substrates with better than 8 micro-inches of surface finish. The rf matching networks are composed of microstrip inductors and thick-film capacitors and resistors. The metallization of the lines is formed by a combination of vacuum deposition and electroplating to produce a titanium-palladium-gold film stable at temperatures up to 500°C.

Photo-lithographic techniques are used to produce the required circuit pattern, including transmission lines, inductors, and interconnections. Grounding for dc and rf is achieved through metallized substrate holes which are filled with conductive silver epoxy during the assembly of the module. The rf transistor pellets of the first and second stages are mounted on silver heat spreaders, while the third-stage pellet is in the form of a chip carrier consisting of a beryllia substrate with internal input-matching circuitry.

Pellet-acceptance criteria are established by mounting random pellets of each wafer on conventional packages and testing them for power output, gain, and efficiency at the highest end of the frequency band, 470 MHz. Wafers with borderline characteristics are rejected, and the probability of high module yield is increased. Static dc beta tests are also performed on the module during the assembly cycle to assure that the pellets have not been damaged during the cleaning and mounting operation. Dynamic rf evaluation of the third-stage chip-carrier is performed prior to its insertion into the module. Each carrier is pre-tested in a discrete-circuit plug-in fixture at 470 MHz for power output, gain efficiency, and load-pull capability.

Chip carrier

The rf characterization of high-frequency power-transistor pellets in chip form has, up to now, been a major problem in the fabrication of rf power-hybrid modules because the exact input output and gain characteristics of each of the pellets used in the circuits were not known. Recent developments in high-frequency chip-carrier construction have provided a vehicle that allows the evaluation of each transistor pellet to be made under dynamic conditions. In addition, because of its minimum parasitics, the carrier serves as a tool to evaluate the ultimate performance capability of a transistor chip.

The chip carrier shown in Fig. 5 has been designed to aid in the determination of the characteristics of a 15-W, 12-V output pellet prior to its insertion into the final module. An emitter-base thin-film capacitor is placed on the carrier and, together with the parasitic base-lead inductance of the bond-wires, performs an impedance transformation, effectively increasing the real part of the input impedance of the pellet. Impedance measurements on the input of the carrier, made using slotted-line techniques, show an input impedance at 470 MHz with a real part of approximately 2.2 ohms and

Table I — RF performance of ship carrier at 470 MHz with discrete component fixture. (Vcc = 12.5V).

$P_{in}(W)$	$P_{out}(W)$	$\eta(\%)$
3	15.8	61
3.5	16.3	60
4.0	17.0	61

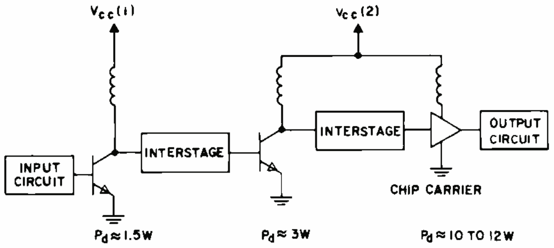


Fig. 6 — Stage-by-stage diagram of R47M15 module.

an imaginary part of $+j1$ ohms. Table I shows the typical performance of the carrier at 470 MHz using a discrete component fixture. The use of a chip carrier with its beryllia substrate in the final stage considerably improves the thermal characteristics of that stage. Fig. 6 shows a stage-by-stage diagram of the R47M15 module with the approximate dissipation indicated for each stage.

40970, 30-W add-on

Developments in transistor design and manufacturing technology and techniques, and improvements in internal matching-circuit design have produced a uhf 30-W device, the 40970, capable of a 5-to 6-dB gain across the 406- to 512-MHz band. Details of this technology are shown in Fig. 7.

The input-circuit design enables the user to build reproducible broadband circuits with minimal input vswr, yet provides flexibility for special performance requirements. The device design provides reliable high-power operation and assures the ability of the transistor to function after severe equipment malfunction.

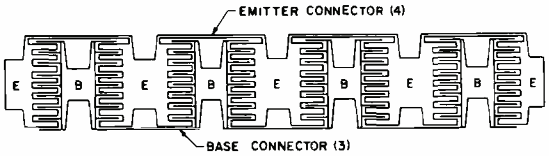
40970 technology

The problem of input-impedance matching normally associated with uhf transistors at low collector voltages (12.5) has been solved in the form of the built-in input-matching network in the 40970. A calibrated length of base-bond wire along with an internally mounted shunt capacitor is used to produce a lumped-constant, miniature, T-section, matching network within the transistor package. Fig. 7c shows the actual bonding arrangement and equivalent circuit. Note that the transistor base inputs are connected at a high impedance level with some isolation between cells.

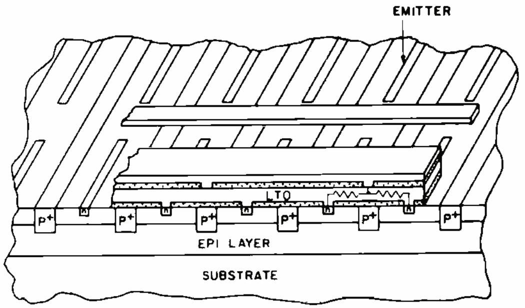
There are some power-sharing advantages to the arrangements of Fig. 7c; however, the main advantages are the higher input impedance and low device Q. These features are of great advantage in both narrowband and broadband circuit design. Impedances in excess of 2 ohms, with a Q of 1 to 2, are easily realizable. The 2-ohm impedance level was chosen to provide maximum flexibility for the user; further increases in impedance would result in general frequency-response limitation along with an inability to optimize the circuit for narrowband conditions within the operating-frequency range of the transistor. Additional advantages are derived from the nature of the input-matching networks. The quarter-wave impedance-matching characteristics of the networks provide for optimization in one portion of the band, usually the high-frequency end. This optimization provides for gain roll-off at lower-band frequencies; however, this circuit-induced roll-off is generally compensated by the approximately 6-dB-per-octave increase in transistor gain with decreasing frequency. The result of a properly optimized input circuit, therefore, is a flat response over the frequency range of interest.

The results of such an input circuit optimization can be shown by reviewing the performance of the 40970 — a 30-W, 12.5-V, 406- to 512-MHz transistor with internal input matching. Narrowband

MULTIPLE BASE STRUCTURE - 8 BASE CELLS

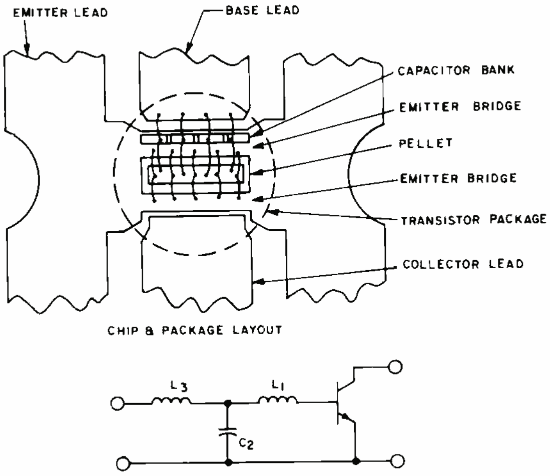


(a) MULTIPLE BASE STRUCTURE-8 BASE CELLS



(b) EMITTER SITE BALLASTING, LTO

BUILD-IN PASSIVE INPUT MATCHING CIRCUIT ELEMENT



(c) BUILT-IN PASSIVE INPUT MATCHING-CIRCUIT ELEMENT

Fig. 7 — Details of the 40970 technology.

Table II — Narrowband performance of 40970.

Freq (*MHz*)	P_{in} (*W*)	P_o (*W*)	η_c (%)	Z_{in} *range* (*ohms*)	
406	9	32	70	2.9+*j*2.0	2.35+*j*1.8
470	9	32	70	3.1+*j*3.9	2.6+*j*3.6
512	9	31.5	68	3.2+*j*2.6	2.8+*j*2.2

performance is shown in Table II. The data show that the gain is actually flat across the uhf mobile band. The input matching network is quite broadband; the impedance variation is small and well within broadband-circuit range. The device has its highest real impedance, and hence is easiest to use, at the highest frequency in its bandwidth. The imaginary-reactance variation is basically a result of the response of a T network in which the largest inductor, L_3 in Fig. 7c, is the input base-lead inductance.

40970 in a broadband circuit

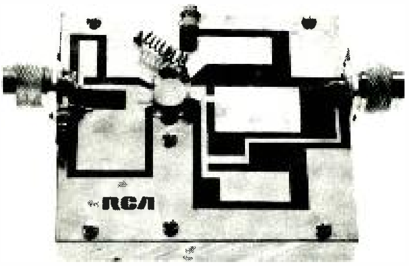


Fig. 8 — 450-to-512-MHz broadband amplifier using the 40970.

To demonstrate the broadband performance capability of the 40970, a 450-to-512-MHz amplifier was constructed; the amplifier is shown in Fig. 8. Both input and output matching networks were developed from Chebyshev lumped-constant tables; they are pseudo-Chebyshev networks in this design because of the input and output reactive terms, which cannot be totally resonated over the entire amplifier bandwidth. In the amplifier design, the package inductance is used as the first matching element, and forms a T with a low-loss capacitor to ground (Allen-Bradley or RMC leadless discs are excellent for minimum losses at uhf frequencies). The remainder of the LC components are formed using 1/32-inch Teflon-fiberglass board. The inductors were specified lengths of high-Z_o line, while the capacitors were specified lengths of low-Z_o line. Values of each were calculated in the following manner:

AIR LINE

$\epsilon_r = 1$

$Z_o = (L/C)^{1/2}$

$v = (LC)^{-1/2} = 3\times10^{10}\,\text{cm} = 1.18\times10^{10}\,\text{in.}$

Inductance - per - length

$Z_o/v = L$

$L = Z_o\,(\text{ohms}) / 1.18\times10^{10}\,\text{in.}$

$= Z_o \times 0.085\,\text{nH/in.}$

Capacitance - per - length

$1/Z_o v = C$

$C = 1/Z_o \times 1.18\times10^{10}\,\text{in.}$

$= (1/Z_o) \times 85\,\text{pF/in.}$

MICROSTRIP LINE @ ϵ_r

Inductance - per - length

$L' = \epsilon_r^{1/2} \times Z_o \times 0.085\,\text{nH/in.}$

Capacitance - per - length

$C' = \epsilon_r^{1/2} \times (1/Z_o) \times 85\,\text{pF/in.}$

Therefore, for a 50-ohm line on Teflon-fiberglass ($\epsilon_r = 2.6$), L = 6.8 nH/in, while

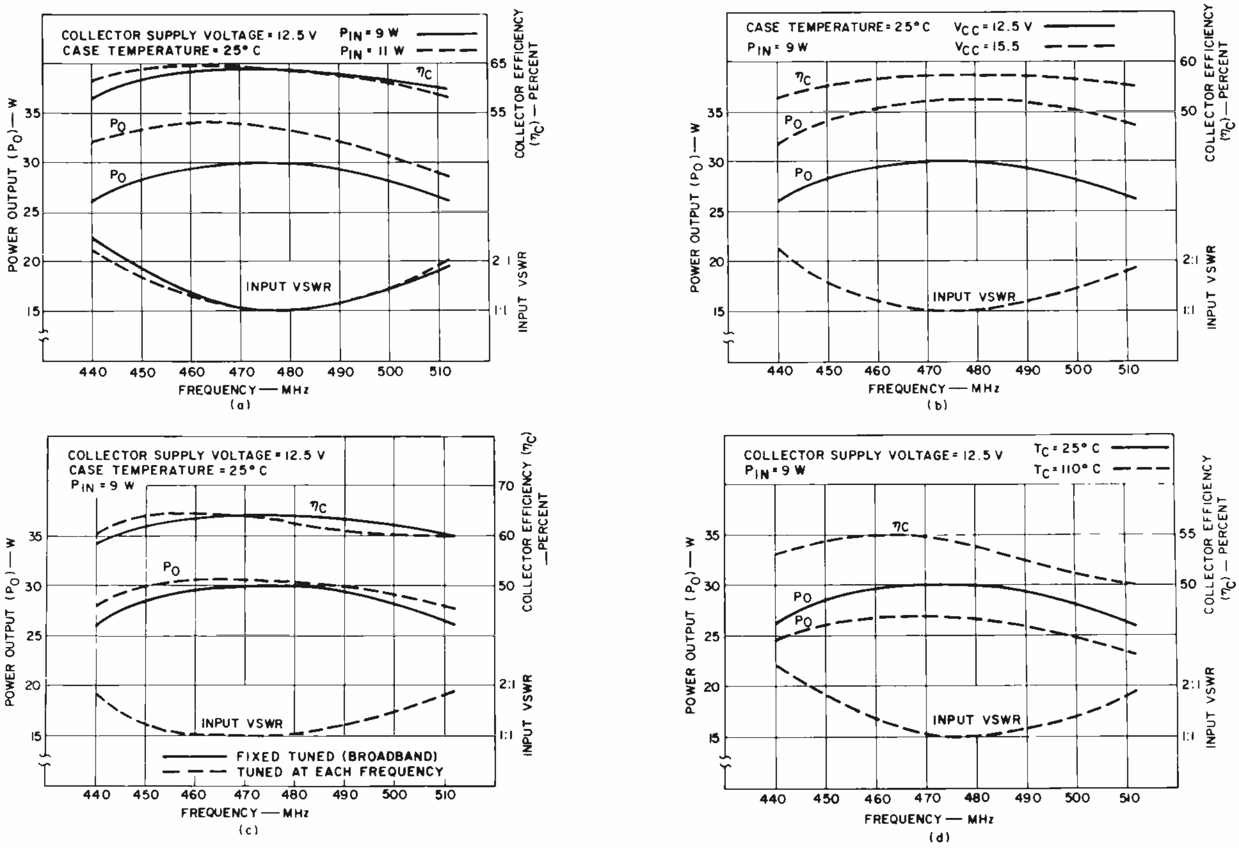


Fig. 9 — Performance of the broadband-amplifier of Fig. 8.

a 20-ohm line on the same material would yield C = 6.8 pF/in.

Performance across the 450- to 512-MHz band under rated input, overdrive, and high line-voltage conditions, in addition to elevated heat-sink temperature, is shown in Fig. 9.

The broadband circuit design includes one input- and one output-tuneable capacitor. These capacitors allow for amplifier optimization for gain and/or efficiency at the frequencies of the lower band. This optimization provides for better performance in band-edge areas and gives the mobile-radio manufacturer greater flexibility in meeting a customer's special needs.

Improved thermal and load-mismatch capability of the 40970

The most stringent requirement to be met by a transistor used in a mobile unit is that of load-mismatch. This requirement demands that the transistor be capable of withstanding any amplifier load from open to short circuit. Many times this condition occurs at high line V_{CC}, which can reach 15.5 V after line and fuse losses. The solution to the mismatch problem lies in the emitter and collector ballasting. Emitter ballasting, as shown in Fig. 7b, consists of a silicon resistor placed over each emitter site; the reverse bias caused by the resistor tends to equalize the current flow in each emitter: as one emitter attempts to draw more current, the resulting increased I_eR_e voltage drop reduces the effective V_{BE} to that cell and, therefore, reduces the drive to that cell. Ballasting also improves the forward second-breakdown characteristics, as the I_eR_e back-bias tends to cancel a portion of the V_{BE} increase with temperature. Collector ballasting utilizes an optimal double layer collector epitaxy ("contoured epi") with individual layer thickness and resistivity chosen to provide reverse second-breakdown protection. The combination of these transistor design features enables the 40970 to be 100% load-mismatch tested at ∞:1 vswr, rated P_{in}, and with V_{cc} = 15.5V under JEDEC load-mismatch notation.

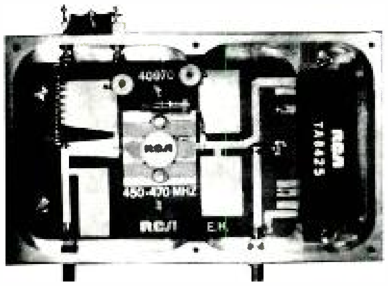


Fig. 10 — Two-stage gain block providing 30-W output and consisting of an R47M10 and a 40970.

The ability to operate at elevated heat-sink temperatures has been met in the 40970 through a layout that provides an $R_{\theta JC}$ of 1.5°C/W; this low thermal resistance allows the device to operate satisfactorily under adverse temperature conditions. At a P_o of 30 W, a heat-sink temperature of 100°C produces a pellet temperature of approximately 145°C.

The effect of ballasting protection and thermal capability is of prime importance in broadband operation. While average thermal resistance appears to allow operation under a 200°C pellet temperature, the non-optimum load conditions inherent in a broadband circuit can cause peak pellet temperature to exceed 200°C. Only through uniform ballasting located as close to each emitter site as possible and coupled with an excellent thermal system can a device provide reliable operation under such conditions.

30-W chain

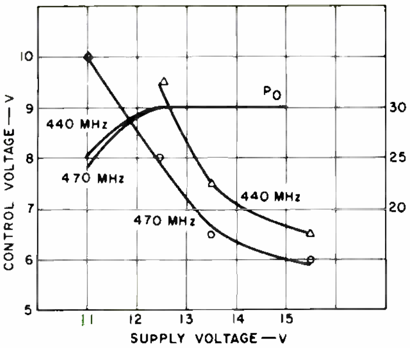


Fig. 12 — Result of driving the 40970 transistor with the R47M10 module.

The R47M10 and the 40970 represent the first steps toward a "power-gain-block" approach to mobile-radio, rf-power-amplifier design. They provide the tools for 6-, 12-, and 25-W radio design, broadband or narrowband, with a minimum of design work for the mobile-radio manufacturer.

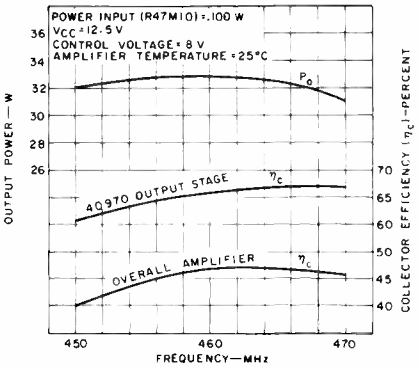


Fig. 11 — Performance data for the power-gain block of Fig. 10 in the 450-to-470-MHz range.

An example of this approach is the RCA "instant radio" circuit shown in Fig 10. This two-stage gain block provides a minimum of 30 W of output power from a 0.1-W input from 450 to 470 MHz; the driver is a 10-W R47M10, while the output stage consists of a 40970 mounted in a 450- to 470-MHz broadband circuit. While this circuit is compact (~ 5 × 3 in.) it produces the 30 W of broadband power with typical efficiencies of 40 to 45%; performance is shown in Fig. 11. The RCA thermal systems, both modular and discrete, assure excellent performance at elevated heat-sink temperatures; the two-stage gain block will power-slump less than 10% at a heat-sink temperature of 75°C.

The flexibility of the power-gain block concept using the R47M10 and 40970 can be extended to output power regulation through the use of the R47M10 gain-control stage. Through regulation of the control-pin voltage, which controls the V_{CC} of the first-module stage, the output power can be maintained at a desired level independent of the circuit-gain characteristics of the R47M10 or 40970. An example of the result of the use of this technique is shown in Fig. 12. The control voltage necessary to maintain the constant output power of 30 W is plotted as a function of the supply voltage at 440 and 470 MHz; the tests were run on a 15-W R47M10 and on the 40970 in the 450- to 512-MHz broadband circuit. The plot shows a constant output power of 30 W until the supply voltage becomes too low to sustain that level of output power.

Acknowledgments

The authors thank E. Hand and D. Kemp for their work in the construction and test of the modules and circuits discussed in this paper.

Microwave system for distress signaling by disabled motorists

Dr. L. Schiff | Dr. H. Staras

A motorist who is disabled and needs help, for either himself or his car, is in a good deal of difficulty if that disablement happens to occur on one of our high-speed, limited-access highways. This problem is particularly acute at night when few passing motorists are willing to stop to aid him and the police patrols are relatively infrequent. This paper describes a microwave system to enable motorists to get help quickly and efficiently.

On some toll highways, motorists are advised that when they become disabled they should signal their distress (say by raising the car's hood). Passing motorists note this and inform the toll collector at the first toll booth they come to. The difficulties with such a system are that it requires cooperation by the passing motorist and that the toll collector cannot be told whether the disabled motorist requires the police or an ambulance or simply a few gallons of gasoline. Other highways have installed special telephones every mile or so to be used by disabled motorists. The difficulty in this is that the motorist must walk to this telephone (if he is able to walk) and this is not particularly safe, especially at night or in inclement weather.

An emergency signaling system could solve many of these problems for motorists in distress. Such a system should be quick and reliable. It should be operable by the motorist from his car and it should be capable of telling the highway or police authority operating the system what type of service is desired (*e.g.*, police, ambulance, tow truck).

This type of service is desirable for the highway authority and the public. The magnitude of the problem is revealed by statistics released by the New York Thruway Authority. The New York Thruway is a 559-mi. toll road of the interstate type that carried 3.9×10^9 vehicle miles in 1969. In that year, there were 94,158 vehicles breakdowns that necessitated emergency service and 5,442 accidents that required police and/or ambulance service. Said another way, there were 170 breakdowns/mile/year or yet another way, 1 breakdown/40,000 vehicle miles traveled. The last is particularly useful in estimating the vehicle breakdown rate on any stretch of highway, if the traffic intensity is known.

Basic system principles

The system obviously calls for in-vehicle devices for signaling. In addition, the highway must be equipped with interrogator units placed about every ten miles along the highway making sure that one exists at every highway exit. All motorists desiring this distress-signaling capability must have vehicles equipped with transceivers. Then, when a motorist needs aid, he puts his transceiver unit in the transmit mode by pressing one of a number of buttons corresponding to different "canned" digital messages (such as *send tow truck*, *send police*, *send medical help*). This message is emitted repeatedly by an appropriate rf signal of very low power. (Capable of being received at a maximum range of 100 ft or so.) Meanwhile the vehicles passing the disabled vehicle have their transceivers in the normal or receive mode. When they get within 100 ft or so of the disabled vehicle, they pick up the transmitted signal and the digital message is detected. This message is stored in a register in the passing vehicle. The passing vehicle travels on until it gets to an interrogator unit. Each interrogator unit acts alternately as transmitter and receiver. That is, it transmits on the same frequency, a short-range digital message that identifies it as an interrogator and then goes into the receive mode to await a response. This cycle is repeated endlessly. Vehicles that contain no message in their

---

Authors Schiff (left) and Staras

Leonard Schiff, Communications Research Laboratory, RCA Laboratories, Princeton, N.J., received the BEE from City College of New York in 1960, the MSEE from New York University in 1962, and the PhD from the Polytechnic Institute of Brooklyn in 1968. From 1960 to 1966 he was employed by Bell Telephone Laboratories, Inc., Murray Hill, N.J., where he was concerned with various aspects of electronic switching systems. Since 1967, he has been employed by RCA Laboratories, Princeton, N.J. He has been concerned with data transmission systems and various types of vehicle location systems. He has also worked on various system aspects of mobile radio especially techniques for making these systems more spectrally efficient and more efficient in their traffic carry capacity. He has authored a number of technical papers in these areas. Dr. Schiff is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

Dr. Harold Staras, Head, Radio Systems Research, RCA Laboratories, Princeton, N.J., received the BS from City College of New York in 1944, the MS in physics from New York University in 1948, and the PhD from the University of Maryland in 1955. Dr. Staras has had over 25 years of professional experience in research and advanced development, primarily in areas relating to propagation, antennas, and communication systems. He played an instrumental role in the development of troposcatter in the 1950's. Since that time he has continued to participate in basic studies with emphasis on new and novel communication systems, especially those utilizing unique modes of propagation and radiation. These include an island as a natural slot antenna, dipole characteristics in magneto-ionic media, the effect of high-altitude nuclear explosion in communication systems, and the effect of scattering from rough surfaces on some data communication systems. At present, Dr. Staras is responsible for developing new communication systems at very high frequencies. Under his direction, analytic and experimental studies have been undertaken in AVM systems, in X-band propagation tests, in a spectrum efficient dispersed array mobile communication systems, and in a distress calling system to permit motorists with disabled vehicles to call for assistance. He is the author of about 2 dozen published technical papers in recognized and professional journals. During the year 1961-62, he was a Guggenheim Fellow and visiting professor at the Technion-Israel Institute of Technology. He is a senior member of the IEEE and served on its Wave Propagation Committee. He is also a member of several study groups of the CCIR and Commission II of URSI, and on several occasions was an official U.S. delegate to international meetings of these bodies.

Reprint RE-18-6-21
Final manuscript received November 15, 1972.

registers do not respond. But when the vehicle that is carrying the distress call comes within range of the interrogator and picks up its signal, it responds by going into the transmit mode and transmits the digital message in its register via a destructive readout. The interrogator, of course, picks up the message and from the interrogator, it can be relayed to any central dispatching point. Each vehicle transceiver thus functions in a three-fold manner:

1) It issues the proper distress call message inputted by the driver (or as another desirable feature, automatically inputted if an impact switch for crash detection is triggered).
2) It allows the vehicle in which the message resides to function as the inadvertent courier of the distress call.
3) It relays the message to the first interrogator unit passed after the pick-up point.

Now, in principle, such a system can be made to work at a number of different frequencies. X-band was chosen for a number of technical and economics reasons. Perhaps the most compelling reason was that, X-band, compared to lower frequencies, is realtively uncongested and would be ideal for the short-range, low-power communication links used by this system.

To determine, on a theoretical basis, how effective this system would be, a simple mathematical model was set up. It was assumed that interrogator units are set up to be τ minutes of driving time apart from one another in normal conditions and that a breakdown occurs somewhere at random between two interrogator units. The passing traffic (counting only vehicles equipped with this service) intensisty is λ cars/min. in each direction and it is assumed that their arrivals at the breakdown form a Poisson process. We assume that all vehicles traveling in the direction of the disabled vehicle and equipped with the service receive the distress message. Because propagation conditions may be marginal for vehicles traveling in the opposite direction, it is assumed that they pick up the message with probability p. Under these assumptions, it is possible to compute the probability that the delay between message inception and receipt at an interrogator unit exceeds a given amount. The results are plotted in normalized fashion in Fig. 1 for $p = 0$, 0.1, and 1 respectively. The derivation is in the Appendix. As an example of the use of these results, consider the following situation. The average number of equipped vehicles passing the breakdown is 2 cars/min. ($\lambda = 2$). The average driving distance between interrogator units is 5 min. ($\tau = 5$), and only vehicles traveling in the direction of the broken-down car are able to receive the disablement message ($p = 0$). The median delay is then 3 min. and less than one call in 100 is delayed more than 6 min.

System details and variations

Since the system is operative only on properly equipped highways, it is desirable to have special units at each highway entrance; these road units are identical to the transmitter sections of the interrogator unit and is used to turn the car unit *on*—that is, switch it from an inactive state to a "ready to receive" state and light an appropriate light to inform the driver. This will serve a double purpose. Since only a vehicle in the ready-to-receive state can hope to have its disablement message picked up, the driver knows when he can use the service. The unit also transmits one bit to inform the unit's logic which way the vehicle is going. If the car unit is later put in the disablement or transmit mode, this bit will be transmitted out, together with the other bits indicating what kind of call it is. Since this bit is then relayed via the courier car and interrogator to the highway authority, the central dispatcher knows which side of the road the call is coming from—something that is desirable in efficient dispatching for limited-access highways.

Thus, the message passed from disabled car to courier car contains the direction and the type of service needed. It should carry, in addition, one other piece of data — the unique identity number of the vehicle originating the call. This will aid is dissuading people from turning in false alarms. If they know their identity is being turned in together with the call for help they will be more careful about vandalizing the system or using it capriciously. The courier car then carries in its register the vehicle number, direction, and type of service for the disabled vehicle. Now upon receipt of this message, the courier car will start to accumulate distance traveled in a separate register (obtained from counting speedometer cable pulses). When the courier car reaches an interrogator unit and receives the interrogation signal, it responds with the four pieces of information — 1) vehicle number 2) direction 3) type of service and 4) distance from disabled car — which are then received by the interrogator unit. There are actually two different types of interrogator messages. Both result in the courier car transmitting the contents of its registers and resetting. The difference is that with one type of message the car unit is reset to the "read to receive" state and with the other type the car unit is deactivated. The latter type of message is, of course, associated with interrogator units placed at an exit rather than along the highway.

The above type of service could supply a basic and reliable service that a motorist could use with confidence. However, some observers feel that some type of acknowledgment procedure must be provided in such a system for the motorist in distress. With participating cars having both transmitters and receivers as this system necessitates (even though the communications range is only 100 ft or so) various types of acknowledgment procedures are possible. Three such procedures are outlined below.

Acknowledgment only

In the first possible procedure, distressed motorists get acknowledgment very quickly but of a limited type. In this procedure, vehicles that are disabled alternate between transmitting their messages and listening for replies. Vehicles in the ready-to-receive state, upon receipt of the message, not only store the message but, on a strictly one-shot basis, transmit the identical message out. The disabled vehicle picks this transmission up and, if it agrees with what was sent, records a "success". After the disabled vehicle records N such successes it both shuts off and lights a light to tell the motorist that his message has been accepted by the system.

While this does not tell the driver that the highway authority has his call, it tells him it is on the way. It has the dual function of shutting his transmitter *off*. Motorists passing him after this time pick up no message and are hence free to pick up messages from other motorists that might be disabled a little further down the road and before the next interrogator.

Acknowledgment and assurance

Of course, in the above scheme, a disabled motorists only has assurance that his call has entered the system but not that it has reached the central authority that will dispatch help. This type of acknowledgment can be provided instead of the type of acknowledgment provided above. Recall that each interrogator unit has a communications link to the central authority. Up to this point, that system has been treated as a one-way link — from the interrogator to the central point. If the link is two way, the highway authority can direct the interrogator to change the message it sends. This changed interrogator message consists of a special preamble to identify what sort of message it is plus the number of the disabled vehicle that is disabled down stream. Vehicles encountering this interrogator respond as before — by sending any call they have stored or by not transmitting if they have no call to relay. In any case, however, this special type of interrogator signal indicates to the car unit that it should store the transmitted vehicle number in a special register. The vehicle then proceeds along the highway. If it picks up a distress call (including a vehicle number), it tries to match the number against the number in the special register. If there is no match, it treats the distress call in the normal manner. If there is a match, it transmits the vehicle number. Now just as in the first case, disabled vehicles cycle between transmit and receive, and just as in that case, receipt of its own number serves as acknowledgment and shut-down signal. In this case, however, acknowledgment comes not from vehicles picking up the distress call but from the dispatching authority via cars that, in this case, act as inadvertent couriers of the acknowledgment message. Special messages of this type can be send not only by interrogators but by the transmitters (in this case with variable message) at highway entranes up stream from the breakdown.

Direct acknowledgment

One obvious undesirable feature of the above plan is that the disabled motorist must wait for an acknowledgment until another equipped vehicle brings it to him. It is even possible to eliminate this feature and have an acknowledgment transmitted from the central dispatcher to the disabled vehicle essentially immediately. This involves a more elaborate system and the use and modification of the vehicle's a.m. radio receiver.

The basic principle is that each highway authority can relay its vehicle numbers of disabled vehicles to a commercial a.m. radio broadcast station that reliably covers the highway section on which the breakdown occurred. The a.m. station then broadcasts the vehicle number out (at a very slow rate) using subaudio signaling. The vehicle's a.m. radio receiver is modified to detect this subaudio digital signaling and treats it as an acknowledgment, provided the number matches the unit's number. Thus, this type of acknowledgment would at least be simple in concept provided the disabled motorist could tune to the correct a.m. station. He cannot simply be told the proper station for the area via signs posted along the highway because it cannot be assumed that his memory or his tuning accuracy is that good. Further, he cannot simply tune his a.m. radio until his detector detects the fact that sub-audio signaling is being received. This may be a sub-audio signal from an a.m. radio station many hundreds of miles away being received due to some unusual topographical and atmosphereic condtions. However, there still is a way of tuning reliably. Let each a.m. broadcast station that sends acknowledgments transmit a sub-audio pilot frequency in addition to the sub-audio signalling. In general, stations have different frequency pilots taking great care that no two such stations that can be picked up in the same region have the same pilot frequency. Now, as each vehicle enters the highway or a section of a highway served by a different a.m. station (and hence having a different pilot frequency) its unit is, in effect, informed as to correct pilot frequency by the activating transmitter or interrogator respectively. The digital message received uniquely identifies the pilot and is stored. When a disabled motorists tries to pick up the station sending acknowledgments, he slowly tunes across the a.m. band until his detector matches the received pilot frequency with the digital message stored. At that point, he is given an indication that he is tuned to the correct station and he awaits acknowledgments.

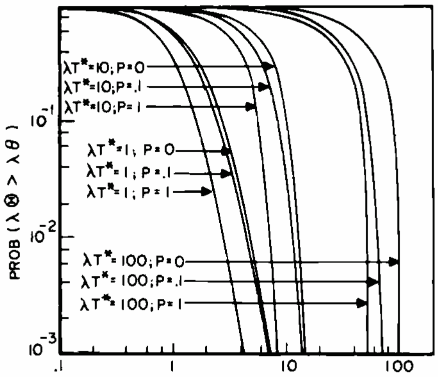


Fig. 1 — Probability that the time to get a report to a road unit exceeds a specific time as a function of traffic.

Getting a system started

The problem with such a system is getting it started. Obviously, the usefulness of such a unit in a disabled vehicle depends on having a large enough number of other equipped cars to relay the distress message. The curves of Fig. 1 can be used to estimate the maximum spacing of interrogator units that can be tolerated (related to τ via the average road speed) and more importantly the minimum number of properly equipped automobiles that, on average, must pass a given point on a highway (λ in Fig. 1). The quantity λ, on any road section of length L, over and time period T for which the statistics are stationary is given by $\lambda = M/LT$ where M is the total vehicle miles accrued over that road section in that time by equipped vehicles. One must ensure that in any situation λ is sufficient This is particularly important in a test situation.

Because it is important to test such a system, the units will initially not be built into automobiles but will undoubtedly be stand-alone units (say, for example, that such units are handed out at the entrance of toll roads and collected at exists). One potential difficulty with such non-built-in units — the variability in signal strength depending on where the unit is placed — has been investigated. With a roadside transmitter and a car with a receiver driven by, the variations in signal strength as a function of unit position (the antenna is, of course, built into the unit) have been found. From the best position in which the unit can be in, to the worst position the unit can be in, the total variation was 25 dB. With the modulation scheme envisioned (FSK/a.m.) this should be quite acceptable.

Conclusion

While the purpose of the system is to allow distress calling by motorists, it involves placing a short-range digital transceiver in automobiles. The possibilities for the types of system that can be built around these transceivers is open ended. For example, roadside units that are identical to interrogator units, but which send different messages, could alert drivers to dangers ahead if the car unit were coupled to a visual display for the driver. These units could be portable for additional flexibility on the part of the highway authority. As yet another use, each interrogator unit can have a unique identity number that it transmits in addition to its regular message. A sub-class of vehicles, such as highway patrol cars, having these in-car units can have logic that causes them to store the interrogator number (and replace it with the next number when the next interrogator is passed). Hence, each such car unit knows the last interrogator passed. This information, when coupled with conventional mobile facility can provide a vehicle-location capability making for more efficient deployment of vehicles.

In the final analysis, however, everything depends on the cost/benefit ratio of this system as a motorist aid device. In such a system, the costs break down to the cost per vehicle and the cost per highway mile. There are extremes in which either of these two may be made zero. At one extreme are systems in which each unit is equipped with a high-power transmitter capable of directly reaching the highway authority (making cost per mile zero); the other extreme has no cost per vehicle (*e.g.*, a highway telephone system or the FLASH system). We feel that at the one extreme the cost/benefit ratio is too high and at the other extreme the basic system objective of being able to signal directly from the car and without the cooperation of passing motorists is not achieved. Because of the short range required of the car transceiver, it is very difficult to imagine transceivers that are intrinsically less expensive. Because road units are put up so infrequently (every 10 miles or so seems reasonable) the cost per mile is low. Of course, the benefit isn't as great as in some ultimate system. Some delay in getting the message in as the road traffic moves down stream has to be tolerated as one example, and an interactive communications is basically not possible for another. However, the cost/benefit ratio makes this a viable system.

Appendix — Delay between message inception and receipt

First consider the case $p = 0$. Assume the traffic passing the disablement averages λ cars per unit time and the arrival process is random (Poisson). The probability density of the time for the first arrival T is given by

$$P_{T1}(t_1) = \begin{cases} \lambda \exp(-\lambda t) & \text{for } t \geqslant 0 \\ 0 & \text{otherwise} \end{cases} \qquad (1)$$

Assume further that the driving time between interrogator units is τ and that breakdowns occur uniformly at random between interrogators. The distribution of the time T_1 for the courier car to get the message to the interrogator is then given by

$$P_{T1}(t_1) = \begin{cases} 1/\tau & 0 \leqslant t_1 \leqslant \tau \\ 0 & \text{otherwise} \end{cases} \qquad (2)$$

If Θ is the random variable $T_1 + T$ and $F(\theta)$ its corresponding c.d.f. then

$$F(\theta) = \int_0^{\theta} dt \int_0^{\theta - t} dt_1\, (\lambda/\tau) \exp(-\lambda t) \qquad \text{if } 0 < \theta \leqslant \tau$$

$$= (1/\lambda\tau)[\exp(-\lambda\theta) + \lambda\theta - 1]$$

and

$$F(\theta) = \int_0^{\theta-\tau} dt\, \lambda \exp(-\lambda t) + \int_{\theta-\tau}^{\theta} dt \int_0^{\theta - t} dt_1 (\lambda/\tau) \exp(-\lambda t)$$

$$= 1 + [\exp(-\lambda\theta)/\lambda\tau][1 - \exp(\lambda\tau)] \qquad \text{if } \theta > \tau$$

If triggering to the other side of the road is accomplished with probability p and the traffic rate is λ, the effective rate is $\lambda' = p\lambda$. Let T_1 be the driving time to the interrogator down stream and T_2 the driving time to the interrogator up stream (where the across the road cars must deposit their call). Let Θ_1 and Θ_2 be the time to get the call to the down stream and up stream interrogators respectively and Θ be the minimum of the two.

Then

$$G(\theta, T_1) = \text{prob}[\Theta \leqslant \theta \mid T_1]$$
$$= 1 - \text{prob}[\Theta_1 > \theta;\ \Theta_2 > \theta \mid T_1]$$
$$= 1 - \text{prob}[\Theta_1 > \theta \mid T_1]\, \text{prob}[\Theta_2 > \theta \mid T_1]$$

Noting that $T_1 + T_2 = \tau$, we distinguish the following six cases for which $G(\theta, T_1)$ is easy to find by direct integration

Case I: $T_1 \leqslant \tau/2$

Case Ia: $-\ \theta \leqslant T_1$ for which $G = 0$

Case Ib: $-\ T_1 < \theta \leqslant \tau - T_1$ for which $G = 1 - \exp[-\lambda(\theta - T_1)]$

Case Ic: $-\ \theta > \tau - T_1$ for which $G = 1 - \exp[-\lambda(\theta - T_1)]\exp[-\lambda'(\theta - \tau + T_1)]$

Case II: $T_1 > \tau/2$

Case IIa: $\theta \leqslant \tau - T_1$ for which $G = 0$

Case IIb: $\tau - T_1 < \theta \leqslant T_1$ for which $G = 1 - \exp[-\lambda'(\theta - \tau + T_1)]$

Case IIc: $\theta > T_1$ for which $G = 1 - \exp[-\lambda(\theta - T_1)]\exp\{-\lambda'(\theta - \tau + T_1)\}$

Noting that the c.d.f., $F(\theta)$, is obtained by averaging $G(\theta, T_1)$ over the random variable T_1

$$F(\theta) = G(\theta, t)\, p_{T1}(t)dt$$

$$= (1/\tau) \int_0^{T1} G(\theta, t)dt$$

and substituting in the above results, we have

For $0 < \theta \leqslant \tau/2$

$$F(\theta) = (1/\tau) \int_0^{\theta} [1 - \exp(-\lambda\,\theta) \exp(\lambda t)]dt$$

$$+ (1/\tau) \int_{\tau-\theta}^{\tau} [1 - \exp(-\lambda'\theta) \exp(\lambda'\tau) \exp(-\lambda' t)]dt$$

$$= (1/\lambda\tau)\{2\lambda\theta - [1 - \exp(-\lambda\theta)] - (1/p)[1 - \exp(-p\lambda\theta]\}$$

For $\tau/2 < \theta \leqslant \tau$

$$F(\theta) = (1/\tau) \int_0^{\tau-\theta} [1 - \exp(-\lambda\theta) \exp(\lambda t)]dt$$

$$+ (1/\tau) \int_{\theta}^{\tau} [1 - \exp(-\lambda'\theta) \exp(\lambda'\tau) \exp(-\lambda' t))]dt$$

$$+ (1/\tau) \int_{\tau-\theta}^{\theta} \{1 - \exp[-(\lambda + \lambda')\theta]\exp[\lambda'\tau]\exp[(\lambda - \lambda')t]\}dt$$

$$= (1/\lambda\tau)\{\lambda\tau + [p/(1-p)] \exp(\lambda\tau) \exp(-2\lambda\theta)$$
$$- 1/[p(1-p)]\exp(p\lambda\tau)\exp(-2p\lambda\theta) + \exp(-\lambda\theta) + (1/p)\exp(-p\lambda\theta)\}$$

For $\theta > \tau$

$$F(\theta) = (1/\tau) \int_0^{\tau} \{1 - \exp[-(\lambda + \lambda')\theta]\exp[-\lambda'\tau]\exp[-(\lambda - \lambda')t]\}\, dt$$

$$= (1/\lambda\tau)\{\lambda\tau - [1/(1-p)]\exp[-(1+p)\lambda\theta][\exp(\lambda\tau) - \exp(p\lambda\tau)]\}$$

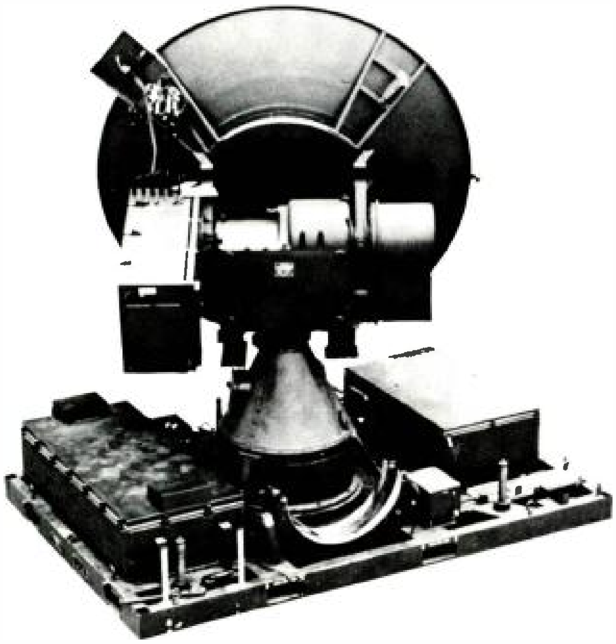
Automatic checkout and monitoring in the AN/TPQ-27 radar system

H. P. Brockman

The paper describes automatic monitoring equipment built into a precision tracking radar system to detect and isolate faults. The purpose of the monitoring equipment is to minimize the mean time to repair faults and to exercise the system for pre-mission alignment and calibration. In addition, it is used to periodically check for performance degradation in key areas of the system. The paper describes the design approach used to meet the above requirement. Three types of signals are monitored: analog, digital, and switch closure. A list of each type and the techniques used to monitor each are described; the design approach for pre-mission alignment and calibration is also outlined. Tests performed are RF alignment of the boresight axis, range tracking accuracy, angle servo calibration and accuracy, and receiver figure-of-merit measurements.

Herbert P. Brockman
Signal and Data Processing Engineering
Missile & Surface Radar Division
Moorestown, N.J.
received the BSEE from the University of Maryland in 1950 He worked on various subsystems for airborne fire-control radars at Westinghouse prior to joining RCA in 1959. As a Senior Member of the Engineering Staff at the Missile and Surface Radar Division of RCA for the past 13 years, he has been responsible for the design and development of various subsystems in many different radar systems This work has encompassed nearly all aspects of overall radar system design, with particular emphasis on checkout and monitoring equipment. In addition to his work on the AN/TPQ-27, he has worked on automatic monitoring subsystems for BMEWS, SAM-D and more recently the CAMEL radar, which is currently under development. Mr. Brockman has written technical papers for the *RCA Engineer* and several other electronic publications on automatic monitoring and other topics during his career.

RE-18-6-14
Final manuscript received November 15, 1972.



In complex radar systems, an automatic monitoring system is often required to detect and isolate faults to specific locations in the system.[1] This function should be performed on-line to minimize mean time to repair faults and to assure a high confidence level in the operational readiness of the system. It is also desirable to provide a method of exercising the system for pre-mission alignment and calibration, and to check for performance degradation that may affect operational readiness of the system.

The AN/TPQ-27 is a portable tactical radar system used for precision guidance of military aircraft and consists of a command and control shelter, a communications shelter, and a precision-tracking radar (Fig. 1). The radar contains the transmitter, antenna and pedestal, receivers, and signal proces-

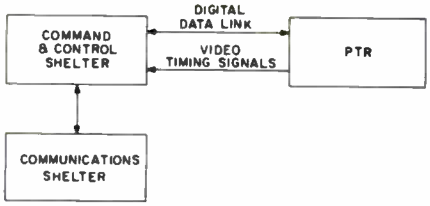


Fig. 1—AN/TPQ-27 radar system showing PTR interface.

Table I—Signal types monitored.

Analog signals	*Digital control signals*	*Switch closures*
Crystal currents	Pretriggers	Waveguide switches
Power supplies	Transmitter trigger	Antenna servos
Transmitter detected video	Az angle gate	Temperature sensors
Transmitter discriminator error	El angle gate	Interlocks
Beacon AFC error	Beacon Code	
AGC voltage	Target detection pulses	
CFAR voltage	CFAR loop summary	

sor. The radar may be located as far as 300 ft from the command and control shelter to take advantage of hilly terrain. Communications between the two units is accomplished by a single digital-data link and by a coax cable which provides the timing pulses for the radar displays. Although various diagnostic tests are performed on all major units of the system, this paper is limited to a discussion of an automatic checkout and monitoring system for the precision tracking radar (PTR). This system allows on-line monitoring of critical radar signals and eases off-line pre-mission checkout.

Design approach

Since the radar is remote from the command and control shelter, a fully automatic monitoring system was required by the customer. Thus the automatic checkout and monitoring (ACM) is designed to operate from the system computer since the ACM has a direct interface with the PTR via the digital data link which controls the radar's operation. The relationship of the ACM equipment to the remainder of the PTR is shown in Fig. 2. All data to and from the computer is sent via the radar data buffer which has a direct interface with the ACM equipment as well as other major units of the radar. The ACM equipment also has a direct interface with all other units of the PTR for monitoring key test points in the system.

This arrangement has several features that make it a very economical monitoring system.

1) Since the computer has direct control over both the radar and ACM, synchronization of the monitoring function is easily accomplished on a noninterference basis with normal radar operations; test stimuli to exercise the system for monitoring are likewise easily generated.
2) The direct interface between the radar data buffer and the ACM facilitates a digital address scheme for remote selection of each test point to be monitored, as well as a return path to the computer for quantized monitoring data. Upper and lower limits for all analog monitoring points are stored in the computer to establish *go, no-go* criteria and to print out actual test point values as well as the location and out-of-tolerance conditions of each test point.
3) The quantizing function and the transmission of input and output data from both the radar and ACM are time shared with each other to minimize hardware. It should be noted, however, that these features and economics were realized only because the ACM was built into the radar from the initial design phase instead of being added later.

On-line monitoring

The selection of test points for on-line automatic monitoring required a detailed study of each subsystem in the PTR. The characteristic of each monitoring-point candidate was studied using criteria listed below in a more-or-less descending order of importance. Although these criteria were developed specifically for the AN/TPQ-27 system, they are generally applicable to other systems as well.

1) Failure of monitoring equipment will not degrade signal output.
2) Failure renders entire system inoperative.
3) Failure results in partial system failure.
4) Degradation results in degraded system performance.
5) Degradation or failure localizes fault to specific component or function.
6) Degradation or failure localizes fault to small area of subsystem.
7) Degradation or failure localizes fault to a subsystem and the test point is readily accessible.

To meet the maintenance requirements of the overall system, 75 test points were selected. They fall into three general categories: analog, digital control signals, and switch closures. A listing of each signal type in these categories is shown in Table I.

The approach used to monitor these signals can best be described by referring to the ACM equipment block diagram in Fig. 3. A seven-bit monitoring address assigned to each test point is received from the computer via the radar data buffer and stored in the address register. The address is then

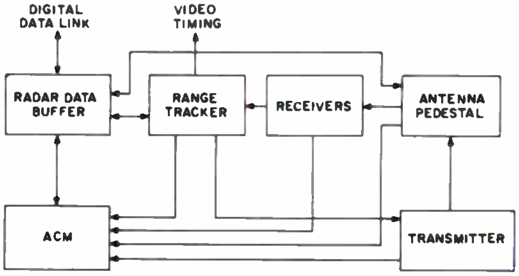


Fig. 2—ACM interface with precision tracking radar.

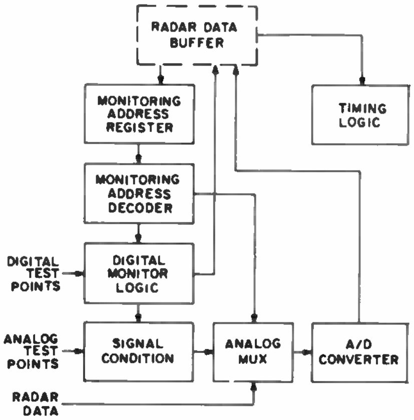


Fig. 3—Automatic checkout and monitoring block diagram.

decoded in the monitoring address decoder which has one output enable line for each binary number in the address register. Each test point is monitored sequentially, one at a time, every 8 ms. The computer correlates the test point data with the address command it sent to the monitoring equipment, and in this way isolates faults to specific test points. All 75 test points are monitored in 0.6s. Selection of each analog signal is accomplished using a multiplexer (MUX) containing hybrid integrated circuit field effect transistors (FETs) to avoid DC offsets. The normal operating signal range of the FETs is ± 10 V. A low output impedance is obtained from the MUX by using an operational amplifier connected as a voltage follower. An 11-bit analog-to-digital (A/D) converter is employed to digitize the MUX output to a resolution of 10 mV. The A/D output is then stored in a shift register in the radar data buffer for transmission to the computer. Preset limits for each analog signal are stored in the computer where the *go, no-go* comparison is made. It should be noted that analog monitoring data and the analog radar data share the same MUX and A/D converter so that only one A/D converter is required in the PTR.

Digital monitoring

Digital test points are multiplexed using digital logic as illustrated in Fig. 4. Digital timing pulses such as pretriggers and shift pulses are checked for presence or absence by storing their presence in a flip-flop. Each flip-flop is reset at the end of the complete monitoring sequence. Thus if the pulse is absent, the flip-flop does not become set and a fault is indicated by a *one* on the *Q′* output of the flip-flop. Multiplexing is accomplished using a NAND gate with one input consisting of the stored digital signal and one input consisting of the decoded monitoring address for that test point. An output from the addressed gate is obtained only if a fault is present. Switch-closure test points are monitored in the same way, except that no storage flip-flop is required. The outputs from all NAND gates are OR'ed together in a large NOR gate for transmission to the computer as a single bit of data. Computer correlation of this bit with its associated address isolates a fault to a specific address.

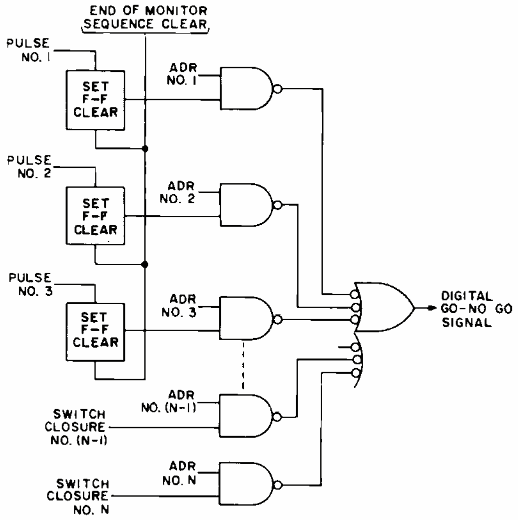


Fig. 4—Digital logic for monitoring pulse presence and switch closures.

Analog signal conditioning

Video signal test points are converted to a DC voltage prior to being multiplexed and digitized, since they are asynchronous to the A/D converter sample rate. This is accomplished using the peak-detector circuit shown in Fig. 5. A 100-ohm terminating impedance is provided to terminate narrow video pulses in the characteristic impedance of the coax transmission line. Taps are provided on this termination to provide a means of changing the gain of the peak detector to normalize input signals having peak values from 1.0 to 5.0 V. An integrated circuit digital comparator of the Fairchild type μA710 is employed, with a threshold level in the order of 10 mV.[2] That is, if the pulse level of the positive input exceeds the DC or pulse level on the negative input by greater than 10 mV, the output will switch from a low to a high digital level (*i.e.*, approximately +3 V.) The rise time of the comparator output is of the order of 20 ns so that video pulses as narrow as 0.2 μs and occurring at a PRF of 250 pps may be peak detected accurately. The comparator output is fed to a conventional diode peak detector and then to an integrated-circuit operational amplifier having a gain of 20. Feedback from the DC output to the negative input of the comparators causes the DC level there to rise to the same level as the peak of the video pulse. The 10-to-1 ratio of the feedback resistor to the grounded input resistor sets the gain of the overall peak detector to a value of 10. It should be noted that negative video pulses can be detected using the same circuit by simply reversing the + and − input terminals. Where signal loading does not permit terminating the input in 100 ohms, the signal may be connected directly between the + and − input. Because of the excellent common-mode rejection characteristics of the comparator and because the two input line impedances are balanced, the input ground return may be isolated from the peak detector ground.

When monitoring of either video or DC analog signals from remote loca-

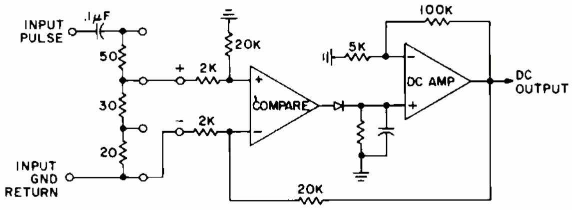


Fig. 5—Peak detector circuit.

tions common-mode noise on the signal may be a serious problem. Common-mode signals are eliminated by using operational amplifiers with balanced input impedances. For this reason DC test point signals, such as AGC voltage, are fed to operational amplifiers having balanced inputs as illustrated in Fig. 6. This is accomplished simply by making the two resistors in the non-inverting input the same as the two resistors in the negative feedback loop.

Output signals from the peak-detector circuit are fed to the multiplexer to be digitized as their addresses are called up. The digital representation of the signal is tested against stored limits in the computer.

Off-line checkout

The primary purpose for off-line checkout is pre-mission alignment and calibration of the PTR as well as a check for performance degradation which may affect the operational readiness of the system. Tests that may be performed in checkout mode are RF alignment of the boresight axis, range-tracking accuracy, angle-servo calibration and accuracy, and receiver figure-of-merit measurements. Except for the last measurement, all these tests are performed while the radar is locked onto a boresight tower located approximately 300 ft away.

Since the boresight tower is a passive device containing only a simple corner reflector, a rather sophisticated scheme of target simulation is required to generate realistic dynamic targets for radar tracking purposes. The techniques employed to accomplish this may be explained by referring to Fig. 7 which shows both signal flow and the manner of injecting the simulated target into the system. The simulated target is delayed in range by means of a delayed trigger to the transmitter (*i.e.*, delayed from the zero-time trigger which normally triggers the transmitter). The delayed trigger, in turn, is obtained from a range counter which is designated to a specific range interval by the computer. The transmitter is operated at full power but most of the energy is switched into a dummy load by a waveguide switch and directional coupler. A small part of the energy is obtained from the directional coupler to form the ACM (simulated target) signal which is fed through a second waveguide switch to the antenna via a circulator. It should be noted that the peak power through the first waveguide switch is about 100 kW while the power through the second is about 1.0 mW in checkout mode and 100 kW during on-line operation. The difference in power levels is 80 dB and the open circuit isolation of each waveguide switch is of the order of 60 dB, so that two switches in series are required to keep the leakage power low with respect to the desired power of 1.0 W. Otherwise, the leakage power would far exceed the desired ACM signal power, resulting in an excessive and uncontrolled level of power at the antenna. With the gain characteristics of the antenna and the corner reflector on the boresight tower, 1.0 mW of transmitted power provides a returned signal power of sufficient signal-to-noise ratio for radar tracking measurements.

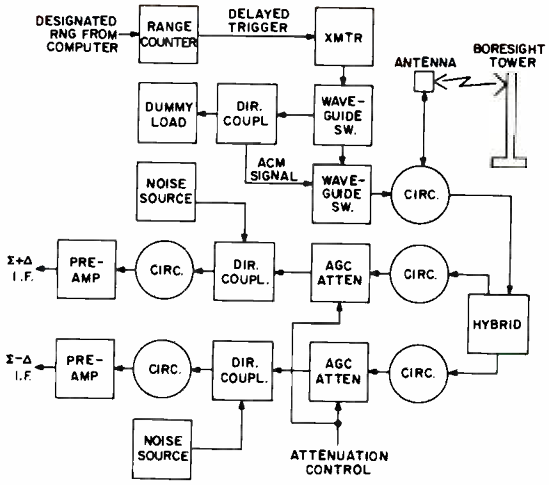


Fig. 7—Signal flow for PTR checkout.

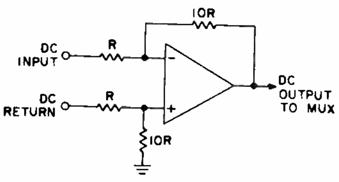


Fig. 6—Balanced DC amplifier.

The received signal is fed through a hybrid to extract the two error signals required for monopulse tracking (*i.e.*, $\Sigma+\Delta$ and $\Sigma-\Delta$). These signals form two error-signal channels, each composed of a circulator, a programmable AGC attenuator, and directional coupler, another circulator, and a mixer preamplifier from which the IF signals are obtained. The circulators absorb any energy reflected from the AGC attenuator, since the latter has a high VSWR; this attenuator is used to prevent signal limiting for close-in targets. The directional coupler is used to inject noise in the system for "figure of merit" measurements, described later.

Except for the signal path through the waveguide switches, the signal flow from transmitter to antenna and the return path from the antenna to the receiver preamplifiers and into the signal processor is identical to the normal signal flow for on-line operation. Hence all the major elements of the PTR are exercised in a normal manner with the aid of the simulated target.

Initial lock-on to the boresight tower is accomplished manually by the operator to determine its location with respect to the PTR. Once its coordinates are determined, they are stored in the computer so that thereafter the radar locks onto the boresight tower automatically. Checkout mode is initiated by pressing a *simulation on* button which sets up all the preconditions (such as, waveguide switching, target-range designation, transmitter-power on, and antenna-angle designation) so that automatic lock-on can be accomplished. After lock-on, any one of the following tests may be selected by means of a typewriter input command to the computer, and performed automatically under computer control:

- RF alignment of antenna axis
- Tracking accuracy test
- Range tracking test
- Angle error gradient calibration
- Receiver figure of merit

Test results are printed out at the end of each test on a hard-copy printer, together with the specification limits of of each test.

RF alignment of antenna axis

Since the electrical axis of the antenna varies with respect to the mechanical axis in frequency and polarization, it is necessary to determine the azimuth and elevation bias for each operational condition. Lock-on to the boresight tower is obtained and the azimuth and elevation encoder positions are recorded automatically. Then under computer control the antenna is rotated 180° in azimuth and is plunged in elevation through the zenith to the elevation of the target so that lock-on is obtained again. The new readings of the encoders are then recorded. From this data, new values of the azimuth and elevation bias are calculated and printed out for operator analysis. At the operator's discretion, the bias corrections may be changed in the computer via keyboard input. It should be noted that prior to this test, the antenna pedestal must be levelled manually to avoid introducing errors in the measurement.

Tracking accuracy test

This periodic test checks the standard and mean deviation of the radar in azimuth, elevation, and range from the previously measured fixed position of the boresight tower. The test is performed as a check against possible settling or other movement of the pedestal which would affect its coordinate position. The test is performed automatically by averaging 128 readings of each axis, including range, and comparing these averages with previously stored average values in the computer. Again, the operator has the option of changing the deviation constants in the computer via keyboard input. Releveling of the antenna must be performed if gross errors occur, but this task is normally infrequent.

Range tracking test

This test provides a means of checking the range tracking accuracy of the system for a constant-velocity target and one that varies sinusoidally in range as follows:

$$R = K_1 \sin t$$

or

$$R = K_2 \sin 10\, t$$

The test is initiated by typewriter input command and performed automatically in the same manner as tests described earlier. After lock-on, the range designation is varied in accordance with the selected modulation by the computer. The results obtained from the range tracker are then compared in the computer with the input modulation to determine the tracking accuracy. In this way, a direct measurement is made of the system capability to track high-velocity or highly accelerating targets.

Angle error gradient calibration

This test provides a means of automatically calibrating the gain, or *K* factor, of the angle-servo loops to minimize the error gradient. This is especially important in the AN/TPQ-27 system since the servo loops are closed through the computer. That is, the computer performs the computations associated with the transfer function in the servo loop.

To perform the calibration, the antenna is locked-on the boresight tower and the computer then introduces a forcing function to force the antenna +2.0 mils off the target in azimuth and then −2.0 mils off target. A comparison is made between the magnitude of the forcing function required to drive the antenna 2.0 mils in each direction. The value of *K* in the transfer function is then adjusted by the computer to get equal movement in both directions for equal and opposite forcing functions. The test is repeated in the same manner to calibrate the *K* factor associated with the elevation servo. Each of the new *K* factors is printed out for operation evaluation. At operator discretion, both *K* factors may be changed via keyboard input.

Receiver figure-of-merit test

The figure-of-merit test provides a means for checking for degradation in the noise figure of the receivers. Unlike the other tests, the boresight tower is not used and the transmitter is not radiating. The test is performed using a noise source at the front end of each receiver channel as illustrated in Fig. 7. Two measurements are taken, one with the noise source *on* and one with it *off*. To minimize the effect of noise picked up by the antenna, the AGC attenuators are activated to insert 24 dB of attenuation in series with the antenna and receivers. The change in signal power obtained from the receivers with the noise source *on* and *off* is determined by measuring the change in AGC voltage for each condition. Signal switching to set up preconditions for each measurement is controlled by the ACM equipment through monitoring address selection. Although the change in AGC voltage due to the noise source is of the order of only a few tenths volt, the AGC voltage is digitized to a 10 mV resolution by an 11-bit A/D converter in the ACM equipment. Since the slope of the AGC curve in volts/dB of noise power is known for a good receiver, (*i.e.,* one with an acceptable noise figure) this constant and the difference between the two AGC volatge readings are used by the computer to calculate the figure of merit of the receiver. Using this approach, a 3.0 dB degradation in the noise figure of each receiver channel can be detected readily.

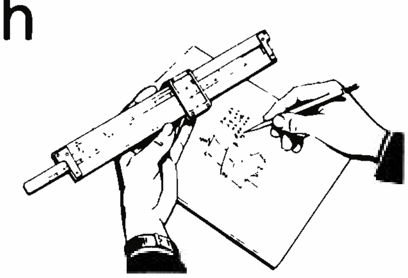
Conclusions

The first step in developing an effective monitoring system is to establish criteria for test point selection. The design concepts developed for signal conditioning of both analog and digital monitoring points and the monitoring scheme for sequential monitoring of each test point are techniques that may be applied to any automatic monitoring system. Although the various tests outlined for automatic alignment and calibration of the system with a boresight tower were developed to meet the specific requirements of the AN/TPQ-27 radar, the concepts used may find application to other radar systems as well.

References

1. Brockman, H. P.—"Automatic Checkout and Monitoring of Large Complex Systems," *RCA* reprint PE-307; *RCA Engineer*, Vol. 11, No. 5 (March 1966).
2. Giles, J. V.—"The μA710 and μA711 High-Speed Comparator," *Fairchild Semiconductor Linear Integrated Circuits Applications Handbook*, Library of Congress Catalog #67-27446.

Engineering and Research Notes



Method of quenching and regeneration of chemical plating baths

Nathan Feldstein
RCA Laboratories
Princeton, N.J.

In technologies in which a metal is deposited on a substrate, there are many applications that require that the metal coating have a precisely controlled thickness. Since thickness of the metal being deposited is usually directly proportional to the time in the plating bath (either in electrolytic or electroless plating), the deposited metal thickness may usually be controlled by removing the coated substrate from the bath after a measured length of time.

However, there are applications where it is not practical to abruptly remove the substrate being plated from the bath. For example, it may be desired to plate a multitude of fine particles in suspension in a liquid. The plated particles may be needed for magnetic or catalytic applications, or for other purposes. In this type of situation it is usually not practical to remove the particles from the liquid carrier at the end of a controlled plating time. It also may not be convenient to remove the particles from a suspension which has been formed by deliberately decomposing an electroless plating bath so that particle size can be controlled.

The present process involves the use of certain improved poisoning agents added to an electroless bath to stop the plating action. These poisoning agents, which are all oxyanions, render the plating catalyst on the substrate ineffective, when used in excess of a critical concentration. Although it was previously known that sulfides and selenides could be added to an electroless plating bath to inhibit the plating action, when these substances are present in a bath they alter the composition of the deposit and may impart undesirable properties thereto. Also, they are difficult, or impossible, to completely remove from the bath, once added, hence the plating bath cannot be satisfactorily regenerated. Another disadvantage of sulfides and selenides as inhibitors is that some of them actually increase the plating rate at some concentrations.

In the present process, the poisoning agents used to stop plating action are the anions: arsenite (AsO_2), nitrite (NO_2), bromate (BrO_3), iodate (IO_3) and nitrate (NO_3). These are added to the plating bath as their alkali metal salts, when it is desired to stop the plating action. The exact amount needed to be added is different for each anion, for each plating bath, for different substrate areas, and even for the same bath composition under varied plating conditions, but the following are examples.

When nickel is the metal being deposited, a typical electroless plating bath may be as follows:

$NiSO_4.6H_2O$	25 g/l
$NaH_2PO_2.H_2O$	25 g/l
$Na_4P_2O_7.10H_2O$	50 g/l

and sufficient NH_4OH to produce an initial pH of 10.5. In these examples, the bath was not agitated during plating. It was maintained at 25°C with a plating time of 10 minutes.

The substrate being plated had a total geometrical surface area of 52 cm^2 with a surface roughness of 40μ in. This area may be in the form of a single slab or fine particles but the method is particularly useful for the latter type of substrate.

Before being immersed in the plating bath, the substrate was sensitized with stannous ion and activated with palladium, in conventional manner.

Where sodium nitrate ($NaNO_3$) was used as the poisoning agent, the minimum amount required was about 8×10^{-2} molar although to make the poisoning action more certain in this instance and in the others which follow, it is preferable to add two or three times the minimum amount. For the other poisoning anions, the minimum molar concentrations were:

$BrO_3 = 5\times10^{-3}$; $NO_2 = 2\times10^{-3}$: $IO_3 = 6\times10^{-6}$; and $AsO_2 = 8\times 9\times10^{-5}$

One of the advantages of using the above listed anions as catalyst poisoners in electroless plating baths is that they can readily be removed from the baths, if desired, by circulating the bath through an ion exchanger, although some of the other anions may also be removed at the same time and these may have to be replenished. In this way, the plating bath may be regenerated after a period in which plating has been halted, thus eliminating wasteful disposal of solutions.

Although the method has been illustrated with a nickel-phosphorus plating bath, it is applicable to deposition of other metals such as nickel-boron, copper and cobalt, and especially those which are used in the recording of magnetic information.

Reprint RE-18-6-13 | Final manuscript received September 28, 1972.

Measurement of thermal conductivity of thin samples


E. Belohoubek


J. Mitchell


F. Wozniak

Microwave Technology Center
RCA Laboratories
Princeton, New Jersey

The thermal conductivity of a material is generally determined by measurement of the temperature difference between two points on a relatively long sample through which a controlled amount of heat flow is passed. In some cases it is important, however, to determine the conductivity of a rather thin sample where interface losses may become dominant. An example is the thermal conductivity of a thin wafer of *BeO* used commonly as a heatsink for various solid state power devices. As such a wafer becomes thinner and thinner, the overall conductivity is determined more by the interface than the bulk conductivity of the material. This short note addresses itself to this problem.

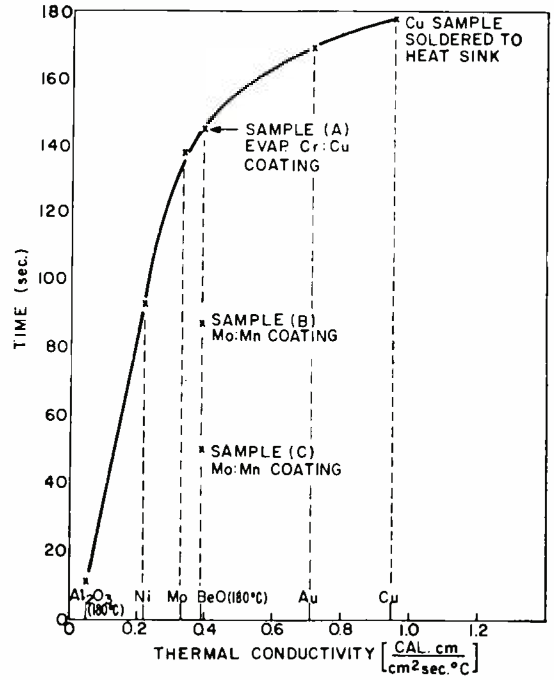


Fig. 1 — Thermal conductivity measurement setup.

Since an absolute measurement of the thermal conductivity of a thin sample is very difficult, a relative extrapolation method was used. Fig. 1 shows a sketch of the measurement setup. The test samples, in our case rectangular wafers (0.060×0.060×0.015 in.), are first soldered to a large heat sink with a high temperature solder such as *Au/Sn* (eutectic temperature 280°C). The other side of the sample is soldered with a lower melting solder such as *Pb/Sn* (eutectic temperature 181°C) to the tip of a heat gun. The tip was shaped to have the same cross-section as the test piece. After cooling the entire assembly to a constant given temperature, for example, by immersion in water at room temperature, a constant heat flow (monitored by the voltage and current of the heat gun) is directed through the sample to the large heatsink. The time elapsed until the sample with the heatsink drops off from the heat gun is a measure of the thermal conductivity of the sample. The higher the conductivity, the better heatsunk the sample/solder-gun interface, and the longer the time before the assembly drops off. This test is repeated with various materials of known conductivity as well as with the one to be measured.

Since this method compares only different materials relative to each other, factors that normally affect the accuracy of absolute measurements such as heat radiation which makes it difficult to determine the actual amount of heat flow, and temperature errors at the measurement points do not enter in this technique. Correct results with good accuracy (±10%) and reproducibility can be obtained provided certain precautions are taken: The assembly must be cooled to the same starting temperature each time; drafts are to be avoided, best by enclosing the setup with a heat shield; the melting point of the *Pb/Sn* joint must be well defined *i.e.*, *Au* coated surfaces must not be used since they would change the eutectic temperature of the solder joint; the heat flow must be kept constant by monitoring the ac power input to the heat gun; the tip of the heat gun must be well shaped and cleaned and any solder flow on the sides of the sample must be avoided by either a stop-off or *Cr* plating.

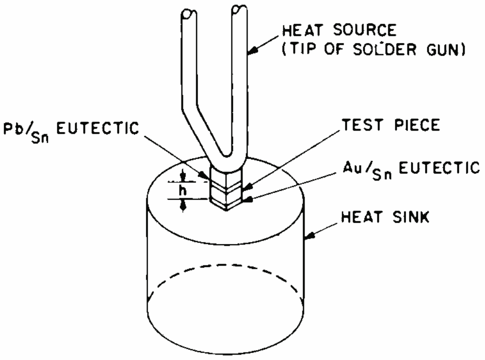


Fig. 2 — Plot of thermal conductivities.

Provided the above precautions are taken, reproducible results can be obtained and a graph as shown in Fig. 2 is derived. Here the time for each test sample is plotted against its known thermal conductivity. The drop off points for various known materials are averaged over a number of tests and a smooth curve is extrapolated through these points. The thermal conductivity of *BeO* with two types of interfaces is also shown. With thin-film *Cr-Cu* evaporated metallization, the measured thermal conductivity agrees closely with the published bulk value of the material at the corresponding temperature of 180°C. With a fired-on *Mo Mn* coating applied to both sides using thick-film techniques, the thermal conductivity of the *BeO* wafer is; however, considerably lower because of the glassy interface at the metallization layer. Two types of samples obtained from different vendors were measured and the averaged results listed as sample B and sample C. The increase in thermal resistance becomes especially pronounced in thin wafers where the glassy interface is a substantial portion of the overall thickness.

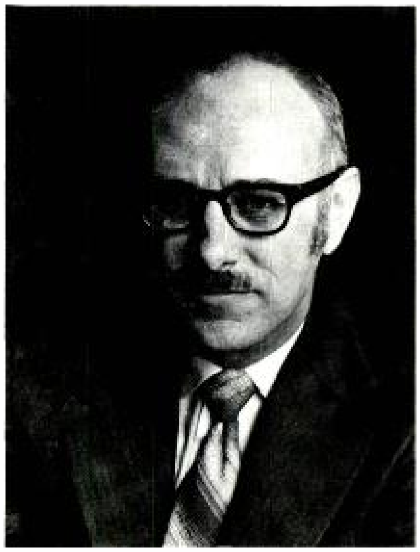
The measurement technique described here should also be suitable for evaluating the interface thermal resistance of braze or solder joints.

Reprint RE-18-6-13| Final manuscript received February 14, 1973.

Engineering News and Highlights

Kennedy

Trevarthan



Underwood

Kennedy named VP of Operations and Engineering, NBC, as Trevarthen Retires

Don Durgin, President, NBC Television Network has appointed **John R. (Jack) Kennedy**, Vice President, Operations and Engineering, NBC.

Mr. Kennedy, who has been with the National Broadcasting Company since 1935, and has recently been serving as Director, Technical Operations, West Coast, moves to NBC's New York offices to assume his new duties. He will report to **Herbert Schlosser**, Executive Vice President, NBC-TV. He will replace **William Trevarthen**, who retired April 1.

Mr. Kennedy began his career in New York in September, 1935, when he was employed as a page. He later moved into the engineering area and became a field engineer in radio. During his early days with the company he served as engineer for the popular national radio broadcasts of the big bands from various New York hotels, and, in 1942, was engineer on Bob Hope radio broadcasts.

He served during World War II as an Air Force radar officer, holding the rank of captain at the time of his discharge in 1946. He then returned to NBC in New York, and attended night classes at Brooklyn Polytechnic Institute, earning an engineering degree in 1950. In the early 50's Mr. Kennedy was heavily involved in the engineering developments during the ransition of broadcasting from radio to elevison.

He was transferred from the New York headquarters to the West Coast offices in 1956, and was promoted to Manager, Technical Operations, West Coast, in July, 1960. He became director of the department in 1968.

Mr. Trevarthen joined NBC in 1938 as a maintenance engineer. During 1942-1943, he was a research associate at Harvard University. In 1943, he returned to the NBC Blue Network as a staff engineer. Subsequently, the Blue Network was sold and became the American Broadcasting Company. Mr. Trevarthen was Vice President of Production Services at ABC when he rejoined NBC in 1959 as Director of TV Network Operations. In 1960, he was elected Vice President of Operations and Engineering at NBC.

Under his direction, NBC-TV emerged as the "Full Color Network" as the number of color hours programmed rose dramatically in the early 1960's until the day in 1966 when NBC-TV became the first network to present its entire schedule—daytime, nightime and weekend—in full color.

Other significant highlights in color broadcasting during Mr. Trevarthen's tenure have been NBC's centralization of its major California facilities in its Burbank complex to facilitate color expansion in 1962; and the formation in 1965 of a committee of its own color experts by NBC under the chairmanship of Mr. Trevarthen, to make available to advertisers, agencies and producers the technical ability and creative expertise of NBC's vast color television experience.

Underwood heads Engineering Education

Frank W. Widmann, Manager, Engineering Professional Programs has announced the appointment of **William J. Underwood** as Manager, Engineering Education. In his new position, Dr. Underwood will be primarily responsible for the continued development of RCA's Continuing Engineering Education Program.

Dr. Underwood brings to his new position a background in both engineering and education. After receiving a BSEE from West Virginia University in 1950, he worked in color tv receiver research at Philco. He joined RCA in 1952 as an engineer recruiter in the newly formed Engineering Personnel function in Camden. From 1954 to 1958, he served as Manager of Employment at Moorestown during MSRD's build-up for the BMEWS Program.

Since 1958, Dr. Underwood has pursued a career in education and training within RCA's Industrial Relations function. His most recent position was Administrator, Training and Applied Behavioral Science at the Corporate Offices in New York. With assistance from RCA's Tuition Loan and Refund Plan and a David Sarnoff Fellowship, he completed a Masters and Doctorate in Educational Psychology at Temple University.

Dr. Underwood holds membership in the American Psychological Association, the NTL Institute of Applied Behavioral Science, the Organization Development Network and the American Society for Training and Development. He has taught at both Drexel University and Temple University and has authored numerous publications in the areas of education and the behavioral sciences.

David Sarnoff Professor of Management dies

Professor **Donald G. Marquis,** M.I.T.'s first David Sarnoff Professor of Management Technology met a sudden and untimely death on Saturday, February 17. Professor Marquis, known and respected by many at RCA, was distinguished in several fields. During the past ten years, he had devoted himself to a better understanding of how to successfully manage research and development. His findings that market needs stimulate innovation has had direct impact upon RCA's technical management. Other ideas fostered by Professor Marquis, such as the entrepreneurship studies by Professor Edward Roberts and the technical communication studies of Professor Thomas Allen, have found a receptive audience at RCA. In recognition of the work which Professor Marquis initiated at M.I.T., RCA endowed professorial chairs at M.I.T. and Harvard and it took little effort for RCA and M.I.T. to agree that Professor Marquis should be the first David Sarnoff Professor of Management Technology.

Prior to joining M.I.T. in 1959, Dr. Marquis was Chairman first of the Department of Psychology at Yale University (1942-45), and then of the Department of Psychology at the University of Michigan (1945-57). During World War II, he served as Executive Secretary of the Army/Navy National Research Council Vision Committee and later was Chairman of the Committee on Human Resources, Research and Development Board of the Department of Defense. He was a member of Phi Beta Kappa, IEEE, the American Psychological Association (President, 1947-48), Sigma Xi, the Society for General Systems Research, the Boston Research Directors Club and the Council of the American Academy of Arts and Sciences.

Professional activities

RCA Laboratories

Dr. David A. deWolf has been elected to full membership in Commission VI (Radio Waves and Transmission Information) of the U.S. National Committee of the United Scientific Radio Union (URSI).

Government and Commercial Systems

S. K. Magee recently received the Distinguished Colleague Award — the highest honor conferred by the Electronic Systems Committee of the Aerospace Industries Association. The award recognizes Mr. Magee's "many years of outstanding national service in the field of Avionics Engineering."

Promotions

Electromagnetic and Aviation Systems Division

A. Gattuso from Data Terminals Principal Member to Mgr. D & D Engineering (H. M. Hite, Data Terminals, Van Nuys)

P. B. Korda from Special Proj. Engrg. Mgr., Elec. D & D Engrg. to Mgr., Electronics Engrg. (F. Corey, Van Nuys)

A. Levy from Special Proj. Engrg. Adm., Producibility Evaluation to Mgr., Design Engrg. (P. Korda, Van Nuys)

Electronic Components

A. E. Hardy from Eng. Ldr. Prod. Dev. to Mgr., Chemical & Physical Labs. (D. D. Van Ormer, Lancaster)

L. C. Reidlinger from Eng., Prod. Dev. to Eng. Ldr., Prod. Dev. (A. E. Hardy, Lancaster)

M. R. Royce from Sr. Eng. Prod. Dev. to Eng. Ldr. Prod. Dev. (A. E. Hardy, Lancaster)

Solid State Division

L. French from Ldr., Tech. Staff to Mgr., Design Automation, Technology Center (G. B. Herzog, Somerville)

D. Jacobson from Ldr., Tech. Staff To Mgr., Design Engrg., Solid State Power Operations (N. C. Turner, Somerville)

W. Lawrence from Ldr., Tech. Staff to Mgr., Pilot Production, Liquid Crystal Engrg. Dept. (P. L. Farina, Somerville)

C. Leuthauser from Mbr., Tech Staff to Ldr., Tech. Staff, Solid State Power Operations (H. C. Lee, Somerville)

R. Minto from Mbr., Tech. Staff to Ldr., Tech. Staff, Solid State Power Operations (D. Jacobson, Somerville)

H. Schindler from Sr. Mbr., Tech Staff to Ldr., Tech Staff, Liquid Crystal Engrg. Dept. (P. L. Farina, Somerville)

Consumer Electronics

W. Bietz from Quality Assurance Engr. to Mgr., Reliability Analysis Lab. (D. E. Peyton, Rockville)

A. J. Bisti from Sr. Mbr., Engrg. Staff to Ldr., Engrg Staff (J. A. McDonald, Indianapolis)

C. D. Boltz from Mbr., Engrg. Staff to Ldr., Engrg. Staff (J. A. McDonald, Indianapolis)

B. L. Borman from Mbr., Engrg Staff to Ldr., Engrg. Staff (H. R. Warren, Indianapolis)

T. J. Christopher from Mbr., Engrg. Staff to Ldr., Engrg. Staff (J. A. McDonald, Indianapolis)

B. L. Dickens from Sr. Mbr., Engrg. Staff to Ldr. Engrg. Staff (H. R. Warren, Indianapolis)

R. Graham from Ldr., Liaison Engrg. to Mgr., Procured Prod. Engrg. (R. Flood, Rockveille)

I. Indiano from Ldr., Engrg. Staff to Mgr., Mech. Design (R. Flood, Rockville)

M. E. Miller from Mbr., Engrg. Staff to Ldr., Engrg. Staff (J. A. McDonald, Indianapolis)

W. C. Roberts from Sr. Mbr., Engrg. Staff to Ldr., Engrg. Staff (H. R. Warren)

J. J. Serafini from Mbr., Engrg. Staff to Ldr., Engrg. Staff (H. R. Warren, Indianapolis)

J. Shelby from Assoc. Mbr., Eng. Staff to Ldr., Eng. Staff (W. Liederbach, Rockville)

F. R. Stave from Mbr., Engrg. Staff to Ldr., Engrg. Staff (J. A. McDonald, Indianapolis)

R. Steitz from Mbr., Engrg. Staff to Mgr., Semiconductor Mfg. (S. Dolen, Rockville)

J. H. Wharton from Sr. Mbr., Engrg. Staff to Ldr., Engrg. Staff (R. K. Lockhart, Indianapolis

RCA Global Communications, Inc.

O. T. Rhyne from Engr. to Mgr., Engrg. Adm. (G. P. Roberts, Anchorage)

R. Shaver from Engr. to Group Ldr. (L. Correard, Computer Switching Engrg., New York)

A. Tonkoschkur from Engr. to Group Ldr. (L. Correard, Computer Switching Engrg., New York)

Staff Announcements

RCA Corporation

Robert L. Werner, RCA Executive Vice President and General Counsel has announced the election of **Eugene E. Beyer,** Jr., as Vice President and General Attorney.

Executive Vice President and General Counsel

Eugene E. Beyer, Jr., Vice President and General Attorney, has announced the following organization: **John D. Hill,** Staff Vice President and Trade Regulation Counsel; **Ray B. Houston,** Staff Vice President and General Attorney, Commercial, Government Products, and Staff Activities; **Wilber A. Osterling,** Staff Vice President and General Attorney, Consumer Products, Components and Services; **John H. Bermingham,** Counsel, Corporate Affairs; **Kevin McInerney,** Tax Counsel; and **Sidney K. Nadelson,** Senior Counsel, International.

Marketing

James J. Johnson, Vice President, Marketing, has announced the SelectaVision Program as follows: **John F. Biewener,** Staff Vice President, Business Planning and Control — SelectaVision Program; **Patrick S. Freely,** Manager, Business Planning and Control — SelectaVision Program; **Donald P. Dickson,** Staff Vice President, Programming Distribution — SelectaVision Program; and **Thomas J. McDermott,** Staff Staff Vice President, Programming Acquisition — SelectaVision Program.

Laboratories

William M. Webster, Vice President, Laboratories, has announced the following organization: **George D. Cody,** Director, Physical Electronics Research Laboratory; **Nathan L. Gordon,** Director, Systems Research Laboratory; **Gerald B. Herzog,** Director, Solid State Technology Center; **Charles A. Hurford,** Manager, Industrial Relations; **Jerome Kurshan,** Manager, Administrative Services, **Kerns H. Powers,** Director, Communications Research Laboratory; **Richard E. Quinn,** Director, Finance and Technical Services; **Jan A. Rajchman,** Staff Vice President, Information Sciences; **Paul Rappaport,** Director, Process and Applied Materials Reserach Laboratory; **Thomas O. Stanley,** Staff Vice President, Research Programs; **Fred Sterzer,** Director, Microwave Technology Center; and **James J. Tietjen,** Director, Materials Research Laboratory.

Jerome Kurshan, Manager, Administrative Services has announced the following organization: **Paul Brown, Jr.,** Manager, Technical Relations; **Charles C. Foster,** Manager, Scientific Publications; **Eric M. James,** Manager, Facilities, and **Carl E. Kurlander,** Manager, Materials.

Richard E. Quinn, Director, Finance and Technical Services has announced the following organization: **Vincent M. Bartholomew,** Manager, Graphics Services; **Ralph H. Myers,** Manager, Finance; **Matthew Pfeiffer,** Manager, Model Shop, and **Raymond G. Shankweiler,** Manager, Engineering Services.

Thomas O. Stanley, Staff Vice President, Research Programs has announced the organization as follows: **Robert C. Duncan,** Administrator, Research Staff Services; **Emil V. Fitzke,** Administrator, Research Staff Services; **Craig Havemeyer,** Manager, Management Information Systems; **George C. Hennessy,** Manager, Marketing; **Al Pinsky,** Administrator, Scientific Information Services; and **Thomas J. Wheeler,** Manager, Market Development.

William M. Webster, Vice President Laboratories announced the following reassignment of the various research groups that now constitute the Consumer Electronics Research Laboratory:

The TV Systems Research group, **Jay J. Brandinger,** Head, will transfer to the Systems Research Laboratory. Dr. **Brandinger** will report to **Nathan L. Gordon**, Director of that laboratory.

The High-Density Recording Project group, **H. Nelson Crooks,** Manager; and the Video-Systems Research group, **Eugene O. Keizer,** Head; will transfer to the Process and Applied Materials Research Laboratory. Messrs. Crooks and Keizer will report to **Paul Rappaport,** Director of that laboratory, who will assume responsibility for the "SelectaVision" Video Disc project at the Laboratories.

The Electro-Optic Systems Research group, **Charles B. Oakley,** Head, will transfer to the Communications Research Laaboratory. Mr. Oakley will report to **Dr. Kerns H. Powers,** Director of that laboratory.

The Displays and Device Concepts Research group, **John A. vanRaalte,** Head, will transfer to the Materials Research Laboratory. Dr. vanRaalte will report to **Dr. James J. Tietjen,** Director of that laboratory.

Paul Rappaport, Director, Process and Applied Materials Research Laboratory has announced the organization as follows: **Glenn W. Cullen** continues as Head, Materials Synthesis Research; **Chih Chun Wang** is appointed Fellow, Technical Staff; **Leonard P. Fox** is appointed Head, SelectaVision Processing Research; **Richard E. Honig** continues as Head, Materials Characterization Research; **D. Alex Ross** continues as Manager, Division Liaison; **Daniel L. Ross** is appointed Head, Organic Materials and Devices Research; **George L. Schnable** continues as Head, Process Research; **Charles W. Mueller** continues as Fellow, Technical Staff and **Karl H. Zaininger** continues as Head, Solid State Device Technology.

William M. Webster, Vice President, RCA Laboratories, has announced the appointments of **Leonard P. Fox, S. Yegna Narayan,** and **Daniel L. Ross** as Research Group Heads.

Engineering

Howard Rosenthal, Staff Vice President, Engineering has announced the organization of Engineering as follows: **Arnold S. Farber,** Staff Engineer; **Kenneth H. Fischbeck,** Staff Technical Advisor; **Russell G. Groshans,** Staff Engineer; **Edwin M. Hinsdale,** Staff Engineer; **Doris E. Hutchison,** Administrator, Staff Services; **Harry Kleinberg,** Manager, Corporate Standards Engineering; **Eric M. Leyton,** Staff Engineer; **Arthur Sherman,** Staff Engineer; **Raymond E. Simonds,** Director, RCA Frequency Bureau; and **Frank W. Widmann,** Manager, Engineering Professional Programs.

Engineering Professional Programs

Frank W. Widmann, Manager, has announced the organization of Engineering Professional Programs as follows: **W. O. Hadlock,** Manager, Technical Communications; **Edgerton R. Jennings,** Manager, Technical Information Services, and **William J. Underwood,** Manager, Engineering Education.

RCA Records

Rocco M. Laginestra, President, RCA Records has announced the appointment of **Donald S. McCoy** as Acting Manager, SelectaVision Video-Disc Engineering.

Government and Commercial Systems

David Shore, Division Vice President, Government Plans and Systems Development has announced the appointment of **Roger L. Boyell** as Manager, Systems Engineering.

Communications Systems Division

James M. Osborne, Division Vice President, RCA Government Communications Systems has announced the appointment of **David T. Gross** as Manager, Sanguine Program.

Aerospace Systems Division

Stanley S. Kolodkin, Division Vice President and General Manager, has announced the following appointments: **Duane M. Belden** as Plant Manager for Aerospace Systems Division and **Eugene B. Galton** as Director, Marketing.

Electromagnetic and Aviation Systems Division

F. H. Krantz. Division Vice President and General Manager, has announced the appointment of **Henry W. Gauger** as Plant Manager.

Solid State Division

Daniel P. Del Frate, Division Vice President, Marketing has announced the appointment of **Dale W. Ludlum** as Manager, Advertising, Solid State Division.

Carl R. Turner, Manager, Power Transistors has announced the promotion of **George S. Scholes** and **Paul R. Thomas** to Marketing Managers in the Power Transistors organization; **Hon C. Lee,** Manager, Market Planning and Applications Engineering; and **David S. Jacobson,** Manager, RF and Microwave Devices Design.

Consumer Electronics

William C. Hittinger, Executive Vice President, Consumer and Solid State Electronics has announced the Consumer Electronics organization as follows: **Marvin H. Glauberman** as Division Vice President, Audio Products Division and **Donald S. McCoy** as Division Vice President, Development Engineering. Mr. Hittinger has also announced the appointment of **Roy H. Pollack** as Division Vice President, Black and White Television Division.

Electronic Components

Joseph H. Colgrove, Division Vice President and General Manager, Entertainment Tube Division has announced the following appointments: **William G. Hartzell,** Division Vice President, Engineering and **Charles W.** Thierfelder, Division Vice President, Manufacturing.

Awards

Aerospace Systems Division

Ed Wirtz was selected as the engineer of the month for March 1973 for his work on the design and field demonstrations of the Bowling Pin Automatic Sensing System.

The team of **Douglas O. Blake, George B. Dodson, Howard E. Fineman, Charles H. Franks, Richard E. Hanson, Lawrence M. Hill, L. Robin Hull, Barry W. Jackson, Angelo Muzi,** and **Steven M. Schlosser,** from Vehicle Test Systems at ASD received the team technical excellence award for March 1973. The award recognizes the team's performance and achievements on two programs with the U.S. Army Tank-Automotive Command (TACOM) for the development of various types of Built-In Test Equipment (BITE) for Army vehicles. The multiple phases of the two contracts involved the concept, development, and feasibility evaluation of various configurations of vehicle BITE.

Communications Systems Division

Henry I. Hillman of Digital Communications Equipment, Government Communications Systems, has received a Technical Excellence Award for his long term and continuing work in the development of computer assisted test generation for digital integrated circuits. His efforts have resulted in computer programs which allow an engineer to generate a comprehensive test sequence at a reasonable cost.

Electromagnetic and Aviation Systems Division

Donald G. Kelling has received a professional excellence performance individual award for his efforts on the Automatic Tuning Techniques Program. The Automatic Tuning Technique (ATT) Program required state-of-the-art design and tight schedule delivery of a set-on receiver using a microsonic dispersive delay line as the frequency determining element.

Frank Sayano, Principal Member, Advanced Systems, received a professional excellence performance individual award for his outstanding technical contributions to the Maxi-Decoy Program. The Maxi-Decoy Program encountered many diverse and complex technical problems including the determination of valid effectiveness criteria, equipment modeling, and extensive computer programming difficulties.

A professional excellence performance team award has been given to the Automatic Bowling Scoring System (ABSS) Design and Development Team led by **Joseph B. Fischer,** Manager, Cus-

Left to right: F.C. Corey, Chief Engineer, congratulates EASD award winner D. G. Kelling; E. A. Cornwall, Mgr., EW Engineering and R. D. Posner, Mgr., Solid State Microwave add their congratulations.

Left to right: F. C. Corey, Chief Engineer, and EASD award winner K. F. Sayano; W. E. Hatfield, Mgr., Army & AF EW Systems and D. K. Gilbertson, Mgr., Advanced Systems add their congratulations.

EASD Team award winners (left to right): K. D. Gaspar, E. R. Hibbert, F. C. Corey (Chief Engineer), E. P. Hense, J. B. Fischer, S. W. Stoddard (rear), M. R. Schmidth, R. A. Ito, R. D. Law, W. L. Ross, M. Stolz, H. M. Hite (Mgr., Data Terminals). A. J. Freed and E. Wirtz were not available for the photo.

tom Data Terminals and **Arthur J. Freed**, Manager, Custom Terminal Products. The team members are **K. C. Gaspar, E. P. Hense, E. R. Hibbert, R. A. Ito, R. D. Law, W. L. Ross, M. R. Schmidt, S. W. Stoddard, M. Stolz** and **E. Wirtz** (ASD Burlington). In a ten month period ending October 1972, this team designed, implemented, checked out, and successfully tested the ABSS prototype. This technically challenging job was completed on time and under budget despite very tight schedule and budget constraints.

RCA Laboratories

Sixty-one scientists on the staff of RCA's David Sarnoff Research Center in Princeton have received RCA Laboratories Achievement Awards for outstanding contributions to electronics research and engineering during 1972.

Recipients of the awards and brief descriptions of the work for which they were honored are:

Vladimir S. Ban, "for fundamental studies leading to an improved understanding of the reactions occurring curing the vapor growth of III-V compounds."

Alvin S. Clorfeine, "for continuing development of the theory and circuit techniques for Trapatt diodes."

Roger L. Crane, "for innovations in the analysis of motion-induced noise in towed underwater antennas."

Nathan Feldstein, "for improvements in color-tube mask fabrication."

John G.N. Henderson, 'for research leading to improved television i.f. filters."

Karl G. Hernqvist, "for contributions to the development of the RCA gas laser product line."

Gerald S. Lozier, "for ingenuity and diligence in the solution of color-kinescope fabrication problems."

Richard A. Sunshine, "for contributions to an improved understanding of failure mechanisms in silicon p-n junctions."

Taylor Warren, "for contributions to software systems."

William H. Barkow, Josef Gross, George W. Heisserman, and **John W. Mirsch**, "for a team effort in research and development leading to a self-converging toroidal yoke."

Harold Blatter, Billy W. Beyers, and **Lawrence D. Ryan**, "for a team effort leading to a unique interactive video-display device employing digital and television techniques."

James E. Carnes, and **Michael G. Kovac**, "for a team effort in advancing the theory and technology of charge-coupled devices."

John D. Cavett, Ralph DeStephanis, Denis P. Dorsey, Edward C. Douglas, Robert S. Hopkins, and **Williams E. Rodda**, "for a team effort in the research and development that led to the RCA Videovoice system."

Kern K.N. Chang, Shing-Gong Liu, H. Kawamoto, James F. Reynolds, Virgil Lawson, H. John Prager, John J. Risko, and **Arye Rosen**, "for a team effort in the development of S-band Trapatt amplifiers."

Louis S. **Cosentino, Reuben Mezrich, Eugene M. Nagle. Wilber** C. **Stewart**, and **Frank S. Wendt**, "for a team effort in developing a read/write holographic memory

P. Anthony Crossley, and **William E. Ham**, "for a team effort in establishing process-control techniques for silicon on sapphire."

Ronald E. Enstrom, S. Yegna Narayan, John P. Paczowksi, Ross Stander, and **Thomas E. Walsh**, "for a team effort in developing a new gallium arsenide varactor UHF television tuner."

Bernard Goldstein, Jules D. Levine, and **Ramon U. Martinelli**, "for a team effort in the perfection of the negative-electron-affinity effect in silicon and a theoretical and experimental investigation into the mode of the surface-activation process."

Joseph J. Hanak, Hans W. Lehmann, and **Roland Widmer**, "for a team effort in improving methods of preparing composite materials for acousto-electric applications."

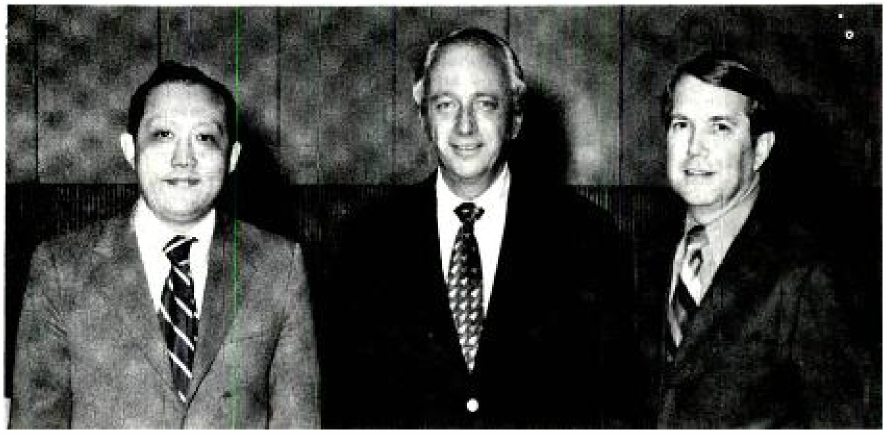
Alfred C. Ipri and **John C. Sarace**, "for a team effort in demonstrating the advantages of silicon on sapphire in ultra-low-voltage, low-power, high-speed counter circuits."

Roger E. Miller, and **George W. Webb**, "for a team effort in discovering superconductivity above twenty degrees kelvin in niobium-gallium."

William Phillips, and **David L. Staebler**, "for a team effort in research leading to improved materials and techniques for electro-optic holographic storage"

Richard H. Roth, and **Allen H. Simon**, "for a team effort in the design, implementation, and performance analysis of a sophisticated general-purpose time-sharing system oriented for the research community."

Richard Williams, Alfred H. Willis, and **Murray H. Woods**, "for a team effort in research leading to a better understanding of internal photoemission in silicon/silicon dioxide interface and its correlation with device failure mechanisms."



Dr. Chih-Chun Wang (left) and Dr. Roger L. Crane (right) have been named Fellows of the Technical Staff of RCA Laboratories by Dr. William M. Webster (center), Vice President, RCA Laboratories, in Princeton, N.J.

Crane and Wang named RCA Laboratories Fellows

Dr. Roger L. Crane and **Dr. Chih-Chun Wang** have been named Fellows of the Technical Staff of RCA Laboratories in Princeton, N. J. In naming the new Fellows, **Dr. William M. Webster**, Vice President, RCA Laboratories, said the Fellow designation is comparable to the same title used in universities and technical societies. It is given by RCA in recognition of a record of sustained technical contributions in the past and in anticipation of continued technical contributions.

Dr. Crane has done noteworthy work in numerical analysis and mathematical modeling, and in the use of digital computers for solving scientific problems, while Dr. Wang has made a number of significant contributions to the study and synthesis of materials used in electronic devices.

Dr. Crane was Class Valedictorian when he received the BSEE from Iowa State University in 1956. After working for the Univac Division of Sperry Rand for three years, he returned to Iowa State and was awarded the MS and PhD in Mathematics in 1961 and 1962, respectively. He joined RCA Laboratories in 1963. His mathematical analyses have contributed to the design of a number of new RCA products as well as to the improvement of existing ones. He has also developed design techniques employed by RCA product divisions. Dr. Crane has received four RCA Laboratories Outstanding Achievement Awards. The latest is for "innovations in the analysis of motion-induced noise in towed underwater antennas." He has published numerous technical papers. He is a member of the IEEE, the Society for Industrial and Applied Mathematics, the Association for Computing Machinery, and several honor societies, including Sigma Xi, Tau Beta Pi, Eta Kappa Nu, Pi Mu Epsilon, and Phi Kappa Phi.

Dr. Wang received the BSCE in 1955 from the National Taiwan University. After working as an assistant engineer at the Taiwan Alkali Co. from 1956 to 1958, he received the MS in Physical Chemistry from Kansas State University in 1959 and the PhD in Physical Chemistry from Colorado State University in 1962. From 1962 to 1963, he received post-doctoral training in Physical Chemistry at the University of Kansas. Dr. Wang joined RCA Laboratories in 1963. He has developed new growth methods and fabrication techniques for a variety of important electronic material systems, including bulk single crystals, thin films and epitaxial composites. The successful development of these material systems has led to the realization and/or improvement of devices in the integrated circuit, microwave and electro-optics fields. Dr. Wang has received three RCA Laboratories Outstanding Achievement Awards. The latest was for: "advances made in the synthesis of lead oxide photoconductive thin films" used in tv camera tubes for live colorcasts. He has published 28 technical papers and has received 4 U.S. Patents. Dr. Wang is a member of the American Chemical Society, Electrochemical Society, Sigma Xi, Sigma Pi Sigma, and Phi Lambda Upsilon. He is listed in *American Men of Science*, *Leading Men in the United States of America*, *Who's Who in the East*, and *International Biography of Contemporary Achievement*.

Bille is Ed Rep for Broadcast

Andrew C. Billie has been appointed Editoral Representative for the Broadcast Engineering group at Meadow Lands, Pa. In this capacity, Mr. Billie is responsible for planning and processing articles for the *RCA Engineer* and for supporting the corporate-wide technical papers and reports program.

In addition to his Editorial Representative responsibilities, Mr. Billie is Leader of the Broadcast Technical Publications Group for the Broadcast Transmitter/Aural Engineering Section at the Meadow Lands Facility of the Communication Systems Division. In this capacity, he is responsible for the Television Broadcast Transmitter and Aural Engineering Technical Publications. Mr. Billie joined RCA in 1966 as a Senior Technical Writer for the Television Broadcast Transmitter product line.

Prior to joining RCA, Mr. Billie served five years with the Martin-Marietta Company in Baltimore, Md. on the Titan (OSTF/1) Missile Logistics Program as an Engineering Writer and one year with Vitro Laboratories in Silver Spring, Md. where he was Project Supervisor of the ASW (Anti-Submarine Warfare) Technical Writing Group. Mr. Billie received the AAS in Electronic Technology from DeVry Technical Institute in 1960 and has attended West Virginia University, John Hopkins University, and Washington & Jefferson College in Washington, Pa. He is a candidate for graduation in 1973 for a Bachelors Degree in Mathematics. In addition, he has taken graduate work at Washington & Jefferson.

S. N. Lev retires

S. N. Lev, Division Vice President, Manufacturing, for the RCA Government and Commercial Systems organization, retired recently after a 39-year career with RCA.

Mr. Lev prepared for RCA employment at the University of Pennsylvania where in 1931 he earned the BSEE. A year later he received the MSEE under a Moore School of Electrical Engineering fellowship at Penn.

After his initial two years as a tester, Mr. Lev was assigned to handle the test process and the design of test equipment for the first 100 RCA television receivers built for field experiments in New York.

By 1941 Mr. Lev had become Supervisor of the old RCA Manufacturing Division Laboratory in Camden. He moved on to Manager of tests and inspections of the proximity fuse project during World War II.

After the war Mr. Lev was made Camden Plant Manager for the RCA Victor Division's Home Instruments Department with responsibility for setting up the first facility for mass production of tv receivers. His success in this assignment was signalled in 1948 when he received the RCA Victor Award of Merit.

In the fifties Mr. Lev held several manufacturing posts in RCA's commercial product and defense organizations. These led to his promotion in 1960 to Division Vice President and General Manager of the Missile and Surface Radar Division in Moorestown. Two years later he was appointed Division Vice President, Manufacturing, for the former Defense Electronic Products organization. After only three years he again was called on to serve as a General Manager, this time with responsibility for the West Coast Division in Van Nuys, Ca.

Mr. Lev then headed the former Defense Communications Systems Division in Camden for a two-year period before returning to his staff position with manufacturing responsibility for the five G&CS divisions.

Licensed engineers

When you receive a professional license, send your name, PE number (and state in which registered), RCA division, location and telephone number to: *RCA Engineer*, Bldg. 204-2, RCA, Cherry Hill, N.J. As new inputs are received, they will be published

Global Communications, Inc.

S. L. Latargia, Globcom, N.Y. PE048947; New York

Government and Commercial Systems

Jack H. Wolff, G&CS, Camden, N.J. PE19920; New Jersey.

Degrees granted

Michael DeVito, EC, Harrison	MS, Mgmt, Neward College of Engineering; 5/73
Bryan Dornan, EC, Harrison	BSEE, Newark College of Engineering; 5/73
Wesley C. Henry, MSRD, Moorestown	BS, Business Adm., LaSalle College; 5/73

RCA Review, March 1973

Volume 34, Number 1

Contents

The *RCA Review* is published quarterly. Copies are available in all RCA libraries. Subscription rates are as follows (rates are discounted 20% for RCA employees)

	DOMESTIC	FOREIGN
1-year	$6.00	$6.40
2-year	10.50	11.30
3-year	13.50	14.70

As an industry leader, RCA must be well represented in major professional conferences . . . to display its skills and abilities to both commercial and government interests.

How can you and your manager, leader, or chief-engineer do this for RCA?

Plan ahead! Watch these columns every issue for advance notices of upcoming meetings and "calls for papers". Formulate plans at staff meetings—and select pertinent topics to represent you and your group professionally. Every engineer and scientist is urged to scan these columns; call attention of important meetings to your Technical Publications Administrator (TPA) or your manager. Always work closely with your TPA who can help with scheduling and supplement contacts between engineers and professional societies. Inform your TPA whenever you present or publish a paper. These professional accomplishments will be cited in the "Pen and Podium" section of the *RCA Engineer*, as reported by your TPA.

Dates of upcoming meetings—plan ahead.

Ed. Note: Meetings are listed chronologically. Listed after the meeting title (in italic type) are the sponsor(s), the location, and the person to contact for more information.

JULY 9/27, 1973	*Science and the Unfolding of Technology* — IEEE Mexico Section, AAS, Conacyt, Mexico City, Mexico. *Prog info:* Bruno DeVecchi, Martin Mendalde No. 1054, Mexico City 12, Mexico.
JULY 10/12, 1973	*Video & Data Recording Conference* — IERE, IEEE UKRI Section *et al*, Univ. of Birmingham, Birmingham, England. *Prog info:* IERE, 8-9 Bedford Square London W.C. 1 B 3RG England.
JULY 10/12, 1973	*Joint Space Mission, Planning and Execution Meeting* — AIAA, ASME, and SAE, Stauffer's Denver Inn, Denver, Colorado. *Prog info:* Maurice Jones, Manager, Information Services, ASME, United Engineering Center, 345 E. 47th., New York, NY 10017.
JULY 10/12, 1973	*Space Mission Planning and Execution Meeting* — AIAA, ASME, SAE, Brown Palace Hotel, Denver, Colorado. *Prog info:* Paul Drummond, Manager Conferences and Divisions, ASME, 345 East 47th St., New York, NY 10017.
JULY 15/20, 1973	*IEEE Power Engineering Society Summer Meeting & EHV/UHV Conference* — S-PE, Vancouver Hotel, Vancouver, B.C. Canada. *Prog info:* D. G. McFarlane, British Columbia Hydro & Pwr. Auth., 970 Burrard St., Vancouver 1 B C. Canada.
JULY 16/19, 1973	*Intersociety Conference on Environmental Systems* — SAE, ASME, AIAA, AIChE, Hilton Inn, San Diego, CA. *Prog info:* Maurice Jones, Manager Information, 345 E. 47th Street, New York, NY 10017.
JULY 15/20, 1973	*Summer Meeting of the Power Engineering Society* — IEEE, City of Vancouver, British Columbia, Canada. *Prog info:* D. J. Turland, Publicity Chairman, IEEE Summer Meeting 1973, Box 2189, Vancouver 3, B.C.
JULY 18/20, 1973	*Acoustical Holography and Imaging International Symposium* — G-SU, Stanford Res. Inst., ASA, Rickeys Hyatt House, Palo Alto, Calif. *Prog info:* P. S. Green, Stanford Res. Inst., Menlo Park, Calif. 94025
JULY 23/26, 1973	*Nuclear & Space Radiation Effects Conference* — S-NAPS, USAF, DNA, USAEC, Utah State Univ., Logan, Utah. *Prog info:* D. K. Myers, Fairchild Semiconductor, 545 Whisman Rd., Mountain View, Calif. 94040.
AUG. 12/17, 1973	*Intersociety Energy Conversion Engineering Conference* — G-ED, S-AES, AIAA, et al, Univ. of Penna., Phila., Penna. *Prog info:* Dan Mager, POB 443, Lexington, Mass. 02173.
AUG. 14/16, 1973	*Microwave Semiconductor Devices, Circuits and Applications* — The Office of Naval Res. and IEEE (G-CT, G-ED, G-MT&T) Ithaca Section, Cornell University, Ithaca, New York *Prog info:* Herbert J. Carlin, School of Electrical Engineering, Phillips Hall, Cornell University, Ithaca, New York 14850.
AUG. 13/17, 1973	*8th Intersociety Energy Conversion Engineering Conference* — AIAA, ACS, AIChE, ANS, ASME, IEEE and SAE, University of Pennsylvania, Philadelphia, PA. *Prog info:* Maurice Jones, Manager Information, 345 E. 47th Street, New York, NY 10017.
AUG. 22/24, 1973	*Product Liability Prevention Conference* — G-R et al, Newark College of Engineering, Newark, NJ. *Prog info:* IEEE, 345 E. 47th St., New York, NY 10017.
AUG. 27/30, 1973	*Electrical Signals from the Brain* — IEE, IEEE UKRI Section, EEG Soc., Univ. of Oxford, Oxford England. *Prog info:* IEE, Savoy Place, London W.C. 2R OBL, England
SEPT. 9/12, 1973	*Fall Meeting of the American Ceramic Society, Elec. Div.* — Sheraton-Biltmore, Atlanta, GA. *Prog info:* Dr. David L. Wilcox, Program Chairman, IBM Corporation, Dept. K16, Bldg. 282, Monterey & Cottle Roads, San Jose, CA 95193 and Dr. Richard M. Rosenberg, Assistant Program Chairman, E.I. duPont de Nemours & Co., Inc., Electronic Products Div., Wilmington, DE 19898.
SEPT. 10/12, 1973	*The Fifth International Congress on Instrumentation in Aerospace Simulation Facilities* — IEEE, California Institute of Technology, Main Campus, Pasadena, CA. *Prog info:* Mr H. F. Swift, Head, Materials Physics Research, University of Dayton Research Institute, Dayton, OH 45469.
SEPT. 10/12, 1973	*Petroleum & Chemical Industry Technical Conf.* — S-IA, Regency Hyatt Hotel, Houston, TX. *Prog info:* R. H. Cunningham, Atlantic Richfield Co., POB 2451, Houston, TX 77001.
SEPT. 10/12, 1973	*Int'l Congress on Instrumentation in Aerospace Simulation Facil.* — S-AES, Calif. Inst. of Tech., Pasadena, Calif. *Prog info:* H. F. Swift, Univ of Dayton Res. Inst., Dayton, OH 45469.
SEPT. 11/14, 1973	*Western Electronic Show & Convention (WESCON)* — Region 6, WEMA, Civic Audt., & Brooks Hall, San Francisco, CA. *Prog info:* WESCON, 3600 Wilshire Blvd., Los Angeles, CA 90010.
SEPT. 16/20, 1973	*Jt. Power Generation Technical Conference* — S-PE, ASME, Marriott Hotel, New Orleans, LA. *Prog info:* L. C. Grundmann, Jr., New Orleans Public Svc., Inc., 317 Baronne St., New Orleans, LA 70160.
SEPT. 18/19, 1973	*Modulator Symposium* — G-ED, U. S. Army, United Engrg Ctr., New York, NY. *Prog info:* S. Schneider, USAEC, Fort Monmouth, NJ 07703.
SEPT. 19/22, 1973	*Fall Meeting of the American Ceramic Society, Structural Clay Prod. Div.* — TraveLodge at 6th South, Salt Lake City, Utah. *Prog info:* The American Ceramic Society, Inc., 65 Ceramic Drive, Columbus, OH 43214.
SEPT. 23/26, 1973	*Fall Meeting of the American Ceramic Society, Basic Science and Ceramic-Metal Systems Div.* — William Penn Hotel, Pittsburgh, PA. *Prog info:* The American Ceramic Society, Inc., 65 Ceramic Drive, Columbus, OH 43214.
SEPT. 24/27, 1973	*Intersociety Conference on Transportation* — ASME, Brown Palace Hotel, Denver, Colorado. *Prog info:* Ms. Marion Churchill, Manager, Conferences and Divisions, ASME, 345 E. 47th St., New York, NY 10017.
SEPT. 26/29, 1973	*Fall Meeting of the American Ceramic Society, Mateials & Equipment & White Wares Divs.* — Bedford Springs Hotel, Bedford, PA *Prog info:* The American Ceramic Society, Inc., 65 Ceramic Drive, Columbus, OH 43214.
SEPT. 25/28, 1973	*Automatic Control in Glass* — IFAC, Purdue University, West Lafayette, Indiana. *Prog info:* Purdue University, Div. of Conf. and Continuation Svcs., West Lafayette, IN 47907.

Calls for papers—be sure deadlines are met.

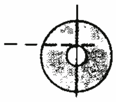
Ed. note: Calls are listed chronologically by meeting date. Listed after the meeting title (in italic type) are the sponsor(s), the location, and the deadline information for submittals.

APR. 21/25, 1974	*Int'l Circuits & Systems Theory Symposium* — S-CAS, *et al* Sir Francis Drake Hotel, San Francisco, Calif. *Deadline info:* (ms) 10/15/73 *to* L. O. Chua, Dept. of EE, Univ. of Calif., Berkeley, Calif. 94720.
APR. 22/26, 1974	*1974 European Conference on Electrotechnics (EUROCON)* — IEEE, Reg. 8 and Convention of Nat'l. Soc. of Engrs. in Western Europe, Amsterdam, The Netherlands. *Deadline info:* (abst) 10/15/73 300-500 word threefold *to* EUROCON '74 Office, Local Secretary: Ing. G. Gaikhorst, c/o F.M.E., Nassaulaan 13, the Haugue, the Netherlands.
MAY 5/8, 1974	*Offshore Technology Conference* — TAB Oceanography coor Comm., *et al*, Astrohall, Houston, Texas. *Deadline info:* (abst) 9/1073 *to* J. A. Klotz, Union Oil Co., Box 76, Brea, Cal. 92621
MAY 20/23, 1974	*1974 International Symposium on Subscriber Loops and Services* — Comm. Soc. of the IEEE Can. Dept. of Comm. & Bell-Northern Res., Ottawa, Canada. *Deadline info:* (abst) 7/1/73 (papers) 12/15/73 *to* General Chairman: Mr. Alex Curran, Bell-Northern Research, P. O. Box 3511, Station C, Ottawa, Canada.
JUNE 1974	*Special Issue on Microwave Control Devices for Array Antenna Systems — G-MTT Transactions. Deadline info:* (papers) triplicate 9/1/73 *to* Dr. L. R. Whicker, Code 5250, Naval Research Laboratory, Washington, DC 20390.
JULY 14/19, 1974	*IEEE Power Engineering Society Summer Meeting* — S-PE, Disneyland Hotel, Anaheim Conv. Ctr., Anaheim, Calif. *Deadline info:* (ms) 2/1/74 *to* S. H. Gold, Southern Calif. Edison Co., POB 800, Rosemead, Calif. 91770.
JULY 15/19, 1974	*Frontiers in Education* — IEEE, IEEE G-Ed, IEEE United Kingdom and Rep. of Ireland Sect., IEE Ed. and Management Div., ASEE-Ed. Res. & Methods Div. City University, London, England. *Deadline info:* (papers) 10/5/73 (250-word syn) *to* 1974 Frontiers in Education Secretariat, c/o The Conference Department, The Institution of Electrical Engineers, Savoy Place, London, England WC2R OBL and Lindon E. Saline, Manager, Corporate Education Services, General Electric Company, Crotonville, PO Box 151, Ossining, NY 10562 USA.
SEPT. *18/19, 1973*	*Eleventh Modulator Symposium* — IEEE, G-ED, Belmont Plaza Hotel, Lexington Avenue & 49th Street, New York, NY *Deadline info:* 6/22/73 (abst) original and 10 copies *to* Program Chairman, Sol Schneider, Electronics Technology and Devices Laboratory (ECOM), Ft. Monmouth, NJ 07703.
NOV. 11/13, 1973	*Photovoltaic Specialists Conference* — G-ED, Stanford University, Rickey's Hyatt House, Stanford, Calif. *Deadline info:* 6/1/73 (abst) *to* Richard Statler, Naval Res. Lab., Washington, DC 20390.
NOV. 13/16, 1973	*Magnetism & Magnetic Materials Conference* — S-MAG, AIP, Statler Hilton Hotel, Boston, Mass. *Deadline info:* (abst) 7/20/73 *to* A. F. Mayadas, IBM Res. Ctr., POB 218, Yorktown Heights, NY 10598.
NOV. 14/16, 1973	*Nuclear Science Symposium* — S-NPS£ USAEC, NASA, Sheraton Palace Hotel, San Francisco, Cal. *Deadline info:* (A&S) 6/15/73 *to* P. L. Phelps, Lawrence Livermore Labs., Livermore, Cal.
JAN. 27/FEB. 1, 1973	*IEEE Power Engineering Society Winter Meeting* — S-PE, Statler Hilton Hotel, New York, NY. *Deadline info:* (ms) 9/1/73 *to* J. G. Derse, 1030 Country Club Rd., Somerville, NJ 08876.
MARCH 1974	*Special issue on Computer-Oriented Microwave Practices — The IEEE Transactions on Microwave Theory and Techniques, G-MTT. Deadline info:* (MS) 7/2/73 *to* Guest Editor, Dr. J. W. Bandler, Dept. of Electrical Engineering, McNaster University, Hamilton, Ontario, Canada.
APR. *1/5, 1974*	*IEEE Power Engineering Society Underground Transmission and Distribution Conference* — S-PE, Dallas Convention Ctr., Dallas, Texas *Deadline info:* (abst) 3/1/73 *to* N. E. Piccione, L. I. Lighting Co., 175 E. Old Country Rd., Hicksville, NY 11801.

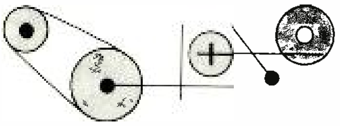
Abbreviations of Sponsor Agencies

AAS	American Astronautical Society
AAAS	American Association for the Advancement of Science
ACS	American Chemical Society
AEA	American Economic Association
AIAA	American Institute of Aeronautics and Astronautics
AIChE	American Institute of Chemical Engineering
AIIE	American Institute of Industrial Engineers
AIP	American Institute of Physics
ANS	American Nuclear Society
ASCE	American Society of Civil Engineers
ASM	American Society for Metals
ASMA	Aerospace Medical Association
ASME	American Society of Mechanical Engineers
ASQC	American Society for Quality Control
IEE	Institute of Electrical Engineers
IEEE	Institute of Electrical and Electronic Engineers (Group and Society Names are also abbreviated) *e.g.* G-EM for group on Engineering Management or S-PE for Power Engineering Society)
IERE	Institute of Electronics and Radio Engineers
IES	Industrial Engineering Society
IFAC	International Federation of Automatic Control
ISA	Instrument Society of America
NSPE	National Society of Professional Engineers
ORSA	Operations Research Society of America
OSA	Optical Society of America
SAE	Society of Automation Engineering
SME	Society of Manufacturing Engineers
SMPTE	Society of Motion Picture and Television Engineers
USNC/URSI	United States National Committee/*Union Radio Scientifique Internationale*
WEMA	Western Electronic Manufacturers Association

Patents Granted



to RCA Engineers



Astro-Electronics Division

Suspension System — D. R. Melrose, D. S. Binge (AED, Hghtsn.) U.S. Pat. 3727865, April 17, 1973

Missile & Surface Radar Division

Wide Dynamic Range Product Detector — F. I. Palmer, J. R. Fogleboch (MSRD, Mrstn.) U.S. Pat. 3705355, December 5, 1972

Multi-Mode, Monopulse Feed System — J. P. Grabowski (MSRD, Mrstn.) U.S. Pat. 3701163, October 24, 1972; Assigned to U.S. Government.

High Power Microwave Switch Including a Plurality of Diodes and Conductive Rods — V. Stachejko (MSRD, Mrstn.) U.S. Pat. 3711793, January 16, 1973

TMo Mode Exciter and a Multimode Exciter Using Same — O. M Woodward (MSRD, Mrstn.) U.S. Pat. 3715688, February 6, 1973

Color Television Recorder-Reproducer System — T. V Bolger (MSRD, Mrstn.) U.S. Pat. 3716663, February 13, 1973

Single Error Channel Monopulse System — J. P. Grabowski and W.E. Powell, Jr. (MSRD, Mrstn.) U.S. Pat. 3714652, January 30, 1973, Assigned to U.S. Government

Electromagnetic and Aviation Systems Division

Computer Input-Output Chaining System— W. A. Helbig, Sr. (EASD, Van Nuys) U.S. Pat. 3728682, April 17, 1973

Government Engineering

Carry Skip-Ahead Network — R. L. Pryor (ATL, Cam.) U.S. Pat. 3728532, April 17, 1973

Electrically Variable Waveguide Phase Shifter Comprising a Slab of Semiconductive Material — S. Gray, B. J. Levin, D. J. Miller (ATL, Cam.) U.S. Pat. 3721923, March 20, 1973

Multiple-Phase Logic Circuits — A. K. Rapp U Bharali (G&CS, Micro Ele., Som.) U.S. Pat. 3706889, December 19, 1972

High Frequency Power Transistor Support — A. J. Leidich, M. E. Malchow (G&CS, Micro Ele., Som.) U.S. Pat. 3710202, January 9, 1973

Palm Beach Division

Input Circuit for Multiple Emitter transistor — C F. Madrazo, R. G. Saenz (Palm Bch. Div., PBG) U.S. Pat. 3727072, April 10, 1973

Zero Crossing Point Switching Circuit — C. J. Aiduck, R. A. Mancini (PBP Lab., PBG) U.S. Pat. 3702941, November 14, 1972

Crystal Controlled Digital Logic Gate Oscillator — R. A. Mancini (PBP Lab., PBG) U.S. Pat. 3699476, October 17, 1972

Gate Circuit — C. F. Madrazo, E. M. Fulcher, K P McDonach (PBP Lab , PBG) U.S. Pat. 3699355, October 17, 1972

Computer Systems

Digital Signal Decoder Using Two Reference Waves — G. V. Jacoby, G. J. Mesiener (Sys. Dev., Marlboro) U S. Pat. 3728716

Electronic Components

Negative Resistance Semiconductor Coupled Transmission Line Apparatus — A. Rosen, J. F. Reynolds (EC, Pr.) U.S. Pat. 3721918, March 20, 1973

Variable Delay Line Utilizing One Part Reflection Type Amplifier — B. E. Berson, C. L. Upadhyayula (EC, Pr.) U.S. Pat. 3721930, March 20, 1973

Deflection Yoke for Use with In-Line Electron Guns — W. H. Barkow, J. Gross (EC, Pr.) U.S. Pat. 3721930, March 20, 1973

Fabrication of Focus Grill Type Cathode Ray Tubes — H. B. Law (EC, Pr.) U.S. Pat. 3722044, March 27, 1973

Dual-Gate MOS-FET Oscillator Circuit with Amplitude Stabilization — J. F. Sterner, G. D. Hanchett (EC, Hrsn.) U.S. Pat. 3723905, March 27, 1973

Solid State Division

Load Sensing Circuits — J. C. Sondermeyer (SSD, Som.) U.S. Pat. 3721889, March 20, 1973

Field-Effect Translator Circuit for Detecting Changes in Voltage Level — R. C. Heuner, R. P. Fillmore (SSD, Som.) U.S. Pat. 3702943

Fabrication of Liquid Crystal Devices — H. Sorkin, R. I. Klein (SSD, Som) U.S. Pat. 3698449, October 17, 1972

Voltage-Controlled Oscillator Using Complementary Symmetry Mosfet Devices — G. W. Steudel (SSD, Som.) U.S. Pat. 3702446

Shaped Riser on Substrate Step for Promoting Metal Film Continuity — A. G. F. Dingwall (SSD, Som) U.S. Pat. 3703667, November 21, 1972

Regulated Ignition System — R. S. Myers (SSD, Som) U.S. Pat. 3709206, January 9, 1973

Overcurrent Protection Circuit for a Voltage Regulator — W. R. Peterson (SSD, Som.) U.S. Pat. 3711763, January 16, 1973

Input Transient Protection for Complementary Insulated Gate Feild Effect Transistor Integrated Circuit Device — G. W. Steudel (SSD, Som.) U.S. Pat. 3712995, January 23, 1973

Circuit for Improving Operation of Semiconductor Memory — A. G. F. Dingwall, J. M. Jorgensen (SSD, Som.) U.S. Pat. 3714638, January 30, 1973

A Sample and Hold Circuit — D. Hampel, J. B. Lerch (SSD, Som.) U.S. Pat. 3671783, June 20, 1972; Assigned to U.S. Government.

Data Translating Circuit — R. C. Heuner, S. J. Niemiec (SSD, Som.) U.S. Pat. 3716723, February 13, 1973

Circuit for Minimizing the Signal Currents Drawn by the Input Stage of an Amplifier — H. Amemiya, S. A. Graf (SSD, Som.) U.S. Pat. 3717821, February 20, 1973

High Voltage Processing of Cathode Ray Tubes — E. A. Gronka (SSD, Som) U.S. Pat. 3698786, October 17, 1972

Fabrication of Liquid Crystal Devices — H. A. Stern (SSD, Raritan) U.S. Pat. 3701368, October 31, 1972

Switching Circuits — G. D. Hanchett (SSD, Som.) U.S. Pat. 3727080, April 10, 1973

Integral Thyristor-Rectifier Device — A. W. Thomas, J. M. S. Neilson, L. S. Greenberg (SSD, Som.) U.S. Pat. 3727116, April 10, 1973

Heat Sinking of Semiconductor Integrated Circuit Devices — C. F. Wheatley, Jr. (SSD, Som.) U.S. Pat. 3723833, March 27, 1973

Consumer Electronics

Method of Joining Solder Balls to Solder Bumps — R. R. Steitz (CE, Indpls.) U.S. Pat. 3719981, March 13, 1973

Electromagnetic Focusing and Deflection Assembly for Cathode Ray Tubes — J. H. Wharton (CE, Indpls.) U.S. Pat. 3721931, March 20, 1973

Parts and Accessories

Indoor Antenna or Similar Article — J. D. Callaghan (P&A, Deptford) U.S. Pat. D226274, February 6, 1973

RCA Limited

Cathodochromic Sodalite and Cathode Ray Tube Employing Same — I. Shidlovsky (Ltd., Cowansville) U.S. Pat. 3705323, December 5, 1972

Quadrant Photodiode — R. J. McIntyre, H. C. Springings (Ltd., Montreal) U.S. Pat 3714491, January 30, 1973

Research and Engineering Laboratories

Electroless Copper Plating Solutions with Accelerated Plating Rates — N. Feldstein, J. A. Weiner (LABS, Pr.) U.S. Pat. 3720525, March 13, 1973

Charge Coupled Memory — W. F. Kosonocky (LABS, Pr.) U.S. Pat. 3720922, March 13, 1973

Memory System Using Variable Threshold Transistors — E. C. Ross (LABS, Pr.) U.S. Pat. 3720925, March 13, 1973

Method of Transferring Magnetic Toner Particles in an Image Configuration and Apparatus Therefor — E. C. Giaimo, Jr. (LABS, Pr.) U.S. Pat. 3721553, March 20, 1973

Waveform Generating Circuit — P. E. Haferl (LABS, Zurich, Switz.) U.S. Pat. 3721857, March 20, 1973

Disabled Vehicle Signalling System — L. N. Schiff, H. Staras (LABS, Pr.) U.S. Pat. 3721955, March 20, 1973

Physically Small Combined Loop and Dipole All Channel Television Antenna System — J. J. Gibson, D. W. Peterson (LABS, Pr.) U.S. Pat. 3721990, March 20, 1973

Optically-Scanned Liquid-Crystal Projection Display — I. Gorog (LABS, Pr.) U.S. Pat. 3723651, March 27, 1973

Method of Making Semiconductor Devices Mounted on a Heat Sink — K. P. Weller, C. P. Wen (LABS, Pr.) U.S. Pat. 3728236, April 17, 1973

Signal Transfer System for Panel Image Sensor — P. K. Weimer (LABS, Pr.) U.S. Pat. 3728555, April 17, 1973

Semiconductor Assembly — M. Caulton (LABS, Pr.) U.S. Pat. 3728589, April 17, 1973

Gate Protective Device for Insulated Gate Field-Effect Transistors — R. A. Sunshine (LABS, Pr.) U.S. Pat. 3728591, April 17, 1973

Electroluminescent Device Comprising a Transition Metal Oxide Doped with a Trivalent Rare Earth Element — W. M. Yim, P. N. Yocom (LABS, Pr.) U.S. Pat. 3728594, April 17, 1973

Computer Memory with Improved Next Word Accessing — J. A. Weisbecker (LABS, Pr.) U.S. Pat. 3728686, April 17, 1973

MOS Transistor with Aluminum Oxide Gate Dielectric — M. T. Duffy (Labs., Pr.) U.S. Pat. 3702786, November 14, 1972

Broadband Microwave Apparatus Using Multiple Avalanche Diodes Operating in the Anomalous Mode — H. Kawamoto, E. L. Allen, Jr (Labs., Pr.) U.S. Pat 3702971, November 14, 1972

Variable Threshold Memory System Using Minimum Amplitude Signals — E. C. Ross (Labs., Pr.) U.S. Pat. 3702990, November 14, 1972

Fusible Semiconductor Device Including Means for Reducing the Required Fusing Current — E. J. Boleky, III (Labs., Pr.) U.S. Pat. 3699403, October 17, 1972

Memory System Including Buffer Memories — G. M. Hunter (Labs., Pr.) U.S. Pat. 3699533, October 17, 1972

Sonic Page Composer for Holographic Memory — G. A. Alphonse (Labs., Pr.) U.S. Pat. 3698794, October 17, 1972

Apparatus for Charging a Recording Element with an Electrostatic Charge of a Desired Amplitude — E. C. Giaimo, Jr. (Labs., Pr.) U.S. Pat. 3699335, October 17, 1972

Semiconductor Device Including Fusible Elements — E. J. Boleky, III (Labs., Pr.) U.S. Pat. 3699395, October 17, 1972

Photoemissive Electron Tube Comprising a Thin Film Transmissive Semiconductor Photocathode Structure — J.J. Tietjen, B.F. Williams, C. C. Wang (Labs., Pr.) U.S. Pat. 3699401, October 17, 1972

Memory Subsystem Array — J. R. Burns (Labs., Pr.) U.S. Pat. 3701984, October 31, 1972

Liquid Crystal Color Display — J. A. Castellano (Labs. Pr.) U.S. Pat. 3703329, November 21, 1972

Liquid Crystal Display Element Having Storage — J. E. Goldmacher, G. H. Heilmeier (Labs. Pr.) U.S. Pat. 3703331, November 21, 1972

Light Modulator and Display Device — G. W. Taylor (Labs., Pr.) U.S. Pat. 3703332, November 21, 1972

Relief Phase Holograms — W. J. Hannan (PBP Lab., PBG) J. P. Russell, A. H. Firester, (Labs., Pr.) U.S. Pat 3703407, November 21, 1972

Achromatic Depth-of-Field Correction for Off-Axis Optical System — W. J. Gorkiewicz, J.A. VanRaalte (Labs.,Pr.) U.S. Pat. 3704936, December 5, 1972

Semiconductor Device — R. H. Dean (Labs., Pr.) U.S. Pat. 3706014, December 12, 1972

Method of Improving the Gamma of a Cathodochromic Display Device — P. M. Heyman, I. Gorog (Labs., Pr.) U.S. Pat. 3706845, December 19, 1972

FM Stereophonic Receiver Detection Apparatus and Disabling Means — A. L. Limberg (Labs., Pr.) U.S. Pat. 3707603, December 26, 1972

Apparatus for Etching of Thin Layers of Material by Ion Bombardment — R. E. Quinn (Labs., Pr.) U.S. Pat. 3708418, January 2, 1973

Intelligence-Handling Device Having Means for Limiting Induced Electrostatic Potential — J. A. Van Raalte, V. Christiano (Labs., Pr.) U.S. Pat. 3708712, January 2, 1972

Organic Electroluminescent Cells Having a Tunnel Injection Cathode — J. Dresner, A. M. Goodman (Labs., Pr.) U.S. Pat. 3710167, January 9, 1973

Apparatus for Efficiently Converting Microwave Energy into Acoustic Energy — G. A. Alphonse (Labs., Pr.) U.S. Pat 3710283

Velocity Adjusting System — R. C. Palmer (Labs., Pr.) U.S. Pat. 3711641, January 16, 1973

Magneto-Electric Apparatus for Reproducing an Image on a Recording Element — E. C. Giaimo, Jr. (Labs., Pr.) U.S. Pat. 3712733, January 23, 1973

Operation of Memory Array Employing Variable Threshold Transistors — E. C. Ross (Labs., Pr.) U.S. Pat. 3713111, January 23, 1973

Luminescent Screen Comprising Phosphor Cores Luminescent in First Color and Phosphor Coatings Luminescent in Second Color — R. D. Kell (Labs., Pr.) U.S. Pat. 3714490, January 30, 1973

Semiconductor Device or Monolithic Integrated Circuit with Tungsten Interconnections — J. M. Shaw (Labs., Pr.) U.S. Pat. 3714521, January 30, 1973

Pyroelectric Photoconductive Elements and Method of Charging Same — H. G. Kiess (Labs., Zurich, Switz.) U.S. Pat. 3713322, January 30, 1973

Transistor Deflection Circuits Utilizing a Class B, Push-Pull Output Stage — G. Schiess (Labs., Zurich, Switz.) U.S. Pat. 3715621, February 6, 1973

Photochromic Display and Storage Device and Method of Operation Thereof — D. L. Ross (Labs., Pr.) U.S. Pat. 3715212, February 6, 1972

Radiation Sensing and Signal Transfer Circuits — P. K. Weimer (Labs., Pr.) U.S. Pat. 3715485, February 6, 1973

Method of Making Semiconductor Devices — L. S. Napoli, J. J. Hughes (Labs., Pr.) U.S. Pat. 3716429, February 13, 1973

RCA Staff

Process for Forming an Isolated Circuit Pattern on a Conductive Substrate — S. F. Burtis (Staff, Cam.) U.S. Pat. 3704207, November 28, 1972

Special Contract

Decoding of Color-Encoded Phase Grating — A. Macovski (Special Contract Inv.) U.S. Pat. 3702725

Information Systems

Reversible Fixture for Positioning Magnetic Memory Cores — C. G. Warner, J. H. Kade (CP Mem., Needham Heights) U.S. Pat. 3698057, October 17, 1972

Edge Connector — J. B. Gallager, Jr. (CS, Cam) U.S. Pat. 3710303, January 9, 1973

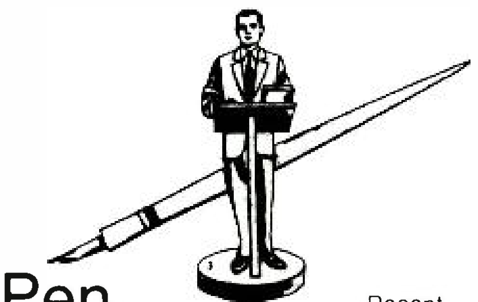
Web Position Detector Using Temperature Sensing Elements 8 J. C Schorr (CS, Marlboro) U.S. Pat. 3711001, January 16, 1973

Decoder for Delay Modulation Signals — G. J. Meslener (CS, Marlboro) U.S. Pat. 3713140, January 23, 1973

Magnetic Transducer Fabrication Technique — H. Z. Weaver (CS, Marlboro) U.S. Pat. 3706132, December 19, 1972

Graphic Systems Division

Scanning System Which Includes Means for Controlling Picture Sampling Density — H. E. Haynes (GSD, Dayton) U.S. Pat. 3715498, February 6, 1973



Pen and Podium

Recent
RCA
technical papers
and presentations

Both published papers and verbal presentations are indexed. To obtain a published paper, borrow the journal in which it appears from your library, or write or call the author for a reprint. For information on unpublished verbal presentations, write or call the author. (The author's RCA Division appears parenthetically after his name in the subject-index entry.) For additional assistance in locating RCA technical literature, contact: **RCA Staff Technical Publications, Bldg. 2-8, RCA, Camden, N.J. (Ext. PC-4018).**

This index is prepared from listings provided bimonthly by RCA Division Technical Publications Administrators and Editorial Representatives—who should be contacted concerning errors or omissions (see inside back cover).

Subject Index categories are based upon standard announcement categories used by Technical Information Systems, Corporate Engineering Services, Bldg. 2-8, Camden, N.J.

Subject Index

Titles of papers are permuted where necessary to bring significant keyword(s) to the left for easier scanning. Authors' division appears parenthetically after his name.

SERIES 100 BASIC THEORY & METHODOLOGY

105 Chemistry

. . . organic, inorganic, & physical.

RF Sputter-Etching, The Interaction of Photoresists with Metals and Oxides During—J.L. Vossen, E.B. Davidson (Labs,Pr) *J. of the Electrochemical Soc.* Vol. 119, No. 12, pp. 1708-1714; 12/72

125 Physics

. . electromagnetic field theory, quantum mechanics, basic particles, plasmas, solid state, optics thermodynamics, solid mechanics, fluid mechanics, acoustics.

BRILLOUIN SCATTERING, Ultrasonic and Theoretical Studies of Acoustic Anomalies in Crystals Showing Jahn-Teller Phase Transitions—J.R. Sandercock, S.B. Palmer, R.J. Elliott, W. Hayes, S.R. Smith, A.P Young (Labs,Pr) *J. Phys. C: Solid State Phys.*, Vol. 5, No. 21, pp. 3126-3146; 10/31/72

SURFACE RESISTANCE, Comments on Superconducting—R.C. Alig (Labs,Pr) *Phys. Rev. B.*, Vol 7, No. 3, p. 1188; 2/1/73

130 Mathematics

. . . basic & applied mathematical methods.

KORTEWEG-DE VRIES EQUATION for Multiple Collisions of Solitons, Exact Solution of the Modified—R. Hirota (Labs,Pr) *J. Phys. Soc. Japan*, Vol. 33, No. 5, pp. 1459-1463; 11/72

PATTERN VERIFICATION Using Statistically Equivalent Blocks, Distribution-Free—G.W. Beakley, E.B. Tuteur (Labs,Pr) *IEEE Trans. on Computers*, Vol. C-21, No. 12, pp. 1337-1347; 12/72

STATISTICAL ANALOGY, An Introduction to—O.G. Allen (M&SRD, Mrstn) Dinner Mtg. of the Cleveland section of the American Society of Quality Control, Cleveland, Ohio; 12/12/72

140 Circuit & Network Theory

. . . methods for circuit synthesis & analysis, network topology, equivalent circuit methods.

NOISE FIGURE Nomogram—J.L. Christensen (MSRD,Mrstn) *Electronic Design*, 2/15/73

TRANSISTOR MODELING, Large Signal Microwave Frequency—R.G. Harrison (RCA Ltd., Ste. Anne de Bellevue) Chapter 3: *Semiconductor Device Modeling for Computer-Aided Design* Mc-Graw-Hill; 1972

160 Laboratory Techniques & Equipment

. . . experimental methods & equipment, lab facilities, testing, data measurement, spectroscopy,electron microscopy, dosimeters.

GAS AMBIENT in Electron Tubes and Solid State Devices, Analysis of the—S.A. Decker (EC,Har) Pittsburgh Conf. on Analytical Chemistry and Applied Spectroscopy, Cleveland, Ohio; 3/73

REFLECTIVITY MEASUREMENTS at 0.6328 and 10.6 microns, Comparative Study of—A. Waksberg, D. Bennett (RCA Ltd., Ste Anne de Bellevue) *Canadian Aeronautics and Space Journal*, Vol 18, No. 10; 12/72

170 Manufacturing & Fabrication

. . . production techniques for materials, devices & equipment.

CERAMIC Circuit Boards—H.S. Veloric (SSD, Som) Drexel Univ., E.E. Seminar; 12/72

EPITAXIAL GROWTH TECHNIQUES for Transferred Electron Oscillators and Amplifiers—T.E. Walsh, I.J. Hegyi (EC,Hr) IEEE Electron Devices Technique Conf., New York, N.Y.; 5/1-2/73

PLATING on Plastics - As a Method for Producing a New Type of Cathode-Ray-Tube Shadow Mask—N.Feldstein (Labs,Pr) *Plating*, Vol. 60, No. 1; 1/73

PRODUCTION CONTROL Systems, Utilizing Time-Share Computers in—R.H. Higgins (EC,Hr) IEEE Conf., N.Y.; 3/27/73

TRANSFERRED ELECTRON DIODES, The Influence of Fabrication Techniques on the Electrical and Thermal Characteristics of—T.E. Walsh, J.J. Napoleon, A. Efstathiou (EC,Hr) IEEE Electron Devices Technique Conference, New York, N.Y.; 5/1-2/73

VAPOR PHASE GROWTH SYSTEMS, Effects of Natural and Forced Convection in—B.J Curtis, J.P. Dismukes (Labs,Pr) *J. of Crystal Growth*, Vol. 17, pp. 128-140; 1972

175 Reliability, Quality Control & Standardization

. . . value analysis, reliability analysis, standards for design & production.

FAILURE MECHANISM Model, Degradation of MNOS Memory Transistor Characteristics and—J.W. Tuska, M.H. Woods (Labs,Pr) *Proc. of the 10th Annual Reliability Physics Symp.*, pp. 120-125; 1972

INTERCONNECTIONS—B.R. Schwartz (MSRD,Mrstn) *ElElectronical Design*; 1/73

PLASTIC PACKAGE for Integrated Circuits, High-Reliability—H. Khajezadeh (SSD,Som) 1973 Reliability Physics Symp., Las Vegas, Nevada; 4/73

PRINTED CIRCUITRY METALLIZATION Reliability in—A Case for Improved Sensitizers—N. Feldstein (Labs,Pr) AES 4th Symp. "Plating in the Electronics Industry", Indianapolis, Indiana; 1/31/72

PROCESS CONTROL Using CD4000A Series Parts—D. Block (SSD,Som) *Electronic Products Magazine* Seminar; 3/6/73

TRANSFERRED ELECTRON DIODES, Fabrication Techniques and Screening Procedures for High Reliability—T.E Walsh (EC,Har) IEEE Reliability Physics Symp., Las Vegas, Nevada; 4/3-5/73

180 Management & Business Operations

. . . organization, scheduling, marketing, personnel.

AUTOMOTIVE Industry—A.Marmann (SSD,Som) *Modern Electronik*, Sweden; 1/73

SERIES 200 MATERIALS, DEVICES, & COMPONENTS

205 MATERIALS (ELECTRONIC)

. . . preparation & properties of conductors, semiconductors, dielectrics, magnetic,electroptical, recording, & electromagnetic materials

EULITES Bi^4Ge^{12} and $Bi^4Si^3o^{12}$ Refractive Indices and Electro-Optic Coefficients of the—D.P. Bortfeld, H Meier (Labs,Pr) *J. of Appl. Physics*, Vol. 43, No. 12, pp. 5110-5111; 12/72

FERROCYANIDE Ion, Less-Than-Bandgap Photosensitivity of ZnO and Dye Sensitization by—T. Freund (Labs,Pr) *Surface Science*, Vol. 33, pp. 295-305; 1972

GaAs Acoustoelectric Domains in, On and Off Axis—A.R. Moore, J.W. Davenport (Labs,Pr) *J. Appl. Phys.*, Vol. 43, No. 11, 11/72; pp. 4513-4517

GaN, UV dc Electroluminescence from—J.I. Pankove (Labs,Pr) *J. of Luminescence*, Vol. 5, pp. 482-484; 1972

III-V Compounds Mass Spectrometric and Thermo-dynamic Studies of the CVD of Some—V S. Ban (Labs,Pr) *J. of Crystal Growth*, Vol. 17, pp. 19-23, 1972

InP MULTILAYER STRUCTURES, Vapor Growth and Electrical Properties of—R.E. Enstrom, J.R. Appert (Labs,Pr) 1973 Informal Workshop on Compound Semiconductors for Microwave Devices, NYC; 2/12/73

LIQUID CRYSTALS VII. The Mesomorphic Behavior of Homologous p-Alkoxy-p-Acyloxyazoxybenzenes—M.T. McCaffrey, J.A Castellano (RCA Labs,Pr) Molecular Crystals & Liquid Crystals, Vol. 18, pp. 209-225; 1972

n-GaAs, A Practical Technique for Controlling Field Profile in Thin Layers of—R.H. Dean (Labs,Pr) *IEEE Trans. on Electron Devices*, Vol. ED-19, No. 11, pp. 1144-1148; 12/72

n-GaAs, Reflection Amplification in Thin Layers of—R.H. Dean (Labs,Pr) *IEEE TRANS. Electron Devices*, Vol. ED-19, No 11, pp. 1144-1148; 12/72

SILICON FILMS on Sapphire, Accumulation and Inversion-Layer Hall Mobilities in—A.C. Ipri (Labs,Pr) *Appl. Phys. Letters*, Vol. 22, No. 1, pp. 16-18; 1/73

SILICON-ON-SAPPHIRE Films, The Development of a Dual Rate Technique for the Growth of—G.E. Gottlieb, J.F. Corboy, Jr. (Labs,Pr) *J. of Crystal Growth*, Vol. 17, pp. 261-270; 1972

SILICON on Spinel: The Interaction Between Deposition Constiuents & the Substrate Surface—G.W. Cullen, F.C. Dougherty (Labs,Pr) *J. of Crystal Growth*, Vol. 17, pp. 230-240; 1972

SnO^2:Sb and In^2O^3:Sn, The Properties of very Thin RF Sputtered Transparent Conducting Films of—J.L. Vossen, E.S. Poliniak (Labs,Pr) *Thin Solid Films*, Vol. 12,pp. 281-284; 1972

THIN FILM Structure in the Brillouin Spectra of—J.R. Sandercock (Labs,Pr) *Phys. Rev. Letters*, Vol. 29, No. 26, pp. 1735-1738; 12/25/72

THIN SILICON-ON-SAPPHIRE FILMS, Surface-Charge Effects on the Resistivity and Hall Coefficient of—W.E. Ham (Labs,Pr) *Applied Phys. Letters*, Vol. 21, No. 9, pp. 440-443; 11/72

TRANSFERRED ELECTRON DIODES, The Influence of Fabrication Techniques on the Electrical and Thermal Characteristics of—T.E. Walsh, J.J. Napoleon, A. Efstathiou (EC,Har) IEEE Electron Devices Technique Conf., New York, N.Y.; 5/1-2/73

210 Circuit Devices & Microcircuits

. . . electron tubes & solid-state devices (active & passive),integrated, array, & hybrid microcircuits, field-effect devices, resistors & capacitors, modular & printed circuits, circuit interconnection, waveguides & transmission lines.

215 Circuit & Network Designs

. . . analog & digital functions in electronic equipment: amplifies, filters,modulators, microwave circuits, A-D converters, encoders, oscillators, switches, masers, logic networks,timing control functions, fluidic circuits.

AGC LOOP Stabilized ALC-RF Threshold Detector Provides Fast Slew Rate—R.J. Turner (MSRD,Mrstn) *Electronics*, 12/72

AMPLIFIER, 5W, Low Distortion, High Sensitivity—A.J. Leidich, L. Teslenko, C.F. Wheatley, Jr. (SSD,Som) IEEE Solid-State Circuits Conf., Philadelphia, Pa.; 2/73

AMPLIFIER, Programmable Power Switch—M.V. Hoover (SSD,Som) *Electronic Engineering Times; 11/20/73*

AUDIO AMPLIFIERS, Power Bandwidth in—J.F. Alves (SSD,Som) IEEE Fall Conf., Chicago, Ill.; 12/72

BOOSTED B+ Regulator For the SCR

Deflection System—W.F. Dietz (SSD,Som) IEEE Fall Conf.. Chicago, Ill.; 12/72

FREQUENCY MODULATOR, Serrasoid—B.Zuk. J.P. Keller (SSD,Som) IEEE Solid-State Circuits Conf., Philadelphia. Pa.; 2/73

HYBRID REGULATORS, Designing with—K.Kugele (SSD,Som) *Electronic Engineering Times;* 12/72

MHW CONVERTER, Performance Models for the—R.R. Lorentzen (EC,Har) IECEC Mtg , Philadelphia, Pa.; 8/12-17/73

PULSE GENERATOR Gigahertz-Rate Hundred-Volt—H.Kawamoto (Labs,Pr) *IEEE J. of Solid-State Circuits.* Vol. SC-8, No. 1, pp. 63-66; 2/73

PHASE-LOCK LOOP, The RCA COS/MOS CD4046 Micro-Power—D.Morgan (SSD.Som) *Electronics Magazine;* 9/11/72

SCR DEFLECTION, Yesterday, Today and Tomorrow—W.E. Babcock (SSD,Som) IEEE Fall Conf., Chicago. Ill.; 12/72

SOLID STATE RELAYS,Power Switching Using—T.C. McNulty *(SSD,Som) IEEE International Conf., New York. N.Y.; 3/73*

THYRISTOR REGULATOR Circuit for SCR Deflection—W.F. Dietz (SSD,Som) Fernseh Technische Tagung (TV Broadcast Receiver Seminar) Braunschweig, W. Germany; 10/72

TRANSFERRED ELECTRON AMPLIFIERS Using Distributed Equalizer Networks. Design and Performance of—C.L. Upadhyayula, B.S. Perlman (Labs,Pr) *IEEE J. of Solid-State Circuits,* Vol. SC-8. No. 1, pp. 29-36: 2/73

TRANSFERRED-ELECTRON OSCILLATORS, Varactor Tuned—D.Mawhinney (EC.Har) '73 Microwave Conf., Brighton, England; 6/73

220 Energy & power Sources

. . . batteries, solar cells, generators, reactors, power supplies.

CMOS-A Status Report—A. Bishop. P. Jones (SSD,Som) SEMINEX. Sunbury, England; 2/26-3/2/73

COSMOS TRANSISTORS for Linear Circuit Applications, An IC Array of—M.V. Hoover (SSD,Som) *Electronic Products Magazine* Seminar; 3/6/73

FIELD EFFECT TRANSISTORS, Insulated Gate and Their Applications—G.D. Hanchett (SSD,Som) IEEE Westchester Country Subsection; 12/12/72

INTEGRATED CIRCUITS, Silicon Gate CMOS—T.G. Athanas, S.S. Eaton, H. Klareich (SSD.Som) IEEE Int'l Electron Devices Mtg., Wash., D.C.; 12/72

LIGHT-EMITTING DIODES, Frequency Response of GaN—J.I. Pankove, J. Berkeyheiser (Labs,Pr) *Proc. of the IEEE,* Vol. 60, No. 11, pp. 1456-1457; 11/72

LINEAR IC'S and Some of Their Applications, A Bouquet of—M.V. Hoover (SSD,Som) Semiconductor Specialists (Distributors) Seminar, Chicago. Il; 2/73

LINEAR Integrated Circuits—L. Avery (SSD.Som) SEMINEX. Sunbury, England; 2 26-3/2/73

PHASE COMPARATOR, COS/MOS—J.O. Preisig, R. Feryszka (Labs,Pr) Intl. Solid-State Circuits Conf., Philadelphia, Pa.; 2/16-18/73

SEMICONDUCTORS, Performance Tests of—T.M. VanLier (SSD,Som) International Meeting on Applications of Mini-Computers; 10/72 and *Technical Review of University of Liege, 10/72*

SILICON COLD CATHODE, Scanning Beam Performance From a Negative Electron Affinity Activated—A.D. Cope, E. Luedicke, J.P. Carroll (EC,Har) Solid State Circuits Conference, Philadelphia, Pa.; 2/14-16/73

TE DIODES, Characterized High Reliability—T.E. Walsh, J.J. Napoleon. A. Efstathiou, I. Hegyi (EC,Har) '73 Microwave Conf., Brighton, England; 6/73

TRANSFERRED-ELECTRON DEVICES Take on More Role in Microwave Systems—B.E. Berson (Labs,Pr) *Electronics, 12/4/72*

TRANSFERRED ELECTRON DIODES, The Influence of rication Techniques on the Electrical and Thermal Characteristics of—T.E. Walsh, J.J. Napolen, A. Efstathiou (EC,Har) IEEE Electron Devices Technique Conf., New York. N.Y., 5/1-2/73

TRANSIT-TIME DIODES, A Unified Small-Signal Theory of Uniform-Carrier-Velocity Semiconductor—H. Johnson (Labs,Pr) *IEEE Trans. on Electron Devices.* Vol. ED-19, No. 11, pp. 1156-1166; 11/72

TRAPATT CIRCUITS, Lumped-Element—A.S. Clorfeine, H.J. Prager, R.D. Hughes (Labs,Pr) 1973 Int'l Solid-State Circuits Conf., Philadelphia, Pa.; 2/14-16/73

TRAVELING-WAVE TUBE, The Miniature—N Schindler, P.M. Freeling, H. Wolkstein (EC,Har) '73 Microwave Conf., Brighton, England; 6/73

TRAVELING-WAVE TUBES, Super Broadband—H.J Wolkstein, P. Puri, M. Freeling (EC,Har) '73 Microwave Conf., Brighton, England; 6/73

TRAVELING-WAVE TUBES, The Technology of Miniature—M.Schindler, R. Sikora (EC,Har) IEEE Electron Devices Techniques Conf., New York, N.Y.; 5/1-2/73

LITHIUM-COUNTAINING SOLAR CELLS Voltage and Power Relationships in—T. Faith (AED, Hgstn) 9th IEEE Photovoltaic Specialists Conf.. Silver Springs, MD; 5/2/72

225 Antennas & Propagation

. . . antenna design & performance, feeds & couplers, phased arrays, radomes & antenna structures, electromagnetic wave propagation, scatter, effects of noise & interference.

ANTENNA for Domestic Satellite Communications, A New Earth-Station—P. Foldes (RCA Ltd., Ste. Anne de Bellevue) *RCA Review* Vol. 33, No. 4; 12/72

INTERFERENCE with Diversity in a Mobile-Radio Environment, Statistical Suppression of—L. Schiff (Labs,Pr) *IEEE Trans. on Vehicular Tech.,* Vol. VT-21, No. 4, 121-128, Nov 1972

PHASE SHIFTER, Millimeter Wave—G.G. Weidner (ATL,Cam) Thesis Graduate Record Moore School, Univ. of Penn.; 12/15/72

240 Lasers, Electro-optical & Optical Devices

. . . design & characteristics of lasers, components used with lasers, electro-optical systems, lenses, etc. (excludes:masers).

BIVICON Tube - A New Double Vidicon—R.L. Spalding, S.A. Ochs, E. Luedicke (EC,Har) SMPTE Annual Technical Mtg., Chicago, Illinois; 4/8/73

CO^2 LASER Discharge, Gain Correlation with Sidelight and Plasma Impedance Properties of a—R.A. Crane, A.L. Waksberg (RCA Ltd., Ste Anne ce Bellevue) *Canadian Journal of Physics (Notes),* Vol. 50, No. 23; 12/1/72

HOLOGRAM Storage and **F**ixing in Fe-Doped $LiBnO^3$—D.L. Staebler (Labs,Pr) Physical Sciences Colloquium, IBM Research Center, 2/9/73; Invited Seminar, United Aircraft Research Labs, 2/9/73

IMAGE SENSORS, The Design and Operation of Charge-Coupled—P.K. Weimer, W.S. Pike, M.G. Kovac, F.V. Shallcross (Labs,Pr) IEEE Solid State Circuits Conf., Philadelphia. Pa.; 2/14/73

INTEGRATED OPTICS The New Look in Handling Light—J.M. Hammer (Labs,Pr) Delaware Valley Chapter American Vac. Soc. Mtg., Fort Washington, Pa.; 1/18/73

INTEGRATED OPTICS A Review—H.P. Kleinknecht (Labs,Pr) The Institute of Applied Physics, University of Bern, Zurich, Switzerland; 12/72

LASER DIODES, Radiation Trapping in—M. Ettenberg, H.F. Lockwood, H.S. Sommers, Jr. (Labs,Pr) *J. of Appl. Phys.,* Vol. 43, No 12, pp. 5047-5051; 12/72

SEMICONDUCTOR LASERS: Devices—H. Kressel (Labs,Pr) *Laser Handbook.* Chap. B5, pp. 443-495, North-Holland Pub. Co., Amsterdam; 1972

ULTRASONIC HOLOGRAPHY for Medical Diagnosis—D. Vilkomerson (Labs,Pr) Seminar, Stanford Univ.; 1/17-18/73

VIDICON SILICON TARGET: Performance and Limitations—R.G. Neuhauser, P. Huston, G. Robinson, P Rube (EC,Har) Society of Motion Picture and Television Engineers Mid Winter Television Conf., Miami, Florida; 1/18/73

VISTACON Understanding the—R.G. Neuhauser (EC,Har) Society of Motion Picture and Television Engineers Mid Winter Television Conf., Miami, Florida; 1/18-20/73

245 Displays

. . .equipment for the display of graphic, alphanumeric, & other data in communications, computer, military, & other systems, CRT devices, solid state displays, holographic displays, etc.

DIGITAL DISPLAY SYSTEMS, Liquid Crystal Driven by "CMOS" Offer Minimal Power—R.C. Heuner (SSD,Som) NEREM '72. Boston. Mass.; 11/72

280 Thermal Components & Equipment

. . . heating & cooling components & equipment, thermal measurement devices, heat sinks & thermal protection designs, etc.

CONVERTERS, Thermal Performance of Foil Insulated SiGe—R.R. Lorentzen (EC.Har) IECEC Mtg.. Philadelphia, Pa.; 8/12-17/73

SiGe THERMOELECTRIC PROPERTIES, Updated—A. Amith (EC,Har) IECEC Mtg., Philadelphia, Pa.; 8/12-17/73

THERMOELECTRIC DEVICES, Dynamic Performance of Foil Insulated SiGe—R.D. McLaughlin (EC,Har) IECEC Mtg., Philadelphia, Pa ; 8/12-17/73

SERIES 300 SYSTEMS, EQUIPMENT, & APPLICATIONS

---

305 Aircraft & Ground Support

. . .airborne instruments, flight control systems, air traffic control, etc.

DATA STORAGE and Retrieval Device for Aircraft—P.L. Nelson, R.H. Norwalt (EASD, Van Nuys) SID Int'l Symp. NYC, N.Y.; 5/73

315 Military Weapons & Logistics

. . . missiles, command & control.

AEGIS Weapon System—F.G Adams (MSRD.Mrstn) Lions Club, Camden, N.J.; 2/7/73

320 Radar, Sonar, & Tracking Systems

. . . microwave, optical, & other systems for detection, acquisition, tracking, & position indication.

RADAR Fundamentals, Synthetic Aperture—W.C. Curtis (ASD,Burl) Boston Chapter IEEE Lecture Series on Modern Radar Theory; 1/2/73

VEHICLE-LOCATION SYSTEM, An X-Band—J. Shefer, G.S. Kaplan (Labs,Pr) *IEEE Trans. on Vehicular Tech.* Vol. VT-21, No. 4, pp. 117-120; 11/72

340 Communications Equipment & Systems

. . . industrial, military, commercial systems, telephony, telegraphy, & telemetry, (excludes: television & broadcast radio).

MOBILE TECHNOLOGY Update, RCA—M.O'Molesky (SSD,Som) Pye Telecommunications, Cambridge, England; 9/72

345 Television & Broadcast Systems

. . . television & radio broadcasting, receivers, transmitters, & systems, televisions cameras, recorders, studio equipment, closed-circuit, spacecraft, & special purpose television.

COLOR PICTURE TUBE SYSTEM, New RCA Precision In-Line—R.L. Barbin, R.H. Hughes (EC,Har) Lansdale Section IEEE, Lansdale, Pa.; 3/20/73

TELEVISION Camera, Spaceborne—M.H. Mesner (AED,Hgstn) South Brunswick Rotary Club, South Brunswick, N.J.; 12/14/72

360 Computer Equipment

. . . processors, memories, & peripherals.

HOLOGRAPHIC STORAGE Media, Recyclable—J. Bordogna, S.A. Keneman (Labs,Pr) All-Union Symp. on the Physical Principles of Holography, Novosibirsk, USSR,; 1/29-2/3/73

MEMORIES, Optical Computer—J.A. Rajchman (Labs,Pr) Swiss Federal Institute of Technology, Lausanne, Switzerland; 2(15/73

Author Index

Subject listed opposite each author's name indicates where complete citation to his paper may be found in the subject index. An author may have more than one paper for each subject category.

Electronic Components

Amith, A., 280
Barbin, R.L., 345
Carroll, J.P., 210
Cope, A.D., 210
Decker, S.A., 160
Efstathiou, A., 205. 210
Freeling, M., 210
Hegyi, I.J., 170. 210
Higgins, R.H., 170. 365
Hughes, R.H., 34345
Lorentzen, R.R., 215
Luedicke, E., 240
Mawhinney, D., 215
McLaughlin, R.D., 280
Napoleon, J.J., 170. 210
Neuhauser, R.G., 240
Ochs, S.A., 240
Puri, P., 210
Robinson, G., 240
Rule, P., 240
Schindler, M., 210
Sikora, R., 210
Spalding, R.L., 240
Walsh, T.E., 170. 175. 205. 210
Wolkstein, H., 210

RCA Limited

Bennett, D., 160
Crane, R.A., 240
Foldes, P., 225
Harrison, R.G., 140
Waksberg, A., 160. 240

Missile and Surface Radar Division

Adams, F.G., 315
Allen, O.G., 130
Christensen, J.L., 140
Scwartz, B.R., 175
Turner, R.J., 215

RCA Laboratories

Alig, R.C., 125
Appert, J.R., 205
Ban, V.S., 205
Beakley, G.W., 130
Berkeyheiser, J., 210
Berson, B.E., 210
Bordogna, J., 360
Castellano, J.A., 205
Clorleine, A.S., 210
Corboy, J.F., 205
Cullen, G.W., 205
Curtis, B.J., 170
Davenport, J.W., 205
Davidson, E.B., 105
Dean, R.H., 205
Dismukes, J.P., 170
Dougherty, F.C., 205
Elliott, R.J., 125
Enstrom, R.E., 205
Ettenberg, M., 240
Fedistein, N., 170. 175
Feryszka, R., 210
Freund, T., 205
Gottlieb, G.E., 205
Ham, W.E., 205
Hammer, J.M., 240
Hayes, W., 125
Hirota, R., 130
Hughes, G.S., 320
Ipri, A.C., 205
Johnson, H., 210
Kaplan, G.S., 320
Kawamoto, H., 215
Keneman, S.A., 360
Kleinknecht, H.P., 240
Kovac, M.G., 240
Kressel, H., 240
Lockwood, H.F., 240
McCaffrey, M.T., 205
Meier, H., 205
Moore, A.R., 205
Palmer, S.B., 125
Pankove, J.I., 205. 210
Perlman, B.S., 215
Pike, W.S., 240
Poliniak, E.S., 205
Prager, H.J., 210
Preisig, J.O., 210
Rajchman, J.A., 360
Sandercock J.R., 125. 205
Schiff, L., 225
Shallcross, F.V., 240
Sheler, J., 320
Smith, S.R., 125
Sommers, H.S., 240
Staebler, D.L., 240
Tuska, J.W., 175
Tuteur. E.B., 130
Upadhyayula, C.L., 215
Vilkomerson, D., 240
Vossen, J.L., 105. 205
Young, A.P., 125
Weimer, P.K., 240
Woods, M.H., 175

Solid State Division

Alves, J.F., 215
Athanas, T.G., 210
Avery, L., 210
Babcock, W.E., 215
Bishop, A., 210
Block, D., 175
Dietz, W.F., 215
Eaton, S.S., 210
Hanchett, G.D., 210
Heuner, R.C., 245
Hoover, M.V., 210, 215
Jones, P., 210
Keller, J.P., 215
Khajezadeh, H., 175
Klareich, H., 210
Kugele, K., 215
Leidich, A.J., 215
Marmann, A., 180
McNulty, T.C., 215
Morgan, D., 215
O'Molesky, M., 340
Teslenko, L., 215
VanLier, T.M., 210
Veloric, H.S., 170
Wheatley, C.F., 215
Zuk, B., 215

Index to *RCA Engineer* Volume 18

This index covers Vol. 18-1 (June-July 1972), 18-2 (Aug.-Sept. 1972), 18-3 (Oct.-Nov. 1972), 18-4 (Dec. 1972-Jan. 1973), 18-5 (Feb.-Mar. 1973), and the present issue, (April-May 1973). Since *RCA Engineer* articles are also available as reprints, the reprint number (PE-000) is noted throughout. *RCA Engineer* papers are also indexed along with all other papers written by the RCA technical staff in the annual *Index to RCA Technical Papers.*

Subject Index

Titles of papers are permuted where necessary to bring significant keyword(s) to the left for easier scanning. Authors' division appears parenthetically after his name.

SERIES 100 BASIC THEORY & METHODOLOGY

105 Chemistry

. . . organic, inorganic, & physical.

CHEMICAL PLATING BATHS, Method of quenching and regeneration of—N. Feldstein (Labs.Pr) **18-6** RCA Reprint 18-6-13

125 Physics

. . electromagnetic field theory, quantum mechanics, basic particles, plasmas, solid state, optics thermodynamics, solid mechanics, fluid mechanics, acoustics.

MICROSONICS Technology, Growing Importance of—Dr. D.A. Gandolfo. C.L. Grasse. G.D. O'Clock, Jr., (ATL,Van Nuys) **18-2** RCA Reprint Booklet. *RCA Advanced* Technology. PE-569. RE-18-2-3

130 Mathematics

. . . basic & applied mathematical methods.

COMMUNICATIONS Systems Research, Mathematics in—Dr. L. Schiff (Labs.Pr) **18-3** RCA Reprint 18-3-13. PE-571

CROSS CORRELATION FUNCTIONS, The Meaning of—M.S. Corrington (ATL,Cam) **18-3** RCA Reprint RE-18-3-21

DIGITAL CONVERSION, Angle to Sine Cosine—L.W. Poppen (EASD. Van Nuys) **18-1** RCA Reprint RE-18-1-10

DIGITAL CORRELATION with Partial Summation and Received Date Foldover—H.A. Ulrich (MSRD,Mrstn) **18-3** RCA Reprint RE-18-3-16

IMAGE ENHANCEMENT Techniques—D.B. Gennery (SvCo. PAFB,Fl.) **18-3** RCA Reprint RE-3-12

OPERATIONS Research, Methodology and Techniques of—Dr. A.K. Nigam (Labs,Pr) **18-3** RCA Reprint RE-18-3-10, PE-570

REAL-TIME DIGITAL Processing, Dynamic Characteristics of Several Algorithms for—R.C. Blanchard (ASD,Burl) **18-3** RCA Reprint RE-18-3-17

WALSH FUNCTIONS, Solution of Differential and Integral Equations with—M.S. Corrington (ATL.Cam) **18-3** RCA Reprint RE-18-3-14

140 Circuit & Network Theory

. . . methods for circuit synthesis & analysis, network topology, equivalent circuit methods.

WORST-CASE Circuit Analysis Using the Moment Method—F.E. Oliveto (MSRD,Mrstn) **18-1** RCA Reprint RE-18-1-3

SIMULATION Methodology for LSI Computer Design—A.S. Merriam, H.S. Zieger (ATL,Cam) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-14

160 Laboratory Techniques & Equipment

. . . experimental methods & equipment, lab facilities, testing, data measurement, spectroscopy,electron microscopy, dosimeters.

INTEGRATING SPHERE for Use with a Spectroradiometer—A.L. Lea. L.J. Nicastro (ATL.Cam) **18-2** RCA Reprint RE-18-2-17

ION IMPLANTATION—Dr.E.C. Douglas. Dr. C.W. Mueller (Labs.Pr) **18-2** RCA Reprint RE-18-2-22. PE-572

THERMAL CONDUCTIVITY of Thin Samples. Measurement of—E. Belohoubek. J. Mitchell, F. Wozniak (Labs.Pr) **18-6** RCA Reprint RE-18-6-13

170 Manufacturing & Fabrication

. . . production techniques for materials, devices & equipment.

ADVANCED PACKAGING with Thin-Film Microcircuits—R. Brown, W. Grieg (Labs,Pr) **18-5** RCA Reprint RE-18-5-21

HOT-OIL-WAVE Technique, Alloying Electrodeposited Solder on Printed Circuit Boards by a—F.J. Papiano (AED,Pr) **18-1** RCA Reprint RE-18-1-25

MICROCIRCUIT PACKAGING Concepts Using Digital Computer Simulation, Evaluation of—R.M. Engler (SSD.Som) **18-3** RCA Reprint RE-18-3-11

SCRIBING AND DICING of Processed Silicon-On-Sapphire Wafers—R.L. Loper (ATL.Van Nuys) **18-3** RCA Reprint RE-18-3-21

TWEEZERS, Magnetic—W.A. Mulle (MSRD,Mrstn) **18-3** RCA Reprint RE-18-3-21

COS/MOS IS A HIGH-RELIABILITY TECHNOLOGY—Dr. G.L. Schnable (Labs.Pr) M.N. Vincoff (SSD.Som) **18-4** RCA Reprint RE-18-4-7

COS/MOS STANDARD-PARTS LINE COMES OF AGE—R.C. Heuner (SSD.Som) **18-4** RCA Reprint RE-18-4-17

180 Management & Business Operations

. . . organization, scheduling, marketing, personnel.

Advanced Technology Laboratories Profile—M.G. Pietz (ATL.Cam) **18-2** RCA Reprint Booklet. *RCA Advanced Technology.* PE-569 RE-18-2

COS/MOS MARKETS—A.J. Bosso (SSD.Som) **18-4** RCA Reprint RE-18-4-6

ECOS AT INTERCON '72—W.O. Hadlock (R&E.Cam) **18-2** RCA Reprint RE-18-2

EX-RCA'ersPIONEERS IN ELECTRONICS—J.P. Dunn. F.J. Strobl (R&E.Cam) **18-4** RCA Reprint RE-184

Hertz Corporation—A Profile—J.C. Phillips (R&E.Cam) **18-3** RCA Reprint RE-18-3

LABORATORIES, The Role of—Dr. J. Vollmer (PBD,Palm Bch) **18-2** RCA Reprint Booklet *RCA Advanced Technology*, PE-569. RE-18-2-1

MARKETING, The Role of Advanced Technology—A.T. Hospodor (ATL,Cam) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569. RE-18-2-2

RESEARCH Conference, RCA-MIT—W.O. Hadlock (R&E,Cam) **18-5** RCA Reprint RE-18-5-23

SHAPING THE FUTURE at RCA: Concluding Remarks—Dr. J. Hillier (R&E) **18-1** RCA Reprint RE-18-1-21

SHAPING THE FUTURE at RCA: Descriptions and Summaries—W.O. Hadlock (R&E.Cam) **18-1** RCA Reprint RE-18-1-21

SHAPING THE FUTURE at RCA: Keynote Address—A.L. Conrad (Staff, N.Y. **18-1** RCA Reprint RE-18-1-21

SOCIAL RESPONSIBILITYAn Interview with Dr. E. Ramberg, The Scientist and (Labs.Pr) **18-2** RCA Reprint RE-18-2

SERIES 200 MATERIALS, DEVICES, & COMPONENTS

205 MATERIALS (ELECTRONIC)

. . . preparation & properties of conductors, semiconductors, dielectrics, magnetic,electroptical, recording, electromagnetic materials

MAGNETIC BUBBLE Technology—Dr. A. Akselrad. L.S. Onyshkevych, Dr. R. Shahbender. C. Wentworth (Labs.Pr) **18-4** RCA Reprint RE-18-4-4

210 Circuit Devices & Microcircuits

. . . electron tubes & solid-state devices (active & passive),integrated, array, & hybrid microcircuits, field-effect devices, resistors & capacitors, modular & printed circuits, circuit interconnection, waveguides & transmission lines.

CHARGE-COUPLED Devices and Applications—J.E. Carnes, W.F. Kosonocky (Labs,Pr) **18-5** RCA Reprint RE-18-5-22

CMOS/SOS, Recent Developments in—W.F. Gehweiler, H.W. Kaiser, J.I. Pridgen, W.J. Stotz (ATL,Cam) *18-2* RCA Reprints Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-16

COS/MOS Integrated Circuits, Fundamentals of—R.A. Bishop, D.R. Carley (SS-Europe, England) **18-4** RCA Reprint RE-18-4-2

COS/MOS Simplifies Equipment Design—R.E. Funk (SSD,Som) **18-4** RCA Reprint RE-18-4-18

COS/MOS Technology, Development of—T.G. Athanas (SSD,Som) **18-4** RCA Reprint RE-18-4-13

MICROWAVE-INTEGRATED-CIRCUIT Layouts, Computer-designed—W.L. Bailey, R.E. Kleppinger (SSD,Som) **18-3** RCA Reprint RE-18-3-7

MOS—An RCA Pioneered Technology; COS-/MOS—RCA's Thrust in Digital Logic—H. Weisberg (SSD,Som) **18-4** RCA Reprint RE-18-4-12

POWER TRANSISTORS in Automotive Applications—W.P. Bennett, J.S. Vara (SSD,Som) **18-6** RCA Reprint 18-6-12

215 Circuit & Network Designs

. . . analog & digital functions in electronic equipment: amplifiers, filters,modulators, microwave circuits, A-D converters, encoders, oscillators, switches, masers, logic networks,timing & control functions, fluidic circuits.

A to D Converters, High Speed—J.R. Barger, D. Benima (ATL,Cam) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-19

AM RADIO, Integrated Circuit for—L. Baar (SSD,Som) **18-1** RCA Reprint 18-1-1

CONVERTER, Logic-Level-To-Pulse—M. Lipka (MSRD,Mrstn) **18-2** RCA Reprint RE-18-2-12

COS/MOS Circuits for Consumer Applications—D.R. Carley (SSD,Som) **18-4** RCA Reprint RE-18-4-9

COS/MOS Custom Design, Doing your own Thing—G.J. Waas (SSD,Som) **18-4** RCA Reprint 18-4-15

COS/MOS Integrated Circuits in the Automobile Environment—D.K. Morgan (SSD,Som) **18-4** RCA Reprint RE-18-4-11

COS/MOS Memory Module, A Multilayer, Hybrid Thin-Film 1024x3—F. Gargione, W. Keyzer, G. Noel (Labs.Pr) **18-4** RCA Reprint RE-18-4-1

COS/MOS Phase-Locked-Loops, Versatile Building Block for Micro-Power Digital and Analog Applications—D.K. Morgan, G. Steudel (SSD,Som) **18-4** RCA Reprint RE-18-4-7

COS/MOS Technology, Timekeeping Revolution Through—S.S. Eaton (SSD,Som) **18-4** RCA Reprint RE-18-4-20

ELECTRONIC IGNITION Comes of Age—R.S. Myers (SSD,Som) **18-6** RCA Reprint RE-18-6-31

FULL-WAVE RECTIFIER, Transformerless—C.F. Wheatley, Jr. (SSD,Som) **18-4** RCA Reprint RE-18-4-6

VOLTAGE REGULATOR for Less Than $8.00, Build a Dual-Tracking—A.Sheng (SSD,Som) **18-1** RCA Reprint RE-18-1-25

VOLTAGE REGULATOR, Multi-Phase Energy-Pump—E. Lachocki (GCS,Cam) **18-1** RCA Reprint RE-18-1-16

225 Antennas & Propagation

. . . antenna design & performance, feeds & couplers, phased arrays, radomes & antenna structures, electromagnetic wave propagation, scatter, effects of noise & interference.

ANTENNA RANGE, G&CS—W.C. Wilkinson (MSRD,Mrstn) **18-5** RCA Reprint RE-18-5-16

COMMUNICATION ANTENNAS for Viking Mars Lander—W.A. Harmening, W.C. Wilkinson, O.M. Woodward (MSRD,Mrstn) **18-5** RCA Reprint RE-18-5-19

FERRITE PHASE SHIFTERS for AEGIS, High Power Latching—L.J. Lavedan, Jr. (MSRD,Mrstn) **18-5** RCA Reprint RE-18-5-2

FILTERPLEXER, New VHF—D.G. Hymas, J.J. Matta, P.C. Nole, A.N. Schmitz (CSD,Cam) **18-5** RCA Reprint RE-18-5-19

LOW BACKLOBE ANTENNA for Airborne Missile-Warning System—H.Honda (ASD,Burl) **18-5** RCA Reprint RE-18-5-15

PHASE SHIFTER and Driver Design for the AN/SPY-1 Phased Array—H.C. Goodrich, N.R. Landry (MSRD,Mrstn) **18-5** RCA Reprint RE-18-5-11

PHASED-ARRAY RADAR Systems, High-Efficiency Avalanche Diodes (TRAPATT) for — Dr. K.K.N. Chang, Dr. H. Kawamoto, Dr. V.A. Mikenas, H.J. Prager, Dr. J. Reynolds, A. Rosen (Labs.Pr) **18-5** RCA Reprint RE-18-5-13

PHASED ARRAYS, Cabling Designs for—L.F. Jurkiewicz, I.D. Kruger (MSRD,Mrstn) **18-1** RCA Reprint RE-18-1-14

TELEVISION RECEIVING ANTENNAS in Blue and Gold—J.D. Callaghan, D.W. Peterson (P&A,Deptford) **18-5** RCA Reprint RE-18-5-5

ULTRA-LIGHTWEIGHT Deployable Antennas—W.S. Sepich (MSRD,Mrstn) **18-5** RCA Reprint RE-18-5-6

VERTICAL PATTERNS for TV Antennas, Computer-Aided Design of—Dr. Krishna Praba (CSD,Cam) **18-5** RCA Reprint RE-18-5-18

240 Lasers, Electro-optical & Optical Devices

. . . design & characteristics of lasers, components used with lasers, electro-optical systems, lenses, etc. (excludes:masers).

GaAs ILLUMINATORS, for Night-Vision Systems, Pulsed—W.W. Barratt (ATL,Cam) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-13

PHOTOMULTIPLIER SENSORS with a Continuously Variable Field of View—P. deBruyne (ASD,Burl) **18-4** RCA Reprint RE-18-4-6

SENSOR ARRAYS for Imaging Systems, Visible and Infrared—A. Boornard (ATL,Cam) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-5

TARGET-DESIGNATION SEEKER, Wide-Angle Laser—G.J. Ammon, D.G. Herzog (ATL,Cam) H.C. Sprigings (EC,Ltd., Montreal) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-18

YAG LASER Techniques, One Gigabit—C.W. Reno (ATL,Cam) **18-2** RCA Reprint Booklet, *rca advanced Technology*, PE-569, RE-18-2-9

245 Displays

. . . equipment for the display of graphic, alphanumeric, & other data in communications, computer, military, & other systems, CRT devices, solid state displays, holographic displays, etc.

DIGITAL DISPLAYS, Liquid Crystals and COS/MOS Offer Minimal-Power—R.C. Heuner (SSD,Som) **18-4** RCA Reprint RE-18-4-19

ELECTRICALLY CONTROLLED LIGHT VALVES for Use in an Optical Memory, Array of—J.A. Rajchman (Labs,Pr) **18-1** RCA Reprint RE-18-1-25

HOLOGRAPHIC STORAGE of Multicolor Information—G.T. Burton, B.R. Clay (ATL,Burl) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-11

HoloTape System—W.J. Hannan (Labs,Pr) **18-1** RCA Reprint RE-18-1-18, PE-561

IMAGE INTENSIFIERS in Law Enforcement Applications, Second-Generation—G.N. Butterwick, R.G. Stoudenheimer (EC, Lanc. **18-1** RCA Reprint RE-18-1-7

MILLIMETER WAVE Imaging—B.R. Feingold, Dr. B.J. Levin, D.J. Miller (ATL,Cam) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-21

250 Recording Components & Equipment

. . . disk, drum, film, holographic & assemblies for audio, image, & data systems.

MULTISPECTRAL RECORDING with Synthetic Gratings—S.L. Corsover (ATL,Cam) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-7

255 Audio Components & Applied Acoustics

. . . microphones, loudspeakers, earphones, etc., sound transmission & control ultrasonic equipment (excludes: sonar & audio recording equipment).

SPEAKER IDENTIFICATION, Automatic—W. Meeker, A. Nelson, J. Richards (ATL,Cam) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-4

270 Materials (Mechanical)

. . . preparation & properties of structural, adhesive, protective, hydraulic, & lubricant materials.

AIR-SLIDE System, Directional—A.J. Bianculli (SSD,Som) **18-1** RCA Reprint RE-18-1-25

275 Mechanical, Structural, & Hydraulic Components

. . . bearings, beams, gears, servo's, valves, etc.

DRIVE System, Asynchronous—G.J. Moore (CE,Indpls) **18-1** RCA Reprint RE-18-1-25

280 Thermal Components & Equipment

. . . heating & cooling components & equipment, thermal measurementdevices, heat sinks & thermal protection designs, etc.

REFRIGERATION Systems for Spacecraft—P.E. Wright (ATL,Cam) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-20

SPACECRAFT SIMULATION,Thermal Steady-State—R.A. Lauer, M.K. Theus (AED,Pr) **18-3** RCA Reprint RE-18-3-4

THERMAL MANAGEMENT Techniques, Novel—P.E. Joy, Jr., B. Shelpuk (ATL,Cam) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-8

SERIES 300 SYSTEMS, EQUIPMENT, & APPLICATIONS

305 Aircraft & Ground Support

. . .airborne instruments, flight control systems, air traffic control, etc.

COMMERCIAL AIRBORNE AVIONICS, Frequency Spectrum of—G.A. Lucchi (EASD,Van Nuys) **18-6** RCA Reprint RE-18-6-7

HOVER SENSOR for Heavy-Lift Helicopter, Precision—D.G. Herzog (ATL,Cam) **18-2** RCA Reprint Booklet, *RCA Advanced Technology*, PE-569, RE-18-2-10

310 Spacecraft & Ground Support

. . . spacecraft & satellite design, launch vehicles, payloads, space missions, space navigation.

GEOSTATIONARY SPACECRAFT, Propulsion for—Y. Brill, R.Lake, J. Mavrogenis (AED,Pr) **18-3** RCA Reprint RE-18-3-1

315 Military Weapons & Logistics

. . . missiles, command & control.

ENGINEERING MANAGEMENT Tools, AEGIS Weapon System—Dr. J.T. Nessmith (MSRD,Mrstn) 18-1 RCA Reprint RE-18-1-13

NUCLEAR BLAST Effects on Communication Cables, Simulation of—E. Van Keuren (GCS,Cam) **18-3** RCA Reprint RE-18-3-6

320 Radar, Sonar, & Tracking Systems

. . . microwave, optical, & other systems for detection, acquisition, tracking, & position indication.

AEGIS Weapon System Acquisition—W.V. Goodwin (G&CS,Mrstn) **18-1** RCA Reprint RE-18-1-22

AUTOMATIC LOCATION AND TRACKING of Vehicles, An X-Band Signpost System for—G.S. Kaplan, Dr. L. Schiff (Labs,Pr) **18-6** RCA Reprint RE-18-6-6

AUTOMOTIVE DOPPLER RADAR Speed Sensor—H.C. Johnson, A. Presser (Labs,Pr) **18-6** RCA Reprint RE-18-6-27

DISTRESS SIGNALING by Disabled Motorists, Microwave System for—Dr. L. Schiff, Dr. H. Staras (Labs,Pr) **18-6** RCA Reprint RE-18-6-21

DISTRIBUTED-AMPLIFIER TRANSMITTER, High-Freuquency High-Power Multi-Octave—D.L. Pruitt (MSRD,Mrstn) **18-5** RCA Reprint RE-18-5-8

DRIVER ALERT AND INHIBITION—A New Systems Approach to Motor-Vehicle Traffic Safety—A.S. Clorfeine (Labs,Pr) **18-6** RCA Reprint 18-6-22

HARMONIC RADAR for Automobile Collision Avoidance—Dr. J. Shefer R.J. Klensch (Labs,Pr) **18-6** RCA Reprint 18-6-11

HATRIC, Harbor Traffic Ranging, Identification, and Communication—E. Jellinek (GPSD,Cam) **18-6** RCA Reprint RE-18-6-8

LUNAR SOUNDER Experiment for Apollo 17—Dr. S.L. Goldman, E.J. Nossen (GCS,Cam) **18-5** RCA Reprint RE-18-5-8

MULTIFUNCTION RADAR, Computer Control of a—Dr. W. W.W. Weinstock (MSRD,Mrstn) **18-1** RCA Reprint RE-18-1-5

RADAR SYSTEMS, Displays for Modern—G.A. Senior (MSRD,Mrstn) **18-5** RCA Reprint RE-18-5-4

SECANT: A Solution to the Problem of Mid-Air Collisions—J.L. Parsons (EASD,Van Nuys) **18-6** RCA Reprint RE-18-6-4

TRAFFIC CONTROL, Satellite Systems for Civilian Vehicle—B.P. Miller (AED,Pr) **18-6** RCA Reprint RE-18-6-9

325 Checkout, Maintenance, & User Support

. . . automatic test equipment, maintenance & repair methods, installation & user support.

AUTOMATIC CHECKOUT AND MONITORING in the AN/TPQ-27 Radar System—H.P. Brockman (MSRD,Mrstn) **18-6** RCA Reprint RE-18-6-20

Author Index

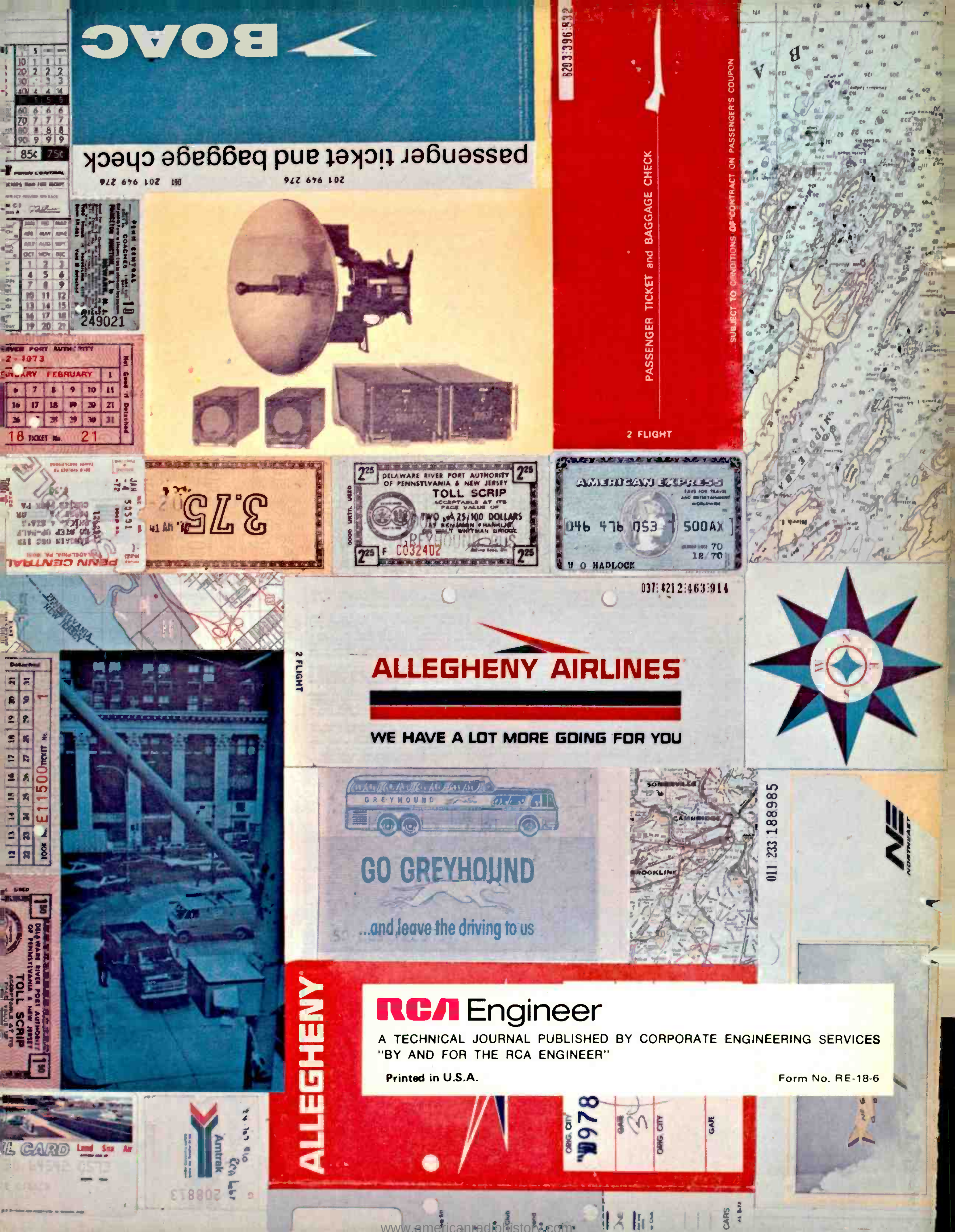
Subject listed opposite each author's name indicates where complete citation to his paper may be found in the subject index. An author may have more than one paper for each subject category.

Editorial Representatives

The Editorial Representative in your group is the one you should contact in scheduling technical papers and announcements of your professional activities.

Government and Commercial Systems	**Aerospace Systems Division**	P.P. NESBEDA*	Engineering, Burlington, Mass.
		J.J. O'DONNELL	Industry Systems, Burlington, Mass.
	Electromagnetic and Aviation Systems Division	C.S. METCHETTE*	Engineering, Van Nuys, Calif.
		J. McDONOUGH	Engineering, Van Nuys, Calif.
	Astro-Electronics Division	I.M. SEIDMAN*	Engineering, Princeton, N.J.
		S. WEISBERGER	Advanced Development and Research, Princeton, N.J.
	Missile & Surface Radar Division	D.R. HIGGS*	Engineering, Moorestown, N.J.
	Government Engineering	M.G. PIETZ*	Advanced Technology Laboratories, Camden, N.J.
		J.E. FRIEDMAN	Advanced Technology Laboratories, Camden, N.J.
		J.L. KRAGER	Central Engineering, Camden, N.J.
	Government Plans and Systems Development	E.J. PODELL*	Engineering Information and Communications, Camden, N.J.
	Communications Systems Division		
	Broadcasts Systems	R.N. HURST*	Studio, Recording, & Scientific Equip. Engineering, Camden, N.J.
		R.E. WINN	Broadcast Transmitter & Antenna Eng., Gibbsboro, N.J.
		A. C. BILLIE	Broadcast Engineering, Meadowlands, Pa.
	Commercial Systems	A.M. MISSENDA*	Advanced Development, Meadow Lands, Pa.
	Government Communications Systems	A. LIGUORI*	Engineering, Camden, N.J.
	Palm Beach Division	P.M. WOOLLEY*	Palm Beach Product Laboratory, Palm Beach Gardens, Fla.
Research and Engineering	**Laboratories**	C.W. SALL*	Research, Princeton, N.J.
		I.H. KALISH	Solid State Technology Center, Somerville, N.J.
		M.R. SHERMAN	Solid State Technology Center, Somerville, N.J.
Electronic Components		C.A. MEYER*	Chairman, Editorial Board, Harrison, N.J.
	Entertainment Tube Division	J. KOFF	Receiving Tube Operations, Woodbridge, N.J.
		J.H. LIPSCOMBE	Television Picture Tube Operations, Marion, Ind.
		E.K. MADENFORD	Television Picture Tube Operations, Lancaster, Pa.
	Industrial Tube Division	J.M. FORMAN	Inudstrial Tube Operations, Lancaster, Pa.
		H.J. WOLKSTEIN	Microwave Tube Operations, Harrison, N.J.
Consumer and Solid State	**Solid State Division**	E.M. McELWEE*	Chairman, Editorial Board, Somerville, N.J.
		J. DiMAURO	Solid State Division, Mountaintop, Pa.
		S. SILVERSTEIN	Power Transistors, Somerville, N.J.
		E.M. TROY	Integrated Circuits, Somerville, N.J.
		J.D. YOUNG	Solid State Division, Findlay, Ohio
	Consumer Electronics	C. HOYT*	Chairman, Editorial Board, Indianapolis, Ind.
		R. BUTH	Engineering, Indianapolis, Ind.
		R.C. GRAHAM	Audio Products Engineering, Indianapolis, Ind.
		F. HOLT	Advanced Development, Indianapolis, Ind.
		E. JANSON	Black and White TV Engineering, Indianapolis, Ind.
		W. LIEDERBACH	Ceramic Circuits Engineering, Rockville, Ind.
		J. STARK	Color TV Engineering, Indianapolis, Ind.
		P. HUANG	Engineering, RCA Taiwan Ltd., Taipei, Taiwan
Services	**RCA Service Company**	M.G. GANDER*	Consumer Products Administration, Cherry Hill, N.J.
		W.W. COOK	Consumer Products Service Dept., Cherry Hill, N.J.
		R.M. DOMBROSKY	Techanical Support, Cherry Hill, N.J.
		R.I. COGHILL	Missile Test Project, Cape Kennedy, Fla.
	Parts and Accessories	C.C. REARICK*	Product Development Engineering, Deptford, N.J.
RCA Global Communications, Inc.		W.S. LEIS*	RCA Global Communications, Inc., New York, N.Y.
		G. ROBERTS	(Acting) RCA Alaska Communications, Inc., Anchorage, Alaska
National Broadcasting Company, Inc.		W.A. HOWARD*	Staff Eng., New York, N.Y.
RCA Records		M.L. WHITEHURST*	Record Eng., Indianapolis, Ind.
RCA International Division		C.A. PASSAVANT*	New York, N.Y.
	RCA Ltd.	W.A. CHISHOLM*	Research & Eng., Montreal, Canada
Patents		M.S. WINTERS	Patent Plans and Services, Princeton, N.J.

*Technical Publications Administrators (asterisked * above) are responsible for review and approval of papers and presentations.



RCA Engineer

A TECHNICAL JOURNAL PUBLISHED BY CORPORATE ENGINEERING SERVICES
"BY AND FOR THE RCA ENGINEER"

Printed in U.S.A.

Form No. RE-18-6