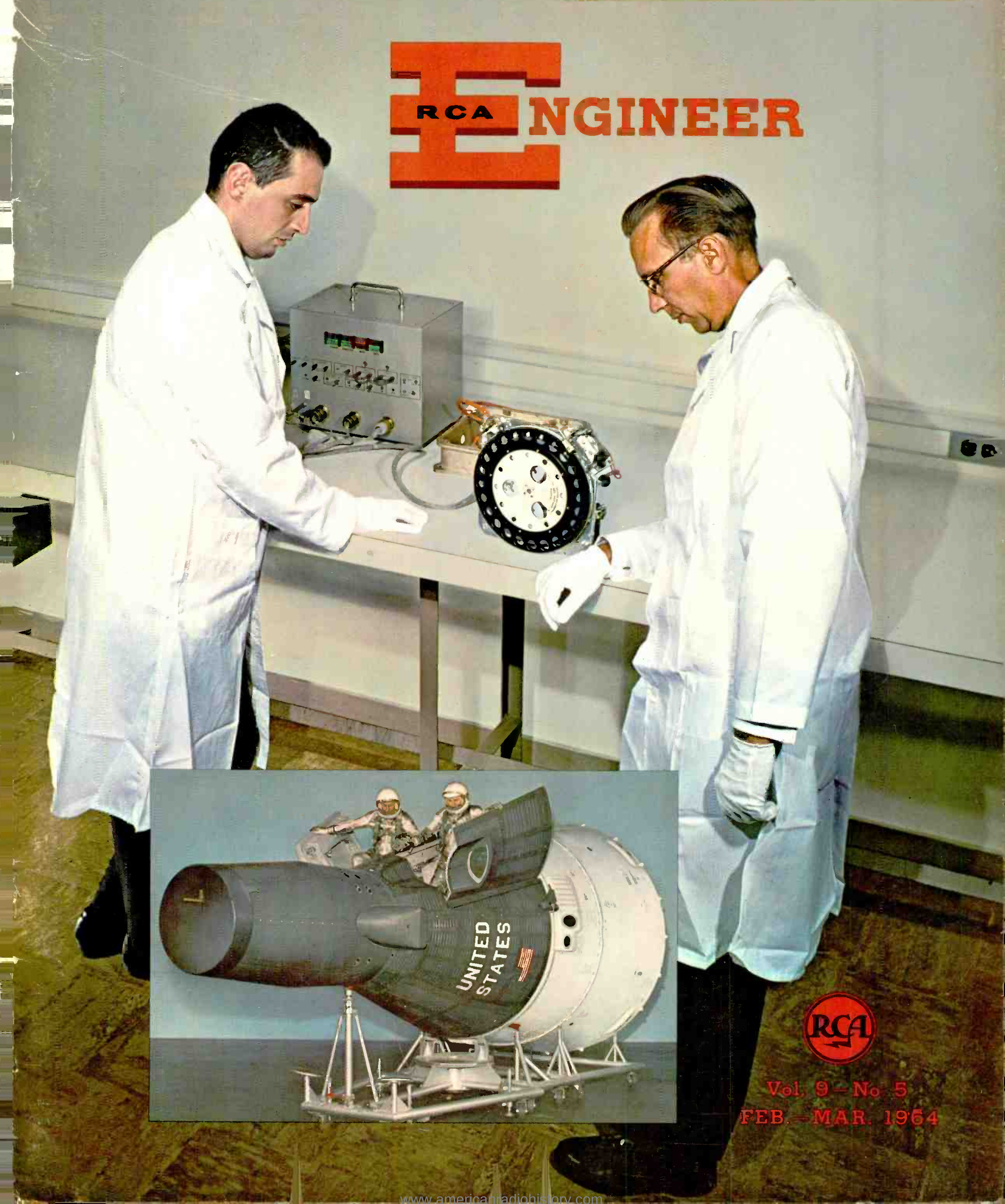
J. D. Callaghan, 215-800

RCA ENGINEER



RCA

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OUR COVER

Under white-room conditions, A. S. Katz, Project Engineer, and H. R. Warren, Mgr., Magnetic Recording Design and Development, both of the DEP Communications Systems Division, Camden, examine a miniature digital recorder designed for the GEMINI two-man space capsule shown in the inset. (Cover art director, Jack Parvin. Background photo, Rodman Allen. Inset photo courtesy McDonnell Aircraft Corp.)

Magnetic Recording

In the late 30's, I was assigned my first magnetic recording project by E. W. Kellogg. Because of the high carbon content and hence supposedly superior magnetic properties, a steel ribbon ⅛ inch wide, imported from Sweden, was used. This was not the beginning of magnetic recording within RCA, for I recall "Doc" Kellogg relating his experiences at the first RCA laboratory (a field installation at Riverhead, Long Island, in 1919 when RCA was being formed) and his efforts in magnetically recording wireless signals on wire. Needless to say, the results with the steel tape were not outstanding. I believe, however, this effort heralded RCA's entry into the magnetic recording field, as it was the beginning of the Corporation's continuously increasing developmental program on magnetic recording.

With the introduction of plastic-base magnetic tape in the late 40's, magnetic recording came into its own. Using AC instead of DC bias, the results were quite outstanding. Within a short period of time, magnetic tape replaced the lacquer disk for broadcast recording. Shortly thereafter, it became a standard medium for recording the original sessions for phonograph records. Of commercial significance, too, was the introduction of a magnetic stripe on the photograph film for sound recording.

The results obtained in audio recording so well demonstrated the capabilities of magnetic recording that industry soon began to utilize it for other purposes. That the uses are many and varied is well illustrated by the articles that appear in this issue. Improvements in tape, magnetic heads, equipment, and techniques have resulted in the application of magnetic recording to many projects where the chance of success seemed highly improbable in the beginning. Further improvements are forthcoming, and the RCA Victor Record Division's recent entry into the tape manufacturing field is just another step towards advancement and strengthening of RCA's position in the whole magnetic recording field.

H. E. Roys

H. E. Roys
Chief Engineer
RCA Victor Record Division
Radio Corporation of America

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PAPERS

NOTES

DEPARTMENTS

A TECHNICAL JOURNAL PUBLISHED BY **RADIO CORPORATION OF AMERICA,** PRODUCT ENGINEERING 2-8, CAMDEN, N. J.

● *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.*

An index to RCA ENGINEER articles appears annually in the April-May issue.

"But I'm not going to take with me any written reports about our work on guided missile power plants. It's all in my head. I'm merely going to tell Bill Smith about it when I get to Europe, and Bill is an RCA employee."

"Sorry, you can't do that without a State Department license. It would be a violation of the Mutual Security Act of 1954 (22 U.S.C.A. 1934), the maximum penalty for which is a fine of $25,000 and two years imprisonment."

"No, it hasn't been published yet, but the work our group is doing in pulsed-laser radar is well known in this country and in Canada. We have even given talks about it here. So why can't I talk to Professor Jones of Cambridge University about it when he comes to visit me at Camden next month?"

"Sorry, if you do that without a license from the Office of Export Control, Bureau of International Commerce, you will have violated the Export Control Act of 1949 (50 U.S.C.A. App. 2021). The maximum penalty is $10,000 and one year imprisonment.

The Engineer and the Corporation

LEGAL RESTRAINTS ON THE EXPORTATION OF TECHNICAL DATA

C. E. YATES, Counsel

RCA Laboratories, Princeton, N. J.

THESE two hypothetical cases were purposely picked to show how far-reaching are the laws and regulations that govern the exportation of technical data, and how important it is that each engineer be informed of the legal limitations.

For simplicity, let me start by defining the area that this article is intended to cover. First of all, negatively, the exportation of Government-classified technical data will not be treated here. That calls for separate additional safeguards of which most of us are aware.

Second, I will not write about special clearances required by the DOD, AEC, NASA, or any other Government department or agency pursuant to the express provisions of a Government contract. Suffice it to say that such clearances *must be separately obtained if required by contract* with the particular department or agency. The engineer should, in any such case, check with the appropriate Government Contract Administrator in his own RCA division.

Third, there is the subject of the exportation of commodities, viz., materials, devices, components, apparatus, etc. This is another area that I will not attempt to cover in this article. Under the Mutual Security Act there is a list of "Arms, Ammunition and Implements of War" (known as the "Munitions List") specified in a regulation issued by the Department of State entitled "International Traffic in Arms" which may not be exported without a specific license. Don't be misled by the caption. "Arms, Ammunition and Implements of War", because the list includes many components and parts specifically designed for use in military weapons but usable in commercial items. In addition, under the Export Control Act, there is a "Positive List" of chemicals, metals, wood, glass, petroleum products, scientific instruments, machinery, apparatus, etc. which may not be exported without a specific license unless covered by a general license known as "General License GLV". *Don't assume that you can carry into a foreign country in your pocket even a minute sample of experimental material without serious risk to RCA and to you.* Consult the responsible RCA International Division representative about obtaining any necessary licenses and shipping the material.

So, to sum up the coverage of this article, its objective will be to touch on some of the highlights of the exportation of unclassified technical data as controlled by the Mutual Security Act of 1954, the Export Control Act of 1949, and lastly, though not mentioned above, the Patent Act (35 U.S.C.A. 1).

Because of the complexities involved in the interpretation and application of the various laws to the exportation of technical data, no attempt will be made here to cover all the ramifications, nor even to spell out the guidelines in sufficient detail to enable the individual engineer to make his own determination as to what can or cannot be exported without a specific license. *In fact, the desirability of frequent consultations with RCA Law Department personnel merits particular emphasis.*

Before we come down to the specific controls, we should understand that *exportation* is a very broad term. It covers the release of technical data for use outside the United States (except that any release to Canada is not considered exportation in the regulations issued under the first two laws mentioned above). Exportation includes not only actual shipment, by mail or in person, out of the United States, but the furnishing of data in the United States to persons with the knowledge or intention that the persons to whom they are furnished will take such data out of the United States. The term embraces oral, visual, and written releases, and includes releases of technical data:

1) to foreign visitors to RCA plants, laboratories or offices in the United States (including such visitors even if they are employees of one of RCA's foreign subsidiaries, such as those in Zurich and Tokyo),

2) to aliens employed at any RCA location in the United States either temporarily or under an exchange visitor program or other similar basis,

3) by RCA employees while abroad, and

CARLYLE E. YATES a member of the RCA Law Department and Counsel, RCA Laboratories, is also an Assistant Secretary, RCA. He has been with RCA since 1942. Mr. Yates graduated from Hamilton College, Clinton, New York, in 1923 with an AB. He received his LLB in 1927 from Harvard Law School where he was Editor of the "Harvard Law Review." In 1927, he became an Associate of Cahill, Gordon, Reindel & Ohl in New York City. In 1930, he joined General Cable Corporation in New York City and during the period through 1940 was Vice-President and General Counsel, member of the Board of Directors and Executive Committee, and Secretary of the Corporation. Mr. Yates became Assistant to the General Counsel of the Trustees of Associated Gas and Electric Corporation of New York City in 1940, a position he held until 1942, when he joined RCA as Assistant General Attorney. In 1945, he was named Assistant General Counsel of NBC. He assumed his present position in 1947. A member of the New York and Federal Bars, Mr. Yates is a member of the Federal Communications Bar Association and the Association of the Bar of the City of New York. He also is a member of Phi Beta Kappa and Delta Sigma Rho.

4) by participation in conferences or symposia where aliens are present.

Also, while Canada is specifically excluded from the above definition, technical data may not be exported to Canada with the knowledge or intention that they will be re-exported or transhipped to some other foreign country.

MUTUAL SECURITY ACT OF 1954

Regulations hereunder are issued and administered by the Department of State and cover the exportation of technical data *"relating to the articles designated . . . as arms, ammunition, and implements of war"*.

Technical data are defined as *"any professional, scientific or technical information relating to arms, ammunition, and implements of war, including but not limited to, any model, design, photographic negative, document or any other thing containing a plan, specification or descriptive information of any kind"*.

No such technical data may be exported without a specific State Department license unless they fall in one of the following six exemption categories (but even if such data do qualify for one of these exemptions, they still may not be exported, without a license, to the Soviet Union, Soviet bloc countries, Communist China, North Korea, any of the territories of Viet-Nam which are under de facto control of the Communists, or any other area that may come under Communist control):

1) Technical data in published form and available for public dissemination.

2) Technical data already reviewed and approved for public release by an authorized agency of the Department of Defense.

3) Technical data exported pursuant to a Government-approved manufacturing license or technical assistance agreement.

4) Technical data exported pursuant to a Government contract specifically calling for the transmission of the data.

5) Certain technical data relating to firearms not in excess of caliber .50.

6) Technical data relative to sales bulletins, operational maintenance manuals, and sales promotion manuals covering equipment, where exportation of the equipment itself has been authorized, including additional copies of any such items previously approved for export.

EXPORT CONTROL ACT OF 1949

Regulations hereunder are issued and administered by the Office of Export Control, Bureau of International Commerce, of the Department of Commerce, and cover technical data relative to everything exportable excepting arms, ammunition and implements of war, gold, narcotics, nuclear material and facilities for its production or utilization, vessels (except for scrapping), natural gas, electric energy, and tobacco seed and plants. Here we should note particularly that, unlike the State Department regulations governing arms, ammunition and implements of war, the Export Control regulations must be complied with in order to export technical data even though such data have been approved for public release by the Department of Defense. The definition of *technical data* in the Export Control regulations is substantially similar to the State Department's definition above and need not be repeated here.

No such technical data subject to Export Control regulations may be exported without a license, either a "validated license" from the Office of Export Control for which written application must be filed and which authorizes the specific exportation applied for, or a "general license". Three of these general licenses are worth describing here, because much technical data may be exported under general license without application to the Office of Export Control or any other formality; actually, they are exemptions written into the regulations.

General License GTDP (General Technical Data Published)

This license permits the exportation of technical data generally available in published form, i.e., by definition:

1) sold at newsstands or bookstores;
2) available by subscription or purchase without restrictions to any person or available without cost to any person;
3) granted second class mailing privileges by the United States Government; or
4) freely available at public libraries.

Of course, any such published data may be freely talked about and, in contrast to the corresponding exemption in the State Department's regulations relative to technical data on arms, ammunition and implements of war, the exportation of GTDP—licensed data may be extended to any part of the world, including the Soviet Union and the Soviet bloc.

General License GTDS (General Technical Data Scientific)

This license permits the exportation to any part of the world of unpublished unclassified technical data *provided they are scientific* (i.e., in the area of science as distinguished from technology, or comprising the results of fundamental research rather than applications to materials, devices, apparatus, systems, etc.) or educational data. In particular, such data *must not "directly and significantly relate to design, production and utilization in industrial processes"*.

General License GTDU (General Technical Data Unpublished)

This license is available in cases where the technical data to be exported are neither generally available in published form (GTDP) nor scientific or educational data (GTDS). However, this license is *much more restrictive* than either GTDP or GTDS.

In the first place, it is good only for export to friendly countries (i.e., excluding the so-called "Subgroup A" countries, and Poland and Cuba).

Secondly, technical data relating to such items as civil aircraft and components, electrical and electronic instruments specially designed for testing or calibrating airborne direction finding, navigational and radar equipment, airborne transmitters and receivers and transceivers, airborne direction finding equipment, and airborne electronic navigation apparatus and airborne radar equipment may not be exported under General License GTDU.

Thirdly, if the technical data to be exported consist of or include "advanced developments, technology, and production know-how" or "prototypes" or "special installations" (not including, however, advertising catalogs or pamphlets, sales technical data, or maintenance, repair and operating data) which have "significance to the common security and defense of the United States", they *may not* be exported under General License GTDU.

PATENT ACT (EFFECTIVE JANUARY 1, 1953)

Section 184 of the Patent Act provides that, in the absence of a license from the Commissioner of Patents, *no person shall "file or cause or authorize to be filed in any foreign country prior to six months after filing in the United States any application for patent or for the registration of a utility model, industrial design, or model in respect of an invention made in this country"*. This is the third and last of the three important laws imposing restrictions on the exportation of technical data.

The purpose of the six-month time interval is to give the Commissioner of Patents an opportunity to check with the Department of Defense and other departments or agencies of the Government to determine if the publication or disclosure of the invention by the granting of a patent would be detrimental to the national security. If such detriment could be caused, the Commissioner then issues a Secrecy Order, and the application is "sealed" and cannot mature into a patent until the Secrecy Order is rescinded.

Before "exporting" any technical data about an RCA invention, whether it be an invention made by you or one conceived by another RCA employee, it is important that you check with the Law Department to be sure 1) that there is no Secrecy Order issued and still outstanding with respect to the patent application, and 2) that, if a patent application has not yet been filed (or if the period of six months from the United States filing date has not yet expired), a determination can be made as to whether the invention is one having significance to the national security.

THE ROLE OF RCA INTERNATIONAL

A final note of caution concerns the role of the RCA International Division in the exportation of technical data. RCA's foreign licensees under "technical aid" license agreements are entitled to certain technical data as defined in the respective agreements. The International Division representative at your location (or the Manager, Licensee Services, RCA International Division, at Camden, Harrison, Indianapolis, or New York) is aware not only of the various export control restrictions but also of the contract provisions which spell out what technical data the particular licensees are entitled to receive. The responsibility for exporting technical data to foreign licensees who are entitled to receive them lies with personnel in the International Division. Thus, the RCA engineer should not, on his own, export technical data to a foreign licensee unless requested or authorized by someone in the License Operations Division of RCA International.

ENGINEERING TAPE PRODUCTS AND SYSTEMS— A COMPANY-WIDE PROGRAM

The importance of magnetic tape devices and systems to RCA'S product line and the need to apply the full resources of our research, development, and product-design organizations to the technical problems of these machines led to a corporate-wide "Tape Systems Symposium" in early 1962. Papers were presented on data processing, video recording, magnetic tape, and magnetic pickup heads, as well as theoretical considerations for system optimization. Participation included technical representation from the RCA Laboratories, and the applied research and design groups of the DEP, EDP, Broadcast, and Record Divisions. The focusing of attention on the cohesive and common features of such diverse and extensive technology served as an impetus for the collection of papers in this present issue. (The content of the papers herein has, of course, been updated consistent with new developments in the field since the symposium.) As an introduction, this paper summarizes RCA efforts in this field and includes a tabulation of the technical characteristics of specific RCA equipment. Details on much of this work are presented in the papers that follow.

H. KIHN, Staff Engineer

Research and Engineering, Princeton, N. J.

ALTHOUGH the tape and tape-systems industry is huge by any standard, its phenomenal growth was largely post World War II when plastic base tape with powdered magnetic materials came into wide use, replacing wire and steel tapes which harked back to the work of Poulsen, Carlson, and Carpenter, among others. Although the advent of sound recording and reproduction provided the major impetus for improved tape and reproducers, it was the development of video tape equipment and the extensive use of tape stations as important elements in data processing systems which established the foundations of this rapidly growing industry. It has been estimated that the industry sales of magnetic tape for all uses was $60 million in 1962 and would reach $130 million by 1965. Another source estimated the 1963 breakdown of tape sales to equipment manufacturers to be *audio*, $29 million; *computer*, $25 million; *instrumentation*, $20 million; and *video*, $9 million; and that these markets will grow at a minimum rate of 10% per year.

It is interesting to compare the 1962 domestic industry sales of computer *tape* ($23 million) with the value of computer *tape systems* of approximately $450 million installed in 1962. Although this rate of *systems sales* to *tape sales* varies from one application to another, it illustrates well how magnetic tape can provide the basis for a *tape systems* industry twenty times its size. It is evident, therefore, why extensive divisional effort in this field is justified on its own merits as a business, and as an important contribution to NBC, to broadcast, computer, defense, and consumer products, and to the RCA Service Co., in their general systems activities.

The severe requirements of uniformity, durability and freedom from dropouts imposed by the computer and video usage of magnetic tape has brought a new dimension to tape research and development, and huge investment in facilities for the manufacture and testing of precision tapes. The factor of durability of tapes and magnetic heads looms as important development projects because of the high head-to-tape speeds of modern video recorders and computer tape stations and the need to get intimate contact to provide adequate signal output. The latter is an exponential function of the head-to-tape spacing d according to the relation *loss* (db) $= 55\ d/\lambda$, where λ is the signal wavelength on the tape.

The electromechanical aspects of the tape transport have undergone extensive improvements in recent years with the purpose of increasing the absolute time-base stability, despite increasing head-to-tape speed to attain higher information rates. The use of air bearings, fast-acting servo systems, electronically variable delay line (EVDL) compensation, and low-inertia tape-demand systems, including start accommodators and vacuum chamber storage, have made modern machines precision equipment indeed. Precision time base performance characteristic is an important asset in radar doppler tape processors and TV recorders. To simplify machine loading and to protect the tape from careless handling and environmental conditions conducive to tape damage, increasing use of tape cartridges is evident.

The frequency which can be reproduced on tape follows the relation $f = V/\lambda$, where V = head-to-tape velocity. Thus, the approach to higher frequencies (greater information rates) have been to both increase V and reduce λ. The former reached the limit where recording time was reduced to a few minutes if the normal longitudinal mode was used, so the transverse mode — wherein the high velocity is attained by rotating heads (quadruplex, octoplex, etc.)—came into wide use in video recorders. Wavelength λ has been reduced to fractions of a mil by use of narrow gap heads, close head-to-tape spacing and thin magnetic coatings on the tape.

Recent developments to reduce the number of magnetic heads and consequently the switching problems in transverse scan have tended toward helical—or slant-track recording techniques. In this technique the number of heads required is related to the number of tracks or channels by $N_h = N + 1$, which indicates that a one-track system would require two instead of four magnetic heads as in the transverse quadruplex system. Synchronous systems, as in TV having adequate vertical blanking time, can accomplish helical scan with *one* head.

Developments in modulation of the

HARRY KIHN received his BSEE from The Cooper Union Institute of Technology in 1934, and his MS from the University of Pennsylvania in 1952. Mr. Kihn joined RCA in 1939 as a research engineer associated with television receiver and circuitry development. During World War II, as a member of the technical staff of RCA Laboratories at Princeton, he performed research relating to radar for automatic bombing and altimeters. With the advent of color television development in the post-war period, he played a prominent part in the development of receiver circuitry. Subsequently he was engaged in further radar reaseach and directed research in pulse code and digital communication and computer systems. Since early 1960, he has been a Staff Engineer on the RCA Research and Engineering Staff, in charge of coordinating RCA technical activities in data processing, semiconductor devices, and other fields, including both defense and commercial applications. He is a Fellow of the IEEE, and is a Member of Sigma Xi.

TABLE I—RCA Tape Recording and Reproducing Systems

"RCA Division" indicates where the work is being done as of this writing; it does not necessarily indicate where the work began.

Category and RCA Div.	*Model*	*Use or Type*	*Tape Speed, ips*	*Record & Playback Time, minutes*	*Type of Modulation*	*Frequency Response or Info. Rate*	*Time Base Stability, nsec or flutter %*	*No. of Channels or Tracks*	*Remarks*
CATEGORY I									
Home Instr. Div.	1YB1 1YB29A	cartr., mono.	3¾–1⅞	120 music, 240 voice	DR	50 cps–15 kc	—	—	Home entertainment Product line
	1YC1 3YD1	cartr., stereo	3¾–1⅞	60 stereo, 120 mono, 240 voice	DR	50 cps–15 kc	—	—	
Brdcst. & Comm. Div.	RT21A,B	mono & stereo	A: 3¾–7½ B: 7½–15	120 @ 3¾ ips; 1.5 rewind (2400-ft reel)	DR, 80-kc bias	50 cps–15 kc (15 ips); 40 cps–10 kc (7½ ips); 50 cps–7.5 kc (3¾ ips).	0.1% to 0.25%	4-head dual half track	Professional ¼″ audio tape recorder system
	RT37 RT7B	stereo cartr. mono	7½	Up to 31	DR, 80-kc bias	50–12 kc	<0.2%	—	
CATEGORY II									
DEP-MSR	PTS	TRADEX	1100	5 (30″ reel)	digital FM	3 Mc 4.5 Mc	±15 nsec	7, 8	Radar instrumentation
RCA Labs.	Compact Recorder	video-audio	120	12 (7″ reel) 60 (15″ reel)	FM, low video DR, hi video DR, audio	300 kc 300 kc–2.5 Mc 50–10 kc	<0.1%	1	Research unit
DEP-CSD	SL-100	GEMINI	1⅞ 41¼	240 10.9	Various NRZ and RZ combinations digital and/or Analog	5–12 kc 112.6 kc	±2% 0.1%/sec/sec	2–7	Miniaturized lightweight low power 400 cu in, 12 lbs, 10 watts
DEP-AED	QRA-1	TIROS video	50	1.5	FM 85 ± 15 kc	62.5 kc	0.05% in 250 cps BW	2	Miniaturized lighweight high G capability, wide temperature range, low power consumption, high reliability tape recorder-reproducers. Approx. specs: weight 16 lbs, diam. 14″, height 7″, temp. range 5°C to 55°C; G forces 10–18
	QRA-2	NIMBUS-AVCS	30	8	FM 73 to 120 kc	60 kc	0.2% in 5-kc BW	4	
	QRA-3	NIMBUS-HR1R	3¾ 30	115 7.2	FM 10 kc	2.5 kc	0.2% in 5-kc BW	4	
	QRA-4	621A video	50	1.5	FM 85 ± 15 kc	62.5 kc	0.1% in 300 cps BW	2	
	QRD-1	621A telemetry	7.5 60	64 8	pulse width pulse code	172 bits/sec 900 bits/sec	0.1% in 300 cps BW	6	
	QRD-2	OGO EOGO	0.297 18.9	720 11.5	NRZ to RZ	1,000 bits/sec 64,000 bits/sec	500 nsec	9	
	QRD-3	OGO POGO	1.18 37.9	180 5.7	manchester coding	4,000 bits/sec 128,000 bits/sec	500 nsec	9	
CATEGORY III									
Brdcst. & Comm. Div.	TR-22, TR-3, TR-4, TR-5 (portable)	Quadruplex TV Broadcast	15; 7½	96 (14″ reel)	FM	30 cps–4 Mc	±10 nsec	1 + audio and control	TR-22, transistorized rec & play; TR-3, play only; TR-4, rec + play; TR-5 portable rec + partial play
DEP-CSD	DCDS	octaplex radar data	6 (rec) 0.3 (play)	20 (14″ reel)	FM (10.75 Mc carrier)	7.5 Mc	±10 nsec	2	Dual channel dial speed
	ST 502 GT 502	airborne, video ground reproducer	—	60	FM (7.5 Mc carrier)	100 cps–6 Mc	100μsec/msec	2 (two-sided tape) plus two 25-kc channels	—
	PT 300	portable video (quadr.)	7½	60 (9″ reel)	FM	30 cps–4 Mc	150 nsec per head cycle	1 + audio	Compatible with TR-22
	GT 200	wideband recorder-reproducer (octoplex)	15	60 (12½″ reel)	FM	30 cps–4 Mc	±1 μsec	2 plus 5 auxiliary	—
DEP-App. Res.	MIPIR, MARS, ARIS	helical scan, 3 head	30 (head-tape 1,900)	24 (10½″ reel)	FM (5 Mc carrier)	30 cps–4 Mc	200 μsec/scan	3 (MIPIR); 2 MARS, ARIS	

signal upon the tape have contributed to improvements in signal-to-noise ratio, increased the signal packing density and minimized the effect of nonuniformity of magnetic characteristics of the tape. In addition to amplitude modulation (i.e. "direct recording"), other widely used techniques include single-side frequency modulation, pulse or RZ or NRZ (non-return-to-zero), biphase, and quadriphase modulation.

The activities of the various RCA divisions involved in tape or tape systems manufacture and development, afford a perspective in this regard. These activities may be generally divided into five categories. Although these are somewhat arbitrary, since there is a good deal of overlap among them, they represent a useful compartmentation on the basis of functional use and the technology involved:

Category I: These include *low* tape speed, *continuous* tape motion, *longitudinal* tape travel, *stationary* magnetic head recording systems.

Category II: These include *medium* and *high* tape speed, *continuous* tape motion, *longitudinal* tape travel, *stationary* magnetic heads, *instrumentation* and *low-video frequency* recording systems.

Category III: These include *medium* tape speed, *continuous* tape motion, *longitudinal* or *helical* tape travel, with *high speed transverse* magnetic head motion, *high video frequency* recording systems.

Category IV: These include *medium* and *high* tape speed, *intermittent* tape motion, *longitudinal* tape travel, *stationary* magnetic head, *digital* tape recording systems.

Category V: This includes the manufacture of magnetic tape, magnetic heads, and other components as well as research activities in these areas and in magnetic materials used therein.

In order to simplify the presentation of the corporate activities in tape recording. Table I has been prepared, arranged according to the categories defined above. The criteria of comparison is on the basis of important performance characteristics such as: area of tape usage, time duration of recording and reproduction, the information bandwidth, type of modulation, system time basis stability (jitter, flutter and wow), bit density etc. It is not intended that this table be an exhaustive list of all the specifications of the machines, but rather an abbreviated catalog which reveals the widespread involvement of RCA divisions in tape recording and reproduction.

Although the various tape recording systems have been categorized largely on the basis of the tape and recording head motion, each of these may incorporate a variety of modulation techniques which are uniquely designed to optimize signal to noise, information bandwidth handling capability, freedom from dropouts, and bit or information packing density on the tape. While in the conventional sound tape recording system the modulation system is straight analog or linear modulation, the instrumentation field may utilize pulse coding, biphase or quadriphase modulation or FM single or double sideband. The video machines have largely standardized on single-sideband FM with carrier fre-

TABLE I—cont'd

Category and RCA Div.	Model	Use or Type	Tape Speed, ips	Record & Playback Time, minutes	Type of Modulation	Frequency Response or Info. Rate	Packing Density, bits/in	No. of Channels or Tracks	Remarks
CATEGORY IV									
EDP	381	tape sta.	30 F&R, 90 rewind	1200-ft reel	NRZ	10,000 char/sec read & write	333⅓	6 info, 1 par	3, 4, or 6 tape decks; ½" tape.
	382	tape sta.	60 F&R, 120 rewind	1200-ft reel	NRZ	20,000 char/sec read & write	333⅓	6 info, 1 par	3, 4, or 6 tape decks; ½" tape.
	581	tape sta.	100 F&R	2400-ft reel	pulse (RZ)	33,333 char/sec	333⅓	14 info, 2 par	Dual recording of ¾" each character.
	582	tape sta.	100 F&R, 150 rewind	2400-ft reel	NRZ	66,667 char/sec	666⅔	14 info, 2 par	
	681	tape sta.	150 F&R 225 rewind	2400-ft reel	NRZ	120,000 char/sec	800	14 info, 2 par	Variable length ¾" Data Recording. Dual recording each character. Read-after-write check.
	3485	industry-compatible tape sta.	150 F&R, 300 rewind	2400-ft (10½" reel)	—	30,000, 83,400, or 120,000	200, 556, 800	7 channel	

Model	Use or Type	Gap µinch	Track Width, mils	Tape Width, inches	No. of Tracks
CATEGORY V—Heads					
Brdcst. & Comm. Prod. Div.:					
A	301 record file	250	10	—	2
B	381	500	32	½	7 + DC erase
C	582	250	18	¾	16 read after write
D	681	40	20	¾	16 read after write
E	special	200	26	1⅛	20
H	581	250	20	¾	16 & DC erase
J	early compact video	35	80	¼	2
MI-40760 ball brg, MI-40790 air brg	video	90	10	2	1
MI-40791 ball brg, MI-4799 air brg	video	90	5	2	1
RCA Laboratories: Compact experimental video recorder		40 & 20	400	¼	3 & 3
DEP-CSD:					
	TIROS	90	40	¼	2
	OGO	250	25	½	9
	NIMBUS	90	50	½	4
	SAT-INSP	250	36	½	6
	DAMP	40	30	¾	1, 2, 7
	TRADEX	40	30	1	7, 8
	GEMINI	90	50	¼	2
	MTE	250	25	½	8
	MADRE	250	40	Disk	—
	TRADEX (Floating)	500	40	Disk	—
	DC erase (dbl.-coat tape)	—	—	2	—

Type	Use	Tape Width, inch	Base Film mils	Mag. Coating mils	Yield (5% elong.) lbs	Signal to print-thru ratio, db
CATEGORY V—Tape						
RCA Victor Record Division *All types have 250-oersted intrinsic coercivity and 850-gauss retentivity.*						
15A	all purpose	¼	1.45	0.40	4.5	48
15M			1.45	0.40	5.5	48
15AL	low print thru	¼	1.42	0.44	4.5	53
15ML			1.45	0.44	5.5	53
10A	long play	¼	0.96	0.40	3.1	44
10M			0.97	0.40	3.7	44
5M	extra long play,	¼	0.5	0.40	2.25	40
5TM	dbl. strength		0.5	0.40	2.75	40
301	computer	½	1.45	0.45	5.5	—

Notes:
BW—bandwidth
DR—direct recording (i.e., AM)
par—parity bit
info—Information bit
F&R—forward and reverse
RZ—return to zero
NRZ—nonreturn to zero

quencies in the neighborhood of 5 to 10 Mc, depending on the signal bandwidth.

The digital machines generally use pulse recording. Here, too, a variety of modes are involved, although NRZ has become the rule in advanced machines such as the 582 and 681 tape stations for reasons of increased information capability and ease of erasure.

The following discussions provide additional insight into the equipment listed in Table I.

CATEGORY I

Category I may be represented by the large consumer market type tape recorder as well as the higher quality broadcast, industrial and military sound systems. The principles of operation of these units are well known and except for transistorization and the use of stereo and cartridge tape packages, little of technical novelty has been introduced in recent years. These are, however. an important part of our Home Instruments and Broadcast and Communication Division's Product Line and a customer for the Record Division Tape Manufacture.

CATEGORY II

Category II encompasses the widest spectrum of tape devices, speeds and types of modulation, which is so characteristic of the instrumentation field. Included are lightweight, compact, low power, satellite video tape machines, radar doppler processors, an experimental compact video recorder and a large class of telemetry recorders and reproducers of great importance to our space and defense effort.

CATEGORY III

Category III equipments are oriented largely toward television and similar video presentation in which an economy of tape for a given bandwidth stored and a flickerless presentation, without the need of intermediate storage, is essential. It has become the backbone of the television broadcast industry and as such is of great importance to RCA. Because of its advanced state of development, the use of this type of tape system is expanding into the high information rate instrumentation field where the higher cost is warranted by the technological and military requirements. The TR-22 in the Broadcast field and PT 300 in military TV recording are representative of this class of machine.

CATEGORY IV

The machines of Category IV are, at present, largely confined to providing large bit capacity serial storage for data processing systems. The characteristics of these intermittent-motion machines, as contrasted to the continuous running transports used in the previously mentioned instrumentation and video recorders, are the ability to start and stop the tape rapidly and to transport the tape in either direction in response to command signals. The limited internal memory capacity of most data processing system requires that only a small portion of the information stored on a reel of tape can be transferred to the memory at any one time. To accomplish this the tape must be started quickly, run for a short period of time until the required information is located, transferred to the memory and stopped until the system is ready to receive or transmit more data. This cycle is repeated until the data processing is completed.

In most data processing systems, such progress has been made in the speed of logic circuitry and reduction of memory cycle time, that the tape system is the limiting factor in the speed of computation. Great effort is therefore being expended in increasing the speed of tape machines and packing density on the tape, as evidenced by the progression from type 381 to the type 681 tape stations, and providing auxiliary high capacity *magnetic disk* or *magnetic card* storage. The latter two devices are "magnetic recording machines" capable of parallel, rather than serial input and output, and possess higher-speed processing capability than magnetic tape machines.

Because of the importance of accuracy in every information bit stored on computer tape, such novel features as *parity bits, read after write and correct*, or simultaneous duplication of information on parallel tracks are included in advanced tape stations. This approach is rarely necessary in most of the analog applications of tape recordings. An important requirement of digital tape machines is that the tape in the vicinity of the heads and capstans be isolated from the reels by a slack-takeup mechanism because of the high acceleration inherent in its operation. Furthermore, a means of sensing the amount of tape in these loops is required so as to actuate the servomechanism which controls the movement of the reels. Either a moveable takeup arm or a vacuum column may be employed. In the former, the movement of the tape actuates the takeup arm providing the sense signal for the servo. In the latter, the end of the tape loop in the vacuum column is sensed by a photoelectric or pressure sensing device which generates the servo signal. This feature, too, is different from the analog machines of the first three categories.

CATEGORY V

In all the tape machines of the four categories discussed heretofore, the common denominator is the quality of the magnetic tape used for the information storage function. Among the essential characteristics of the tape are: uniform oxide particle-size to provide high-resolution capabilities; smooth and durable tape surface to minimize deposition of oxide upon the pickup head and to insure extended tape life; and the absence of foreign matter and nodules to eliminate dropouts, particularly for digital use. The use of a Mylar substrate has largely solved the tape stretch problem—although the trend toward thinner substrates for increased *play* time on a given diameter reel has aggravated this problem. An important concern is the trend toward thinner oxide layers as recording speeds are increased, thereby reducing the life of a reel of tape unless more durable binders are developed and used. Much research is being carried on in the area of new materials other than iron oxide which possess better high-frequency performance and are capable of higher information packing density. An extensive program to develop tape which satisfies these requirements at a reasonable manufacturing cost is under way at the Record Division in Indianapolis and at the RCA Laboratories in Princeton.

An interesting approach to increased utilization of a given length of tape so as to increase its information storage capability by a factor of two, is the development of *double-sided tape*. Both sides of the tape carry a magnetic oxide coating of the proper thickness and separated by a suitable thickness of Mylar substrate such that there is little cross-talk between the information on the two sides. The use of wavelengths which are small with respect to tape thickness, and novel scanning techniques involving a minimum of coincident tracks as in transverse head machines where this has been tried, contribute to the isolation between the two sides. Because of the importance of magnetic tape in the data processing operations and the catastrophic consequences of imperfections in the tape upon the continuity of operation of these systems, a 100% tape testing program is being carried on in Indianapolis and in EDP, Camden.

The magnetic head, as the interface between the tape and the tape station electronics, is a crucial element in the tape recording system. This device determines to a large extent the resolution or information packing density, the signal output, the channel cross talk and the minimization of down time for servicing the tape equipment. Complexity of magnetic heads range from the single-channel low-cost heads of the consumer products to the multiple channel precision quadruplex and octoplex heads on air-floated bearings, incorporating fractional-mil gaps and hardened material magnetic pole tips for long life. One may surmise the care involved in designing a structure housing eight magnetic heads, spaced exactly 45° apart (10 seconds of arc accuracy) and rotating at 28,000 rpm with negligible variation in head-to-tape spacing, despite the enormous centrifugal forces inherent in such angular velocity.

Because of the importance of heads to RCA's tape equipment, advanced engineering development and design are carried on in both the Broadcast Division and the DEP Communications Systems Division in Camden. The necessary precision manufacturing and specialized test facilities required are provided by the Broadcast Division in Camden.

SUMMARY

This paper has briefly summarized the characteristics and applications of magnetic tape recording devices developed and manufactured by RCA. It becomes apparent that there are few electronic systems which involve so many diverse technical disciplines *(mechanical, magnetic,* and *electronic)* as a magnetic tape system.

Among the considerations involved in the complex and precise *mechanical* system are: the tape transport requiring stability and freedom from jitter at high speeds and in computer tape stations, precise servo control of tape position; the severe dynamic environment of multiple magnetic heads rotating at tens of thousands of RPM; the minimization of frictional forces and abrasion of both magnetic heads and tape as well as provision for adequate tensile properties of the latter.

The *magnetic* systems, including both head and tape, involves the design of microscopic air gaps to accurately control the fringing magnetic field coupled to the tape; and in the tape itself, control of the magnetic coercivity, remanence and *B-H* loop squareness characteristics are important performance goals.

The electronic and signal processing system includes signal amplification, sophisticated modulation techniques (amplitude, FM, pulse, multiphase, etc.) to abstract undistorted signals from a basically nonlinear magnetic element, under optimum signal to noise conditions, or to increase the information packing density on the tape. The electronics may involve the use of electronically variable delay lines to compensate for limitations in mechanical stability of the system, particularly in applications where doppler signals must be processed or synchronizing signals be accurately timed.

The economic value of these systems to RCA may be judged from their importance to our consumer and broadcast product lines, their key position in television, in instrumentation and telemetry and in modern data processing and their contribution to the proper performance in many aspects of our space and defense business. The explosive growth of magnetic tape recording in the last decade will continue unabated into the next, with known applications pressing on the technological frontier of tape and tape systems. When one considers the present and projected business in this field it becomes apparent why continued research development, and improvements in manufacturing technology in tape and tape systems are important elements in RCA's plans for the future.

ADVANCED MAGNETIC-RECORDING TECHNIQUES AND EQUIPMENT

To meet the growing demands for higher density storage, increased bandwidth, lower power, and lighter weight, magnetic recording engineers must constantly search for new techniques. This paper discusses some of these techniques and their application by the Magnetic Recording Section of the DEP Communications Systems Division, and describes specific equipment in which many state-of-the-art techniques are used.

To appreciate fully the advances made in magnetic recording in a relatively short period of time, note that magnetic recording was in its infancy at the end of World War II; at that time, it was difficult to achieve 15-kc audio at a tape speed of 15 ips (0.001-inch wavelength).

One of the first advancements resulted from the need to reduce the quantity of tape for a given amount of recorded information. Magnetic heads were developed with finer gaps capable of resolving ½-mil (0.0005-inch) wavelengths; this development resulted in a tape speed of 7.5 ips. The continuing need for a reduced quantity of tape for a given amount of information lead to the use of half-track audio recorders—that is. two tracks were recorded in the space of one.

RCA's continued development work resulted in another two-to-one reduction in tape speed (3.75 ips) and at the same time doubled the number of tracks (four tracks on ¼-inch tape). Concurrent with the development of audio recorders was the development of tape stations for the storage of large volumes of data for computer use. Henceforth, a need for the storage of television pictures led to the development of magnetic tape recorders with a 4-Mc bandwidth.

In more recent times a need for both dual-channel wideband recording and high-density recording has arisen. Dual-channel wideband recording is essential in closely correlating the signal from two separate radar returns and in recording one wideband channel of analog signals along with a channel of high-bit-rate digital signals. In both cases the isolation between channels must be at least 36 db.

The importance of weight and size in airborne and spaceborne recorders necessitated the development of techniques for greatly reducing the amount of tape required for recording a given amount of data. Also, because of the limited power in spacecraft, the recorders must have high operating efficiency.

H. R. WARREN, Mgr.
Magnetic Recording Design and Development
Communications Systems Division
DEP, Camden, N. J.

SOME NOVEL TECHNIQUES

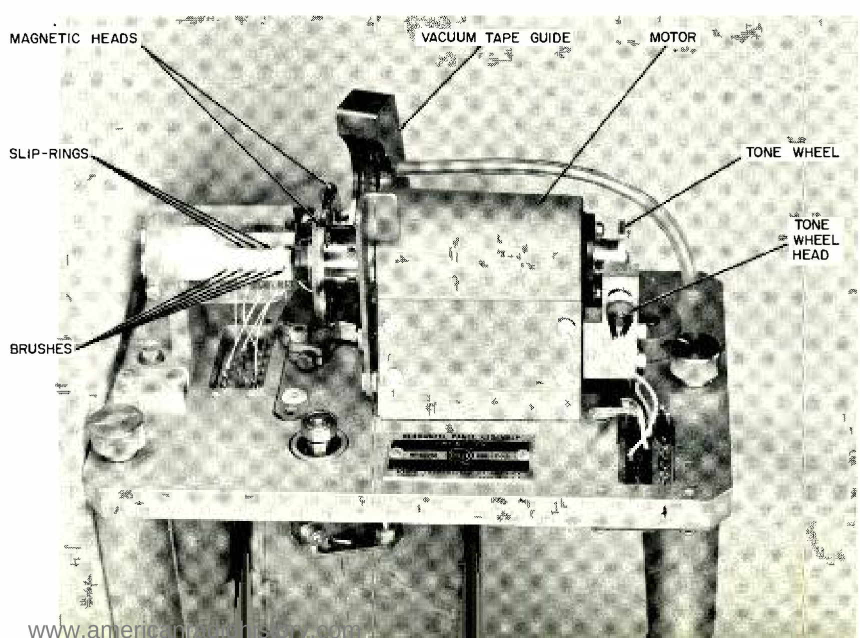
To fufill the above needs, magnetic recording engineers of CSD have developed several novel techniques. To satisfy the demand for dual-channel wideband operation, the *octaplex* scan system was developed. This technique allows the recording of two simultaneous wideband channels with 0.1-μsec interchannel time displacement with isolation between channels of over 36 db. The high-density analog need was satisfied in some cases by narrow-track recording. In other cases, recording on both sides of thin-base, double-coated tape was the answer. A combination of narrow-track recording and double-coated tape allowed a giant step to be taken in increasing the information per unit volume of tape. The need for high-density digital recording was satisfied by the development of a *modified diphase system*[1] in which 3,300 bits/inch per track can be recorded. This packing density is about three times greater than that currently available in computer applications.

Octaplex Scanning

The octaplex scanning system is based on the earlier development of transverse-scan recording in which a two-inch wide tape is moved longitudinally at 15 ips while being scanned transversely (at right angles to its direction of motion) by each of four recording heads equally spaced on the periphery of a 2-inch-diameter scanning wheel. Fig. 1 shows a standard quadruplex scanning assembly for television recording. With a rotational speed of 14,400 rpm and a longitudinal tape speed of 15 ips, 64 transverse scans per inch are made across the width of tape.

The octaplex scanning method allows the simultaneous recording of two channels of wideband information. In the development of the octaplex system, the primary objectives were minimum interchannel time displacement and low crosstalk. Earlier attempts to achieve the minimum interchannel time displacement by other companies resulted in the location of the heads of the *A* channel so that they are parallel and so that their gaps are in-line with the heads of the *B* channel. However, this close spacing results in excessive interchan-

Fig. 1—Closeup of quadruplex scanning assembly.



H. R. WARREN graduated from the University of Georgia with a degree in Physics in 1953. There, he was elected to Sigma Pi Sigma, physics honorary. He then joined RCA in 1953, and after completing the RCA training program, was assigned to the development of a battle announcement system for the Coast Guard. Later he specialized in the field of magnetics with emphasis on the development of recording heads. He has developed the multichannel heads for video frequencies used in recording television signals on magnetic tape. These heads have the capability of resolving wavelengths as small as 60 microinches. He has also developed heads for audio use with a frequency response of 15,000 cps when used with tape running at 3¾ ips. He has been responsible for the development of all the heads for RCA's magnetic-tape memory development program. As a result of one of his developments, RCA now uses a replaceable-gap head in cinemascope equipment. His work with replaceable-gap heads led to the conception of a floating gap head for recording in contact with rigid recording media. A pulse packing density of over 1,000 pulses per inch is made possible in magnetic memories.

nel crosstalk. The interchannel time displacement resulting from this arrangement is approximately 1 μsec. Since the time relationship between pulses recorded simultaneously on two sequential heads in a single-channel operation can be held to a fraction of a microsecond, it was apparent that when another channel of information was recorded with another set of four heads located at 45° from the original set, the time error between the original set and the second set was reduced by a factor of 2; therefore, 0.1-μsec interchannel time displacement could be achieved. Since the heads of the *A* channel are located at 45° from the heads of the *B* channel, maximum separation is achieved; thus, in the octaplex system the crosstalk is greatly reduced. The octaplex tape recording format is shown in Fig. 2. Fig. 3 shows the arrangement of eight heads equally spaced around the periphery of a 2-inch-diameter wheel. The signals to and from the heads of both channels are carried by a common slip-ring assembly, with a design that limits the crosstalk to approximately 40 db.

In an airborne system where the power must be conserved, special attention must be given to such items as the frictional drag of the slip rings in a headwheel assembly. In the system shown in Fig. 3, the slip rings are clustered on a common shaft. Slip rings of ¼-inch diameter are needed to allow sufficient separation of the leads to achieve the 40-db isolation between the *A* and *B* channels. However, for airborne applications the amount of power required to overcome the friction of ¼-inch slip rings would be extremely high. In addition to the power problem, if wider bandwidth is needed, even greater separation of the leads is needed; thus, the design in Fig. 3 means even larger slip rings. The solution to the problem of lower crosstalk at higher frequencies is shown in Fig. 4. The slip rings of channel *A* are on the "headwheel end" of the motor shaft (Fig. 4a). The slip rings of channel *B* are on the opposite end of the motor shaft (Fig. 4b). The leads of *B* extend from the heads through a small hole which is drilled through the entire length of the motor shaft. This technique of "isolation-by-distance" of the slip rings of the *A* and *B* channels eliminates the requirement for large (¼-inch) slip rings. The slip-ring size in Fig. 2 is 0.090-inch, approximately 2.8 times smaller than the slip rings shown in Fig. 3. Using this technique, motor power is greatly reduced and over 80-db isolation between channels is achieved.

Narrow Track

The next step in meeting the additional requirement of higher packing density of information was achieved by the reduction of both the recorded track width and the space between the recorded tracks. Fig. 5a shows a normal 10-mil-wide track and the 5-mil separation used in the standard television recorders. Use of this format in an airborne recorder yields 66.6 transverse tracks per inch when the longitudinal speed of the tape is 24 ips and when 1,600 head transverses per second are made. Fig. 5b shows the new tape-recording format in which both the recorded track width and the inner-track spacing have been cut in half. The track width is 5 mils and the spacing between the tracks is 2.5 mils. The reduction of the track width, however, does reduce the signal-to-noise ratio by 3 db from that of the 10-mil track and 5-mil spacing. The 3-db track-width loss has been more than

Fig. 2—Octaplex tape format.

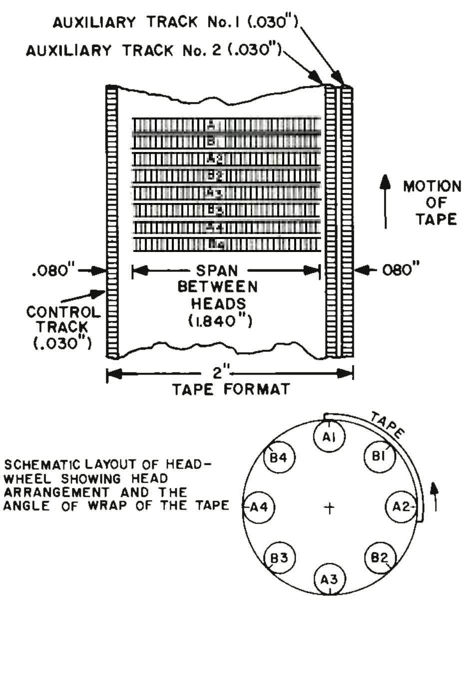
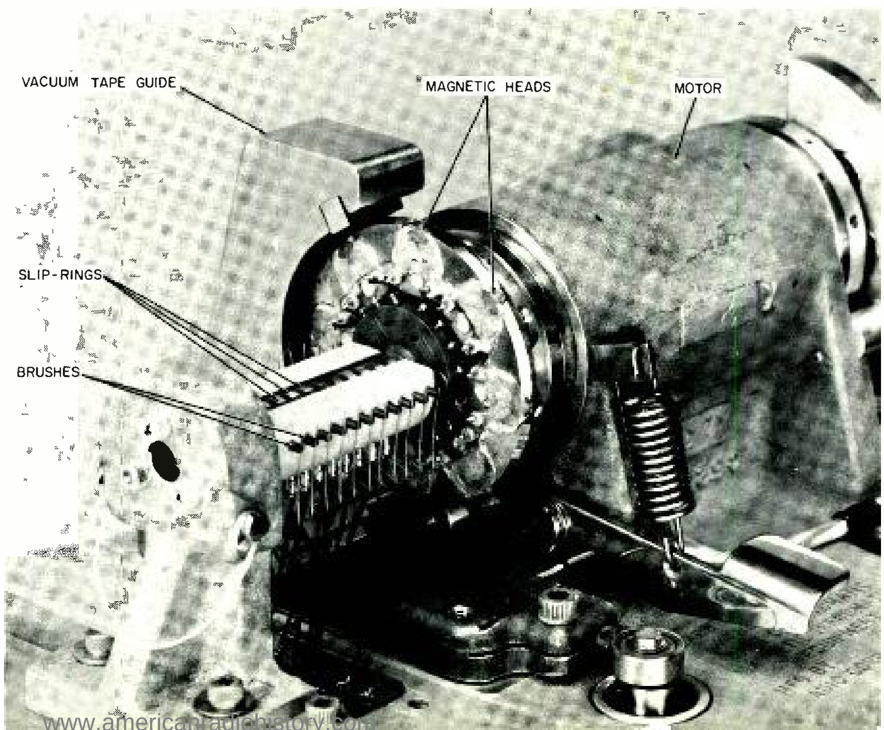


Fig. 3—Octaplex headwheel—arrangement of the eight magnetic heads.



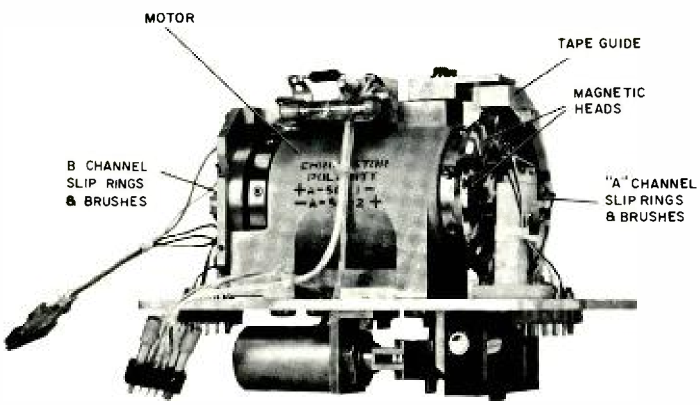


Fig. 4a—Airborne application of octaplex headwheel assembly.

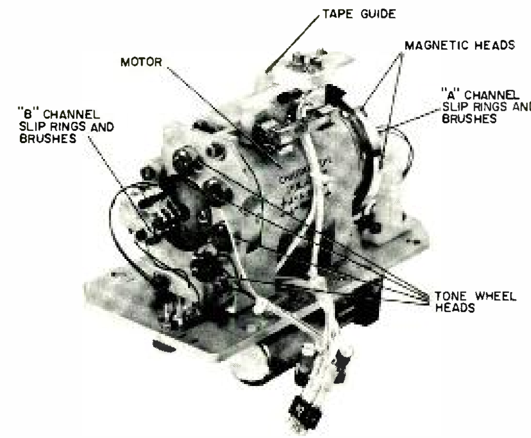


Fig. 4b—Octaplex headwheel assembly for ground application.

adequately regained by improvements achieved in head material and improvements in magnetic tape. Using the new narrow-track format, twice the number of transverse tracks per inch can be recorded ($2 \times 66.6 = 133$ transverse tracks per inch).

To summarize the developments at this point, the two-channel octaplex operation combined with the narrow-track technique allows two channels to be recorded in the original space of one channel; and for the single-channel quadraplex operation, twice the recording time is achieved. The density of information recorded on magnetic tape has thus been increased by a factor of two.

Double-Coated Tape

The next step was to develop a double-coated tape; this also uses the transverse scan method. Fig. 6a shows a 1-mil base of polyester tape with coating thickness of 0.35 mil (a total thickness of 1.35 mils). Fig. 6b shows the new tape with a base thickness of 0.5 mil, both sides of which have been coated with 0.2-mil oxide (total, 0.9-mil). Two identical scanning assemblies are used, one for each side of the tape. As the tape moves forward, the first headwheel assembly records; as the tape moves in the opposite direction, the other assembly records. Considering only the double-coated aspect of this development, twice the amount of information per unit length of tape can be recorded.

But what about crosstalk from one side of the tape to the other? The crosstalk from one face of the tape to the scanning head on the opposite face of the tape can be illustrated by the separation loss curve in Fig. 7. Note that when the separation of the magnetic head from the tape surface is equal to one recorded wavelength, the output is decreased 54 db. Consider the condition where a recording has been made on the *A* side of the tape and the tape is scanned by a magnetic head on the *B* side, and the recorded signal on the *A* side of the tape is an FM signal whose wavelength is approximately 0.3 mil. Fig. 7 illustrates that the separation due to the base thickness plus the coating thickness is 0.7 mil, and the losses are much greater than 54 db. Thus, crosstalk from one side of the tape to the other presents no problem.

Contact Printing

Contact printing describes the condition under which a recording is transferred from one face of the tape to the other face at high temperatures. Since the FM recording technique results in an extremely short recorded wavelength, azimuth of the magnetic head is extremely critical. If an azimuth error is judiciously chosen for the magnetic heads on each side of the tape, the contact printing will also have an azimuth error. An azimuth error of 3° on each side of the tape will result in a contact printing azimuth error of 6°. This total error reduces the contact printing crosstalk to greater than 60 db, even under the conditions of maximum contact printing.

Erase

To erase the *B* side of the tape after having recorded a signal on the *A* side, the fringing field of the erase head must be confined to a distance equal to the thickness of the *B* side of the tape plus the base thickness. In the case where the base thickness is 0.5 mil and the coating thickness is 0.2 mil, the fringing must be limited to a maximum of 0.7 mil. The effective fringing of an erase-head gap is approximately equal to the gap length; consequently, a head designed for this tape and coating thickness must have a gap in the order of 0.2 mil.

Modified Diphase

A new technique, called *modified diphase*,[1] allows the recording of binary bits at a rate approximately equal to the bandwidth of the recorder system. If the information is in a return-to-zero (RZ) format, it is converted to a continuous signal in which logical *1*'s and

Fig. 5—a) standard wide-track tape format; b) narrow-track format.

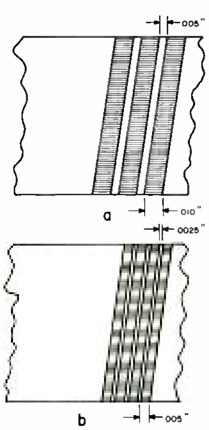
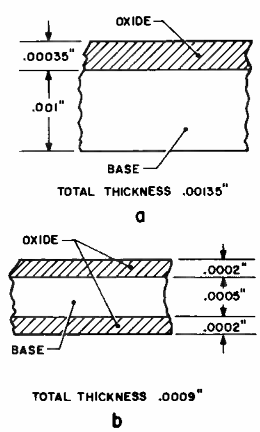


Fig. 6—a) standard tape; b) double coated tape.



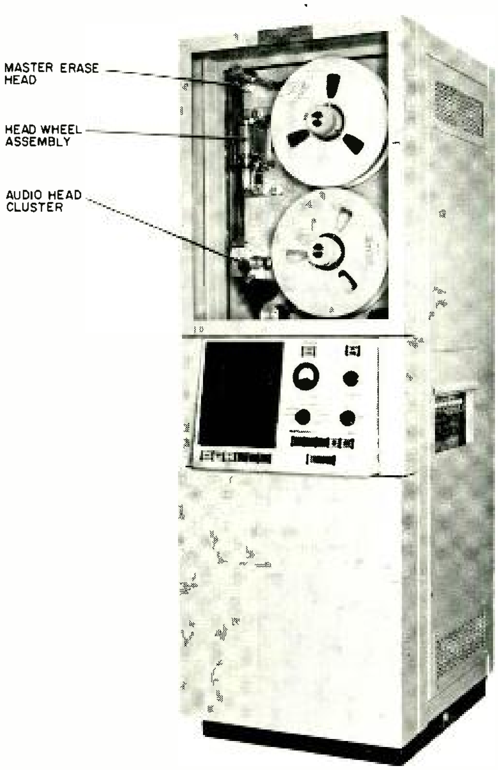


Fig. 8—Rack-mounted wideband recorder-reproducer.

0's change the phase of the continuously recorded signal. Using this technique, a rate of 3,300 bits/inch per track has been demonstrated with a dropout rate of 1 bit in 10^6. The combination of modified diphase and transverse scan recording results in the achievement of recording and reproduction of a 10-Mc-bit-rate signal.

RECORDING EQUIPMENT

We now turn to the development of hardware which incorporates the techniques previously described.

Wideband Recorder-Reproducer (GT 200)

A wideband recorder-reproducer was developed for recording data from two separate radar systems (see Fig. 8). The equipment uses the transverse scan technique and the octaplex head assembly. In addition to the recording of two 4-Mc video channels, it also records sweep- and antenna-position data on five auxiliary tracks. Packaged in a single rack, the recorder-reproducer can record 1 hour of two-channel information. Interchannel crosstalk is greater than 36 db with a signal-to-noise ratio of 36 db. The transport is shock-mounted for shipboard operation. The octaplex headwheel design is an extension of the standard television headwheel panel design. An additional requirement of the equipment is operation in a television mode in which the octaplex headwheel panel may be replaced by a standard television headwheel panel. In the television mode, television signals may be recorded and reproduced in the same format as the RCA broadcast video tape recorders, TRT-1B, TR-2, and TR-22.[2,3] Thus, interchangeability of tapes between machines is achieved. Except for monitor tubes, the equipment features solid-state electronics throughout.

The first equipment of this type has been delivered to the Naval Electronics Laboratory in San Diego, California and has recorded and reproduced two simultaneous radar presentations successfully.

Airborne Video Recorder and Ground Reproducer System

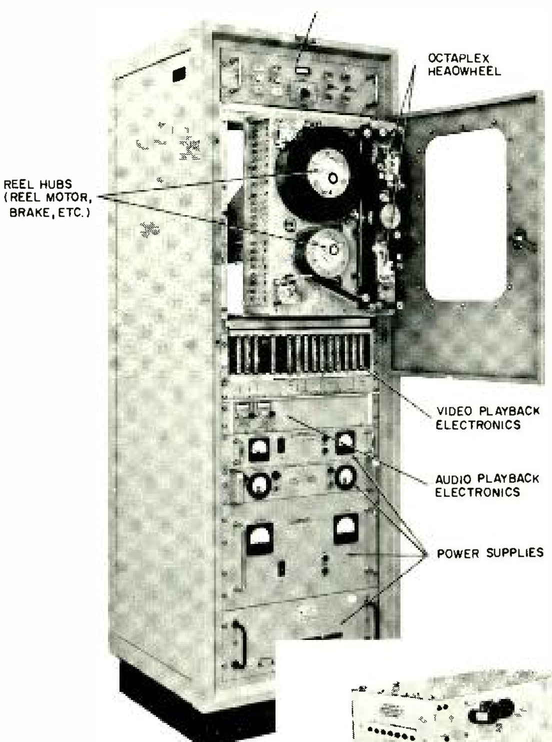
Fig. 9 shows the recorder for airborne application; it is a record-only machine with the capability of recording two simultaneous 6-Mc bandwidth channels with two 25-kc-bandwidth audio channels. To achieve 50 minutes of recording, ¾-mil double-coated tape is used. Recording of 25 minutes is done on one side of the tape with a transverse scan assembly, and an additional 25 minutes of recording is achieved with another scanning assembly as the tape passes in the reverse direction. This unit employs the octaplex controlled-erasing, and narrow-track recording techniques. The airborne unit is contained in 1.3 cubic feet. When inserted into a single-rack playback equipment, the airborne unit becomes a recorder-reproducer.

SL-100 Recorder-Reproducer

The SL-100 was developed originally for the GEMINI program.[1] The modified diphase system is used to record 3,300 bits/inch per track. Using ¼-inch tape, this unit can record up to seven tracks. Operating at 24 volts-DC, the unit consumes 10 watts in either the record or playback modes. Because of its small size and ability to record and reproduce under vibration, it is ideally suited for airborne and spacecraft operations. A 2,300-foot reel of instrumentation tape (¼ inch wide and 1 mil thick) allows 4 hours of recording at 1⅞ ips. A hysteresis speed converter[1] allows playing the tape in the reverse direction at a higher speed, e.g., the recorder plays back 22 times faster than it records.

Portable Video Recorder PT-300

The PT-300 is the first truly portable wideband (4-Mc) recorder (Fig. 10).



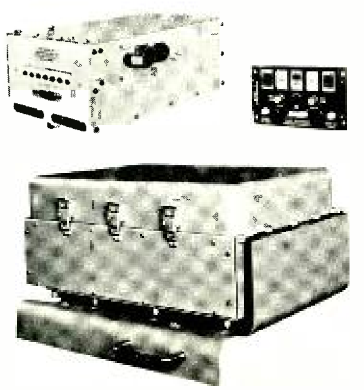
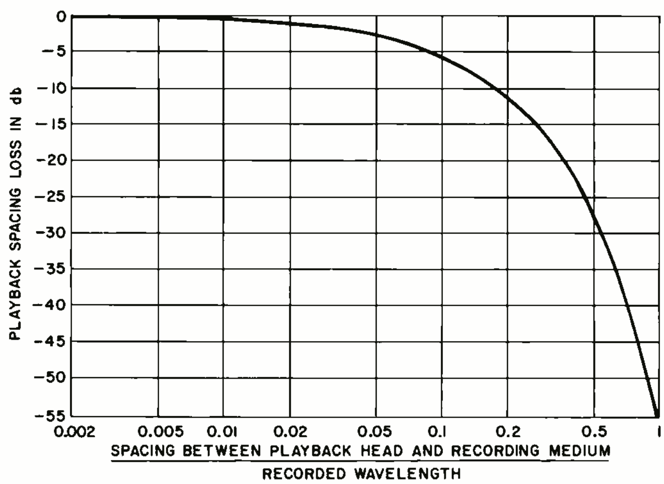


Fig. 9—Airborne video recorder (inset) and ground reproducer system.

Fig. 7—Curve of separation / wavelength losses.



The narrow-track (5-mil track, 2.5-mil spacing) technique allows 1 hour of recording at 4-Mc bandwidth. The recorder is designed in three separate packages: power supply and servo package (16" x 19" x 5") transport package (16" x 18" x 11") and the control panel (6" x 13" x 6"). The transport weight is 55 pounds; the power supply servo, 35 pounds; and the control panel, 6 pounds. Operating from a single 28-volt supply, the recorder requires 15 amps.

Tapes recorded on the PT-300 can be played back on the RCA TRT-1B, TR-2, and TR-22 commercial television recorders.[2,3] Although small and compact, the PT-300 uses a standard, narrow-track headwheel assembly.

MAGNETIC RECORDING RESPONSIBILITIES AND SUPPORT TO OTHER RCA DIVISIONS

There are occasions when the most critical subsystem in a major system is the magnetic tape recorder. Often, the basis on which a contractor is chosen for a major system is the advanced techniques used in the magnetic recorder; that is to say, the magnetic recording techniques that are proposed determine the ultimate capability of the major system. The proposal of a high-precision, 14-channel, broad-band recorder for the TRADEX program was a major contributing element in the contract being awarded to RCA.[1] This tape transport stores 15 channels of broad-band data at a tape speed of 1,000 ips, while maintaining a speed stability of two parts in 100,000. CSD designed and developed the breadboard model and the first prototype for the DEP Missile and Surface Radar Division, Moorestown.

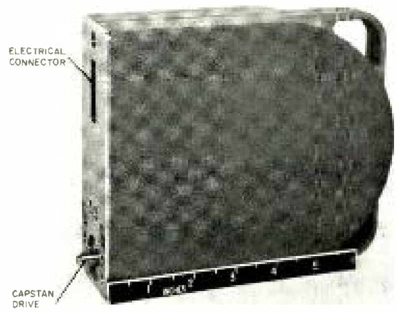
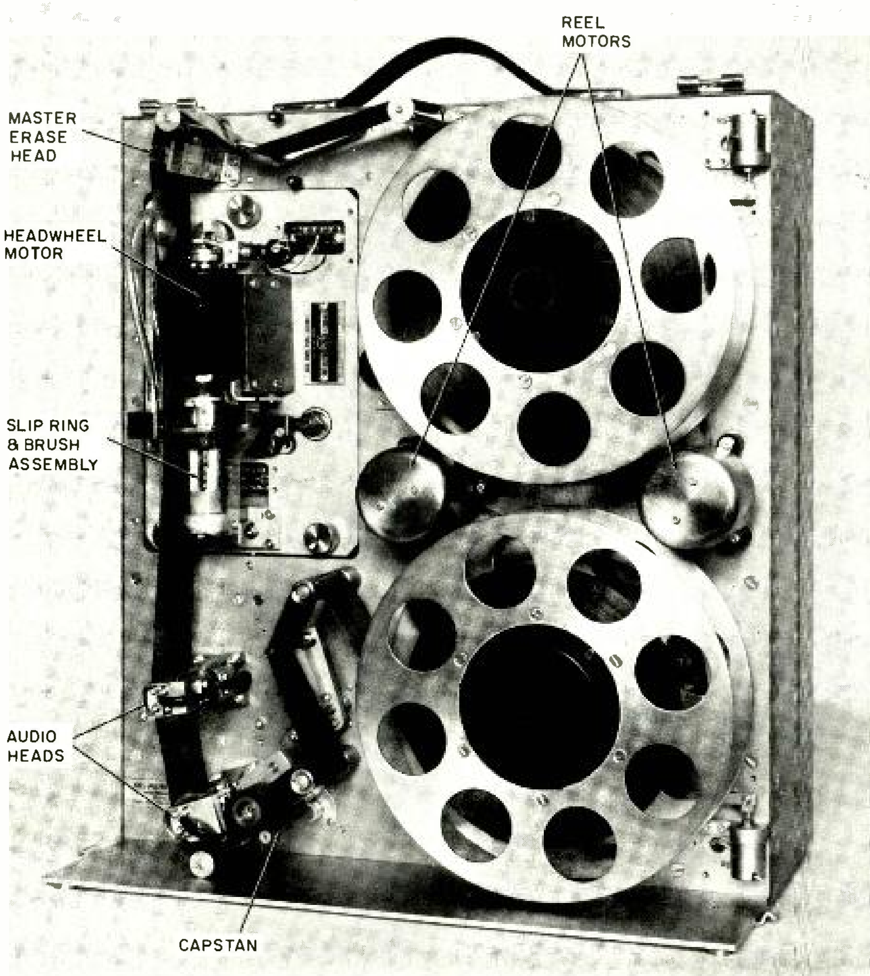


Fig. 11—Sealed tape cartridge for multipurpose test equipment (MTE).

Fig. 10—Portable video recorder.



The RCA sealed-cartridge approach to the Multi-System Test Equipment Program of the DEP Aeropsace Systems Division, allowed a reduction of weight and size of four to one over the competition (Fig. 11). This approach was a key element in the award of a contract to RCA.

In support of other RCA engineering activities, both in and out of CSD, the Magnetic Recording Equipment Section has developed and is supplying high-resolution heads for programs[5] such as NIMBUS, ORBITING GEOPHYSICAL OBSERVATORY (OGO), TIROS, and GEMINI. Such heads require extreme sensitivity and short-wavelength resolution.

CONCLUSION

The dynamic flow of the magnetic recording technology has been demonstrated—from need, to research and development, to hardware. The future trends seem to be toward higher quality, better signal-to-noise ratios, smaller-size and lighter-weight equipment, recording at higher frequencies, and greater packing density. Packing density per unit volume of tape is the area of most rapid progress. RCA has combined narrow-track tape and the modified diphase and octaplex recording techniques to design, build, and deliver digital recorders with a packing density of 256,000 bits/in^2, at a 10-Mc bit rate. *As a comparison from the storage point of view, this packing-density capability is an order of magnitude greater than that of present computer storage devices.* Through the development of thin-base, double-coated tape and narrow-track recording, we have increased analog packing density by a factor of six in the last four years. A factor-of-four increase in digital and analog packing density is envisioned for the next four years.

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4. J. M. Uritis and B. A. Cola, "A High-Speed Precision Tape Recorder," *this issue.*
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THE DESIGN OF SATELLITE TAPE RECORDERS— AFTER TIROS I

Discussed herein are some of the improvements in satellite tape-recorder design since the first TIROS. Elements of the new designs include system requirements, tape transport, sensing heads, motor-drive and speed-changing techniques, and means of compensation for angular momentum. Examples include design applications in the AVCS (Advanced Vidicon Camera System) recorder and the HRIR (High-Resolution Infrared) recorder of the NIMBUS meteorological satellite, as well as in the recorders for other spacecraft.

A. D. BURT, S. P. CLURMAN, and T. T. WU

Astro-Electronics Division, DEP, Princeton, N. J.

THE primary function of satellite tape recorders is to store information acquired during phases of the orbit when there is no direct communication link between the satellite and its ground stations. When the satellite is in position to establish a communication link, the recorded information is read out and communicated through the satellite transmitting system. A secondary function may be provided by a recorder which records and reads out at different speeds. This function causes bandwidth compression or expansion of the original data, which may be required for tactical reasons. An example of this is a recorder which continuously stores low-frequency data during, say 95 minutes of orbit time, and then reads out all data during the relatively short time of ground station contact; say, eight minutes.

The data to be stored may include any of a wide variety of signals, such as video, infrared spectrum, inputs from sensors measuring physical conditions in space, telemetry signals reporting the state of the satellite itself, and communication relay signals. Most of the discussion in this paper will refer to the recording of satellite video signals.

In addition to its data record-reproduce function, the recorder must be integrated into the satellite system. This usually means that a stringent budget of weight, power, and space has been allotted to the recorder. Finally, extreme ruggedness and reliability must be designed and demonstrated in order that it survive the launch and orbital environments, and to ensure continued operation over increasingly long missions.

The object of this paper is to discuss some of the more recent recorder developments and considerations at the RCA Astro-Electronics Division since the launching of the first TIROS satellite.[1]

SYSTEM REQUIREMENTS FOR RECORDERS

Satellite projects which require recorders usually invoke specifications which include type of signals, signal bandwidth, storage capacity, weight, power, size, etc.

An example of such system specification occurred in the program for the NIMBUS weather satellite. The NIMBUS project required the development of two high-performance recorders: an Advanced Vidicon Camera System (AVCS) recorder and a High Resolution Infrared (HRIR) recorder.[2]

The AVCS recorder was specified as a four track, single-speed machine which records and reproduces three channels of video signals and one timing channel. The three video signals are received from three independent vidicon cameras, each of which scans 800 TV lines per picture in 6.5 seconds. Each video signal has a bandwidth of 60 kc and is frequency-modulated by the recorder's circuitry before being recorded on tape.

A. D. BURT attended Drexel Institute Evening School and University of Pennsylvania during 1925-1928, and 1930-1932. He was a student engineer at the General Electric Co., from 1928 to 1930, and transferred to RCA Victor Company in 1930, as an engineer, where he did development work on vibrators, magnetic circuits, phonograph pickup, turntable drive systems, and motors. During this period, he proposed the present geometric series of values used for resistors. In 1946, he became Manager of the Record Changer and Tape Systems engineering section of the RCA Victor Home Instrument Division. At AED, he is engaged in the evaluation and solution of electromechanical problems related to tape recorders for satellite use. He has seven issued patents and has written and presented several technical papers related to phonographs and tape recorders. Most recently he co-authored a technical article, "The History of the Phonograph," at the request of the "Encyclopedia Britannica."

STANLEY P. CLURMAN received a BSME degree from the City College of New York in 1941, and an MS degree from the Stevens Institute of Technology in 1945. In 1941, he joined the Curtiss Wright Propeller Division, where he advanced to Senior Stress Analyst; from 1946 to 1948, he was a member of the staff of MIT and worked on a Navy materials study program. Later, he became project engineer with Sperry Gyroscope Company. He served as Chief Mechanical Engineer of the Hogan Laboratories, New York City, from 1951 to 1955. Mr. Clurman joined AED in 1958, and is now an Engineering Leader in charge of advanced recorder design. He was part of the original team that developed the first TIROS recorder. During 1960-62, he was responsible for all satellite recorder work at AED, including those for TIROS, NIMBUS, OGO, and several classified programs. He has contributed to work on dielectric tape storage devices. He did early development work on continuous-motion film transports, magnetic couplings, and vacuum-mechanical material considerations. He is now responsible for work on the tape transport for the NASA pre-prototype dielectric camera, of the panoramic scan, continuous-motion film type. Mr. Clurman is a senior member of AIAA, SMPTE and IEEE and a member of Sigma Xi. He has published three technical papers and has ten patents issued to him.

T. T. WU received his BSEE from Syracuse University in 1952 and his MSEE degree from Columbia University in 1957. Before joining RCA, Mr. Wu worked on the design of material handling equipment and automatic controls. Mr. Wu joined the Astro-Electronics Division in 1958, where he specialized in logic-system, tape-recorder, and circuit design. He designed and developed circuits for the NIMBUS AVCS and HRIR tape recorders, the digital work generator for Project DAMP. He also worked on the analyst console for Project ACSIMATIC and the sun-angle computer for the TIROS ground station.

(**Editor's Note:** Mr. Wu recently left RCA, and his photograph was not available.)

Each video tape track is capable of storing 64 individual picture frames, including a tape wastage allowance for stopping and starting the transport between each frame. The timing channel carries a 50-kc subcarrier signal which is amplitude-modulated 50% in accordance with a standard Minitrack pulsed timing signal.

The HRIR recorder was specified as a four track, two-speed machine which records one channel of infrared analog data and one timing channel for an interval of 128 minutes, and reads out all data in 8 minutes. The infrared input signal has a bandwidth of 5 kc, and is also frequency-modulated by the recorder's circuitry before being recorded on tape. The timing data is a 10-kc subcarrier signal which is amplitude-modulated 50% for Minitrack timing pulses, similar to the AVCS unit. Recording at low speed, the recorder runs for 64 minutes from start to end-of-tape and records on two tracks. At the end-of-tape, the motor is automatically reversed, and the input signals are switched to the alternate two tracks. This extends the recording time to 128 minutes with a loss of approximately 1 second of data during the reversing interval. During reproduction, the tape speed is increased to eight times the recording speed, and all four tracks are read out in parallel, in 8 minutes. Two of the tracks are read out, of course, in the inverse sequence to that in which they were recorded.

For both recorders, it was specified that the flutter be kept to a minimum, consistent with the resolution of the rest of the system. Both recorders were required to have a maximum uncompensated angular momentum of 0.015 lb-in-sec.

DESIGN OF THE MAGNETIC HEAD-TAPE SYSTEM

The use of FM subcarrier recording for video signals involves both advantages and disadvantages for the recorder designer. The advantages are: There need be less concern with flatness of response or partial loss of signal level than would be the case for "direct" recording, since FM demodulation, when preceded by full limiting circuitry, is virtually AM-insensitive. There is less concern with harmonic distortion; in fact, limiter circuits reduce all signals to square waves at one point in the playback process. A disadvantage is that the signal-packing density of the tape is reduced below that possible in "direct" recording.

In the NIMBUS recorders, we have used full metal-faced magnetic heads with 90 microinch (0.000090-inch) gaps. When used in conjunction with tape having thin oxide coating, we have been able to reliably use maximum subcarrier packing densities of 4,000 cycles/in. Since the NIMBUS AVCS video signal is transformed into a subcarrier frequency which deviates between 120 and 73 kc, the selected tape speed of 30 ips causes a maximum packing density of 4,000 cycles/in and a minimum packing density of 2,433 cycles/in. At these high packing densities, no bias is required for good subcarrier reproduction. Saturation recording is used, and the record-head current is varied with frequency to give the optimum playback signal level. Fig. 1 shows the playback characteristic of the AVCS magnetic head at a tape speed of 30 ips. The optimized recording current is also shown here. In typical four-channel heads, the four individual characteristics are matched within 2.5 db within the usable range of 73 to 120 kc.

Signal erasure is most commonly accomplished by fixed permanent magnets, in order to reduce circuit complexity. This is only feasible where information may be destroyed during the first playback and, where playback is permissible during rewind, after recording. Mechanically moveable magnets are regarded as undesirable devices for satellite application.

A situation in which permanent-magnet erasure was not permissible existed in the HRIR recorder, since two pairs of tracks were recorded in series by tape reversal and head switching. A fixed permanent magnet would erase the first pair of tracks during recording of the second pair. To meet this problem with a minimum of components, two identical four-channel head blocks are used. During recording, two channels in the "downstream" block carry the recording current while two channels in the "upstream" block perform erasure. After tape reversal, the two previously unused pairs of channels are used similarly, but the "upstream" and "downstream" roles are reversed. The result is that, in each block, two channels are used for erasure and two channels are used for recording. During playback, only two heads in each block are used.

TRANSPORT DESIGN

In the design of our transports, we have followed the concept of minimizing the number of elements in contact with the tape, including the elimination of edge-guiding components, since these tend to generate new disturbances in the tape movement. We have also used transport configurations in which the magnetic coating does not make moving contact with any surface, except for the necessary case of the magnetic heads. This approach reduces tape wear and maximizes the tape life.

Such a configuration is used in the tape transport shown in Fig. 2. In this picture, the magnetic heads have been removed to show the capstan area clearly. The tape is stored on and exchanged between two coaxial reels which are in parallel planes, approximately ¾ inch apart.

The tape leaves one reel, passes around a series of four rollers, and enters the second reel. Two of the roller axes are inclined at slight angles to the reels' axis in order to lead the tape out of the plane of one reel and into the plane of the second reel. These angles are computed so that, if all components were perfect, the tape would track perfectly. To correct for any unavoidable small errors, however, two of the rollers are slightly crowned to provide a restoring action for any small lateral displacements of the tape.

The tape passes around one of the rollers twice—once upon leaving one reel, and again upon entering the second reel. This roller is belt-driven by the motor, and serves as the tape-drive capstan. The

Fig. 1—Response curve of magnetic heads.

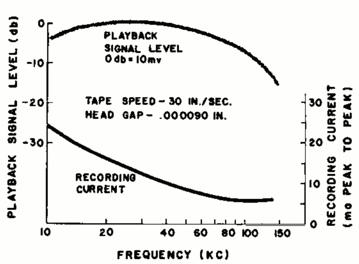
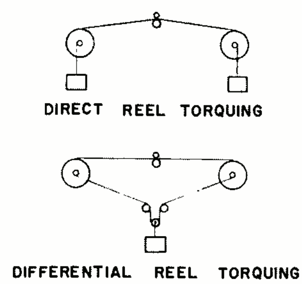


Fig. 2—Closeup of transport.

Fig. 3—Reel torquing techniques.



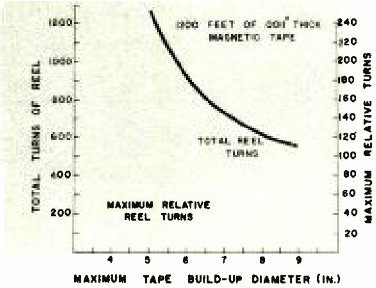


Fig. 4—Reel turns vs. tape length.

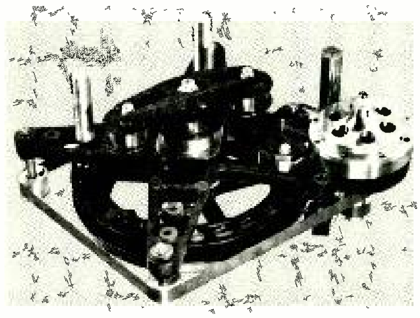


Fig. 5—Underside view of transport.

Fig. 6—Breadboard of the planetary drive.

capstan has an effective tape wrap of nearly 360°. The double contact of the tape with the capstan constitutes, in effect, a closed-loop system; this tends to cancel out, at the capstan, disturbing torques due to some low-level transients in the tape tension.

An additional factor which is necessary to permit the above mechanism to function is a technique for providing positive tape tension. This is done by constant-torque "Negator" springs, which torque the two reels in opposite directions. The resultant tape tension is nearly constant, and is independent of the direction of tape motion, the tape speed, and the presence of motor torque. Since the tension is always present, and the tape has a large angle of wrap, a very satisfactory frictional grip between the tape and capstan is developed, and the capstan can drive the tape without the need of pressure rollers. This is a desirable situation, since pressure rollers must be regarded as noise generators.

A brief discussion of the Negator mechanism will be of interest. If each reel were torqued by separate constant-torque springs, they could be regarded as being torqued by weights hanging on strings. This system, shown schematically in Fig. 3a, would work well, but it has a drawback. The Negator springs would have to rotate through the total number of reel revolutions. Referring to Fig. 4, it will be seen that for the case of a 7-inch diameter reel, 1,200 feet of tape would require 740 turns of the reel. It is not feasible to get this large a number of turns directly into Negator springs. Some form of gearing could be used, of course, to couple the springs to the reels and reduce the number of turns. In any high-quality recorder, however, it is usually desirable to eliminate all toothed gearing, no matter how indirectly it is coupled to the tape-head realm.

If the spring system is mounted on one reel and coupled to the other reel the two reels are torqued one against another (Fig. 3b). The springs now "see" only the relative turns between the two reels. Again in Fig. 4, for the same example of a 7-inch diameter reel, it will be seen that the maximum number of relative turns between reels is 50 for 1,200 feet of tape. This is a reduction in required spring rotation to nearly 1/15 of the total reel turns, and permits a feasible spring design. It also reduces the spring energy, and, therefore, the spring weight, for the case cited, to 1/30 that for direct torquing!

The Negator spring mechanism for the NIMBUS tape transport is visible in Fig. 5 facing the base casting on the side opposite that of the reels.

Motor Drive System

The hysteresis-synchronous type motor has been widely used in RCA satellite recorders. It is, admittedly, not the most efficient motor type available. However, it has a number of other important advantages. It provides an exactly constant speed, when driven by a precision oscillator, without any of the complications or "dither" of a servo system. It has good starting-torque characteristics, and, since its rotor has no specific orientation, it has none of the difficulties (characteristic of polarized-rotor synchronous motors) of pulling into synchronism with high-inertia loads. Since no brushes are involved, the reliability is high and is limited only by the failure rates of ball bearings and stationary windings—an irreducible minimum for conventional motors. It permits the use of power-saving circuitry. By starting the motor at high voltage and switching to a lower value after synchronous speed has been reached, the rotor is magnetized to a higher level than if operated at the lower voltage.

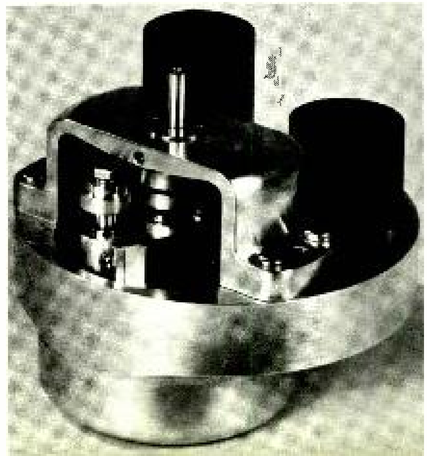
Low levels of flutter are usually required in a precision satellite recorder. It is, therefore, important that the motor not contribute significant disturbance to the mechanical system. A hysteresis motor, when powered by regulated AC voltage, has no torque variation except for a slight ripple due to the cyclic variation of magnetic-reluctance path during the course of one rotor revolution. When the motor is a high-speed type—powered, for example, at 400 cycles—this torque ripple will be 400 cycles and 800 cycles, and will generally be well-attenuated at the tape-drive capstan. Moreover, a high-speed motor (e.g., 6,000 to 12,000 rpm), when coupled to the capstan by a low-compliance transmission like a Mylar belt, will contribute a significant flywheel effect to the capstan motion.

Speed Changing Techniques

In applications where more than one tape speed is required, we have used one of two techniques. If the speed-change ratio is less than 10:1, we have used combinations of pole switching and electrical-frequency change. A typical case is the motor for the NIMBUS HRIR recorder, which has two independent windings, permitting operation as a 4-pole or 8-pole motor. By switching from 400-cycle energization of the 8-pole motor, the rotor speed is dropped from 12,000 rpm to 1,500 rpm.

When the required speed-change ratio is much larger than 10:1, this technique becomes undesirable, since the lower-speed mode of operation will become very inefficient, and will transmit increased torque ripple. For higher-speed change ratios, we have developed a two-motor, belt-and-pulley planetary transmission. This system is illustrated best by the breadboard-demonstration model in Fig. 6. Here, two motors are coupled to the same output shaft by a planetary belt mechanism. The output-shaft speed will be the sum of the input contributions from each motor. Each motor is coupled through an appropriate reduction ratio to the planetary-system input. By driving either motor singly, and immobilizing the second motor, the output

Fig. 7—Prototype planetary drive.



shaft speed may be changed over any ratio required. An interesting option of this system is that it can provide a four-speed transmission device if the two motors are operated both singly, as described above, and also, simultaneously with like and opposite directions of rotation. This scheme, however, will only allow independent selection of two of the speeds.

An extremely valuable second attribute of this device for two-speed applications is that it will permit using, for the low-speed mode, a low-power motor which does not have to fill the needs of the high-speed mode. When power budgets are extremely low, and also different for high- and low-speed modes, a designer may be extremely grateful for this situation. A prototype of the planetary drive for another tape recorder designed by RCA is shown in Fig. 7.

In the design of speed-change mechanisms we have, in general, avoided clutches and other time-honored mechanical speed switching devices in favor of purely electrical switching. This has been done for reasons of reliability.

Angular Momentum Compensation

The attitude of an earth-oriented satellite is controlled by a stabilization system which has a limited corrective capacity. When a tape recorder starts or stops, a reactive torque is developed. This will have an affect on the satellite attitude. Also, while the recorder is running at constant speed, there is a gyroscopic effect which increases the effective inertia which the stabilization system must control. Both of these effects will degrade the precision of attitude control, and will waste energy in the stabilization system. Both of these effects are proportional to the net angular momentum of the recorder, and both effects will be eliminated if the net angular momentum can be made equal to zero.

This condition requires that $I\Omega = 0$ at all positions of the tape on the reels and at all positions of the Negator springs between the reels. In this design, the change in momentum resulting from these two variables is sufficiently complex to preclude meeting the condition $I\Omega = 0$ with any simple means of compensation. Increasing the diameter of the reel hubs will reduce the variation resulting from each of these variables for a given length of tape. The price paid for such a reduction, however, is an additional fixed value of momentum, additional weight, and an increase in size.

Consideration of all of the several factors resulted in the selection of a hub diameter of 6.00 inches for a tape length of 1,250 feet. With 1.0-mil-base Mylar tape, this results in a build-up to 7.56-inch diameter (hub plus tape) when all of the tape is on one reel, and to 6.82-inch diameter when half of the tape is on each reel. These diameters result in a reel turn-differential of some 36 turns. Two Negator springs are employed to maintain the tape tension over this differential. The action is such that the springs are wound on a "sun" hub fixed to one reel when all the tape is on either reel. When half of the tape is on each reel the Negator springs are wound on two "planet" hubs, mounted on the other reel.

The tape velocity, as it is unwound from one reel and wound on the other, is a constant and is determined by the surface velocity of the capstan. This results in not only a change in inertia, but a change in angular velocity of the reel-tape system as well. This, together with the cyclic transfer of Negator-spring material, results in the rather complex variation in angular momentum of the reel-tape-Negator system. The reel-tape-Negator system rotates in a direction opposite to that of the motor-pulley-roller system. The former varies in angular momentum, while the latter has a constant angular momentum. Early in the design, an analysis showed that the angular momentum of the reel-tape-Negator system exceeded that of the motor-pulley-roller system. The logical point to add the compensating momentum is at the capstan shaft, since it serves there a dual function of momentum compensation and flywheel action which reduces wow and flutter.

Experimental tests using a ballistic torsional pendulum, and without any compensating flywheel on the capstan shaft, gave an "average" value of 0.27 lb-in-sec of uncompensated angular momentum. A flywheel was designed to compensate this value of angular momentum using a dense alloy—Heavimet—to keep its weight at a minimum.

Fig. 5 shows the flywheel mounted on the capstan shaft. Fig. 8 shows the experimental results obtained with this flywheel incorporated into the tape transport.

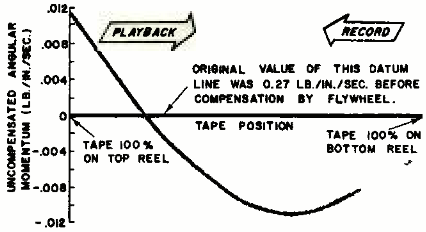


Fig. 8—Angular momentum variation curve.

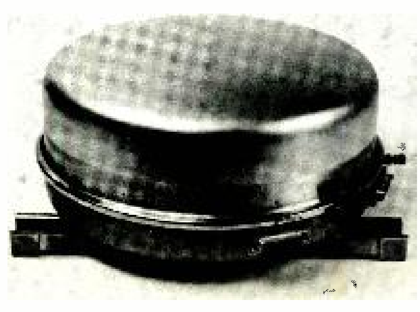
RECORDING ELECTRONICS

The AVCS and HRIR systems require FM modulators to modulate the video signal before its recording on the tape. These systems also have AM recording electronics for recording reference or clock signals.

The FM modulators used in these systems are voltage-controlled oscillators (VCO) which are DC coupled to provide low frequency response. These VCO's incorporate specially developed circuits, and their performance surpasses that of the corresponding modulators in the TIROS weather satellite. The new circuits have extremely high linearity over a very wide range of modulation; high frequency stability—as little as 0.004 %/°C variation; improved reliability; symmetrical square wave output; and high-precision frequency and deviation setting.

The improvements are due to a basic change in design. On TIROS, the VCO utilizes a free-running multivibrator as an oscillator. One of the problems inherent in multivibrator circuit design is a small probability that the multivibrator might not oscillate when the DC power is applied. In the NIMBUS system, a relaxation oscillator is used which will not lock-up under any condition. The relaxation oscillator generates a linear sawtooth waveform, by charging a capacitor from a current source and by discharging it through a high-speed switch. The sawtooth waveform is used to trigger a flip-flop which produces a symmetrical square wave with constant amplitude. In the AVCS system, a hybrid tunnel diode and transistors are used in the high-speed switch. The fall time of the sawtooth is about 0.04 μsec, while the sawtooth period is variable from 5 to 7 μsec. The AVCS circuit is designed to produce a square-wave output of 73 kc when the input is −6.5 volts, and 120 kc when input is −11.5 volts. In the HRIR system, an all-transistor circuit is used, because of lower frequency requirements. The circuit produces a 10-kc square-wave output when the video sig-

Fig. 9—Hermetically sealed recorder.



nal is 0 volts, and 8.25-kc output when the video signal is −6 volts. The linearity of these circuits is from 0.1 to 0.2%. The temperature stability is 0.02 %/°C for AVCS, and 0.004%/°C for HRIR, over the temperature range between 0 and 50 °C. To record the reference frequency which is AM-modulated by the Minitrack signals, a simple, direct, record amplifier is used for recording. The high-frequency bias normally used in direct recording is eliminated, since it is not required to reproduce with high linearity in this case.

In the HRIR system, electronic switches are used to switch record, erase, and playback signals between two pairs of head.

PLAYBACK ELECTRONICS

During the playback, the video signal is amplified, limited, and filtered in both the AVCS and HRIR systems. The preamplifier is designed for low noise, high gain, and low power drain. It is followed by a limiter circuit to remove any amplitude modulation due to the head-response characteristics or tape dropout. The harmonics generated in the limiting process are then removed by a low-pass filter.

The reference frequency, with Minitrack modulation, is reproduced by a high-gain preamplifier. Since it reproduces only the reference frequency, a compensation network such as used in a conventional direct reproduce system is not necessary. The elimination of the compensation network reduces the size and weight of the circuitry.

POWER INVERTER

The recorders use AC motors. It is necessary to have a power inverter to convert primary satellite DC power to AC power to drive the motor. The TIROS recorder system required a DC power input of about 18 watts to the power inverter, compared with 2 or 3 watts for the electronics. Thus, any increase in power-inverter efficiency will markedly reduce the total recorder power-system requirement.

In the AVCS and HRIR systems, particular attention has been paid to the circuit and transformer design to increase the overall efficiency well above 90%. In addition, a high-voltage start and reduced voltage-run method is used to reduce further the DC power requirements. In the present design, the DC power requirement is approximately 8 watts to the power inverter to drive the recorder motor after it has been switched to its running voltage.

A latching relay is used to provide the means of switching output-transformer taps under load. To avoid damage to the relay contacts from arcing, and to avoid switching transients to the power transistors, zener diodes are used for suppression. The original circuit was still operating without miss or degradation after 1.8 million operations.

In the AVCS motor circuit, a novel braking system is used to provide a quick stop. The braking is done electrically, in the motor, whenever DC power is removed. A latching relay is used to do the switching, and no power is need for this circuit. A life test was conducted on this relay with no failure in 1 million cycles of operation. The electrical braking reduces the stopping time from more than 4 seconds to about 0.5 second. Further, it provides a small residual magnetic locking torque to prevent the coasting due to Negator spring torque. Since no mechanical linkage is used in this system, no wear-out problem is present, and high reliability is assured.

ENCLOSURE DESIGN

The transport and all circuitry are enclosed with a hermetically sealed enclosure, shown in Fig. 9. Some idea of the interior packaging arrangement may be obtained from Fig. 10, in which the upper half of the enclosure has been removed. Each vertical array of circuitry consists of two epoxy-fiberglass circuit-board assemblies which have been cemented together for mutual stiffening. Each ensemble is then given a conformal coating of epoxy resin to immobilize all components and leads.

The enclosure is hermetically sealed by a Viton *O*-ring joint and pressurized with 16 psi of a gas consisting of 90% nitrogen and 10% helium, the latter being included to permit measurements of leakage rates. The maximum allowable initial leakage rate for an enclosure while in a high vacuum chamber is 1×10^{-4} cm/sec. Using this initial leak rate, and assuming an exponential rate of decay of pressure, it has been calculated that the pressure will reach 0.1 psi, absolute, in 23 years. This is regarded as still pressurized, as far as outgassing effects of lubricants and other materials are concerned.

PERFORMANCE

During steady-state operation, the AVCS recorder draws 10 watts at 24.5 volts-DC. The HRIR recorder draws 9 watts in its high-speed mode and 7 watts in the low-speed mode, at 24.5 volts DC.

These units will operate without damage or degradation of performance under the highest laboratory vacuums, and within temperature ranges of −15 to +60 °C. They will survive, without damage, vibration levels of 25 g-RMS, and random noise between 20 and 2,000 cps.

Typical flutter values for the AVCS recorder are 0.02%-RMS between 0.5 and 30 cps, and 0.10%-RMS between DC and 5,000 cps.

A more meaningful demonstration of the recorder's capability may be seen in the 800 TV line video samples (shown in Figs. 11 and 12), which were recorded and played back by the AVCS recorder functioning as a link in the complete video system.

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Fig. 10—Recorder packaging.

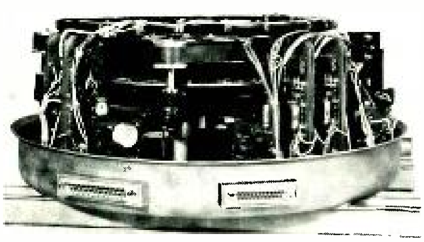


Fig. 11—Video test pattern.

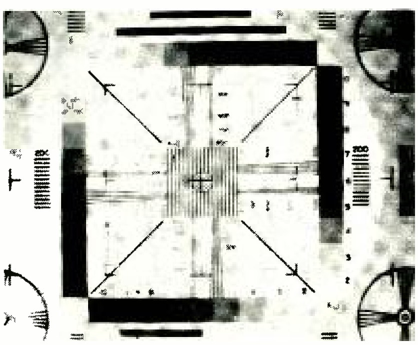


Fig. 12—Sample video copy.

Fig. 1—The GEMINI recorder.

HIGH-PACKING-DENSITY DIGITAL RECORDER FOR THE GEMINI SPACECRAFT

In instrumented, orbiting spacecraft, much data must be continually recorded and then very quickly read out during the short period of the orbit when it is in telemetry contact with a ground station. This lightweight (14.5-pound), low-power (12.5-watt) digital recorder-reproducer for the GEMINI two-man spacecraft records two channels of pulse-code-modulated information simultaneously at 5,120 bits/sec for 4 hours at a tape speed of 1⅞ ips. Packing density is 2,730 bits per linear inch on each track, with reproduction errors of less than 1 in 10^5 bits. Complete read-out is at 41¼ ips in a total of 10.9 minutes.

A. S. KATZ

Magnetic Recording Equipment Engineering
Communications Systems Division, DEP, Camden, N.J.

MANNED spacecraft missions have brought about numerous advances in digital telemetry technology. A vital link in such telemetry systems is the digital PCM (pulse code modulation[1]) recorder-reproducer. Such digital recorders are needed in spacecraft telemetry systems for continuous montioring and recovery of instrumentation data generated by the spacecraft systems. Since the spacecraft can communicate directly with ground stations via a transmission link for only a small portion of its mission, a recorder-reproducer system must continuously record vital data and then reproduce that data in the shortest possible time when the spacecraft is in contact with a ground station. Sophisticated digital magnetic recording techniques had to be developed to meet this requirement.

SPACECRAFT RECORDER REQUIREMENTS

A digital telemetry recorder-reproducer for manned spacecraft must be extremely compact and light in weight, and it must consume minimum power. The amount of data storable by such a recorder and the accuracy of reproduction must be maximized. The recorder must also perform reliably throughout the rugged environment of the orbital and re-entry phases of the mission while remaining within the severe constraints of space vehicles.

The PCM recorder-reproducer, developed by the Magnetic Recording Engineering section of RCA's Communications Systems Division for the GEMINI two-man space flight, has been designed to meet such requirements (Figs. 1-3).

A. S. KATZ graduated from the Drexel Institute of Technology, Philadelphia, in 1957 with a BSEE; he received his MSEE in 1963. He joined RCA Airborne Systems Division upon graduation in 1957. Mr. Katz was responsible for design and development of the missile auxiliary electronics for the ASTRA program and an Electrical Panel Simulator for the Army. He has two patents pending on special pulse measurement equipment for a missile check-out system. He has also participated in the design of digital logic circuitry and complex sweep generators for an Optical Character Recognition System. He joined the Magnetic Recording Equipment Engineering Department of the Surface Communications Division in early 1960. At that time, he was given the responsibility for the design of a new method of recording and playing back digital information for which he has a patent pending. Mr. Katz was responsible for developing new techniques and circuitry to increase the packing density of digital information on magnetic tape, beyond the present state-of-the-art; this program resulted in the diphase recording technique for which he has a patent pending. Mr. Katz is currently the Design Project Engineer for the GEMINI recorder program.

GEMINI RECORDER DESIGN FEATURES

The GEMINI recorder-reproducer is contained within 431 cubic inches, weighs 14.5 pounds, and consumes only 12.5 watts of power. It can continuously record two channels of PCM information simultaneously at 5,120 bits/sec, for 4 hours at a tape speed of 1⅞ ips. On

Fig. 2—A. Witchey (left) and H. Z. Weaver adjust the front plate of the capstan drive system. The recorder is assembled in a controlled environment which along with 100% parts inspection are among the many precautions taken to insure high reliability. (Also see front cover, this issue.

command, such information is reproduced at 22 times the recorded speed (41¼ ips) in 10.9 minutes.

The use of an advanced recording technique permits the recording of the digital information on magnetic tape at a packing density of 2,730 bits per linear inch of tape on each track. Information is reproduced with error rates of less than 1 in 10^5 bits. To accomplish this accuracy over the entire mission, specific consideration was given to the tape transport design and to the selection of recording and reproduction techniques.

Compactness a Necessity

It was necessary to design a mechanical system (within the allowable size and weight) which was structurally sufficient not only to withstand the vibration and shock of the launch and re-entry phases of the mission, but also to impart a minimum of spurious head-to-tape motion, thus minimizing jitter of the reproduced data. Since relative head-to-tape separation (on the order of 0.1 mil; i.e., 0.0001 inch) with resultant signal amplitude variations can be expected during the high-vibration periods of launch and re-entry, the recording technique had to be (for accurate detection) independent of the amplitude of the reproduced signal.

Magnesium For Low Weight

The tape transport (Fig. 4) consists of a stuctural magnesium laminated motor board on which the two coaxial reels, capstan drive system, 24-volt-DC-to-400-cps two-phase power inverter, and electronics are fastened. For minimum weight and maximum strength, magnesium was used extensively.

Hysteresis Speed Converter For Low Jitter

Since a coaxial reel system is used, it is necessary to transfer tape from one reel to another by executing two 90° twists in the tape. The twists in the tape set up differential stresses across the width of the tape which cause it to seek a natural path through the capstan and head assembly. Dynamic skew measured across the tape indicates a total skew of less than 50 microinches (0.000050 inch).

The requirement for a drive mechanism capable of imparting a dual tape speed with minimum jitter, while conforming to the overall requirement for minimum size, weight and power, resulted in the design of a *hysteresis speed converter*. This drive mechanism employs no mechanical contacting parts and is operated in a manner similar to that of a hysteresis motor. The speed converter operates in a choice of two speed modes by energizing either of two stationary coils, thus magnetically coupling the capstan shaft to the motor via the selected polyester belt system.

The high-frequency oscillatory components of the motor are not transmitted (as jitter) to the capstan, since the polyester belt system is essentially a low-frequency bandpass filter, filtering out the high-frequency jitter components.

The use of a precision 400-cps two-phase frequency source in conjunction with a hysteresis synchronous motor and belt drive results in a total RMS low-frequency capstan speed variation of 1 part in 1,000.

Constant Torque—Constant Tension

The tape reel assembly consists of two coaxial reels and two dynamically balanced, constant-tension spring assemblies. A total of 2,300 feet of polyester base tape (0.25 inch wide and 0.83 mil

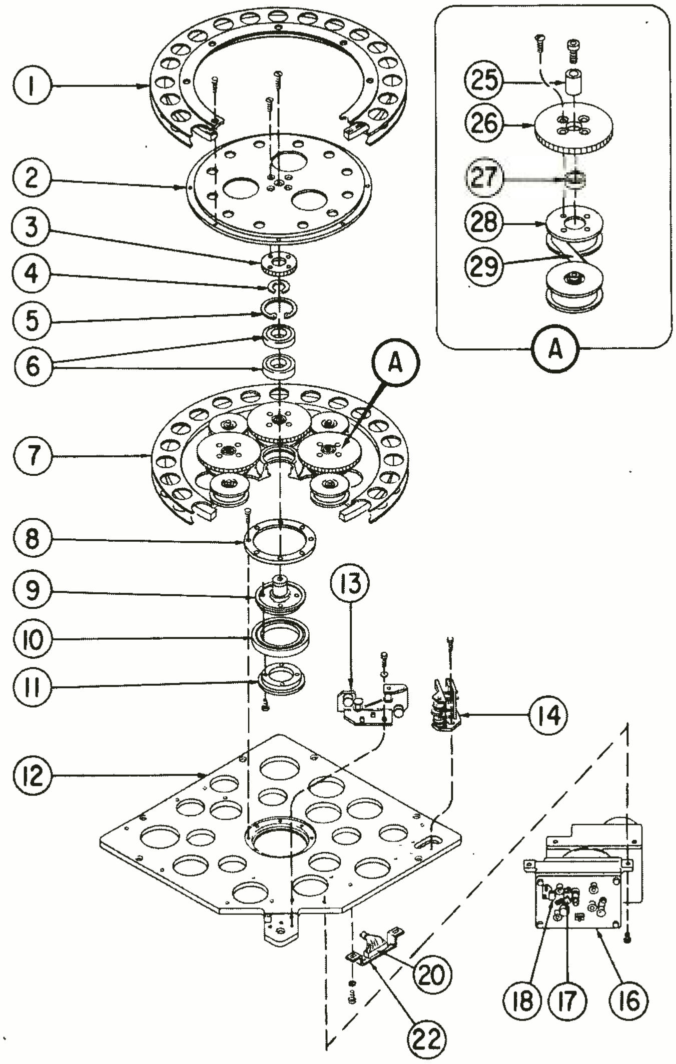


Fig. 4—Tape transport assembly; all parts are mounted on a magnesium motor board.

1. Flanged reel outer
2. Disk-upper reel ass'y
3. Spur gear pinion
4. Retaining ring, external
5. Retaining ring, internal
6. Ball bearing(s)
7. Lower reel
8. Bearing retainer
9. Post, reel bearing
10. Torque tube bearing
11. Bearing retainer
12. Motor board
13. Guide roller block
14. End of tape switch
16. Capstan drive ass'y
17. Magnetic head
18. Magnetic head
20. Connector, micro miniature
22. Bracket, connector mounting
25. Spacer, heat seat
26. Spur, gear drivtn
27. Ball bearing
28. Spool, negator
29. Spring, negator

Fig. 3—G. S. Newcomb (left), and E. R. Ware conduct an environmental test in the Camden Environmental Test Facility to check performance under extensive vibration, equivalent to that of the spacecraft re-entry phase.

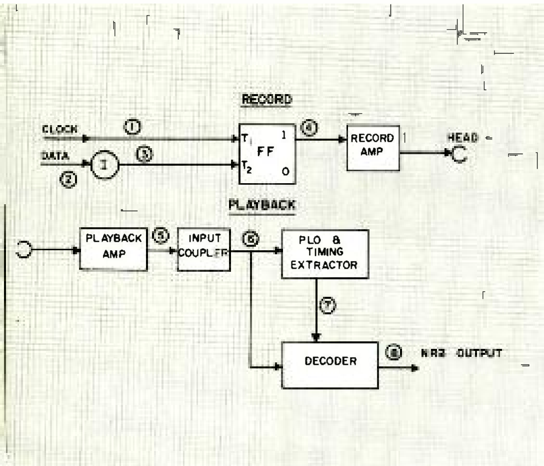


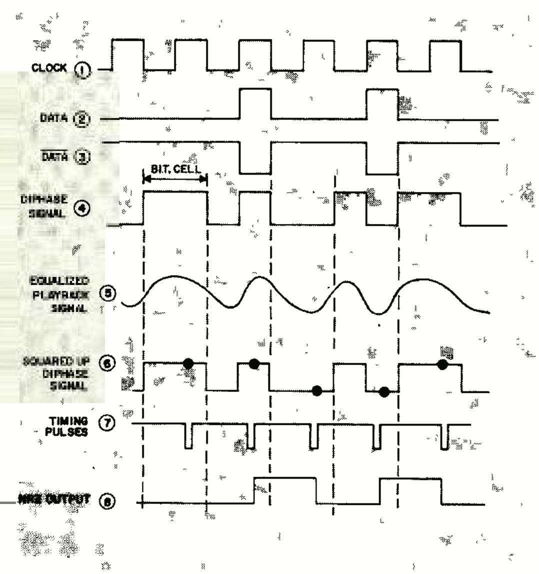
Fig. 5—Simplified diphase system block diagram showing the record and playback modes.

thick) is stored and exchanged between the two coaxial reels. Tape tension is maintained by the essentially constant-torque, constant-tension spring system which torques one reel against the other and eliminates the need for reel motors. The reel hub-assembly can be attached to an adapter for playback of the recorded tape on a standard (National Association of Broadcasters) hub.

Low Magnetic Head Maintenance

The magnetic heads are of all-metal construction in keeping with the design requirements for long life and minimum maintenance. The magnetic heads require no maintenance for 750 hours of continuous use. At the end of that period, the heads are cleaned and the tape changed as a preventive maintenance precaution. Heads of similar construction have endured up to 3,000 hours of sustained use with less than 3-db loss in playback signal amplitude. Both record and playback heads have a gap length of 90 microinches, which provides the required definition of the record and playback signals. Full-width intertrack shielding is used to minimize cochannel interference. The geometry of the magnetic tape track conforms to IRIG (Inter-Range Instrumentation Group) telemetry standards for 0.25-inch-wide tape.

Fig. 6—Diphase system waveforms.



Modified Diphase Technique

The recording and accurate reproduction of digital information on magnetic tape at a packing density of 2,730 bits/inch on each track necessitated the development of a signal-processing technique for digital recording. Conventional techniques for the recording of digital information are severely limited at packing densities in excess of 1,000 bits/inch. Inadequate pulse resolution, pulse crowding, and tape skew are among the many limiting factors. The signal processing technique, which is the RCA *modified diphase system*, encodes the digital information prior to recording and, on playback, decodes and reconverts the reproduced signal into standard NRZ (non-return-to-zero) form.

The application of the RCA modified diphase system to the recording art has been based on a thorough analysis of the problems inherent in the design of a high-density digital recording system. Eliminated are the serious problems of pulse crowding and tape skew which arise when conventional NRZ recording techniques are extended to high packing densities. The system is also insensitive to extreme variations in playback signal amplitude due to tape inperfections and head-to-tape separation. The diphase technique is essentially a phase-modulated carrier process. RCA and others have used phase-modulation technique extensively for data communications because of its high performance in narrow-bandwidth channels. Since a magnetic tape recording system at high packing densities is quite similar in behavior to a normal communications channel, phase modulation is a natural candidate.

SPACECRAFT RECORDER OPERATION

A simplified block diagram and associated waveform chart are shown in Figs. 5 and 6. The incoming clock and inverted RZ (return-to-zero) data are each fed to separate trigger inputs of a binary flip-flop. The flip-flop undergoes a transition on the negative-going edge of both the clock and the inverted RZ data signal. By defining a bit cell as shown on the waveform chart, it may be seen that a transition occurs in the center of bit cell each time a logical *1* is received, and no transition occurs in the center of bit cell when a logical *0* is received.

The output of the flip-flop is termed the diphase signal, since the digital information is inherent in the change in phase (or lack of change in phase) in the center of a bit cell. The diphase signal is then fed to the record amplifier.

During the reproduce mode the signal picked up by the magnetic head is fed to the playback amplifier. Here it is amplified approximately 60 db, filtered, and equalized in order to compensate for the effects of the head-to-tape system. The equalized signal is then fed to an input coupler where approximately 40 db of hard limiting is provided, with the result that the system is insensitive to an amplitude variation up to 40 db in the reproduced signal.

The squared-up diphase signal is fed simultaneously to the timing extractor and decoder. The timing extractor consists of a precision one-shot, monostable multivibrator whose period is set to a ¾-bit cell. The one-shot is triggered from the leading edge of each diphase bit. In this manner, timing pulses are accurately positioned in the last ¾-bit cell on a bit-by-bit basis. In the decoder, the timing pulses are used to interrogate the phase of the squared-up diphase signal. The phase of the diphase signal is interrogated with consecutive timing pulses; thus, a *0* is detected whenever a change has occurred in the polarity of the diphase signal between any two consecutive timing pulses. If, however, the polarity of the diphase signal is identical at the sampling times of two consecutive timing pulses, a *1* has occurred. Essentially, the detection of a *1* or a *0* is dependent on the change (or lack of change) in polarity of the diphase signal at the sampling times of any two consecutive timing pulses. The detected output in NRZ form is fed to a transmitter via a PCM filter for transmission to a ground station.

CONCLUSION

The GEMINI recorder-reproducer described here is presently undergoing extensive testing to determine its performance in an environment similar to that which it will encounter in space flight. It is scheduled for use in the first Project GEMINI two-man space flight.

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MAGNETIC HEAD DEVELOPMENT AND DESIGN

The Magnetic Head Engineering group of the Broadcast and Communications Products Division is responsible for the development, design, and product support for all the heads required for RCA's line of commercial video tape recorders. In addition, the group develops special heads for other RCA areas such as Applied Research, Communications Systems Division, and Missile and Surface Radar Division of DEP. It has in the past supplied designs to Electronic Data Processing for the present line of computer tape stations. Special skills and equipment are utilized to constantly improve the state of the art. Reviewed herein are some of the engineering considerations, materials, and techniques.

B. F. MELCHIONNI, Mgr.

Audio, Projector, Magnetic Head, and Scientific Equipment Engineering
Broadcast and Communications Products Division
Camden, N.J.

In any magnetic recording system, the focal point is the magnetic head; here, the information is transferred to the tape, disk or storage drum to be played back at some future time. On playback, the recording procedure is reversed and information on the magnetic storage medium excites the head and is played back through the recording system. Thus, the substantial design and development effort concentrated on the magnetic head is vital to both commercial and defense applications of tape recording systems.

EARLY ALL-METAL HEADS

When RCA entered into the data-processing field in the early fifties with the BIZMAC computer, the Magnetic Head Engineering activity that is now part of the Broadcast and Communications Products Division (BCP) was formed to design the necessary heads for the tape transport. The magnetic head designed for the BIZMAC recorder was one of the first all-metal heads in computer work. Other heads had been built where only metal contacted the tape but this was done by undercutting the plastic potting compound around the heads. This is an interesting consideration in the design of a stationary head where the tape will be moving across it. Most data recording heads consist of a number of individual tracks in one basic head structure; some heads also require a *read* gap immediately following the *write* gap, doubling the number of gaps per track in a particular head assembly.

MULTIPLE-HEAD STRUCTURES

In the design of a multiple-head structure, the most common approach is to have the heads flush with the surrounding support structure. This type of head is simpler to fabricate in production and is adequate for most tape stations employing a properly designed pressure pad to keep the tape in contact with the head.

In the design of some tape systems, a more intimate contact than that described above is required; furthermore, it cannot be attained by simply increasing the force on the pressure pad because of the adverse effects on tape stability. This problem has been overcome in several of our head designs by making the pole pieces *proud* in the vicinity of the gap. This technique allows the tape to make most intimate contact with the gap and not the support structure. However, this intimate and at times necessary type of contact increases head wear.

CONSIDERATIONS OF HEAD WEAR

Head wear, ever present in *contact recording* systems, is likened to dragging

TABLE I—Glossary of Terms

Track Width: The width of the recorded track on the tape.

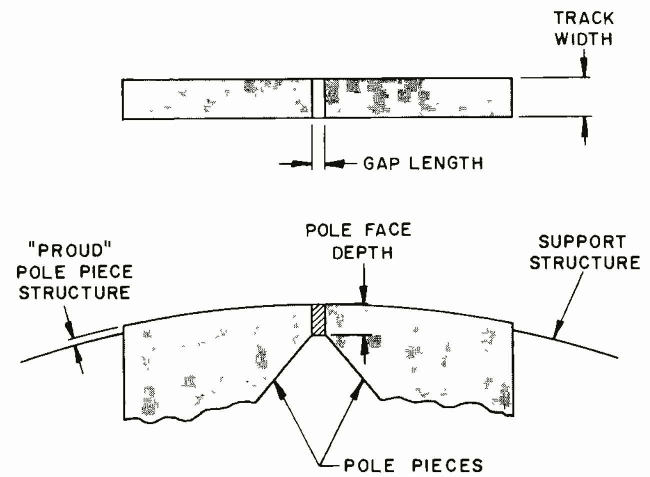
Head Gap: A physical break made by the insertion of non-magnetic material between the pole pieces.

Gap Length: Sometimes referred to also as gap width. It is usually expressed in micro inches (10^{-6} inch) and is the controlling factor in determining the resolving characteristics of the head assembly. Reducing the size of the gap increases the resolution but also lowers the output. Increasing the tape speed will increase resolution but also increase head wear. Optimum head design requires striking the best balance between these interrelated parameters.

Pole-Face Depth: The depth of the gap to allow for head wear. Control of this dimension is critical in multichannel heads to obtain uniform output.

Proud Head: A head design where the pole piece is raised above the surrounding surface for maximum contact with the tape. In actual practice the tape is deformed and literally flows over the head and gap.

Pole Pieces: The parts of a head structure that carry the magnetic flux from the core to the gap and tape.



a metal bar across the pavement: the rate of wear is a direct function of the pressure per unit area and of the distance the bar is dragged across the pavement. In the most popular flush-head design, both the heads and the surrounding surfacets contact the tape. This results in more evenly distributed forces and, subsequently, less head wear per lineal foot of tape. In the present proud head design, the tape contacts only the pole tips, and the pressure per unit area increases with a subsequently higher rate of wear. However, this greater head wear has been a willing sacrifice to obtain the higher performance desired.

With the use of harder pole-tip materials and assembly techniques we have been able to build heads that have achieved the intimate contact required without any loss in head life. Such a head was designed specifically for the DEP Missile and Surface Radar Division (MSR) *High-Speed Precision Instrumentation Tape Recorder*.[1]

To solve the wear-vs-performance problem required the special skills and facilities of the Magnetic Head Group. Initially, a head using proud pole pieces with conventional laminations was tried by MSR. Although this head met all the original specifications when tested on a loop machine, it would not maintain such performance for any length of time when put on a reel-to-reel machine; this was due to the wearing of the pole tips at the relatively high speeds—thus, creating a smearing of the gaps. A complete new head design program was then undertaken by the BCP Magnetic Head Design Group using new and different head materials and configurations. The new heads were fabricated successfully and are now in use on this system with excellent results.

ADVANCED HEAD DESIGN FOR RCA ELECTRONIC DATA PROCESSING

The basic head designs for RCA Electronic Data Processing (EDP) product line of computed tape stations were done by the BCP Head Design Group for the RCA 501, 601, and 301 systems.[2,3] The

B. F. MELCHIONNI graduated from the Temple University Technical Evening School in 1951. Since 1947 he has been a member of the Broadcast Studio Engineering staff. During this period he has engaged in the development and design of broadcast transmitter equipment, television cameras, television film projectors, television and audio tape recorders and other television terminal equipment, in addition to his work in magnetic recording heads. He is currently Manager of the Audio, Projector, Magnetic Head, and Scientific Equipment Engineering group of the Broadcast and TV Equipment Division. He is a member of the SMPTE.

heads for the 501 and 301 systems were of relatively conventional designs with 16 and 7 tracks, respectively. The RCA 601 system, however, required a read and write gap in the same head displaced by 0.2 inch. This created additional problems of providing good shielding to assure minimum crosstalk between channels as well as between the read and write gap lines. Both *C* and *I* configurations were developed; the *C* sections with their windings are part of the main head halves and the *I* return sections; they are imbedded in the center section used to support the shielding between the read and write gaps.

In the design of magnetic heads for multichannel systems employing narrow tracks, the uniformity of output is quite critical from channel to channel. This is a problem in tape guiding as the tape wanders across the head differently on different machines; to minimize this effect and to reduce the requirements in the transport design, the recording heads have a slightly wider track than those of the playback heads.

Where high bit-densities and extremely accurate timing between tracks is required, it is necessary to hold the *gap scatter* very accurately; when this is coupled to a read-write head configuration with a relatively thin center section, special techniques must be employed. A head to meet such requirements was developed and built for an Advanced Development program in EDP. This special head employed a unique floating center section, which, when clamped to the head halves, would not deform the gap lines formed by the lapped faces of the two halves. Gap scatter requirements of about 25 microinches (0.000025 inch) has been met on heads using this technique.

MAGNETIC HEAD APPLIED RESEARCH

An integral part of any magnetic head development and design activity is the constant search for improved materials that will yield higher sensitivity and increased life. Thus, such research goes on constantly, on company-sponsored programs. The results of this research are put into practical use as soon as possible and then the cycle starts again to push the state-of-the-art still further. Much of this work is applicable to fixed heads for longitudinal recording (such as the high-performance heads previously described) as well as to the more pressing problems confronted in rotating-head assemblies such as the video headwheel panel.[4]

The first RCA video panels using an *A* configuration head design (Fig. 4) were developed by H. R. Warren's group when he was a member of DEP Applied Research. Two pole tips of alfenol (an alloy of aluminum, iron, and nickel) were used with a cross bar of ferrite which carries the coil. Such a configuration resulted in a very short flux path in the pole tips; this was necessary because of the high loss-characteristics of alfenol in magnetic circuits.

The sensitivity of this magnetic head

Fig. 1—RCA 501 head.

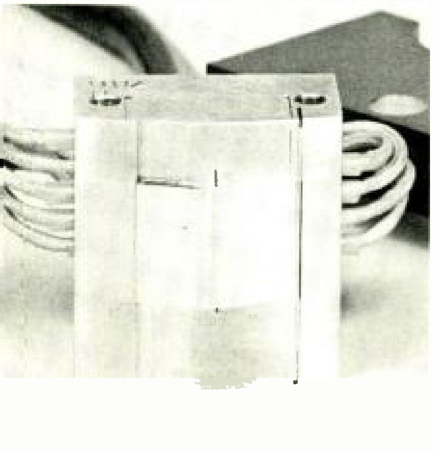


Fig. 2—The TRADEX head.

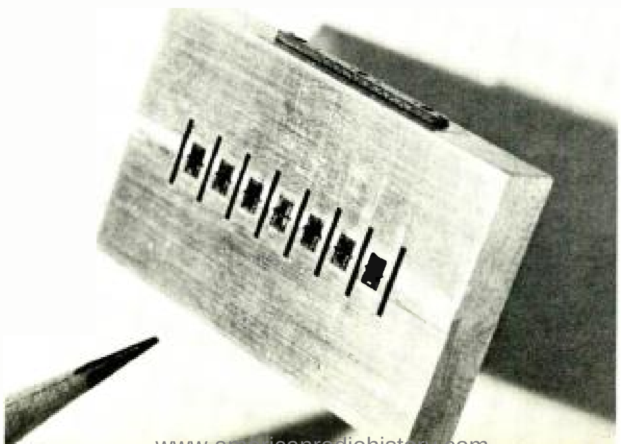
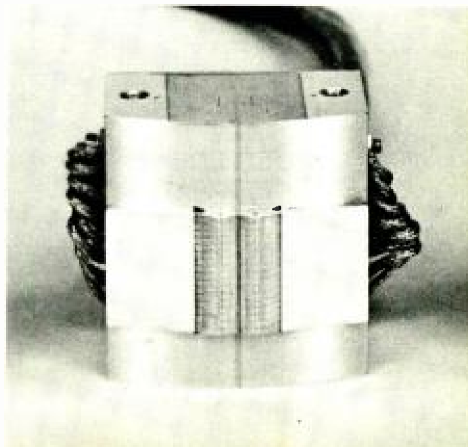


Fig. 3—MH-582 read-write head for RCA 601 station.



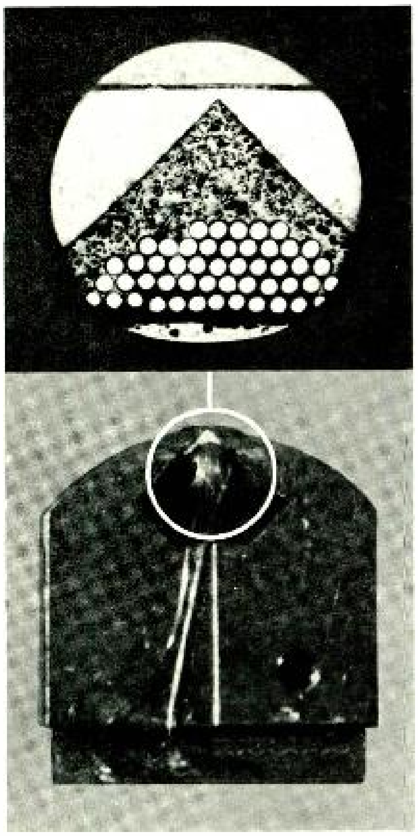


Fig. 4—Photomicrograph enlargement of "A" head configuration; white circles in the enlargement are actually the cross section of the coil wires.

was adequate and headwheel panels were used successfully for many years in RCA video tape recorders for commercial as well as military applications. However, head wear seriously limited the useful life of the panel. With the high head-to-tape speeds (approximately 1,560 ips) employed in the viedo recorder and with the high head-to-tape pressures required to get the intimate contact necessary for high-quality performance, the only solution remaining was to improve the wear characteristics of the pole-tip material; at the same time, any possible improvement in sensitivity would surely be welcomed.

With these goals in mind, a major breakthrough was accomplished in 1960 when an aluminum-iron-silicon alloy was found. This was pursued by RCA and is now the alfecon pole tip material currently in use in all RCA video headwheel panels produced for commercial use.

Many variations of the alfecon alloy were tested for wear and sensitivity before the present alloy was selected. When the final selection was made exhaustive life tests were carried on in the laboratory; accelerated life tests were all but meaningless and the tests had to be performed finally under actual operating condiitons. The new alloy proved to be capable of increasing the life (in actual practice) by a factor of about 3 or 4; this increase in life substantially reduces user costs to run the machine.

With this increase in life, came a gratifying increase in sensitivity which enables the heads to be driven less in recording; nevertheless, the proper signal level from the system was retained in playback with a slightly better signal-to-noise ratio. Since June 1962, the new head material has been used on all headwheel panels. Needless to say, customer acceptance has been most gratifying.

NARROW-TRACK HEADWHEELS

As the state-of-the-art progressed with the new pole-tip material, industry was ready for a machine running at half the then sole standard speed of 15 ips. It was reasoned that with the increased life (approximately four times that of the previous material), a head could be made only half as wide—and although it would wear at approximately twice the rate of the standard head, it would provide the user a two-to-one advantage over the older design. This was true enough provided the loss in signal (because of the narrower track) would not become a problem; although no problem did arise, the shorter life seemed to be a step backward.

With this problem confronting us, another design program was based on improving the standard alfecon head. In January 1962, a new pole-tip configuration head-assembly was demonstrated successfully. This pole-tip configuration (Fig. 5) is similar to that of the standard head assembly used for 15 ips which lays down a 0.010-inch-wide track. The only difference is that pole tips are notched in the vicinity of the gap down to 0.005 inch wide for 7½-ips tape speed.

The Fig. 5 narrow-track configuration satisfied all new requirements of minimum loss in head-to-tape contact area and maintained substantially the same life for either type of head assembly.

The narrow-track headwheel was also adapted in July 1962 by the DEP Communications Systems Division for special applications such as octaplex headwheel.[5]

HIGH-SPEED, WIDEBAND RECORDING REQUIREMENTS

Specific design proposals are often based on use of an existing equipment but with much greater bandwidth requirements; such an application is the *Wideband Recording System.*[6] This basic design is similar to the standard quadraplex panel; but, to meet bandwidth specifications, the headwheel panel must rotate at approximately 28,800 rpm, twice the speed of the standard panel.

A standard air-bearing panel was reworked to include a new headwheel assembly containing eight heads for a dual-channel system; this method required a new head with a shorter ferrite to improve efficiency of the head. Also, a different assembly structure was required to withstand the higher centrifugal forces developed at the higher speeds. To minimize crosstalk between sets of heads, the headwheel unit was constructed with a set of slip rings on either end of the shaft (Fig. 6); wires to the upper slip ring are fed through a hollow shaft which carries rotor and wheel assemblies.

A LOW-SPEED APPLICATION

Concurrent with the design of the high-speed panel for Applied Research, a low-speed panel based on our standard video headwheel panel was also designed (Fig. 7). This headwheel runs at a much lower speed, providing a 200:1 reduction in head-to-tape speed, and allowing for a 200:1 expansion in the time base of the signal.

3-HEADED ASSEMBLY

Another program for DEP Applied Research was the development of a three-head wheel assembly for DEP's helical scan machine. The final unit employed a larger-diameter headwheel with three heads; head design was similar to the standard video arrangement in which heads are imbedded in the wheel. Assistance was given to Applied Research in the design of the wheel and the drum, specifically in the area of the aerodynamic problems associated with a slant-track recording transport. The headwheel shaft is a belt-driven, air-bearing assembly with relatively large bearing surfaces.

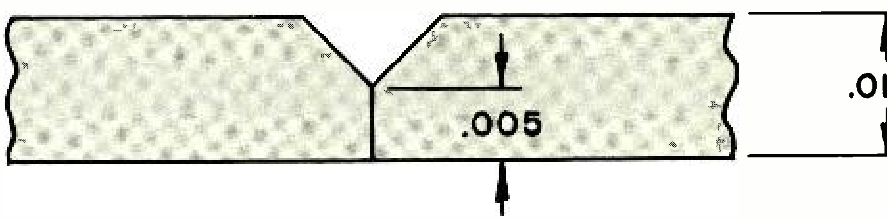


Fig. 5—View looking down on a narrow-track head.

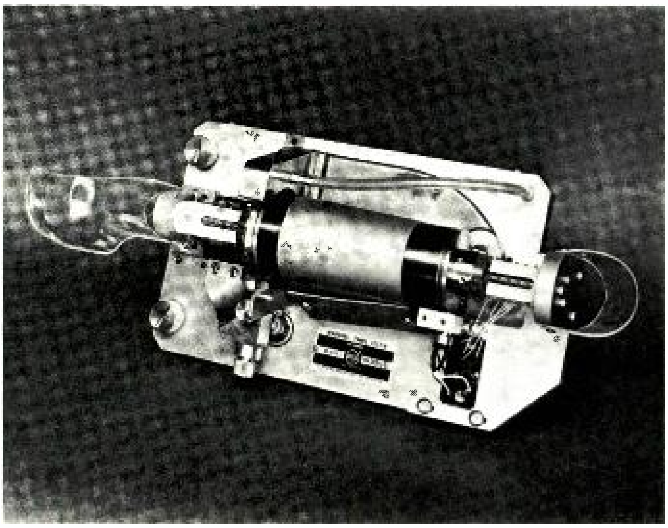


Fig. 6—A high-speed, dual-channel, dual-speed panel.

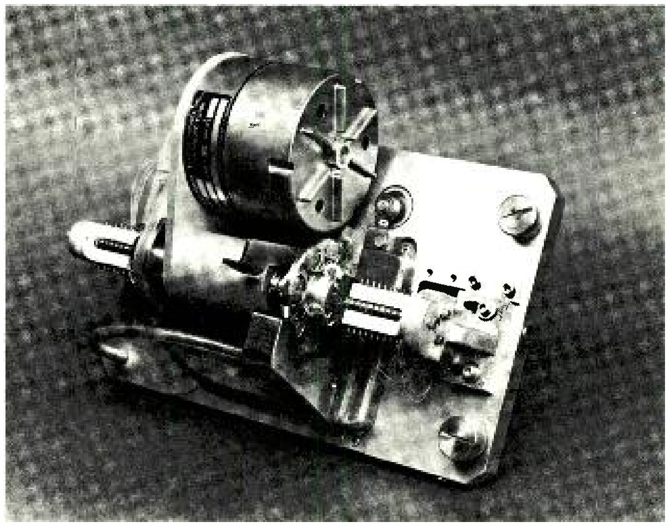


Fig. 7—A low-speed, dual-channel, dual-speed panel.

MAGNETIC HEAD PRODUCTION

Closely allied to the Magnetic Head Engineering Activity is the Magnetic Head Production Facility, which is part of the Broadcast and Communications Division manufacturing operation. This manufacturing facility has produced all of the heads for RCA's EDP tape transports designed by the Magnetic Head Engineering activities.

Additionally, this production facility manufactures the video headwheel panels for the RCA Television Tape Recorder. This panel is very exacting in its requirements and has necessitated a new approach in production and in the necessary engineering support. In conjunction with the factory, a constant evaluation and improvement program is carried on to improve the performance and reliability of the panel as well as to improve production techniques for these very precise assemblies.

CONCLUSION

The Magnetic Head Engineering Group is primarily a product design and development activity; but, due to the nature of the work, the advance development aspects and the production requirements must remain closely related. To this end, much advanced development work is carried on by this same activity.

Constant engineering effort to improve the state-of-the-art in magnetic head design assures a quality of performance necessary to support the magnetic recording industry in its constant quest for better performing, more economical tape systems. Major improvements in basic heads are promised in the future, based on work now underway in conjunction with the RCA Laboratories in the area of improved materials and head configurations.

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Fig. 8—A three-head wheel arrangement for slant-track recording.

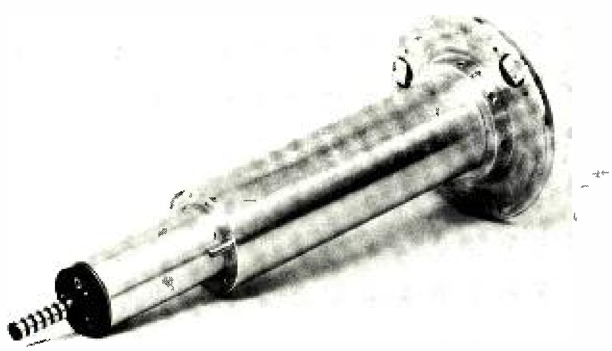
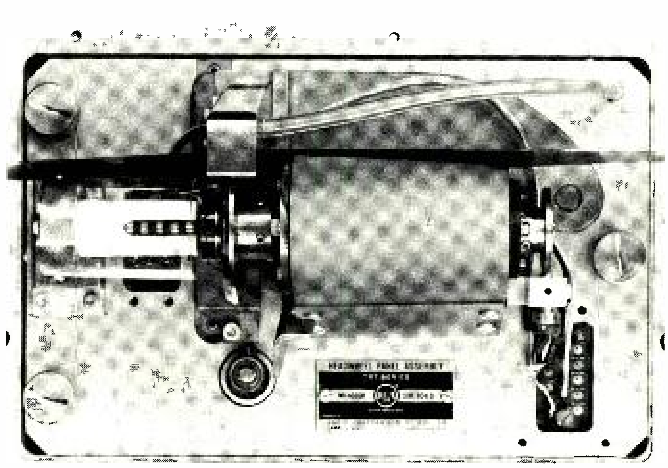


Fig. 9—A video headwheel panel.



HEAD-TAPE RELATIONSHIP IN DIGITAL-DATA MAGNETIC RECORDING SYSTEMS

The performance of magnetic tape recording systems is limited by various parameters of the tape coating and the read-write heads. This paper presents a qualitative description of the mechanisms involved in these performance limitations, and outlines the direction future developments must take to ensure further improvement in the performance of digital-data magnetic-tape recording systems.

DR. J. G. WOODWARD
RCA Laboratories, Princeton, N. J.

THE hysteretic magnetic behavior of ferromagnetic materials is well-known. This behavior is described by the familiar diagram of Fig. 1. If a ferromagnetic material is subjected to a magnetic field H_s which is sufficiently strong to drive the material into magnetic saturation, the material retains a residual magnetism called the saturation remanent induction B_s after the magnetizing field is removed. Similarly, when a field $-H_s$ of the opposite polarity is applied and removed, the material retains a residual magnetism $-B_s$. Thus, a ferromagnetic material possesses two distinct and reproducible states of remanent induction. This property makes these materials natural candidates for use in digital data-storage systems, where the $+B_s$ state may represent a *0* and the $-B_s$ state a *1*. Indeed, magnetic storage devices have become indispensable elements in digital systems. These storage devices have taken the form of a variety of types of core memories and also of several types of moving-medium recording systems such as magnetic drums, disks, and tapes.

Each of these magnetic storage devices has its particular set of advantages and shortcomings and, hence, performs most effectively in a certain type of application in a digital system. Magnetic-tape recording offers the advantage of providing an almost-unrivalled density of stored information when measured in terms of the number of bits per unit volume of the storage medium. This capability, combined with the reliability and convenience of use which are now possible, and with the fact that the data recorded on a magnetic tape can be erased completely or changed bit by bit as desired explains the popularity of this form of storage. Despite these advantages, a continued search is underway for improved materials, components and techniques for increasing the recorded density of information which can be reliably handled by a magnetic tape-recording system. A number of more or less sophisticated circuits and techniques have been devised for use in conjunction with the basic tape-recording elements to increase significantly the capabilities of the system. Nevertheless, certain fundamental limitations in performance remain which are inherent in the magnetic and mechanical relationship between the tape and the recording and playback heads which write and read out the signal.

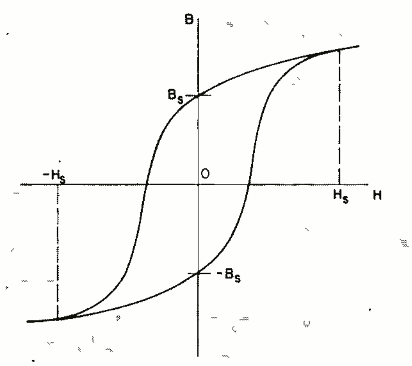
It is the purpose of this discussion to outline the basic head-tape relationships in order to show qualitatively the types of limitation existing in present-day magnetic-recording equipment and to indicate the direction which developments must take to further increase the density of recorded information.

THE RECORDING PROCESS

In modern commercial digital magnetic-tape recording systems the recording medium consists of a smooth, flexible plastic tape usually between 10^{-3} and 2×10^{-3} inch thick, on one surface of which a coating of magnetic material has been deposited. The thickness of the coating is commonly between 0.1×10^{-3} and 0.5×10^{-3} inch. A high-precision mechanical transport pulls the tape at a nearly constant speed over a recording head, with the magnetic coating of the tape close to or in contact with the pole faces of the head. The head consists of a magnetic

DR. J. G. WOODWARD received the BA from North Central College in 1936, the MS in Physics from Michigan State College in 1938, and the PhD in Physics from the Ohio State University in 1942. He held teaching assistantships in Physics from 1936 to 1942 while in graduate school at Michigan State and Ohio State. In March 1942 he joined the research department of RCA in Camden, New Jersey, and later that year moved to the newly-formed RCA Laboratories in Princeton, New Jersey. His research has been in a variety of fields including the study of vehicular radio noise, underwater sound, ferroelectricity in barium titanate, electromechanical feedback devices, rheological measurements at audio frequencies, musical acoustics, sound-reinforcement systems, stereophonic sound reproduction, magnetic-tape recording and disk-phonograph recording. He currently holds the position of Head, Audio Recording Group in the Acoustical and Electromechanical Laboratory. Dr. Woodward is a Fellow of the Acoustical Society of America, the Audio Engineering Society, and the American Association for the Advancement of Science. He is a member of Sigma Xi.

Fig. 1 — The magnetization hysteresis loop of a ferromagnetic material.



core on which is wound a coil carrying a magnetizing current. A fringing magnetic field extends outside the core in the region of a non-magnetic gap in the core, and the tape coating becomes magnetized as it passes through this fringing field. The recording situation is shown diagrammatically in a sectional view in Fig. 2. The polarity of the magnetization in the tape depends, of course, on the polarity of the currents in the coil of the recording head, and the tape may be left in either of its two remanent states corresponding to forward or reverse directions of current flow. If the direction of current flow is reversed at various times as the tapes move past the head, a corresponding pattern of remanent magnetization will be left in the tape coating, as sketched in Fig. 3. If the tape travels a considerable distance between the times of current reversal, the boundaries between regions of opposite polarity in the tape are clearly defined when measured in terms of the distance of tape travel per unit time.

However, if the switching rate is increased without a corresponding increase in tape speed the boundary between adjacent regions of opposite polarity becomes less and less definite until, ultimately, a small region surrounded by oppositely-magnetized regions can no longer be resolved. At the same time phase shifts may occur which will introduce timing errors in pulses reproduced from the tape in playback. In order to describe these effects we will now consider in more detail the magnetic field in the neighborhood of the recording gap and the way in which the field configuration influences the recording process.

THE RECORDING FIELD

The magnetic field lines in the fringing field associated with the non-magnetic gap in the recording head follow almost semi-circular paths between the portions of the core on opposite sides of the gap. Only in the region very close to the gap do the field lines deviate greatly from semi-circular paths. Such a fringing field is sketched in a cross-sectional view in Fig. 4. In general, at any point above the pole pieces the fringing field will have both a longitudinal component (parallel to the tape motion) and a perpendicular component (perpendicular to the surface of the tape). The longitudinal component is almost entirely responsible for the magnetization on the tape, while the vertical component usually produces only second-order effects. This is the case because the longitudinal component is the stronger of the two in the region of the fringing field through which most of the tape coating passes, and also because the coating is given a preferred magnetic axis in the longitudinal direction during manufacture of the tape. Consequently, only the longitudinal components of the field will be considered here.

The results of a calculation of the longitudinal field component around the gap are plotted in Fig. 5. The ordinate gives values of the field strength in terms of H/H_o, where H_o is the field strength inside the gap where the field is uniform. The abscissa is the distance in the direction of tape travel away from the central plane of the gap, measured in units of x/l where l is the gap length. The various curves plotted correspond to various distances above the surface of the pole faces, measured in units of y/l. The plots of Fig. 5 show the field in air. The configuration of the field is altered only slightly by the presence of magnetic tape on the head[1], since the permeability of the tape is quite small ($\mu \approx 4$).

Gap lengths between 0.1×10^{-3} and 10^{-3} inch are used in commercial equipment. Gap lengths as short as 0.02×10^{-3} inch are sometimes used in experimental equipment. Since the thickness of the tape coating is comparable to the gap length, there will be a considerable difference in the magnetizing-field strength at various depths in the coating as it passes over the recording gap. The separation between the head and the tape coating is also a factor in determining the configuration of the field through which the tape passes. In some applications the head is intentionally spaced from the moving coating by about 0.1×10^{-3} inch to reduce wear. Even when "in-contact" operation is intended, an effective separation exists due to roughness of the tape surface. This effective separation has been estimated to range between 0.02×10^{-3} and 0.1×10^{-3} inch, depending on the condition of the tape surface.

With this background, let us now consider the magnetization process in the tape as it passes the recording gap.

MAGNETIZATION OF THE TAPE

Another way of depicting the magnetic hysteresis of the tape coating will be useful in this discussion. As was shown in Fig. 1, when the material is saturated by a sufficiently-strong applied field and the field is then reduced to zero, the material is left in a remanent state, B_r. If the material is saturated, and subsequently a field of the opposite polarity and of any magnitude is applied and reduced to zero, the material will be left in some other remanent state. If the remanent induction is measured for each of a number of values of applied field, a hysteresis loop such as is shown in Fig. 6 results, in which H is the value of the applied field and B_r is the remanent induction resulting from each value of H. For qualitative purposes the loop of Fig. 6 may be thought of in terms of the

Fig. 2 — Magnetic tape recording process.

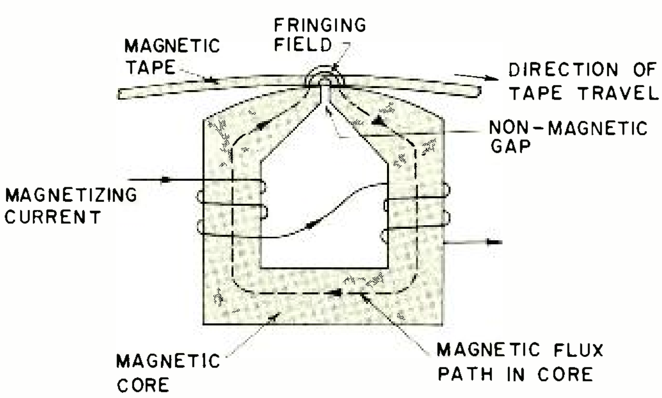
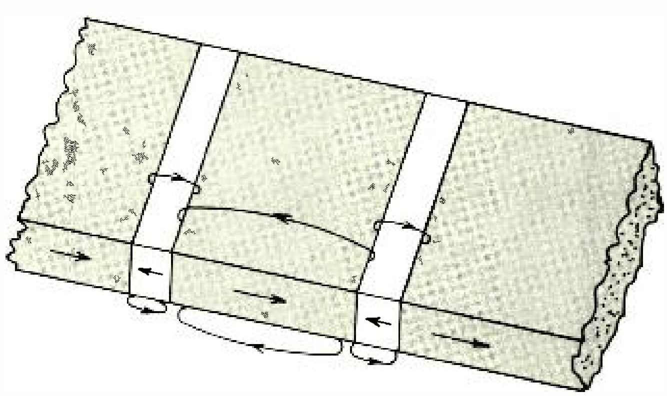


Fig. 3—Pattern of magnetization in a magnetic tape coating.



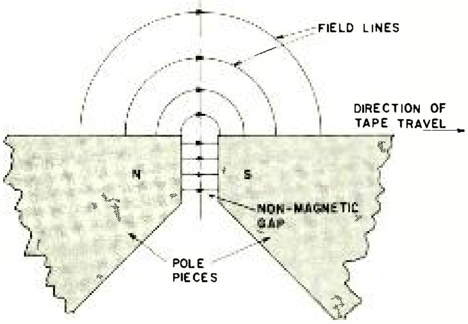


Fig. 4 — The magnetic field in the vicinity of a recording gap.

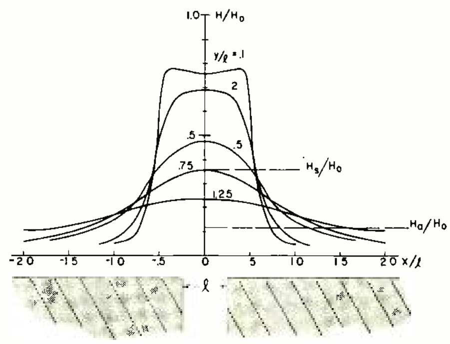


Fig. 5 — The longitudinal component of the field at a recording gap. The y/l parameter refers to distance above the surface of the recording head.

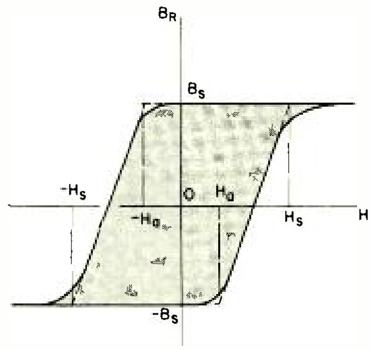


Fig. 6 — Remanent magnetization in a tape coating as a function of applied field.

parallelogram completed by the dashed-line extensions at the corners of the loop. Thus, H_s is defined, as before, as the field which results in the maximum remanence B_s. A minimum field H_a is required before any change in remanence can be observed.

The magnetic characteristics described by Fig. 6 can now be combined with the gap field described by Fig. 5 to predict the pattern of magnetization impressed on the tape when the current is reversed in the recording head. As an illustrative example let us take a case in which the gap and tape dimensions are such that the front surface of the tape coating will be spaced by 0.1 l and the back surface by 0.75 l from the recording-head surface. In order to relate the H/H_o ordinate of Fig. 5 to the H abscissa of Fig. 6 we must take into account the necessity of saturating the tape coating throughout its entire thickness as it passes the recording gap. This is an important requirement for digital recording systems in which the signs of individual bits must be reversed. If a saturating field did not extend completely through the tape, variations in head-to-tape spacing or in instantaneous recording current might cause an incomplete removal of previously-recorded information, with the result that the signal-to-noise ratio would be degraded, and the probability of an error in read-out would be increased. Therefore, as a minimum requirement in the present example, the field strength above the center of the gap at a distance of 0.75 l above the head should be H_s. The value of H_a, below which the magnetization in the tape is not affected, will be determined by Fig. 6 and can be located on the ordinate of Fig. 5. Horizontal dashed lines indicating the levels of H_s/H_o and H_a/H_o have been drawn in Fig. 5. The intersections of these lines with the family of curves determines the region in which recording takes place at the various distances above the head.

When a steady current of the required magnitude flows in the head, all of the tape which has passed the gap will be saturated in one polarity. If the direction of the current is reversed, all portions of the tape in regions where the field is greater than H_s at that instant or which subsequently move through these regions will be saturated in reverse polarity. All portions of the tape which do not encounter fields greater than H_a will retain the original polarity of saturation. At the instant of current reversal some portions of the tape will be in regions where the field has values between H_a and H_s. These portions will be left with values of remanent induction between B_s and $-B_s$, in accordance with the characteristic shown in Fig. 6. The resulting pattern of magnetization on the tape is depicted in Fig. 7. Instead of a sharp plane of demarcation between regions of positive and negative saturation in the tape there is a sizeable region of transition, indicated by the shaded area in Fig. 7. Within this region the remanent induction decreases gradually from B_s to zero to $-B_s$. The locus of the points of zero field is indicated by the dotted line. The exact shape of the transition region is strongly dependent on the absolute field strength, the gap and tape dimensions, and the magnetic characteristics of the tape. The important fact to note is that a transition region exists having dimensions comparable to the tape thickness and the gap length, and that the region is shortest at the front surface of the coating and may become very extensive at the more remote surface. The transition region lies, for the most part, beyond the trailing edge of the recording gap.

The manner in which the transition region is a factor limiting the record-

Fig. 7 — Pattern of magnetization in a tape coating following a step-function reversal of the recording field.

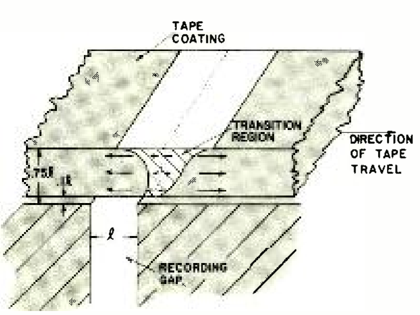


Fig. 8 — Pattern of magnetization in a tape coating for a short-duration reversal of the recording field.

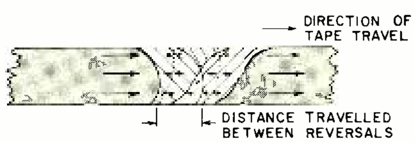
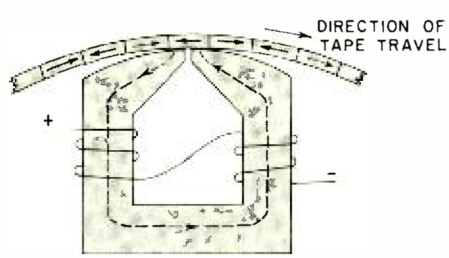


Fig. 9—The magnetic tape playback process.



ing resolution (or the density of recorded information) becomes apparent when the qualitative analysis just made for a step function in the recording current is extended to the case of a short-duration pulse. In this case, after a short interval following a current reversal, a second reversal returns the current to its initial polarity, and two transition regions are left in the tape as sketched in Fig. 8. Since the transition regions overlap, a portion of the first region is overlaid and reversed in polarity by the second region. Consequently, the volume of the coating left saturated by the first reversal is smaller than would be the case if the transition regions were of infinitesimal extent, and the signal representing the recorded pulse will be reduced in magnitude in playback. If the pulse duration is made so short that the reduced magnitude of the signal in playback is close to the noise level, a readout error may occur. Although it is not immediately evident, and the mechanism will not be considered further here, it can be shown that the alteration of the magnetization pattern in the tape due to recording short-duration, closely-spaced pulses results in timing errors in readout as well as the errors due to the reduced magnitude. In some applications the timing errors may be more serious than the errors arising from the reduced magnitude of the pulses.

On the basis of the preceding discussion, one can suggest certain directions in which developments should move to reduce the limitations on the attainable information density in the recording process. The obvious moves are to make the gap length shorter, to make the tape-coating surface smoother and thereby provide a more intimate tape-head contact, to make the tape coating thinner so all portions of the coating will traverse the recording field at nearly the same distance from the head surface, and to provide a recording medium having a B_R-vs-H characteristic which has steeper sides (a square-loop characteristic). When the coating is made thinner, a material having a higher B_S should be used to maintain a sufficiently high output with the reduced volume of material. Also, with the thinner coating a more wear-resistant material will be required. Recent studies[2] have suggested that while a medium having a square-loop characteristic may be desirable for reducing errors due to a reduced magnitude of pulses in playback such a characteristic may not be best for reducing timing errors, and that in some applications a compromise may be required. This point deserves further experimental and analytical investigation.

HEAD-TAPE RELATIONSHIPS IN PLAYBACK

In addition to the limitations imposed by the recording process, other, and comparable, limitations are imposed by the head-tape relationships existing in the playback process. In order to isolate the playback from the recording effects we will suppose the magnetic recording medium to contain an ideal pattern of magnetization, i.e., to be uniformly magnetized through the thickness of the coating and to have regions of opposite polarity separated by infinitesimally-short transition regions in planes perpendicular to the tape surface and to the tape motion. This is the situation depicted in Fig. 3. The limitations inherent in playback are primarily geometric in their origin and are not critically affected by the magnetic characteristics of the recording medium. Three such resolution-limiting factors exist. Their effects have been termed *scanning loss*, *separation loss*, and *azimuth loss*. Since these factors have been known for many years and have been described in many places in the technical literature[3,4], they will be discussed only briefly here.

By way of background, the basic playback process will first be described with reference to Fig. 9, which depicts an ideally-magnetized tape moving over the pole pieces and the gap in the playback head. Field lines leaving the tape in the vicinity of the gap enter the core on one side of the gap and follow paths through the core to re-enter the tape on the other side of the gap. As the tape moves past the head, the varying pattern of magnetization in the tape causes the number of field lines passing through the core to change in magnitude and polarity with time with the result that a time-varying EMF is generated in the coils wound on core. The EMF is proportional to the time-rate-of-change of the magnetic field, so that ideally the voltage at the terminals of the playback head is proportional to the derivative of the remanent magnetic induction in the tape as it passes the head. Hence, a rectangular pulse recorded on the tape produces a positive-going spike and a negative-going spike in the readout signal. If the recorded pulses have transition regions between segments of opposite polarity the readout pulses, instead of being ideal spikes, take the form of positive and negative pulses of considerable duration and of smaller magnitude. A corresponding loss in resolution occurs. This, however, is a manifestation of the limitation in the recording process already discussed. The first playback

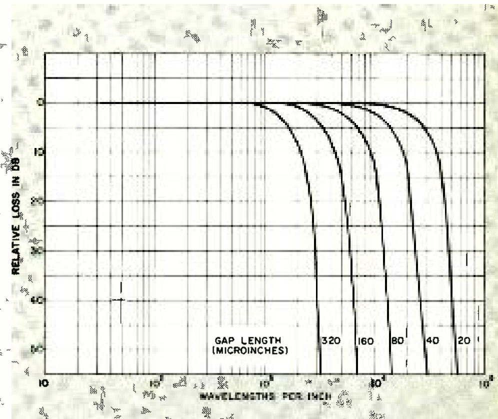


Fig. 10 — Playback scanning loss for recorded sine waves.

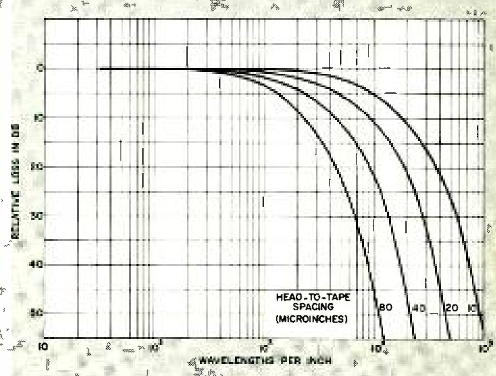


Fig. 11 — Playback separation loss for recorded sine waves.

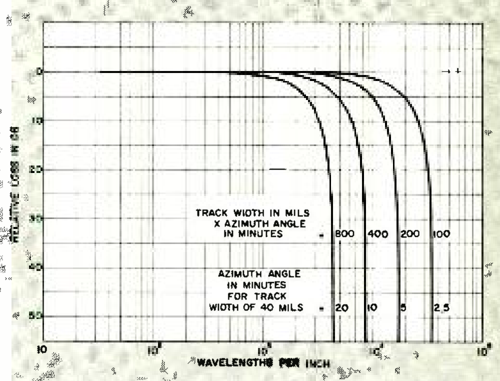


Fig. 12 — Azimuth loss for recorded sine waves.

limitation to be considered will be the scanning loss.

SCANNING LOSS

Scanning losses occur when the gap length of the readout head is comparable to the length of the pulses recorded on the tape. Clearly, if a train of pulses has been recorded such that the gap length is equal in extent to two adjacent pulses of opposite polarity the net number of field lines threading the core is zero for any position of the tape along the head, and no electrical signal is developed. Even before this extreme condition is reached the magnitude of the readout signal is reduced by an amount depending on the ratio of the pulse length to the gap length. The mathematical analysis of scanning losses has been carried out for recorded sine waves with the result shown in Fig. 10. Here the abscissa is the number of wavelengths per inch on the tape and the ordinate is the scanning loss measured in decibels. Curves for several lengths of playback gap are shown. The curves of Fig. 10 represent the playback response to a recorded sinusoidal magnetization pattern. They can be related to recorded rectangular pulses by considering the number of Fourier components required to give an adequate synthesis of the pulses. Between five and ten Fourier components usually must be passed without serious attenuation if signal deterioration due to scanning loss is to be negligible. This, clearly, requires a short gap length in a high-resolution recording system.

SEPARATION LOSS

In the playback process, as in the recording process, a reduction in resolution occurs if the magnetic coating is not in intimate contact with the head. Theoretical values of the separation loss as a function of the number of wavelengths per inch of tape, with separation as a parameter, are plotted in Fig. 11 for recorded sine waves. As in the case of scanning loss, these data can be applied to the case of recorded pulses in terms of the number of Fourier components which must be passed without attenuation to adequately represent the pulses. The separation loss is a function of the ratio of the head-to-tape spacing and the wavelength and amounts to approximately 55 db loss per wavelength of separation. Since the thickness of the tape coating may not be negligible in comparison to the recorded pulse lengths, the separation loss will be different for distances from the head surface into the coating, and short-wavelength components will suffer more attenuation than the long-wavelength components. If the separation loss in playback is to be minimized, the coating surface should be very smooth to permit an intimate head-tape contact, and the coating should be thin to avoid serious relative loss of the short-wavelength components.

AZIMUTH LOSS

A recorded track on a tape always has an appreciable width in order to provide a reasonable signal-to-noise ratio and to make the head-track alignment feasible mechanically. Because of the finite track width it is highly desirable that the azimuth angle, i.e., the angle which the gap edges make with the direction of tape travel at each instant be precisely controlled. If the tape behaved in exactly the same manner in every passage over the recording and playback heads, azimuth angle variations would not present a problem. However, even in the best tape transports some variability in azimuth angle inevitably occurs. This is due to tolerances in the dimensions of the tape and of the tape-guidance system, and to lateral curvature or skewing of the tape. Consequently, the azimuth angle in playback often will be somewhat different from the angle at the instant of recording. Hence, the gap in the head will be reading different phases of the recorded signal from one edge of the track across to the other edge, with the result that a partial cancellation of the signal occurs in the head. This leads to losses of the type plotted in Fig. 12 where the loss in decibels is shown on the ordinate and the number of recorded sinusoidal wavelengths per inch along the tape is shown on the abscissa. The parameter for the four curves is the product of track width and the difference in azimuth angle in recording and playback. These curves can be applied to pulse recording by again considering the Fourier components. For high-density recording systems the tape-guidance system must be made to control the tape motion very precisely, indeed.

Azimuth angle variability also produces another type of error, since in digital-recording systems a number of parallel tracks are recorded on the tape. When the azimuth angle is different in recording and playback, timing errors occur between tracks. That is, some tracks may be advanced or delayed relative to other tracks as the azimuth angle varies, and signals from the various tracks which should be read out simultaneously are read at different instants. Attempts to overcome this problem have led to the development of a number of sophisticated electronic techniques to recognize and correct for timing errors.

CONCLUSIONS

In this paper we have attempted to present a qualitative description of the recording and playback processes in digital tape-recording systems with emphasis on those factors which offer basic limitations to the density of recorded information on the tape. Only the most important features could be considered. Such factors as the perpendicular component of the recording field, self-demagnetization of the tape, the particulate structure of the magnetic coatings, the finite permeability of the recording medium and of the recording and playback heads also influence the system performance but usually only in second-order phenomena. The principal factors controlling the recording process are the magnetic characteristics of the recording medium, the thickness of the recording medium, the head-to-tape separation, and the gap length of the recording head. The principal factors controlling the playback process are the gap length of the playback head, the head-to-tape separation, and the thickness of the recording medium. In addition, variability of the azimuth angle results in reduced performance capability of a system. Control of the azimuth angle is necessary in both recording and playback, although electronic correction techniques usually are applied only to the playback signal.

Knowledge of these elementary factors has led to improved tape and tape-recording systems in RCA as well as elsewhere. The direction of development is toward thinner, smoother, more wear-resistant tape coatings having higher remanent inductions and generally square-loop magnetic characteristics. Also, shorter gap lengths are used in both the recording and playback heads, and more precise transports have been devised. Some of the limitations due to the head-tape relationships can be alleviated to some degree by means of sophisticated electronic techniques. However, many of these techniques can be used even more effectively if the basic limitations are further reduced. During recent years the tape stations in each generation of computer have offered significantly increased capabilities because of the developments listed above. And the end of such developments is still not in sight.

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MAGNETIC TAPE FOR HIGH-SPEED APPLICATIONS

Although magnetic tapes are vital for the operation of computers and video recording systems, they form a weak link in the chain of highly sophisticated equipment. The design of hardware has progressed at a far higher rate than that of the tape, leaving the machines dependent on a marginal product. The evolutionary process of tape development is a slow one, the art is known only to a few, the approaches are controversial—will this change in the future? In support of RCA's substantial business in the television and computer field, as well as in audio products (including audio tape) there is in RCA Laboratories a continued research effort on magnetic tapes. This paper discusses the state of the art of magnetic tape for high-speed applications and some of the problems associated in developing products for future needs.

Dr. H. BAUER
RCA Laboratories
Princeton, N. J.

DR. HERBERT BAUER is a member of RCA Laboratories where he is conducting research on organic materials related to electronic applications. He is at present responsible for the Laboratories Computer and Video Magnetic Tape Program. He joined RCA in 1960 after four years with DuPont's Photo Products Department where he was engaged in polymer chemistry research. Dr. Bauer received his PhD in chemistry from the University of Vienna in 1951. After a year as a research assistant at the University of Graz, Austria, he was awarded the National Research Council of Canada Post-doctoral Fellowship. He joined the staff of the National Research Council in 1953 to conduct research in carbohydrate chemistry. In 1961, Dr. Bauer received an RCA Laboratories "Achievement Award" for research in non-silver halide photographic systems. He is a member of the American Chemical Society, the Austrian Chemical Society, the Chemical Institute of Canada, and Sigma Xi.

Only twenty years have passed since the first reels of magnetic tape came off a production line and already industry-wide sales are approaching the $100 million mark. This growth appears even more remarkable for a product, that has not significantly changed since its conception. What has changed in these twenty years, is the rapidly growing number of applications for magnetic tapes. Today these new applications account for three quarters of the total tape market; for the next few years they promise a 15% to 20% annual growth of the market[1]. In essentially all of these new applications the magnetic tape is used at "high speeds", referring in this case to the relative speed between the magnetic tape and the tape head, regardless of whether the tape slides over a stationary head or the head is moved over a stationary tape. Most tape applications for data processing and for the storage of video information fall into this category, while the low-speed market is divided between the traditional audio recording field and some special instrumentation applications. There is no sharp separation between the two areas, since in addition to tape speed other operating conditions also influence the stresses on the tape is subjected.

The actual tape speeds in relation to an assumed stationary head range in most modern computer tape stations from 75 to 150 inches per second. They reach 1,600 inches per second or approximately 75 miles per hour in commercial video tape recorders, and this figure is often exceeded in special applications. Whereas the high tape speeds in computer tape stations are essential in reducing access time to a particular piece of information stored on the tape, the tape speeds in video recorders are dictated by the high frequency of the signals, i.e., by the information density per unit time which has to be recorded.

An advanced commercial computer tape is at present able to store 900 coded characters per square inch and 600,000 per cubic inch of tape. This means that the information content of approximately 150 single-spaced typewritten pages can be stored in 1 cubic inch of tape. Furthermore, the 600,000 characters may be recorded or read in less than 10 seconds. A reel of tape priced at $50 may store up to 14 million characters, or 3,500 typewritten pages, at a cost of $3.50 per million characters.

New computer tapes sold by RCA are inspected, repaired and guaranteed to be 100% dropout or error-free. Depending on the conditions of use, they will start to show signs of wear and to cause errors after 10,000 passes over the heads; this point may be reached in some rare applications after a few hours; in others, it will last for years.

The performance of magnetic tape in storing pictorial information is not quite as impressive. Assuming approximately equal picture quality or signal to noise ratio, video magnetic tape is certainly surpassed by photographic film in the storage capacity per unit area; the storage capacity per unit volume of the two media is at present about equal. However, the immediate availability of the stored information and the ease of copying outweigh other factors.

HIGH-SPEED TAPE REQUIREMENTS

Most difficulties encountered in the present use of magnetic tapes at high speeds can be traced to the unavoidable sliding contact between the tape and the magnetic heads. As yet, no practical solution avoids this close mechanical coupling between tape and tape head.

The necessity for intimate tape-to-head contact arises from the need for short-wavelength recording and the shallow penetration depth of the magnetic impulse into the coating. In a computer tape station, a drop-out or error signal will result from any imperfection in the tape coating which lifts the tape momentarily more than 0.001 inch away from the head, and the computing operation will be stopped immediately. In video recording systems, where the shortest wavelength on tape is in the order of 0.0002 inch, a separation of the tape from the head by only 0.00005 inch will reduce the recorded signal by approximately 10 db. The signal loss will be the same, whether the separation is caused by an irregularity inherent in the tape surface or by any additional layer interposed between the tape and the head.

Problems of friction can rather easily be dealt with in mechanical systems where a selection of structural materials and suitable liquid lubricants is available. They become of a different

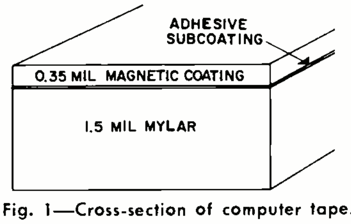

Fig. 1—Cross-section of computer tape.

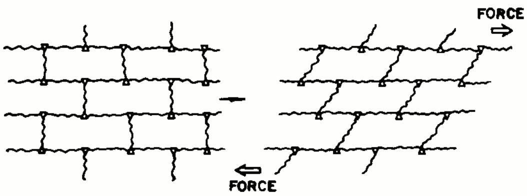

Fig. 2—A uniformly crosslinked polymer network obtains its strength from the even distribution of the applied forces over a large number of chemical bonds.

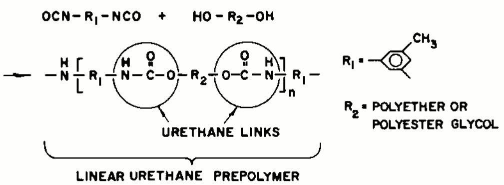

Fig. 3—Formation of linear polyurethanes by reaction of diisocyanates with diols.

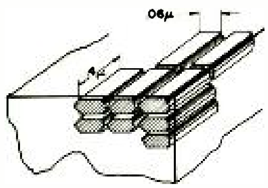

Fig. 4—Model of an ideally oriented and packed magnetic coating.—Average particle size of magnetic material.

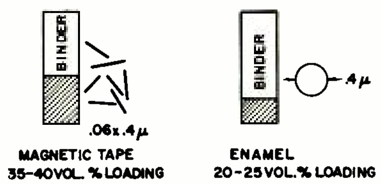

Fig. 5—Comparison of pigment loadings in an enamel and a magnetic tape coating.

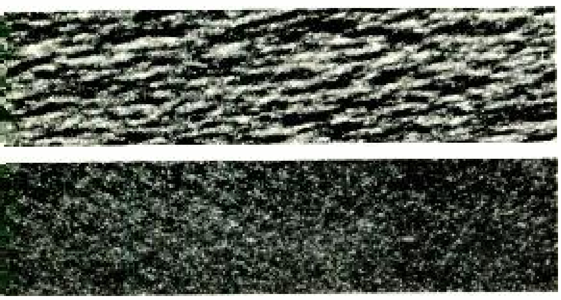

Fig. 6—Surfaces of magnetic tape coatings, magnification 170x: (top) poor dispersion; (bottom) good dispersion.

magnitude, however, when the material composition is dictated by other requirements such as having specific magnetic or electrical properties. The magnitude of the abrasive forces becomes apparent, if the speeds involved and the lack of lubricants are considered. The abrasion problem is further magnified by the additional, high accelerative forces to which the tape is subjected in certain computer operations. The tape is alternately started and accelerated to its full speed in 4 to 5 msec and stopped again at the same rate. often many times in a single second. The exerted accelerative forces may amount to 150 times the earth's gravitational force and repeatedly extend and relax the whole tape structure. The heat of friction raises the temperature of the tape surface to 100 to 230°F, and has to be dissipated without affecting other properties.

From the above it can be concluded that the main mechanical properties which determine the suitability of a magnetic tape for high-speed uses are those connected with abrasion resistance and surface structure. On the one hand. the surface of the tape is required to be of almost optical perfection; the surface has to permit a continuous contact of all parts of the tape with the tape head. On the other hand, a slightly grainy structure of the tape surface is desirable to avoid the tremendous increase in adhesive forces connected with ultrasmooth surfaces. The magnetic requirements for a computer and video tape do not differ considerably from those of a good quality audio tape. They would, by themselves, be easily attained. Maintaining the difficult balance between output and wavelength response, and wear and surface characteristics will be further discussed when the magnetic material dispersion problems are considered. The build-up and dissipation of electrostatic charges resulting from sliding the tape over guides and heads presents another problem in some magnetic tape coatings. In computer tape stations with weighing bins, i.e., where the tape is tensionless and free to follow electrostatic attractions. the problem is particularly acute. Magnetic materials, polymeric binders, and support films are high resistivity materials, and ways and means for increasing the conductivity of the finished tape have to be found.

Most of the remaining mechanical properties of high-speed tapes are also intimately linked with the wear performance. High strength of the base material, high flexibility, and elastic recovery of the coating, good adhesion of the coating to the base film, hardness of the coating to prevent deformation and embedding of foreign materials on winding, are just a few. Abrasion products should be absent and if they occur they should be powdery for easy removal. Close tolerances in tape width, straightness and smoothness of the slit edges are also of great importance.

ABRASION RESISTANT POLYMERIC BINDER MATERIALS

A cross-section through a common computer tape (Fig. 1) shows three layers: the *support film*, the *magnetic coating*, and often a *subcoating* to provide adhesion between them. Magnetic tape coatings consist of a dispersion of a magnetic material, usually small particles of gamma iron oxide in a polymeric binder. Nitrocellulose and later polyvinyl chloride (PVC) co-polymers have served for a long time as the binder materials in the magnetic tape industry. PVC as a linear polymer is readily dissolved in common solvents, its high polarity and easy modification by copolymerization make it an excellent material for dispersing oxidic pigments; fair adhesion to common base films is also obtained with it. Most vinylchloride polymers, however, are hard and brittle, and shrink considerably during solvent removal. In order to make the coatings pliable and to reduce the high shrinkage, high concentrations of plasticizers are incorporated; this renders the coatings soft and low melting which in turn makes them vulnerable to abrasion. Although the "art" of formulation has optimized thermoplastic coatings, at best high quality audio tapes and perhaps marginal computer tapes have resulted.

The mechanical properties of polymers can be greatly improved by crosslinking linear polymers to form three-dimensional networks. In this manner, materials are made available which range from highly resilient rubbers to hard. yet tough enamels. At present, crosslinked polymers are used in only a few commercial high-speed tapes.

Surveying the large number of available crosslinked polymers, materials that show elastomeric properties appear promising as magnetic tape binders. The three-dimensional regular network structures of elastomers with uniformly distributed crosslinks permit a uniform distribution of applied tensile stresses which gives these materials superior strength characteristics paired with high elongations (Fig. 2). Materials with outstanding properties belong to the class of polyurethane elastomers. They have excellent abrasion resistance and, in fact, have found such diverse uses as covering the leading edges of aircraft wings and heel lifts for ladies' shoes.

The designation "polyurethanes" refers to a class of high-molecular-weight compounds characterized by the recurrence of urethane linkages at regular intervals along the polymer chain. The urethane linkage is generally formed by the reaction of a difunctional isocyanate with a difunctional alcohol (Fig. 3). While aromatic diisocyanates (such as tolylene diisocyanate) are almost exclusively used for the isocyanate portion, the diol portion can be selected from a wide variety of available materials. This permits an adjustment of the desired physical properties in the final polymer. To obtain useful products, the diol portion of the polyurethane generally comprises a linear polymer which may be either a polyester or a polyether (R_2 in Fig. 3). The molecular weight of the polyol, its chemical nature, the number of methylene or other groups between ester or ether linkages, all determine whether the final product will be a soft elastomer or a hard, impact resistant solid.

Further variation of the polymer properties can be obtained by the nature and number of crosslinks introduced. The crosslinking reaction is usually initiated after the linear urethane prepolymer has reached a predetermined length.

Polyfunctional alcohols, amines, or water vapor may be used as crosslinking agents. By selection of the proper compound, again the chemist has the possibility to tailor specifically the properties of the final product to his needs.

DISPERSION OF MAGNETIC MATERIALS

The degree of dispersion of the magnetic material in the coating not only determines the magnetic characteristics of the tape, but also has a strong influence on the mechanical properties of the tape and on the structure of the tape surface. An idealized model (Fig. 4) would consist of a tightly packed, well aligned, uniform arrangement of the magnetic particles, each one completely surrounded and bonded by a layer of the binder polymer. In such an arrangement, the magnetic output and resolution would be optimized for the material in question, the magnetic material would act as a reinforcing filler for the polymer and the surface would be flawless and mirror smooth.

In practice, this idealized model is never accomplished. The difficulties arise from four factors: pigment volume concentration, particle size, particle shape, and the inability of many binder polymers to wet the oxidic material. In comparison with a high grade enamel the pigment loading (i.e., the ratio of magnetic material to binder) is almost doubled (Fig. 5). This high content of a filler medium increases the number of voids in the coating due to insufficient binder to fill completely all interstices. This problem is magnified by both the extremely small particle size and the high acicularity of the magnetic material. Furthermore, binder polymers belonging to the class of urethane elastomers lack almost completely any affinity to the highly polar surfaces of the magnetic material. As a consequence, many magnetic coatings are porous and contain particle agglomerates. This manifests itself in low cohesive strength and rough surfaces. Research on these deficiencies involved thorough evaluation of the surface chemistry and resulted in a considerable improvement (Fig. 6).

Since crosslinked polymers are insoluble, the usual step of dispersing the magnetic material in the polymer solution is not applicable. The difficulty is overcome by dispersing the magnetic material in prepolymers, short linear sections of polymeric compounds which after coating are chemically linked to each other in the crosslinking or curing reaction. The chemical reaction takes place as soon as the reactive species are combined. Therefore, the addition process and coating operating have to be closely controlled. The curing reaction is generally accelerated by elevated temperatures, and has to be carried out over extended periods. Ovens have to be designed for the handling of long tape lengths in a continuous process.

PRECISION COATING TECHNOLOGY

The application of very thin layers of highly viscous, thixotropic and unstable dispersions represents a major problem in coating technology. Coating thickness variations should not exceed 10%. This means that the wet coating thickness has to be maintained within 10% of 0.0006 inch, if a uniform dry coating thickness of 0.0002 inch is required with a formulation having a 3:1 dry-down ratio. Variations in the thickness and flatness of the base film will necessitate the use of coating techniques which provide automatic compensation.

The complete elimination of all foreign materials such as dust, dirt or gas inclusions is technically not feasible. From presently available data, one can conclude that it is not possible to produce even single reels of high-quality computer tape completely free of dropout-causing imperfections without resorting to some kind of a surface finishing technique such as polishing, calendering, or time consuming hand repair. At present, one can count an average of 20 to 40 dropouts on computer tapes manufactured under the most carefully controlled conditions. These defects must be hand repaired before the tape is sold to the ultimate user. Further improvements in process technology will reduce the number of defects to a more acceptable level.

CONCLUSIONS AND FUTURE

Already, experimental computer tapes and tape stations with storage capacities of 1,500 to 2,000 characters per square inch, 1.5 to 2.0 million per cubic inch, and 25 to 35 million per reel are being designed. Tape coating thickness is being reduced to 0.0001 inch. Start-stop times of 1.5 msec are being approached. The tape will be enclosed in hermetically sealed cartridges to keep out dirt and dust and to eliminate manual handling. Electronic techniques for reducing the sensitivity towards tape defects are being explored. The cost of tape and tape handling equipment will rise exponentially, but it will be justified by an equal rise in performance.

Research towards improved magnetic tapes for high-speed applications requires a peculiar blend of scientific and technological disciplines. The successful solution of the outlined problems will depend on the close cooperation between the polymer and surface chemists, the rheologists and the chemical engineers. Close contact should be maintained at all times with the design engineers responsible for future tape systems. New concepts such as air flotation of the tape at the heads may serve as an interim solution to the wear problem. New magnetic materials with higher magnetic moments and with improved surface characteristics should help reduce some of the other problems. A better understanding of the influences of chemical structure on the mechanical properties of polymers should also result in coatings defying abrasive forces more effectively.

The successful evolution of future computer and video tapes will largely hinge on the application of fundamental knowledge gained in studying the materials problems outlined in this paper.

ACKNOWLEDGEMENT

Dr. N. E. Wolff and Mr. S. M. Bennet have contributed significantly to the magnetic tape research efforts at RCA Laboratories. Dr. N. E. Wolff's helpful suggestions concerning this paper are gratefully acknowledged.

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A HIGH-SPEED PRECISION INSTRUMENTATION TAPE RECORDER

This multiple-channel, wideband precision tape recorder was developed as a basic element in a tracking radar system to be used in multiple target environments. All signals received by the radar tracking the target in real time are tape recorded. Thus, all targets viewed by the radar during a "live" exercise can be repeatedly acquired, tracked, and analyzed through playback at a later date. To permit recovery of maximum information, data is recorded in the form of unprocessed radar IF signals; then on playback, the optimum signal-processing system recovers each target parameter of interest.

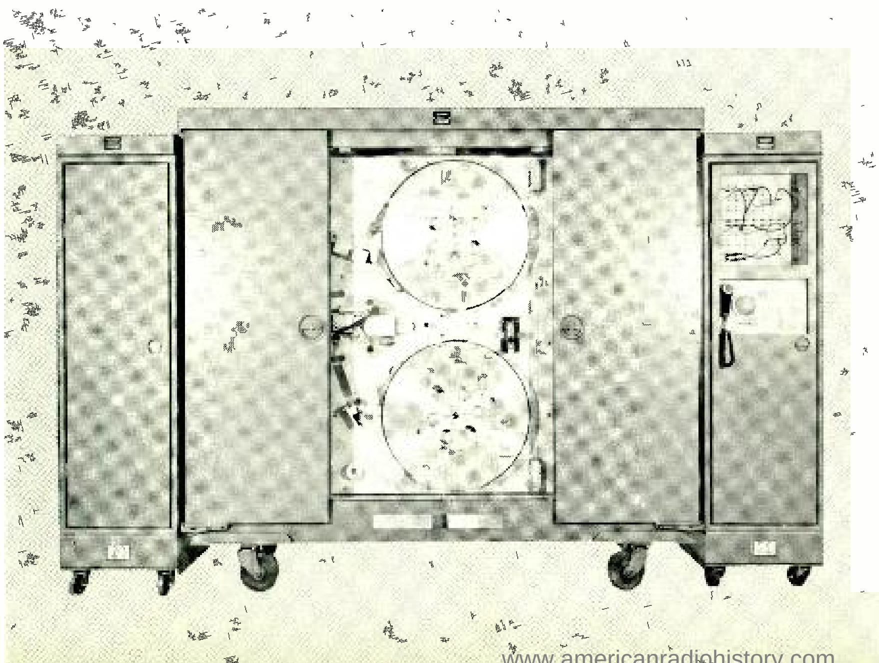
B. A. COLA and J. M. URITIS

Missile and Surface Radar Division
DEP, Moorestown, N. J.

RADAR target parameters such as range, doppler, and angle position must be measured precisely; at the same time, target resolution and relative amplitude must be preserved. Such performance requirements impose challenging demands on a radar tape recorder—particularly signal-to-noise performance, gain and phase tracking between channels, gain linearity, transport velocity stability, and interchannel jitter.

Fig. 1 shows the complete radar tape recorder designed to meet these standards of performance. The radar tape recorder provides 15 channels with a bandwidth capability in excess of 6 Mc; the recorder operates at a tape speed of 1,180 ips and a velocity stability of better than 1 part in 10^5. The recording time is 6 minutes. The radar system utilizes these capabilities to record 8 channels of 3.5 Mc video radar signals along with 7 wideband channels of timing, digital, and other reference signals for processing by the radar in serial form.

Fig. 1—The high-precision instrumentation tape recorder.



RECORDER OPERATION

The radar tape recorder (Fig. 2) stores ungated IF information from the UHF and L-band receivers so that during subsequent playbacks, targets can be acquired and tracked in angle, range, and doppler.

The receiver-exciter sends repetition rate pulses to the UHF and L-band transmitters where the power is stepped up and sent to the antenna for transmission. The receiver-exciter receives the returns from targets and sends them to the tape recorder and tracking receiver.

The tracking receiver (in conjunction with the range tracker) tracks targets in angle, range, and doppler during real time or from tape playback. The tracking receiver also provides AGC, scintillation, doppler, and range information to describe the target to the data recorder. The tracking receiver also provides azimuth and elevation errors to the angle servos that drive the pedestal, keeping the antenna on target during live track.

By recording the radar returns on tapes, it is possible to separate and analyze the targets of a missile shot as many times as desired and, thereby, effect an economy of radar systems and missile firings.

Based on the principal radar system requirements of Fig. 3, specifications for the radar tape recorder were determined. Requirements for frequency and polarization diversity and for monopulse angle tracking resulted in a need for eight signal channels. Range and doppler accuracies were improved through the use of a recorded IF reference signal and a range clock signal. Additional channels were used for a transport servo-speed reference, pedestal angular position data, and time-of-day codes—resulting in a 15-channel machine (see chart of Fig. 4).

The principal specifications for the radar tape recorder are listed in Fig. 5. Reasons for some of these specifications are described herein. The signal-to-noise (S/N) specification is dictated by the desired system dynamic range. Velocity stability is necessary to assure doppler tracking accuracy as well as to minimize the occurrence of spurious signal spectral lines due to transport velocity modulation. Gain and phase track specifications assure accuracy in the measurement of target angle offset. Gain and phase linearity maintains good target resolution by avoiding pulse distortion or distortion echoes. Low interchannel jitter is important in measuring accurately the signal polarization vector, range, and angle. Bandwidth is determined by the radar pulse characteristic; at the signal input to the recorder, the pulse is in the form of a cosine squared.

BASIC DESIGN FACTORS

To accomplish the specifications set forth, a basic decision was made to use FM rather than AM recording on all tracking video signal channels for the following reasons:

1) Gain linearity and gain tracking are very difficult to achieve in an AM system because of the effect of the nonlinear magnetization characteristic of the tape and because of variations in tape sensitivity.
2) An FM system minimizes the effects of tape drop outs, variations in sensitivity of the magnetics and AM variations introduced by changes in the effective head-air-gap with tape pressures. Good gain linearity can be achieved by frequency modulators and demodulators.

The choice of FM recording results in the disadvantage of greater circuit com-

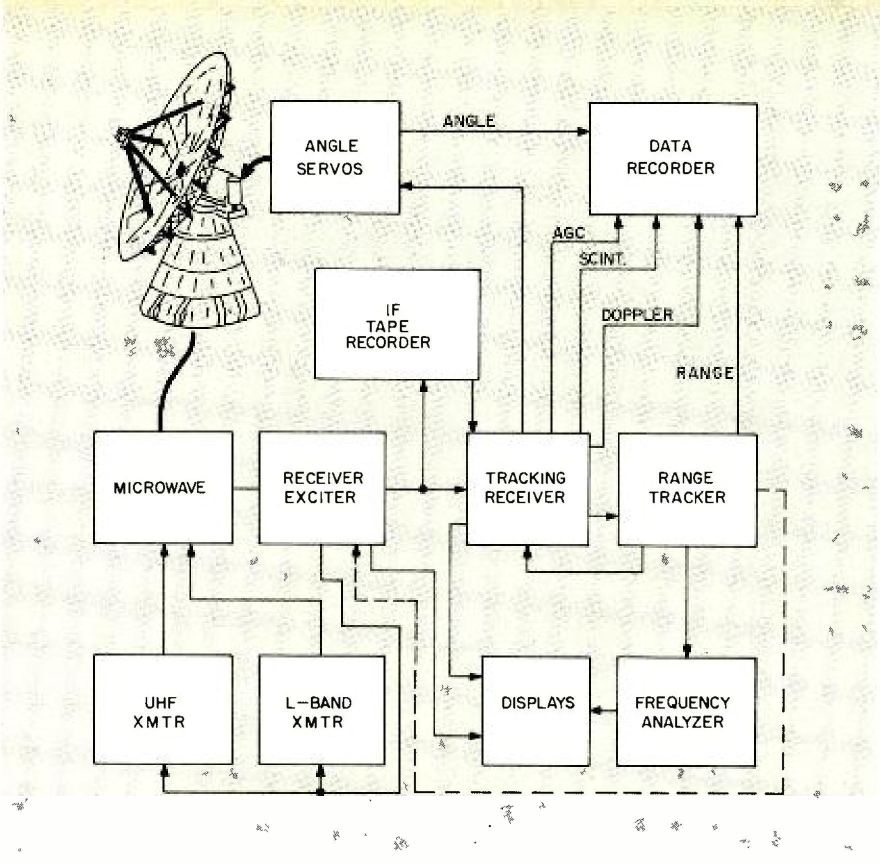


Fig. 2—Acquisition of data by tracking radar plus recording and storage of such data by precision tape recorder.

plexity because of the above requirements for frequency modulators and demodulators and also the need for more bandwidth than that in an AM system. In FM, the bandwidth required to pass the sideband frequencies depends on the desired S/N performance, and on a minimum FM carrier frequency that prevents fold-over of the side frequencies. The final choice resulted in a 4.5-Mc FM carrier frequency with significant sideband frequencies extending from 0.2 Mc to 8 Mc.

The 8-Mc bandwidth required that the relative speed between tape and head exceed a minimum value determined by the magnetic head gap-length. Since head gap-length could not conveniently be made less than 40 microinches (0.000040 inch), a tape speed of 1,180 ips was used; at this speed, *6 miles of tape are required to provide 5 minutes of recording time*. Because of the requirement for multiple channels, longitudinal recording was chosen.

The basic design criteria for the tape recorder were established, based on a consideration of signal-to-noise, gain tracking, gain linearity, bandwidth and multiple channel capability.

TAPE TRANSPORT AND SPEED CONTROL

Satisfying the requirements for velocity stability and interchannel jitter depended to a large extent on the mechanical perfection of the tape transport and the performance of the servo speed control. The main elements of the transport are shown in Fig. 6. The recorder components are assembled to a jig plate which is accurately aligned and attached to a rigid frame to assure a precise tape path. The complete assembly is shock-mounted within its cabinet. The 5-minute recording requirement resulted in 30-inch-diameter reels weighing 50 pounds and containing 6 miles of 1.1-mil magnetic tape plus 2,500 feet of clear leader at each end. The tape is accelerated to full recording speed in 60 seconds and is stopped in the same time. The reels are equipped with quick-disconnect knobs to facilitate fast reloading and permit uninterrupted recording with two transports. Tape guides and tensioners are air lubricated so that frictional contact to the tape occurs only at the capstan edge-guide and at the magnetic heads.

TABLE I—Radar Requirements

a) polarization diversity
b) frequency diversity
c) monopulse operation
d) dynamic range, 40 db
e) bandwidth, 6 cps—3.5 Mc
f) noise, −40 db
g) distortion, −40 db
h) coherent operation

i):	*static accuracy*	*resolution*	*granularity*
azimuth, mil	0.2	0.1	0.02
elevation, mil	0.2	0.1	0.02
range, yards	5	20	2
doppler, cps	2	9	1

TABLE II—Recording Channels

IF:
- UHF:
  1. Reference
  2. Azimuth—vertical polarization
  3. Elevation
  4. Reference
  5. Azimuth—horizontal polarization
6. Elevation
- L band:
  7. Reference—vert. polarization
  8. Reference—horiz. polarization
9. 1.5-Mc, IF reference cancellation

10. Angle and edit data
11. Range data
12. 100-kc clock
13. 2,500 pps servo speed reference
14. 5-Mc range clock
15. Audio edit

TABLE III—Performance Specifications

Tape speed, 1,180 ips, max.
Speed stability, 1 part in 10^5
Number of tracks, 15
Tape, mylar 1" wide, 1.1 mil thick
Tape length, 6 miles
Record-playback, 5 min @ 1,180 ips
Start-stop time, 1 minute
Rewind time, 10 minutes
Reel size, 30" diameter
Capstan drive, air turbine
Capstan bearings, air bearings
Tape guides, air guides

HEADS:

Gap length, 50 μ inch
Track width, 20 mils
Gap scatter, 40 μ inch max.
Track spacing, 63 mils
Mounting: precision magnetic record-playback heads on precision machined rocker arms which are completely replaceable with only one adjustment, head pressure (by two self-locking coarse and fine adjust screws).
Environment: 70° air conditioned

FM RECORDING (8 channels):

Modulation frequency response, 6 cps—3.0 Mc within ± 1.5 db
Signal to noise, 40 db min., (0 to P)/RMS
All distortion, −40 db max.
Gain tracking: differential gain between any two channels over 40-db dynamic range within 0.5 db.
Phase tracking: differential phase between any two channels over a 40-db dynamic range within 10° of 1.5-Mc signals.
Phase linearity: Within 3° of 1.5 Mc signal for 1 cycle variation; within 1° of 1.5 Mc signal for greater than 1 cycle variation.
Phase jitter: 0.04 μsec maximum between adjacent channels; 0.1 μsec maximum across entire tape.
Frequency stability, 30 cps deviation of 1.5-Mc signal
Crosstalk, 50 db max.

DIRECT RECORDING (7 channels, 6 equipped for digital signals):

Signal to noise, 30 db min.
All distortion, −30 db min.
Crosstalk, −50 db max.
Amplitude modulation, 10% max.
Phase jitter, 0.04 μsec maximum between adjacent channels; 0.1 μsec maximum across 15 channels.
Frequency stability, 30 cps deviation of 1.5-Mc signal

DIGITAL ELECTRONICS (4 channel capability):

Pulse repetition rate, maximum 1.2 Mc
Pulse width, minimum, 0.4 μsec; maximum, 50% duty cycle
Rise time: 0.1 μsec. max.

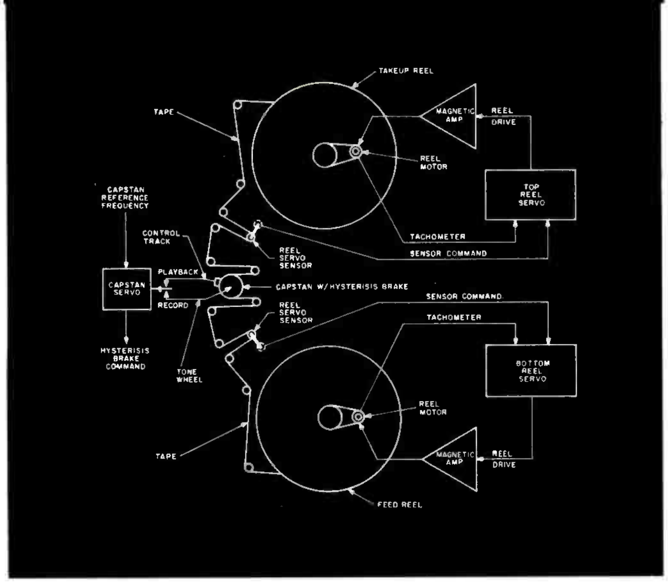


Fig. 3—Tape transport.

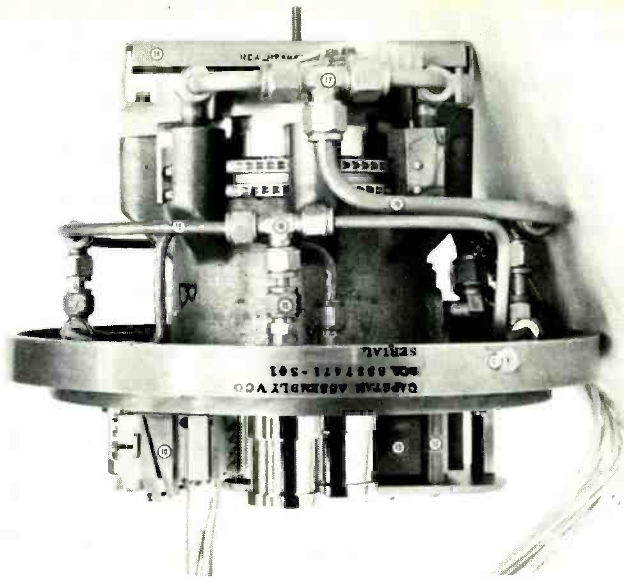


Fig. 4a—Capstan-head subassembly.

Remote Control of Recording

Remote control of recording, subsequent repeated playbacks, and rewinds dictated that the tape remain threaded and taut during and following each run. To accomplish this, programmed acceleration and deceleration cycles were employed at the start and end of the tape runs. A length of clear polyester leader is attached to each end of the tape; transitions from clear leader to tape are sensed photoelectrically to initiate the program.

Capstan Assembly

The capstan-head assembly of Fig. 7 is designed for quick replacement by utilizing an air manifold which automatically seals upon installation of the capstan. Two blocks of magnetic heads, one an 8-track and the other a 7-track are supplied by the RCA Broadcast and Communication Products Division. Heads are prealigned on arms for fast replacement once initial adjustment of the head arm support has been made.

Tape Speed Control

To achieve constant tape speed, the capstan assembly employs an air-turbine drive and hydrostatic air bearings. Capstan speed is sensed by a tone wheel and controlled by a hysteresis brake; both are integral parts of the capstan shaft. To minimize longitudinal vibrations, the tape is stabilized by making simultaneous contact with both the capstan and the heads. Since the tape is not perfectly smooth nor of uniform thickness, it is necessary to relieve the capstan surface behind the area where the heads contact the tape.

Velocity Stability

The velocity stability specification of 1 part in 10^5 imposes a severe runout requirement on the capstan assembly; the angular velocity generates flutter components of 87 cps and higher multiples which are above the bandwidth of the capstan-servo correction capability. Therefore, the dynamic runout of the capstan must be held to less than 20 microinches; it is done by using the ultimate in precision grinding, hand lapping, and dynamic balancing. An additional benefit in reducing the effects of capstan runout is derived from depressing the heads into the tape above the capstan grooves; thus, the heads may be firmly positioned at a fixed radius from the rotational axis of the capstan. Head contact pressure is controlled by a very precise adjusting screw which advances the head only 5 mils per revolution. Pressure applied is measured as an increment of the capstan hysteresis brake current.

Phase Jitter

Mechanical resonances throughout the tape path produce variations in tape tension, resulting in minute (but not inconsequential) variations in tape velocity at the capstan. Such variations can be caused by improper tape guide design, or by insufficient damping where resonant systems exist in the tape path, as at the tape tensioners. Since these effects

Fig. 5—Reel servo system.

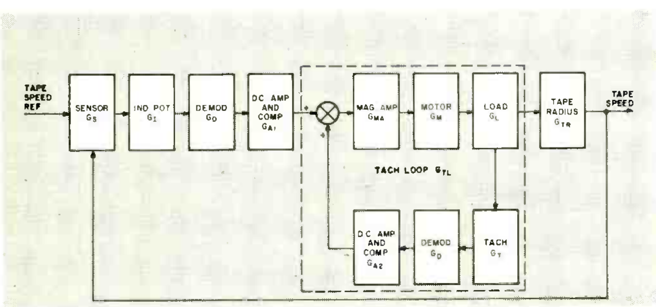


Fig. 6—Capstan servo system.

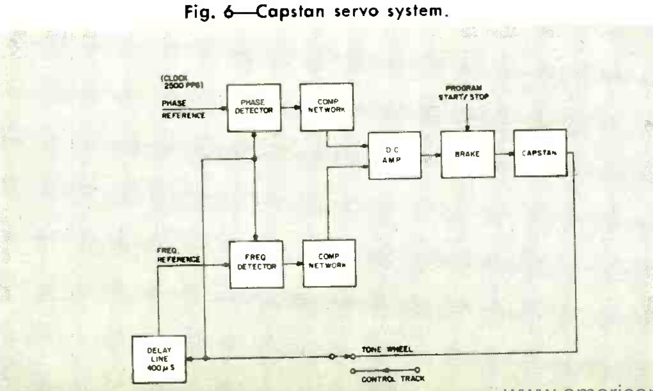
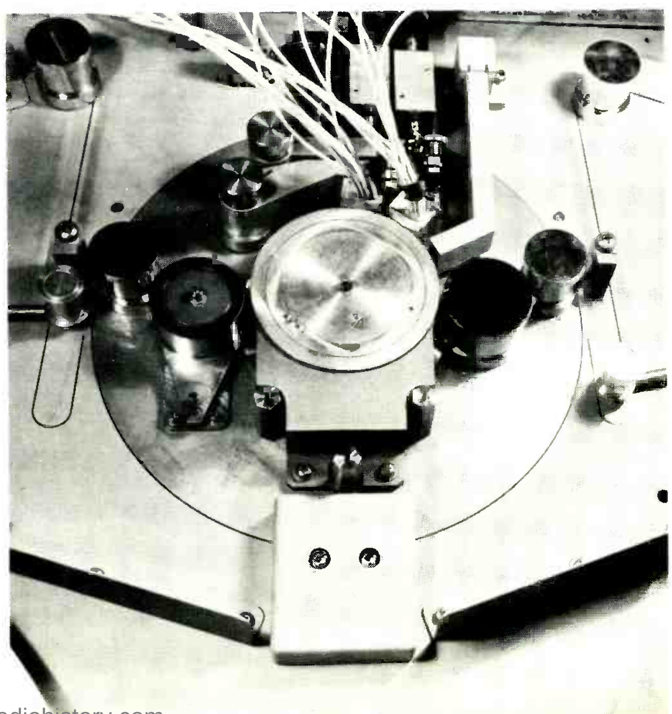


Fig. 4b—Detail of capstan and heads.



are not necessarily uniform, or in-phase across the width of the tape, they produce the undesirable effect defined in the specifications as "phase jitter." The allowable phase jitter between signals (recorded half the width of the tape apart) is ±20 nsec; this corresponds to roughly a differential displacement of 24 microinches.

Various refinements effected to reduce phase jitter include the following: 1) very smooth, solid flange reels which are two-plane dynamically balanced, 2) windage guards which completely encircle both reels, 3) an adjustable edge guide adjacent to the supply reel to control lateral weaving of the tape as it enters and leaves the reel and 4) precise alignment of all tape guides.

Transport Air System

Compressed air, supplied by a remote unit at 100-psi nominal pressure, operates the transport. Air is oil free and dried to −40° F dew point. Outlet air-supply filters and filters at the air inlets to the cabinet and to the capstan air-bearing line protect the air-pressure regulating valves and the close-fitting capstan bearings. In the event of a compressor failure, a reserve air supply brings the transport to a safe halt. Pressure-sensitive switches are set a few pounds below the lower limit of the normal pressure variation range of the air supply. When the air-supply pressure falls below a predetermined value, turbine air is cut off and the transport goes into its programmed stopping cycle. Mechanical brakes on the reel spindles stop the reels quickly to minimize tape spillage in the event of a power failure or loss of tape tension.

Tape Reel Servo Control

Each tape reel is belt driven by a two-phase 400-cps induction motor and controlled by an independent servo system. The control signal for the reel servo loop is obtained from the tape sensor device nearest the particular reel involved (see Fig. 6). The stator of the induction potentiometer is excited by an AC reference supply and produces an error signal proportional to the velocity error of the tape at the reel. The AC-induced voltage in the rotor, which is the error signal, is amplified and applied to a carrier-referenced demodulator; then, the DC output of this circuit is used to drive the operational amplifier shown in Fig. 8. An additional feedback loop is provided by an AC tachometer on the servo motor shaft. The 400-cps signal is demodulated to DC to make it compatible with the tape error signal; it is easier to realize the proper stability networks in the DC domain, and AC quadrature problems are completely eliminated — providing a more stable design with less effort. The tachometer feedback signal is combined with the tape speed-error signal in a summing operational amplifier to compensate for the non-linearity of the magnetic amplifiers which are as the servo power amplifiers. The summing operational amplifier output is the servo control signal used to drive the magnetic amplifier; the magnetic amplifier controls the 400-cps power supplied to the reel servo motor.

Capstan Servo Control

The capstan servo drives the tape with highly precise speed control by two servo loops: one a frequency lock, and the other a phase comparison control to obtain high sensitivity (Fig 9). Pulses derived from the capstan tone wheel and proportional to tape speed are passed through a 400-μsec delay line; capstan speed is varied by the servo until the pulse frequency corresponds with the delay of the line. The 400-μsec delay line is equivalent to a tone-wheel frequency of 2,500 pps (this servoing of the capstan speed to near synchronous value is called a frequency lock). When a frequency lock occurs, the phase of the reference 2,500 pps begins to zero beat with the tone wheel; thus, a phase error is produced which adjusts the capstan speed to a full phase lock.

The phase detector producing the speed-control signal is extremely sensitive; the slightest change of capstan tone-wheel frequency results in a considerable phase error. Once the capstan servo is locked in, complete control of the speed is maintained by the phase loop. The basic speed control of the capstan driving the tape is obtained by applying air pressure to the capstan turbine. The turbine air pressure would drive the capstan at a speed much higher than needed; however, the servo controlled hysteresis brake reduces it to the desired value. The capstan speed is locked to a crystal oscillator by servoing the tone wheel during the *record* mode. During the *playback* mode, the control track, a recorded 2,500-pps reference frequency standard, is servoed to the same crystal oscillator. The slight difference between the capstan speed and the tape speed is removed by this playback servo technique. Electronically variable delay lines are used in those channels requiring additional velocity refinement corrections to the radar data (Fig. 10).

The technique of comparing the playback of a recorded 2,500-pps crystal clock with the same crystal clock and using the resultant error voltage to drive the capstan cancels out all low-frequency speed variations of the tape. However, this method does not remove high-frequency components of speed variation resulting from such sources as capstan asymmetry and high-frequency tape flutter. The capstan turns at 87 cps and introduces Fourier series tape-speed components 174 and 261 cps in both record and playback modes; such components cannot be servoed out because of the limited response of the capstan. To remove the effects of the capstan asymmetry and other speed deviations, electronically variable delay lines are inserted into all channels that need precision speed stabilization; a control voltage advances and delays each channel of data in order to make the tape information appear to be coming from a perfectly constant speed tape.

The control of these electronically variable delay lines is accomplished with the closed-reference automatic-time-correction (ATC) loop of Fig. 10. When the capstan servo has locked in, the reference playback signal averages 2,500-pps —but there will be expansions and contractions of the pulse periods for the reasons previously described. This reference playback signal is inserted into an electronically variable delay line that removes the high-frequency speed variations. The tape-playback 2,500-pps reference is compared to the clock-reference 2,500 pps in a phase detector; the resultant error signal changes on a pulse-to-pulse basis. This error is amplified and the ATC loop stabilized by passing the signal through an operational amplifier with the proper transfer function.

The resultant amplified error output is used to drive the reference delay line, completing a closed loop. It is apparent that the error signal created will advance or delay the playback pulses to slave them to the clock-reference 2,500 pps by removing the high-frequency components of flutter. At this point, the 2,500-pps reference passing through the delay has had the stabilization of the capstan servo control and the ATC servo electronic correction. The signal that

Fig. 7—Automatic time correction (ATC) servo loop.

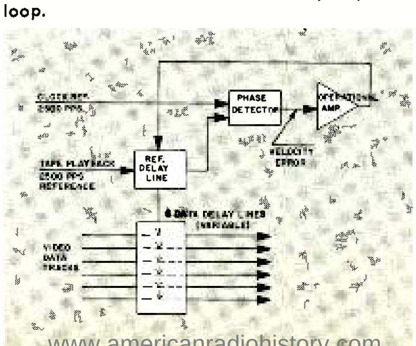
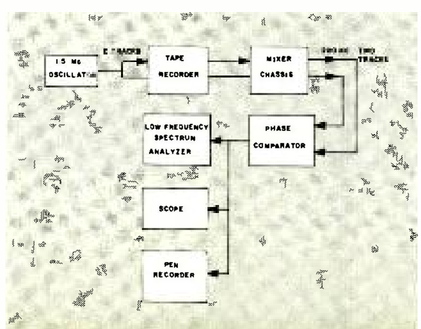


Fig. 8—The intertrack jitter measuring system.



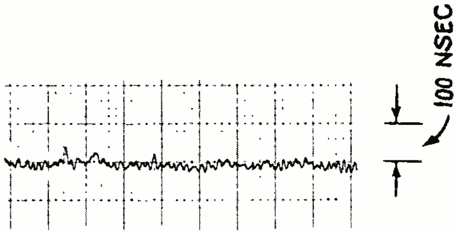


Fig. 9—Typical pen recording of intertrack phase jitter (shown are tracks 4 and 10).

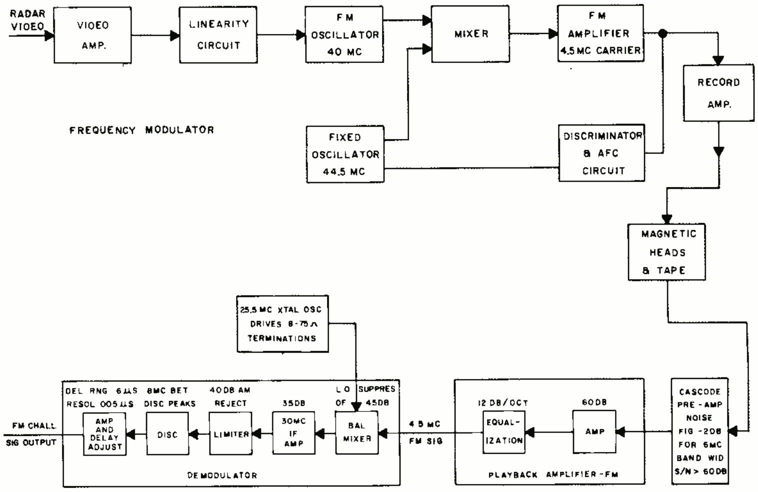


Fig. 10—Elements of a typical FM channel.

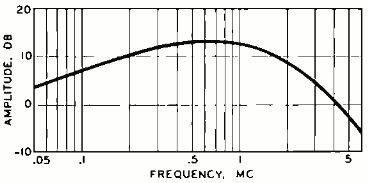


Fig. 11—Unequalized head output versus amplitude. (0 db = 1 millivolt.)

drives the reference delay line also drives the six signal delay-lines because the speed correction required is approximately the same for all channels.

The interchannel jitter must be small in order to make this type of delay line correction effective; moreover, this condition is assured by meticulous design of the tape transport. There must be very little phase jitter between channels, since the correction signal of the ATC servo loop is not only applied to the reference line, but also (as an open-loop correction) to all of the signal delay lines.

To measure intertrack jitter during the mechanical development of the tape transport, the precise measuring technique of Fig. 11 was used. It consists of recording a 1.5-Mc sine-wave signal upon the two tracks in question, playing these channels back, and then mixing them down to 200 kc. The exchange of phase angle between the two signals remains the same at 200 kc as it was at 1.5 Mc, and it can be handled by a commercially available phase meter. The output of the phase meter was observed on a scope, spectrum analyzer, and pen recorder. A typical pen recording of the intertrack phase jitter is shown in Fig. 12.

SIGNAL ELECTRONICS

The most interesting aspects of the signal electronics for the radar tape recorder relate to the problems of linearity and bandwidth in the precision FM channels. Fig. 13 shows the elements of a typical FM channel. In the record mode, the signal in the form of radar video pulses is converted to an FM signal in a modulator. It is then amplified in a record amplifier which drives the record-playback head as a constant-current generator. On playback, the signal is amplified in a preamplifier and then in a playback amplifier which includes aperture equalization to compensate for the magnetic-head frequency response characteristic. The signal is then reconverted to a radar video signal in the frequency demodulator.

The bandwidth required in an FM system is dictated by the rise-time requirement; the system S/N ratio is a function of this bandwidth. The following equation is used for S/N calculation in an FM system. If A is the carrier amplitude, ΔF is the peak deviation due to the signal, N is the RMS noise per unit bandwidth, and f_2 and f_1 define the bandwidth following the frequency detector, and a is the difference frequency between carrier and noise N:

$$S/N = \frac{1}{A\Delta F}\sqrt{\frac{\int_{B_1}^{B_2} 2a^2(N_1^2 + N_2^2)\,da}{B}} = \frac{\sqrt{2}\,N}{\sqrt{3}\,A\Delta F}\left[\frac{f_2^3 - f_1^3}{f_2 - f_1}\right]^{\frac{1}{2}}$$

Assuming $N = 0.0037$ volts-RMS/Mc (48-db tape machine), $A = 1$ volt pulse-to-pulse, $\Delta F = 1.5 \times 10^6$ (maximum frequency deviation of the carrier), $f_2 = 3.5 \times 10^6$ cps, and $f_1 = 6$ cps, then $S/N = 43$ db.

From this expression, it can be shown that a peak frequency deviation of 1.5 Mc achieves S/N performance greater than 40 db assuming that the ratio of peak carrier to RMS tape noise per megacycle is 48 db.

The radar tape recorder was designed to record radar pulses with a video bandwidth of 3.5 Mc; for the frequency modulation of these signals, a 4.5-Mc carrier was used to minimize the effect of "fold over" (side frequency terms) in the FM signal.

The frequency modulation is accomplished by the mixing of two varicap-type oscillator signals, one at 40 Mc and the other at 44.5 Mc, to obtain a 4.5-Mc difference frequency. The 40-Mc oscillator frequency is deviated as a function of the video input, but the 44.5-Mc oscillator is held fixed except for some small frequency corrections applied by the discriminator and AFC circuit to hold the output centered at a frequency of 4.5 Mc.

One of the severe design problems in building a frequency modulator is to achieve the linearity specifications of a precision radar system. The modulator nonlinearity is due to the varicap diodes varying in a nonlinear manner as a function of the video input voltage; in addition, the resonance formula is inherently nonlinear. To overcome this problem, a diode circuit inserts an inverse characteristic to the nonlinearity between the video amplifier and the FM oscillator; the result is a linear frequency swing as a function of the video input.

As previously explained, FM is the best method for recording precision radar data; however, this technique is not without its difficulties. To preserve the FM information, the proper equalization of amplitude and phase must be used, and the worst culprit to compensate for is the magnetic recording process. Perhaps the most serious difficulty encountered is due to the nonlinearity of the tape, heads, and circuits through which FM information is passed. Analysis shows that if an FM spectrum centered at f_0 frequency is passed through a nonlinear transfer function, spectra at multiples of f_0 appear with frequency deviations multiplied by the multiple number. As an example the spectrum at four times the carrier of 4.5 Mc has four times the deviation of the spectrum at 4.5 Mc. Of all these spectra, only the second is close enough to affect the fundamental spectrum demodulation; consequently (in the demodulation technique) the second harmonic must be balanced out.

In low-frequency demodulation techniques, the carrier is limited heavily and converted into a square wave. The crossings of the FM may not be equally spaced, but the limiting process includes diode circuits that adjust the symmetry of the square wave, assuring only odd harmonic content, and therefore a clean demodulated signal.

In the heterodyne technique of demodulation used, the 4.5-Mc FM signal is mixed up to 30 Mc where heavy limiting takes place. The second harmonic of 30 Mc is easily filtered without affecting the quality of the 30-Mc information; because of this, symmetrical limiting is not important, relaxing the design of the limiter circuit. In addition, a Foster Seeley discriminator can be used as an effective and simple circuit compared, to the low-frequency discriminators required at recorded carrier frequency.

EQUALIZATION

The primary problem of equalization is related to the need for compensating the amplitude-versus-frequency response of the magnetic playback process. The flat amplitude and linear phase responses required to meet the performance specifications for the radar tape recorder were achieved. The following equation, however, shows that the amplitude response of the playback process is not flat and further that the phase response is linear. Therefore, the equalization must compensate for the amplitude response of the playback process without introducing a nonlinear phase characteristic.

Analysis of the magnetics problem results in the following equation for the output voltage from a playback head, assuming a sinusoidal recorded flux on the tape.

$$e(t) = 2N\pi\theta_m f \left[\frac{\sin\left(\frac{\pi\delta}{\lambda}\right)}{\frac{\pi\delta}{\lambda}}\right] \cos\left[\frac{2\pi}{\lambda}\left(X + \frac{\delta}{2}\right)\right]$$

Where: λ = recorded wavelength, f = recorded frequency, δ = the head gap length, N = turns on the head, X = distance along the tape, and θ_m = maximum flux density.

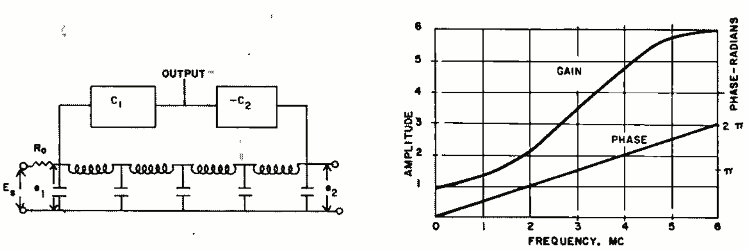
This equation includes gap effect and differentiation, a combination causing the function to rise with frequency f and to drop off with the $[\sin(\pi\delta/\lambda)/(\pi\delta/\lambda)]$ factor at high frequencies. The output cosine wave is 90°, displaced from the original sinewave recorded input, and contains an additional phase shift term $\pi\delta/\lambda$. Notice that, as the wavelength or frequency varies, the phase shift changes linearly, and when the gap width equals the wavelength the phase shift is 180°. It can be seen that there is no inherent nonlinear phase characteristic in the magnetic process.

The factor $[\sin(\pi\delta/\lambda)/(\pi\delta/\lambda)]$ is zero when the recorded wavelength λ decreases to the point where it equals the head gap δ, which means that the output voltage is zero. Since δ for our heads is 40 microinches, δ for the highest frequency of interest was chosen to be three times this value in order to have an output at high frequencies.

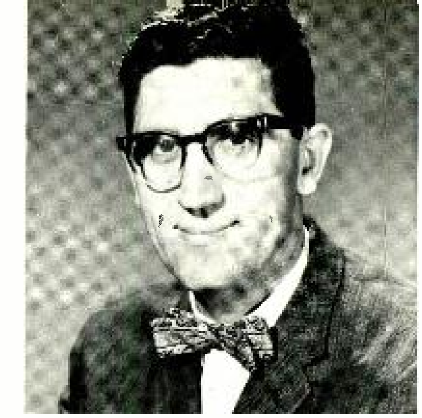
The high end of the FM spectrum is about 8 Mc so that the required tape speed can be computed from $V = f\lambda$. An f of 8 Mc and a λ of 120 microinches gives a computed velocity of the tape of about 1,000 ips. Fig. 11 shows the amplitude response of one of the magnetic heads, measured experimentally at a 1,000-ips tape speed; this checks closely to the shape of a plot of the above equation for head output voltage.

To equalize the curve of Fig. 14 between several hundred kilocycles and 8 Mc, it is possible to use an aperture-type correction; this essentially represents the magnetic-gap characteristic. The circuit of Fig. 15 was used to equalize the high-frequency amplitude drop-off. This network obtains the required amplitude boost with linear phase over the frequency band; in addition, such a scheme has no insertion loss. This circuit is given in Fig. 15 together with a graph of its transfer function.

Fig. 12—Aperture correction circuit and phase-gain curves obtained.



JOSEPH M. URITIS graduated from Newark College of Engineering in 1937 with a BSME. Before joining RCA in 1946, he was a design engineer for Bernard Aviation Equipment Corp., New York City. In 1941, he engaged in the design and test of main propulsion and auxiliary shipboard equipment at the Philadelphia Navy Yard. At RCA, Mr. Uritis has designed disk recorders for broadcast studios and other commercial applications. As a member of the Advanced Development Group, he was responsible for conception of the tape files used in RCA Electronic Data Processing equipment. In video recording, he was active in the design and development of the time division multiplex video recorder, and later, the quadruplex color video recorder. He was responsible for the design of the Broadband Recorder (AN/TLH-1) built for the Signal Corps. When the BMEWS program started, he designed magnetic drums and discs for that project, and later was responsible for design of the TRADEX tape transport. During design of the precision tape recorders for Bell Labs, he was responsible for the mechanical design. Mr. Uritis holds 8 patents in the recorder field.



BENJAMIN A. COLA graduated from Drexel Institute in June 1950 with a BSEE. At this time he joined RCA and worked on the design of power supplies, video circuits, TV airborne cameras, naval radar tracking equipment and servo mechanisms in the Special Devices Department. A period of one year was spent on systems analysis of shoran bombing and reconnaissance equipment. He received an MSEE degree in June 1955 at the University of Pennsylvania. In August 1955 he was transferred to the newly formed Missile and Surface Radar Section, where he worked on analog data processing assignments for TALOS, ATLAS, BMEWS, DAMP, and TRADEX. His most recent assignment was design project engineer on the development of a precision high speed tape recorder.

CONCLUSION

Two tape recorders have been in continuous operation on the pacific missile range for almost a year and have recorded and preserved much valuable data for further analysis and evaluation. The advanced techniques employed have proven invaluable in the study of missile re-entry.

ACKNOWLEDGMENT

Credit for work on the original Tradex tape recording system, which was a forerunner of the high-speed precision tape system described in this paper, is due to H. R. Warren and his associates in the DEP Communications Systems Division. Also, credit for magnetic head design is extended to the Magnetic Head Development and Design Group of the Broadcast and Communications Products Division, under the direction of B. F. Melchionni.

This project was completed successfully because of the tireless efforts of many people with varied skills. It would be unjust not to mention two of the technical giants, Thomas Bolger and Jackson, who did so much to bring this project to fruition.

ADVANCED TAPE EQUIPMENT FOR INSTRUMENTATION RECORDING

Reviewed are recent developments in recording electronics and tape transports for wideband recorders—longitudinal, transverse, and helical-scan transports; solutions to switching transients and time-base stability problems; and data-reduction techniques. Reductions in switching transients and advances in time-base stability, combined with multichannel capabilities of helical-scan equipment, answer many demands of radar data reduction by eliminating need for data multiplexing. A further advantage in the instrumentation field is the ability to combine real-time data storage and data readout into a single magnetic recording system.

F. D. KELL, Ldr.
Recording Mechanics

and

J. D. RITTENHOUSE, Ldr.
Recording Systems and Development

Applied Research
DEP, Camden, N. J.

PROBLEMS encountered in recording wideband data on magnetic tape derive from the implications of the simple, basic equation:

$$\lambda = \frac{v}{f}$$

Where: λ = wavelength of the recorded signal, v = relative velocity between the record-reproduce head and the tape, f = frequency of the signal being recorded.

For a given frequency, the shorter the recorded wavelength the lower the head-to-tape velocity required. However, recorded wavelength (or, more exactly, the resolvable wavelength) is fixed by the state of the art in head design and manufacture. Therefore, the shortest λ is, in general, fixed by the best head structure available. Then, for a specified frequency, the head-to-tape velocity required is calculated. With the available wavelength resolution fixed, the method of obtaining the appropriate scanning velocity becomes the primary consideration in wideband recording. Since this velocity is obtained by maintaining a relative motion between the tape and heads, design of the tape transport is of paramount importance.

F. D. KELL received the BSME degree from Drexel Institute of Technology in 1957. As an undergraduate, he worked with RCA on cooperative assignments. Now, at the University of Pennsylvania he is a candidate for the MSME. In 1957, he became a permanent member of DEP Applied Research. He has since made major contributions to the development of a family of helical-scan video recorders and was responsible for the introduction of air lubrication to the headwheel mechanism of commercial video recorders. In addition, Mr. Kell also headed the development of a precise satellite tape transport which featured extremely low power consumption and inherent angular momenta cancellation. His contributions to this and other programs have resulted in 14 patent applications. In 1962 he was promoted to Leader, Recording Mechanics in DEP Applied Research.

J. D. RITTENHOUSE received the BSEE from Drexel Institute of Technology in 1958. Upon joining RCA in 1958, he became a member of the RCA graduate study program, on which he received his MSEE from the University of Pennsylvania in 1960. He then joined DEP Applied Research, where he is now an Engineering Leader. He has concentrated on recording and data-processing systems. Recently he has been concerned with the systems concepts of transverse and helical-scan equipments for defense applications. His group is responsible for the development work on helical scan in RCA. On recent projects he has been concerned with various encoding techniques for recording information on tape and has studied narrowband FM modulation techniques, synthesizing the record-playback processes on a computer. Mr. Rittenhouse is a member of Eta Kappa Nu, Tau Beta Phi, and Phi Kappa Phi.

TAPE TRANSPORTS

To appreciate problems of designing tape transports, consider some typical parameters. For example, if a recording head is capable of resolving a wavelength of 150 microinches (0.000150 inch) and if a frequency response of 7 Mc is desired, the head-to-tape speed required is in the order of 1,000 ips. The FM bandwidth resulting from using the 7-Mc direct-record bandwidth is of the order of 3.5 to 4.0 Mc. The 1,000-ips head-to-tape speed poses the mechanical problem of obtaining such head-to-tape speed while realizing a practical and economical transport.

There are two basic approaches to solving this problem. The longitudinal-scan method, used several years ago in the RCA Broadband Recorder and recently in the recorders for TRADEX[1] and the Precision Tape System, moves the tape at the required speed over a stationary head. The second approach holds the tape essentially motionless while the head moves past it; this technique, featuring rotary scanning, has been realized at RCA in two forms. The more familiar rotary scan is the transverse-scan technique employed for television recording; this technique has been extended in many cases into the instrumentation field. The other form of rotary scan is the helical-scan technique. Several laboratory models, one field-type 3-channel radar recorder, and six 2-channel radar recorders have been constructed using this technique, which offers several advantages over the longitudinal scan and the transverse scan.

Each type of machine (the longitudinal scan, the transverse scan, and the helical scan) has some advantages over the other two. The selection of type of scan for a particular program must be based on an evaluation of these advantages and disadvantages.

Longitudinal Scan

The main advantages of the longitudinal scan are: the availability of many parallel channels (up to 15 on 1-inch tape), the absence of switching transients caused by commutation of heads (there is no commutation of heads), and the realization of a speed reduction of data in a relatively simple manner. The main disadvantage of the longitudinal scan is that at the head-to-tape speed involved, massive tape reels are required for a practical recording period. For instance, the TRADEX machine (5-minute recording period) requires 36-inch reels hold-

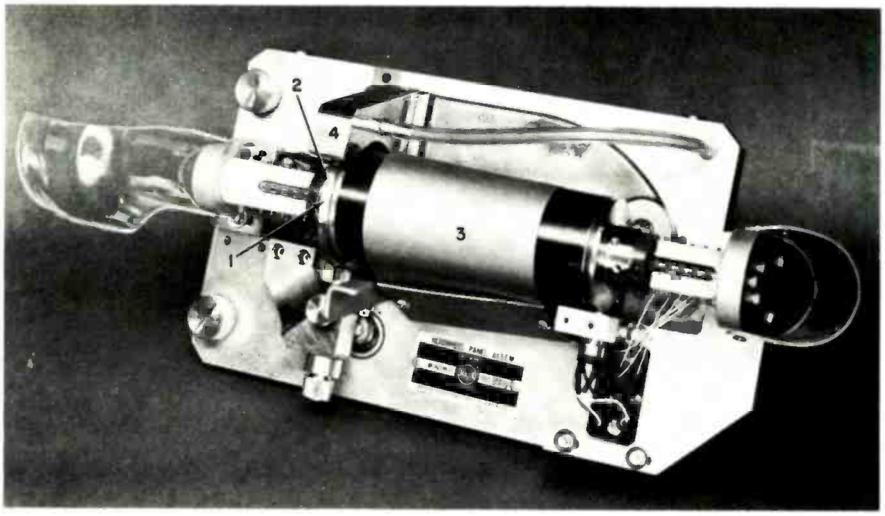


Fig. 1—Typical transverse-scan assembly.

ing 7 miles of tape.

Contrary to common belief, each of the three types of scan exhibits tape interchangeability problems, even the longitudinal type. The specific problems of the longitudinal scan are manifested in the strict requirements for channel alignment across the multichannel head, for precision mounting of the head, and for the tape-tension servo.

Transverse Scan

The main advantages of the transverse-scan technique are its high-level performance and its acceptance as the standard for the television industry. Approximately 2,000 television broadcast units are in use throughout the world. A typical transverse-scan assembly is shown in Fig. 1. The most important elements of this unit include the headwheel (*1*) in which the video heads (*2*) are mounted, the headwheel motor (*3*), and the vacuum guide (*4*). The vacuum guide forms the tape around the headwheel and controls the depth the heads indent the tape. The scan assembly shown is a two-channel unit which requires eight heads to continuously record two channels; each head records and reproduces during only slightly more than 90° of every rotation. In operation, the tape moves through the vacuum guide parallel to the axis of rotation of the headwheel, thus producing the pattern of the transverse scan.

Helical Scan

The helical scan combines the advantages of the transverse scan with the simplicity and multichannel capability of the longitudinal scan. However, it is not well known to most people in the recording industry, whereas both the transverse and longitudinal scans are. The helical scan also has a problem of head commutation, but the rate of commutation is usually slower than that employed on a transverse-scan recorder. However, new switching techniques, described later in this paper, permit practical negation of the switching transients which result from commutation of the heads.

The helical-scan recorder generates a diagonal scan pattern on the tape by moving the tape helically around a scanning wheel in an assembly which is illustrated in Figs. 2 and 3. The most significant elements of this helix assembly are the two helical guides (*1*) and (*2*), the headwheel (*3*) and the video heads (*4*). The drives for this scan assembly are similar to the transverse scan, with separate drives for headwheel and tape. The wrap of the tape about the headwheel is formed naturally by the helical tape path, while the head pressure against the tape is determined by the balance between tape tension and the pressure of the air supplied to lubricate the tape as it moves around the helix. In Fig. 3, the helix is shown pivoted into the position for headwheel maintenance. The particular headwheel shown is a two-channel assembly which contains three video heads spaced 120° apart. During every rotation of the headwheel each of these heads records and reproduces during 250°, which through appropriate switching, is sufficient for recording two continuous channels.

In general, the number of heads in a helical-scan system is greater by one than the number of information channels, whereas four heads are used for every information channel in transverse scan because of the limited tape wrap angle.

Although transverse-scan and helical-scan equipments are best for obtaining very large bandwidths and reasonable storage times, they suffer from two imperfections: time-base error (a problem

Fig. 2—Helical-scan headwheel assembly (closed).

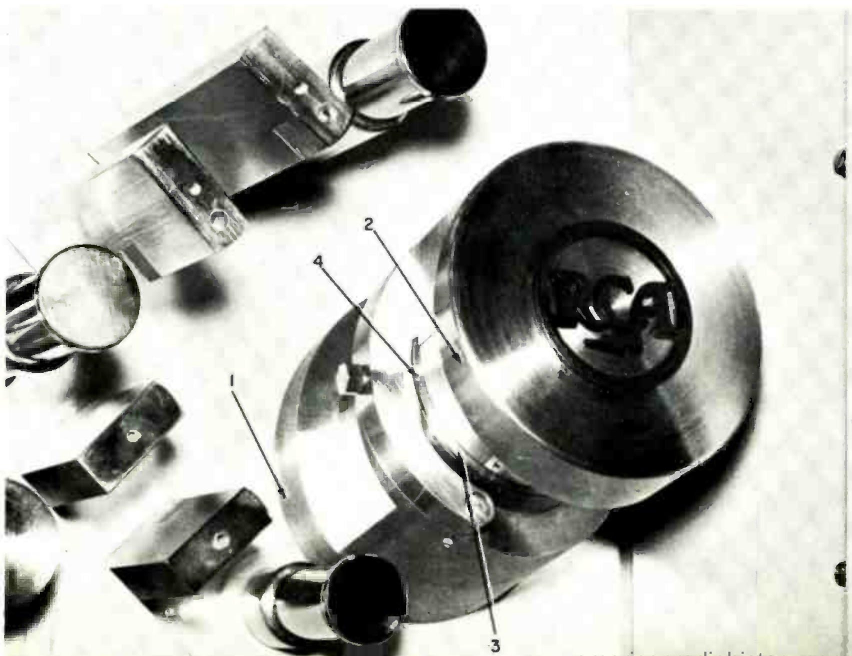
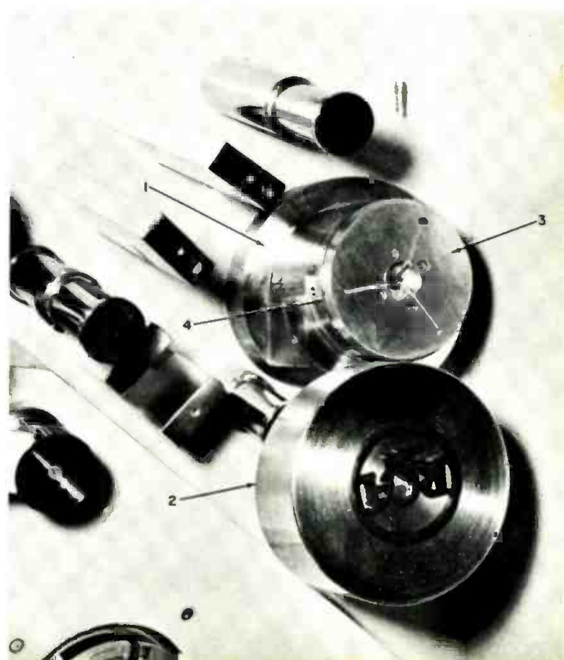


Fig. 3—Helical-scan headwheel assembly (open).



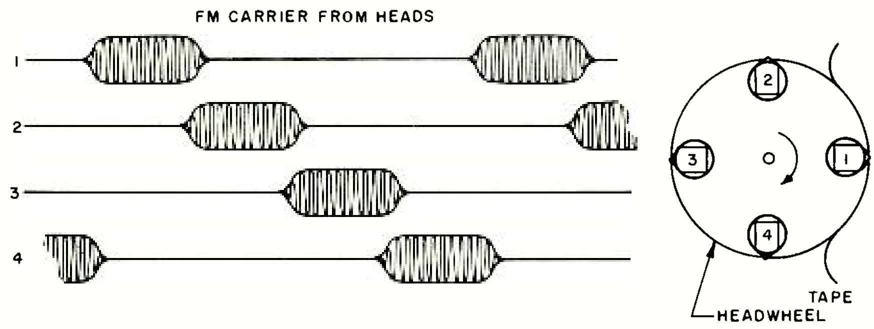


Fig. 4—Waveforms before switch

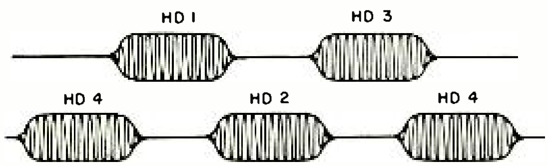


Fig. 5—Waveforms of FM after first (4x2) FM switch.

common to all types of recorders) and commutation transients (a problem peculiar to rotary-head recorders). Solutions to both of these problems are presented below. Although developed specifically for a transverse-scan recorder, the techniques described are applicable also to a helical-scan recorder.

SOLUTIONS TO SWITCHING TRANSIENTS AND TIME-BASE STABILITY PROBLEMS

Switching Transients

Frequency modulation is the mode of encoding information for most instrumentation applications; this fact is the key to complete negation of switching transients through a technique known as *fade switching.*

Assume the rotary headwheel in Fig. 4 to be rotating in a clockwise direction. During this rotation, the tape, as shown, may be considered to be advancing out of the page. During the recording process, the four heads can be energized in parallel. Therefore, we can be certain that the one or two heads contacting the tape will be recording. Because of the multiplicity of heads, recording presents no particular problem. There is *no* transient generated in the *record* process.

In the reproduce mode, however, a different situation prevails. Since only the head, or heads, in contact with the tape can reproduce a signal, the output from any given head is discontinuous, and a continuous output can be achieved only by a proper combination of the outputs of all four heads.

The envelopes of the outputs from the four heads are shown in Fig. 4. Note that overlap of the envelopes provides signal redundancy.

In recently constructed recording systems (the Dual-Channel, Dual-Speed equipments) where the headwheel speed is 480 rps, the overlap time is approximately 70 usec. During these 70 usec, the "switcher," which combines the waveforms of Fig. 4 into a single continuous waveform, must "switch" its output from the head leaving the tape to the head engaging the tape. It is during this time interval, when the switcher moves its output from one head to another, that the "switching transient" is generated.

Fundamentally, the switching transient results from the difficulty of maintaining an exact time relationship between the signals from the head leaving the tape and the signals from the head engaging the tape. Angular errors in the positioning of the heads, head wear, and changes in tape dimensions combine to defeat efforts to eliminate the transient mechanically.

It is not always sufficient to provide an adjustment so that an operator can tune out these errors. Tape jitter and vibration, plus inability to maintain absolutely constant headwheel speed, cause errors of a highly dynamic nature, changing the time base of the recorder not only during the switching interval, but also during the passing of a single head across the tape. The reduction of these dynamic errors to about 100 nsec is the best attainable at present with electromechanical systems, an accuracy not approached in conventional longitudinal tape recorders.

Switching transients and tenth-microsecond timing errors can be tolerated in many applications. For example, in broadcast television the transients are hidden in the horizontal retrace of a picture line. Also, for certain instrumentation applications, the generation of a switching transient is not particularly bothersome since the switching transient may be synchronized with the recorded information, or it may be identified and dealt with accordingly. With good switching diodes, the switching discontinuity can be reduced to a width of 100 nsec with an amplitude no greater than the peak noise level at the output of the recorder. This technique, known as rapid "video" switching, has been applied successfully in several types of instrumentation recorders.

However, the ideal rotary-head recorder should have no switching transients or information dropout due to head commutation; techniques for the elimination of these objectionable parameters are described below.

The 100-nsec dynamic error remaining after final electro-mechanical servo correction may be composed of slow-rate headwheel errors, switching errors due to inaccurate positioning of the vacuum shoe, and "quadrature" effects due to interchangeability problems. In order to explain the effects of fade switching we will, for the moment, neglect the quadrature and headwheel servo effects, and will concentrate on only those due to the vacuum guide (or tape shoe). The magnitude of a typical shoe error might be 30 nsec; this error occurs as an instantaneous jump in recorder time base at the commutation rate of the heads. The transient elimination scheme is initiated by combining the four outputs of

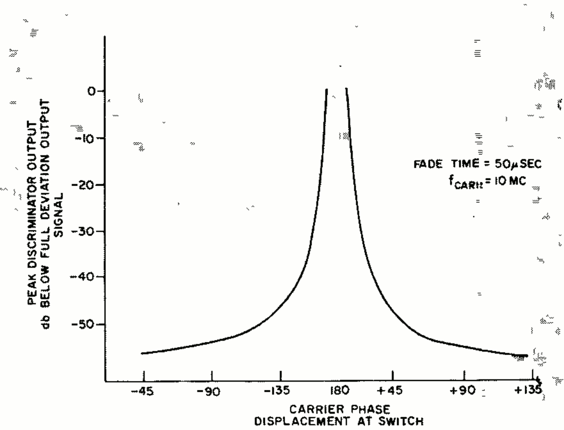


Fig. 6—Theoretical fade switch performance.

the heads in Fig. 4 into two channels of information, as shown in Fig. 5. From this figure we can draw two important conclusions:

1) *redundant data exists during overlap time,*
2) *the maximum instantaneous phase error during overlap is 30 nsec.*

Neglecting for the moment that the 30-nsec time-base error may be reduced further, we may conjecture as to transient levels as we commutate these two channels of information into one final serial channel. It was previously mentioned that frequency modulation is the key to the transient-free switch. If the FM signal is switched instantaneously, a 30-nsec time-base error will occur and will appear as a 30-nsec phase discontinuity in the carrier. Such a discontinuity will provide an impulse transient at the output of the FM discriminator.

If, however, these two channels fade into one another during the overlap time, a gradually changing phase error exists on the FM carrier. The rate of change of phase is small, producing a negligible transient at the output of the discriminator. Assuming an FM carrier of 10 Mc, an interval of 30 nsec corresponds to $(30/100) \times 360 = 108°$ of phase shift which occurs through a fade period of 50 usec. The nonlinearity of the FM system requires that the exact level of this transient be obtained on a computer. However, as a first approximation we can use the relationship:

$$\frac{\triangle f}{f} = \frac{\triangle T}{T},$$

Where: $\triangle f$ = the apparent carrier deviation during T, f = the carrier frequency, $\triangle T$ = the 30-nsec time-base error, and T = the fade period. Substituting the numbers, we see that $\triangle f$ corresponds to a deviation of about 6 kc. Normally, a total of 2 Mc will be deviated so that the switching transient becomes $(2 \times 10^6)\ (6 \times 10^3) = 333$ units below our peak output signal. It should also be noted that fade switching is effective only up to 180° of phase differential between the switched waveforms. At this point the 180° relationship between the added carriers results in complete carrier cancellation, which produces a transient from the FM discriminator. Fig. 6 shows typical fade switch performance.

Based on these results, it can be said that for all practical purposes, *there is no switching transient.*

Time-Base Stability

Another major problem, time-base stability, has been solved in response to the demands for more sophisticated

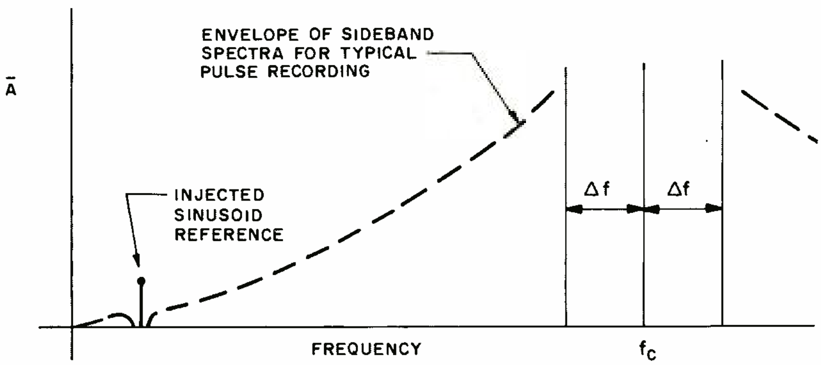


Fig. 7—FM record spectrum showing injected pilot tone for time base reference.

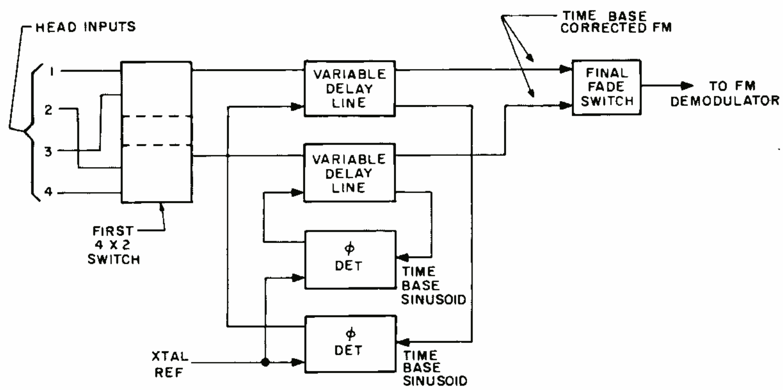
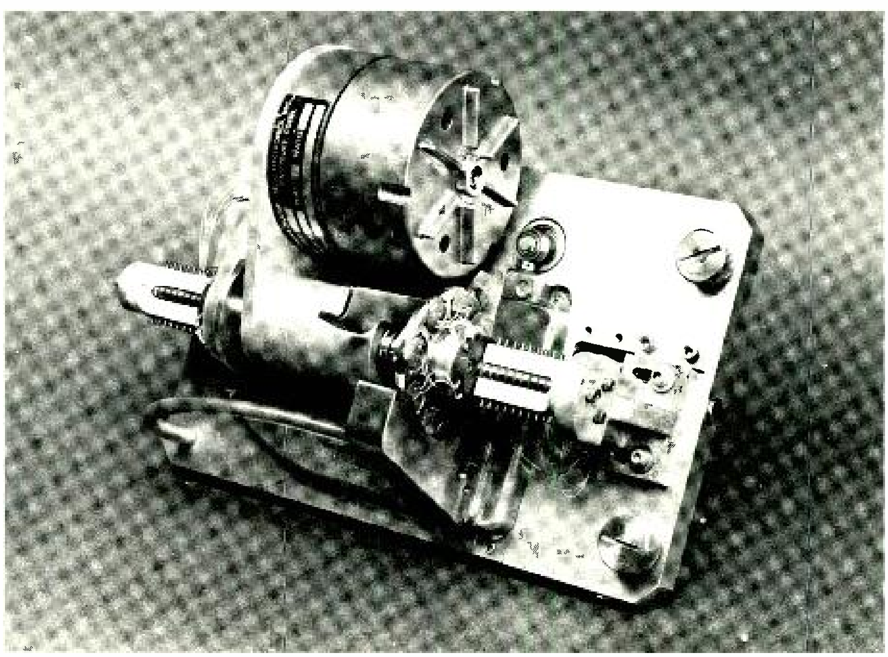


Fig. 8—Closed-loop electronically variable delay line system.

Fig. 9—Headwheel assembly for time-expansion equipment.



radar systems. The time-base system described below is the elite of a group of systems that employ electronically variable delay lines for time-base correction.

It has been noted that 100 nsec of error is the minimum obtainable from the electromechanical system. Consequently, if further reductions in time-base error are made, they must be achieved through devices other than the basic servos. Analysis of the error rates involved reveals that the sampling rate and the bandwidth of the error-nullifying device must be higher than those of the basic servos if rapid rate errors are to be significantly reduced. The familiar "once-around" indicator, or "tonewheel," no longer possesses enough information to describe the time base of the video signal as the head scans the tape. For this reason, other signals which describe time-base errors must be utilized. Television tape recorders have such a signal in the form of horizontal sync pulses.[2] The general-purpose radar or sine-wave recorder, however, has no preknowledge of the characteristics of its input signal; therefore, another means of generating an accurate time-base signal is necessary.

Happily, the unique vestigial sideband FM system employed in the record-reproduce process permits a means of establishing such a time-base signal. A portion of available tape bandwidth is not occupied by any significant sideband spectra. It is, therefore, used to provide a record of time base during recording by *adding* in an accurate small-amplitude sinusoid from a crystal source (see Fig. 7). During playback this sinusoid, when compared with the same crystal, provides a means of measuring time-base error. It is important to realize that this time standard is recorded on the same track with the information signal, thus providing an accurate measure of the time-base error experienced by that signal during recording and reproduction.

After a means of error detection has been established, the means for nullifying that error must be accomplished. As is often the case, techniques developed by the Broadcast Division's Electronic Recording Group were borrowed and changed to provide the desired error-correction capabilities. Specifically, electronically variable delay lines are employed to nullify the time-base errors.

The closed-loop block diagram shown in Fig. 8 is employed on the Dual-Channel, Dual-Speed recording equipment. A reference sinusoid frequency of 1 Mc is used. The closed-loop approach permits the realization of several additional benefits. Notice that the lines are used in the FM domain, permitting time-base correction *before* final *fade* switching, thus reducing the phase error prior to the fade switch. Furthermore, time-base correction in the FM domain, if accomplished quickly enough, can dynamically compensate for quadrature effects, thus solving many interchangeability problems. This closed-loop system, under test at this writing, is achieving a time-base accuracy of ±10 nsec. The rms value of that error is less than five nanoseconds, equivalent to less than 5 feet of range error, a new standard of excellence for radar recording accuracy.

DATA REDUCTION TECHNIQUES

So far we have described recent improvements in the general performance capabilities of scan-type recorders used as data-storage devices. In many instances, however, tape equipment may also facilitate data reduction or data presentation by providing time compression, time expansion or repetitive readout.

Time Expansion

An equipment developed recently provides a 200:1 expansion of real time, which permits on-line computer reduction of data. This equipment incorporates two transverse-scan tape machines. One records and reproduces two channels of wideband data in real time; the second accepts tapes prepared by the first and reproduces them at 1/200th the real time rates. The tape and head-wheel drives developed for this equipment provide extremely accurate, yet slow, speeds; both use hysteresis synchronous motors as prime movers. The speeds of the output members are reduced through spliceless Mylar belts similar to those employed in TIROS recorders. The speed of both assemblies is precisely controlled through servos which modulate the frequency of the motor power. Fig. 9 shows the head-wheel assembly for this time-expansion equipment.

Repetitive Readout

One potential capability of the helical-scan equipment which has been explored for several data-processing systems is the ability to repetitively read out in real time a desired segment of data. Basically, this is accomplished simply by stopping the tape with the desired information track around the scanning wheel. However, since the diagonal track was recorded with the tape moving, it does not align perfectly with the scanning path of the headwheel when the tape is stationary. Alignment, however, can be effected by reading on a helix assembly which is slightly larger in diameter than the record helix assembly. The slight difference in diameter causes a slight difference in the scan angle between head and tape and permits a complete track to be continuously scanned by the wheel. The length of the time segment which can be read out repetitively in such an equipment is limited only by the system bandwidth and the diameter of the helix assembly. The system bandwidth determines the head-to-tape speed, and the diameter of the helix assembly determines the length of the track.

Time Compression and Repetitive Readout

The combination of time compression and repetitive readout has been proposed for data which is to be presented on visual displays. In a typical application the data is received at data and frame rates which would cause flicker upon display. A typical solution to this problem is a tape equipment which incorporates two helical-scan assemblies. One of these assemblies records incoming data with a slow-moving recording head; the second assembly reproduces the data at a higher rate. If the recorded tracks are made sufficiently wide, the readout head will reproduce the same data repetitively. This repetitive readout will increase the output frame rate. Continuous processing by this technique requires that the ratio of frame rates be equal to the ratio of data rates.

SUMMARY

The advances attained in time-base accuracy and switching-transient reduction have significantly improved the usefulness of scan-type recorders for instrumentation applications. The combination of these techniques with the multichannel capabilities of the helical-scan equipment will answer many demands of radar data-reduction systems by eliminating the need for data multiplexing.

A further enhancement of the role of tape equipment in the instrumentation field in many instances is yielded by the ability to combine real-time data-storage requirements and data-readout requirements into a single magnetic-recording system.

In conclusion, the tailoring of high-performance tape equipment to the needs of a specific system has become an advanced art.

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Fig. 1—Indianapolis computer tape test center.

MAGNETIC TAPE TESTING

A tape test center has been created at Indianapolis where evaluation is carried out on all tape products to assure customers that our products meet all magnetic specifications. A physical test laboratory, complementing the work done in the test center, carries out the physical tests on all tapes.

G. P. HUMFELD, Mgr. and **R. D. BROWNING, Admin.**
Compound and Tape Formulations *Tape Products Performance*
RCA Victor Record Division, Indianapolis, Ind.

Magnetic tape finds many applications in home, industry, education and government. Technically, we are interested in discussing tape applications in computer machine operation, instrumentation recording, and audio recording. Within these technical divisions there exist two general marketing areas—commercial, and the U. S. Government.

General-purpose audio tapes probably have the least-critical magnetic and physical specifications because of the subjective nature of the recording. Here, the importance of individual bits of information is minimized. In order to meet Government specifications audio (and instrumentation) tapes must duplicate within extremely close tolerances the sensitivity, output level, distortion, and bias requirements of standard reference tapes supplied by the Bureau of Ships. Also, they must meet all the physical property tests as outlined later in this article.

For computer use, tapes must have completely uniform surfaces free from pinholes and nodules or bumps. These defects invariably result in errors during recording and read-out. The oxide surface must not abraid away during tape usage. The oxide coating must withstand temperatures well above 100°F. without the surface becoming soft or sticky. The magnetic pigment must be well dispersed in the lacquer binder to permit magnetic recording at high packing densities. Tape tensile strength and elongation properties must pass certain minimum and maximum values to assure ruggedness of performance at high tape speeds. Width and thickness tolerances must be carefully measured and closely controlled in order to meet the mechanical and magnetic limitations of any given computer machine design.

MAGNETIC TAPE TEST CENTER

The test center is in a specially designed white room which is maintained at 50% relative humidity and 70°F.

In cooperation with RCA Electronic Data Processing, test stations were built using the same type of transport upon which the tape would ultimately be used (Fig. 1). An automatic test program was incorporated using a read-after-write head assembly to check for dropouts, noise errors, and skew. Each tape tester also checks for the presence of *begin tape* and *end tape* markers, and indicates the total length of tape on a reel.

Computer Tape Testing

The tape is first threaded on the tape transport. The programming device then records a signal simultaneously on all tracks at a pulse-packing density at least 25% above that ultimately used in computer operations. All recorded tracks are read out while writing and must reproduce each bit at an amplitude at least double that required to register in a computer tape station logic. If any recorded bit fails to produce the necessary output voltage, it is automatically reread to determine whether it is a transient or permanent error. Tape surface defects, such as pinholes, nodules, and dirt produce a loss in signal. The machine is designed to stop with the defect positioned so that it can be examined and repaired if possible. Perfect tapes are not being produced by manufacturers today, hence all tapes ultimately used must be repaired. A nodule or a piece of lint or dirt stuck to the tape surface can be removed by a light wipe with a special tool. If the defect is repaired properly the machine will pass this point on retest and continue testing.

After the dropout test, the tape is then subjected to a noise test during rewind. For computer tape, *noise* refers to any spurious voltage pulse generated by a flux change while running a DC saturated tape over the reproduce head. Any noise pulse due to loss of tape-to-head contact or lack of oxide on the tape which is greater than 10% of the average signal amplitude is cause for rejection of the tape. A pinhole is an example of a defect which may generate such a noise pulse.

Equipment maintenance is very important to reliability in testing, so all test stations are calibrated each shift.

Fig. 2 — Computer tape wear test simulator.

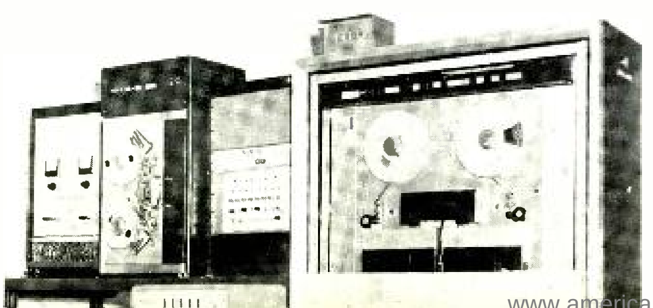
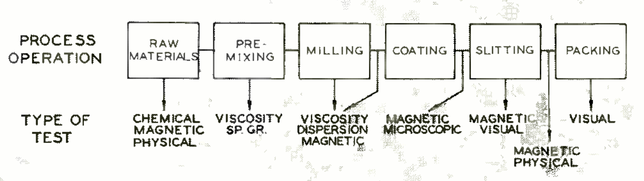


Fig. 3 — Quality tests in tape manufacture.



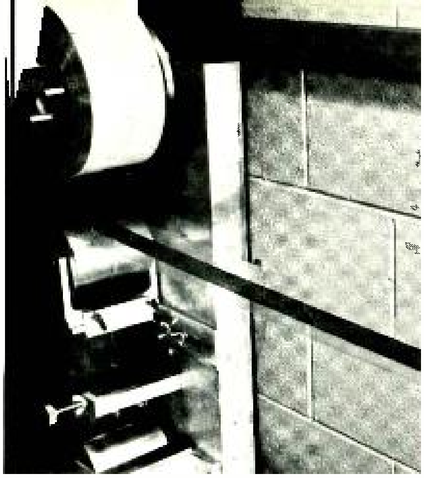


Fig. 4 — Control laboratory coating machine.

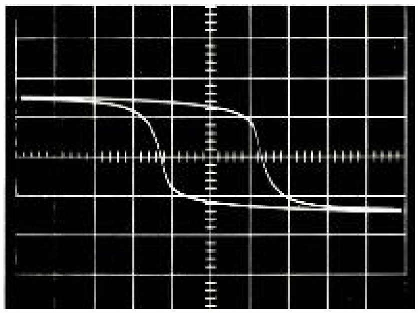


Fig. 5 — Hysteresis curve of a magnetic tape.

Fig. 6 — Production sampling.

In addition, more thorough preventive maintenance checks are made on a weekly and monthly schedule.

Wear characteristics are determined on a statistical sampling basis on wear test simulators. These simulators are mechanical duplicates of the computer transport, as shown in Fig. 2. In the short-length wear or abrasion-resistance test a tape is recorded with 20 discrete messages each approximately 1 inch long with a 0.5-inch inter-message gap. The transport is then programmed to read in both directions with the pressure roller impact occurring in the message area. A tape must run for at least 5,000 passes in each direction without the loss of a bit of information.

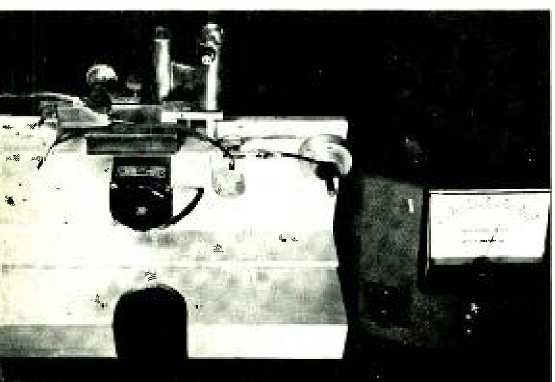
For the oxide rub-off test, the tape is written continuously throughout its entire length and then programmed to read back and forth, checking for read errors. An acceptable tape must make 12 passes over the heads without error or evidence of coating buildup on the heads or guides.

Quality is further assured by environmental testing to observe the effect of humidity and elevated temperatures upon coating adhesion, layer to layer adhesion and cupping. Such tests compress years of service into a few short test hours. Finally, measurements are made on overall tape length, width, tensile strength and coating opacity to assure perfect mechanical operation on the machines.

Fig. 7 — Audio production test equipment.

Fig. 8 — Process control test laboratory.

Fig. 9 — Electronic coating thickness indicator.



Audio Tape—Magnetic Tests

A pictorial representation of the quality tests on audio tape is shown in Fig. 3. Oxide slurry is drawn from each mixing machine and coated on a miniature coating device in the Control Laboratory before being released for production use (Fig. 4). This test tape is placed in a 1,000-oersted, 60-cycle magnetic field and the resulting hysteresis loop projected on an oscilloscope indicates the magnetic characteristics of the coating (Fig. 5). From this loop, measurements are made of the coercivity H_c, retentivity B_r, and loop squareness or degree of orientation of the magnetic particles in the coating. General-purpose audio tapes normally have an intrinsic coercivity of about 250 oersteds, a retentivity of approximately 900 gauss, and a squareness of about 0.8.

Production coatings are checked on the same hysteresis loop tracer by testing short lengths of tape slit from the web as it emerges from the drying ovens (Fig. 6). As production slitting progresses, sample reels are tested for sensitivity, output, long and short wavelength response, bias, distortion, noise, print-through, and output at various distortion levels. A custom-built test station (Fig. 7) enables technicians to perform all these tests rapidly so that any deviation from RCA standards is detected immediately, and only high quality tape will pass on to the visual inspection and packaging operation.

PHYSICAL TEST LABORATORY

Exhaustive physical and environmental tests, requiring up to 24 hours in some cases, are performed in the Control Laboratory shown in Fig. 8. These tests are described in detail in the following paragraphs and include tests for evaluation of both Government Services Administration (G.S.A.) and regular commercial tapes.

Visual Examination: Tape surface quality can be evaluated by microscopic examination. These tests are aimed to guard against poor surface texture, a corrugated coating surface, surface nodules, or foreign particles of dirt imbedded in the coating. These defects can have a direct bearing upon output and short wavelength response. Other visual tests involve observations on quality of slitting and uniformity of wind-up of reels and hubs.

Coating Thickness: Coating thickness must be accurately measured and carefully controlled to produce a high quality tape product. An electronic gage (Fig. 9) converts vertical motion of a sensing probe into a signal which is amplified and read out on a sensitive microammeter graduated in increments of an inch. The coating thickness of general use audio tape approximates

ROBERT D. BROWNING graduated in 1948 from Auburn University with the BS degree in Electrical Engineering. He joined RCA as a Recording Engineer in the New York Studios in early 1949. In 1955 he was transferred to the RCA Chicago Studios and was Manager, Recording, there until 1957. He then joined Ampex Corporation and was Manager, Quality Control Division, at their Magnetic Tape Plant in Alabama until he rejoined RCA in 1962. He is presently Administrator, Product Performance, at the Magnetic Products Plant in Indianapolis, Indiana. He is a member of the Audio Engineering Society and the American Society for Quality Control.

GEORGE P. HUMFELD graduated from Purdue University in 1937 with a BS in Chemical Engineering. He worked as a chemist in a non-ferrous foundry for five years after graduation and then joined the U. S. Rubber Company as a rubber compounder during the war years. He joined RCA in 1946 as an engineer in the Record Compound Group and was appointed Manager of that group in 1956. This activity was expanded to include formulation development work on magnetic tape products when RCA entered the tape manufacturing field. He is a member of the American Chemical Society and the Society of Plastics Engineers where he has served as a National Councilman.

The authors: (l.) Robert Browning and (r.) George Humfeld.

0.0004 inch. However, coatings as thin as 0.0001 inch are becoming practical for applications in computers.

Tape Width: Tape width is closely controlled by the precise setting of the slitting machine. An optical comparator (Fig. 10) is used to determine width accurately. Standard measurements for a ¼-inch tape are 0.246 ± 0.002 inch. For ½-, ¾-, and 1-inch-wide tapes, the limits are +0.000, −0.003 inch.

Yield Strength: Fig. 11 shows the tensile machine used to stretch ¼-inch tape at a constant rate of 12 inches per minute until the specimen reaches the yield point. Minimum acceptable values for cellulose acetate are 4.7 pounds for 1.5-mil film and 3.2 pounds for 1-mil film. For polyester (Mylar) film, minimum acceptable values are 5.5 pounds and 3.7 pounds, respectively.

Shock Tensile Strength: A pendulum-type impact tester as shown in Fig. 12 subjects ¼-inch tape to the striking force of a free-swinging pendulum. Impact strength is determined by calculating the difference between the original energy value of the pendulum at the start of the test and the pendulum energy remaining after break. This difference is a function of the travel (in an upward arc) by the pendulum following impact with the sample. For cellulose acetate, the minimium values are 0.35 foot-pounds for 1.5-mil film and 0.25 foot-pounds for 1-mil-thick, ¼-inch-wide tapes. Comparable minimum polyester values are 0.58 for either thickness of ¼-inch tape.

Elongation Under Stress: This consists of applying a specified load to a 20-inch length of ¼-inch tape for a period of 3 hours at room temperature and observing the amount of permanent stretch the tape maintains 3 hours after the load is removed. The maximum values for cellulose acetate are 1% for both 1.0-mil and 1.5-mil film; maximum values for polyester are 0.30% for 1.5-mil and 0.50% for 1.0-mil-thick polyester.

Humidity Stability (Cupping) Test: A two-chamber box is used for this test. One chamber is maintained at 90% relative humidity and the other at 15% relative humidity. Both are maintained at 90°F (Fig. 13). Duplicate samples are mounted in a horizontal clamping device and stored in each environmental condition for 16 hours. The environment causes the tape to curl, i.e., the edges of the tape either rise or fall. A low-power telescope is used to view the tape ends and measure the angle between the horizontal and a line tangent to the edge of the tape. The arithmetic difference in degrees between the angle measured on the desiccated tape and the angle measured in the same manner on the humidified tape gives the value for this test.

Layer-to-Layer Adhesion (Blocking): A 3-foot length of ¼-inch tape is wound onto a ½-inch-diameter mandrel under the tension of a 1,000-gram weight clamped to the lower end of the tape during windup. After the weight is removed the loose end is fastened with pressure-sensitive tape. This assembly is then stored in an environmental chamber, first for 18 hours at 130°F and 85% relative humidity, and then for four hours at 130°F and 5% relative humidity. A good tape at the end of this test will spring free when the tape fastener is removed. There will be no sticking of adjacent layers and no separation of the oxide coating from the coated surface.

Flammability: Flammability of tape is determined by conducting burning tests in a carbon dioxide atmosphere. Tape coatings containing materials which will support combustion in such an inert atmosphere are not accepted by the industry.

Fungus Resistance: Fungus growth is a problem in tropical sections of the world and coatings must not support spore growth. Four fungi used in these studies are: aspergillus niger, aspergillus flavus, penicillum luteum, and trichoderma T-1. Test samples are inoculated with a composite spore suspension of these types and incuhated for a period of 21 days at 28° to 30°C. Tapes showing no growth or only a slight trace of fungus such as might develop from an unusual mass of spores in the original inoculum are considered acceptable.

CONCLUSION

Quality must first be built into a product before it can be accepted in the field. This is being done regularly in the 158 various products currently in production. Test effort such as described in this article assures the producer and the customer of a continuing level of high-quality product.

Fig. 10 — Optical comparator.

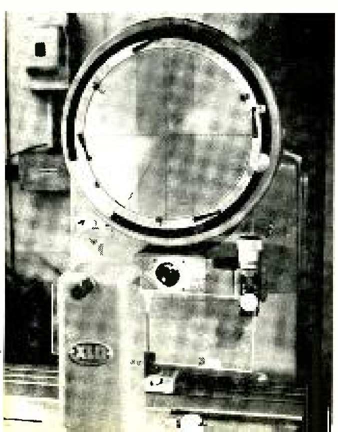


Fig. 11 — Tape tensile strength test.

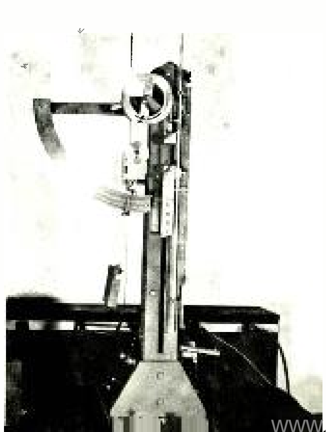


Fig. 12 — Pendulum impact tester.

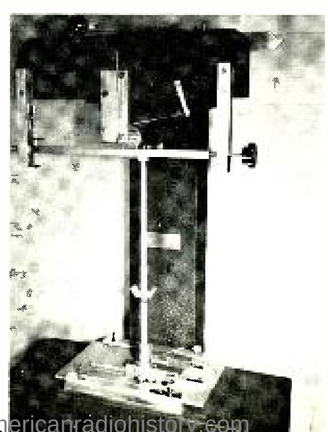
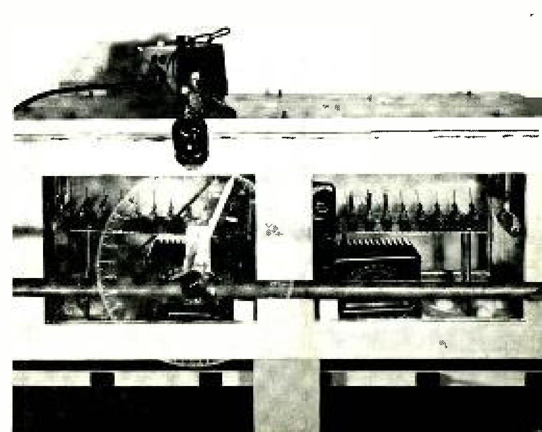


Fig. 13 — Humidity stability test equipment.



TV TAPE RECORDING—A REVIEW OF TECHNIQUES AND EQUIPMENT

Since the announcement in 1959 of an RCA color television tape recorder, a succession of models have appeared. These are reviewed briefly in tracing the development of the television tape recorders down to the current all-transistor types TR-22 and TR-3, -4, and -5, and the major technical efforts that have led to improved performance.

A. H. LIND, Mgr.

Studio and Scientific Instruments Engineering
Broadcast and Communications Products Division, Camden, N. J.

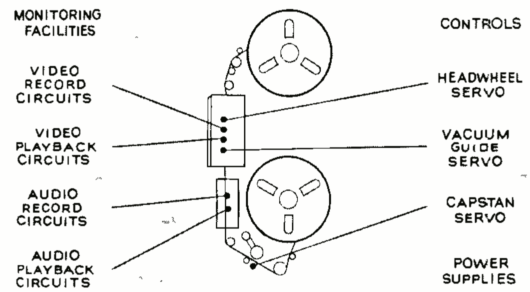


Fig. 1—Quadruplex TV tape recording.

PERUSAL of the technical literature reveals that a great deal of research on various approaches to wideband signal recording preceded the actual design of a workable, practical wideband video tape recorder. In addition to the tape motion required to transport the magnetic medium past the magnetic heads, a much higher head-to-tape speed is achieved by moving the head so that it scans transversely in a narrow path *across* the tape oxide surface. To provide a succession of such transverse tracks without loss of signal, four magnetic heads were chosen to scan the tape in sequence. The heads are mounted in 2-inch-diameter wheel which is rotated at high speed to achieve the necessary head-to-tape speed. This time-sequential multiplexing of the four heads gave rise to the choice of the descriptive term *quadruplex* to designate the system.

EFFECT OF COLOR TV

The potential of color TV made it mandatory that a product-line TV recorder be capable of recording and reproducing both black and white and color video signals. Through the combined and coordinated efforts of many engineers and scientists at the RCA Laboratories, RCA Defense Electronic Products, and the group then called RCA Industrial Electronic Products, an acceptable system was developed and designed.[1]

Public announcement of the color TV recorder was made by demonstrations to the technical press in October 1957. In 1958, a small number of engineering prototypes, designated VTRX (Fig. 1), were delivered for use—principally by NBC for color program delay between the east and west coast. It contained all the basic functions required for a TV tape recorder (Fig. 2). While the video recorder development gave rise to increased sophistication in the video signal-handling circuitry, the areas in which major efforts were applied were the servomechanism, electromechanical, and precision mechanical assemblies. Mechanical tolerances of microinches (millionths of an inch) and seconds of arc become commonplace in quantity production of assemblies at competitive prices.

SOME BACKGROUND

One of the most intriguing applications of magnetic recording since the early work of Poulsen is the use of this technique to record television picture signals. The recording and storing of electrical signals by magnetizing microscopic oxide particles through the application of a magnetic field has been generally known for decades. The most successful magnetization method has been to immerse the oxide particles in a fringe field emanating from a gap in soft magnetic material; the soft magnetic core is part of an electromagnet. Such an assembly is universally called a magnetic head.

To obtain maximum efficiency, the iron oxide particles customarily coated on plastic tapes and the gap of the magnetic head are held in as intimate proximity as possible. The magnetic head gap-size determines, in practice, the shortest wavelength that can be recorded. A spacing loss due to surface roughness also influences the intimacy of contact and can be a factor in determining the shortest useful wavelength that can be recorded.

The shortest wavelength that can be recorded and the electrical signal frequency corresponding to this wavelength are directly related by the relative motion of the tape and the magnetic head. Thus, the matter of head-to-tape speed relationship becomes paramount when high-frequency recording is considered. For example, if the minimum wavelength usefully recorded is assumed to be 200 microinches (0.000200 inch)—then a head-to-tape speed of 1,000 ips is required to record a signal of 5 Mc (assuming the signal is recorded in a single channel). Experience has shown that satisfactory tape recordings can be made with tracks, or patterns, only a few thousandths of an inch wide.

(For more-detailed discussions of RCA television tape recording techniques and equipment, see the papers listed in the *Bibliography*.)

TRT-1 RECORDERS

Accelerated development and design effort resulted in the first production model, the TRT-1A (Fig. 3). Deliveries from production began in 1959. Although numerous improvements were made in performance over the VTRX, perhaps the most substantial gains were in servomechanism stability and video headwheel panel improvements. Some of the video headwheel panel improvements can be appreciated by observing the contrast between the VTRX panel and the TRT-1A panel shown in Fig. 4. As the TRT-1A recorders were placed into operation, much valuable field experience started feeding back to the design engineers. This, plus benefits from continuing development work, were incorporated in a redesigned recorder, the TRT-1B, which became available in 1960. The TRT-1B had increased operational flexibility, better monitoring facilities, and included a signal processing amplifier that provided clean sync and blanking in the output signal and was the first transistorized unit used in TV recorders.

TR-11 RECORDER

As experience with the TRT-1's grew, it became clear that a simpler machine could make good pictures. By limiting the operational flexibility and monitoring facilities, a second, lower-cost recorder was made available in 1961. Because of the heavy engineering load in Camden, this recorder, the TR-11, was engineered in the Broadcast and Communications Products Division, Hollywood, California plant. A substantial reduction in size was achieved (compare Fig. 5 and Fig. 3), with corresponding reduction in power requirements. The TR-11 was intended primarily for small broadcast stations and educational TV applications.

TR-22 TRANSISTORIZED RECORDER

The increasing importance of transistors and the desire for more-compact recorders were key considerations behind the TR-22 all-transistor recorder

(Fig. 6), that was introduced at the 1961 National Association of Broadcasters convention.[2,3] The TR-22, shown in Fig. 6, has been a very gratifying commercial success. The basic recorder is completely a solid-state design. The only vacuum tubes are in the picture and waveform monitors. The size, weight and input power are all very substantially reduced from that of the TRT-1B predecessor.

The TR-22 was designed in two versions: The first is a domestic version for 525-line, 60-field TV signals with 60-cycle AC power. The second is a 3-standard switchable recorder designed to accommodate 525-line, 60-field; 625-line, 50-field; and either 405-line, 50-field or 819-line, 50-field signals. In the second case, the input power is 230-volt, 50-cycle AC.

LATEST FAMILY OF TV TAPE MACHINES: TR-3, TR-4, AND TR-5

The newest series of RCA television tape machines includes the TR-3, TR-4, and TR-5. These new machines reflect design advances in decreased size, improved performance, lower power consumption, and greater mobility. The machines continue to employ the quadruplex recording system and thus are fully compatible with the more than 2,000 professional TV tape recorders now in worldwide use.

The TR-3 is a *playback*-only machine (Fig. 7). It is analogous to a TV film chain, since prerecorded tapes are replayed in it with its output being a video signal. It is very appropriate to introduce a playback-only machine at this time because it has become common practice for broadcast studios to utilize one or more tape recorders to play back tapes previously recorded on other machines.

The TR-4 is an expanded version of the TR-3, in which recording and monitoring circuitry is added. It thus becomes a smaller edition of the well-accepted TR-22.

The TR-5 is packaged in a small cabinet which can be easily moved and transported, and complements the TR-3 in that it is intended as a *recorder*. Its mobility for both in-studio and remote recording makes it very attractive as an addition to existing TV tape recorder installations. All three of the new tape recorders are available in both domestic and international models. The international models can be switched for operation at either of two scanning standards.

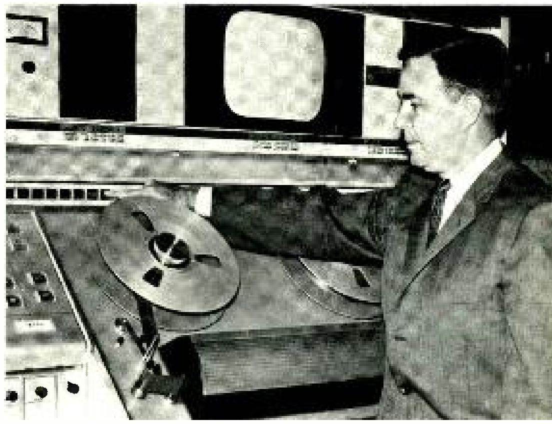
THE "PIXLOCK" SERVO

During the period of TR-22 development and design, an accessory precision headwheel servo unit for the TRT-1 recorders was designed. This unit, called the *pixlock* servo (Fig. 8), has subsequently been incorporated in a large portion of the TRT-1 recorders. In addition to providing substantially improved performance (absolute time lock of the playback signal to within $\pm$ 0.1 μsec with respect to a crystal controlled reference timing signal), this accessory was the second all-transistor unit to become a commercially designed product. It reduced the space and power requirements for the headwheel and capstan servos by factors of 8 and 10, respectively. As a result of this substantial space saving, the TR-11 was redesigned to incorporate the improved performance provided by the transistor servo circuits as well as the more compact units. This redesign also presented the opportunity to make numerous other design improvements including the ability to handle color signals. The redesign recorder became the TR-2 (Fig. 9).

SLOW-SPEED ASSEMBLY

An important step forward was made when it became possible to reduce the longitudinal tape speed from 15 ips to 7.5 ips. This development was made

A. H. **LIND** received the BSEE in 1946 and the MSEE in 1949, both from the University of Wisconsin. He has been a member of the engineering staff of the RCA Broadcast and Communications Products Division since 1946; until 1950, he was engaged in TV camera development and design. From 1950 to 1953 he was Manager, TV Terminal Equipment Engineering and directed the development and design of such terminal equipment as sync generators, video switches, video distribution amplifiers, etc. From 1953 to 1959 he was Manager, Broadcast Audio and Mechanical Devices Engineering; this group developed and designed audio and TV magnetic recorders, TV projectors, associated film equipment, and broadcast audio equipment. From 1959 to 1962 Mr. Lind was Manager, Electronic Recording Products Engineering and directed the development and design of magnetic tape recording equipment. In February 1962, he was also made responsible for Scientific Instruments Engineering, which has the electron microscope as its principal product. Mr. Lind is presently Manager of Studio and Scientific Instruments Engineering. He is a member of the



IEEE, the SMPTE, and the Franklin Institute; also, Tau Beta Pi, Eta Kappa Nu, and Pi Mu Epsilon. He has participated as a member of many industry technical committees and currently is chairman of the SMPTE Video Tape Recording Committee.

Fig. 2—The VTRX color tape recorder was housed in seven racks (one, a monitor, is not visible here); left photo shows (l to r) the signal, control and transport racks; right photo shows (l to r) power supply and two servo racks.

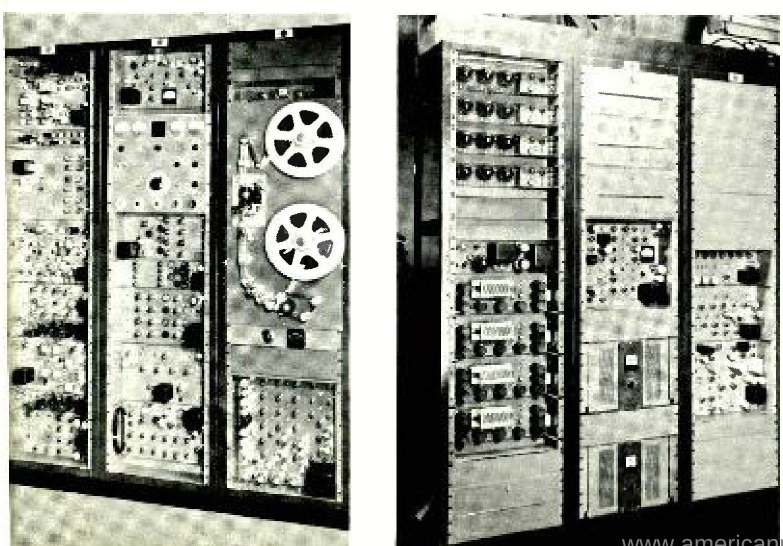
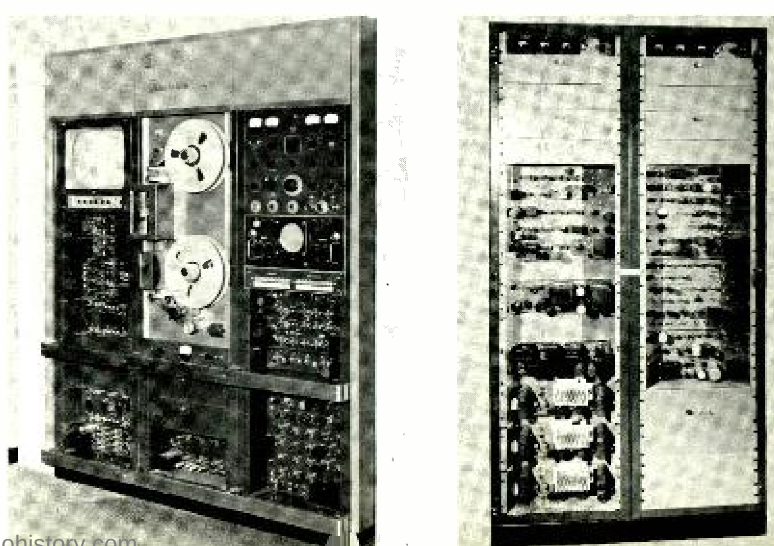


Fig. 3—TRT-1A first production-model TV tape recorder: five racks were used; left photo shows signal, transport and control racks; right photo shows power supply and servo racks.



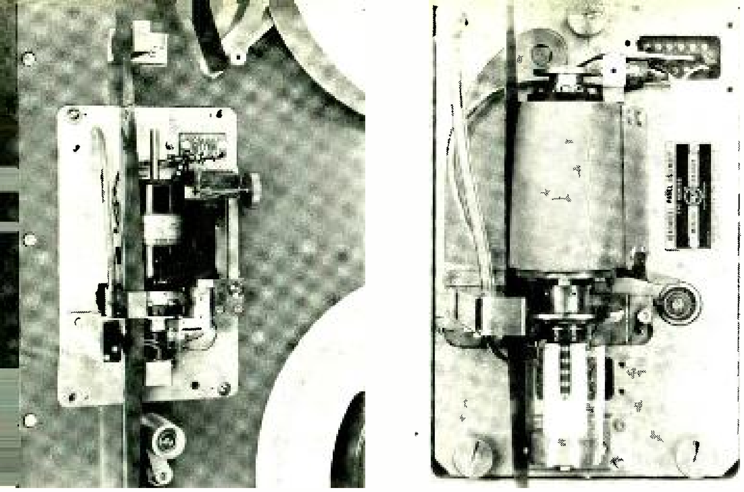


Fig. 4—Left photo: VTRX headwheel-panel assembly; right photo, TRT-1A headwheel panel assembly. In both, the entire headwheel panel assembly is demountable.

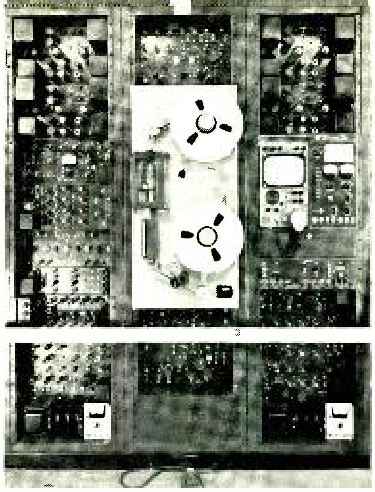


Fig. 5—TR-11 TV tape recorder; this unit shows a 40% decrease in size, employing only three racks.

Fig. 6—The TR-22, industry's first all-transistor TV tape recorder; size is again substantially reduced and reliability improved.

available as a modification accessory for all existing RCA recorders in 1962; this modification added the 7.5-ips speed as a switchable second speed. The 50% saving in initial tape cost was an important economic consideration. The reduction in size and weight of a given recording was also important for both storage and shipping reasons. The 7.5-ips tape speed was made feasible by greatly improved wear, life, and sensitivity performance of the video magnetic head assemblies.[3] A continuing development program had raised the head life from a dubious 100 hours (the guaranteed minimum) to an expectancy in excess of 400 hours. Other head-design changes permitted the recording of the necessary half-width video tracks with hardly any discernible reduction in signal-to-noise performance.

VIDEO MAGNETIC HEADWHEEL ASSEMBLY

In addition to the basic task of providing workable video magnetic heads mounted in a rotating wheel, many problems were encountered and overcome in providing a long-lasting, high-speed, high-performance mechanism in which the heads are mounted. Two areas of substantial development and design effort are the bearings used for the high-speed shaft and the slip-ring brush assembly which is required to carry the electrical circuits to and from the magnetic heads. Through the years, effort has been applied to obtain ball bearings that are well manufactured, carefully and properly lubricated, and designed to work economically and well in the overall assembly; thus, a very satisfactory level of performance has been achieved. Constant vigilance in the area of quality control is vital to maintaining satisfactory performance. An alternative of using air films for lubrication of the rotating high-speed shaft was suggested several years ago after the successful application of this technique to precision tape capstan assemblies by DEP Applied Research. In 1960, the first application of air bearings in headwheel panel assemblies was made experimentally.[5,6,7] The resulting product design is shown in Fig. 10. Both the radial and axial bearings are air-lubricated. Air is introduced into the bearing journals from an external source of supply at approximately 35 psi. Since the rotating shaft does not make contact with the bearing journals, (Fig. 11) the only points of mechanical load are the frictional load of the slip-ring brushes and the frictional drag of the magnetic heads on the tape oxide surface. As a result, the servo performance with respect to time stability (freedom from jitter) is substantially improved both in peak performance and average performance. Furthermore, bearing life is substantially extended and is limited primarily by the ability to keep the air supply to the bearings clean.

A continuing program on materials for improved magnetic head pole pieces and coil cores resulted in the introduction of alfecon in 1961.[4] This pole-tip material increased the service life by three to four times over that achieved with the previously used alfenol. Work continues in this area with the expectancy that ferrite materials in some still-to-be-determined form will be a further step toward longer head life with improved signal performance.

COLOR TV RECORDING REFINEMENTS

Early work with the quadruplex recorder established that its time stability for periods of one or two TV lines was adequate to maintain the accuracy of the chrominance portion of the color signal to the corresponding subcarrier burst signal adequate for color playback. However, since color receivers did not, and still do not, demodulate the color information on a line-at-a-time basis, this stability is not adequate.

Double-Heterodyne Technique

The first successful approach to compensating for the phase errors introduced by the recorder was to use a double-heterodyne technique that in effect stabilized the color phase errors which are inherent in the basic recorder. This technique utilizes a local

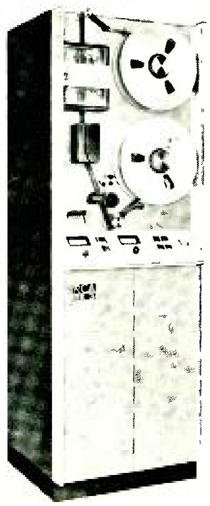


Fig. 7—TR-3 all-transistor TV tape player represents the first unit to be devoted to "playback only."

Fig. 8—TRT-1 pixlock servo control unit stabilizes the mechanical scanning within $\pm$100 nsec.

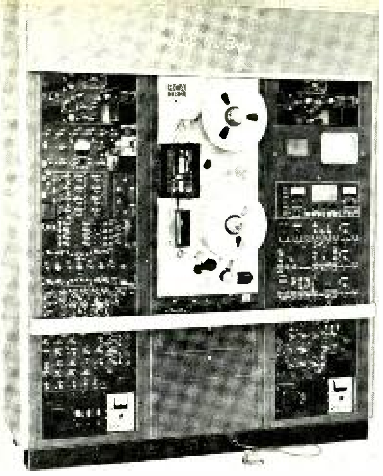


Fig. 9—TR-2 economy TV tape recorder is a modification of TR-11.

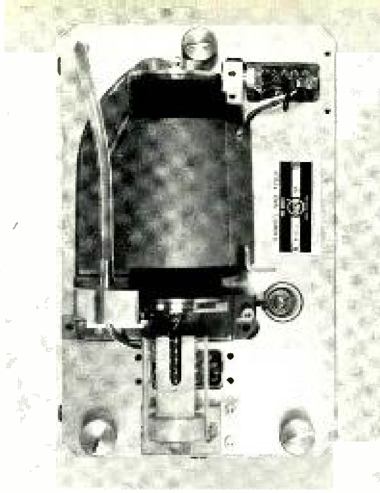


Fig. 10—Air bearing headwheel panel assembly.

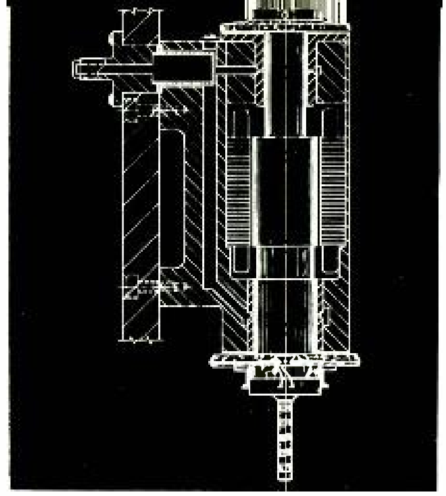


Fig. 11—Air bearing panel.

oscillator which is locked to the tape color subcarrier bursts on a line-at-a-time basis; the chrominance signal is then double heterodyned; first, against an oscillator which varies as the tape burst signal varies, and secondly, against a stable carrier locked to the local crystal-controlled color subcarrier standard.[8] Fig. 12 shows the heterodyne color processing equipment used with the TRT-1A recorder.

The heterodyne color processing equipment was redesigned to improve its stability, reduce the distortion in waveform processing and reduce its size for the TRT-1B. This equipment is shown in Fig. 13.

The double-heterodyne approach to color processing involved a degree of compromise in the overall frequency response performance and the overall time-stability performance of the TRT-1 recorders. Since it was not practical to handle the entire video spectrum in the heterodyne process, frequency division of the video signal was introduced. Only the high-frequency chrominance portion of the signal was passed through the heterodyne process, thus any jitter that appeared in the low-frequency "luminance" signal appears at the output of the machine unattenuated.

Automatic Timing Control

Other approaches that might permit handling the entire video signal through one path and controlling the delay or velocity of transmission through that path were investigated. Practical success was reached when electrically controllable delay networks were developed, based on the use of electrically variable capacitors that are simply specially-designed, reverse-biased semiconductor diodes.[9] This technique of the stabilization was used first in monochrome automatic timing control for the TRT-1 series of recorders. After the successful introduction of monochrome units (in which the timing error is established by comparing the trailing edge of the tape signal sync with an external stable sync signal and subsequently using this error signal to modulate the delay in an electrically controllable delay network) a next step was to apply the same technique to process the tape-playback color signal.

In the case of a color signal, the tape color subcarrier burst phase is compared to a stable external color subcarrier signal to determine the error. The error signal is then used to modulate the delay in a modest range delay network to eliminate the chrominance phase errors incurred in the tape recording-playback process. The color automatic-timing control units (Fig. 14), when incorporated in the TR-22 TV tape recorder, make the color recorder performance substantially better than that achieved with the double-heterodyne equipment.

CONCLUSION

The TV tape recorder has justified its widespread acceptance in the TV industry on both technical and commercial grounds. As it continues to mature, those closely associated with it anticipate many more interesting and rewarding developments.

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Fig. 12—Color signal processing rack for TRT-1A.

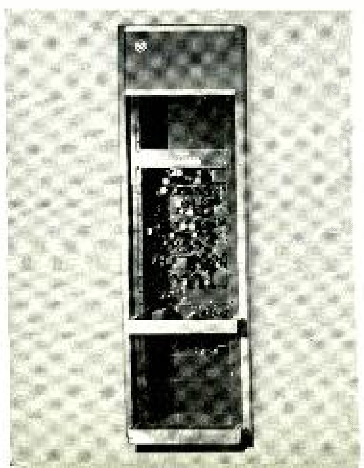


Fig. 13—Color signal processing rack for TRT-1B.

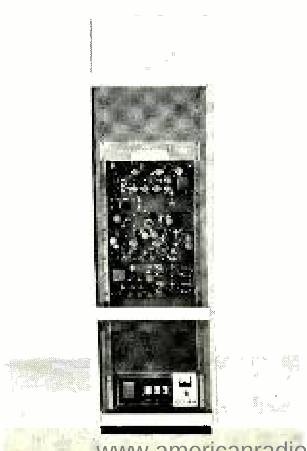


Fig. 14—The six color ATC modules for TR-22, shown partially withdrawn.

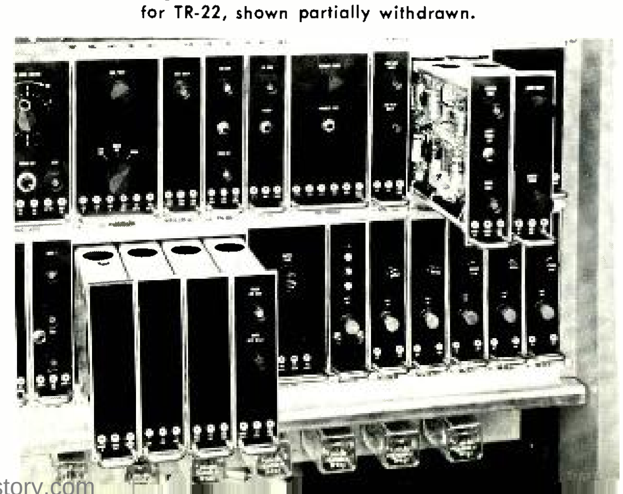


Fig. 1—Three photos from the picture monitor showing scene material with a) quadrature, b) skewing, and c) scalloping distortions.

AUTOMATIC TIMING CORRECTION FOR MODERN COLOR TELEVISION TAPE RECORDERS

The recording and reproduction of color-television picture signals on magnetic tape has posed many challenging problems in addition to those which have been solved in monochrome television tape systems. The most important color problem is that of time-base stability. This paper describes the means developed for color tape playback in the RCA TR-22 Television Tape Recorder,[1] which solves the problem of time base stability.

A. C. LUTHER, Mgr.

Television Tape Recorder Engineering

Broadcast and Communications Products Division, Camden, N. J.

The mechanical scanning process of the quadruplex recorder produces various distortions of the timing of the reproduced picture signal. Many of these effects are residual to the process of segmentation of the picture signal into 16- or 17-line groups for recording on each transverse track on the tape. The appearance of some of this type of picture distortion in a monochrome signal is shown by Fig. 1. Each of these effects is readily minimized and made negligible for monochrome transmission by proper adjustment of the transverse scanning mechanism and the recorder circuits, but this does not ensure good color reproduction. The amplitude- and phase-modulated subcarrier which transmits the color information in the composite color video signal requires far greater timing accuracy. A picture displacement from line-to-line of 0.03μsec is not visible in a monochrome picture, but the same displacement represents a phase shift of 40° to the color subcarrier, which will produce a serious hue shift in the color picture. The maintenance of such precision on a day-to-day basis with present TV tape recorders requires skilled operators and constant attention, both of which are costly and often just not available in the field. Therefore, it is desirable to develop means to reduce the precision required in the transverse scanning for playback of a tape recording.

A further source of color instability is the time base jitter resulting from nonuniformities of the mechanical motions of the recorder. Even with the most sophisticated servo system available (Pixlock), the residual jitter may be of the order of 0.1 μsec (130° of subcarrier phase) which is intolerable for color. Fortunately, it has been possible to develop devices for correction of both segmentation and jitter errors simultaneously.

AUTOMATIC TIMING CORRECTION (ATC)

Practical experience with quadruplex recorders in the field has shown that it is reasonably easy to maintain the total of all time base errors to less than 1.0 μsec peak-to-peak. Therefore, a correction device should have at least 1.0 μsec of correction range in order to achieve the goal of non-critical operation of the recorder system. This kind of control range is within the capability of electronically-variable delay lines based upon the properties of silicon diode capacitors. Therefore, an all-electronic corrector is feasible.

Given an electronically-variable delay line, it becomes necessary to develop time base error measuring circuits in order to derive proper control of the delay line. This may be done by the use of phase detector circuits comparing the timing of the TV sync pulses to a suitable reference pulse. There are two ways to arrange such a system. Fig. 2 shows both *open-loop* and *closed-loop* control systems. These two systems differ substantially in their capability for rapid correction of errors. The closed-loop system, which might at first appear more desirable, is limited in rapidity of correction by the sampling process inherent in the sync pulse phase detector. Since the response of a sampled-data feedback loop must necessarily require a number of sampling intervals for stabilization, and we obtain only one sample per TV line from the sinc pulse comparator, the fastest control response of the closed-loop system would be several TV lines in duration. This would be unsatisfactory for our purpose, since we have seen (Fig. 1) that the segmentation time base errors of the tape process can produce large changes in timing from one line to the next so our corrector must be able to change its delay by the full range from one line to the next. In fact, the entire delay change must occur within the blanking interval, so that it is not seen in the picture.

The open-loop corrector is capable of one-line response, and it therefore is the system which has been developed. As applied in the RCA TV Tape Recorders, such a device is called ATC (automatic timing corrector). The ATC is capable of correcting jitter and segmentation errors for monochrome picture signals, but it does not complete the job for color signals. For complete color operation of the tape recorder, the color ATC unit is required in addition to the ATC. Both of these units are available for the TR-22 recorder[1] as accessories which fit right in the TR-22 console as seen in Fig. 3.

ELECTRONICALLY-VARIABLE DELAY LINE

The double-width module of the ATC unit contains the electronically-variable delay line (EVDL). This line consists of 84 sections with fixed iron-core coils and silicon diode capacitors. The horseshoe arrangement of this line shown in Fig. 4 effectively bends the line in half to fit it in the module length without introducing any discontinuity. The rest of the double module contains the video driver and output amplifier circuits which complete the video path through the ATC unit.

As seen in Fig. 5, the video passes through the line in single-ended fashion, while the control of the line is push-pull. This is necessary to balance out transients which are coupled from the control busses to the video path by the capacitance of the diodes every time the control voltage is changed.

Since the EVDL is to be used in an open-loop control system, it is essential that the delay vs. input voltage characteristic be highly linear for proper tracking of control voltage to be maintained over the entire delay range. The capacitance-vs.-voltage characteristic of the silicon diode is highly nonlinear and of course delay varies as the square root of capacitance which is a further non-linearity. Therefore, a nonlinear amplifier (NLA) is introduced in the control path to correct

ARCH C. LUTHER, JR. graduated from the Massachusetts Institute of Technology in June 1950 with a BSEE degree. He joined RCA in July 1950 in the Broadcast and Television Engineering Department. He has worked on the design and development of sync generators, camera control equipment, monitors, switching equipment, and other items of television studio equipment. Mr. Luther is now Manager of Television Tape Recorder Engineering in the Broadcast Studio Engineering Department, and is responsible for development and design of television tape recorders and accessory products. He holds 25 United States Patents in the field of television. He is affiliated with Eta Kappa Nu, the Society of the Sigma Xi, and IEEE.

for these effects. The delay-vs.-voltage characteristic at the input of the NLA is then accurately linearized. The NLA also contains the phase splitters and error driver amplifiers for feeding the delay line.

Driving the control voltage to the delay line is a difficult task in itself, since the diodes represent a capacitance load, and a fairly fast response must be achieved—during which time the positive and negative busses must remain accurately balanced so that transients coupled to the video will cancel. Furthermore, the drivers must at all times present a negligibly low impedance to the line over the entire video passband because the driver represents the ground return for the capacitors of the delay line. This is accomplished by the combination of complementary-symmetry emitter followers on each error bus and additional fixed capacitance to ground to insure a low impedance at the higher video frequencies.

As the diode capacitance is modulated, both the delay and the characteristic impedance of the line will change. The line is terminated at both ends with fixed resistances which are accurately matched to the line impedance at the center of the delay range. As modulation away from this point takes place, an increasing mistermination results. The total amount of delay modulation which can be achieved by a line of given length must therefore be limited so that the reflections produced by mistermination never become great enough to be visible. This is a reasonable compromise.

Additional considerations in the delay line are concerned with the location and duration of the delay-change transient which occurs when the delay is set for each TV line in the picture. Since a large timing shift may occur when the recorder switches from one head to another during the playback process, it is essential that the head switching take place *before* the timing error is meas-

Fig. 2—Open-loop and closed-loop timing-error correctors.

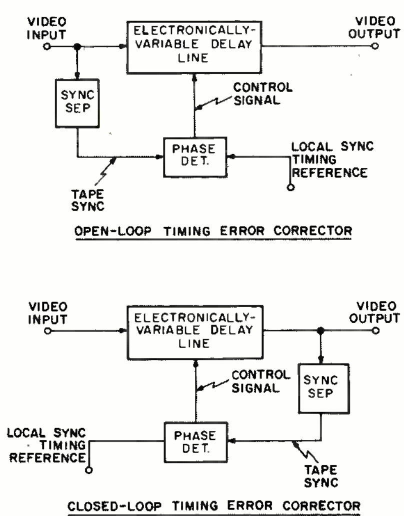


Fig. 3—TR-22 tape recorder module area highlighting the monochrome ATC and color modules.

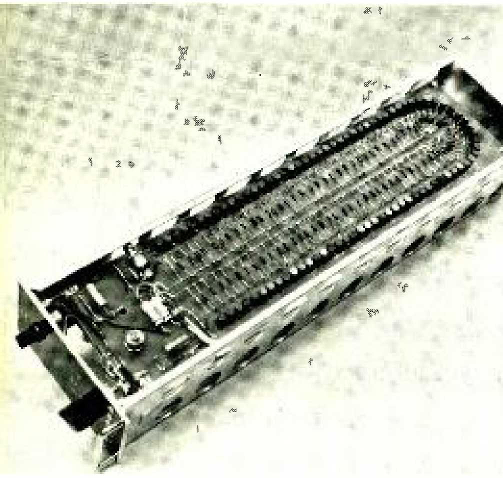


Fig. 4—ATC delay module showing 84-section variable delay line.

ured to set the delay for the next TV line. Head switching in RCA recorders is located during the horizontal sync pulse; therefore, the trailing edge of sync is used for delay error measurement by the ATC. This arrangement allows the greatest tolerance for switching pulse location.

The delay-change transient must be contained within the width of horizontal sync, because it must not interfere with the timing of the leading edge of sync (which is used by receivers) and it must not interfere with the color burst, which appears just after the trailing edge of sync (Fig. 6). It is inherent that the delay-change transient in such a variable delay line cannot be shorter than the delay of the line itself, and in practice it is longer than this because of rise time limitations in changing the control voltage to the delay line. Therefore, we split the delay line in two and provide separate control to the two parts to allow a sufficiently short delay change transient to fit within the sync pulse. Fig. 7 shows the arrangement for doing this. You will note that the delay-change transient in the resultant signal occurs ahead of the sync edge which is measured to produce the delay change. This is done by adding fixed delay (dotted in Fig. 7) in the video path before the signal enters the variable delay line.

The ATC system as described is capable of reduction of timing errors by at least 25 times (Fig. 8).

WHY COLOR ATC?

So far we have described the ATC system operating only for monochrome signals. Of course the basic action of reducing time base errors will also be in the right direction to stabilize a color signal, but there are still important limitations to color operation based on an ATC system which works only from the edge of horizontal sync. The first limitation is noise. Using the sync pulse for timing measurement of the signal provides only one sample per TV line, and a relatively wide bandwidth is needed to handle the signal. Therefore, the timing measurement will be affected by the random noise which is added by the tape recorder process, producing an effect known as *positional noise*. For monochrome purposes, the positional noise is at or below the threshold of visibility, so it is not serious; but in color it represents a substantial phase jitter which results in hue instability. For this reason, it is desirable to use the color ATC, so that the greater number of samples per TV line (due to the 8 cycles of subcarrier in the burst) and possible use of narrower bandwidth will reduce the positional noise effect.

A second problem with the use of sync pulse comparison for color is the fact that there is no specified phase relationship between the edge of sync and the color subcarrier. Therefore, the sync pulse can not be used to control the absolute phase of subcarrier. It is even possible that there can be time modulation

Fig. 5—Electronically variable delay line.

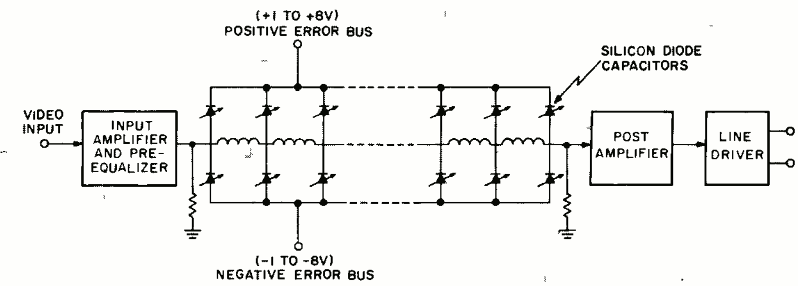
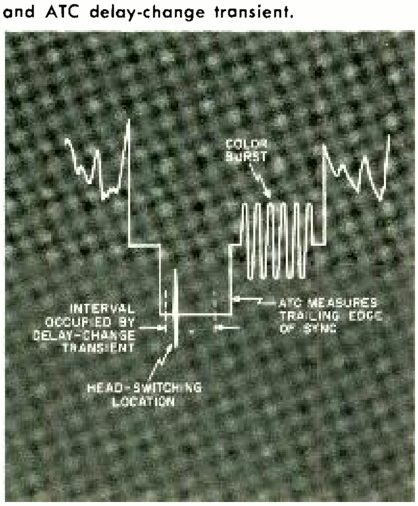


Fig. 6—Waveform of color horizontal-blanking interval, showing location of head switching and ATC delay-change transient.



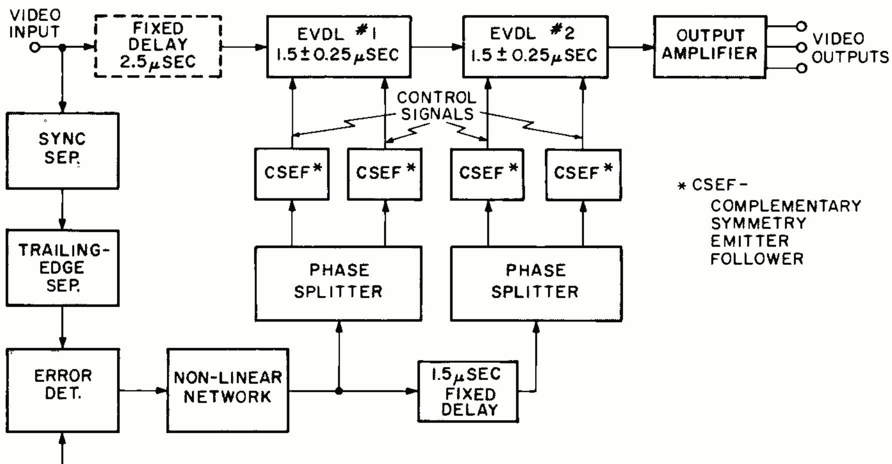


Fig. 7—The ATC, showing splitting of delay line and error driver amplifiers to shorten delay-change transient and locate it properly.

introduced between the sync pulse and the color subcarrier so that it is essential that the final color timing correction be done by comparing the phase of burst with a fixed reference.

A further problem arises because the correcting action of monochrome ATC is not perfect due to residual errors in calibration of the open loop. As stated previously, a reduction factor of 25:1, minimum, is considered practical, but this can still leave enough residual to disrupt color performance if large errors are being corrected by monochrome ATC. The cascading of the color ATC process means that any residual can be theoretically reduced by another 25:1 factor, which then makes it negligible even for color.

COLOR ATC SYSTEM

Color ATC employs the same open-loop control system which we have just described for monochrome signals. The only difference is that the error detector uses burst instead of sync (Fig. 8). The color ATC delay line is shorter, because a delay range of 360° at subcarrier frequency (0.28 μsec) is all that is needed. Because of the shorter line, it is not necessary to split it to contain the delay-change transient within the sync pulse. The NLA and driver considerations are the same as monochrome, in fact, identical circuits are used throughout.

The error detector for color ATC is substantially different and a lot more complicated. This is because it is necessary to make a phase detector with a linear range of 360° at subcarrier frequency. This is accomplished by operating the detector at half-frequency, so that the desired 360° is only 180° to the error detector (Fig. 10). Both the burst and reference subcarrier are divided by multivibrators. The divided burst is used to form narrow sampling pulses and the reference signal forms a sawtooth waveform. A special *inhibit* function on the burst path guarantees that sampling always occurs on the center half of the sawtooth waveform.

By measurement of the phase error of burst with the color error detector circuit, a control signal for the color ATC variable delay line is formed. This is able to correct the phase errors in the composite color signal and thereby stabilize the timing of the signal to provide excellent color performance. However, the job is not done, because the signal must still be passed through the processing amplifier of the tape recorder in order to clean up the blanking and sync pulses and insert a new color burst that will be free from noise. This requires special handling in order to not distort the color components of the signal.

Fig. 8—Picture monitor photos showing typical scene material a) before, and b) after ATC.

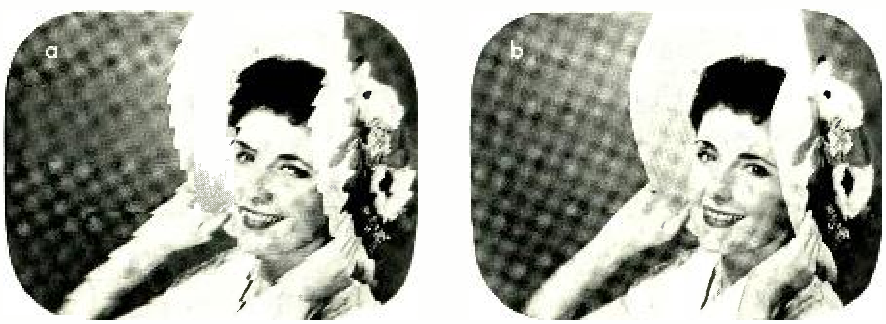
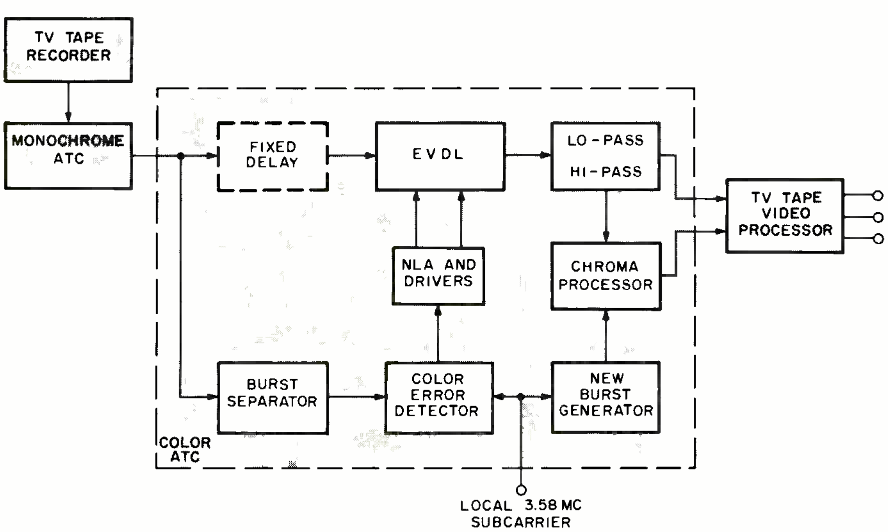


Fig. 9—Color ATC.



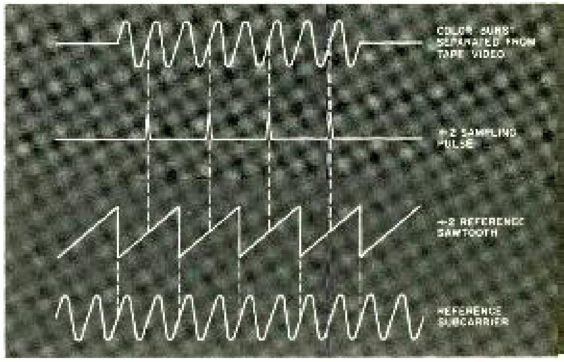


Fig. 10—Waveform of the color error-detector.

The system for processing the color signal consists of splitting the composite color signal into high-pass and low-pass components (Fig. 9). The low-pass component does not contain any color information and therefore can be passed through the standard monochrome tape recorder processing amplifier to clean up blanking and sync. The high-pass signal contains all color information and is processed by special circuits in the color ATC modules to clean up the blanking interval and insert a new burst. Then the high-pass signal is added back to the low-pass signal just ahead of the output amplifier of the processing amplifier.

CONCLUSION

Color ATC thereby provides time base correction on the tape playback signal to a residual error level of a few nanoseconds with respect to the subcarrier reference signal. This allows color tape recording with essentially no bandwidth or color response limitations. With careful operation, the TR-22 with color ATC can record and playback color program material which is indistinguishable from the original live signal.

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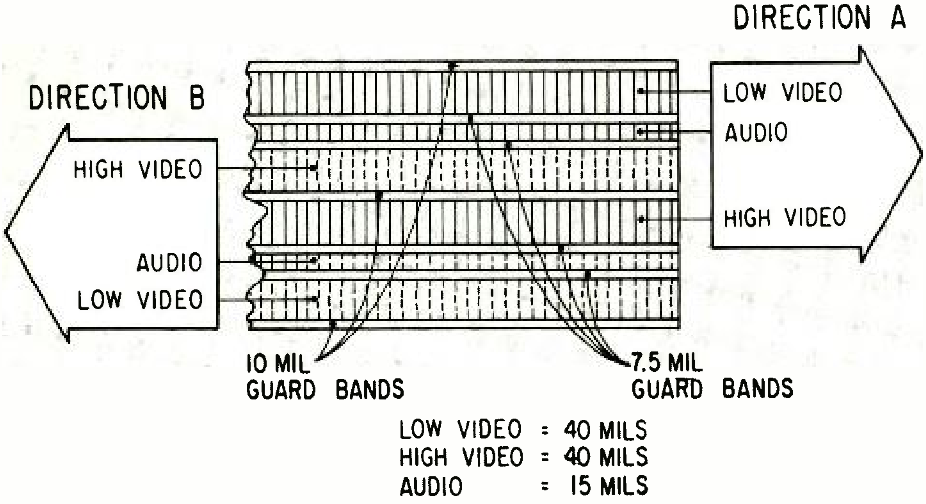


Fig. 1—Simplex track pattern recorded on ¼-inch tape.

Fig. 2—Portable video tape reproducer.

A COMPACT VIDEO TAPE REPRODUCER

This portable laboratory-model tape player reproduces both pictures and sound from prerecorded standard ¼-inch tapes. The complete player—including the transport mechanism, reproducing electronics, power supply and RF transmitter—is contained in a portable case measuring 16" x 11" x 12½". Its self-contained miniature RF television transmitter can couple the reproduced video and sound signals to any number of standard television receivers. Compactness is achieved by using a small transport, printed circuits, and transistor circuitry throughout.

W. D. HOUGHTON, S. NAROFF, and R. F. SANFORD

RCA Laboratories, Princeton, N. J.

Active research on the elements for video tape recording systems has been carried on at the RCA Laboratories for more than a decade. Early in 1956, the results of this effort were publically demonstrated in the form of a home type video tape reproducer. The term *Hear-See* was coined at that time to denote a video tape system for home use. Following this demonstration, several different types of Hear-See video tape recorders and reproducers were built as the art progressed.

Recently, a portable video tape reproducer, contained in a case measuring 16" wide, 11" high, and 12½" deep, has been developed. The reproducer (Fig. 1) was built to show how the results of research on the basic system elements can be applied to the development of a small, compact, and relatively inexpensive reproducing unit for home use. The compactness was achieved through the use of the *simplex* video tape system (Fig. 1) combined with recent developments in both the video tape electronics and the tape transport mechanisms.

The simplex video tape recording system[1] permits the use of ¼-inch-wide magnetic tape on a transport mechanism which, in many respects, is quite similar to that used in high quality audio systems. That is, the heads are stationary, the tape is driven by a capstan and pressure roller assembly, and is drawn from a payoff reel and wound onto a take-up reel. Since the magnetic heads are stationary, a relatively simple head mounting assembly is employed. This feature permits a considerable reduction in both size and complexity compared with video tape systems where the magnetic heads rotate to scan tracks across the tape.

The electronic developments include complete transistor circuitry and the use of a miniature, transistor type, television transmitter which can be adjusted to any one of the lower VHF channels.

The use of transistor circuitry contributes greatly to the reduced size of the player and the miniature television transmitter provides a simple means for connecting the signals reproduced from the tape to the antenna terminals of any standard television receiver by coaxial cable, twin lead or an air path consisting of a simple antenna system.

The mechanical developments in the tape transport mechanism include the use of a single hysteresis synchronous motor and a brake-shoe arrangement with a mechanical feedback control. The motor is coupled to the tape drive capstan through a mechanical isolator and to the take-up reel through a belt and slip clutch assembly. The brake-shoe arrangement provides a constant hold back tension on the tape as it is drawn from the payoff reel.

SIMPLEX RECORDING

Since a description of the playback unit entails a discussion of the signals recorded on the tape, a brief outline of the simplex method of recording is in order.

The term *simplex* is a name given to the magnetic recording system in which the video signal is recorded along the length of the tape by stationary recording heads. This term is used to distinguish it from the quadraplex system[2] in which the video signal is recorded across the width of the tape by a rotating, headwheel assembly, and the helical-scan system[3] in which complete fields are recorded on a diagonal track across the width of the tape by a rotating-head arrangement.

Fig. 1 shows how the signals are recorded on the tape by the laboratory model Hear-See Simplex Recorder. As in audio tape recording systems, two separate recordings can be made on the tape by reversing the direction of the tape travel. That is, after a recording is made on half of the tape in one direction, the tape can be removed from the takeup reel shaft, placed on the payoff reel shaft, and a second recording made on the other half of the tape. The arrows show the tracks that are placed on the tape for each direction of tape travel and the numbers show the widths of the associated tracks and the spacing between tracks.

The video tracks are recorded by a magnetic head containing two separate elements with gap lengths of 40 microinches each; the audio track is recorded by a separate audio head containing a single element with a gap of 100 microinches. The different track widths (Fig. 1) are determined to provide the maximum signal-to-noise ratio with guard bands wide enough to prevent intertrack crosstalk.

Frequency modulation is employed in the recording of the audio and the low-frequency portion of the video band because at the 120-ips tape speed, considerable signal amplitude variations result from unevenness in the tape coatings, magnetic particle clumping and irregularities in the head-to-tape contact. The use of frequency modulation permits the use of clipping and limiting to greatly reduce the effects of these disturbances.

The high-frequency portion of the video signal is recorded directly on tape in order to take full advantage of the maximum head-to-tape response. That is, by recording the high video frequencies directly on the tape the highest frequency reproduced from the tape is used to contribute to the finest detail portions of the reproduced picture. If a carrier were used to record the higher frequencies, a considerable loss in high-frequency detail would result because the carrier would of necessity have to be higher than the highest frequency in the signal. Furthermore, since the high-frequency video band contains only the fine detail portions of the picture such as edge transitions and closely spaced line patterns, the effects of small-signal amplitude variations are not particularly noticeable in the reproduced picture.

Another consideration is that the tape-and-head combination exhibits a transfer characteristic that has a rapidly falling amplitude with increasing frequency. To compensate for this, it is necessary to provide an equalizing network which has a gain characteristic that increases with frequency. Thus, when the reproduced signal is equalized to a more or less constant amplitude the noise has a rising characteristic which appears as a fine-grain pattern in the reproduced picture. Although this noise is noticeable, it is not deleterious until the highest frequency signal-to-noise ratio falls below approximately 10 db.

If a single track were used to record the entire video band on a carrier, then the final picture resolution would be considerably lower for the same tape velocity because the carrier would require a minimum signal-to-noise ratio of 35 db for an adequate low-frequency video signal-to-noise characteristic. This requirement would cause the carrier frequency to be set at a value considerably below that of maximum system response. Furthermore, the highest video frequency would be limited to a value between 50% and 75% of the carrier to maintain an adequate signal-to-intermodulation beat ratio. Thus, for a single track carrier arrangement the speed would have to be increased to a value considerably higher than 120 ips to obtain the same resolution that is now possible in the two-rack system.

REPRODUCING SYSTEM

Audio

As shown in Fig. 3, the carrier, reproduced from the tape by the audio playback head, is amplified by a two-transistor low-noise input amplifier. The signal from the input amplifier is further amplified and then limited in a four-stage diode type limiter. The signal from the limiter is detected by a counter type detector and the audio is selected from the detector output by a lowpass filter. The recovered audio is connected to the sound section of the RF transmitter by a single transistor audio amplifier.

Video

The video section is divided into two parts—*high video* and *low video*—as shown in Fig. 4.

The high video chain contains a two-transistor low-noise high-frequency preamplifier, which amplifies the video band extending from 300 kc to over 2.5 Mc. The preamplifier output is then coupled to a seven-transistor equalizing amplifier with a gain characteristic that rises with increasing frequency. This network is set to have a characteristic that is the exact inverse of that of the signal reproduced from the tape. The equalized signal is then fed to one input of a three-transistor video adder stage.

The 600-kc signal from the low-frequency track is also amplified by a two-transistor low-noise transistor preamplifier. The amplified carrier plus sidebands is then coupled to an equalizer which provides an overall flat response from 150 kc to 1.3 Mc. This band is equalized to insure that the FM carrier and its sideband components have a constant amplitude characteristic to prevent the following limiter stages from introducing unwanted phase distortions into the signal. The output from the equalizer is coupled to a four-stage diode-type limiter and the limited signal is coupled to a two-transistor multivibrator-type frequency doubler.

The frequency doubler elevates the carrier and its sidebands above the 10-cps-to-300-kc modulation band to

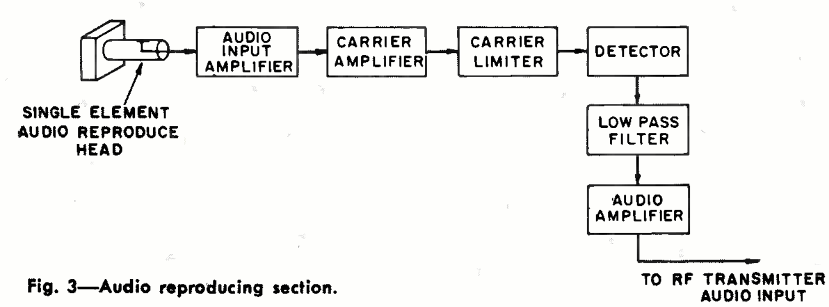
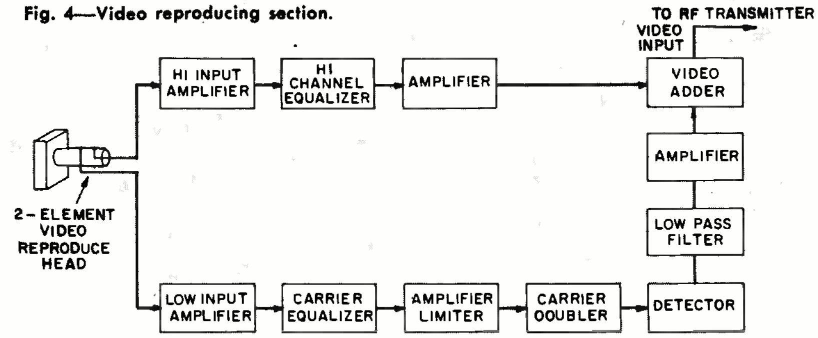


Fig. 3—Audio reproducing section.

Fig. 4—Video reproducing section.



WILLIAM D. HOUGHTON joined the Research and Advanced Development group of RCA Communications, Inc. in 1940 and was transferred to the RCA Laboratories in 1942. From 1940 to 1942, he was assigned to a Television microwave relay research project and from 1942 until 1950, he specialized in time dimension multiplex communications system research at the Rocky Point, New York Laboratory. In 1950 he was transferred to RCA Laboratories, Princeton. Since 1952, he has been a group leader responsible for research on home type video tape systems. Mr. Houghton holds 39 U. S. patents, and has received two individual and two group RCA Laboratories "Achievement Awards." He is the author of several published articles on time dimension multiplex and video tape recording systems. Mr. Houghton is a member of the IEEE, Sigma Xi, and the Acoustical Society of America. He has been active in IEEE activities serving as treasurer, vice chairman, and chairman of the Princeton Section.

SEYMOUR NAROFF joined the Terminal Facilities Laboratory at RCA Communications, New York in 1941, and transferred to the Laboratories Division Communications Section at the same location in 1943. Here, he was responsible for the design and development of numerous electromechanical devices. Besides the work in communications systems, he also designed devices for special projects such as TV Film scanning systems, the RCA BIZMAC, and military systems such as the VOFLAG, TYPHOON and KILLER contracts. In 1956 he was transferred to the RCA Laboratories. He took part in the development of the JANUS II satellite demonstration equipment, and designed the mechanical portion of a radar recorder for the WADC PRESSAR system. From 1959 to the present he has been a member of the video tape group of the Acoustical and Electromechanical Research Laboratory. Here, he has designed and built various tape transport mechanisms for home type video recording systems.

ROBERT F. SANFORD received his BSEE from the University of Arkansas in 1954. From 1952 to 1954 he assisted at the University Research Center as an associate engineer. In June 1954 he joined the RCA Laboratories in Princeton. After his training program, his permanent assignment was with the Special Systems group on color TV. In March of 1958, he transferred to the Acoustical and Electromechanical Research Laboratory where he has been assigned to video tape systems research. During 1961 he developed the heterodyne demodulator for use in testing the quadruplex color tape machine (for which he received an RCA Laboratories "Achievement Award"). Since that time he has been active in the development of transistorized circuits for small compact video tape machines. Mr. Sanford is a member of the IEEE and is presently Business Manager of the local IEEE Publication "P.S.".

prevent undesired beats between the lower carrier components and the higher modulation frequencies at the detector output. The 10-cps-to-300-kc band from the counter-type detector is then selected by a four-element low-pass filter network, and the output from the filter is coupled to the second input on the transistor adder by a single-transistor video amplifier stage. The output from the adder, which covers the video band from 10 cps to 2.5 Mc, is coupled to the video input of the RF transmitter.

RF Transmitter

Fig. 5 shows the elements in the miniature four-transistor VHF television transmitter. As shown, the audio frequency modulates an oscillator with a 4.5-Mc center frequency. The frequency modulated 4.5-Mc carrier is then added to the 10-cps-to-2-Mc video band in a video adding network. The output from the video adder is used to amplitude modulate the output from a crystal oscillator which oscillates at a frequency equal to half the desired channel frequency. The output from the amplitude modulator is then doubled to produce the RF television signal.

The output from the transmitter is coupled to a coaxial connector so that a shielded line may be connected between the tape reproducer and the antenna terminals of any number of standard television receivers. Satisfactory RF tests have been made when the reproducer was connected to the television receiver by means of a pair of rabbit ear antennas.

Power Supply

The power supply (Fig. 6) is a silicon-diode bridge rectifier followed by a transistor regulator set to maintain the voltage at 20 volts-DC. The ripple voltage is 2 mv and the regulation is within 0.2 volts from zero current to 200 ma. The total current drain of the entire electronic unit is 160 ma. and the total power input to the unit is 150 watts.

TAPE TRANSPORT

Fig. 7 shows the elements in the tape transport mechanism. The 1/20-hp hysteresis synchronous motor is used to drive both the capstan and the take-up reel. The capstan and its flywheel are

Fig. 5—RF transmitter section.

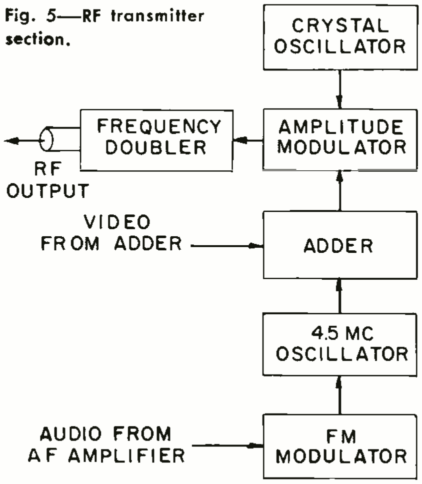
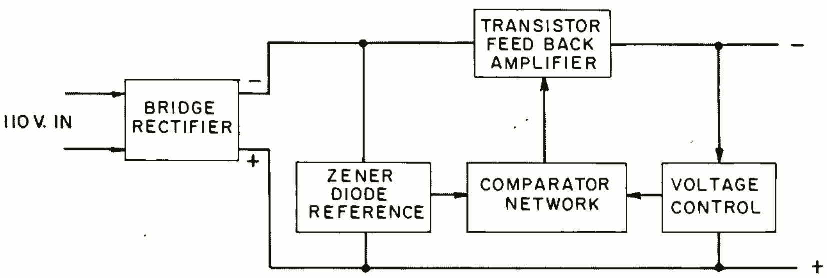


Fig. 6—Power supply.



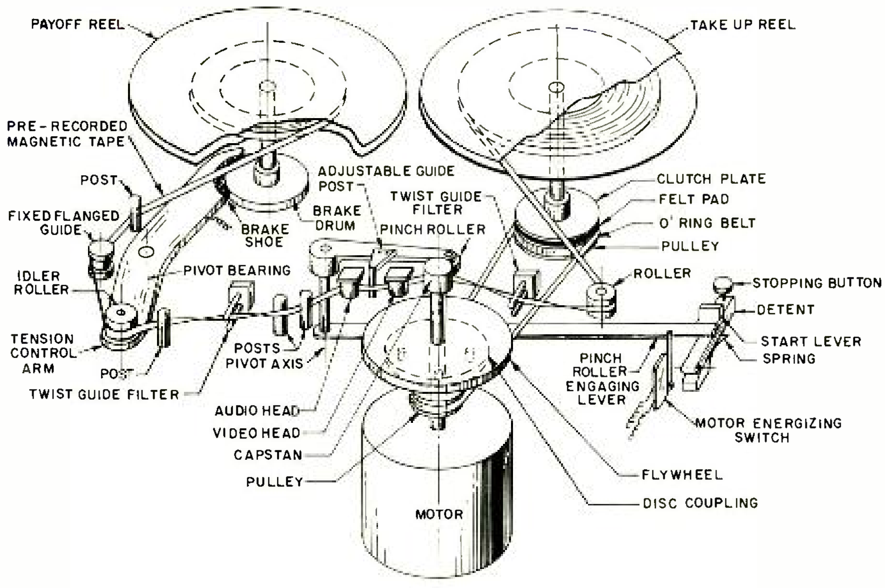


Fig. 7—Tape transport mechanism.

driven through a flexible disk-type coupling by the motor which has a speed of 3,600 rpm (or 60 rps) which coincides with the television field rate. The capstan circumference is made 2 inches in order to move the recorded tape past the magnetic pickup heads at 120 ips. The takeup reel is driven by a neoprene *O*-ring belt from a pulley on the motor shaft to a pulley on a spring loaded felt pad slip clutch mounted on the reel spindle.

The belt offers sufficient isolation so that reel vibrations are not reflected back to the capstan. The pulley ratios are such that the takeup reel tries to pull the tape slightly faster than the capstan delivers it. Thus, the clutch slips slightly at the start and this slip increases as the tape builds up and the rotational velocity of the take up reel decreases.

The guiding arrangement consists of twisting the tape 90° between pairs of guide posts set parallel to the tape deck as shown in Fig. 7. These posts guide the tape, at a fixed distance from the deck, and over the reproducing heads. The compliant nature of the twisted tape also acts as a mechanical filter which tends to absorb high-frequency tension variations.

To maintain a constant tension on the tape as it passes over the reproducing heads, a mechanical brake and feedback control unit operates to place a variable torque on the payoff reel. This is accomplished by the brake drum, the brake shoe assembly, and the tape loop around the idler roller on the tension control arm.

The operation is as follows: if the tape tension tries to increase, the tape loop shortens thereby moving the control arm in a manner such as to reduce the brake action of the payoff reel.

In order to drive the tape, a rubber pinch roller, mounted on a lever arm, presses the tape against the capstan. The pinch roller is moved to the drive position by sliding the start lever which is manually operated and held in place by a detent. The lever also actuates a microswitch which starts the drive motor. To stop the tape, during or at the end of a run, a pushbutton is depressed which unlocks the detent, releases the lever and removes the power from the motor.

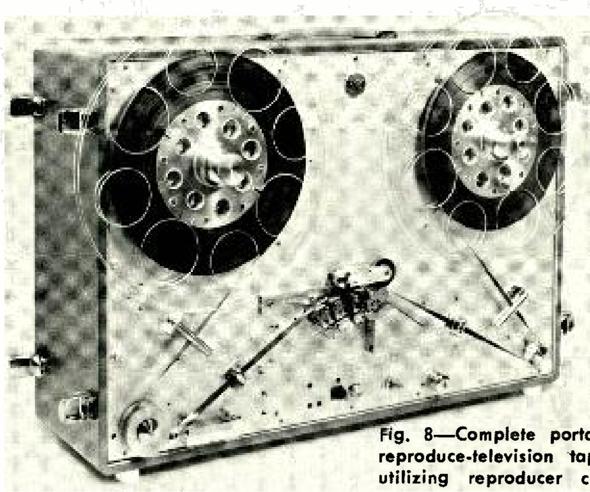


Fig. 8—Complete portable record-reproduce-television tape recorder utilizing reproducer circuitry described in this article.

CONCLUSIONS

The objective of this development was to show that the elements for a home type video tape unit are now available. It remains to be seen if the ideas and techniques incorporated in this unit are adaptable for a mass item commercial market. Fig. 8 shows the most recent development in the form of a complete, portable recording and reproducing system. The reproducing circuitry for this unit is identical to that described above for the portable reproducer.

ACKNOWLEDGEMENTS

It should be appreciated that the developments reported here represent some results of a research and development program in magnetic recording which was initiated at the RCA Laboratories a number of years ago, and that the work is, therefore, dependent on the contributions made in various ways and at various times by our associates in this endeavor. We also gratefully acknowledge the continuing interest and support of Dr. Harry F. Olson, Director of the Acoustical and Electromechanical Research Laboratory of the RCA Laboratories.

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LABORATORY SIMULATION OF INTERACTION BETWEEN THE SOLAR WIND AND THE EARTH'S MAGNETIC FIELD

A controlled plasma—magnetic-field interaction has been achieved, the conditions of which are such as to generally fulfill the scaling considerations of some aspects of geophysical phenomena. The preliminary measurements indicate the sweeping action on a magnetic field by a moving plasma; the formation of a magnetic cavity; the stand-off of plasma; a quasi Van Allen belt whose drift westward can be suggested as a ring-current mechanism; and a polar trapping region. The correlations between the laboratory observations, geophysical measurements, and related theories, where possible, show no serious discrepancies as yet.

Dr. F. J. F. OSBORNE, Dr. I. P. SHKAROFSKY, J. V. GORE

Research Laboratories
RCA Victor Company, Ltd., Montreal, Canada

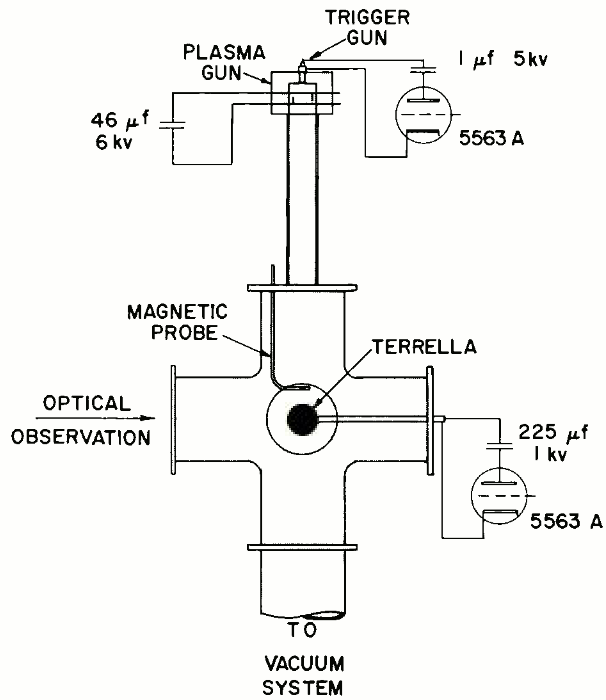


Fig. 1—Configuration of simulation apparatus.

MODERN rocket technology has opened a new era in the exploration of space by permitting measurements *in situ*, as contrasted with the earlier work where measurements were confined to the earth or its atmosphere. These early measurements have provided considerable information on the earth's space environment and led to formulation of a variety of theories[1-5]. Although these theories often have some areas of accord they, in general, vary widely in the physical processes invoked to account for the observations. In short, no present-day theory can successfully explain all the geophysical observations.

With the data obtained in recent years from more extensive "ground" observations and from rockets and satellites, extensive modifications of these theories have resulted, but the diversity amongst the various views remains. This is not surprising in a situation as complex as the earth's outer environment. The ultimate tests of these or other theories must come in comparison with detailed measurement made in space.

Aside from the high cost of space probes, there are other problems. The earth's environment is not controlled and indeed is subject to fluctuations of both random and cyclical natures. While in the past, terrestrial measurements of these fluctuations have provided a great deal of our information on space, they also result in wide ranges of variable in space measurements. The design of definitive experiments involves not only the selection of the parameters to be measured and instrumentation to handle the ranges of these variables, but also the determination of the orbit parameters.

LABORATORY SIMULATION

To aid in the design of the experiment recourse may be made to the laboratory where experiments are on a more or less controlled basis. Since the turn of the century, laboratory simulation of geophysical phenomena has contributed to the development of the theories. Two situations have made laboratory investigations of even greater interest: the advances in plasma physics with the related technology; and the data from space probes better defining the basic space conditions to be simulated.

Laboratory simulation can only be useful if the experiment resembles the situation in nature by retaining the same physical processes (or those postulated), and if the resulting information can be extrapolated back in one form or another to the natural situation. Table I shows some of the parameters involved in various regions of space as compared to those of a typical laboratory simulation. The changes of many orders of magnitude are indicative of the problems.

A detailed study of the scaling possibilities shows that a complete reduction from nature to the laboratory scale obeying all the laws of simultude is far beyond present technology, but under carefully controlled conditions, certain physical processes in selected geophysical phenomena are susceptible to laboratory investigations. One example of this is the interaction of the plasma from the sun or solar wind with the earth's magnetic field.

INTERACTION PHENOMENA

The sun continuously emits a plasma or a neutral flow of charged particles which has been termed the solar wind (or occasionally a solar-breeze). As this rapidly moving plasma encounters the outer fringes of the earth's magnetic field, its magnetohydrodynamic properties enable it to sweep the field before it. As the wind forces its way forward compressing the field as it moves, the plasma encounters higher fields. Finally, the plasma kinetic pressure is balanced by the magnetic pressure and the plasma flow can penetrate no further. In this way, the total magnetic field of the earth is confined by the solar wind into a cavity which is pushed in on the windward side and elongated on the side away from the wind so that it takes the form of a teardrop. This region is often called the *geomagnetic cavity* or the *magnetosphere.*

When the solar wind "gusts" (increases suddenly), the geomagnetic cavity is compressed, as is the magnetic

TABLE I—Comparison of Parameters Found in Nature and in Laboratory

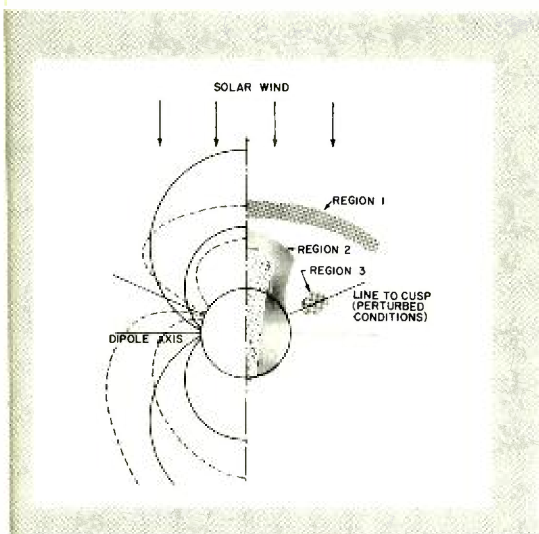
Parameter	*Characteristic Length,* cm	*Charge Particle Density,* cm/sec	*Particle Velocity,* cm/sec	*Magnetic Field, Gauss*
Galaxy	10^{22}	10^{0}	—	10^{-6}
Magnetosphere	10^{10}	10^{1}	10^{7}	10^{-3}
Ionosphere	10^{9}	10^{3} - 10^{6}	—	10^{-1}
Laboratory	10^{0}-10^{1}	10^{12}-10^{15}	10^{6}-10^{7}	10^{3}-10^{5}

TABLE II—Scaling Considerations

Parameter	*Values in Space*	*Desired in Laboratory*	*Obtained in Laboratory*
Ambient Pressure of Neutral Density, mm-Hg	10^{-18}	2×10^{-4} max	10^{-5}
Electron or Ion Density, cm^{-3}	50	10^{13} min	2×10^{13}
Streaming Velocity, cm/sec	10^{8}	2×10^{6} min	10^{6}
Electron Temperature, °K	10^{5}	4×10^{4}	4×10^{4}
Uniform Length of Stream, cm	1.5×10^{13}	10 min	5
Radius of Terrella, cm	6.37×10^{8}	3	3
Magnetic Field at Surface of Terrella, Gauss	0.311	2×10^{3} min	2×10^{3}
Thickness of Interface Transition Region, cm	5.3×10^{4}	0.62	1.2
Radius of Cavity on Sunlit Side, cm	$5.14\ R_E = 3.28 \times 10^{9}$	$2.24\ R_E = 6.72$	$2.5\ R_E = 7.5$
Total Time for a Geomagnetic Storm, sec	10^{5}	10^{-2}	6×10^{-5}

field. The magnetic field at the earth's surface shows a rapid increase, termed the sudden commencement, which is the first characteristic of a magnetic storm. The sudden commencement lasts some minutes, followed by the initial phase of some hours where the field is above normal. The following "main phase" is a long period (hours) where the magnetic field is below the normal value. The reason for this behavior is that the storm action has set up a reaction in the "ring currents" surrounding the earth which try to push the cavity walls out. Because the observer is inside these rings, the reaction appears as a reduction in field. Finally, as the storm subsides, the reaction also decays slowly, and in the "recovery phase," the field returns to normal.

Fig. 2—Plasma-magnetic-field interactions observed experimentally are given on the right-hand side. The solid curves on the left-hand side are the unperturbed magnetic field lines and the dashed curves are estimated perturbed magnetic field lines.



SCALING CONSIDERATIONS

The rather extensive scaling considerations are only summarized here. In order to simulate the solar wind as a magnetohydrodynamic medium, one has to eliminate electron-neutral collisional effects and electron-ion collisions have to be reduced sufficiently for resistivity effects to be negligible and to yield, as a result, a high magnetic Reynolds number. A few ion-ion collisions are, however, favorable to make the thermal pressure isotropic. To minimize gradient effects in the flow, the wind has to be uniform over a sufficient length. Also, the ion kinetic pressure should be greater than its thermal pressure. To simulate the interface between the solar wind and magnetosphere, the magnetic field must be sufficiently strong to give a reasonably large cavity and to make the radius of curvature of the magnetic field lines at least comparable to the ion cyclotron radius. Within the interface, some electron-ion collisions are permitted which will increase its thickness, but ion-neutral and ion-ion collisions must be avoided.

Most of these conditions have been met in this experiment, as shown in Table II. The major deviation from the desired conditions is in the *plasma duration* (total time that the wind acts). The scaled time of 0.01 second is based on a linear time scaling of a magnetic storm. The actual plasma duration in the laboratory of 10 to 100 μsec implies that only the sudden commencement and a portion of the initial phase of the magnetic storm is scaled, but this is not a necessary consequence. If the physical processes involved in the reaction are rapidly generated compared to the interaction time of the wind and field, the whole storm may be simulated with a distorted shorter time scale.

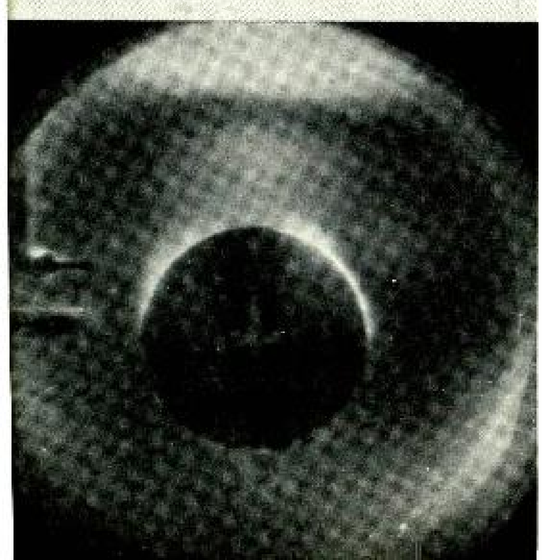


Fig. 3—Photograph of interaction — visible bands across terrella. Westward motion is down the near surface facing the observer. Polar discharge region is visible near the right-hand (north) pole.

LABORATORY EXPERIMENT AND DIAGNOSTICS

Fig. 1 shows the general experimental configuration. The model solar wind is a moving plasma generated by a shock tube driven by a 325-joule capacitor band and triggered by an integral button gun. Streak photographs indicate a plasma velocity V of 10^6 cm/sec and show that the wind is in the nature of several discrete "gusts", super-imposed on a lower density steady wind. The peak electron density N is approximately $2 \times 10^{13}/cm^3$ as measured by a multiple probe transmission diagnostic system operating[6] at 35 Gc. The model earth, or *terrella*, is of 3-cm radius R and is located in a chamber of 15-cm diameter. The pulsed terrella magnetic field is a three-dimensional dipole of magnitude $B_o = 2$ kilogauss (kG) at the equator with a time constant such as to be sensibly constant for about 1 msec, long compared to the shock duration. The measurements of magnetic field are made by small search coils, the outputs of which are integrated and presented on oscilloscopes. Additional measurements have been made using double probes—actively to give relative plasma density and passively to detect voltage gradients.

The visual interaction is recorded by time-exposure photography using both black and white, and color films. Narrowband optical filters and diffraction grating studies have been used to resolve ion species in various interaction regions. Some of the diagnostics have been illustrated previously[7]. In much of this work the wind has been seeded with NaCl. The base pressure of the entire system is about 5×10^{-6} torr.

PLASMA STAND-OFF AND MAGNETIC CAVITY FORMATION

Fig. 2 is a composite sketch summarizing the photographic evidence regarding the various visible discharge regions.

A time-exposure photograph (Fig. 2, Region 1; Fig. 3) reveals a luminous band whose stand-off distance (measured from the terrella center to the interface) depends on magnetic field. For a stand-off distance r of 8 cm, the thick-

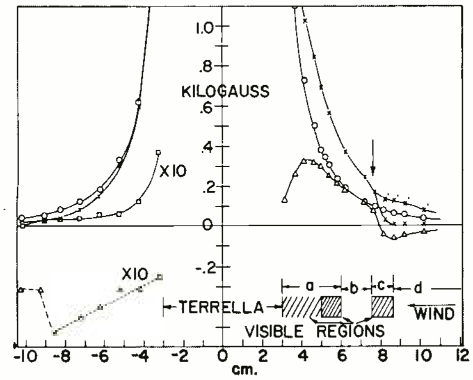


Fig. 4—Magnetic field measurement along line joining the terrella centre to the gun. Data points: o, unperturbed terrella field; x, perturbed field, boundary at rest (greatest penetration); x', perturbed field showing only the maximum initial increase or sweeping action (boundary in motion); Δ, difference between the net "rest" perturbed fields and the unperturbed fields; □, difference between the swept and unperturbed fields. Arrows indicates theoretical stand-off position. Curves marked ×10 are expanded on a 10-fold scale. The wind is incident from the right.

ness of Δr of the visible band is approximately 1.5 cm.

Magnetic-probe measurements have been made in the equatorial plane in the direction joining the gun and the center of the terrella. For purposes of discussing the measurements, the windward side of the terrella is considered in four regions (Fig. 4). From the terrella surface outward to 6 cm (Region a) the magnetic field increases at the time of arrival of the plasma as shown in Fig. 5a. This increase is associated with the action of the plasma sweeping the magnetic field lines to the geomagnetic cavity.

Region b (Fig. 4), 6 to 7.5 cm: The increase in magnetic field is such as to double the unperturbed field. It is interesting to note that space measurements by Cahill and Amazeen[8] show a double increase, while theory (Midgley and Davis[9]; Slutz[10]) predicts a factor of 2.82.

In Region c, 7.5 to 8.5 cm, the initial increase in magnetic field occurs before the moving boundary has reached the probe. This is followed by a rapid decrease as the magnetic field boundary is swept by, indicating that the compressed field boundary is inside this region. This behavior is shown in Fig. 5b. This region approximately includes the visible standoff. Near 7.5 cm, the perturbed magnetic pressure is equal to the wind pressure. Neglecting thermal-pressure effects, the standoff distance in earth radii is given theoretically by:

$$\frac{r}{R} = \frac{(\alpha B_o)^{1/3}}{(4\mu_o NMV^2)^{1/6}}$$

Where: $\alpha = 2$ denotes the experimentally measured doubling of the magnetic field. M is the mass of the ions and μ_o the permeability of free space. This yields $r = 8$ cm. Including the thermal pressure reduces this to $r = 7.7$ cm, the approximate position of the inner boundary. Although thermal effects can displace the boundary nearer the terrella, the thickness of the transition is determined mainly by electron-ion collisions for these experimental conditions. This collisional broadening can be thought of as diffusion, or leakage, of magnetic field lines, and is given by Colgate[11] as $\Delta r = \eta/\mu_o V$ where η is the electron-ion resistivity. Inserting the constants, one obtains approximately:

$$\Delta r[\text{cm}] = \frac{10^{13}}{V[\text{cm/sec}]\ T^{3/2}[^\circ\text{K}]}$$

This yields an electron temperature T of 4.6×10^4 °K for the magnetically observed transition region of 1 cm.

Beyond 8.5 cm, in Region d, after the initial increase the subsequent decrease is sufficient to nullify the resultant field. The initial increase (approximately a factor of 2) arises from the magnetic field swept past the probe and it is followed by the null value as the cavity forms closer to the terrella. This zero-field region appears to correspond to the space outside the geomagnetic cavity.

There is marked similarity between these data and those[8] from EXPLORER XII except for the space measurements showing an erratic field outside the cavity proper.

On the leeward side, the magnetic field near the terrella shows a slight initial increase followed by a decrease in net value. The magnitude of the field increase diminishes rapidly with distance from the terrella, whereas the subsequent field decrease is nearly constant up to 10 cm beyond the terrella. Measurements beyond this distance are hindered by fluctuations in field not associated with the interaction proper.

In all regions, the field returns to its initial unperturbed value after the plasma wind subsides.

QUASI VAN ALLEN BELT

In addition, a second visible discharge (Region 2, Fig. 2, Fig. 3) is observed surrounding the poles on the terrella surface and lying along the magnetic field lines joining these regions. The outer boundary of the plasma lying in the magnetic field lines is about 1 cm within the standoff and the band is about 1 cm thick. The form of this belt is such as to suggest it is an analog of the Outer Van Allen belt, although the mechanism responsible may be different. This visible region exhibits a well defined minimum latitude on the terrella surface and in some circumstances a maximum latitude as well. If the dipole is reversed (Fig. 6) the discharge does not cross the visible side of the terrella, although careful examination shows a weak luminosity at the belt position coming from the leeward side of the terrella. Thus it may be shown that the visible motion of plasma across (or around) the terrella is westward suggesting a westward moving ring current. Streak photographs show further that the azimuthal velocity is about a factor 3 lower than the wind velocity (0.5×10^6 vs. 1.3×10^6 cm/sec).

Recourse to the scaling considerations indicates that the ion motion should be westward but at a considerably lower velocity (a further factor of 6) if the guiding centre motion ideas were applicable. The scaling also indicates that the magnetic field associated with this ring current should be less than 1 gauss or undetectable with the presently used techniques. Examination of the magnetic field plot Fig. 4 shows that in the equatorial plane this inner belt is near, but outside, an amplitude peak in the field perturbation.

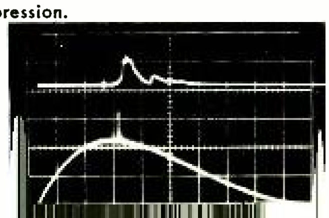
As indicated previously, the principal scaling applies to the simulation of the solar-wind–magnetic field interaction, i.e. the *standoff region.* It is quite possible that the magnetic field of the ring current is detectable. An intensive investigation regarding this point is under way with encouraging, but as yet inconclusive results. If such a field is measured it would indicate that the main phase of a magnetic storm is detectable although it is unclear whether the mechanism producing the main phase is related and properly scaled to that in space.

The use of probe measurements in the vicinity of the terrella has shown that the electric and magnetic field within these belts have a periodic component at a discrete frequency near 1 Mc. This has been tentatively likened to a similar effect observed in space probes in the kilocycle region which scales with the magnetic field. This area is also being studied further.

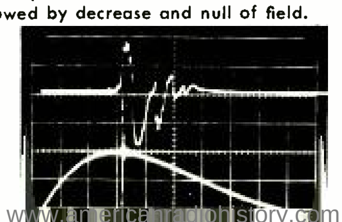
The mechanisms involved in the pro-

Fig. 5—Magnetic field interaction records; upper trace, 20 μsec/cm; lower trace, 0.5 msec/cm.

5a—near terrella showing field increase by compression.



5b—beyond stand-off showing initial increase followed by decrease and null of field.



DR. FRELEIGH J. F. OSBORNE was educated at the Royal Canadian Naval College (1946-48); obtained his BSc at McGill University in 1950 and was awarded his MSc at Laval University in 1951. In 1954 he received a DSc from Laval University. He joined the Research Department of Canadian Marconi Company in 1954 as a Senior Physicist. In 1956 he was made a supervisor. He then transferred to the Electronic Tube Plant, where he developed an S-band electron beam parametric amplifier. In January 1961 he joined the Research Laboratories of RCA Victor as a Senior Member of Scientific Staff. He has since worked on plasma diagnostics, plasma loaded microwave structures, and laboratory geophysical simulation. He was active in the Royal Canadian Navy (Reserve) from 1946-1956, is a member of the Canadian Association of Physicists, the American Physical Society, and is listed in "American Men of Science."

JOSEPH V. GORE received a BA from the University of Saskatchewan in 1960. During 1960 and 1961 he conducted research on the development of a plasma betatron. In 1961 he was awarded an MA from the University of Saskatchewan. After graduation Mr. Gore was employed on the Operational Research Team, Defence Research Board, at Halifax, N.S. In the spring of 1962 he joined the Microwave Research Group of the RCA Victor Company, Ltd. Since joining the group Mr. Gore has been conducting experiments on an isotropic plasma filled waveguides and on the geophysical simulation study.

DR. ISSIE P. SHKAROFSKY graduated in 1952 from McGill University with a BSc and first class honors in physics and mathematics. In 1953 he obtained his MSc conducting his research at the Eaton Electronics Research Laboratory, McGill University. He then joined the microwave tube and noise group at the Eaton Electronics Research Laboratory and received his PhD in 1957. After graduation, he joined the Microwave Research Laboratory where he has participated in research on microwave diffraction, millimetre waves, obstacle gain, laser applications, electromagnetic wave interaction with plasmas and plasma kinetics. Dr. Shkarofsky is an associate member of the Canadian Association of Physicists and a member of the IEEE.

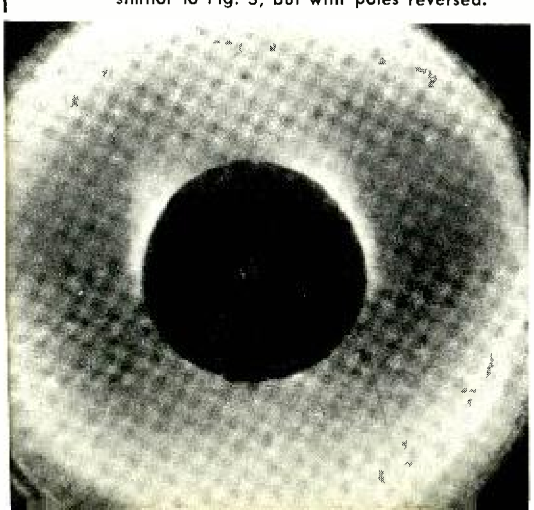
duction of these belts is unknown (as is the case in space) except that the initial injection or generation occurs to windward in the meridianal plane containing the shock source. Although the particle trajectories differ from those of the Van Allen belts in nature, the present evidence indicates that the physical processes are generally scaled and pertinent to the simulation.

POLAR DISCHARGE REGION

A number of photographs of the interaction show a separate region of weak luminosity near the N pole of the terrella but slightly to windward (Region 3, Fig. 2; Fig. 3). The recorded light is extremely sensitive to the angle between the dipole axis and the wind, and requires a slight asymmetry. It appears that this polar discharge region possibly straddles the field lines from this pole. Attempts to produce a similar region at the south pole were unsuccessful with this set up but seem to appear in recent experiments.

The angular extent of this region as measured from the terrella center is probably deceptive in that this line position fluctuates violently during the "gusts of wind" and thus blurring an integrated photograph of this type. The luminosity achieved to date is too low to permit streak photographs of this.

Fig. 6—Photograph of interaction—conditions similar to Fig. 3, but with poles reversed.



The low luminosity of this region suggests several alternative mechanisms—a low number of particles injected (as is also suggested by the sensitivity to asymmetry); a relatively poor trapping in the cusp-like magnetic field geometry; or a very short-lived trap present only during part of the perturbation.

The importance of such a trapping region, if it did exist in nature, is apparent. Such a region would be susceptible to instabilities (Chang[12]) and could provide a particle acceleration mechanism related to auroral effects. It may be noted that this region of the poles at several earth radii *has not yet been explored by satellites.*

CONCLUSIONS

First results on the behaviour of the magnetic field show excellent correlation with the theory and with space data from EXPLORER XII. In addition, the formation of visible bands across the terrella has been observed, the characteristics of which resemble in many ways the Van Allen Belts. Other features have been observed which as yet have not been identified with space phenomena.

The present program is based on a more extensive study of these and other laboratory scale phenomena using a new experimental setup. The new series of experiments are being done in a larger chamber to reduce wall effects and with changes in the shock tube and terrella coil to permit a wider range of variables. The most recent measurements show that the form of interaction is a strong function of the parameters used.

Although the discussion of geophysical phenomena based on laboratory simulation is highly speculative in nature—at least until a great deal more data is analyzed—these preliminary results indicate *that a major contribution to knowledge of the space environment can come from the laboratory.*

ACKNOWLEDGEMENTS

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TELEPHONE CHANNEL NOISE MEASUREMENTS

Many special techniques and terminologies have evolved for determining telephone speech circuit noise. This paper outlines the basic methodology and terms as now widely accepted, and discusses progress toward standardization. For further details, a bibliography of recommended reference works in this field is included.

F. M. BROCK
Microwave Engineering
Broadcast and Communications Products Division
Camden, N. J.

TABLE I—Definitions of Terms

db: Logarithmic power ratio expressed in decibels; db = 10 $\log_{10}$ (P_2/P_1). In the same impedance, decibels can also be expressed in voltage ratio; db = 20 $\log_{10}$ (V_2/V_1).

dbm: Decibels above or below 1 mw = ±dbm.

dbr: Used to refer the signal level at any point in a transmission system to an abitrary point in the system known as the point of zero relative level.

dbw: Decibels above or below 1 watt.

dbv: Decibels above or below a reference voltage of 1 volt. Normally used to define the relative level of a video signal relative to 1 volt peak-to-peak.

dbc: ("db Collins"; used by Collins Radio Co.). Decibels above or below a reference voltage of 0.775 volt-RMS; that is, the db scale on HP-400 series VTVM's.

dbx: Crosstalk coupling measurement; decibels above or below reference coupling.

dbrn: Decibels above reference noise, where the reference noise power is 10^{-12} watt, or —90 dbm at 1,000 cps. Established by the Bell Telephone Co. for measurements with 144-line weighting for noise interference measurements. Now largely superseded by measurements in dba and dbrn-Cm.

dba: Decibels above reference noise, adjusted. Similar to dbrn, except used for interference noise measurements with Bell FIA-HA1 telephone sets, and with the reference noise power at —85 dbm at 1,000 cps.

dbrn-Cm: Decibels above reference noise, adjusted for C-message circuits. Similar to dbrn except used for interference noise measurements with Bell 500 telephone sets, and with reference noise power at —90 dbm at 1,000 cps. This is the interference noise measurement term used on the new Bell Type 3A Noise Meter.

O-TLP: Abbreviation for zero-transmission-level point. A measuring point in the telephone system where the zero reference of 1 mw appears. Also known as the RTLP (reference transmission level point).

dbao: Decibels of adjusted noise interference power referred to 0 dbm at the RTLP. That is, noise of +20 dba at OTLP is +20 dbao; at a —4 db TLP, it is +24 dbao.

dbmo: Decibels of sinusoidal signal, or noise, power referred to 0 dbm at the RTLP. A signal of +7 dbm at OTLP is +7 dbmo; a signal of —15 dbm at a —15 dbr point is 0 dbmo.

psophometric voltage: Interfering noise voltage present at a measuring point in a telephone system, measured as recommended by the CCITT using a psophometer (noise voltmeter). This noise voltage is then converted into psophometric emf (equiv. noise generator emf) by considering the circuit source and load impedances referred to 600 ohms resistive. (*psophometric emf*) = 2 × (*psophometric voltage*) for 600 ohm resistive circuits).

dbmop: An interfering sinusoidal or noise power level in a telephone system measured with a CCITT standard telephone psophometer, and giving the same reading as an 800-cps tone of equal power level in dbmo.

NOTE: Interfering noise levels can also be measured psophometrically in picowatts (10^{-12} watt) by relating the psophometric emf to equivalent output power in a 600-ohm matched system.

Throughout the history of telephone communications, special techniques and terminologies have evolved for determining and measuring telephone speech circuit interfering noises and disturbances. These special techniques and terms form a "language" commonly used in the planning, design, and testing of telecommunications systems to describe the noise (or disturbance) performance of the communications facility. One of the objects of this language is to establish standards of measurements of wanted to unwanted signal powers, as well as the interfering effects of various types of noise powers, in a telephone system.

In the USA, the majority of this work has been conducted by the Bell Telephone Co., while outside the USA, where international agreements were more immediately necessary, recommended standards of telephone noise measurements and terms have been established by the CCITT (Committee' Consultatif Internationale de Telephonique et Telegraphie'). The CCITT forms a part of the International Telecommunications Union, an agency of the United Nations.

Also, various private firms manufacturing or using telephony equipments have contributed some specific terminology. Universal standardization in telephone-noise language will undoubtedly be completed in the future, but for the present a number of different terms, meters, and measurement techniques exist, and will be used for some time to come. As a starting point for this discussion of telephone-noise-measurement language, a list of the most commonly used terms and their accepted definitions is presented in Table I.

SIGNAL-TO-NOISE MEASUREMENTS

Signal-to-noise measurements in telephone systems are commonly made at the switchboard or exchange point, although any point in a telephone system can be used provided it is clearly understood by the system designer, the tester, and the user, what the point is and what measuring instruments are to be used.

For the testing of telecommunications systems involving a multichannel carrier on cable or radio paths, this point is usually selected as the 4-wire voice frequency input-output of each telephone channel and is set to be a zero transmission level point. Then, a pure sine-wave signal of 1-mw (0-dbm) power at either 1,000 cps (Bell Telephone Co.) or 800 cps (CCITT) is injected in the transmit path, and appears as ***signal + noise and distortion*** at the equivalent point in the receive path at an end terminal station. The power level of the received *signal + noise* is measured and compared with the noise power in the same channel without the signal present. Since the noise power is usually more than 30 db below the signal power, the received-signal power is considered to be only the zero-transmission-level power increased or decreased by the *transmission equivalent* (db gain or loss) of the system. Thus, the signal-to-noise measurement becomes one of measuring and categorizing the noise power present in the telephone channel.

This noise power represents an interference with the intelligibility and quality of received telephonic speech, and so must be "adjusted" or "weighted" to some base reference in order that comparisons of telephone-circuit transmission quality may be made. Not only must the frequency response limitations of the telephone set to be used be taken into account, but also the subjective interference effects of various frequencies and power levels in human speech must be considered. Investigations into these effects by the Bell Telephone Co. and by the CCITT have resulted in the noise-interference measurement terms listed in Table I and discussed below:

dbrn

The early telephone-circuit noise-interference measuring set, Type 2A (Bell), was based on a 1,000-cps tone power of 10^{-12} watt, or −90 dbm, as a calibrating reference. This noise measuring set included provision for shaping or "weighting" the frequency response of the measuring circuit to conform to the frequency response characteristics of the 144-line telephone circuits in use at that time. This weighting curve is shown on Fig. 1, where it can be seen that frequencies removed from 1,000 cps are attenuated in a pronounced manner. This curve must be consulted whenever the interfering effect (in dbrn) of frequencies other than 1,000 cps are considered. For a flat frequency band of thermal noise in a 3-kc band of power equal to 1 mw (0 dbm), the 144-line weighting reduces its effect by 8 db, or to −8 dbm.

dba

With the introduction of the Bell FIA-HA1 telephone set with increased sensitivity and bandwidth, a modified form of Bell noise-interference measuring set, Type 2B, was adopted, with a new reference noise at 1,000 cps of 3.16 × 10^{-12} watt or −85 dbm. (This was occasioned by the 5-db-higher sensitivity of the FIA-HA1 telephone set.) Also,

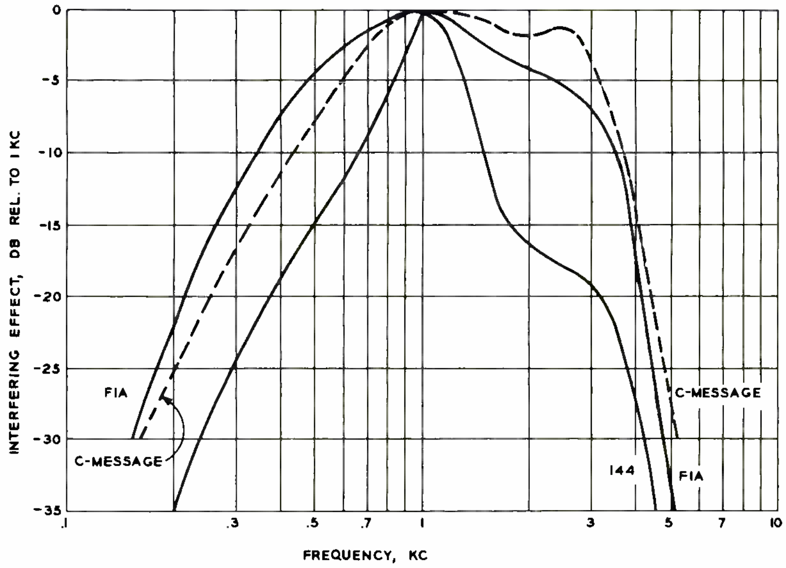


Fig. 1—Telephone circuit frequency-weighting curves.

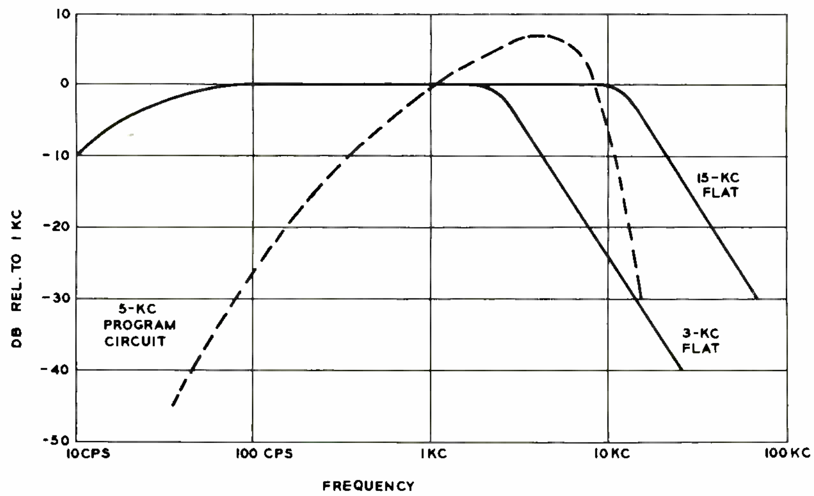


Fig. 2—Additional Bell Telephone Co. weighting curve.

FRANK M. BROCK graduated in 1950 from the University of Alberta, Canada, with a BSEE. He received his MSEE from the University of Pennsylvania in 1962. Following graduation in 1950, he spent a year on the G.E. Test Course with the Canadian General Electric Co. in Canada, and then joined the Electronics Dept. of C.G.E., working on radar and microwave communications equipment. In 1953 he joined the Microwave Engineering Dept. of RCA in Camden, N. J., to participate in the design and development of frequency division multiplex communications equipment and systems. From 1954 to 1957, Mr. Brock was involved in the original development program for the AN/GRC-50 radio relay equipment, in the areas of local service telephone system practices and circuits, and feedback amplifier design. From 1957 to 1960, he contributed to the design of custom multiplex and data equipment, intermodulation noise test sets, and special communications systems wave filters. During 1960 and 1961, he acted as the Project Engineer for the development of the CT-42 solid state FSK telegraph data equipment, and is presently engaged in the development of precision wave filters and networks for communications systems. Mr. Brock is a Registered Professional Engineer of the Province of Ontario, and a member of the IEEE, the IEEE-PGCT, and the IEEE-PGCS. He holds two U.S. patents.

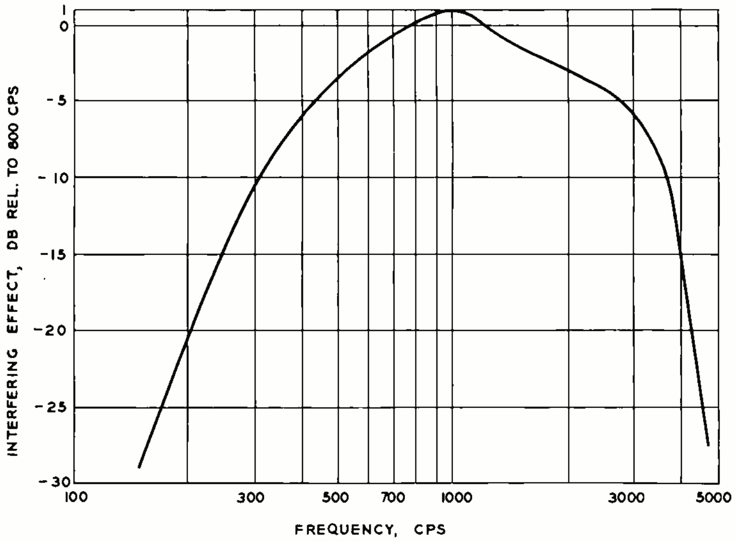


Fig. 3—CCIF "A" telephone circuit frequency weighting curve ("CCIF Recommendations," Vol. III, 1954).

the frequency response of the FIA-HA1 circuits was greatly improved, per the curve marked *FIA* on Fig. 1. Thus, noise frequencies distributed across the 300-to-3,000-cps audio range would have more interfering effect, and in fact the effect of a flat band of thermal noise in a 3-kc band of power equal to 1 mw (0 dbm) is reduced by 3 db, or to −3 dbm. Noise measurements made with the Type 2B noise meter, in *db above reference noise*, are relative to a reference power of −85 dbm, when the noise interference is a 1,000-cps tone. For randomly distributed or for "flat" noise spectra, the FIA weighting is applied to give an effective reference power of −82 dbm. Table II shows various measurements of noise and tone powers in dbrn, dba, and flat weightings.

C-Message Waiting

The latest (1960) Bell noise measuring set, the 3A, provides a new frequency "weighting" network denoted *C-message weighting*. This primarily resulted from the improved frequency response of the Type 500 set, and increases the interfering effect of distributed noise frequencies. In the interests of standardization, the older reference noise level of 10^{-12} watt (−90 dbm) at 1,000 cps is used; however, the wider frequency response of the C-message weighting affects readings of random or "flat" noise powers, and again if a flat 3-kc band of thermal noise of power equal to 1 mw (0 dbm) is considered, its effect is reduced by only 1.5 db, or to −1.5 dbm. The C-message weighting curve is shown on Fig. 1, and level readings in *dbrn-Cm* are included for comparison in Table II. Note that all measurements (other than those of 1,000-cps power) in dbrn *must* include a note as to the weighting used that is, *dbrn-144* or *dbrn-Cm*.

Psophometric emf or Psophometric Voltage

Psophometric noise voltages are read on a psophometer, the CCITT standard noise meter. This instrument is very similar to the Bell meter, the weighting network characteristic (*A* filter, CCIF Recommendations 1954) being almost identical to that for the Bell FIA weighting. The CCIF *A* weighting curve is shown on Fig. 3. If the circuit is other than a 600-ohm matched circuit, the noise voltage measured V_m must be corrected to the reference impedance (i.e.: For a matched circuit impedance of R ohms, the corrected noise voltage V is:

$$V = V_m \sqrt{\frac{600}{R}}$$

The noise or psophometric emf is twice the noise voltage in a matched-impedance circuit. Noise power can also be expressed directly in 10^{-12} watts (picowatts) for psophometric measurement by relating the psophometric emf to the equivalent output power in a 600-ohm matched system. If the measured system is 600-ohm matched, the psophometric voltage can be directly converted to noise power by the curve in Fig. 4.

TEST METERS

All of the noise test meters previously discussed operate in basically the same manner. A linear amplifier with flat frequency response provides the proper input impedance for circuit termination (usually 600 ohms) and sufficient measuring sensitivity for low noise levels; an adjustable attenuator sets this sensitivity and is followed by a frequency "weighting" or filtering network, a square-law detector, and a decibel-calibrated meter of standard integration time (200 msec for 99% response). The square-law detector ensures that a power measurement is obtained, and since the noise measured will be of random fluctuating or impulsive waveform, the integrative time of the meter must be standardized so that readings can be compared. Other frequency weighting networks may be used in the Bell 2B and 3A noise meters to provide:

3-kc flat weighting
15-kc flat weighting
5-kc program circuit weighting

Fig. 4—Psophometric voltage versus noise power in picowatts and dbm (600-ohm circuit).

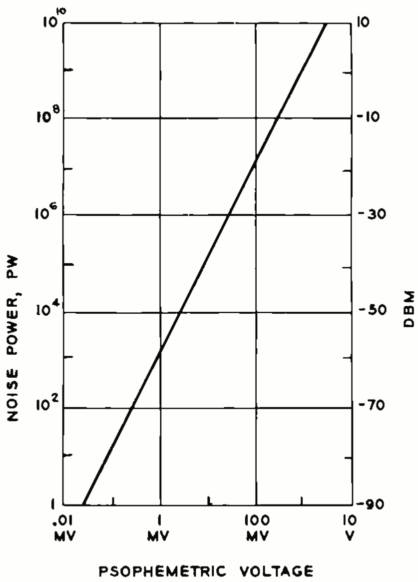


Fig. 5a—Noise (in dba) measurement example with transmission equivalent (TE) of 0 db; thus, signal = 0 dbm, noise = + 20 dba, and S/N = 65 db (FIA).

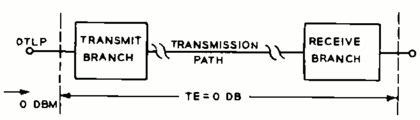
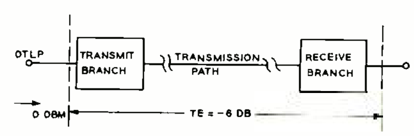


Fig. 5b—Noise (in dbrn-Cm) measurement example with transmission equivalent (TE) of −6 db; thus, signal = 6 db = 0 dbm, noise = + 18.5 dbrn-Cm, and S/N = 65.5 db (Cm).



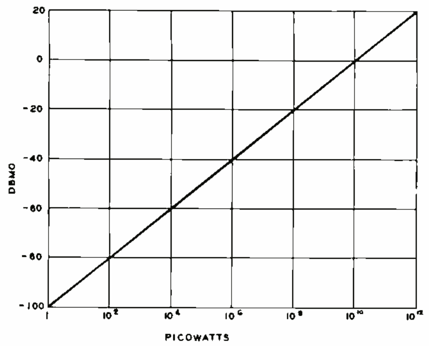


Fig. 6—Simple relationship of dbmo versus picowatts.

TABLE II—Various Measurements of Noise and Tone Powers

Flat 3 kc Band of Thermal Noise dbm	Noise Meter Measurement			Equiv. dbm		
	dba	dbrn	dbrn-Cm	dbm FIA	dbm 144	dbm C-message
0	82	82	88.5	—3	—8	—1.5
—10	72	72	78.5	—13	—18	—11.5
—20	62	62	68.5	—23	—28	—21.5
—30	52	52	58.5	—33	—38	—31.5
—40	42	42	58.5	—43	—48	—41.5
—50	32	32	38.5	—53	—58	—51.5
—60	22	22	28.5	—63	—68	—61.5
—70	12	12	18.5	—73	—78	—71.5
—80	2	2	8.5	—83	—88	—81.5
—82	0	0	6.5	—85	—90	—83.5
—88.5	—	—	0	—91.5	—96.5	—90

Response curves for these weightings are shown on Fig. 2. The program and 15-kc circuit weightings are used for noise measurements on special wide-band telephone circuits designed to carry music as well as speech. The 3-kc flat weighting could be used for noise measurements on telephone channels intended solely for digital data or facsimile transmission.

SYSTEM NOISE MEASUREMENTS

As an example, a telephone system noise measurement test is shown in Fig. 5, with typical levels. Calculation of channel signal-to-noise ratio, or more commonly, *weighted noise at the zero transmission level point,* would proceed as follows:

1) *Test level at 1 kc at ZTLP* = 0 dbm = 0 dbmo
2) *System transmission equivalent between terminal ends indicated* = 0 db
3) *Output test level at 1 kc* = 0 dbmo
4) *Idle channel noise at end terminal, on Bell 2B meter* = +20 dba
5) *Equivalent "interference" power* = —85 +20 = —65 dbm = —65 dbmo
6) *Idle channel signal-to-noise* (FIA) = 65 db

Now change conditions:

1) *Test level at 1 kc at ZTLP* = 0 dbm = 0 dbmo
2) *System transmission equivalent* = —6 db
3) *Output test level at 1 kc* = —6 dbm = 0 dbmo
4) *Idle channel noise, on Bell 3A meter* = +18.5 dbrn — Cm
5) *Equiv. "interference" power* = —90 + 18.5 = —71.5 dhm
6) *Idle channel signal-to-noise (Cm) at —6 dbm point* = —71.5 + 6 = 65.5 db.

System channel noise power can also be expressed directly in picowatts if the measured noise is converted to dbmo and the graph of Fig. 6 used to convert dbmo to pw. This method of expressing telephone system noise performance has advantages for the system designer in that noise power contributions (weighted) from many parts of the system, or system links, may be directly summed to obtain the overall end-to-end expected noise performance.

A convenient graphical method to display the telephone channel noise power relations of Table II is shown on Fig. 7. (This graph was supplied through the courtesy of Dr. R. Guenther, DEP Communications Systems Division, Camden). Fig. 7 also gives telephone-speech volume relationships for telephone sets using the T1 transmitter.

CONCLUSION

This discussion has presented an outline of basic telephone noise measurement terms and techniques. Progress and change towards standardization is continuing, and for current information and additional details on recommended techniques and conditions for specific noise measurements, the interested reader should consult the following bibliography.

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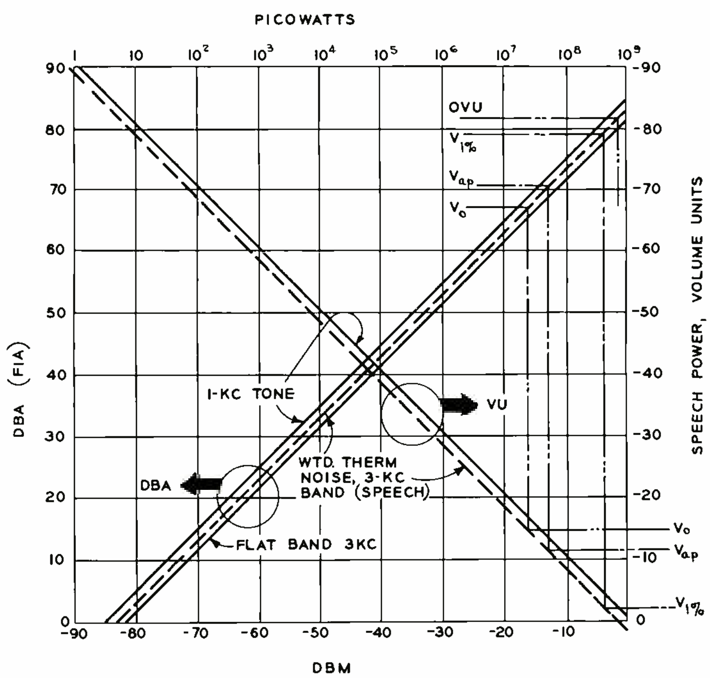
Fig. 7—Relations between 1,000-cps tone power, thermal noise (flat) power, and speech power in a telephone channel. V_o = average volume talker; V_{ap} = volume of RMS talker; $V_{ap} = V_o + 0.115\sigma^2$, where σ = standard deviation; $V_{1\%}$ = volume of less than 1% of talkers.



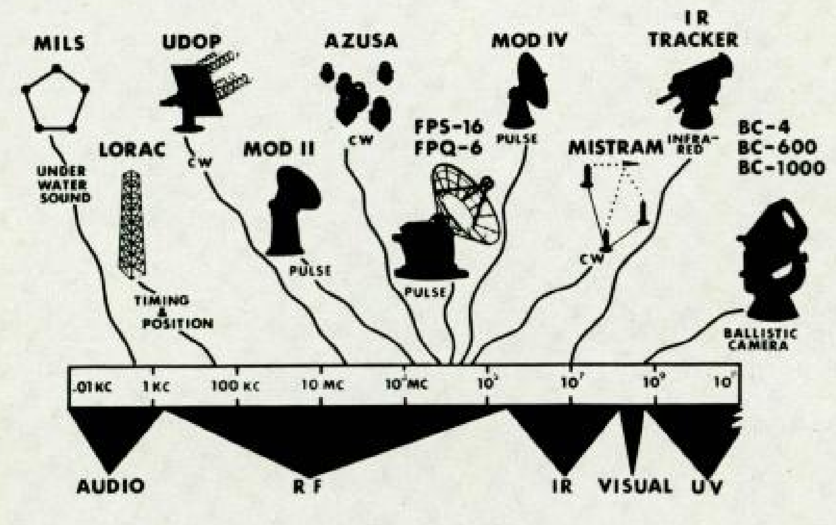


Fig. 1 — Frequency spread of tracking instrumentation.

SOME TRENDS IN ADVANCED RANGE INSTRUMENTATION

Missile and space systems have undergone spectacular development during the past decade. Missile range instrumentation has likewise been undergoing a technical revolution to keep pace with the fast changing test and evaluation requirements. These changes have an important influence on RCA both as technical operator and manufacturer of range instrumentation. Recent trends in metric accuracy requirements, systems configuration, propagation limitations, survey accuracy, error adjustment, system control, and calibration are briefly examined in this paper.

DR. L. E. MERTENS, Staff Scientist
Missile Test Project
RCA Service Company, Patrick Air Force Base, Florida

DR. L. E. MERTENS received his BS and MS and Doctor of Engineering Science all in Electrical Engineering from Columbia University. In 1953, he joined RCA's Advanced Development Section in Camden, working on mathematical analyses, and circuit design. In 1954, Dr. Mertens transferred to Aviation Systems Department and was responsible for systems analysis and planning on airborne fire control, missile guidance, and bombing and navigation systems. In 1957, he joined the ASD Chief Engineers' staff to become responsible for initial feasibility studies on a new approach to interception of satellites in orbit. In 1958 Dr. Mertens joined the staff of the Chief Defense Engineer and assumed coordination of applied research and advanced development programs. In 1959, he transferred to the Surface Communications Division to become Manager of Digital Communications Equipment Engineering. Recently, he moved to the RCA Service Co. as Staff Scientist at Cape Kennedy. Dr. Mertens is a Member of IEEE; American Ordnance Association; the New York Academy of Sciences; Sigma Xi and Tau Beta Pi.

A WIDE VARIETY of instrumentation is employed at the missile test ranges to acquire, transmit, record, process and analyze data on missile and space flights as well as for a multitude of support tests. Major functions of the range instrumentation include providing:

1) Trajectory information for post flight analysis.
2) Trajectory information in real time for range safety, impact prediction, and backup control and guidance functions.
3) Missile performance information.
4) Missile cross section or signature information.

These functions are accomplished with many types of data gathering instrumentation employing operating frequencies spanning the region from audio to ultraviolet as shown in Fig. 1. Even within the so called electronic instrumentation or radar category there is a wide spread of operating frequencies from UHF (400 Mc) through x-band (10,000 Mc). A wide diversity also exists in the system configurations and operating principals such as pulse radar, CW interferometer, doppler radar, trilateration networks, etc. This situation makes any broad generalizations as presented in this paper a necessary but nevertheless hazardous undertaking.

Range instrumentation has been undergoing continuous improvement to meet increased performance requirements brought about by expanded space missions, the need for higher accuracy missile guidance and the requirement for enhancing missile penetration probabilities. These factors have in turn necessitated expanding to global coverage, extending tracking range, increasing metric accuracy, enhancing system resolution and multi-target capability, and measuring target return signal amplitude (Fig. 2).

The Atlantic Missile Range (AMR) has met these requirements by acquiring certain major new instrumentation systems such as MISTRAM, GLOTRAC, MIPIR radars,[1] and ARIS ships as well as by modifying existing instrumentation systems such as the FPS-16, AZUSA and UDOP. Data processing has also been heavily involved.

METRIC ACCURACY

Metric accuracy has increased many fold in the past few years and is expected to increase even further in the near future. The need for highly accurate ve-

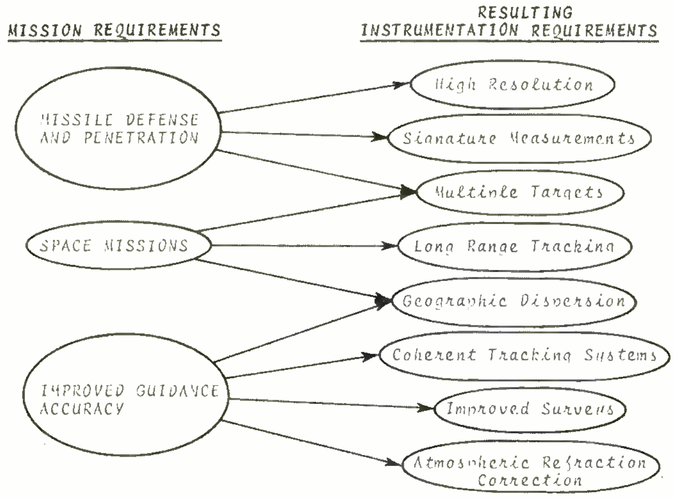


Fig. 2 — Mission requirements and resulting instrumentation requirements.

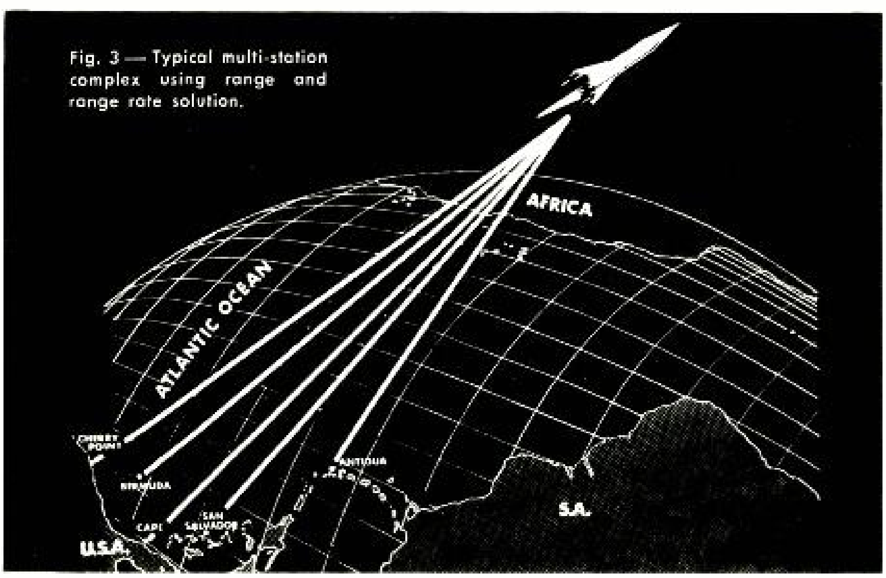


Fig. 3 — Typical multi-station complex using range and range rate solution.

locity information is illustrated by the fact that a velocity error of one foot per second at missile burn out could result in a *one-mile error* at impact on a typical ballistic missile trajectory. Position errors, while important, are relatively less critical in most applications, since a one-foot error in position at burn out would result in only about a one-foot error at impact. While position errors per se may not be critical, it must be remembered that obtaining *vector velocities* to a given accuracy requires obtaining position accuracies of the same order.

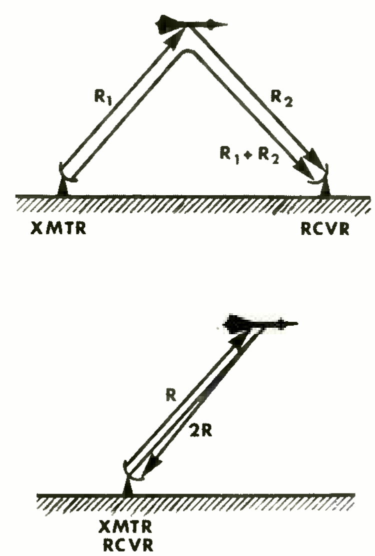
Instrumentation design engineers have developed such excellent new data acquisition systems that major error sources are now, to a very large extent, external to the system hardware. Propagation anomalies, survey errors, and even the uncertainty in the true speed of light in vacuum are now considered as some of the more significant error sources (Table I).

The requirement for velocity accuracy on the order of 1/10 foot per second (or only a few parts per million) is the most difficult to achieve of the current metric requirements.

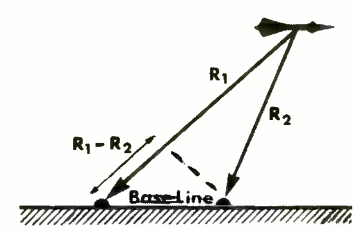
To achieve this high accuracy in velocity, the trend has been toward coherent radar systems having very long baselines and operating at high microwave frequencies. MISTRAM, a new CW interferometer system, for example, employs x-band radiation and has baselines of 10,000 and 100,000 feet. Even longer baselines are likely in the future. A trilateration type of solution (i.e., the GLOTRAC system) using range and range rate with baselines on the order of 1,000 miles will be introduced soon (Fig. 3).

Fig. 4—Basic pulse and continuous wave radar measurements.

a,b) range sums



c) range difference



d) arrival angle

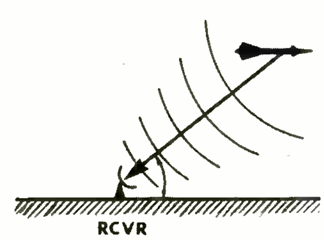


TABLE I—Effects of Several Error Sources External to the Instrumentation

Error Source (External)	*Effect on Data (approx.) ppm*
Uncertainty in velocity of light in free space	1
Uncorrectable refraction errors	Up to 20
Survey	1 - 40

Coherent CW radar systems measuring range sums (UDOP) or range differences (AZUSA and MISTRAM) have conclusively proven their abilities to produce very smooth tracking data with very small random type errors (Fig. 4). Smooth position data is of course very desirable when it is differentiated to provide velocity and acceleration. Coherent systems, however, are not without problems. Principal problems include resolution of the data ambiguities and stability of the baselines. By their very nature, CW systems are highly ambiguous so multiple frequencies and multiple baselines have been used to resolve these ambiguities. When atmospheric conditions vary over the baselines or the target transponder characteristics vary slightly over the transmitted frequency range there will be a problem with calibration stability and ambiguity resolution. Special techniques for electronic baseline stabilization and adjustment for atmospheric refraction have been developed. Much further research and engineering is required in this area if future metric accuracy goals are to be met.

Many of the advantages of the CW coherent radar systems can also be achieved in coherent versions of pulse radars. A pulse doppler modification for pulse radars has been analyzed and proposed by RCA's Missile & Surface Radar Division. Coherent pulsed radars in a trilateration network can achieve required velocity accuracies as well as retain the backup capability of skin tracking in the event of beacon failure or absence. They can also independently range and angle track should other radars in the trilateration network fail.

THE SURVEY PROBLEM

The significant trend to long baseline and multi-station instrumentation systems necessitates a very high degree of survey accuracy for the baselines, and between sites in a tracking complex. The accuracy of existing Atlantic Missile Range geodetic surveys varies from about one part in thirty thousand to better than one part in a million. The lower accuracy surveys generally are in the downrange areas with higher accuracy surveys on the Florida mainland. This means, for example, that there are geodetic uncertainties of several tens of feet with respect to the Bahama Island area, and uncertainties of several hundreds of feet with respect to far downrange stations such as Ascension. While survey accuracy requirements vary from station to station and from one instrumentation to another, it is generally conceded that range survey accuracy up to about 1 part in 500,000 will be needed to calibrate future tracking systems.

A similar situation exists in determining the position of instrumentation ships. Instrumentation ship locations currently may be in error by as much as a mile or more. The more recently developed instrumentation ships, such as the ARIS ships, employing a more sophisticated navigation equipment are expected to have a navigational error on the order of 1,500 feet in the downrange areas. While this navigation accuracy is adequate for present applications, considerably better accuracies (approximately 100 feet for relative locations) will be required in the future if the ships are to be used in high-accuracy, multi-instrumentation networks.

Extensive work is now being planned to improve the geodetic surveys, particularly in the downrange areas. Rocket and satellite observations present one of the best potential approaches for improving geodetic accuracy.[2] The technique is based on the use of several ballistic cameras to simultaneously observe a vehicle-borne light. The position of one or more of the cameras then can be found through triangulation when the position of several of the remaining cameras are known. In this way, a high-precision baseline along the Florida mainland can be used to interconnect surveys of the downrange islands. Electronic instrumentation can be used in place of the ballistic cameras.

PROPAGATION PROBLEMS

Atmospheric propagation errors represent an important and fundamental limitation to the tracking accuracies of our best electronic systems. The refraction effects of the troposphere can and are being compensated for to a very large degree. For many years the atmosphere has been studied and vast amounts of data exist on the vertical distribution of the index of refraction. Ray tracing analysis to determine refraction effects is made using either averages of this accumulated data or using measurements near tracking time made by airborne refractometers, or other meteorological equipments. It has been found that a small (several percent) but significant error remains in these computed corrections. It is this error which presently forms a fundamental limitation to our tracking accuracy. This limit has been reached in several of our new high accuracy electronic tracking systems such as MISTRAM. The magnitude of the refraction effects depends, of course, on weather and tracking geometry and is particularly severe at low elevation tracking angles (where the line of sight transverses considerable distance in the dense lower atmospheric regions). The higher frequency components of the refraction errors can often be effectively filtered. There exists, however, a low frequency cyclic error on the order of 0.1 cycle per second that is particularly troublesome and for which satisfactory compensation methods have not been developed.

The ionosphere introduces tracking errors in addition to those previously discussed for the troposphere. The ionospheric errors, however, are frequency dependent and tend to diminish toward the microwave region. This factor has been one of the motivations toward the use of higher operating frequencies in tracking systems. At present only the UDOP system operating at 450 Mc appears to be seriously affected by ionospheric conditions.

Considerable improvement in our understanding of propagation in the atmosphere and improving refraction corrections is urgently required if we are to make further advances in tracking accuracies.

ERROR ADJUSTMENT

The previous discussion has been principally concerned with the data acquisition aspects of our range systems. The data reduction techniques employed to process the tracking data, however, are just as important in influencing the overall metric accuracy. In addition to smoothing the data to reduce the effects of random or noise-like errors it is desirable to determine and adjust for various low frequency and bias errors. This latter function requires considerable knowledge of the tracking system error model. When there is sufficient redundant tracking data from several systems with favorable geometrical aspects, the error model coefficients can be determined and subsequently used to eliminate or reduce errors in the tracking data. An example of this process is the BET, or *B*est *E*stimate of *T*rajectory, employed at the Atlantic Missile Range. The BET uses data from pulse and CW Radars, as well as certain precise optical instruments. At present the BET employs only a simple linear error model for the various instrumentations systems in making its bias adjustments. Considerable effort is being undertaken to remove limitations imposed on the error models and to improve accuracy of the error adjustment techniques. An advanced error adjustment approach is currently being developed for the new GLOTRAC system for use in near real time.

The application of error adjustment techniques in data processing has several important implications in the instrumentation systems and their design. Most important is the fact that the system error models must be well known and must be stable over reasonable periods of time. Contractors for future systems will be required to develop error models for their system concurrently with the hardware design and development effort. In addition, data processing must be considered an integral part of the overall system philosophy particularly due to the use of error adjustment. Certain applications of error adjustment techniques in the past have led to unusual and unexpected results. The actual performance achieved has often been considerably less than originally anticipated. Understanding the reasons for these difficulties has been a major analytical effort in which the geometry factors, data weighing factors, accuracy of the error model, and non stationarity of the statistical processes must be considered.

SIGNATURE INFORMATION

The target's appearance to various electronic, infrared, and optical sensors has become increasingly important for obvious military reasons. This so called signature data can be collected from many existing pulsed radars in their skin tracking mode, with only slight system modifications. To obtain the most useful signature data several specialized systems have been designed which generally feature: (a) data gathering over a wide frequency range, (b) accurate amplitude calibration capability, (c) high speed data gathering and recording, (d) high range resolution and (e) multiple target capability. Shipborne systems have been particularly useful for their obvious positioning flexibility along critical portions of the trajectory.

The quantity of data from signature systems is generally several orders of magnitude larger than the metric data alone. This has posed severe problems in data reduction which have only been partly solved at present.

CALIBRATION

When new instrumentation is delivered to the missile ranges it must undergo a thorough evaluation and calibration before it can be declared operational. The calibration effort is required to determine the system's accuracy, to isolate the sources of error, and to verify the error model for the system. As tracking systems have become more accurate, the problem of calibration has become correspondingly more difficult. The most difficult part of the problem is finding a suitable standard of reference with adequate absolute accuracy. When the highest accuracy obtainable is required to calibrate electronic systems, the Atlantic Missile Range uses the ballistic camera. The ballistic camera is, however, currently being taxed to its limits by our modern electronic systems and hence improved standards of reference or new experimental techniques will be required when additional accuracy is achieved by the electronic systems.

The use of satellites and missiles to assist the calibration effort has been proposed and is currently undergoing extensive systems analysis. The application of instrumented satellites and missiles for range instrumentation calibration can be reasonably anticipated in the next few years.

CHECKOUT and COORDINATION

All of the trends discussed indicate that future instrumentation systems will continue to grow in both complexity and geographical dispersion. These factors emphasive the need for rapid and accurate system checkout, and coordination. For example, some of the most recent instrumentation systems consist of literally hundreds of racks of electronic hardware. The failure of one component or the misalignment of one adjustment could degrade or completely invalidate the tracking data. Furthermore, considerable time and effort is currently required to perform the various maintenance checkout and calibration procedures. The increased application of automatic and semi-automatic checkout equipment is therefore inevitable. To be most effective the automatic checkout equipment must be engineered into the system as it is initially conceived.

The growing complexity and dispersion of instrumentation systems coupled with the need for quick reaction and future multiple launches makes status monitoring, coordination and control of the instrumentation systems on the range critical factors. At present, missile range status is monitored and controlled by almost completely manual means employing voice and teletype communication. The evolution of this manual system to a semi-automatic, or automatic, control system is currently being analyzed and planned. The elements and philosophy of such an instrumentation control system have many features in common with those of other military command and control systems. That is, there must be: 1) a set of sensors to measure the status and performance of the various instrumentation systems, 2) a communications network to automatically transmit this data to a control center, 3) data processing and display system to evaluate the system status, 4) a communication channel to transmit control information to the various instrumentation stations, 5) and finally a set of displays and/or control actuators to implement the various commands. The growth from a manual system to a completely automatic system will be gradual and evolutionary in nature. Heavy requirements will be placed on strong systems engineering with the objective of reducing costs, improving reaction time, or increasing the overall system effectiveness.

The vast quantities of data from many redundant tracking systems will, of course, tax the communication and processing channels. Advanced work on data compaction and source selection must be continued and expanded.

THE NEXT FIVE YEARS

Continual improvement in metric accuracy can be expected for the next few years. The system hardware itself will not be the limiting factor in most cases. The fundamental accuracy limits will be due to survey and unpredictable atmospheric propagation effects. System configuration will move steadily toward longer baselines and multistation complexes using coherent RF techniques. Data reduction will more optimally process the data using error adjustment techniques based on system error models. Signature-type data will become increasingly important requiring measurements in many frequency ranges and providing vast amounts of data to be processed. The future will see more overall systems engineering to integrate and control the fast growing complex instrumentation networks.

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EVOLUTION OF THE HIGHEST-PRECISION RADAR

. . . The Story of MIPIR

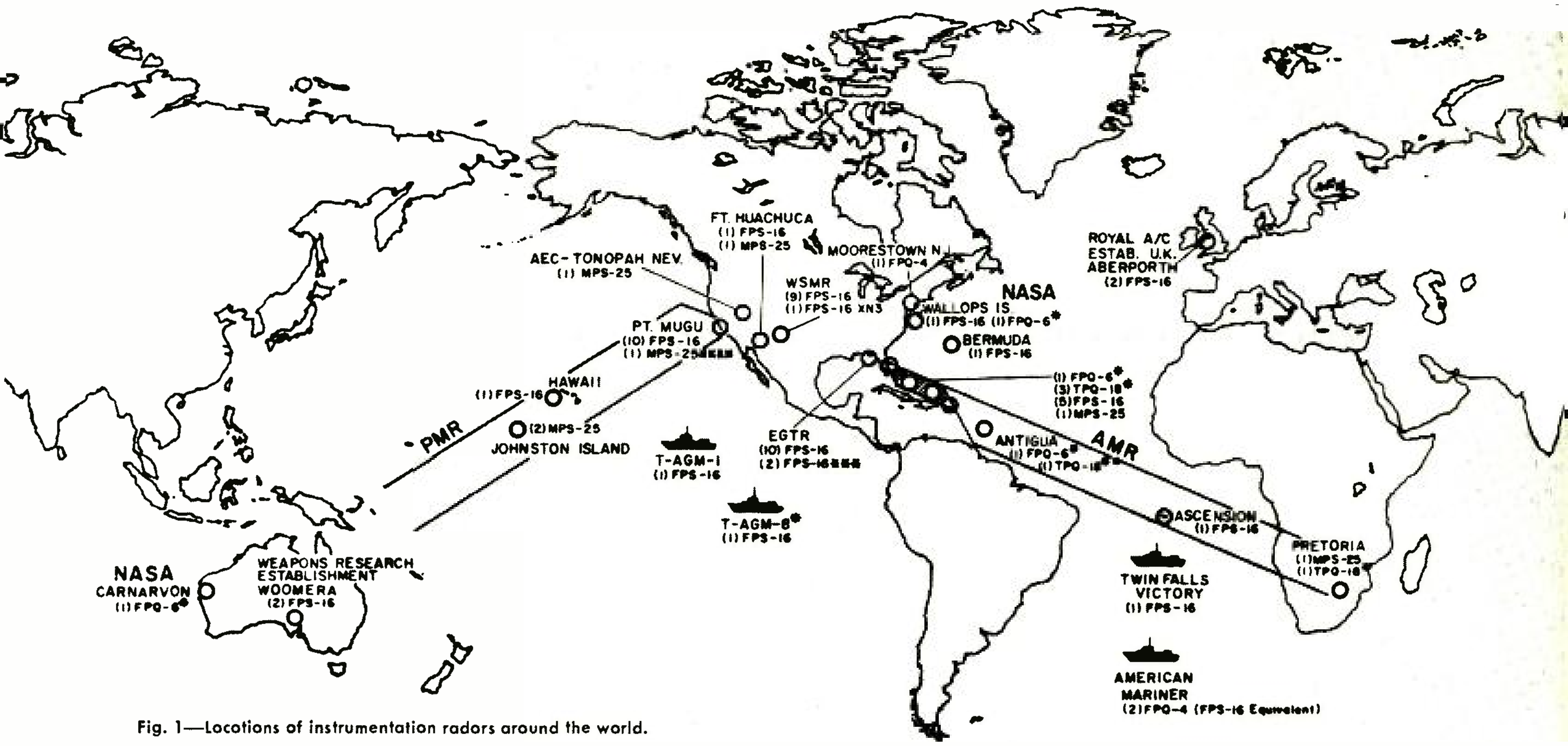

Fig. 1—Locations of instrumentation radars around the world.

Missile and space programs have presented industry with the need for ever more accurate knowledge of the location, speed, and direction of travel of the vehicle. Over the years, the pulsed radar has played a primary role in this measurement mission. This paper tells the story of the latest and most accurate of these radars: the AN/FPQ-6 and its transportable companion, the AN/TPQ-18. Collectively, these radars are known as MIPIR, MIssile Precision Instrumentation Radar.

J. W. BORNHOLDT, Mgr. and **W. J. ROSE, Mgr.**

Production Projects — *Development Systems Projects*

Range Systems Programs
Missile and Surface Radar Division
DEP, Moorestown, N. J.

In the early days of post World War II, the determination of the performance of the various missiles under test depended solely upon modified equipment originally developed primarily for anti-aircraft gun direction. These units, in particular the SCR 584, underwent modifications by each user to better meet his needs in the way of data output. By the early 1950's, the Government recognized that a radar specifically designed for instrumentation was required, and the Bureaus of Aeronautics of the Navy Department was designated the central procurement agency for all the services.

LEADING UP TO MIPIR—THE AN/FPS-16

Because of its experience in precision radar trackers for the BUMBLEBEE and TERRIER programs, RCA was chosen to develop the new radar. Early in the design phases of the TERRIER field model radar, the design was redirected with the result that the *first true instrumentation radar*, the AN/FPS-16 (XN-1)—still in service at Patrick Air Force Base—was finished in 1954. Late in 1954, BuAer and the U. S. Army Signal Corps sponsored two production prototypes of a much more elaborate version, the AN/FPS-16 (XN-2).

This procurement became the forerunner of a large number of production radars, the AN/FPS-16. This, the first precision, monopulse tracking radar developed solely for range instrumentation uses, was so successful that over 50 units are currently in operation all over the world (Fig. 1).

The development of this radar resulted in the most precise tracking radar in production in the free world, yet a unit requiring a minimum of maintenance and suitable for use over environments ranging from deserts to the very edge of tropic sea shores. In addition, the unit could be operated by one man and was designed for use in multiple-radar "chains." In this way, despite the range tracking limitations of one radar, precise data could be obtained from the instant of missile launch until the missile impact hundreds or thousands of miles away. This in turn would provide for range safety information, so critical at launch, for missile control prior to burn out, and for impact prediction and ballistic measurements.

However, it wasn't long after the first AN/FPS-16's were operational that users began to determine that their planned needs were pressing even the capabilities of the AN/FPS-16. During

WILLIAM J. ROSE, has 25 years in electronics which include 14 years in military applications of communications and tracking radar systems as a member of the U. S. Marine Corps and 9 years of activity at RCA as project engineer and supervisor in instrumentation radar and allied systems. Prior to joining RCA in 1954, he served the Marine Corps in developmental programs covering the test and evaluation of radar, radio, and other electronic items. He participated in the development of the TALOS-TERRIER guidance radar, the missile receiver and tracking beacon, and the launch computer. At RCA he became Project Engineer for the later development of the AN/FPS-16 (XN-1). He directed the conversion of this radar for use on the VANGUARD program, integrated it into the Atlantic Missile Range tracking complex, and served as radar consultant to the Naval Research Laboratory during the launching tests. He managed the program resulting in the AN/MPS-25, the trailerized version of the production model AN/FPS-16 radars. Upon assuming the responsibility of Project Leader in 1960, he was directly involved in the conception and development of the AN/FPQ-6 and AN/TPQ-18.

JOHN W. BORNHOLDT, following 1½ years with the Pennsylvania State University as a research assistant on an ionospheric physics program, joined RCA in 1951 as a design and development engineer. For the next three years, he worked on a VLF receiver, VHF automobile antennas for the New Jersey Turnpike, and TV station test equipment. In 1954, he was called to duty with the U. S. Air Force. He returned to RCA in 1956, where he was design engineer responsible for the TALOS system analog computer. In 1957, he transferred to the Range Instrumentation Group as a project engineer on the AN/FPS-16 program. Following his promotion to Leader in 1959, he was selected in 1960 to attend the first Program for Management Development at Harvard University, which he successfully completed in December 1960. Following his return to RCA, Mr. Bornholdt assumed responsibility for Project Management for the production of the AN/FPQ-6 and AN/TPQ-18 (MIPIR) radars. In 1961, he was promoted to Manager and currently serves as the MIPIR and instrumentation radar production Project Manager.

1958 and 1959, modifications improved the AN/FPS-16 in accordance with particular local requirements. During this same period, RCA engineers proposed still other improvements to the radar. Although these other proposals were well received, their implementation was delayed while the planners studied the new ground radar tracking requirements of the dawning space age.

By the end of 1959, however, the trend of actual and requested modifications became clearer. The desire for longer range, more accuracy and precision, and increased operational flexibility called for spectacular advances in the state of the art. On the other hand, the realization that such advances would be incorporated into radars carrying a heavy load of test range activity caused the emphasis to be placed on reliable, conservative, and evolutionary designs.

GROWTH OF TEST RANGE REQUIREMENTS

During this period of the inception of modifications to the AN/FPS-16, Government planning engineers were attempting to predict their range requirements for the years ahead. The coming era of satellites, manned and unmanned, planetary probes, and more complex missiles called for increased capability in almost every respect. At the Atlantic Missile Range, in particular, the requirements in early 1960 were beginning to firm up. These could be summarized as follows:

1) Higher-performance boosters placed a new premium on range safety. Not only must the impact predictions become more accurate, but they must also be made at longer ranges. This requirement, in terms of pulse radar characteristics, was eventually translated into a specification for tracking a target of 1-square-meter cross-section to a range of 300 nautical miles with a precision of 0.05 mils-RMS.
2) The synchronous satellite represented the upper limit imposed by charter upon AMR, and it required precision transponder tracking at ranges to at least 22,000 nautical miles in order to determine accuracy of location and drift rates. This drift measurement plus many other instances of targets having very low angular rates resulted in the need for a tracker with extreme smoothness in its angular serves at these very low velocities.
3) The intermediate stations on the range had to track high performance passing targets at almost any altitude, and this necessity required an instrument featuring very high antenna-mount angular velocity and acceleration capability.
4) The measurement of target trajectory to the accuracies desired meant that the basic data capability of the AN/FPS-16 had to be maintained or improved. Considerable improvement over presently existing modification kits in the area of dynamic lag error correction had to be achieved.
5) The increased mission complexity expected in the years ahead produced an operational paradox. On the one hand, faster reaction times required more automatic target acquisition and tracking features. On the other hand, the inability to predict future mission requirements with certainty called for more manual operational flexibility. Experience on the range also pointed to more reliance on operator judgment in situations where the criteria for automatic operation were unreliable.
6) The requirements for each of the various range stations resulted in specifications for an instrument having a high degree of common features with those at all other stations. Therefore operation, maintenance, and logistics considerations indicated that the same basic radar should be used at any range location.

An examination of the range safety requirements, the most stringent of those mentioned above, provides an insight to the type of equipment needed.

On the same mission involving a single target versus time, a range safety radar could be expected to have to track both *skin* (reflected echo) and *beacon* (transponder). In most circumstances, more than one radar would track the same beacon during some portion of the flight. In order to be properly received by the beacon, all radars must be on the same transmitting frequency with a high degree of assurance. While the AN/FPS-16 has a fixed tuned magnetron of 1-Mw rating, possible frequency variations among magnetrons indicate the use of a tunable transmitter.

The tunable magnetron of the AN/FPS-16 is rated at 250 kw, and the standard AN/FPS-16 on the range in 1960 had a 12-foot antenna and a receiver noise figure of 11 db. With this combination of parameters, the

AN/FPS-16 must have an IF signal-to-noise ratio of about 20 db to achieve 0.1-mil precision, and the lower curve of Fig. 2 shows that this performance is attained at ranges to 35 nautical miles when skin-tracking a 1-square-meter target. By increasing the antenna size to 32 feet and lowering the receiver noise figure to 8 db, a precision of 0.05 mils can be obtained with a signal-to-noise ratio in the IF receiver channels of 10 db. By increasing the transmitted power to 3 Mw, the desired 300 nautical miles can just be achieved as shown by the upper curve of Fig. 2. (This precision, limited by thermal noise, is a function of antenna beamwidth, signal-to-noise ratio, pulse repetition rate, and the servo bandwidth. Examinations of this and other tracking limitations are contained in the references cited in the *Bibliography*.[1-5])

This oversimplified example of the solution to the range safety problem shows the kind of reasoning applied. Similar solutions were posed for each of the many test-range situations. The final result was a radar specification representing the best compromise between requirements and previous equipment developments. Late in 1960, therefore, the Government awarded a contract to RCA to produce the radar to these specifications. As nearly as possible, consistent with the specifications, the radar was to utilize the proved designs of the AN/FPS-16 modification program. Table I shows some of the more significant characteristics of the original AN/FPS-16 compared to those of the new radars, now called the AN/FPQ-6.

MIPIR DESIGN BACKGROUND

Although originally conceived as a series of modifications to an existing AN/FPS-16 radar, it quickly became apparent that a complete new design was involved. Despite this, the initial contract was for procurement of five units, with no development, preproduction, environmental testing, or test model. Indeed, this order was shortly amended to increase the number of units to eight, and then to nine. This contract has been cited by Air Force officials as an excellent example of "concurrence"—the cutting short of all steps leading to eventual on-site full operational capability. In so doing, it required great engineering skill to permit paper designs to be released for production without incurring high costs for subsequent redesigns.

Design of the radar proceeded on this basis from contract authorization; maximum use was made of ultra-reliable component and module designs

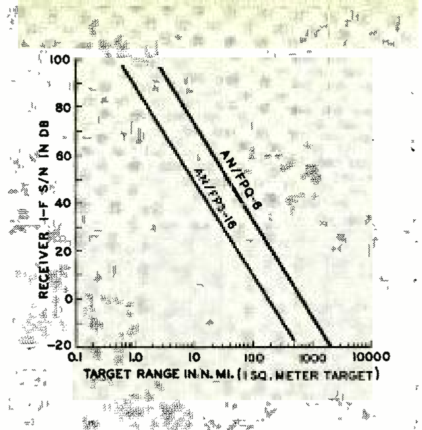

Fig. 2—Range performance.

TABLE I—Comparison of 1960 Standard AN/FPS-16 With Present AN/FPQ-6.

ITEM	*AN/FPS-16	†AN/FPQ-6
Frequency	5,400–5,900 Mc	5,400–5,900 Mc
Antenna:		
gain	44 db	51 db
size	12 ft	29 ft
feed	4-horn	5-horn
polarization	linear vertical (circular with grating)	linear vertical, circular
beamwidth	1.2°	0.4°
type	feed at focal point	cassegrain
Transmitter:		
peak pwr tunable	250 kw, nom.	3.0 Mw, nom.
peak pwr, fixed tuned	1.0 Mw, nom.	—
pulse width	0.25,0.5,1.0 μsec	0.25,0.5,1.0,2.4 μsec
pulse rep freq	Variable to 1,707 pps	160–640 pps
average pwr, tunable	250 w	4.8 kw
average pwr, fixed tuned	1.0 kw	—
output tube	magnetron	klystron
pedestal (antenna mount)		
est. total wt	18,000 lbs	125,000 lbs
azimuth bearing	ball	hydrostatic
servo bandwidth (max)	5.0 cps, nom.	4.8 cps, nom.
max tracking rate	750 mil/sec	500 mil/sec
tracking precision	0.1 mil-RMS	0.05 mil-RMS
Receiver noise figure	11 db	8 db
Range System:		
range meas capability	500 nmi	32,000 nmi
max tracking rate	10,000 yd/sec	20,000 yd/sec
tracking granularity	1 yd	2 yd

* Values common to AMR in 1960
† Present, 1963, values.

from the BMEWS system, and where applicable, the well-tried AN/FPS-16 designs were also incorporated. But major design efforts were required—including such state of art developments as the 20-bit single-speed shaft encoders that were the only feasible way to reliably provide the angular data output precisions required.

To get the required antenna gain, consistent with requirements for reduced mechanical inertias (for maximum servo bandwidth) and capability for both linear and circularly polarized operation, it became necessary to develop RCA's first production Cassegrainian antenna system. The 29-foot, 4,000-pound parabolic reflector on this antenna system is the largest such structure with static surface tolerances in the order of 0.005 inches from the nominal curve and mechanical resonances in the region of 30 cps.

Included in the pedestal design were the conflicting requirements of air transportability and subsequent field erection without degradation of precision or accuracy, the capability of providing better than 0.05 mil precision, a low-speed tracking capability of one revolution per week and an operating servo-pedestal bandwidth of 5.0 cps to allow for rapid acceleration of the mount during target tracking. The resultant antenna pedestal mount represents the current state of the art in such devices—at an overall weight of 125,000 pounds. It has been air-transported to Ascension Is, in the South Atlantic; has been shipped by sea to Australia and the West Indies; and has been trucked overland to Florida and subsequently reassembled *without performance degradation.*

In order to realize the full precision inherent in the system, it was early determined that rapid, real-time correction of the raw data outputs was required for two types of errors, *bias* and *dynamic*. The former, sometimes called *systematic*, includes such items as out-of-level pedestal positioning, non-orthoganality of the pedestal's azimuth and elevation axes, shift of the radar's antenna beam axis with frequency and with antenna position. The dynamic correction is applied to reduce the lag of the pedestal pointing position behind the target position for moving objects. The decision to do the correction digitally led to the need to incorporate a digital processor, which in turn led to the use of the RCA 4101 computer. With this unit, the above corrections can be automatically programmed into the machine prior to a mission, and the data can be transmitted from the radar either in real time, corrected or uncorrected form, merely by the radar operator pushing a button. This became then, the first radar containing an integral general-purpose digital computer.

The conflicting demands for both increased automaticity of radar operation plus increased flexibility for the operator were met by the design of the radar operator console (Fig. 3). This unit features a *T*-shaped grouping of control panels, situated so that an operator at the left can control and monitor primarily ranging functions, the operator at the right primarily angle functions, while a central crew chief will direct them both and can monitor radar performance. The console includes an RCA closed-circuit TV system monitor, with the associated camera mount on the elevation axis of the antenna pedestal, to allow for radar boresighting and visual checking of close-in-targets. Among the many operator aids is the RCA-designed video integrator, used to enhance weak signal returns to quickly differentiate them from the surrounding noise in the display for quicker target identification and acquisition. A solid state switching network gives fast system mode changes, yet represents a significant increase in reliability over the relay system utilized in the AN/FPS-16 radars.

To meet the user's needs for transportable versions of the radar, the AN/TPQ-18 was developed. This radar is functionally identical to the AN/FPQ-6 building type (Fig. 4) and is mechanically identical except for mounting frames for the various racks. In the AN/FPQ-6 there are common housings of 12 racks, while in the AN/TPQ-18 they take the form of shelters, each 8 feet wide, 10 feet high, 16 feet long. Each shelter houses a radar subsystem (receiver, servo, ranging, computer, etc.) and is self-contained to the extent of having its own air conditioning unit and primary-power input control and regulation systems. The commonness between the two types of radar has facilitated several contract changes in plans: one configuration has been rapidly changed into the other.

With this general treatment in mind, the following sections detail the more important design features.

ANTENNA

The antenna specifications called for a reference (sum) pattern gain of 51 db, a beamwidth of 0.4°, and close-in sidelobes not higher than 24 db below the peak of the main beam. Preliminary design studies pointed to the selection of a conventional four-horn "feed-in-front" and reflector, or of a Cassegrain approach. For the conventional feed-reflector configuration, a reflector of 32 feet would be necessary. At the expense of an increase in close-in sidelobes, the Cassegrain would have many advantages:

1) higher efficiency resulting in smaller size for the same gain and less back radiation—lower antenna temperature,
2) increased possibility of accommodating several frequencies C and S or X bands, for example,
3) higher mechanical resonance of the overall reflector-feed-hyperbola assembly—important to the servo design goal of 5.0 cps,
4) lower total mass of the assembly and closer to the elevation axis—also important to the servo design,
5) more nearly optimum feed position for future very low noise receivers, and
6) increased flexibility in achieving polarization diversity.

Government representatives agreed that the many advantages outweighted the "multipath-tracking" disadvantage of the higher sidelobes: the Cassegrainian approach was selected. Tests of the final design, a 30-inch hyperbola and 29-foot reflector with five-horn feed, have shown that the design goals have been met or exceeded.

Fig. 3—Front view of radar console.

ANTENNA MOUNT

The antenna mount, commonly called the pedestal, is probably the greatest single contributor to the successful performance of the radar.

The first problem was the choice of mount configuration. The azimuth-elevation (AZ-EL) configuration represented the best compromise between the experience of U. S. industry and the performance desired. Tracking of high performance targets near zenith presented a special problem to this type mount. However, the *X-Y* mount, a theoretically better tracker at high angles, was not chosen because of physical limitations at low tracking angles—of equal importance in a general purpose instrumentation radar. During the proposal stages the Government considered the addition of a third axis to provide satisfactory performance at all elevation angles—but this mount could not be built within the funding and scheduling allocations.

With the AZ-EL mount decided upon, a compromise had to be made: a very firm requirement for smoothest possible tracking at angular rates as low as 0.01 mils/sec (roughly equivalent to *one earth rotation per week)* took precedence over the need for fastest possible servo response at the higher angles. Dynamic range considerations and torque requirements for precision tracking in a 40-mph wind set the upper velocity limit at 500 mils/sec.

In order to limit the overall radar random error to 0.05 mil-RMS when tracking skin targets at low signal-to-noise ratios, the sticking and sliding friction components of the servo error are held to an absolute minimum. This is one of the requirements that dictated the use of a hydrostatic bearing[7] for the azimuth turntable.

Since it is impossible to design and cut perfect gears, tracking accuracy is degraded because the antenna position cannot be controlled to a precision greater than the magnitude of the drive gearing backlash. The hydrostatic bearing magnifies this problem since its lack of friction tends to cause servo oscillations equal to or greater than the backlash magnitude. Tracking accuracy is ensured by preloading the drive gear train in opposite directions, thereby minimizing backlash problems.

Minimizing the servo tracking lag errors for targets having high angular accelerations and velocities requires that the bandwidth and open loop gain be as large as possible. Bandwidth and gain, however, are limited by the frequency at which locked-rotor resonance occurs. This is the frequency of the mass of the moving parts of the antenna coupled with the spring of the drive gear train when the motor rotor is locked. In order to extend this frequency as far as possible, two drive gear trains in parallel give a gear stiffness twice that of one gear train. Hydraulic drive motors are used since this application requires higher torque-to-inertia ratio, better dynamic response, and smoother slow speed operation than can be obtained from electric motors. A valve-controlled motor system is used rather than a variable-displacement pump-controlled motor since the dynamic response is better.

Fig. 4—AN/FPQ-6 at Patrick Air Force Base.

The pedestal design was further complicated by the requirement for ease of transportation in C-124 and C-133 aircraft. Individual subassemblies are therefore designed to breakdown into suitable packages for loading into these aircraft and to keep the package weight below 25,000 pounds. The design provides for minimum system realignment and checkout when the pedestal is reassembled in the field.

To measure the antenna position and to provide data output to the required precision, RCA designed a new "one-speed" shaft-to-digital converter (encoder). This encoder can provide shaft position measurements to a granularity of twenty binary digits, or one part in 1,048,576. An encoder for each axis (azimuth and elevation) is used. The direct coupling to the shaft to be measured eliminates inaccuracies due to gears, couplings, and tolerance build-up of mechanical parts.

DATA PROCESSOR

The data processing equipment of the radar must take the raw encoder readings in range, azimuth, and elevation and place these in the proper format for transmission to other stations on the range. A requirement also existed to correct the position data supplied by the pedestal encoders for antenna lags due to target dynamics. In the AN/FPS-16 radar, two independent special-purpose subsystems were used, and error correction occurred over a range of input signal-to-noise ratios too limited for the AN/FPQ-6 application.

To accomplish error correction, the monopulse tracking error in each axis servo loop is sampled, demodulated, filtered, digitized, and added to the raw pedestal encoder readings to provide corrected angular position data. Some method must be employed to compensate for the shape of the monopulse error pattern with off-axis targets and for nonlinearities in the receiver AGC system. While a special-purpose computer could again be built to provide the correction processing, cost, schedule, flexibility, and growth considerations favored the use of a reasonably fast, general-purpose instrument with a scientific repertoire. The RCA 4101 was selected as being uniquely suitable for this application.[6]

Error correction now involves digital processing of data resulting from premission calibration operations to generate and store a normalized angle error pattern independent of the signal-to-noise ratio. Subsequent real-time processing of target tracking and calibration data provides the capability for dynamic lag-error correction for all possible values of input-signal strength. Lag error correction to an accuracy of better than 5% is attained.

Having selected the computer primarily for the error correction operation, it is now possible to combine functions which would otherwise require additional special equipment. Therefore, the RCA 4101 also provides the following additional functions:

1) readout of position data,
2) auxiliary readout of range data,
3) correction for pedestal out-of-level condition,
4) correction for antenna droop versus elevation angle,
5) correction for non-orthogonality of azimuth and elevation axis,
6) correction for shift of antenna pointing axis versus frequency,
7) correction for atmospheric index of refraction, and
8) binary to decimal conversion for console display.

At present, no further exploitation of the inherent capabilities of the computer is included in the end-product equipment. However, the list of possibilities is seemingly endless—ranging from more sophisticated real-time signal processing to post-flight data reduction and "spare-time" computation of such items as preventive maintenance criteria.

MIPIR RADAR OPERATION

Following initial erection and testing of the antenna pedestals at the Moorestown antenna pedestal facility and assembly and test of the radar electronics at Moorestown, the radars were shipped to various field sites for emplacement, installation, checkout and acceptance testing by the RCA Service Co. under Morrestown engineering cognizance. The first of these radars, placed in limited operation, was an AN/TPQ-18 on Antigua, W.I.F., used in support of the POLARIS Missile Program on July 1, 1962, *only 18 months after the contract award date*. The first unit accepted by the government was the AN/FPQ-6 located at Patrick Air Force Base, Florida (Fig. 4) on June 5, 1963. Subsequently, another AN/FPQ-6 was accepted by the Government at Antigua, W.I. on June 26, 1963, and AN/TPQ-18 number two was accepted at Moorestown on July 1, 1963 and is currently in operation at Grand Turk Island. At this writing, seven of the nine radars under contract are in the field, including NASA installations at Wallops Island, Va., and Carnarvon, Australia.

Acceptance test data for these radars shows performance has in general met or exceeded requirements, especially as regards precision, which is 0.025 mil-RMS in angle and 2 feet-RMS in range, while the servo bandwidth was slightly below specifications in early units (ranging from 4.2 to 5.0 cps), but still *well above* comparable units of equal weight. Later units have been improved, and *exceed* the specification of 5.0 cps.

FUTURE POTENTIAL

No sooner were these radars in operation before performance enhancements began to become required. The first of these was a C-band parametric amplifier[8] for the Antigua AN/TPQ-18; this reduced the receiver noise figure from 8 to 4 db and thereby enhanced radar acquisition and trackers precision on small or distant targets. Subsequently, similar paramps were ordered for the Wallops Island and Australian units.

Following difficulties in acquiring targets downrange with the Antigua AN/TPQ-18, an antenna beam broadener was developed and is being incorporated in three Australian radars. The development broadens the antenna beam to 1.0° from the present 0.4° by introduction of energy into the error horns of the five-horn feed.

With the incorporation of planned changes, such as pulse doppler, cooled paramps, digital radar designation, and higher transmitter power, the course of history of radar development is beginning to repeat again.

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Engineering and Research NOTES

BRIEF TECHNICAL PAPERS OF CURRENT INTEREST

New Facilities for Printed-Wiring Masters Improve Quality and Lead Time

R. Taynton, *Missile & Surface Radar Division, DEP, Moorestown, N. J.*

An improvement program at Moorestown for the production of printed-wiring masters has cut costs and time. In its first year of operation, a former reject rate on such masters was reduced from 30% to 0%.

A problem with printed wiring has been the treatment of the artwork that is used in its production—photomasters and silk screen drawings produced by the drafting organization. The printed wiring master is used directly, as a tool, in the actual fabrication of the finished item. The accuracy of the finished item is almost entirely dependent on the accuracy of this "picture" (rather than the dimensions attached to it). Early in the BMEWS program, a quality control check instituted on photomasters revealed them not sufficiently accurate to meet manufacturing requirements. Reject rates were between 30% and 40%. An investigation by the M&SR Printed Wiring Product Engineering unit revealed that most rejects could be attributed to treating the master as a drawing when it should have been treated as a tool.

To solve this, drafting personnel who had some printed-wiring experience were selected, formed into a specialized Printed Wiring Drafting unit, and trained with lectures and plant and model shop tours, with emphasis on the drafting-manufacturing interface. A rigid quality control check was implemented on each master drawing to find inaccuracies detrimental to manufacturing, using light tables with accurate glass grids and optical measuring devices. The inspection was concentrated on line definition, density, width, and spacing, and on pad size and location. Tolerances were widened with a change in philosophy from an absolute to a probability system and a proper apportionment of the allowances between the master and the later manufacturing processes.

Many rejects had been caused by improper handling of the masters. Although the material (Estar film) on which the master is made is relatively stable, the information added to it in tape and ink form is subject to damage. The master can pick up reproducible dust when laying on a table. The film can be easily and permanently stretched when subjected to the rolling, heated pressure of a print machine. The masters were subjected to even more of this detrimental handling in their movement in and out of manufacturing plants than were normal drawings relegated to a file.

The obvious solution to the handling problem was to immediately convert the unstable tape and ink information to a more stable form through the use of direct positive photographic reproduction. On a flat vacuum printing frame, the drafting executed black line information was transferred photographically to a direct positive emulsion coated on Estar sheet. The resulting transparent "stable master" has an acceptable resistance to abrasion and abuse in addition to the stability of the Estar film. The same process was used to create a reproduction of the circuit pattern area (tool transparency). Additionally, a paper reproducible of the master was made on the vacuum frame.

Fig. 1—R. Taynton (author, at right) and C. A. Bloom review photomasters and marking drawings in the stable master file.

Thus, handling damage to masters was virtually eliminated, and the "tool" transparency displaced the master in its travels around the manufacturing environments. Similarly, the paper reproducible replaced the master in its travels through roll type print machines. The master was limited to pure storage in a controlled environment. Any changes were incorporated in the immediate storage area, supervised directly by the drafting unit.

These methods have been put into wide usage and have been incorporated in Volume 8 of the *DEP Standards*. One disadvantage of the system is the time lapse created by sending the original to a commercial vendor for the vacuum frame printing. At first, drafting personnel took the tape-and-ink original to the model shop where it was conventionally photographed for breadboard fabrication. Now vacuum frame cronaflex facilities are available within the M&SR Photographic Services Unit, which makes the whole process "in-house." Techniques and lighting arrangements were developed to provide high definition. The Photographic Services Unit as now produced over 1,300 masters, not only with no handling damage but with a 20% cost advantage over vendor services, and a 4-hour delivery.

On a Scheme to Increase Electrostatic Recording Camera Sensitivity

I. M. Krittman, *Astro-Electronics Division, DEP, Princeton, N. J.*

Conceptual descriptions of an electrostatic recording camera developed especially for use in observation satellites were given previously by Hutter, et al.[1,2] Analytical descriptions of ,the operating procedures and performance characteristics of the camera's recording medium, commonly called *Photo-Tape*, will be presented in future AED papers. The purpose of this *Note* is to discuss a proposed scheme to increase the sensitivity of Photo-Tape.[2]

Briefly, the multilayered Photo-Tape *converts* optical input data into electrostatic charge patterns and *stores* these patterns until television readout is required. For these operations the tape employs a photoconducting layer and an insulating layer, respectively. The sensitivity of a Photo-Tape camera is determined by its output signal-to-noise ratio. The latter can be approximated by cascading the theoretical stored-signal and readout-process signal-to-noise ratios. The theoretical readout-process signal-to-noise ratio increases with the signal voltage stored on the tape. But for a given tape and fixed light exposure, this voltage can only be increased at the expense of the stored-signal signal-to-noise ratio.

The proposed scheme to increase tape sensitivity requires modification of the present camera operating procedures, as described below. As a result of light exposure, a voltage pattern is stored on the Photo-Tape surface. In preparation for signal enhancement, the camera parameters are adjusted so that the average secondary-electron emission ratio at the tape surface will be slightly greater than unity. In this region near first crossover, the secondary emission ratio of the Photo-Tape surface increases nearly linearly with the primary-electron energy. During the enhancement process, the tape surface is bombarded uniformly with primary electrons and all the resulting secondary electrons are collected. Local differences in tape secondary emission ratio result from the voltage modulation on the Photo-Tape surface. These produce corresponding local differences in the charging rate on the surface.

The signal gain from enhancement by secondary emission can be as great as V_m/V_1, where V_m is the maximum allowable voltage across the Photo-Tape insulator and V_1 is the peak highlight voltage across the insulator before enhancement. If V_b is the insulator breakdown voltage, then V_m must be less than V_b. If V_s is the voltage swing defining the linear range of the readout current-voltage characteristic, then V_m must also be less than $V_s/(1-a)$, where a is the inverse input contrast ratio. For a typical Photo-Tape, V_b and V_s are 25 and 6 volts, respectively.

Just after exposure the highlight-to-lowlight (peak-to-peak) signal voltage (swing) on the Photo-Tape surface is $r(1-a)V_1$, where r is the cascaded lens-tape response at the spatial frequency under consideration. From above, the enhanced signal voltage can be as great as $r(1-a)V_m$.

Because it involves secondary-electron emission, the enhancement process produces a noise voltage which is also stored on the tape. It can be shown that the root-mean-square noise voltage stored on the tape per highlight bit must be greater than $[e(\delta^2-\delta+1)IT/C^2]^{1/2}$, where e is the electronic charge, C is the Photo-Tape insulator capacitance (per picture bit), I is the enhancement (primary) current, T is the total enhancement time (per picture bit), and δ is the secondary emission ratio of a highlight area of tape at the start of enhancement. But the signal gain is exp $(\alpha\, IT/C)$, where α is the slope of the secondary emission curve near first crossover, so the noise voltage due to enhancement is greater than:

$$\left\{\left[\frac{e(\delta^2-\delta+1)}{\alpha C}\right]\ln(V_m/V_1)\right\}^{1/2}$$

The enhancement process signal-to-noise ratio can be no greater than:

$$\mathrm{SNR} = r(1-a)V_m\sqrt{\frac{\alpha C}{e(\delta^2-\delta+1)\ \ \ln(V_m/V_1)}} \qquad (1)$$

Consider, for example, a 6:1 input contrast ratio ($a = 1/6$), tape resolution of 500 half-cycles per centimeter ($C \approx 2\times10^{-14}$ farad), an initial broad area highlight voltage of 0.5 volt ($V_1 = 0.5$ volt), a secondary emission ratio slope of 0.005 per volt ($\alpha = 5\times10^{-3}$ volt^{-1}) and a near-unity secondary emission ratio ($\delta \approx 1$). Under these conditions, Equation 1 becomes SNR $\approx 90r$ and the maximum possible signal gain is 14.4.

It should be noted that higher gains are possible with lower initial highlight voltages. Also, the enhancement process signal-to-noise ratio varies inversely with the square-root of the logarithm of the gain. Thus for $V_1 = 0.05$ volt, SNR $\approx 66r$ and the maximum possible signal gain is 144.

For the original Photo-Tape parameters cited above, the enhancement process signal-to-noise ratio would be approximately 90 for broad areas ($r \approx 1$). The number obtained by cascading this ratio with the readout-process signal-to-noise ratio for a 7.2-volt signal must now be compared with the readout-process signal-to-noise ratio for a 0.5-volt signal. Although discussion of the readout-process signal-to-noise ratio is outside the scope of this *note*, it is stressed that for all cases, this comparison must be made.

Acknowledgement: This work was sponsored by the Aeronautical Systems Division of the U. S. Air Force Systems Command, Wright Patterson Air Force Base, Ohio, under Contract No. AF33(657)11485.

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Two Simple Pocket-Size Solid-State Noise Generators for Receiver Testing

B. A. TREVOR, *Communications Systems Division, DEP, Tucson, Arizona*

A broadband thermal noise generator of fixed known output provides a convenient and quick method of measuring receiver noise factor. If the noise factor is normal and the receiver gain is adequate, it is highly probable that satisfactory reception will be obtained.

The noise generators described here are pocket-size instruments having a flat output over the HF range of 1 to 32 Mc. They may be designed to have a preset output at any specified level to approximately 30 db above the thermal level at a 50-ohm output impedance. Hence, they are suitable for testing HF receivers.

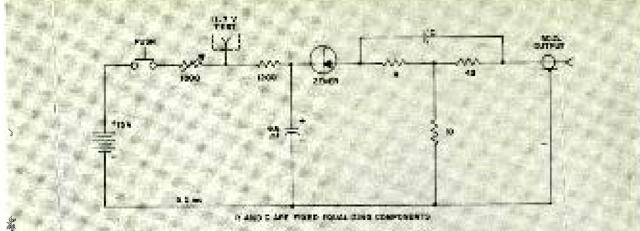


Fig. 1—Simple form of noise generator.

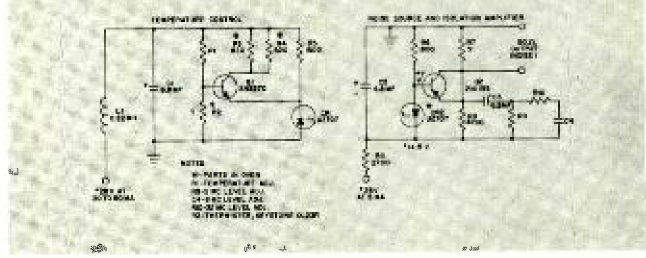


Fig. 2—A more-accurate noise generator.

One simple form of the noise generator is shown in Fig. 1. The noise source is a zener diode of a suitable type. A number of types are suitable such as Unitrode UZ707, 7.5 volt, or Motorola IN754, 6.8 volt. This generator will give a flat output of 20 db above thermal level over the frequency range of 1 to 50 Mc. Because the noise output changes somewhat with diode current, a test jack is provided to permit setting the test voltage to a specified value as the battery ages. Some diodes may change output by several db in extremes of temperature. Hence, the generator shown in Fig. 1 should be used at room temperature if greatest accuracy is desired.

Another more complex and more accurate noise generator is shown in Fig. 2. In this case the zener noise diode is temperature-controlled by means of the thermistor R2, heater resistors R3, R4, and the transistor Q1. The diode, heater resistors, and the thermistor are enclosed in a foamed oven, one cubic inch in size on the printed board. The printed board, 2" x 4", contains all of the components shown in Fig. 2. This generator has a flat output of 30 db above thermal level over the frequency range of 1 to 32 Mc. When connected to a 50-ohm line, the standing wave ratio is better than 1.1:1 with the generator on or off. Output accuracy is better than ±0.5 db over the entire frequency range and over an ambient temperature range of 0 to 50°C.

Aging tests have shown good stability up to 2,000 hours of continuous operation. The simplicity of the devices, using solid-state components, is conducive to high reliability and ruggedness.

To test a receiver it is only necessary to connect the noise generator (turned off) to the receiver antenna input and measure receiver IF noise output. The generator is turned on and the increase in noise is measured. If the increase in noise is greater than 10 db, the receiver noise factor F in db is $F \approx N - I$, where N is the generator output above thermal level in db, and I is the increase in noise in db. *It is important that the receiver response be linear from input to output.*

The low power drain and small size of these generators makes them suitable for inclusion in the receiver to provide a self-checking feature.

Acknowledgement: This development was sponsored as a subtask by the U. S. Navy Electronics Laboratory under Contract Number N123(953)31016A.

Optical Analogy for Cerenkov Radiation from Grazing Electron Beams

J. M. BRUMBAUGH, *Applied Research, DEP, Camden, N. J.*

An optical-analogy concept of the Cerenkov effect, as used in producing microwaves, has been found both useful and intriguing.

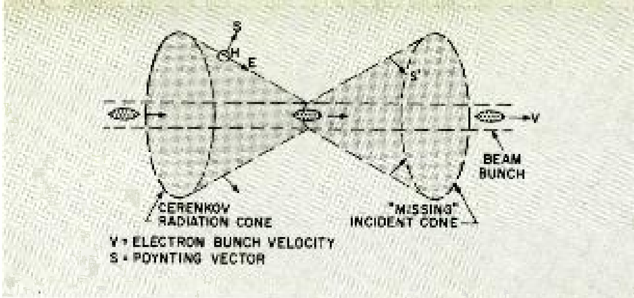


Fig. 1—Electron beam bunches generating expanding-cone wave-fronts.

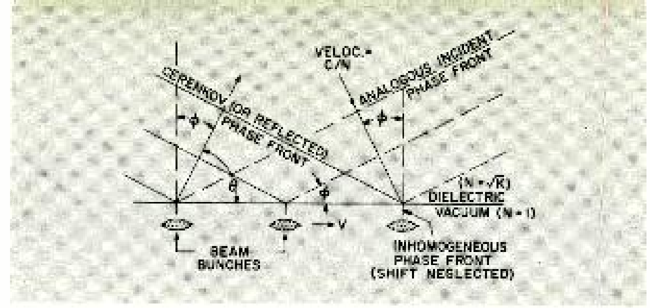


Fig. 2—Bunched wide-ribbon electron beam, grazing a semi-infinite dielectric.

When a dielectric surface is grazed by a bunched, high-velocity electron beam, the microwaves radiated into the dielectric behave as though they are incident on the dielectric-vacuum interface from a distant source and are undergoing total internal reflection at the interface. If such reflection were indeed occurring, inhomogeneous fields would be traveling along the interface, in the vacuum. Instead, in the absence of incident waves, similar traveling fields are being supplied by the moving electron bunches. Basic equations for total reflection and for the Cerenkov effect are quite analogous, and perhaps the most surprising prediction of advanced Cerenkov theory (microwave power approaches zero as beam velocity approaches c, the velocity of light, in a finite path length) turns out to be very plausible on the heuristic basis of the total reflection analogy.

The concept has thus been helpful in understanding and planning some aspects of beam-dielectric experiments and has stimulated further inquiries. Dr. L. W. Zelby[1] has now shown formal equivalence, under quite general conditions, of the two "types" of traveling inhomogeneous fields on the vacuum side of the interface—those produced by total internal reflection, and those produced by a bunched beam. Since no mention of the seeming equivalence of the two phenomena has been found in the literature until recently, this outline is presented to stimulate further reaction.

An example of the parallelism follows. A small-diameter electron beam, considerably bunched and traveling in a vacuum through a long cylindrical hole in a dielectric at a velocity greater than that of wave propagation in the dielectric, generates fields with expanding-cone wave-fronts (phase-fronts) in the dielectric as shown in Fig. 1. These waves of Cerenkov radiation originate as inhomogeneous waves from the beam bunches. However, they also appear essentially equivalent, in the vacuum (near the dielectric surface), to the "transinterface" or "leaky" surface waves which would accompany total internal reflection of the "missing" incident conical waves. These traveling inhomogeneous waves, whatever their origin, will enter the dielectric and propagate as homogeneous waves in a direction determined by their surface velocity.

Consider also the predominant Cerenkov radiation produced by a bunched wide-ribbon beam, grazing the surface of a semi-infinite dielectric, as in Fig. 2. It will look like plane waves originating from the bunch fields and leaving the dielectric surface as though it could just as well have originated from a distant plane-wave source and have been totally reflected at this interface. (Fig. 2 is simplified by omitting the interface phase differences between incident, reflected and transinterface waves.) Here again, the beam bunches replace incident waves in supplying the evanescent fields which must travel in the vacuum along the dielectric surface if there is to be radiation going off into the dielectric. A somewhat similar reference to "missing incident waves" has been found in the work of J. Brown,[2] but the idea was only partially developed.

Basic equations for the Cerenkov and reflection effects are impressively related. For example, the angle Θ between the direction of Cerenkov propagation and the interface is given by $\Theta = \cos^{-1} c/vn$, where v is beam velocity and n is the refractive index. For any particular refractive index, this angle approaches a maximum value of $\Theta_m = \cos^{-1} 1/n$ as v approaches c. For any given index, the critical angle of incidence $\emptyset_c$ for the onset of total reflection is given by $\emptyset_c = \sin^{-1} 1/n$. Thus, $\emptyset_c$ is always the complement of Θ_m, but both indicate the same propagating direction away from the interface.

Lower beam velocities, and consequently smaller values of Θ, correspond to complementary incidence angles greater than $\emptyset_c$ and thus to the range of total internal reflection, with $\Theta = (90° - \emptyset)$ as shown in Fig. 2. If the beam velocity is postulated to equal the velocity of the transinterface waves of a reflection, the Cerenkov angle Θ is always equal to the complement of the analogous incidence and reflection angles, $\emptyset$. From Fig. 2, the phase intercept and the inhomogeneous velocity v' along the interface are $v' = c/n \sin \emptyset = c/n \cos \Theta$. Thus the above equation is a transposition of the Cerenkov equation when $v = v'$.

The rather unexpected prediction that the Cerenkov radiation from a finite length of beam path should approach zero as the beam velocity approaches c[3,4] has been explained on the basis of Lorentz contraction of the beam fields.[4] However, the reflection analogy also gives very direct indication of this as a plausible consequence, by predicting that no Cerenkov radiation can be generated in an interaction path smaller than the optical "skip distance." For example, reflection theory and experiment[5] have shown that fields which penetrate the vacuum, during incidence at an angle slightly greater than the critical angle, become almost bound surface waves on the vacuum side of the interface. Energy from a particular segment of an incident phase front then reenters the dielectric only after traveling a skip distance of *many* wavelengths along the vacuum side of the interface. Meanwhile, a lateral segment of each incident wave has "piled up" into a relatively strong inhomogeneous wave across the interface, moving with the traveling locus of constant incident phase, thus forming a penetrating or quasi-bound surface wave. Equivalently, in the Cerenkov case, when $v >> c/n$ i.e., $v \rightarrow c$), the Cerenkov fields, although very strong, should not penetrate the dielectric until they traverse an interaction path which is *very* long.

Fig. 3 illustrates conditions at a dielectric-vacuum interface for a limited incident ray. The angle of incidence, $\emptyset$, is sufficiently greater than the critical angle, $\emptyset_c$, to give a "skip distance" of only a few wavelengths, but the phase slippage predicted by reflection theory is still appreciable. For the skip distance, Brekhovskikh[6] derives the relation

$$D = \frac{\lambda_k n^2 \tan \emptyset}{\pi \sqrt{\sin^2 \emptyset - 1/n^2}}$$

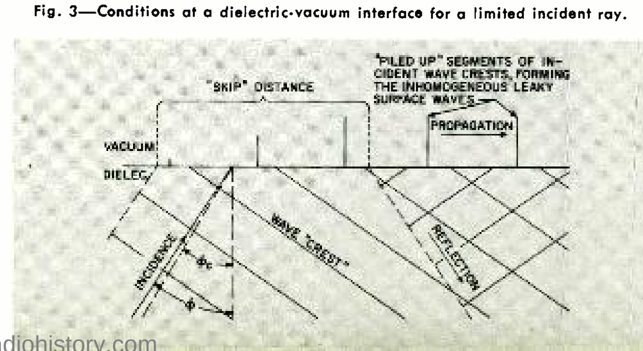
as the simplified form, for $\emptyset$ very near $\emptyset_c$, where λ_k is the wavelength in the dielectric. As an illustration, for $\beta = 0.94$ (1 — Mev electrons) and dielectric coefficient $k = 100$, the skip distance (minimum interaction path) is 10.7 λ_o, where λ_o is free-space wavelength. Consequently, for centimeter-wave radiation, an inordinately long interaction path would be required for the above choice of β and k. However, for the same value of β, but for $k = 2$, the minimum interaction path reduces to only 1.77 λ_o.

Another related similarity which appears to exist between the optical and Cerenkov phenomena is the relation of inhomogeneous field strength to values of Θ in the Cerenkov case and to values of $(90° - \emptyset)$ in the optical case. As the incidence angle $\emptyset$ approaches the critical $\emptyset_c$, for the optical case, there occurs a rapid increase in the "pile-up" of incident wave segments and in the growth of the transinterface wave. This is comparable to the increase (with similarly increasing Cerenkov angle) in the distortion of the field of each beam bunch, and resulting growth of field strength at the interface.

Still not clearly defined is the relation of the changing phase difference (between incident, surface, and reflected waves) at the interface, as the incidence angle $\emptyset$ varies within $\pi/2 > \emptyset > \emptyset_c$, and the changing distortion of bunch fields by the Fresnel "drag" of the dielectric as Θ varies correspondingly.

It is noted that Cerenkov waves are unique in having a unidirec-

Fig. 3—Conditions at a dielectric-vacuum interface for a limited incident ray.



tional property—in the sense that dielectric polarization in the near field does not reverse but pulsates in one direction (a field of AC + DC) as successive waves pass a given point. However, apparently this does not affect the equivalences noted above.

Acknowledgement: This material stems, in part, from a project sponsored by the Air Research and Development Command, RADC, USAF (Contract AF 30(602)2151).

Appreciation is expressed to J. J. Stekert, Dr. J. Vollmer and Dr. L. W. Zelby for their helpful discussions concerning this *Note*.

1. "Cerenkov Radiation as Leaky Surface Waves," *Proc. IRE*, October 1962, pp. 2134-2135. Comments and replies concerning this letter have also been published subsequently.
2. "Types of Waves Which May Exist Near a Guiding Surface," *Proc. IRE*, Vol. 100, Pt. 3, pp. 363-364, November 1953.
3. M. Danos, "Cerenkov Radiation from Extended Electron Beams," *Journal of Applied Physics*, Vol. 26, pp. 2-7, January 1955.
4. L. W. Zelby, "Theory of Cerenkov Effect, Based on Lorentz Transformations," *Journal of Applied Physics*, Vol. 33, p. 2995, Oct. 1962.
5. F. Goos and H. Hanchen, *Ann. Phys.* (6) 1, 333 (1947).
6. *Waves in Layered Media*, Academic Press, N. Y., 1960, Translation by R. T. Beyer.

Improved Three-Terminal Capacitance Measurements Using a Transformer-Ratio Bridge

R. E. Higgs, *Communications System Division, DEP, Cambridge, Ohio*

A significant improvement in accuracy and an extension of the measurement range of three-terminal capacitance has recently been accomplished by the Standards Laboratory of Cambridge Product Engineering through the use of a transformer-ratio bridge technique. Capacitance measurements to 0.0001 pf are now possible. The need for this range extension was made imperative by requests for "referee" measurements to determine vendor compatibility. Inherent in the range extension, one also finds a means of markedly increasing the accuracy level in the calibration of local capacitance standards.

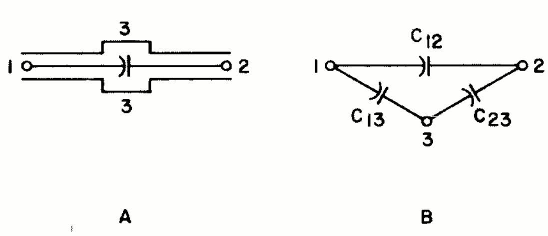
The best certifications provided by the National Bureau of Standards for this laboratory were in the order of 300 parts-per-million (ppm) for two-terminal capacitors and very recently, 120 ppm for three-terminal capacitors. The new Cambridge primary reference, a three-terminal capacitor with extremely low loss and superior stability characteristics, is presently reported to 20 ppm. This capacitor exhibits a temperature coefficient in the order of 2 ppm/°C. Since sufficient history for an extended period of time has not yet been accumulated, stability characteristics are based on data collected by the National Bureau of Standards on similar capacitors over a period of one year.

Through the use of the ratio-transformer bridge technique and the new 20-ppm laboratory reference, the limit of error in direct reading capacitance measurements has been decreased by one order of magnitude. Only one link with the National Bureau of Standards is necessary for capacitance traceability—the 20-ppm laboratory reference.

The accuracy assigned to the measured value of a capacitor is also a function of the voltage ratio of the ratio-transformer used. To cite an example of the accuracies attainable with a ratio-transformer, one such transformer in the custody of the Cambridge Standards Laboratory, and which was recently tested by the National Bureau of Standards, has a reported limit of error of less than 1 ppm. The stability characteristics of this same transformer are such that recalibration at intervals of less than three years are unnecessary.

The effects of stray capacitance which appear in two-terminal capacitance measurements can be reduced through the use of three-terminal capacitors.

Fig. 1—Three-terminal capacitor.



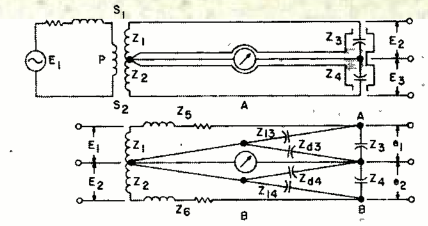
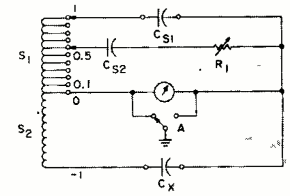


Fig. 2—Equivalent circuit for transformer-ratio-bridge.



NOTE:
R_1 CAN BE IN SERIES WITH EITHER C_{S2} OR C_X

Fig. 3—Basic diagram for ratio-transformer capacitance bridge.

A three-terminal capacitor with its equivalent circuit is shown in Fig. 1. The capacitance of interest is the direct capacitance between points 1 and 2, the capacitance C_{12} in Fig. 1b. Stray capacitances C_{13} and C_{23} in Fig. 1b, comprise the capacitance from terminals 1 and 2 to the shield or case housing the capacitor. This capacitance must be eliminated in highly accurate measurements.

The ratio-arms of a transformer bridge can be considered as being two low-impedance sources supplying voltages of a known ratio, and of opposite phase, applied to two completely shielded capacitors. With the use of Fig. 2 it can be shown how the effect of stray capacitance is eliminated from the direct capacitance.

In Fig. 2a, if the ratio $Z_1/Z_2 = Z_3/Z_4$ then there will be no current through the detector, hence the current through Z_3 and Z_4 must be of equal magnitude; therefore: $E_2/E_3 = Z_4/Z_3$.

Impedance Z_{13} and Z_{14} (Fig. 2b) comprise the impedance between the enclosing shield and line terminals A and B. These impedances are in shunt with impedances Z_1 and Z_2, and have little effect on e_1 and e_2 provided Z_1 and Z_2 are small compared to Z_{13} and Z_{14}, respectively. Impedances Z_{d3} and Z_{d4} are in shunt with the detector, thus the only adverse effect here is a decrease in the detector sensitivity. If Z_5 and Z_6, which are the impedances in the ratio arms of the transformer bridge and are made up of the connecting leads to the internal capacitor standards and the terminals of the capacitor under test, are made very small and are negligible compared to: $1/wZ_{13}$ and $1/wZ_{14}$, respectively, then the error in the ratio E_1/E_2 is very small and: $E_1/E_2 = Z_4/Z_3$.

The addition of a primary winding on the ratio-transformer to induce an EMF in the windings S_1 and S_2 (Fig. 2a) has no effect on the bridge balance, therefore the losses associated with winding P can be ignored.

The windings S_1 and S_2 (Fig. 2a), however, must be positioned symmetrically on the toroidal core to minimize the difference between the self-capacitances of S_1 and S_2. The difference between the open-circuit voltage ratio and the turns ratio depends on the magnitude and the symmetrical distribution of the capacitance between turns in the secondary winding.

By using the accurate ratios provided by a carefully designed ratio-transformer in a bridge arrangement with one arm fixed, and a ratio arm which can be varied, an unknown value of capacitance can be compared to a standard capacitor as shown in Fig. 3. The primary is not shown; it is used only to supply a voltage to the bridge.

By placing C_x in shunt with S_2 (Fig. 3) and then C_{S2}, one of the eight internal three-terminal standard capacitors in the bridge can be positioned at a tap on S_1 to balance the bridge. Losses associated with C_x are balanced with R_1, and at null the voltage across C_x is equal to the voltage across C_{S2}, thus comparing the unknown directly with an internal standard. Provision can also be made to compare an unknown value of capacitance with an external standard C_{S1} for range extension or detecting ΔC between C_x and C_{S1}. Switch *A* provides for two- or three-terminal measurements; it is shown in the three-terminal position.

Acknowledgement: The author wishes to acknowledge the efforts of encouragement provided by W. C. Praeger and P. J. Riley.

Meetings

March 23-26, 1964: IEEE INTERNATIONAL CONVENTION, All PTG's; Coliseum and N. Y. Hilton, N. Y., N. Y. *Prog. Info.:* Dr. F. Hamburger, Jr., Chairman 1964 Tech. Prog. Committee, IEEE, Box A, Lenox Hill Station, N. Y. 21, N. Y.

April 1-2, 1964: 5TH SYMP. ON ENG. ASPECTS OF MAGNETOHYDRODYNAMICS, IEEE-AIAA, MIT; MIT, Cambridge, Mass. *Prog. Info.:* Dr. G. S. Janes, Avco Everett Res. Labs., Everett 49, Mass.

April 6-8, 1964: INTL. CONF. ON NONLINEAR MAGNETICS (INTERMAG), IEEE; Shoreham Hotel, Washington, D.C. *Prog. Info.:* R. C. Barker, 2158 Yale Station, New Haven, Conn.

April 8-10, 1964: ISA MEASUREMENT AND CONTROL INSTRUMENTATION DIV. SYMP., with District III Exhibit; Hotel Floridian, Tampa, Fla. *Prog. Info.:* J. Barker, Taylor Instrument Corp., P.O. Box 13735, Station K, Atlanta 24, Georgia.

April 12-17, 1964: 95TH TECH. CONF. OF THE SMPTE; Ambassador Hotel, Los Angeles, Calif. *Prog. Info.:* SMPTE, 9 E. 41st St., New York 17, N. Y.

April 13-15, 1964: 3RD SYMP. ON MICROELECTRONICS, St. Louis Section; Chase-Park Plaza Hotel, St. Louis, Mo. *Prog. Info.:* T. F. Murtha, % IEEE Headquarters, Box A, Lenox Hill Station, N. Y. 21, N. Y.

April 14-16, 1964: AMERICAN POWER CONF., IEEE et al.: Sherman Hotel, Chicago, Ill. *Prog. Info.:* W. A. Lewis, % IEE Headquarters, Box A, Lenox Hill Station, N. Y. 21, N. Y.

April 19-25, 1964: INTL. CONF. AND EXHIBIT ON AEROSPACE ELECTRO-TECHNOLOGY, IEEE et al.; Westward-Ho Hotel, Phoenix, Arizona. *Prog. Info.:* A. A. Sorenson, The Martin Co., J 359, Baltimore 3, Md.

April 20-22, 1964: FIRST SPACE CONGRESS, Canaveral Council of Tech. Societies; Cocoa Beach, Fla. *Prog. Info.:* W. J. Haberhern, Tech. Prog. Chairman, Titan III, Quality Systems Eng., Mail Unit E-8, Martin Co., Cocoa Beach, Fla.

April 20-24, 1964: RELIABILITY TRAINING COURSE, PTG-R, ASQC; Westbury Hotel, Toronto, Canada. *Prog. Info.:* L. C. Thomas, RCA Victor Co., Ltd., 1001 Lenoir St., Montreal 30, Que.

April 21-23, 1964: SPRING JOINT COMPUTER CONF., AFIPS (IEEE-ACM); Sheraton-Park Hotel, Washington, D.C. *Prog. Info.:* J. Roseman, 2312 Coleridge Dr., Silver Spring, Md.

April 22-24, 1964: SOUTHWESTERN IEEE CONF. AND ELEC. SHOW (SWIEEECO), Region 5; Dallas Memorial Auditorium, Dallas, Texas. *Prog. Info.:* Dr. F. E. Brooks, Ling-Temco, Vought Inc., Dallas 22, Texas.

April 28-30, 1964: 12TH NATL. RELAY CONF.; Oklahoma State Univ., Stillwater, Oklahoma. *Prog. Info.:* D. D. Lingelbach, Assoc. Prof. Elec. Eng., Oklahoma State Univ., Stillwater, Oklahoma.

April 29-May 1, 1964: IEEE REGION 6 ANNUAL CONF., Region 6, ISA; Salt Lake City, Utah. *Prog. Info.:* C. Clark, 719 N. 15 East, Logan, Utah.

May 3-7, 1964: 1964 SPRING MTG., Electrochemical Soc.; Royal York Hotel, Toronto, Ontario, Canada. *Prog. Info.:* Society Headquarters, 30 E. 42nd St., New York 17, N.Y.

May 4-6, 1964: PACKAGING INDUSTRY CONF., IEEE; Nassau Inn, Princeton, N. J. *Prog. Info.:* E. W. Macoy, Amer. Can Co., 100 Park Ave., New York 17, N. Y.

May 4-6, 1964: REGION III TECH. CONF., IEEE; Clearwater, Fla. *Prog. Info.:* P. G. Hansel, Electronic Comm. Inc., 1501-72 St., N., St. Petersburg, Fla.

May 5-6, 1964: 5TH ANN. SYMP. ON HUMAN FACTORS IN ELECTRONICS, PTG-HFE; San Diego, Calif. *Prog. Info.:* Dr. Mel Freitag, 1910 Shire Dr., El Cajon, Calif.

DATES *and* DEADLINES

PROFESSIONAL MEETINGS AND CALLS FOR PAPERS

May 5-7, 1964: 1964 ELECTRONIC COMPONENTS CONF., EIA, IEE, ASCQ; Marriott Twin Bridges Motor Hotel, Washington, D. C. *Prog. Info.:* J. Bohrer, Intl. Resistance Co., 401 N. Broad St., Phila. 8, Pa.

May 6-8, 1964: SOC. FOR EXPERIMENTAL STRESS ANALYSIS SPRING MTG., Hotel Utah and Motor Lodge, Salt Lake City, Utah. *Prog. Info.:* Dr. C. S. Barton, Papers and Proc. Committee, Dept. of Civil Eng. Science, Rm. 198ELB, Brigham Young Univ., Provo, Utah.

May 11-13, 1964: NAECON (NATL. AEROSPACE ELECTRONICS CONF.), PTG-ANE, Dayton Sec., AIAA; Biltmore Hotel, Dayton, Ohio. *Prog. Info.:* Y. Jacobs, 1917 Burbank Dr., Dayton, Ohio.

May 19-21, 1964: INTL. SYMP. ON MICROWAVE THEORY AND TECHNIQUES, PTG-MTT; Intl. Hotel, Kennedy Airport, N. Y. *Prog. Info.:* Dr. L. Swern, Sperry Gyroscope Co., 3 T 105, Great Neck, N. Y.

June 2-4, 1964: NATL. TELEMETERING CONF., IEEE-AIAA-ASA; Biltmore Hotel, Los Angeles, Calif. *Prog. Info.:* W. S. Pope, North American Aviation, Downey, Calif.

June 2-4, 1964: INTL. SYMP. ON GLOBAL COMMS. (GLOBECOM VI), PTG-CS, EC, et al; Univ. of Penn. and Sheraton Hotel, Philadelphia, Pa. *Prog. Info.:* R. Guenther, RCA Comm. Systems Div., Bldg. 1-3-1, Camden, N. J.

June 8-10, 1964: SYMP. ON QUASIOPTICS, PIB-IEEE; Statler-Hilton, N. Y., N. Y. *Prog. Info.:* Prof. L. Felsen, PLB, 55 Johnson St., Brooklyn 1, N. Y.

June 9-11, 1964: 6TH ANN. SYMP. ON ELECTROMAGNETIC COMPATIBILITY, PTG-EMC; Los Angeles, Calif. *Prog. Info.:* J. A. Eckert, Dept. 3441/32, Northrop and Norair, 3901 W. Broadway, Hawthorne, Calif.

June 11-12, 1964: 8TH ANN. PRODUCT ENG. AND PRODUCTION CONF., PTG-PEP; Pratt Institute, Brooklyn, N. Y. *Prog. Info.:* R. R. Batcher, 24-02 42nd St., Douglaston, N. Y.

June 15-16, 1964: CHICAGO SPRING CONF. ON BROADCAST AND TV RECEIVERS, PTG-BTR; O'Hare Inn, Des Plaines, Ill. *Prog. Info.:* J. H. Landeck, Admiral Corp., 3800 W. Cortland, Chicago 47, Ill.

June 16, 1964: AIR AND SURFACE NAVIG. BY ARTIFICIAL SATELLITES, ION, PTG-ANE; Barbizon-Plaza, N. Y. *Prog. Info.:* IEEE Headquarters, Box A, Lenox Hill Station, New York 21, N. Y.

June 23-25, 1964: CONF. ON PRECISION ELECTROMAGNETIC MEASUREMENTS, IEEE; Boulder, Colo. *Prog. Info.:* C. F. Hempstead, Bell Tel. Labs., Murray Hills, N. J.

June 23-25, 1964: SAN DIEGO SYMP. FOR BIOMEDICAL ENG., IEEE; Ocean House, San Diego, Calif. *Prog. Info.:* D. L. Franklin, Scripps Clinic and Res. Found., La Jolla, Calif.

June 24-26, 1964: JOINT AUTOMATIC CONTROL CONF., IEEE, ASME, AIChE, ISA; Stanford Univ., Stanford, Calif. *Prog. Info.:* L. Zadeh, Univ. of Calif., Berkeley, Calif.

Calls for Papers

June 23-25, 1964: CONF. ON PRECISION ELECTROMAGNETIC MEASUREMENTS, IEEE; Boulder, Colo. **Deadline:** Abstracts, **3/15/64.** To: C. F. Hempstead, Bell Tel. Labs., Murray Hills, N. J.

June 23-25, 1964: SAN DIEGO SYMP. FOR BIOMEDICAL ENG., IEEE; Ocean House, San Diego, Calif. **Deadline:** Abstracts, **3/25/64.** To: D. L. Franklin, Scripps Clinic and Res. Found., La Jolla, Calif.

July 6-10, 1964: INTL. CONF. ON MAGNETIC RECORDING, IEEE; London, England. **Deadline:** Abstracts, **12/31/63;** Manuscripts, **3/31/64.** To: Intl. Conf. on Magnetic Recording Secretariat, % The Institution of Electrical Engrs., Savoy Place, London, W. C. 2, England.

Aug. 25-28, 1964: 1964 WESCON SHOW AND IEEE SUMMER GENL. MTG., IEEE; Los Angeles, Calif. **Deadline:** Abstracts, **4/15/64.** To: Dr. Robert R. Bennett, Tech. Prog. Chairman, 1964 WESCON, Suite 1920, 3600 Wilshire Boulevard, Los Angeles, Calif.

Sept. 7-11, 1964: INTL. CONF. ON MICROWAVES, CIRCUIT THEORY AND INFO. THEORY, IECE of Japan, et al; Tokyo, Japan. **Deadline:** Abstract and summary, **3/31/64.** To: Dr. Kiyoshi Morita, % IECE of Japan, 2-8 Fujimicho, Chiyoda-Ku, Tokyo, Japan.

Sept. 17-18, 1964: 12TH ANN. ENG. MANAGEMENT CONF., IEEE-ASME- et al; Pick-Carter Hotel, Cleveland, Ohio. **For Deadline Info.:** Dr. John Saby, Gen. Elec. Co., Nela Park, Cleveland, Ohio.

Sept. 14-16, 1964: 8TH ANN. CONVENTION ON MILITARY ELECTRONICS (MIL-E-CON), PTG-MIL; Washington-Hilton Hotel, Washington, D. C. **For Deadline Info.:** IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Sept. 22-24, 1964: PTG ON ANTENNAS AND PROPAGATION SYMP., PTG-AP; Kennedy Airport, L. I., N. Y. **Deadline:** Abstracts, **3/2/64.** To: Dr. H. Jasik, Jasik Labs., 100 Shames Dr., Westbury, N. Y.

Sept. 23-24, 1964: 13TH ANN. INDUSTRIAL ELECTRONICS SYMP., IEEE, PTG-IECI; Phila., Pa. **Deadline:** Abstracts, approx. **5/1/64.** To: IEEE Headquarters, Box A, Lenox Hill Station, N. Y. 21, N. Y.

Sept. 23-25, 1964: 1ST INTL. CONGRESS ON INST. IN AEROSPACE SIMUL. FACILITIES, PTG-AS, AGARD; Paris, France. **For Deadline Info.:** P. L. Clemens, ARO Inc., Arnold Air Force Sta., Tenn.

Sept. 25-26, 1964: 3RD CANADIAN SYMP. ON COMMUNICATIONS, IEEE; Montreal, Que. Canada. **For Deadline Info.:** A. B. Oxley, Canadair Ltd., Box 6087, Montreal, P.Q., Canada.

Oct. 1964: SYMP. ON OPTICAL INFORMATION PROCESSING, PTG-EC, IEEE; Boston, Mass. **For Deadline Info.:** A. Vanderburgh, MIT Lincoln Lab. B-115, Lexington, Mass.

Oct. 6-9, 1964: ANN. IEEE SYMP. ON SPACE ELECTRONICS, PTG-SET; Dunes Hotel, Las Vegas, Nev. **For Deadline Info.:** Dr. O. L. Tiffany, The Bendix Corp., Ann Arbor, Mich.

Oct. 5-7, 1964: 10TH ANN. COMMS SYMP., PTG-CS; Utica, N. Y. **Deadline:** Abstracts, approx. **6/17/64,** manuscripts, approx. **9/1/64.** To: IEEE Headquarters, Box A, Lenox Hill Station, N. Y. 21, N. Y.

Oct. 19-21, 1964: NATL. ELECTRONICS CONF., IEEE et al; McCormick Pl., Chicago, Ill. **Deadline:** Abstracts, approx. **5/15/64,** manuscripts, approx. **8/1/64.** To: Natl. Elec. Conf., 228 N. La Salle St., Chicago, Ill.

Oct. 12-15, 1964: 19TH ANN. ISA CONF.; New York. **Deadline:** Abstracts, **3/31/64.** To: H. Tyler Marcy, Vice President, Dev., Genl. Products Div., Intl. Business Machines Corp., White Plains, N. Y.

Oct. 21-23, 1964: EAST COAST CONF. ON AEROSPACE AND NAVIG. ELECTRONICS (ECCANE), PTG-ANE; Baltimore, Md. **Deadline:** Abstracts, approx. **6/4/64.** To: IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Oct. 28-30, 1964: SOC. FOR EXPERIMENTAL STRESS ANALYSIS ANN. MTG. AND EXPOSITION; Hotel Manager, Cleveland, Ohio. **For Deadline Info.:** SESA, 21 Bridge Square, Westport, Connecticut.

Oct. 27-29, 1964: FALL JOINT COMPUTER CONF., AFIPS (IEEE-ACM); Civic Center, Brooks Hall, San Francisco, Calif **Deadline:** Abstracts, approx. **5/1/64.** To: Mrs. P. Huggins, PO Box 55, Malibu, Calif.

Oct. 28-30, 1964: SYMP. ON SPACE AND LAB. AND 11TH ANNIVERSARY PTGNS MTG., PTG-NS; Phila., Pa. **For Deadline Info.:** L. Costrell, NBS, U. S. Dept. of Commerce, Wash. 25, D. C.

Oct. 29-30, 1964: ELECTRON DEVICES MTG., PTG-ED; Sheraton-Park, Washington, D. C. **Deadline:** Abstracts, approx. **8/1/64.** To: IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Nov. 4-6, 1964: NEREM (NORTHEAST RES. AND ENGINEERING MTG.), IEEE; Boston, Mass. **Deadline:** Abstracts, approx. **6/7/64.** To: IEEE Boston Office, 313 Washington St., Newton 58, Mass.

Nov. 9-11, 1964: RADIO FALL MTG., IEEE-EIA; Hotel Syracuse, Syracuse, N. Y. **For Deadline Info.:** V. M. Graham, EIA, Eng. Dept., 11 W. 42nd St., N. Y., N. Y.

Nov. 16-19, 1964: 17TH ANN. CONF. ON ENGINEERING IN MEDICINE AND BIOLOGY, IEEE-ISA, PTG-BME; Cleveland-Sheraton Hotel, Cleveland, Ohio. **Deadline:** Abstracts, approx. **8/1/64.** To: Dr. Peter Frommer, Cincinnati 29, Ohio.

Nov. 16-19, 1964: 10TH CONF. ON MAGNETISM AND MAGNETIC MATLS., IEEE-PTG-MTT, AIP, Paddison Hotel, Minneapolis, Minn. **Deadline:** Abstracts, approx. **8/19/64.** To: IEEE Headquarters, Box A, Lenox Hill Station, N. Y., N. Y.

Dec. 3-4, 1964: 15TH ANN. VEHICULAR COMM. SYMP., PTG-VC; Cleveland-Sheraton, Cleveland, Ohio. **Deadline:** Abstracts, approx. **8/15/64.** To: R. E. Bloor, Ohio Bell Te. Co., 700 Prospect Ave., Cleveland, Ohio.

January 12-14, 1965: 11TH NATL. SYMP. ON RELIABILITY AND QUALITY CONTROL, Hotel Fountainbleau, Miami Beach, Fla. **Deadline:** Abstracts, **5/1/64,** manuscripts, **7/14/64.** To: H. E. Reese, Burroughs Corporation, Military Systems Div., Box 305, Paoli, Pa.

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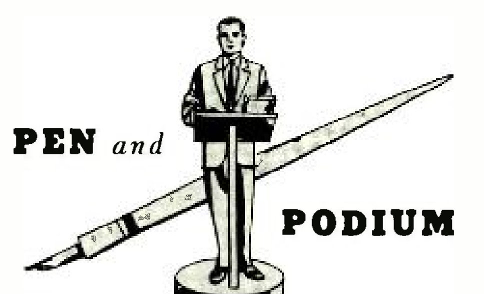

A SUBJECT-AUTHOR INDEX TO RECENT RCA PAPERS

Both published papers and verbal presentations are indexed. To obtain a published paper, borrow the journal from your library—or write or call the author for a reprint. For information on verbal presentations, write or call the author. This index is prepared from listings provided bimonthly by divisional Technical Publications Administrators and Editorial Representatives—who should be contacted concerning errors or omissions (see inside back cover). Comments or suggestions on this index should be directed to E. R. Jennings, Ass't. Editor, RCA ENGINEER, 2-8, Camden, PC-3396.

Editor's Note: *This new Pen and Podium index supersedes the Pen and Podium format used prior to the Feb.-Mar. 1964 issue that listed papers only by divisional source. At the end of 1964, a "Cumulative Index to 1964 RCA Papers", prepared by integrating the indexes that will appear in each 1964 issue, will be available as an* RCA ENGINEER *reprint.*

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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.

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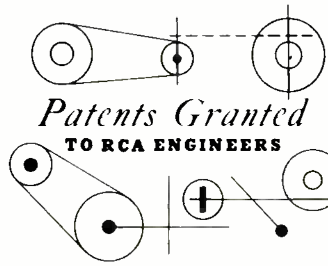

As Reported By RCA Domestic Patents, Princeton

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3,110,956—Jig Loading Apparatus, Nov. 19, 1963; A. Fischer, Jr.
3,110,984—Apparatus for Beveling the Edges of Ceramic Disks, Nov. 19, 1963; L. J. Capralola
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3,114,072—Electrostatically Focused Traveling Wave Tubes, Dec. 10, 1963; E. F. Belohoubek
3,114,663—Method of Providing Semiconductor Wafers with Protective and Masking Coatings, Dec. 17, 1963; J. Klerer
3,115,732—Apparatus for Processing Cathode Ray Tubes, Dec. 31, 1963; J. F. Stewart
3,118,662—Sealing Fixture for Glass Bulbs, Jan. 21, 1964; G. L. Fassett and R. W. Cox
3,119,043—Electron Discharge Device, Jan. 21, 1964; K. N. Karol
3,119,045—Electron Beam Tube with Longitudinally Partitioned Drift Tube, Jan. 21, 1964; F. G. Hammersand and R. T. Schumacher.

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3,111,252—Tape Drive Mechanism, Nov. 19, 1963; M. L. Levene
3,115,076—Communication Printer, Dec. 24, 1963; M. L. Levene
3,115,585—Logic Circuit with Inductive Self-Resetting of Negative Resistance Diode Operating State, Dec. 24, 1963; H. Ditkofsky and A. Feller
3,115,592—Method and Circuit for Compensating for Non-Uniformities in Display Storage Tubes, Dec. 24, 1963; H. M. Scott and C. E. Reeder
3,118,055 — Electronic Digital Information Handling System with Character Recognition for Controlling Information Flow, Jan. 14, 1964; L. S. Bensky
3,118,582—Tape Control Apparatus, Jan. 21, 1964; E. J. Rapoza
3,118,980—Supports for Electrical Apparatus, Jan. 21, 1964; R. E. Hamson
3,119,901—Pulse Signal Demodulator, Jan. 28, 1964; C. V. Bell and J. R. Twinam

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3,111,603—Television Deflection Circuit, Nov. 19, 1963; T. G. Marshall, Jr. and G. C. Seright
3,112,454—Negative Conductance Amplifier, Nov. 26, 1963; R. Steinhoff
3,114,004—Radio Signal Receivers, Dec. 10, 1963; J. O. Schroeder
3,114,047—Decoder Circuits, Dec. 10, 1963; H. Kihn and W. E. Barnette
3,114,795—Color Television Receiver with Penetration Color Tube, Dec. 17, 1963; W. H. Moles
3,114,867—Unipolar Transistors and Assemblies Therefor, Dec. 17, 1963; M. E. Szekely
3,117,269—Battery Charging Circuits, Jan. 7, 1964; L. Pensak
3,117,308—Control Systems, Jan. 7, 1964; I. H. Sublette
3,117,884—Electrostatic Printing Process and Apparatus, Jan. 14, 1964; H. G. Greig
3,118,071—Electrical Circuits Employing Impact Ionization Devices, Jan. 14, 1964; G. B. Herzog and M. C. Steele
3,118,977—Multi-groove Stereophonic Sound Recording and Reproducing System, Jan. 21, 1964; H. F. Olson
3,119,030—Transmission Line Gating Means for Preventing Spurious Pulses from Feeding Back from Output to Input, Jan. 21, 1964; C. M. Wine
3,119,056—Regulated Transistor Oscillator, Jan. 21, 1964; F. L. Hatke and G. W. Gray
3,119,059 — Thermionic Converter Circuits, Jan. 21, 1964; W. B. Hall and K. G. Hernqvist
3,119,072—Rectifying Circuits, Jan. 21, 1964; H. S. Sommers, Jr.
3,119,074—Traveling Wave Semiconductors Amplifier and Converter, Jan. 21, 1964; K. K. N. Chang
3,119,079—Variable-capacitance Diode Balanced Modulator, Jan. 21, 1964; E. O. Keiser
3,119,899—Multiplex Systems, Jan. 28, 1964; G. C. Sziklai
3,119,935—Network Employing Reset Means for Bistable Operating Gating Circuits, Jan. 28, 1964; A. G. Samusenko

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3,113,206—Binary Adder, Dec. 3, 1963; A. Harel
3,114,846—Self-Resetting Tunnel Diode-Transistor Hybrid Pulse Circuit, Dec. 17, 1963; A. I. Pressman
3,115,586—Holding Circuit Allowing Pulse to be Gated for Predetermined Time Set by Charging Circuit, Dec. 24, 1963; G. A. Lucchi

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3,113,237—Adjustable Voltage Supply, Dec. 3, 1963; J. C. Schopp and L. E. Annus
3,114,794—Color Television Receiver Control Apparatus, Dec. 17, 1963; A. J. Torre and J. Stark, Jr.
3,114,796—Color Kinescope Set-up Procedures for Color Television Receivers, Dec. 17, 1963; A. J. Torre and J. Stark, Jr.
3,114,858—Electron Beam Convergence Apparatus, Dec. 17, 1963; J. C. Schopp
3,115,584—Self-Resetting Negative Resistance Diode Inverter Circuit, Dec. 24, 1963; F. C. Yao
3,115,585—Logic Circuit with Inductive Self-Resetting of Negative Resistance Diode Operating State, A. Feller and H. Ditkofsky
3,119,936—Pulse Regenerator with Negative Resistance Diode Biased in High-Voltage by Inductor and Constant-Voltage Source, Jan. 28, 1964; R. H. Bergman
3,119,937 — Two-Diode Monostable Circuit, Jan. 28, 1964; R. H. Bergman
3,119,985—Tunnel Diode Switch Circuits for Memories, Jan. 28, 1964; M. M. Kaufman

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3,114,794—Color Television Receiver Control Apparatus, Dec. 17, 1963; J. Stark, Jr. and A. J. Torre
3,114,796—Color Kinescope Set-up Procedures for Color Television Receivers, Dec. 17, 1963; J. Stark, Jr. and A. J. Torre
3,118,972 — Acoustic Apparatus, Jan. 21, 1964; S. Walczak

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3,114,889—Desired Frequency-Coupling Circuit Having Undesired Frequency Cancellation Trap Located at Voltage Null Point for Desired Frequency, Dec. 17, 1963; J. Avins

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3,118,971—Apparatus for Recording Images, January 21, 1964; R. E. Lovell

Engineering NEWS *and* HIGHLIGHTS

1963 WAS 2nd CONSECUTIVE YEAR OF PEAK RCA SALES AND PROFITS

RCA 1963 sales and profits achieved all-time highs for second consecutive year. Subject to final audit, RCA's 1963 sales will be approximately $1.78 billion, with operating profit after taxes approximating $65 million. Profits from operations in 1963 increased 25%, and gross income increased 2% over 1962. Earnings per common share for the year will be $3.55 to $3.60, compared with the 1962 figure of $2.84.

RCA has now had eleven consecutive quarters of increased profitability over the same periods of the previous years, and the final quarter of 1963 was the single best profit quarter in the 44-year history of the company.

Three principal products and service areas provided a decisive impetus to growth for RCA in 1963:

1) *Color television*, in which profits from sales of color apparatus and related color services increased by 70% over 1962, with color accounting for a major share of the record earnings from all RCA consumer product sales.

2) *Broadcasting*, in which NBC earned substantially greater profits than in its previous record earnings year of 1962.

3) *Electronic Data Processing*, in which RCA's revenue from sale and lease of standard computers and peripheral equipment in the U.S. and abroad increased by more than 50% in 1963, and in which RCA holds firmly to its projected crossover into profitability in the fourth quarter of 1964.

A decline of about 10% in the company's defense business during 1963 was more than offset by commercial and industrial gains. RCA earned, after taxes, less than 2% profit on its military and space business for the full year. While the company continues to contribute importantly to the nation's defense and space programs, it derives from them only a small percentage of its total earnings.

RCA Victor Home Instruments achieved a record 15% sales increase over the previous high of 1962, and dollar volume in TV set sales was the highest of any year in RCA history.

With RCA still the only company producing color tubes in large quantity, production in 1963 continued on a three-shift-per-day, six-day-a-week basis throughout the year, and action was taken to increase color tube production in 1964. NBC's color programming, was approximately 2,200 hours, including 70% of its total nighttime schedule.

RCA Communications, Inc., again led all other U.S. international telegraph carriers in traffic volume and revenue, with sales rising 9% over the 1962 record. The RCA Service Company also achieved peak profits for the year.

In the nation's consumer market, it is predicted that the most vigorous single growth product in 1964 will be color television. Color set sales for 1964 may total between 1.2 and 1.5 million. Public demand for color sets has been established and the total volume of sales will depend largely on the industry's ability to increase its tube-making capacity fast enough to meet that demand. In all its aspects, from manufacturing to broadcasting to servicing, color at the retail level promises to become a billion-dollar industry in 1964.

Electronic data processing should continue in 1964 to rival color as a principal growth factor in the industry. The sale, lease, and servicing of data processing systems probably will expand from 15 to 18% annually in the foreseeable future. RCA expects to continue as one of the major computer manufacturers and to benefit from the industry's growth.

STERZER, BLATTNER, JOHNSON, AND MINITER HONORED FOR "OUTSTANDING PAPER"

In a recent announcement by the International Solid-State Circuit Conference, University of Pennsylvania, four members of the ECD technical staff were honored for their outstanding paper presentation at the 1963 Conference. The citation is to **F. Sterzer, D. J. Blattner, H. C. Johnson,** and **S. Miniter** for their paper entitled "Cuprous Chloride Light Modulators." At a special ceremony on February 19 at the University of Pennsylvania, the authors received a Conference Plaque with the citation "*An imaginative contribution to light modulation.*"—*H. Wolkstein*

DR. OLSON RECEIVES THE JOHN ERICSSON AWARD

Dr. Harry F. Olson, Director of the Acoustical and Electromechanical Research Laboratory of the RCA Laboratories was awarded the *John Ericsson Medal* of the American Society of Swedish Engineers at the Annual Banquet of the Society on February 8, 1964 in New York, New York. The medal is presented every second year and alternately to a Swedish citizen or an American citizen of Swedish extraction in recognition of outstanding achievement in the technical or scientific fields. He was awarded the medal for "*outstanding and valuable scientific contributions in the field of acoustics.*" Dr. Olson joined RCA in 1928, and holds more than 90 U.S. Patents on devices and systems in the acoustical field and is the author of more than 100 papers and the books.

DR. ENGSTROM RECEIVES SWEDISH-AMERICAN OF THE YEAR AWARD

Dr. Elmer W. Engstrom, RCA President, was recently the recipient of the 1963 *Swedish-American of the Year Award* from the Vasa Order. The award, given each year for the past four years to a person born in the United States of Swedish ancestry, is presented for important contributions to the cultural relations between the United States and Sweden. (The recipient in 1962 was Dr. Glenn Seaborg, Chairman of the Atomic Energy Commission.) The award, in the form of a gold plaque, was presented at Skansen, an outdoor museum in Stockholm, in a ceremony attended by several thousand persons.

DEL ROCCILI, HERSEY, AND KRAGER CITED FOR PACKAGING ACHIEVEMENTS

Two RCA Packaging Design Engineers won prizes at the 15th National Championship Packaging and Handling Competition sponsored by the Society of Packaging and Handling Engineers.

Albert Del Roccili, Broadcast and Communications Products Division, Camden, received first prize ($100 bond plus trophy) for a package featuring the use of moulded rubberized hair to cushion a delicate electron gun. In addition to providing a safer pack, the new design is easier to handle and lower in cost.

Rodney E. Hersey, DEP Communications Systems Division, Cambridge, Ohio, was given a second prize ($50 bond plus trophy) for a military package for a MINUTEMAN drawer assembly. The five-piece rack replaced one that used 19 pieces, with overall savings computed at 35%. Also, the new package is reusable.

In addition, **J. L. Krager,** DEP Central Engineering, Camden, was cited in letters to RCA by Admiral O. P. Lattu, of the Navy Bureau of Supplies and Accounts, and by R. E. Beach, President of the National Security Industrial Association, for Mr. Krager's contributions to a Navy workshop seminar on the packaging and handling of critical parts.—*J. Gillespie.*

SIX-MONTH TRAINING COURSE ON TRANSISTOR FUNDAMENTALS AT RCA LABORATORIES

Twenty-four men at the David Sarnoff Center have enrolled in a six-month Semiconductor-Transistor course developed in conjunction with the RCA Institutes, Inc. This training class, taught by **Richard Quinn** of RCA Laboratories, meets in weekly two-hour sessions to study basic principles and applications of semiconductor devices.

—*C. W. Sall*

CABINET PLANT EXPANDS

The RCA Victor Home Intruments Division has announced an expansion program well in excess of $1 million for its Monticello, Indiana, plant which supplies cabinets for television receivers and Victrola phonographs. Upon completion of the construction, the Monticello plant will be one of the largest producers of television and phonograph cabinets in the world.

DR. ZWORYKIN RECEIVES AWARD

Dr. Vladimir K. Zworykin, honorary Vice President of RCA and Director, General Research Laboratory, RCA Laboratories, has been selected to receive the American Society of Metals *Albert Sauveur Achievement Award*. The Sauveur Award Presentation cited Dr. Zworykin's pioneering metallurgical achievements effecting a marked basic advance in metallurgical knowledge. Achievement of practical television stems to a large extent from the pioneering work of Dr. Zworykin whose conception of the first practical tube for picture transmission, the iconoscope, and the development of the kinescope picture tube, formed the basis for all important later advances in the field.

A. J. Vaughan

VAUGHAN NAMED AED CHIEF ENGINEER

The appointment of **A. J. Vaughan** as Chief Engineer of the DEP Astro-Electronics Division, Princeton, N.J., has been announced by **Barton Kreuzer,** Division Vice President and General Manager. Mr. Vaughan was promoted from the engineering technical advisory staff. As Chief Engineer he heads all engineering functions embodied in eight departments.

A native of Breat Britain, Mr. Vaughan joined AED last year. He had been with the Guided Weapons Division of English Electric. He had been Assistant Chief Development Engineer and Chief Engineer for English Electric's Thunderbird missile weapon system. Earlier, Mr. Vaughan was on the engineering staff of the Bristol Aeroplane Company, working primarily on instrumentation for aircraft and missiles. He is a former officer of the Royal Air Force.

Mr. Vaughan holds a science degree from London University's City and Guilds College where he majored in electrical engineering and was an honor student in mathematics. He is a member of the Institute of Electrical Engineers (Great Britain) and an Associate of the City and Guilds of London Institute.

NEW MICROWAVE SOLID STATE ENGINEERING ACTIVITY

Establishment of a new microwave solid state engineering activity at the headquarters of Electronic Components and Devices was announced recently by **C. C. Simeral, Jr.,** Manager, Microwave Tube Operations Department, ECD. **W. J. Dodds** has been appointed Manager, Solid State Device and Pencil Tube Engineering and will head the new activity. This operation will be responsible for the product engineering of such devices as varactor multipliers, parametric amplifiers, tunnel oscillators, amplifiers and down converters. These devices are widely used in electronic equipment for missiles and satellites as well as for commercial communications and radio-relay systems.

Establishment of the new microwave solid state engineering laboratory is a direct outgrowth of the recent consolidation of RCA's Electron Tube Division and Semiconductor Division. Because of the consolidation, the majority of engineering personnel now located at the RCA Microwave Tube Engineering Laboratory in Los Angeles will be transferred to the new activity, at larger quarters, in Harrison, N.J. This move will permit closer liaison with research work at RCA Laboratories in Princeton and semiconductor engineering programs conducted at the RCA plant in Somerville, N.J.

MISTERLY NAMED STAFF VICE PRESIDENT, PATENT OPERATIONS

Appointment of **Frank S. Misterly** as Staff Vice President, Patent Operations, RCA, was announced recently by **Dr. George H. Brown,** Vice President, Research and Engineering. In his new position, he will have responsibility for RCA domestic and foreign patent operations and for the RCA trademark activity. Mr. Misterly graduated from Rensselaer Polytechnic Institute with an ME degree in 1925, and received an LL.B degree from Fordham University Law School in 1931. He joined RCA in 1927 as a patent attorney. In November 1958, he was named Manager of Patent Services, a position he held until his new appointment. Mr. Misterly is a member of the Bar of New York and has been admitted to practice before the United States Supreme Court and the United States Patent Office. He is a member of the New York Patent Law Association and the Association of the Bar of the City of New York.

RCA EXECUTIVES DRS. BROWN, HILLIER AND EWING NAMED TO GOVERNMENT AND INDUSTRY ADVISORY POSTS

Dr. George H. Brown, Vice President, Research and Engineering, was recently reappointed to the science and technology committee of the Chamber of Commerce of the United States. The committee studies and makes recommendations on the problems of advancing science and technology, including industrial research development, governmental and changing national policies.

Dr. James Hillier, Vice President, RCA Laboratories has been appointed by Governor Richard Hughes as a member of the Governor's committee on higher education which will make a study of higher educational resources in New Jersey. The study will include recommendations for the provision of educational opportunities for all qualified persons in New Jersey's institutions of higher learning and for facilities to provide trained personnel for business and government.

Dr. Douglas H. Ewing, Vice President and Technical Director, RCA, has been appointed a member of the Board of Directors of the American Management Association and named to the Board's Executive Committee.

COMPUTER ADVANCED DEVELOPMENT GROUP MERGED WITH DEP APPLIED RESEARCH

The Computer Advanced Development Group has been merged with DEP Applied Research in Camden. This consolidation provides both DEP and EDP with a broader and more effective base for research in computer techniques. The merged organization will continue to be known as DEP Applied Research with **Donald J. Parker** as Manager. **J. Nathaniel Marshall,** who headed the Computer Advanced Development Group, is now Manager of Common Components for EDP and serves as the key point of communications between EDP and Applied Research.

The personnel and equipment of the Computer Advanced Development Group have been moved from Pennsauken, N.J. to Camden. In addition to the laboratory facilities for logic and memory experimentation, the RCA 301 computer formerly in Pennsauken has been moved to Bldg. 10-7 in Camden and is programmed and run by individual engineers for circuit simulation and design automation studies.

The Applied Research program in computer techniques for 1964 consists of programs in machine organization, logic and memory circuitry, and peripheral equipment. Reflecting the broad military and commercial scope of the activity, the individual programs are sponsored by DEP Applied Research and Development Funds, EDP General Engineering and Development Funds, and RCA Laboratories Applied Research Funds. In addition, the group does work for specific customers.

MASSOTH HEADS CAMDEN-COMPLEX COMMUNITY AND PUBLIC AFFAIRS

Effective January 27, 1964, in addition to his other responsibilities, **T. W. Massoth,** Manager, Administration, will become responsible for coordinating community and public affairs for the RCA Greater Camden area complex—including Camden, Cherry Hill, and Moorestown—as well as for all Defense Electronic Products locations. Mr. Massoth will continue to report to **W. G. Bain,** Vice President, Defense Electronic Products, for all his Defense Electronic Products responsibilities, and to **A. L. Malcarney,** Group Executive Vice President, for his Camden area community and public affairs assignment.

TO N.J. ENGINEERS: POTENTIAL CHANGES IN PROFESSIONAL LICENSING LAWS

A special Law Study Committee, appointed in May of 1963 by the New Jersey Society of Professional Engineers, has prepared a number of major and minor revisions to be submitted to the New Jersey Legislature for inclusion in a proposed revision of the existing laws. Those proposed revisions that pass in the Legislature will become law.

Included in the proposed revisions is the *deletion* of the present provisions which permit a qualified individual having 15 years of professional experience to apply for a license *without* taking the written examination after he has reached the age of 40 years.

During a recent meeting of the Engineering Society of Southern New Jersey it was suggested by the undersigned that present provisions regarding licenses be extended 2 years before the revised law would become effective. A motion was made along this line, but was voted down.

Thus, in view of the trend to strengthen the laws in New Jersey, it is strongly recommended that qualified engineers, in both technical and management positions, proceed to apply to the State Board for a PE license *without further delay.* It will likely be much easier to obtain a license in the immediate future than it will be later on.

Requests for application forms and related information should be addressed to: The New Jersey Board of Professional Engineers, 1100 Raymond Boulevard, Jersey City, N.J.—*H. W. Phillips, MSR, Moorestown*

. . . PROMOTIONS . . .

to Engineering Leader & Manager

As reported by your Personnel Activity during the past two months. Location and new supervisor appear in parenthesis.

Electronic Components & Devices

- **I. E. Martin:** from Sr. Engr. Prod. Dev. to *Eng. Leader, Prod. Dev.* (Mgr., Adv. Dev. Engineering-Power Tubes & Vacuum Components) Lancaster.
- **J. G. Ottos:** from Sr. Engr. Prod. Dev. to *Eng. Leader, Prod. Dev.* (Mgr., Environmental Special Equip. & Spec. Eng.) Lancaster.
- **D. A. Pahls:** from Eng. Coordinator, Mfg. & Prod. Eng. to *Eng. Leader, Mfg. and Prod. Engineering,* Mountaintop.
- **A. C. Tunis, Jr.:** from Engr., Mfg. to *Mgr., Super Power Tube Prod. Engineering* (Mgr., Super Power Tube Mfg.) Lancaster.

Record Division

- **P. J. Wymann:** from Engr., Design & Dev. to *Mgr., Adv. Dev., Tape Formulations* (H. E. Roys, Chief Engineer) Indianapolis.

Communications Systems Div.—DEP

- **R. E. Thorngate:** from Sr. Proj. Mbr. Tech. Staff to *Ldr., Design & Dev. Engrs.* (Dr. H. N. Crooks, Cambridge)
- **C. J. Billian:** from Sr. Mbr. Tech. Staff to *Ldr., Design & Dev. Engineers* (P. J. Riley, Cambridge)

Astro-Electronics Division—DEP

- **J. B. Newman:** from Engr. to *Leader, Engineers* (R. Warner, Mgr. Adv. Systems & Oper. Analysis) Princeton.
- **A. J. Vaughan:** from Member Tech. Adv. Staff to *Chief Engineer, Engineering* (B. Kreuzer, Div. V.P. & Gen. Mgr.) Princeton.
- **G. A. Beck:** from Engr. to *Ldr., Eng. System Projects* (C. T. Cole, Mgr., Hightstown)
- **J. Hermann:** from Engr. to *Ldr., Engineers* (G. Hieber, Mgr. Environmental Simulation, Hightstown)
- **G. Hieber:** from Ldr., Engineers to *Mgr., Environmental Simulation* (E. Goldberg, Mgr., Spacecraft Design & Test, Hightstown)
- **J. E. Keigler:** from Ldr., Engineers to *Mgr., Systems Eng. & Integration* (J. Lehmann, Mgr., Space Observation System, Hightstown)
- **D. McCandless:** from Assoc. Engr. to *Ldr., Engineers* (G. Hieber)
- **E. Mowle:** from Engr. to *Ldr., Eng. Systems Projects* (A. Schnapf, Mgr. TIROS, Hightstown)
- **D. L. Sussman:** from Assoc. Engr. to *Ldr., Engineers* (G. Hieber)
- **C. Yutkowitz:** from Sr. Engr. to *Ldr., Engineers* (M. H. Mesner, Mgr., TV Camera Systems, Hightstown)

Aerospace Systems Division—DEP

- **P. B. Korda:** from Ldr. Dev. & Des. Eng. Staff to *Mgr., Electronic Dev. & Design* (J. J. Murphy) Van Nuys.
- **H. Scheuer:** from Sr. Mbr. D&D Eng. Staff to *Ldr., Dev. & Des. Eng. Staff* (J. Murphy, Van Nuys)
- **R. D. Sidnam:** from Ldr., Systems Eng. Evaluation & Res. to *Mgr., Saturn Eng.* (R. Landee, Van Nuys)

RCA Service Co.

- **J. B. Caskey:** from Field Engr. to *Mgr. ARIS Radar & Optics*—Shipboard (S. Candler, Mgr.)
- **H. S. Howard:** from Engr. to *Ldr., Engineers* (C. W. Fisher, Mgr.)
- **N. A. Perna:** from Assoc. Engr. to *Ldr., Engineers BMEWS* (A. Freeman, Mgr.)

Home Instruments Division

- **R. N. Rhodes:** from Mgr. Adv. TV Prod. Dev. to *Mgr., New Electronic Systems* (L. R. Kirkwood, Chief Engineer) Indianapolis. (*correction*)

STAFF ANNOUNCEMENTS

DEP Communications Systems Division, Tucson: **M. L. Touger** has been appointed to the newly created post of Manager, Design Engineering. He was formerly Manager of Magnetic Recording at CSD headquarters facility in Camden.

DEP-Communications Systems Division, Camden: **S. W. Cochran,** Division Vice President and General Manager, CSD, announces his CSD organization as follows: **M. R. Amsler,** Manager, Marketing Department; **J. E. Sloan,** Manager, Data Communications Programs; **O. B. Cunnigham,** Chief Engineer, Engineering Department; **J. A. Doughty,** Manager, Proposals and Presentations; **J. E. Finnegan,** Manager, Equipment Maintenance and Support; **R. W. Greenwood,** Manager, Operations Control; **C. K. Law,** Manager, Aerospace Communications Systems; **J. M. Osborne,** Manager, Minuteman Program; **C. A. Steuernagel,** Manager, Communications Systems Manufacturing; **T. J. Tsevdos,** Manager, Ground Communications Programs; and **J. D. Woodward,** Manager, Product Assurance.

Electronic Data Processing, Camden: Effective January 10, 1964, the Board of Directors of the Radio Corporation of America has elected **A. K. Weber** a Vice President of the Corporation. Mr. Weber will continue as Vice President and General Manager of Electronic Data Processing and will report to **A. L. Malcarney,** Group Executive Vice President.

Effective January 13, 1964, **E. S. McCollister** has been appointed Division Vice President and Operations Manager, EDP. In this capacity, Mr. McCollister will be responsible for Marketing, Product Planning, Engineering, Production, and Project Management activities of the Electronic Data Processing organization. Mr. McCollister will continue to report to **A. K. Weber,** Vice President and General Manager, Electronic Data Processing.

Mr. Weber announces his EDP organization as follows: **E. S. McCollister,** Division Vice President and Operations Manager; **B. G. Anderson,** Manager, Special Programs; **K. Hesdoerffer,** Manager, Product Assurance; **J. N. Landon,** Manager, Personnel; and **J. H. Walker,** Controller, Finance.

Mr. McCollister announces his organization as follows: **A. D. Beard,** Chief Engineer, Engineering; **A. G. Daubert,** Manager, Project Management; **R. G. Dee,** Division Vice President, Marketing; **W. R. Lonergan,** Manager, Product Planning and Programming; and **J. A. Scarlett,** Manager, Operations—Palm Beach.

J. N. Marshall has been named Manager, Common Components and Standards Engineering, EDP, reporting to **A. D. Beard,** Chief Engineer, EDP. Mr. Marshall will coordinate the development and utilization of memory devices, circuits and packaging techniques for RCA's commercial computers, with emphasis on standardization of components. Formerly Manager, Advanced Systems Development Engineering, he will continue his responsibility for engineering coordination with advanced development and research activities of RCA.

ECD Industrial Tube and Semiconductor Division, Harrison: **H. K. Jenny,** Manager, Microwave Engineering, announces his organization as follows: **W. J. Dodds,** Manager, Solid State Device and Pencil Tube Engineering; **M. Nowogrodzki,** Manager, Microwave Engineering Programs; **F. Sterzer,** Manager, Microwave Applied Research; **R. G. Talpey,** Manager, Microwave Support Engineering and Special Products Manufacturing; and **F. E. Vaccaro,** Manager, Traveling-Wave Tube and Magnetron Engineering.

ECD-Commercial Receiving Tube & Semiconductor Division, Needham, Mass.: **F. E. Vinal,** Manager, Memory Products Engineering, announces his organization as follows: **B. P. Kane,** Manager, Memory Systems Engineering; **H. P. Lemaire,** Manager, Advanced Development; **W. O. Olander,** Manager, Applications, Memory Products; and **L. A. Wood,** Manager, Memory Devices Engineering.

Defense Electronic Products (Staff), Camden: Effective Jan. 31, 1964, **S. N. Lev,** Division Vice President, Defense Manufacturing and Program Management, announces his organization as follows: **B. Fein,** Manager, Engineering; **J. R. Shirley,** Manager, Aviation Equipment Department; and **F. O. Ziegler,** Manager, Facilities and Services.

DEP-Aerospace Systems Division, Van Nuys: **C. A. Wolf,** Manager, Operations, Van Nuys, announces his organization as follows: **W. R. McKinley,** Manager, Operations Control; **B. W. Tucker,** Plant Manager, Van Nuys Plant; **I. B. Jenkins,** Manager, Materials and Facilities; **R. W. Landee,** Chief Engineer, Engineering Department; **A. E. Fogelberg,** Manager, Saturn Programs; **J. J. Murphy,** Manager, RACE Program; **M. E. Collins,** Manager, Product Assurance; and **R. V. Javins,** Manager, West Coast Personnel.

DEGREES GRANTED

- **J. Claffie,** DEP-AppRes .... MSEE, University of Pennsylvania
- **J. W. Coleman,** BCD .... Ph.D. (Molecular Biology) University of Pennsylvania
- **F. Koker,** DEP-MSR .... MSEE, University of Pennsylvania
- **V. Stachejko,** DEP-MSR .... MSEE, University of Pennsylvania

REGISTERED ENGINEERS

- **D. F. Schmit,** Vice Pres., Prod. Eng., PE-13134, N.J.
- **H. Cohen,** ECD, PE-13278, N.J.
- **D. Mawhinney,** ECD, PE-13246, N.J.
- **D. R. Purdy,** ECD, PE-13247, N.J.

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To enable RCA to maintain valuable indexes (see *Pen & Podium*, this issue) to its published scientific information, all RCA engineers and scientists should notify their Technical Publications Administrator whenever one of their technical papers is published or presented before a technical society. The TPA should be given the exact name, volume number, and the date of the publication, and/or the exact name of the professional society meeting and the date the paper was presented. Furnishing such information will enable the RCA ENGINEER and the *RCA Review* to make their technical paper indexes more accurate and complete.

The TPA's are: **F. Harris,** RCA International, Clark; **K. A. Chittick,** Home Instruments, Indianapolis; **M. G. Gander,** RCA Service Co., Cherry Hill; **W. A. Howard,** NBC, N. Y.; **C. Frost,** RCA Communications, N. Y.; **A. M. Max,** RCA Victor Records, Indianapolis; **C. A. Meyer,** ECD, Harrison; **T. T. Patterson,** EDP, Camden; **D. R. Pratt,** BCD, Camden; **H. J. Russell,** RCA Victor Co., Ltd., Montreal; **C. W. Sall,** RCA Laboratories, Princeton; and **F. D. Whitmore,** DEP, Camden. Assisting Mr. Whitmore are: **J. Carter,** DSC, Bethesda; **D. Dobson,** ASD, Burlington; **S. Hersh,** ASD, Van Nuys; **C. W. Fields,** CSD, Camden; **T. Greene,** MSR, Moorestown; **M. Pietz,** AR, Camden; and **I. Seideman,** AED, Princeton.

PROFESSIONAL ACTIVITIES

DEP Astro Electronics Div., Princeton: **Robert W. Northup** has been appointed to the Technical Committee on Space Structures of the American Institute of Aeronautics and Astronautics. **Dr. Richard Marsten** has been appointed to the Technical Committee on Communications of the AIAA. —*I. Seideman*

DEP Missile and Surface Radar, Moorestown: **Frank Klawsnik** was one of a panel of five invited to speak at the "Conference on Microwave Components Needs," Boston, Massachusetts on November 3, 1963. — *T. Greene*

ECD, Lancaster, Pa.: **Jules M. Forman** (P.E.) has been appointed by the Board of Directors of Lincoln Chapter of the Pennsylvania Society of Professional Engineers as Chairman of a new committee entitled "Professional Engineering Examination Committee." This committee will coordinate the joint efforts of Professional Engineers from Lincoln Chapter, PSPE, and the Technical Societies Council, representing all engineers from Southeastern Pennsylvania. The primary purpose of this committee is to assist the PSPE State Society to furnish better and detailed questions and answers to the State Registration Board for potential use for the P.E. exam in all engineering fields.—*G. G. Thomas*

Robert G. Neuhauser conducted Television Camera Tube Engineering Seminar in San Francisco on Oct. 21 to 24, 1963. **George E. Jannery** conducted Television Camera Tube Engineering Seminars in Dallas, Texas on Oct. 21, 1963 and in Greensboro, N.C., on Oct. 24, 1963.—*R. L. Kaufman*

DEP Aerospace Systems Div., Burlington: The following courses, with over 160 registered, are being given: Written and Oral Communications, Integrated Electronics. Radar Fundamentals, Radar Systems, PERT. and Management Use of PERT. Also, on Oct. 2, 1963 **D. J. Parker,** Mgr., DEP Applied Research, Camden, conducted a seminar in Burlington on the activities of his group. —*R. E. Glendon*

DEP Communications Systems Div., New York: **Carl Sontz** has been appointed to the Community Planning Board by Borough President Perriconi of the Bronx. He will act as an advisor to the Borough President, the City Planning Commission, and other city agencies concerning housing, social service and welfare, hospitals and health, schools and education, parks and recreation, Civilian Defense and other public functions. —*C. W. Fields*

RCA Service Co., Patrick AFB, Fla.: RCA/MTP Optics Engineering personnel are to participate in planning the Society of Photographic Instrumentation Engineers (SPIE) annual Symposium which is to be held at the Deauville Hotel in Miami Beach, Florida, from 24-28 August 1964. The following appointments have been made: **G. B. Cope,** as Chairman, Technical Program; **W. C. Terry,** as Vice Chairman, Technical Program; **W. A. Price,** as a member of the Technical Program Committee. — *W. L. Strayer*

ENGINEERING LECTURE SERIES BEGUN IN CAMDEN

Communications Systems Division Engineering has initiated a series of talks in Camden to promote the interchange of technical information among engineering groups in the area. Primarily based on recently completed papers and reports, the talks are meant to accomplish several ends: as briefing of engineers on subjects outside their specialty; as "dry runs" for authors scheduled to give papers at symposia; for the further exposition of company reports; and to give creative individuals the opportunity to discuss their accomplishments with their colleagues.

The lectures are given during the lunch hour in the Little Theatre, Building 2. They last 20 minutes, include illustrations, and are followed by a 10-minute question-answer period. The talks will be held approximately bi-weekly, and selected technical films may be shown alternately, as appropriate.

The first talk was given on January 21 on *The Grounding of Electronic Installations*, by **R. F. Ficcki,** CSD, Camden. A standing-room-only audience of 70 included **S. W. Cochran,** Vice President and General Manager of Communications Systems Division. The speaker was introduced by **Dr. R. Guenther,** Chief Scientist of CSD.

The second talk, on February 4, was *Computer Simulation of Data Communication Systems*, by **E. W. Veitch,** Administrator, Data Communications Programs, CSD, and inventor of the "Veitch Diagram," it again drew a standing-room-only audience.

The slant of the talks is intended to be tutorial on a general technical level, to serve as a briefing for engineers representing the variety of specialties in Camden area groups. For more specific information, a listener can arrange to meet with the speaker for further discussion; additionally, available reference works will be posted at each meeting.

While CSD Engineering Publications initiated the series, it is hoped that other Camden area activities will join in providing talks to achieve a fruitful exchange of technical information on a broad scale. Administrator of the program is **C. W. Fields,** Chief Editor, CSD, Building 10-4-4, PC-4468.

E. W. Veitch lectures on computer simulation to an SRO audience in the Camden Little Theater.

D. F. Schmit (left) Staff Vice President, Product Engineering, with E. W. Veitch.

Dr. Richard Guenther (left) congratulates R. F. Ficcki after his lecture on grounding.

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