RCA Engineer

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RCA Limited

RCA Limited is the most important RCA operation outside the United States. It also possesses one of the highest levels of technological and engineering competence in Canada. For the past 50 years, this company has traditionally occupied a commanding position in the Canadian electronics industry and it continues to do so today.

Of the complete line of television and stereo products we sell in Canada, fully 99% are designed by our own engineers and manufactured in our own facilities. We also produce many of our own components, including color picture tubes which we also supply to most other major Canadian manufacturers.

RCA Limited is also deeply involved in the field of high technology communications systems, and we have developed a world-wide reputation for our skills in the design, test, and manufacture of very advanced antenna systems and transponders for communications satellites as well as complete satellite earth stations and terrestrial microwave systems.

Although our operations are, of necessity, scaled down from those in the United States, we have achieved a level of technical sophistication which is comparable in terms of quality with that of our parent company.

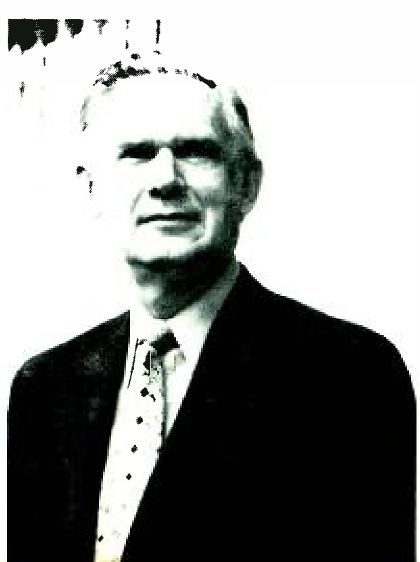
Our research activities, for example, have been extremely productive despite their limited scope. Canadian work on electro-optics was directly responsible for the establishment two years ago of an Electro-Optics Department which presently produces some of the most sensitive solid state detectors available.

Intensive research has also been going on in the area of lasers for communications and our Montreal laboratories still houses the world's longest-lived carbon dioxide laser, which has been operating for more than 27,000 consecutive hours.

In the field of electronic digital display, our engineers have just completed six months of field tests on a color alphanumeric character generator for television applications which is already attracting widespread interest in the international broadcasting community. It is called Video IV and is the first multi-channel system especially designed for broadcasters.

Space permitting, I could continue this recital for some time, but the above examples may illustrate why we are so proud of our operations in Canada and why we are so grateful to the editors of *RCA Engineer* for giving us this opportunity to tell you about them.

We're going places in Canada, and I'm confident that you will be hearing much more from us in the future as we continue to become ever more important in the RCA scheme of things.



G. Denton Clark
President and Chairman of the Executive Committee
RCA Limited
Ste Anne de Bellevue, Quebec

Our cover

Canada's national symbol—the maple leaf—is the background for several examples of the diverse, wide-ranging, product lines offered by RCA Limited in Canada. As demonstrated within the issue, RCA Ltd's products and services are a significant and integral force in Canada's electronics industry, several products and programs—particularly development work in communications—have gained acceptance internationally. **Cover concept:** Joan Dunn; **Photography:** Reg Downs, Davis Photographers, Pointe Claire, Montreal, Quebec

Back cover

...shows the colorful display produced by the Video IV broadcast controller—a new product for the television broadcast industry

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RCA Engineer

• 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 to RCA engineers in a manner most likely to enhance their prestige and professional status.

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RCA Limited — a profile

W. A. Chisholm

RCA Limited, one of Canada's leading producers of diversified electronic equipment and services, is a major force in the development of electronic technology. The company is carrying out significant applied research and development programs for government and industry in Canada, as well as improving electronic products and services for home use. Particularly significant is the work being carried on to improve communications over vast distances and in unique climatic conditions.

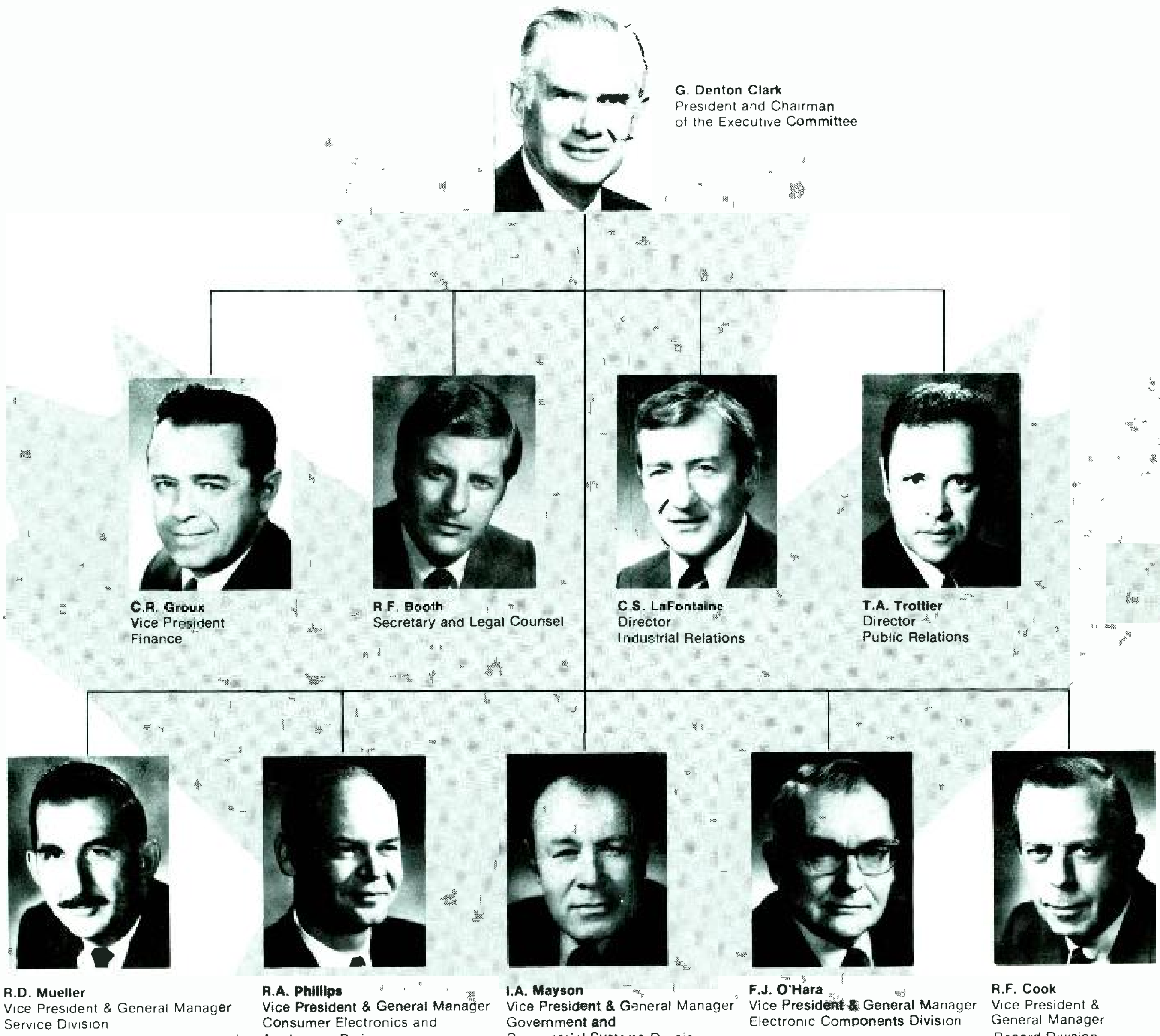

Fig. 1 — Organization of RCA Limited.

RCA Limited headquarters at Ste Anne de Bellevue Quebec.

THE ASSOCIATION of RCA Limited with Canada dates back to the 1890's when a young inventor working with Alexander Bell conceived the revolutionary idea of making phonograph records in the form of flat discs rather than cylinders. The inventor was Emile Berliner, and in 1899 he set up the E. Berliner Company in Montreal. With one press and two employees, he began producing the little six-inch records which were to mark the beginning of an enormous world-wide industry.

By 1924, the company had amalgamated with similar interests in the U.S. to form the Victor Talking Machine Company of Canada Limited. In the meantime, a new company had been established in the U.S. to engage in the wireless communications business. It was known as the Radio Corporation of America and it commenced operations in 1919, one year before radio broadcasting became a commercial reality. Recognizing the possibilities inherent in this new medium, RCA began manufacturing home radio receivers in 1920. Soon RCA was developing new equipment for transmission as well as reception, and in 1923 the company acquired radio station WJZ, New York — the first station of a continent-spanning network that would one day become the National Broadcasting Company.

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RCA was quick to see the value of combining the radio with the phonograph and acquired the interests of the Victor Talking Machine Company in Canada and in the U.S. Later, in Canada it became known as the RCA Victor Company Limited and, in 1968, as RCA Limited.

In Canada, emphasis on research and development permitted the Canadian company to secure a commanding position in the home entertainment field and provided Canadian engineers and scientists with an opportunity to develop highly specialized skills in communications technology — skills which became an invaluable strategic asset during the Second World War.

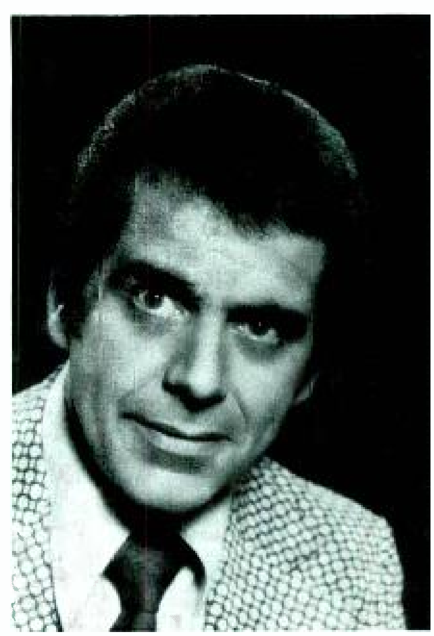
In 1945, RCA built Canada's first microwave relay, and when television came to this country in 1952, RCA built and installed the transmitter and antenna for the first station to go on the air. With the introduction of color television, RCA receivers were the first on the Canadian market, and in 1964 the company opened Canada's first fully integrated color picture tube manufacturing plant at Midland, Ontario.

This continuing emphasis on research and applied technology paved the way for RCA Limited's extensive contributions to space technology. By 1961, scientists at RCA's Montreal Laboratories had developed the technology necessary to design and manufacture the transponder systems for NASA's pioneer communications satellites — Relay I and Relay II. Since that time, RCA Limited has been a major contributor to more than seven important space programs, including Canada's Alouette and ISIS scientific satellite series.

The Company is organized, under its President, Mr. G. Denton Clark, into five major operating divisions. Fig. 1 shows the company organization.

The Company consists of some 6,000 scientists, engineers, managers and other skilled employees and has a current business volume in excess of $160,000,000. Products are designed, manufactured and produced in eight manufacturing plants in Canada. The head office of the Company is in Ste. Anne de Bellevue, Quebec.

William A. Chisholm, Mgr., R&D Administration R&D Laboratories Ste. Anne de Bellevue, Quebec, graduated from the Royal Technical College (Strathclyde University) Glasgow, Scotland, with a Higher National Certificate in Mechanical Engineering. Upon arrival in Canada, he was involved in the design of marine heating equipment for the RCN Hydrographic survey vessels. Following this, Mr. Chisholm joined Canadair Ltd., a division of the General Dynamics Corporation, where he carried out design and analysis of aircraft flying controls and equipment. In 1959 he became Assistant Secretary of the Canadian Aeronautics and Space Institute and Editor of the Institute's Journal. In 1961 he returned to Scotland to take up the position of Project Engineer with Pressed Steel Co. Ltd., Paisley, where he was responsible for the design, manufacture and production of automobiles. In 1963 he rejoined Canadair Ltd., in Montreal, where he designed the landing gear and flying controls on both V/STOL TiltWing aircraft and amphibian aircraft. He was promoted and transferred to the Research and Development group and became involved in helicopter, ground-effect machines and missiles. In 1965 he was appointed "Assistant to the Director of Research & Development". In this capacity he administered the Company R&D activity. He joined RCA Limited in March 1967. His present responsibilities are the business management of the R&D Laboratories, control and supervision of the R&D Program Management Office, and coordination of Research Marketing. Included in these duties are customer contract negotiation and administration; marketing and technical services; the operation and development of the Company Library and Technical Publications; and control of the operations of the R&D Laboratories. Mr. Chisholm is the Technical Publications Administrator for RCA Limited in Canada.



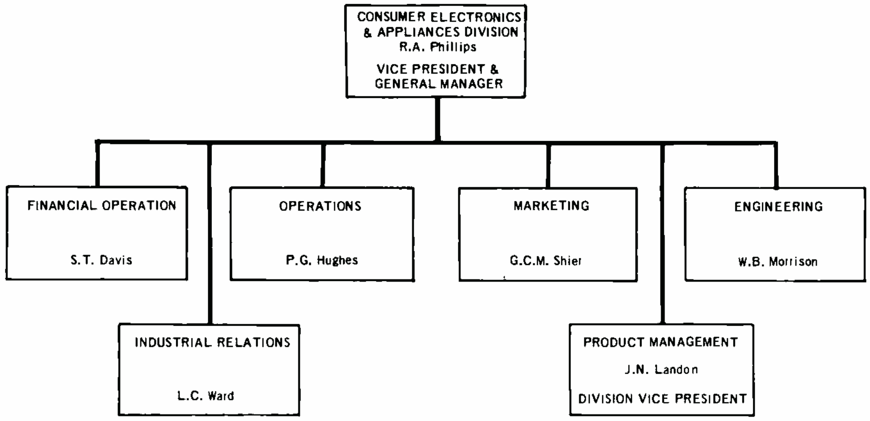


Fig. 2 — Organization of Consumer Electronics and Appliances Division.

Consumer Electronics and Appliances Division

RCA Limited has been recognized for more than 40 years as Canada's leading manufacturer of electronic consumer products. The company is the largest manufacturer of television receivers in Canada and one of the most important producers of RCA consumer products outside the United States.

Under Mr. R. A. Phillips, Vice President and General Manager, the Division is operated through four principal locations in Ontario and Quebec and at sales offices across the country. Plants are located at Prescott, Ontario (television manufacturing); Owen Sound, Ontario (television and stereo cabinets, stereo assembly) and Renfrew, Ontario (television and stereo components). Engineering, industrial design, marketing and advertising activities are conducted at the company's head office at Ste. Anne de Bellevue, Quebec. The organization of the Division is shown in Fig. 2.

Apart from the black-and-white and color television receivers, the Division also designs and manufactures a full line of stereo products specifically oriented toward the Canadian market. This includes everything from medium and high-priced component stereos to full-sized furniture consoles as well as our specially designed "Forma" series of ultra-modern pedestal stereos.

Unlike the parent division in the United States, the bulk of the distribution traditionally has been directly to dealers. This has meant maintaining a coast-to-coast sales organization. This organization is also used to market a complete line of household appliances (such as dishwashers, ranges, refrigerators, freezers, washers and dryers, and air conditioners) which bear the RCA name and which are made to RCA specifications.

The principal thrust, of course, is in electronic consumer products, and in this area a number of innovations have been produced which set the products apart from many of those manufacfured by RCA in the United States.

In television, for example, the design and engineering team developed the Accu-Touch Electronic Tuning System which uses illuminated pushbuttons to change channels rather than the conventional mechanical rotary switch. This improves reliability in the tuning mechanism and has also proven very popular with the public.

The same team was also responsible for the unique Super 90 Color chassis which was initially designed to bridge the gap between the less sophisticated "hybrid" chassis and the more expensive 100% solid-state quality and reliability at a cost which now makes it eminently suitable for use in lower priced receivers.

Canada poses a number of special problems in the manufacture and marketing of electronic consumer products. The country has a population of less than 21 million, yet Canadian consumers demand the same variety of choice and availability of options as people in much more populous nations — a situation which places companies like RCA Limited in a rather difficult position.

In television, for example, the production of a wide range of models employing a variety of chassis and picture tubes for such a limited market has traditionally meant short production runs with frequent changeovers — and a new learning process and the development of separate testing procedures on each occasion. The results were costly both in terms of quality and unit cost of production.

This, together with the competitive threat posed by a rising tide of low priced, high quality imports, led to the development of two radically new programs — IBS (Integrated Business Systems) and QRS (Quality Reliability Service). These programs have proved invaluable in meeting the unique requirements of the Canadian market.

Innovation is not a word taken lightly in the Consumer Electronics and Appliances Division, and it is sincerely believed that some of the ideas developed, and continuing to be developed, in Canada will be of considerable benefit to other divisions within RCA Corporation.

Government and Commercial Systems Division

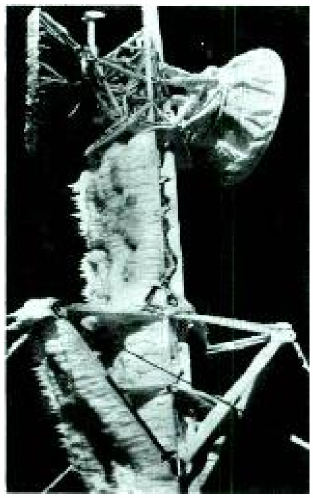
The Government and Commercial Systems Division of RCA Limited, headed by Mr. I. A. Mayson, Vice President and General Manager, is a high technology center devoted primarily to the design and supply of communications systems and equipment to serve government and the telecommunications and broadcast industries (see Fig. 3). It is located within a 225,000 ft^2 modern headquarters complex of RCA Limited at Ste. Anne de Bellevue, Quebec. The operation includes a 22,000 ft^2 research laboratories area, ultra-clean laboratories for design, development and small volume assembly of specialized systems, an environmental test laboratory, and a precision engineering model shop equipped with numerical control machinery. Test equipment, valued in excess of $6 million, is available for research and development work.

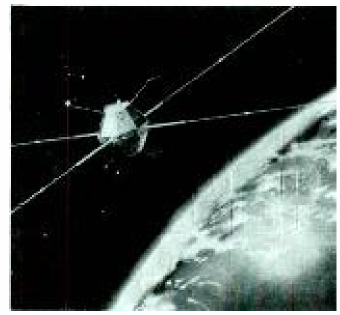
The Division consists of over 800 employees — almost one-half are scientists and engineers — working in seven identifiable business areas:

- Satellite earth stations

- Communications satellite and spacecraft subsystems
- Microwave radio relay systems
- Broadcast systems
- Digital processing systems
- Special electronic defense systems
- Research and development

This Division of RCA Limited represents the entire RCA Corporation in design, development, manufacturing, and installation of commercial satellite earth stations for the Intelsat global networks and transponders for commercial satellite systems and for commercial microwave radio relay systems. It performs worldwide marketing in these fields with a team of specialist sales engineers operating in association with RCA agents and distributors.





Top: Antenna design is one of the G&CS division's many capabilities; left-to-right, Microwave antenna in Canadian rockies; China's first communications satellite earth stations; and ISIS I satellite antenna.
Bottom: Scenes from CE&A division's color receiver manufacturing plants; left, receiver life tests; right, ACCUTOUCH tuning system.

Broadcast systems

Since 1952, when the company provided the antenna and transmitter for Canada's first television station, RCA has remained the country's leading supplier of transmitting equipment. In broadcast systems as in consumer products, RCA has developed special technology to overcome the unique problems posed by Canadian conditions. This has resulted in a number of important technical advances, such as the Wavestack television transmitting antenna which combines the highly directional characteristics required by Canadian broadcasters with the simplicity and durability to make it ideal for use in our climate.

Today, RCA is the largest supplier of broadcast equipment in Canada and is fully capable of supplying every element necessary for the operation of a television or radio station, from the microphone to the antenna.

Microwave radio relay systems

RCA is one of the very few companies in Canada capable of the design and construction of systems that are used to transmit television and radio signals over long distances and to handle high-density telecommunications, telephone, and computer traffic.

RCA has built and installed microwave systems in North America, Europe, Asia, the Middle East, Central America and Australia. These include the 1200-mile Pakistan system, the 813-mile system in Mexico, the 750-mile Liberian system, and the 3,000-mile Trans-Canada System. In all, the company has installed more than 30,000 route-miles of microwave communications in 18 countries.

Satellite earth stations

A natural sequence of the Canadian company's long experience in microwave radio relay was its entry into satellite earth station work in 1959, when it won contracts to develop antenna feed systems for NASA's instrument facility in the Mojave Desert. Feed and ground communications systems designed and built by RCA have now been furnished to stations in Panama, Brazil, Argentina, Morocco, Iran, the Philippines and Thailand. Six complete earth stations have been commissioned for the Intelsat global network: three in Canada, one in India, and two in Pakistan. In 1971, the company was awarded contracts to build the ten large earth stations for Canada's domestic satellite system. In addition, there are two in mainland China — one in Peking and one in Shanghai.

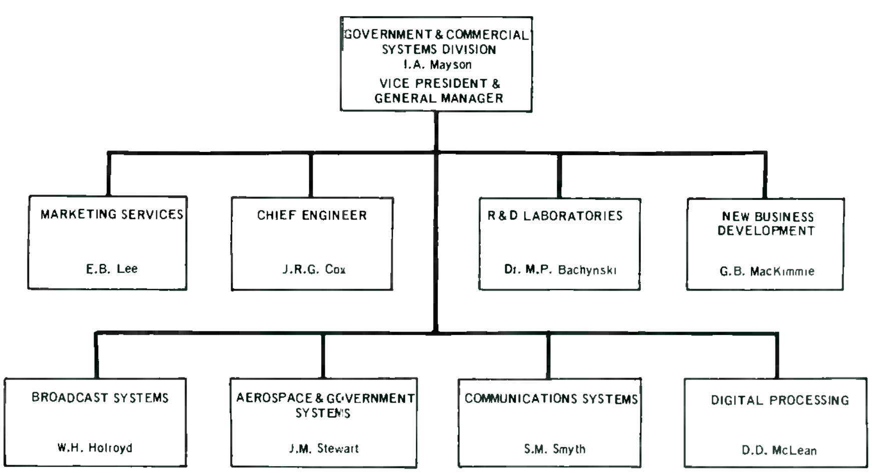


Fig. 3 — Organization of Government and Commercial Systems Division.

One demonstration of these skills was RCA's contribution to the television coverage by satellite of President Nixon's historic visit to China in 1972. With less than six weeks advance notice, Canadian engineers from RCA played a major part in the assembly, transportation, and installation of a satellite earth station at Shanghai.

Communications satellite and spacecraft subsystems

Satellite work at RCA Limited commenced in June of 1961 when NASA approved the Company's aerospace activity for the major development and supply of the transponder system for the Relay communications satellite. This program expanded to include beacon transmitters and satellite simulators.

The experience and organization developed on advanced semiconductor device research within the R & D Laboratories were successively used to furnish telemetry transmitters for Canada's first satellite — Alouette I — and for two major NASA scientific satellites — Explorer XX and Pegasus. In 1963, the R & D Laboratories of RCA Limited prepared and submitted a proposal to the Canadian Defence Research Board which resulted in winning an open Canadian industry competition for the work of orderly transition from Defence Research Telecommunications Establishment to industry of Canada's prime contracting and systems engineering capabilities in scientific satellites. This award led to manufacturing by RCA Limited of the Alouette II satellite, launched in November 1965, and full assumption of prime contractor and design responsibilities for the successive Canadian scientific satellites, the ISIS I and ISIS II.

The company is continuing its association with the Canadian space activity and is supplying the electronics subsystems for the communications technology satellite, a major experiment to develop a low-cost satellite system suited to Canadian needs as well as those of many devleoping nations.

In the United States, RCA Globcom has received FCC approval to own and operate a domestic communications space system and has awarded a prime contract to the Astro-Electronics Division for the complete spacecraft. RCA Limited is a major subcontractor to AED and is supplying the complete communications subsystem, comprising a 24-channel 4- to 6-GHz transponder and a complete antenna field incorporating cross-polarization isolation.

Left: Recording session at RCA Record Division's Montreal studio. Above, top: Electronic Components Division color tv tube plant at Midland, Ontario; Above, bottom: closed-circuit tv system operated at EXPO '67 by Service Division.

Record Division

Since RCA is directly descended from the invention of the disc phonograph record, it is not surprising that the company still operates the most complete and comprehensive recording organization in Canada.

This includes two of the country's best-equipped recording studios, a large-scale pressing plant and an extensive distribution network with offices in Halifax, Montreal, Toronto, Winnipeg, Calgary, Edmonton and Vancouver. This complete recording, manufacturing, and distribution network comes under the control of Mr. R. F. Cook, Vice President and General Manager (see Fig. 4).

RCA has always placed great importance on the development of Canadian talent and has long reflected the bilingual

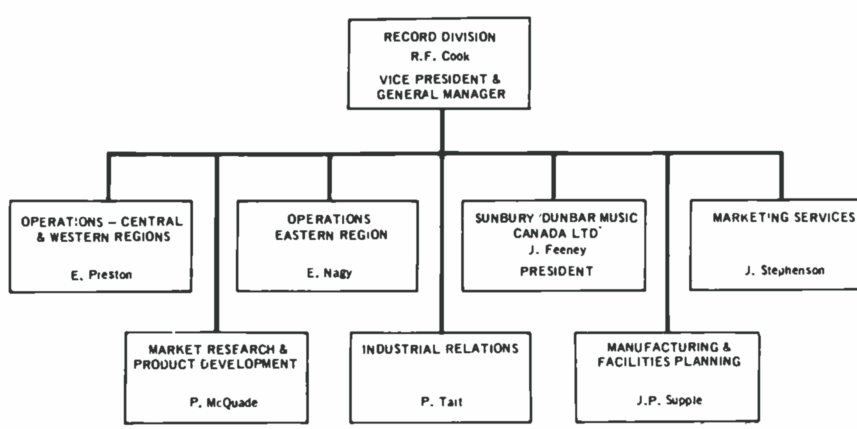


Fig. 4 — Organization of the Record Division.

character of the country by maintaining studios in Montreal and Toronto. Here, artists like Hank Snow, The Guess Who, The Mercy Brothers, Wilf Carter, Lucien Hetu, Claude Landre and many others record on the RCA label for domestic and international distribution.

To reinforce and extend this tradition of encouraging both French- and English-Canadian talent, RCA has been actively recruiting many new groups and individual performers across the country. Two of these new RCA recording groups, Les Scarabees and the Carlton Showband, have each been awarded gold records by *RPM* magazine for having achieved Canadian sales of more than 50,000 singles and 35,000 LP's.

This rapid expansion in artists and repertoire has resulted in the release of a wide range of Canadian records on the international market where they have been generally well received.

RCA's up-to-date facilities and expert technical staff at the Toronto and Montreal studios have now acquired sufficient international recognition for foreign artists like Roger Whittaker, Harry Belfonte, and The Carpenters to have come to Canada to record at RCA.

The Company's reputation for technical excellence also extends to the Smiths Falls, Ontario pressing plant, which operates 24 hours a day producing more than one million records a month for RCA and many other well-known labels. This plant was the first in Canada to use vinyl powder to make records and was instrumental in the development of RCA's famous Dynaflex unbreakable record.

Electronic Components

Mr. F. O'Hara, Vice President and General Manager of the Electronic Components Division heads up that division of the company which supplies the essential building blocks for the electronics industry (see Fig. 5).

In Canada, RCA manufactures hundreds of different components, including electron tubes and color television picture tubes, which find their way into practically every electronic device produced in the country. The quality and reliability of these specialized products have received

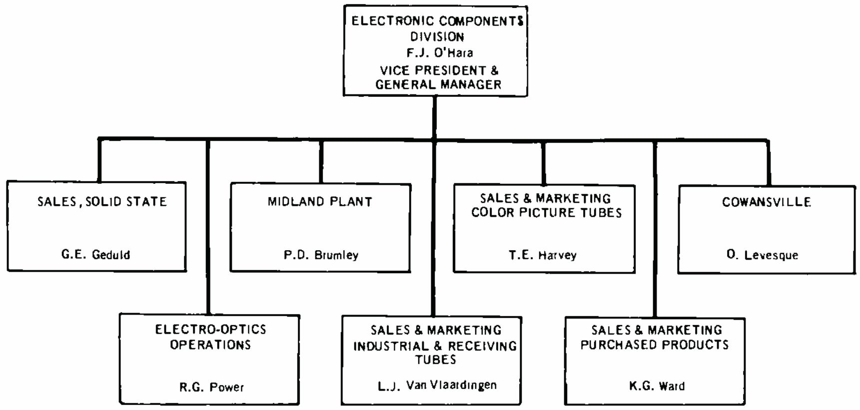


Fig. 5 — Organization of the Electronic Components Division.

international recognition and RCA is now Canada's largest exporter of electronic components.

Much of this success stems from the bold decision to open this country's first color television picture tube plant at Midland, Ontario in 1967. This facility represented the largest single investment ever made in the Canadian electronics industry. Since then, the plant has expanded to its present 363,000 ft^2 and produces color picture tubes in six sizes to suit fifty varieties of screen type. Annual production of these color tubes now exceeds half a million.

The Midland plant has produced more than two million color picture tubes since it opened and has done so without in any way diminishing the quality of its natural environment. Water used in the manufacturing process returns to Georgian Bay even cleaner than when it left and the plant's water purification facility is so efficient that the company was able to supply drinking water to the City of Midland from 1967 until early in 1971, when a new municipal filtration plant was completed. Further recognition of the company's commitment to a clean environment came in 1968 when it was awarded the A. V. DeLaporte Award for clean air and water by the Canadian Institute on Pollution Control.

The Optoelectronics department at Ste. Anne de Bellevue, Quebec, specializes in silicon photodetectors. This new technology will soon find important applications in areas such as laser, radar, communications and computer systems.

Another important Canadian plant is located at Cowansville, Quebec, where 150 employees, most of them French speaking, are engaged in producing electronic tubes.

Service Division

Success in the marketplace calls for more than a superior product. It also requires the support of a first-class service organization. In recognition of this fact,

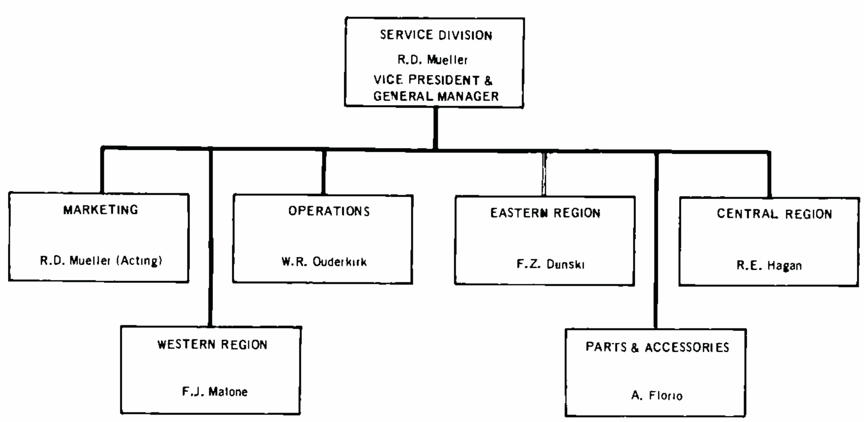


Fig. 6 — Organization of the Service Division.

RCA maintains one of Canada's largest service operations under the leadership of Mr. R. D. Mueller, Vice President and General Manager (see Fig. 6). A staff of 400 skilled technical, administrative, and management personnel provides a full range of services to consumers as well as to commercial and industrial customers.

Fifteen service branches and nine parts depots, located in the major Canadian cities, provide broad product support to the company's consumer customers. Replacement parts for Government, broadcast, and communication customers — within Canada and internationally — are supplied from the central warehouse at Ste. Anne de Bellevue.

In the commercial sector, the Service Division supplies, installs and maintains a variety of information, distribution, and control systems.

The sound systems for such sophisticated cultural centers as the National Arts Center in Ottawa, the *Place des Arts* in Montreal and the Centennial Concert Halls in Winnipeg and Regina were installed and are maintained by the Service Division.

Closed-circuit television systems with applications in highway traffic control, security surveillance in industry and patient observation in hospitals are also part of the division's responsibilities. Such a system was successfully used during EXPO 67 in Montreal to direct crowds and permit even distribution of people at the various attractions on the island.

The Service Division has also supplied and installed CATV studio equipment and hotel-room-status systems. The Division also leases and maintains data communications equipment.

Research and Development Laboratories

The RCA Laboratories at Montreal have, since their formation in 1955, performed several hundred programs for more than fifty customers and agencies. These programs have ranged from consultation, theoretical studies and tradeoff (optimization) analyses to experiments, prototype development, hardware fabrication, and training programs. Included have been activities in major space, communication, commercial and military systems. A wide range of technologies are encompassed by the activities and skills of the Laboratories. These embrace satellite systems, circuit developments, communication systems, computers, laser and laser applications, solid-state devices, integrated circuits, infrared systems, measurement techniques, education technology and information systems.

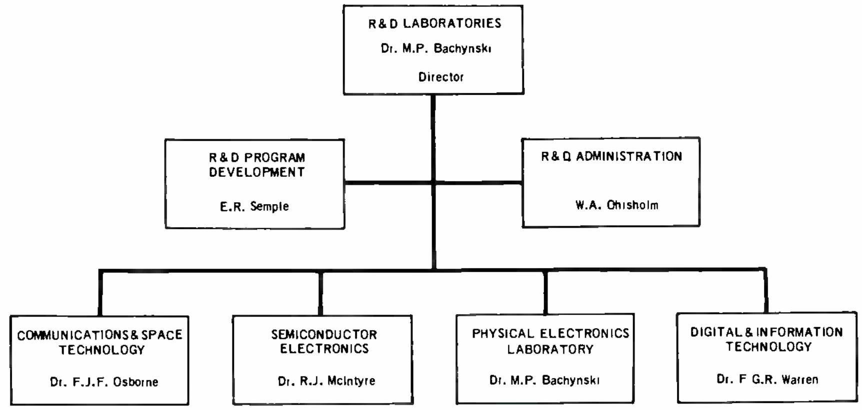


Fig. 7 — Organization of the Research and Development Laboratories.

The Research and Development Laboratories are under the direction of Dr. M.P. Bachynski (see Fig. 7). The current size of the RCA Laboratories, Montreal, Canada, is of the order of 60 staff members, located in 22,000 ft^2 of ultra-modern facility. Of the scientific staff, more than half possess the PhD. A number of the scientists enjoy an international reputation in their fields and serve on a variety of international scientific organizations. More than 200 papers have been published by staff members of the R&D Laboratories in recognized scientific journals. In addition, three text books have been authored by personnel of the Laboratories. Products originating from the Laboratories include *He/Ne* and CO_2 lasers, satellite telemetry transmitters, photodiodes, nuclear radiation detection systems, and educational kits for high school and university experiments. The Laboratories are divided into four major groups.

Semiconductor Device Research Laboratory

Communications and Space Technology Laboratory

Physical Electronics Research Laboratory

Digital and Information Technology Laboratory

Semiconductor Electronics Laboratory

The semiconductor research and development facilities provide a fabrication capability for custom photodiodes, thin-film hybrid microcircuits, microwave integrated circuits, and acoustic surface-wave devices. An adjunct to these facilities is a computer-aided design (CAD) capability used to optimize circuit designs, and to provide a service to customers and other areas of the company. The history of firsts for this laboratory dates back to 1957, with the development of gold-doped germanium infrared detectors for the 2- to 8-μm region, and the fabrication in 1962 of the first high resolution lithium-drifted germanium gamma-ray spectrometer. Current state-of-the-art diode development centers on RCA Limited's unique reach-through avalanche photodiode with controlled avalanche gain.

The Semiconductor Electronics Laboratory is pursuing development in four principal areas:

1) Semiconductor device technology centered on infrared and laser photodetectors;
2) Microwave integrated circuits;
3) Acoustic surface-wave devices;
4) Computer-aided circuit design.

Communications and Space Technology Laboratory

This laboratory develops and maintains in-house capabilities in three broad areas:

1) *Communications devices*: Through analysis, device evaluation and/or application, provides design data regarding utilization and significance of new devices.
2) *Communications techniques*: Evaluates by analysis and/or breadboard demonstration,

new techniques potentially relevant to product lines.

3) *System technologies*: Develops system concepts for specific communications or space missions.

Major studies are presently under way leading to new products and capabilities in the satellite communications field and microwave device area. RCA Limited's extensive experience in these areas is exemplified by its participation in the ISIS and other satellite communications projects. There have been numerous papers written on RCA Limited's activities in these areas, which have placed the research labs in the forefront of several communications technologies, especially those concerned with communication involving space vehicles.

In pursuing technological studies in the communications systems areas, the laboratory is thoroughly systems oriented, and is familiar with the detailed planning of multi-million dollar development programs including normal limitations of time, materials, environment, and the availability of suitable personnel and sources of information. This laboratory can perform a wide variety of trade-off parametric studies as well as the necessary routine liaison planning, consulting, and program review which must be included in long-term development programs, particularly in the spacecraft area.

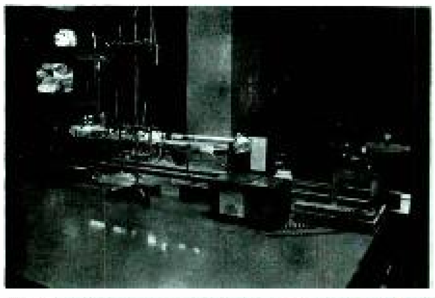
Physical Electronics Research Laboratory

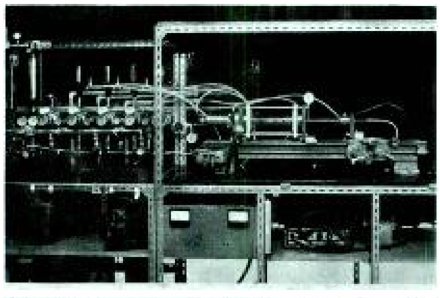
The Physical Electronics Research Laboratory is concerned with lasers and laser applications, plasma devices, and theoretical study of plasma phenomena especially as they pertain to communications. There are other important areas of investigation covered by the laboratory mandate which are less related to products.

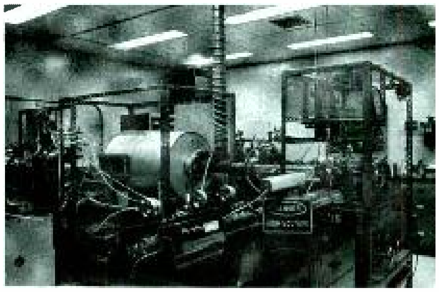
Laser technology in this laboratory is centered on gas lasers of the CO_2 and, more recently, CO variety. In the past, much work has been done on Helium-Neon lasers. Plasma and high energy laser studies have led to an intense light source, presently capable of 150-kW power level, and to fusion studies.

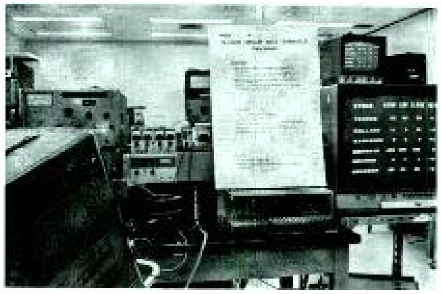
The family of CO_2 laser products includes simple internal-mirror lasers, lasers with one or two Brewster windows and compact ceramic lasers with two Brewster windows, all of which are long-life sealed-off units. The list of accessories which permit complete laser systems are as follows: laser cavities constructed modularly from die-cast aluminum sections, a mirror transducer, 20-kV supply for large 20-W lasers, a laser stabilizer instrument consisting of a photodiode sensor unit, control package and transducer; and a heat dissipator which is a custom-fitted aluminum block for use on up to 5-W lasers. The laser systems employing the stabilizer instrument exhibit stabilities better than 1% in power output, and fm stability of the order 1 part in 10^9 (short term) or 1 part in 10^8 (long term) which is competitive with the best advertised by competitors.

Typical scenes at RCA Ltd's R&D Labs. Clockwise from upper left: He-Ne laser communications sytems; high-intensity light source; high power laser experiment; and closed-circuit data terminal experimental facility.









Digital and Information Technology Laboratory

One major direction in the program of the R & D Laboratories of RCA Limited is digital and information technology. The area of interest encompasses present and future applications of information systems in the home, business, industry or school, and in the field or laboratory, including means of distribution, as well as information processing, storage, and display. This implies many regions of common interest and mutual support with the other activities in the Laboratories, particularly in communications.

The program of studies in information technology is, at the present time, largely built around applications of a proprietary information processing controller. This very flexible, software controlled system is modular in structure and uses parallel processing techniques for greater speed. It has tv-compatible video interfaces with unusual abilities for alphanumeric presentation of data, in black and white or seven colors, and for graphics of moderate complexity, as well as interfaces for communications, input/output and access to external information storage.

The R & D program covers application studies, software development and development of peripheral hardware and associated systems.

Present hardware studies include development of improved alphanumeric and graphic interfaces, development of alphanumeric terminal for use on a television bandwidth multiple subscriber message system, and developmemt of techniques for snatching single-frame pictures from a frequency transmitted at television frame rates.

Research and development in Canada

Dr. M. P. Bachynski

A brief account is given of the development of R & D in Canada. At present a large portion of this nation's R & D is done within federal government establishments. University research is relatively well developed and the graduate schools are of a high standard. Priority is being given by national policies to the development of innovative high technology industries in Canada. A number of companies are responding to these opportunities and it appears that these policies will be successful.

EARLY SCIENTIFIC interests in Canada dealt with natural resources beginning with works on geology published in 1824. The oldest scientific organization of Canadian government is the Geological Survey of Canada created in 1841 as the Geological Survey of the Province of Canada. The initial studies of astronomy in Canada date back to earlier times; the Jesuits in Quebec conducted such investigations as an aid to determining longitude. The first astronomical observatory was founded in 1851 at Fredericton, New Brunswick. Federal government support for astronomy goes back to 1885 when the first longitude surveys were conducted in relation to the construction of railways in Canada.

Fisheries research in Canada began in 1852 with a government of Canada expedition to inquire into the protection of the fisheries of the Gulf of St. Lawrence. This eventually led to the formation of the current Fisheries Research Board of Canada. The establishments of experimental farms as a first step towards agricultural research began in 1884. Surprisingly, research in forestry did not follow until 1917.

Prior to World War I, the Canadian effort on science was concentrated almost exclusively on natural resources. Little basic research was done in the sciences up to this time. Perhaps the notable exception was the work at McGill University by Rutherford, Soddy and Hahn during the period 1902-1907. All three eventually became Nobel laureates but after they had left Canada; Rutherford's Nobel prize in 1908 was, however, based on work he had performed on radioactivity while at McGill.

The next major step in the evolution of science in Canada was the formation in 1917, by a statute of the parliament of Canada, of the National Research Council — a central organization patterned after the British model to plan and coordinate scientific work. The main concern was to meet the needs of industry, including university training to meet these industrial requirements. The proposed approach was for the universities to train more and better pure scientists and for a government research institute to hire them to work on standards and other technological problems faced by industry and to direct or supervise research done by industry in government laboratories.

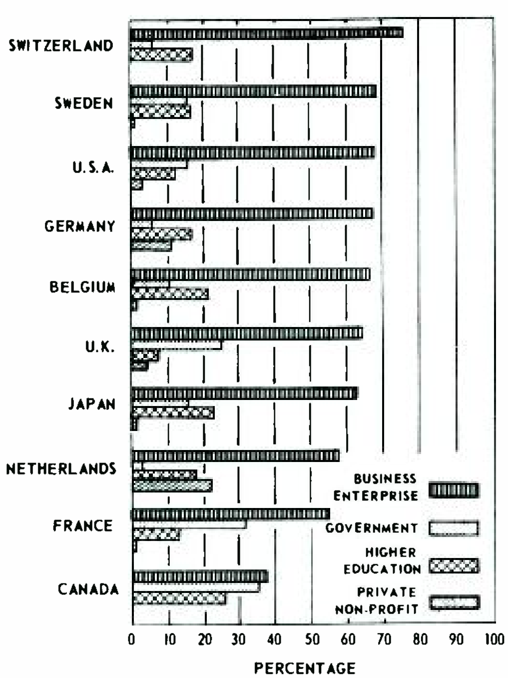


Fig. 1 — Total national R&D expenditures by sectors of performance and country in 1967 (percentages).

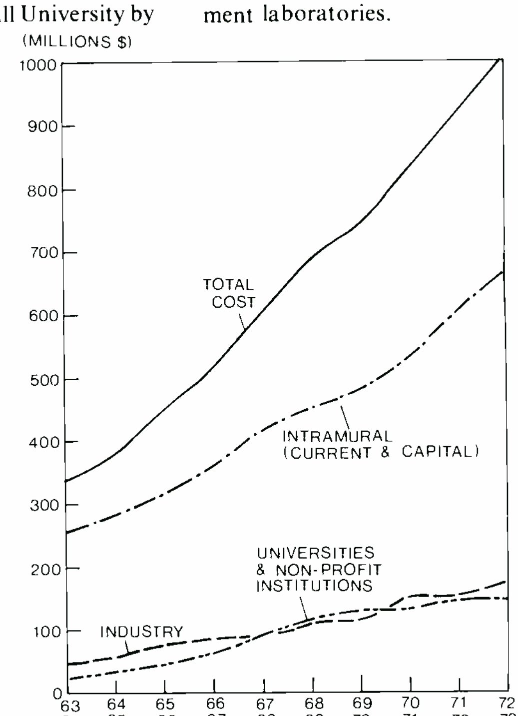


Fig. 2 — Total federal government expenditures on R&D and sector of performance.

Table I — GNP and expenditures on R & D in Canada.

	GNP		*GERD*	
Year	U.S. Dollars (Billions)	U.S. Dollars (Per Capita)	U.S. Dollars (Millions)	% of GNP
1963	40.1	2[illegible]21	413	1.03
1964	43.8	2270	506	1.15
1965	48.2	2455	622	1.29
1966	53.7	2680	720	1.34
1967	57.4	2810	821	1.43
1968	66.1	3188	871	1.31
1969	72.7	3459	959	1.31
1970	81.9	3777	1025	1.25

Table II — Gross expenditure on Research & Development as a percentage of the gross national product. (Source: OECD, 1970, Document DAS/SPR/70).

Country	1963	1967
U.S.A. (1964, 1966)	3.0	2.9
U.K. (1964)	2.3	2.3
France	1.6	2.3
Netherlands (1964)	1.9	2.3
Switzerland		1.9
Germany (1964)	1.4	1.7
Japan	1.5	1.8
Sweden (1964)	1.3	1.4
Canada	1.1	1.4
Belgium	1.0	0.9

From 1912 to 1915 it has been estimated that the total expenditure on university research by government was $277,000. Less than $100,000 was being spent annually by government laboratories for scientific research. Expenditure in industry was probably of this same order of magnitude. Thus there was very little R & D to coordinate. Finally in 1930, the first laboratories for the National Research Council (NRC) were constructed. By 1939 NRC had a staff of 300 and a budget of the order of $900,000. During the course of World War II, NRC established 21 laboratories and grew an order of magnitude larger in its operation.

Post-war growth

During the war Canadian scientists worked closely with scientists of the United States and Great Britain. Thus in the post war era there was a nucleus of people on the frontiers of science and technology looking forward to opportunities for the new technologies in peacetime applications. In this post-war period, a profusion of new government organizations relating to science and technology was established. Some of the most noteworthy included the Atomic Energy Control Board (1946) to regulate and control atomic energy in Canada; Canadian Patents and Development Limited (1947) mainly to make NRC's inventions available to industry; the Defense Research Board (1947); and the Atomic Energy of Canada Limited (1952), one of whose major goals was the development of economical nuclear power for Canada.

The growth of R & D in Canada in recent years relative to the development of the country is shown in Table I, illustrating the growth of the gross national product (GNP) and Gross Expenditure on Research and Development (GERD) for the period 1963-1970. Over that span of eight years the total expenditure has grown by a factor of 2.5, indicating a significant degree of maturity of R & D in Canada. To place the above results in an international perspective, a comparison with other technologically advanced countries is made in Table II in terms of the percentage of GNP devoted to R & D. Although the percentage of GNP devoted to R & D ranks Canada well down the list of leading countries, the growth rate

Morrel P. Bachynski, Director, R&D, RCA Limited, Montreal, Canada, graduated in 1952 from the University of Saskatchewan with the degree of B. Eng. in Engineering Physics. He was awarded the Professional Engineers-of-Saskatchewan prize for the highest scholastic standing amongst the graduating class. In the following year he obtained his MSc degree in physics at the University of Saskatchewan in the field of radar investigations of the aurora. He then joined the Eaton Electronics Research Laboratory, McGill University, where he was awarded a PhD degree in 1955 with a thesis on aberrations in microwave lenses. After obtaining his PhD degree, Dr. Bachynski remained at the Eaton Laboratory carrying out research on the imaging properties of non-uniformly illuminated microwave lenses. In October 1955, he joined the newly created Research Laboratories of RCA Limited, became Director of the Microwave and Plasma Physics Laboratories in 1958 and Director of Research in 1965. Since this time he has conducted research on electromagnetic wave propagation, microwave and plasma physics. Dr. Bachynski is a Fellow of the Royal Society of Canada, a Fellow of the American Physical Society, a Fellow of the Canadian Aeronautics & Space Institute, an Associate Fellow of the American Institute of Aeronautics and Astronautics, a Senior Member of the Institute of Electrical and Electronics Engineers, a Member of the Professional Group on Antennas and Propagation, a Member of the American Geophysical Union and the Canadian Association of Physicists, and a Member of the Canadian Research Management Association. He is President of the Association of the Scientific, Engineering & Technological Community of Canada (SCITEC) and a Member of the National Research Council Associate Committees on Space Research and Radio Science and past Chairman of the Associate Committee on Plasma Physics. He is an Associate Editor of the *Canadian Journal of Physics* and also serves on the Editorial Advisory Board of *Science Forum*. Other activities include: Member of the Advisory Board of the University of Waterloo Industrial Research Institute, Member of the Canadian Manufacturers' Association Committee on R&D, Member of the Electronic Industries Association of Canada Committee on R&D, Member of the Steering Committee for the *Centre del'Energie INRS*, Universite du Quebec, and a Member of the Advisory Committee for the Communications Research Laboratory of McMaster University. He is a past Chairman of the Canadian National Committee of the International Scientific Radio Union (URSI) and was President of the Canadian Association of Physicists during 1968-1969. He is listed in American Men of Science and has been associated with McGill University teaching classes in antennas, electromagnetic theory and plasma physics. In 1963 he was awarded the David Sarnoff Award for Outstanding Individual Achievement in Engineering. He is a co-author of the book "The Particle Kinetics of Plasmas". He is the author of more than 80 publications in recognized scientific journals. In 1973, he was awarded the *Prix Scientique du Quebec* by the Government of Quebec.

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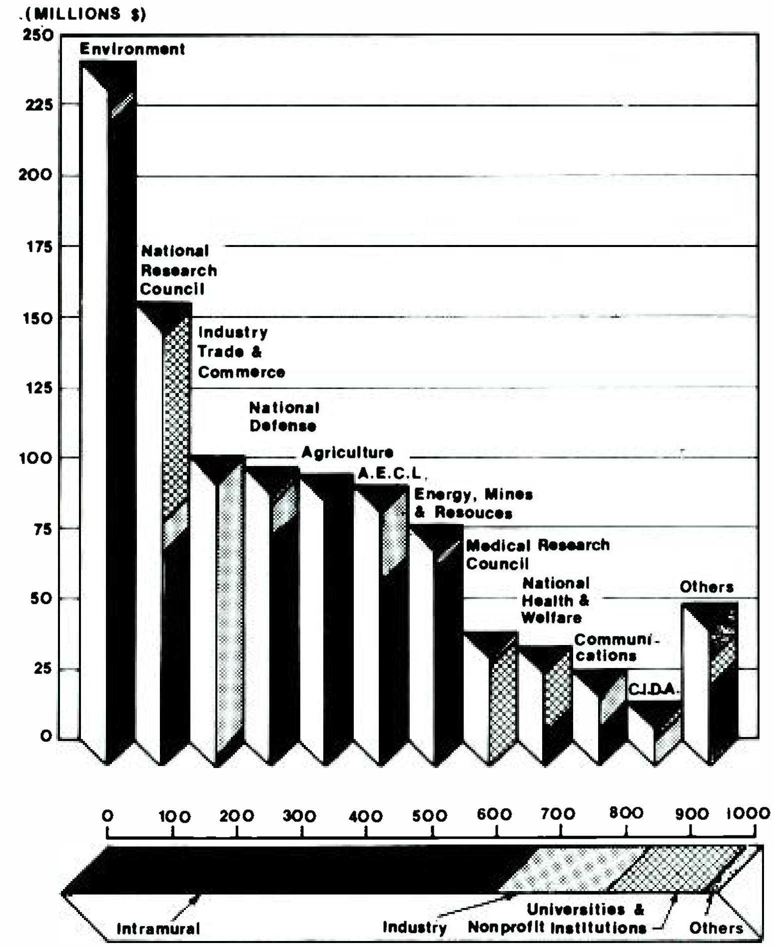

Fig. 3 — Total federal government expenditure on scientific activities by department and by performer 1972-73 (Source: Ministry of State for Science and Technology).

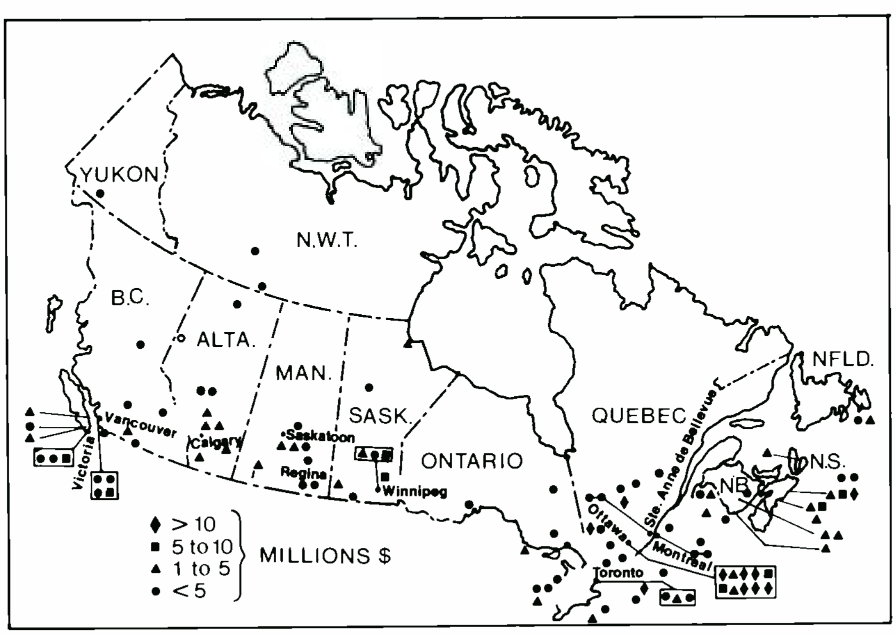

Fig. 4 — Geographical distribution of scientific establishments of federal departments and agencies (Source: Ministry of State for Science and Technology).

(change) in the 1963-67 period was one of the most rapid. A further comparison of the R & D effort in Canada with other countries is given in Fig. 1 to show the sector of performance of the R & D conducted. Further details and comments on the current status of Canadian R & D in government, universities and industry are given in the following sections.

R & D in government

As is evident from the history of R & D in Canada, the growth has been most significant during and following World War II and much of this has taken place in the government establishments themselves. The build-up of Canadian government expenditures on science over the last decade is shown in Fig. 2; as can be seen, the total expenditures have increased by about a factor of 3 over this period.

The total costs to the Canadian government of scientific activities during 1972-73 are shown in Fig. 3. These total costs include scientific data collection, scientific information, feasibility studies and scholarship programs and amount to over one billion dollars.

The largest budget is in the Department of the Environment which operates the weather services in addition to its own laboratories. The next largest budget is that of the National Research Council. About half of its budget is devoted to supporting research in the universities. The work of its own in-house laboratories is known internationally. Dr. Gerhard Herzberg, the 1972 Nobel Prize Winner in Chemistry, is a member of the NRC Laboratories. The Department of Industry, Trade and Commerce has no laboratories of its own and its budget goes almost totally for the support of industry in Canada.

The Department of National Defense has a number of its own laboratories, the most notable being the Defense Research Establishment, Valcartier where the TEA laser was first developed. The Department of Agriculture has extensive laboratories and experimental farms in support of the nation's agricultural industry. Atomic Energy of Canada Limited (AECL) is a crown corporation whose mandate is the commercial development of fission power. They do have significant in-house laboratories but the main program is concerned with the Canadian developed CANDU reactor. The Department of Energy, Mines & Resources has the responsibility for Canada's natural resources. The Medical Research Council is a granting agency for the support of medical research. The Department of Health and Welfare conducts both in-house R & D and supports external research. The Department of Communications has a major laboratory (the Communications Research Center) and supports communications research, particularly satellites, in industry. The Canadian International Development Agency (CIDA) does research to assist developing countries as part of Canada's foreign aid contribution. As can be seen from the summary chart of Fig. 3, about two-thirds of the Canadian government expenditures on scientific activities are performed *in-house*.

The geographic distribution of Canadian federal government scientific establishments over the country is shown in Fig. 4. Although there are establishments over the entire country, the main distribution is in the east and particularly in the Ottawa region. There are six establishments with annual budgets in excess of $10 million in Ottawa compared to one each in Burlington, Chalk River, Valcartier and Dartmouth.

R & D in the universities

In Canada there are 62 degree-granting universities. About 25 of these grant doctorates in various subjects. The largest universities have many faculties recognized throughout the world with high standards, large-scale research programs and student enrollments in excess of 15,000. The Universities of Toronto, Montreal, McGill and British Columbia are in this category. Lectures are given in English in most Canadian universities. However, French is used in others such as the Universities of Montreal, Quebec and Moncton. A few universities use both languages — such as the University of Ottawa and Laurentian University of Sudbury. Overall, Canada is one of the leading countries in terms of expenditure on education (25% of the public expenditure compared to 26% in U.S.A.).

The major growth in university research in Canada has occurred in the late 1950's and early to mid sixties. During the decade 1955-56 to 1964-65, the total current expenditure on research and related equipment increased more than five times, total research funds over seven times and full time graduates engaged in research increased about three times. The growth in R & D aid and operating expenditures of Canadian universities is shown in Fig. 5. Canadian funds account for about 95% of the total devoted to research in Canadian universities. (One estimate places the university contribution itself at about 55% of the total, the federal government at 27%, the provincial government at 8% and the remaining non-Canadian 5% from U.S. federal government agencies.)

The major source of Canadian government funds for university research is through the National Research Council. In 1973 this was of the order of $65 million distributed amongst 45 Canadian universities. Other federal agencies which finance research in universities include the Medical Research Council, the Canada Council, the Defense Research Board, the Department of Health and Welfare and the Atomic Energy Control Board. The principle areas supported have been (in approximately descending order of support) biological sciences, chemistry, engineering, physics and earth sciences.

The total enrollment in Canadian universities has in part followed the increase in operating expenses shown in Fig. 6. The geographic distribution of students in the graduate schools in the natural sciences is shown in Fig. 7; as can be seen Ontario and Quebec account for about 75% of the graduate student population. These two provinces together receive about 60-75% of the total federal funds made available to university research in Canada.

As in many other countries, the explosive

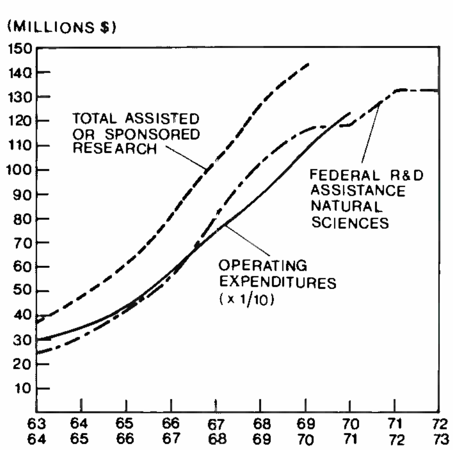

Fig. 5 — Research funds and operating expenditures of universities in Canada.

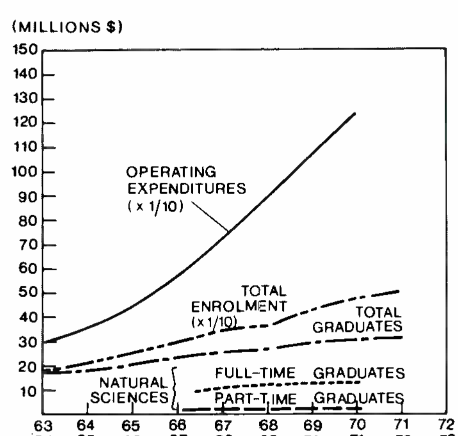

Fig. 6 — Total graduate and undergraduate enrollment at Canadian universities — 1963-64 to 1972-73.

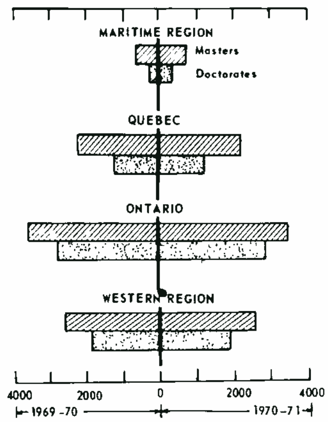

Fig. 7 — Total graduate enrollment in Canadian universities — Natural Sciences by region (Source: Canadian Association of Graduate Schools).

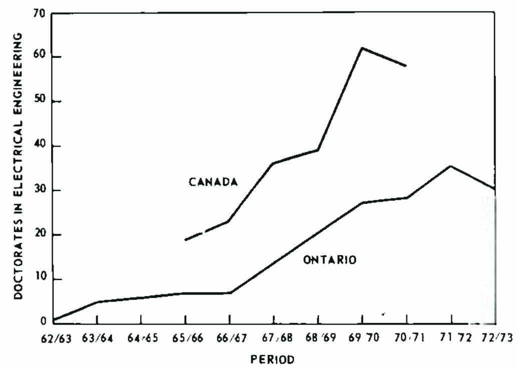

Fig. 8 — Growth in numbers of doctorate graduates in electrical engineering in Ontario and in Canada.

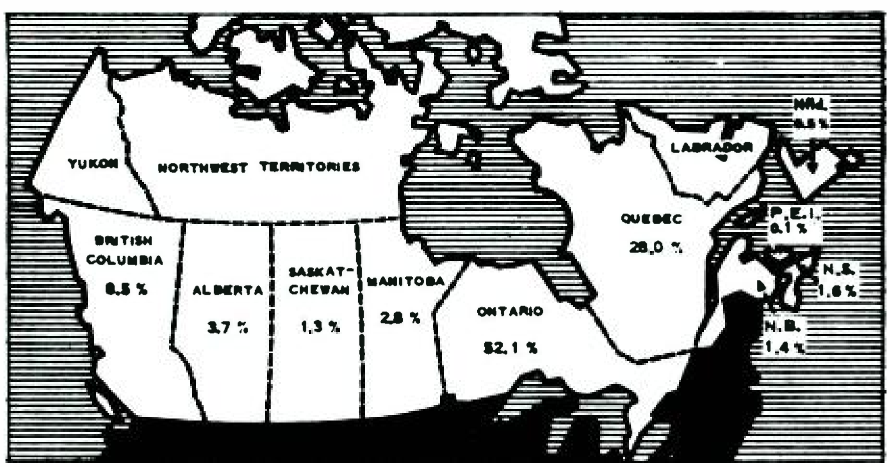

Fig. 9 — Distribution by province of manufacturing production (1965) (Source: Hawker Siddeley Review 5, No. 1 1967).

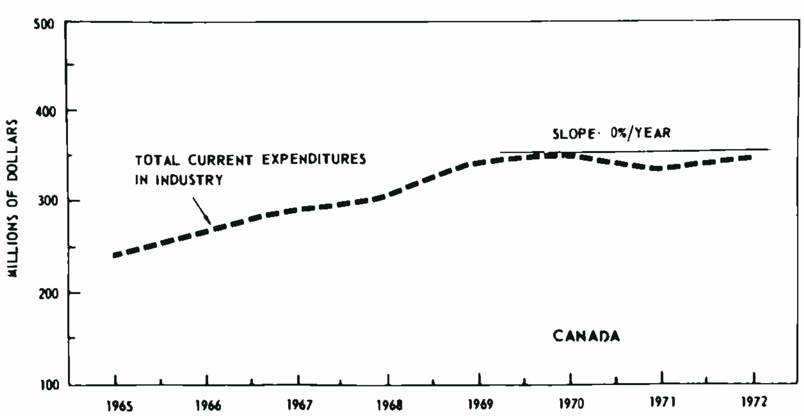

Fig. 10 — Total R & D expenditures in Canadian industry.

enrollment in the graduate schools in Canada has tended to level off in the early 70's. This has been particularly true for the physical sciences and engineering. Currently the universities seem to be in more or less of a steady-state situation with roughly the same numbers in the graduate schools annually. The steady-state condition is shown (Fig. 8) for the case of doctorates in electrical engineering. In summary, research in Canadian universities is generally of a high standard. The student population has been fairly steady in recent years. The era seems to be more one of consolidation than expansion.

R & D in industry

The pattern of Canadian industry is characterized by the relatively large number of primary industries based on the country's natural resources. There are now, however, fast growing industries with highly developed technologies. Some of these are subsidiaries of foreign concerns, mostly the United States. The influence of the United States is dominant in financial, production, distribution as well as in technical areas. As a result there are strong north-south economic forces, often in conflict with the east-west aspiration of the Canadian nation.

Compared with other countries, the economic pattern of Canada is much closer to that of the United States than to that of industrial countries in Western Europe. In the manufacturing sector, the economic patterns are somewhat different for the various regions of Canada (Fig. 9). In Ontario, manufacturing industries represent more than two-thirds of the province's production and nearly as much in Quebec. These two provinces do about three-quarters of the total manufacturing in Canada. Canadian manufacturing is generally faced with a wide variety of products and with fairly small and short production runs thereby requiring more versatile use of production means.

As in most industrial countries, R & D activities in Canada are highly concentrated in a few industries notably electric and electronic equipment, aeronautics and space, chemical and pharmaceutical industries. These industries account for 50-60% of the total R & D expenditure in Canadian industry. The total R & D industry expenditures in Canada over the last few years are shown in Fig. 10; after a period of growth in the 60's, the total expenditures over the last four years have remained more or less constant. The distribution of the federal government expenditures on scientific activities amongst the industrial, educational, and intramural activities is shown in Fig. 11. As can be seen, the industrial percentage has been remaining more or less constant. In relation to other countries, the percentage of industrially performed R&D (financed in Canada by government) is generally less than most industrially developed nations — and is illustrated in Fig. 12. Not only has the federal government contributed less proportionately to R&D performed in industry than in many other industrialized countries, but industry in Canada itself has invested a much smaller share in R&D than that of most industrialized nations (Fig. 13). In total, only about 200 Canadian industrial firms have R&D establishments of more than 5 scientists or engineers.

Government aims

Recognizing that technological advancement is a key factor in economic growth and that R & D is a cutting edge for this advancement — and faced with an increasing dependence on exports and an increasing labor force which is growing at a faster rate than in most industrialized countries, the Canadian government has in recent years taken steps to enhance the technological capability of its industry. The aims of these policies can be summarized as follows:

- to help create new jobs for Canadians (including the highly trained manpower graduating from the universities).
- to create an industry that is more modern and competitive in the domestic and international markets.
- to help ensure that R & D results are translated more effectively into additional Canadian industrial capability through new products and services.

New policies

The following are the new policies recently adopted:

1) *Incentives to conduct R & D in industry.* There are basically four schemes. These allow any research expenditure to be deductible in calculation of income tax including capital expenditures, a tax free grant of 25% on all capital expenditure for R & D and on current expenditures on R & D in excess of the average of the previous five years, grants of up to 50% of the costs of research and advanced development projects, grants up to 50% of the industrial design, operational and administrative costs for short term projects related to product or system innovation and reimbursement to industry of a portion of the salary of postdoctorate fellows when the fellowships are held in industry. These incentives are summarized in Table III.

Since the goals of these incentives are to increase the international competitive position of Canadian industry and to create jobs in Canada, they require that the participating Company agrees to make every effort to retain in Canada the development or production work resulting from the R & D carried out under the grant. However, if it is not feasible to carry out such production in Canada, the Company can negotiate with the Canadian government for permission to license the results to a foreign firm.

2) *Contracting out to industry a progressively larger portion of government-funded R & D.* A declared policy has been to contract out more and more of the R & D needs of federal government departments or agencies to industry in Canada. These are basically "open bid" competitive procurements. To date the magnitude of the contracts awarded to industry has not changed drastically due to the fact that the contracting out had to be done within existing Departmental budgets. Plans are underway to make new money available to "contract out", which, if the economic position of the country permits, would allow the goals of the policy to be realized.

3) *Increased Canadian content in procurement by the Canadian government.*

4) *Foreign take-over legislation* undergoing debate in parliament will require that the take-over is "for the benefit of Canada". The benefit includes ability to innovate and to perform the required R & D in Canada. Branch-plant operations for the manufacture of foreign designs solely for the Canadian market are being discouraged.

Government assistance

Considerable assistance has been afforded by the Canadian government to Canadian-based firms in telecommunications and microcircuits where the development is being done chiefly in Canada. A number of U.S. subsidiaries operating in Canada have also responded rapidly to the opportunities presented by the incentives by setting up R & D establishments and manufacturing plants for specialized portions of their product line. These incentive policies together with an abundance of energy in Canada point to the successful establishment of an innovative high technology industry in Canada which will serve international markets.

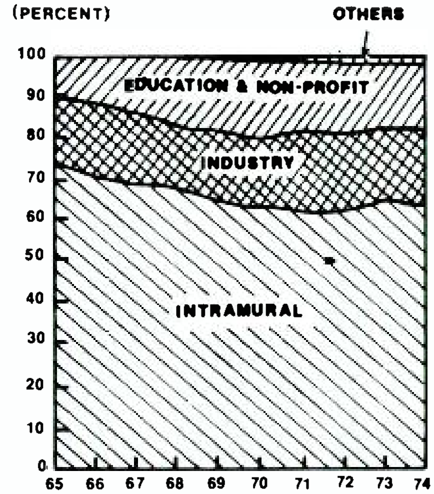

Fig. 11 — Distribution of federal expenditures on scientific activities (Source: Ministry of State for Science and Technology).

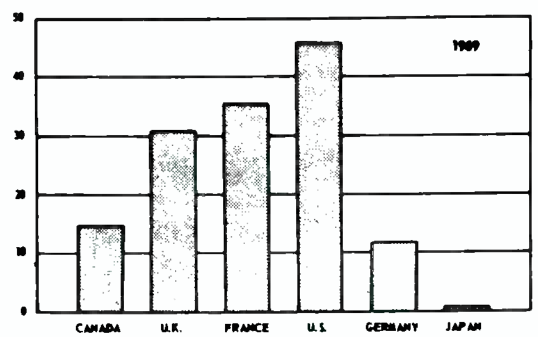

Fig. 12 — Percentage of industrially performed R & D financed by government.

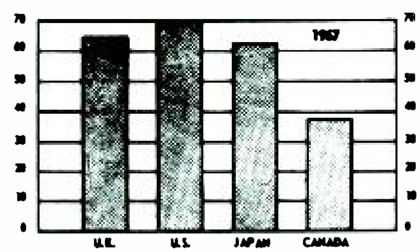

Fig. 13 — Percentage of total national R & D spending performed by industry.

Table III — Canadian government incentives for industrial R & D.

- Section 72 income tax act
  -R&D expense tax deductible
- IRDIA tax-free grants of 25%
  - capital expense
  -current expense in excess of 5 year avg.
- DIR - Defense Research Board
  - ~ 50-50 cost shared R&D programs
- IRAP - National Research Council
  - up to 50-50 cost shared R&D programs
- IPF - National Research Council
  $9000 for each "Fellow" employed
- PAIT - Department of Industry
  -up to 50% of total costs on advanced development projects
- DIP - Department of Defense
  same as PAIT but applicable to defense
- IDAP - Department of Industry
  -up to 50% of costs of industrial design short term projects

Integrated business system — a new approach to television design and manufacture

W. B. Morrison

The Consumer Products and Appliances Division of RCA Limited has developed a modular concept of television design and manufacture that improves product costs, factory productivity, and quality. At the same time, this approach provides designers and product planners with the flexibility needed to produce a wide range of product styles and options in the quantities necessary for the Canadian marketplace.

William B. Morrison, Chief Engineer, Consumer Electronics & Appliances Division, RCA Limited, Montreal, graduated from University of Toronto in 1936 with the Bachelor of Applied Science, and remained on the staff of Electrical Engineering Department as an Instructor in Electrical Measurements from 1936 to 1938. Mr. Morrison joined RCA Victor in Montreal in 1938 and was assigned to Television Engineering in Camden, N. J. He returned to Canada in 1939 and presented first televisior demonstrations to technical societies and Canadian public He was involved in development of mobile communication equipment during the war, including a unique, precise, frequency-selection system and an automatic antenna-tuning principle. He became head of electrical development on home instruments in 1946 and was promoted to Chief Engineer in 1957, where he has been responsible for the development of a broad line of home instrument products for the Canadian market through the development era of fm, black and white television, stereo, fm multiplex and color television, and has presented numerous introductory papers to various technical oganizations in Canada during the formative years of these new technologies. He is a Member of the Institute of Electrical Engineers and the Corporation of Professional Engineers of Quebec. He is a Member of the Canadian Standards Association, Subcommittee on Radio and Television Devices, and a past chairman of the Consumer Products Engineering Committee of the Electronics Industries Association of Canada.

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THE Canadian Television Manufacturing Industry faces a series of challenges which require unique and innovative solutions if it is to remain a viable industry in Canada:

1) The Canadian Television market amounts to less than 10% of the annual unit sales in the United States.

2) The Canadian consumer is exposed to the advertising from the United States and demands an equal variety of choices in styles and features.

3) The Canadian market is much more vulnerable to imports, and approximately 40% of the color receivers and 60% of the black-and-white receivers were imported in 1973.

4) There are as many television manufacturers in Canada as in the United States.

The impact of these factors on a Canadian manufacturer can be highlighted as follows:

1) A relatively small number of units must be divided among a wide variety of models. Since the total requirements justify a minimum number of assembly lines, this wide variety of chassis types and instruments necessitates frequent changes on each line. These changes mean lost time, new learning curves for the employees, and the resulting drop in efficiency and quality level.

2) Product planning does not have adequate flexibility to readjust plans as sales patterns develop. Consequently, even their initial commitments on certain models may exceed sales demands. This results in excessive commited inventory which represents costly investment and depreciated value.

3) Material procurement efficiency is limited by the relatively small requirements for a large assortment of components and assemblies. Thus cost penalties for small quantity ordering are incurred.

4) The cost pressures exerted by the increasing percentage of competitive imported product erodes the pricing structure, hence the profitability.

RCA Limited, Consumer Electronics Division, recognized that no single effort by Engineering, Industrial Design, Product Planning, Manufacturing, or Marketing could provide any significant improvement in this deteriorating situation. Consequently, an Integrated Business System (IBS) task force comprising all segments of the Division was created to tackle this formidable task.

Standardization and flexibility

It became obvious that the solution centered very much on two key words *standardization* and *flexibility*: standardization to improve product costs, factory productivity, and quality levels; flexibility to provide the marketplace with the right product, at the right time, and in the right quantities.

Engineering Design became the focal point for the first major step in this program, the initial phase embraced only color television consoles. This limiting of scope was deliberate because of manpower demands, tooling cycles, and manufacturing facilities. However, it was recognized that any effective standardization program eventually had to embrace a much larger segment of the television production, and the original planning visualized this expansion as a second phase.

A new engineering concept of a television chassis was conceived which abandoned the conventional idea of one chassis per model and broke it up into three functional assemblies: tuner and control assembly, signal processing assembly, and deflection high voltage assembly.

A complete television receiver could then be considered as a combination of the five appropriate assemblies: cabinet, picture tube, tuner and control assembly, signal processing assembly, and deflection assembly (See Fig. 1).

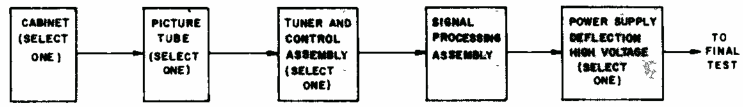

Fig. 1 — Final instrument assembly.

Final instrument assembly

This program of assembly development made it possible to produce any desired combination of features—from the minimum cost non-AFT model with rotary tuner and vacuum-tube deflection to a deluxe remote control solid-state model with pushbutton electronic tuning—simply by selecting the appropriate combination of tuner and deflection assemblies to operate with a standardized signal processing assembly. (See Fig. 2).

Tuner

Even with the most rigid standardization program, more than one version of at least the tuner and control assembly is still required; however, the product planning activity became involved in the challenge to reduce these variations to the absolute minimum. The first generation of tuners developed for this program consisted of two basic assemblies: A rotary tuner type with variations such as AFT, non AFT, and remote; and a pushbutton varactor version, with and without remote.

Some additional versions were required in this first family of tuner assemblies because it was necessary to adapt to existing mask assemblies until a standardized mounting system could be incorporated in new tooled masks.

Signal processing

The signal processing assembly used the modular concept of the XL 100-type circuitry as the basis for this unit. It was mounted in a plastic frame which could be mounted in a variety of positions and which contained all the male pins for the cables which interconnected the three assemblies.

Since the functions performed by this unit were essential in every color receiver built—regardless of external appearance, extra features, or picture size—the standardization of this complex portion of the circuitry became an important factor in the whole design philosophy.

Power supply and deflection

The SCR deflection system as used in the XL 100 circuitry became the heart of the power supply and deflection assembly. However, it was recognized that a lower cost deflection system was also required to meet competitive pressures. Consequently, another much less expensive deflection assembly using only four tubes was developed.

To optimize the standardization concept, these two deflection assemblies were made mechanically interchangeable so that all mounting details, control locations, and ventilation requirements were identical.

Program implementation

The successful implementation of this program depended on two basic principles:

1) All the tuner assemblies must present a uniform electrical interface to the other assemblies, and the two deflection and power supply assemblies must not only present equivalent supply voltages to the other assemblies but must also operate with equivalent drive signals from the signal processing assembly.

2) Each of the assemblies must have stand-alone characteristics so that it can be tested as a unit with adequate control parameters to ensure that it will work with any combination of the other two assemblies which it will meet only at final assembly in the cabinet.

Special test procedures and facilities were developed to ensure these stand-alone capabilities. Fortunately, this additional facilitation could now be justified, since the variety of testing requirements were narrowed considerably. For example, the annualized requirements for the signal-processing assembly and all its associated modules could now be forecast reasonably accurately and a much more refined test procedure could be processed for this assembly. It was also now possible to retain the same skilled personnel at each test site on a continuous basis with the result that productivity and quality of workmanship could benefit.

The most dramatic improvement in factory productivity however was in the flexibility which was apparent at final assembly.

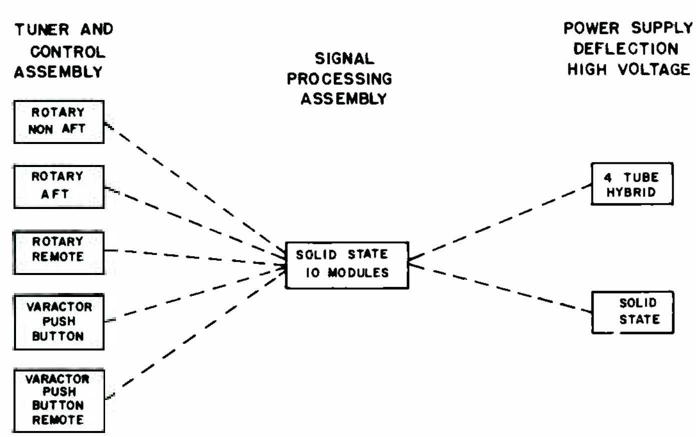

Fig. 2 — Basic chassis assemblies.

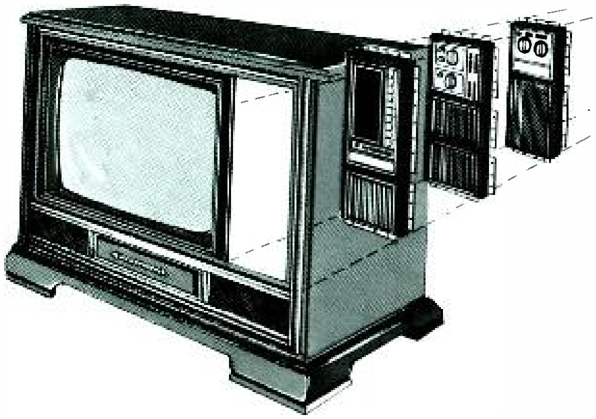

Fig. 3 — Flexibility of design in 25" V console control area.

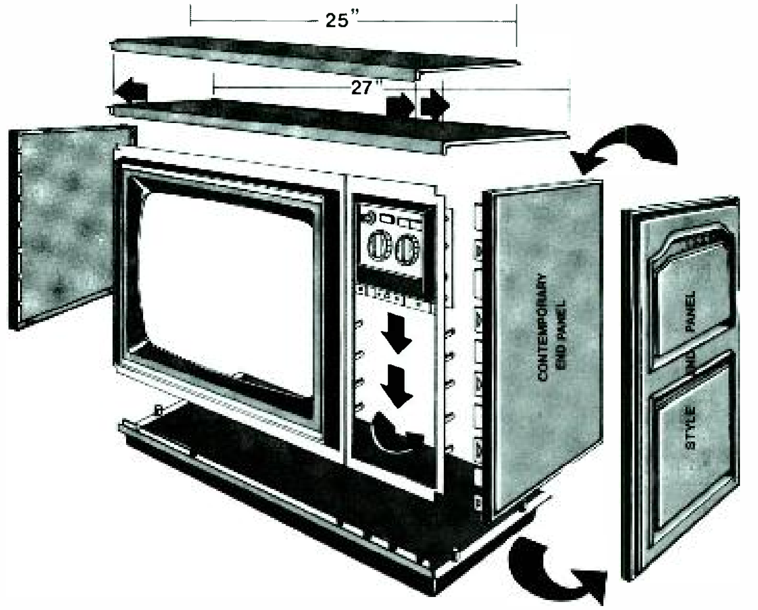

Fig. 4 — Flexible dimensions and styles of 19" V table tv.

The loss of productivity which resulted every time a significant change in model occurred on the production line usually dictated that longer than optimum runs of each model would be produced before change over. This not only resulted in an excessive percentage of the inventory being made up of unneeded merchandise, but it also delayed the availability of models required in the marketplace.

With the new IBS program of modular chassis assembly, it only became necessary to feed the required cabinets and picture tubes into the final assembly process and the appropriate three chassis assemblies could be installed to provide the desired model. Thus, quantities as low as a hundred of different models have been assemblied in sequence on the final assembly line with negligible loss of productivity.

This dramatic improvement in flexibility in final assembly logically led to an investigation of wooden-cabinet assembly procedures, since the conventional approach could certainly not provide equivalent flexibility in cabinet supply.

A study was instituted in conjunction with the Industrial Design activity, and it became evident that a large proportion of the color-television cabinets could be constructed with a limited number of basic dimensions without stifling the creativity of the designers.

Three basic widths were established, with an accompanying reduction in number of chassis shelves, mounting skids, and carton sizes. Standardized top assemblies for these three widths could also be used on a majority of the models with a final shaping operation on the edge just before final assembly being all that was necessary to give a distinctive look to each particular model. Similarly, the number of end panels could be drastically reduced by using standardized dimensions.

The standardization of chassis mounting also meant that three basic back covers to match the three cabinet widths would meet all the requirements regardless of which chassis assemblies were specified. This program of standardization of basic cabinet modules meant that economical quantities of each of these could be built in continuous runs and assembled as required for specific instruments.

This standardized program of chassis and cabinet assemblies was instituted in May 1972, for the 1973 product line. Since it applied to all color console products the benefits became significant, but could not be optimized since only the console portion of the factory assembly procedures could be adapted to this new concept.

Extension of the program

A second overlapping phase had already been started to broaden the standardization program and apply it to a much more significant percentage of the color requirements. The goals accomplished during this phase can be outlined as follows:

1) Design a plastic frame which became the basic structural front of every console cabinet. This frame served a multitude of functions, since it not only became the main element in the maintenance of cabinet structural stability, but it also provided facilities for picture tube mounting, automatic picture tube centering, and the ultimate in flexibility for Industrial Design in the area of controls and speaker enclosures. This last feature was achieved by providing an opening with exactly 3 to 1 ratio in dimensions and with a multitude of mounting facilities along the vertical edges. Industrial Design thus had three square areas which could be used for a variety of tuner and control assemblies, speaker baffles, and such auxiliary items as radio or clock when desired. In addition to the additional flexibility which this frame provided, it also represented a saving over the conventional die-cast mask assembly (See Fig. 3).

2) Develop a plastic cabinet program for the 19V family of models, since this represented the second largest segment of the color market. RCA Limited had been procuring all plastic color cabinets from U.S. sources because of the high costs involved in tooling each particular design. However, with the application of a standardization principle which could apply to a wide variety of appearances and features, it became economically desirable to proceed with a local tooling program. A unique approach to plastic cabinet construction was evolved which conceived the cabinet as a combination of a bottom, a front, a top, two ends, and a back. A novel interlocking principle was developed to provide a built-up cabinet which would have the equivalent rigidity of the conventional single molded cabinet.

Features of this design involved the extensive use of inserts in the molds of the individual panels. These provided two basic widths of top, bottom, front and back, two alternative widths of control area, and

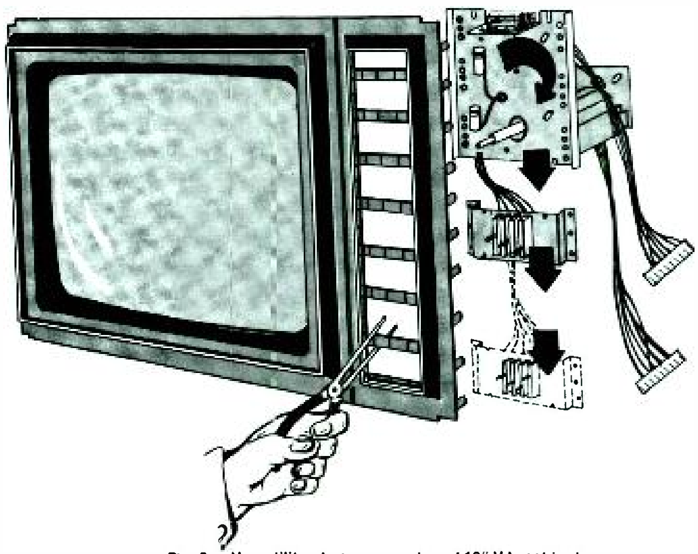

Fig. 5 — Versatility of narrow version of 19" V tv cabinet.

flexibility in end-panel appearance to simulate a variety of furniture styles. The separately molded assemblies also meant that appropriate mix-and-match color ensembles could be provided from solid color panels without any additional finishing processes (See Fig. 4).

The control area dimensions of the wider version were made to conform in width with the console design, and the height was exactly 2½ times as great. This meant that the two basic squares as used in the console assemblies for the tuner assembly and speaker assembly could also be used in these instruments. The additional 1 2 square area available provided a convenient location for clock, radio, or decorative insert as required.

The control area in the narrower version was provided with a series of ribs across the opening and a multiplicity of mounting bosses at regular intervals (See Fig. 5) These ribs were notched at the ends so that the ones which interfered with the control area—whether top, middle, or bottom—could be snapped off and the remaining ones were available as a mounting floor for any overlays or decorative trim. Thus, a wide variety of designs in the control and speaker area could be achieved from a standardized tooled plastic front.

The tooling costs for this approach to a plastic cabinet were not appreciably different from that of one specific complete cabinet mold, but the extra versatility available as a result of the numerous inserts and the standardized control area provided RCA Limited with the flexibility needed.

3) Develop the necessary deflection packages for this new cabinet configuration which would have the same basic circuitry, components, and printed-circuit boards as the console units. Conjunctively with this repackaging, the performance of both the four-tube version and the solid-state version was upgraded to provide brighter, crisper pictures and take advantage of the higher permissible voltage on the 19V and 25V picture tubes.

4) Develop a series of tuner and control assemblies which would be adaptable to both consoles and portables and which had sufficient flexibility to provide versions which would be distinctively different in product produced for other equipment manufacturers as compared with the RCA product line. This distinctive difference was achieved by a basic 90° rotation of the square containing tuners and controls. A second generation electronic tuning assembly utilizing 12 pushbuttons which could be switched between 12 vhf channels and 12 uhf channels, and which could be adaptable to 12 additional cable channels, was also part of this program.

The completion of this second phase has now provided RCA Limited with a family of assemblies which fulfills the needs for 80% of their total color television requirements in 1974. The only exceptions to this program have been the small-screen models where the newly developed in-line picture tubes have required a different mechanical and electrical chassis.

The applicable 80% now have a signal processing assembly which is identical in every receiver. The same family of tuner assemblies can be used in both 19V and 25V models. The pairs of deflection assemblies, although packaged differently for 19V and 25V models, have identical electrical interface with the other required assemblies, and each pair for a specific tube size have identical mechanical characteristics. Thus, the tools are in place to create any new model with minimum lead time and in the desired quantities.

Further applications

The IBS concept is also ideally suited to the export color business where CCIR standards utilizing the PAL principle are common, but the requirements for tuning channels and power supply vary from customer to customer. The special requirements for CCIR color are all concentrated in the signal-processing assembly, including the unique circuitry for PAL-type transmissions. Thus, a CCIR standardized signal-processing assembly has been developed which can be matched up with the necessary tuner and power supply assemblies to meet the requirements of any customer. The stand-alone charactersitics of these assemblies provides the flexibility necessary to ship either as finished instruments or as pretested assemblies, depending on the customers' facilities and import restrictions. The modular cabinet can also be shipped in kit form and the flexibility of the system enables the customer to generate a family of models from standardized kits of parts.

Conclusions

The mechanics of product planning, material control, and inventory control have not yet been optimized to take full advantage of this flexibility and standardization, but the Integrated Business System as originally conceived in 1969 is functional. Immediate benefits in factory operations are apparent. Longer range benefits of lower material costs, improved field quality, and better control of inventory will have much more significant influence on RCA Limited's future in the television manufacturing field.

Acknowledgments

Although all activities in the Division have contributed to the success of this program, the engineering effort, directed by G. Storz, Manager of Mechanical Engineering, would not have been effective without the enthusiastic co-operation of Industrial Design who accepted the standardization program as a challenge rather than as a restriction. Special contributions by J. Tourangeau in the program of standardization of console cabinets and P. Lavallee in the imaginative approach to modular plastic cabinet design are gratefully acknowledged.

Stress, test, analysis and reliability — STAR program

E. J. Byrum | S. Prasow

At RCA Limited, an important part of the Consumer Electronics and Appliance Division's quality, reliability, and serviceability activities is the STAR program. Stress, test, analysis and reliability (STAR) has resulted in 1) a higher degree of quality and reliability, 2) reduced warranty costs, and 3) creation of a quality product image with customers.

THE STAR PROJECT is a system for stabilizing components under operating conditions by accelerating the detection of initial and developed failures in television receivers before they are shipped to the customer from the Prescott assembly plant. Historical data indicates that a significant number of service calls occur during the warranty period because of unstabilized set adjustments, shifting of factory adjustments during transportation, and initial component failures. The means to accelerate the detection of failures and stabilize television receivers was accomplished by using a cycled stabilizing period and shock test before final testing and alignment.

Edward J. Byrum, Plant Manager, Consumer Electronic and Appliances Division, Prescott, Ontario, RCA Limited, received a BA in mathematics from New York University in 1952 and a MS degree in Industrial Engineering in 1956 from Stevens Institute of Technology. Mr. Byrum joined RCA in June of 1951 in Harrison, N.J. as an hourly employee and in March of 1952 joined the Harrison Manufacturing-Engineering Department. In 1962 Mr. Byrum was transferred to the RCA International Division and was sent to Aquila, Italy as an Engineering Consultant on receiving tubes manufacturing problems. In 1964, Mr. Byrum transferred to RCA Limited in Canada and was the Chief Engineer and plant Manager of the Cowansville receiving tube plant in the Province of Quebec. In 1971, he was transferred to the position of plant Manager of the tv assembly plant in Prescott, Ontario. Mr Byrum is a Senior Member of the IEEE, serving as Vice-Chairman of the Montreal Section and holding other responsible offices in the IEEE. In addition, he is the past President of the Society of Industrial Application of Mathematics and has held other civic and organizational offices as President or Director.

Sholem Prasow, Operations Research, Management Systems and Services, RCA Limited, Ste Anne de Bellevue, Quebec., received the BAS in Engineering Physics from the University of Toronto in 1967 and is currently completing a PhD in Operations Research from the University of Pennsylvania. Mr. Prasow joined RCA as the first Operations Research Intern in 1970, working in the Princeton Operations Research Department. There he developed a simulation model designed to simulate the financial impact of new product development timing and funding decisions in a competitive industrial environment. In 1972 Mr. Prasow joined RCA Limited as Manager of Operations Research where he has become involved in product and inventory planning systems, financial planning, forecasting, warehouse location, reliability studies, risk analysis, and centralization-decentralization studies.

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STAR procedure

After assembly and test, all sets are fed on motorized conveyors after being vibrated for five seconds with power *off* and are powered for a period of three hours at an elevated voltage of 128V (normal is 120V). During the three-hour stabilizing period, the sets are brought up to operating temperature for a period of one hour, and then (for the remaining two hours) alternately cycled with power *on* and *off* for short periods of time to simulate home operating usage. When the television sets approach the end of the three-hour run (operating at their normal temperature), they receive a final *customer inspection and alignment*. This accelerated three-hour simulation is the equivalent of twelve hours live operation in the customer's home. Sets showing defects under "STAR" are reworked, recycled, and retested by "STAR" before being shipped.

Projected results

From tests and engineering evaluations conducted at the Prescott facility, the projected results from the "STAR" system will:

1) Reduce the total defects in sets shipped — and reduce the potential defects which arise due to handling and vibration.
2) Provide timely defect information for factory or engineering corrective action. Formerly, such information was provided only after the television sets were sold and required service calls.
3) Result in a significant potential reduction of the number of service calls in the field, thereby lowering the RCA warranty expense.

Factory analysis and work program

The approach to solving the problem was to stress each tv instrument both mechanically and electrically to produce the majority of defects that might occur. In this way, each defect could be analyzed immediately, and appropriate corrective action taken on the assembly line. The end result would be a highly reliable tv instrument. The special stressing of the instrument was to be in addition to the normal instrument testing and adjustments performed in the factory.

Electrical stressing

In the stressing area, it was determined empirically that the instrument would be operated at high line voltage and cycled as many times as possible with at least one or more long cooling-off periods. It was also established that the instruments would be brought up to operating temperature prior to any cycling. Using this approach, the components would be getting as severe a stress as possible, without exceeding part specifications. The current line of instruments was checked for temperature rise; from these tests, it was concluded that a one-hour *on* period at high line voltage would be adequate to bring the majority of the instruments up to temperature (Fig. 1). A large number of tv instruments was then placed on test using the following power cycle at high line voltage for eight hours:

60 min. *on*	5 min. *off*
5 min. *off*	15 min. *on*
15 min. *on*	30 min. *off*
5 min. *off*	60 min. *on*
15 min. *on*	5 min. *off*

The power-cycling test produced results indicating that 85% of the defects would occur in the first three hours of operation (Fig. 2). Therefore, it was concluded that a three-hour electrical stressing (with the last thirty minutes being an *on* cycle) would pull out 85% of the defects occurring in the first eight hours of operation.

Mechanical shock

To achieve mechanical shock, required the pursuit of further avenues to gather information concerning the *G* force normally transmitted to the tv instrument during transportation. The required *G* force was then simulated by a vibrator running at approximately 900 vibrations/min for three to four seconds. A number of instruments were checked to make certain that the life of the instrument was not in any way affected. The mechanical stress was done with power *off*.

However, vibration was not the only mechanical stress required. It was found that drop tests on instruments exerted *G* forces of around 15 *G's* in the drop direction. To stress instruments in this manner, bumping stresses of approximately ten *G's* were designed into

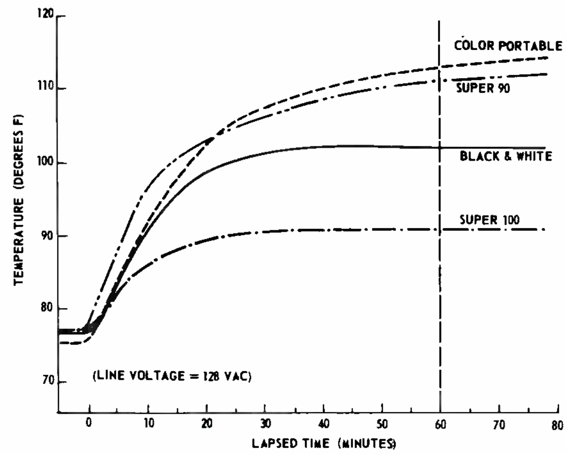

Fig. 1 — Required warm-up time.

the STAR System. Therefore, with both the bumping and the vibration built into the system, the mechanical stressing would reveal any near shorts or mechanical defects that normally occur due to transportation.

Design of conveyor system

To achieve both the electrical and mechanical stressing (without holding up the production flow), a conveyor system was designed for each final assembly line. A moving conveyor was installed in the air space over the existing final assembly line; to cope with the production level of the assembly line and provide the three-hour electrical stress cycle, approximately 520 feet of conveyor was required. A feed rail supplies the high line voltages and by a system of microswitching, each insrument receives the power cycling previously described.

The required mechanical stressing was built into the assembly portion of the STAR System. A radiated signal supplies a color test pattern for the first one hour of continuous operation.

Test Philosophy

To test the instruments properly, a new philosophy had to be achieved; a special training program oriented toward the customer acceptance of quality products was set up. The STAR test procedures were discussed by management with specially selected testers. STAR personnel was specially trained by using definitions of defects and by specifying areas that customers might criticize in the product delivered to their home; in addition, emphasis was given to the areas where certain final adjustments and touchups would be required when the instrument stabilized, following accelerated testing. The instrument final testers are located at the end position of

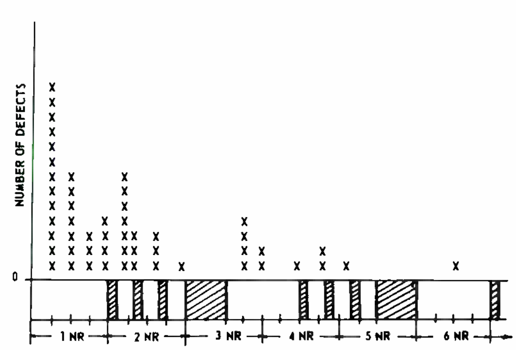

Fig. 2 — Distribution of defects (using predescribed power cycle).

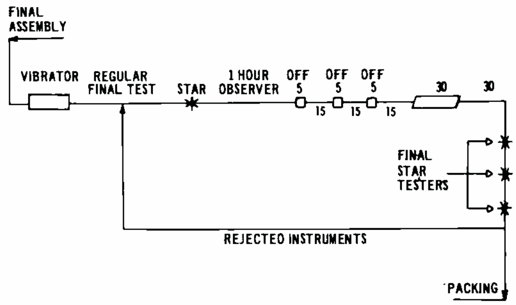

Fig. 3 — The flow diagram above gives the essential location of each of the personnel in STAR and the cycled time on the conveyor system.

the STAR line before the instruments are put into shipping cartons (Fig. 3).

Test procedure

Each assembly line has at least two STAR testers, one called a test observer and the other a final tester. The number of STAR final testers is determined by the daily output of the production test line.

The STAR test observer is located on a platform nine feet above the assembly line running alongside and overlooking the last half hour of the first one-hour *on* period. The test observer's function is to tag the following type of defects:

Weak color	Insufficient width
Dead	Poor contrast
No pix	Poor brightness
No raster	Arcing
Insufficient height	

The STAR test observer also promptly turns off instruments that have no raster or show signs of heavy arcing and records the symptoms. When a number of the same type of defect occurs, the STAR test observer phones the foreman responsible for the area under question. The remaining final testers, located on ground level, have several other functions to perform as well as to test, reject and record all defects. As the instruments stabilize after test, the following functions are touched up for best performance:

1) Kine cut-off or screen adjustments,
2) Noise control,
3) Vertical height and linearity,
4) Focus, and
5) Dc convergence.

Along with these functions, the instrument is cleaned and the customer controls positioned so that the instrument produces a good color picture on any channel with adequate sound, when first turned *on* in the customer's homes.

Instruments having cabinet defects are tagged and returned to regular final assembly, trouble shooting, or touch up (Fig. 3). Once the instrument cabinet is repaired, the set returns through STAR once more, prior to being packed. Any instrument rejected after going through STAR more than two times is submitted to Design Engineering for analysis.

Defect reporting system

An elaborate symptom and defect reporting system was placed in STAR whereby daily symptom reports are issued from the information supplied by the test observers and the final testers. From these reports immediate action is taken on repetitive rejects. All STAR defects are recorded on pink tags and troubleshooting reports to keep them separate from regular production rejects. The reporting and recording system includes a complete follow-up on chassis or other assemblies that are rejected at final assembly. Thus a complete history of defects is thoroughly analyzed. From weekly summaries, management is kept informed regarding actual instrument and assembly defects. Where necessary, efforts are directed toward designers and suppliers to eliminate weak components or circuitry.

Reliability analysis

This section describes the analysis of failure data provided at the Prescott facility. The results indicate that STAR will save 0.18 service calls per set. However, 0.16 failures per set will be discovered during the "STAR" test run.

The supporting data consists of 686 color tv sets specially tested and screened by the Resident Engineer and Manager of Quality Control at Prescott. Solid state, hybrid and portable units were included in the test. In an eight-hour period, 122 defects (17.8%) were detected. Half the defects were component failures, while a total of 101 defects (14.8%) were detected in the first three and one quarter hours.

The analysis proceeded as follows: The initial failures were presumed to have occurred at six minutes. The exact times of the failures were entered into a regression program. A Weibull reliability curve

Table I — Simulation analysis of 1000 sets.

Number of sets that failed	*Without STAR*	*With STAR*	*Difference*
Failed 0 Times	489	577	88
Failed 1 Time	334	310	16
Failed 2 Times	135	82	53
Failed 3 Times	34	20	14
Failed 4 Times	7	2	5
Failed 5 Times	1	1	0
	—	—	—
Expected Total Failures	739	555	184

Note: The expected number of failures is calculated as below:

Without STAR	334 x 1 + 135 x 2 + 34 x 3 + 7 x 4 + 1 x 5 = 739
With STAR	318 x 1 + 82 x 2 + 20 x 3 + 2 x 4 + 1 x 5 = 555
Difference	16 x 1 + 53 x 2 + 14 x 3 + 5 x 4 + 0 x 5 = 184

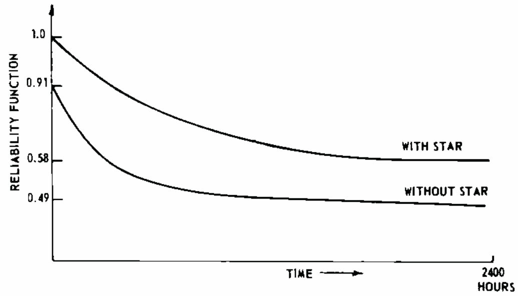

Fig. 4 — Reliability function $R(t)$: probability that set will not fail before time, t.

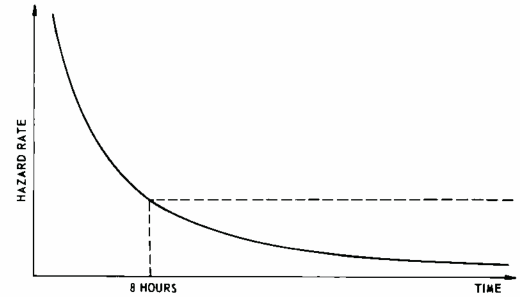

Fig. 5 — Hazard rate (the instantaneous failure rate was found to decline over time). The hazard-rate curve found in the first 8 hours was projected two different ways to 2400 hours (results were the same either way).

of the following form fitted the data extremely well:

$$R(t) = \exp\left[-t^{0.22}\ 7.77\right]$$

$R(t)$ is the probability that the set will still be working at time t in hours The correlation coefficient was 0.99, indicating an excellent fit. A plot of $R(t)$ is shown in Fig. 4. Note that without STAR only 91% of the sets are still working after the first few minutes. By the end of 2,400 hours, only 49% of the sets are still working without having needed a service-call. Fig. 4 also shows the reliability curve for the sets that would have the STAR test. By the end of 2,400 hours, 58% have not failed.

A simulation program was developed to estimate the number of service calls per set. A comparison of the results with and without STAR is shown in Table I. The behavior of 1,000 sets was simulated for a 2,400-hour period. The STAR sets required 184 less service calls (18%).

To determine the number of sets that fail during the STAR test, the simulation program was run for a simulated 3.25 hours. For every 1000 sets tested, 145 would fail at least once. This result compares with the 14.8% of the original 684 sets that failed in the first 3.25 hours. Out of these 145 sets, 129 failed once, 15 failed twice and one failed three times. Therefore, the total number of failures during the stress run would be 162 per thousand (16.2%).

Fig. 5 shows the instantaneous failure rate or hazard rate. Note that it declines very rapidly in the early life of the set. This explains why 0.18 calls per set are saved in the field while only 0.16 failures per set are detected by STAR. Because of STAR, the sets are aged more before being sent to the consumer. The declining hazard rate of Fig. 5 shows that the older sets become, the less inclined they are to fail. Not only does STAR catch initial failures, but the aging of the set reduces the developed failures in the field.

A sensitivity analysis was performed to investigate the robustness of the results. Since data was only collected for eight hours, it was decided to investigate the effect of the exact shapes of the curve on the savings expected. Instead of projecting a declining hazard rate, the hazard rate prevailing at eight hours was projected as a constant (Fig. 5). Using this assumption, the amount of the savings did not differ significantly from 0.18 calls per set.

Since not all sets are on the same warranty program, the simulation period was run for three months instead of one year. The savings due to STAR were slightly higher using this assumption than they were for the one-year simulation period illustrated in Fig. 6.

Summary

The STAR testing program has been incorporated on a progressive basis at all color final-assembly lines in the Prescott plant, and the initial results of the STAR test correlated quite well with the projected data on early life defects.

There has been insufficient exposure of STAR-tested merchandise in the customers' homes to provide any sufficient supporting evidence of improved quality in the field, but the impact on outgoing quality due to the instant feedback in the factory has been very significant.

The ultimate objective of STAR should be a steady reduction of defects at this test, thus indicating that the workmanship, component quality, and design shortcomings have been detected, and the internal feedback has resulted in the necessary corrective actions being taken.

The trend toward better quality merchandise as reflected in STAR reports is already very encouraging and will inevitably reflect in an improved RCA quality image in the field.

Acknowledgments

The authors gratefully acknowledge the contributions made by the Senior Prescott Management Team, with special credit to Jim MacKay, Bill Moore, Maurice Coombs and Werner Guenkel for their zeal and initiative in the successful operation and development of STAR.

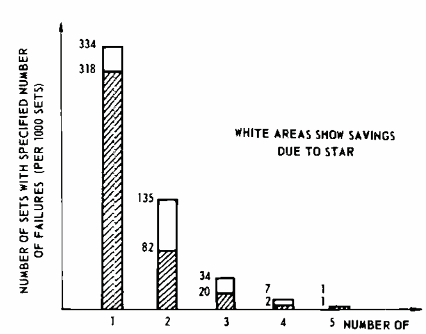

Fig. 6 — Results of simulation of 1000 television receivers.

Dr. Harry J. Moody Fellow, Communications & Space Technology Laboratory, RCA Limited Research Laboratory, Montreal, Canada; graduated in 1948 from the University of Saskatchewan with the degree of B Eng in Engineering Physics. He obtained a National Research Council Bursary, and Studentship to continue work with the University of Saskatchewan Betatron. He obtained his MSc degree in Physics in 1950 for studies of radioactive chlorine 39. He spent a year at the University of Illinois working with the 300 MeV. Betatron, and then returned to Canada to take a position at the National Research Council. He obtained a PhD degree from McGill in 1955 for work on total cross sections for high energy neutrons. He then joined the Research Laboratory of the Canadian Marconi Company and worked in a number of fields, including component reliability, frequency modulation techniques, electron-beam type parametric amplifiers and crossed field devices. In 1961 he joined the Research Laboratories of RCA Limited, in Montreal, as a Member of Scientific Staff to work in the field of millimeter waves. During the course of this work he made substantial contributions to four of a series of twelve review volumes put out by the Research Laboratories on the subject of millimeter waves. In 1968, he had responsibility for establishing an experimental millimeter wave communication link at 15 and 35 GHz for Project Mallard. The equipment was capable of measuring bit-error rates in a digital-bit stream under various environmental conditions. In 1966 he extended his interest in the electromagnetic spectrum to the infrared doing work on various military systems including infrared detection systems, infrared countermeasures systems, infrared simulation systems and laser ranging systems. For some time he worked in the field of electronically-scanned antenna arrays, during which he determined the systematic design techniques for the Butler Matrix and made detailed studies of waveguide slot parameters. A survey report on electronic scanning techniques and a report on experimental and theoretical properties of radiating waveguide slots and series fed slotted arrays resulted from this work. In late 1968 he provided the antenna design for the RCA study for the Canadian Domestic Communication Satellite. This antenna was fully optimized to provide full Canada coverage from synchronous orbit at both 4 GHz and 6 GHz. He has been involved in a number of satellite system studies. These include, besides the Telesat Project, several uhf communication satellite studies, the communication technology satellite, the U.S. Domestic Communication System and a millimeter-wave radiometer study for measuring atmospheric water vapor remotely. He is a member of the Canadian Association of Physicists.

Dr. Freleigh J.F. Osborne, Director, Communications & Space Technology Laboratory, RCA Limited Research Laboratories, Montreal, Canada; was educated at the Royal Canada Naval College (1946-48); obtained his BSc at McGill University in 1950 and was awarded his MSc at Laval University in 1951 for a thesis on Application of the Secondary Electron Emission Multiplier to a Mass spectrometer. In 1954 he received a DSc from Laval University for a thesis on Secondary Electron Emission of Beryllium Copper. He joined the Research Department of Canadian Marconi Company in 1954 as a Senior Physicist, working primarily in the fields of component reliability, systems and instrumentation. In 1956 he was made a supervisor and as such directed a variety of projects including the development of an S-band Electron Beam Parametric Amplifier. In January 1961 he joined the Research Laboratories of RCA Limited as a Senior Member of Scientific Staff. He has since been particularly active in the area of plasma measurements and techniques, leading and contributing to programs on plasma diagnostics, plasma loaded microwave structures, laboratory simulation of geophysical phenomena, and laboratory studies of the interactions between a satellite and its plasma environment. In 1965 he became Director of the Microwave and Plasma Physics Laboratory, now the Plasma and Space Physics Laboratory. In 1968-69 he was project manager of the RCA Limited/TRW/SPAR team which carried out a systems trade-off and design study for the Canadian Government of the Canadian Domestic Communications Satellite System, and subsequently was Manager of Systems Engineering for the Telesat Canada Program Definition Phase. Since then, as Director of the Communications and Space Technology Laboratory, he has led a variety of plasma programs as well as several studies of advanced space communications systems. He was active in the Royal Canadian Navy (Reserve) from 1946-1956, is a member of the Canadian Association of Physicists, and the American Physical Society. He is Chairman of Commission IV of the Canadian National Committee of the International Scientific Radio Union (URSI), a member of the National Research Council of Canada Associate Committee on Radio Science, the Defense Research Board of Canada Advisory Committee on Military Radar and Communications Research, a member of the Working Group on Data Handling and Satellite Technology for the Canada Center for Remote Sensing, and a member of the National Research Council of Canada Physics Division Advisory Board. He has been associated with McGill University teaching a class in plasma physics, and is listed in American Men of Science.

Feasibility study of a two-band uhf communications satellite

Dr. H.J. Moody | Dr. F.J.F. Osborne

A study has been carried out on a geostationary satellite communication system in the uhf band. The system was intended to provide voice communications to small isolated communities in the canadian arctic on a single voice-channel-per-carrier basis. Systems using either dual-spin or 3-axis stabilized spacecraft were found feasible.

Authors note:

We would like to point out that this paper is extracted from a larger report which considered several alternative spacecraft configurations for the mission. In particular a concept of a rigid-panel 3-axis configuration based on the earlier Satcom concepts was considered as an attractive possibility. However the detailed design and cost data required to be reported in the study were not available for such a configuration and precluded it from presentation as a recommended configuration at the time of reporting. Undoubtedly today it would be a prime contender. Notwithstanding this limitation, we feel the paper is of interest because it illustrates the type of mission planning studies presently being undertaken by the Canadian Government and suggests some approaches to a mission where traffic is difficult to predict or is potentially highly variable in nature and density.

When the satellite communications became a reality within the last decade, its value for northern communications was immediately recognized in Canadian Government circles. A quotation below from a recent paper[1] illustrates Canadian government policy and action in Satellite Communications.

> "The significance of satellite technology to communications within Canada can hardly be overestimated. In March 1968 the government published a White Paper announcing its intention to promote and encourage a domestic satellite system. In June 1969 legislation created the Telesat Corporation. Capitalization is based upon implementing a mainly long-haul system in the 4 and 6 GHz bands, with some low-capacity ground stations in northern locations. This system has been described in the literature and is not of course practicable for mobile or man-transportable terminals.".
>
> "In 1969, partly in recognition of the anticipated explosive growth of communications and of the new services which would become technically feasible, the federal Department of Communications was created. The system to be described is part of the Department's strategic planning activity to explore and evaluate new satellite communications applications of special significance to Canada, and particularly as in the present case, when government itself is the principle potential user".

The work summarized here[2] was performed under DSS Contract PL 3610-1-0622 Serial OPL2-0005, under the design authority of the Department of Communications. The program extends a previous study[3] which showed that it is feasible to develop, under specific constraints, a communications system *intended for low-capacity voice telephone services to remote areas of Canada* and presented alternative design concepts which could be implemented in either the 225- to 400-MHz band or in the 1500 MHz band. The study reported here extended the general concept and developed designs appropriate to simultaneous operation in the 225- to 400-MHz and 2.5-GHz bands.

The traffic model provided by the Department of Communications designates four classes of user as shown in Table 1. Thus at the lower band, capability was to be provided to serve mobile and transportable stations with differing satellite EIRPs (effective isotropic radiated power), while at the higher band, radio program distribution and higher quality fixed station telephony was required.

Table I — Traffic model.

Band	*Service*	*Eclipse*	*Carriers*	*Frequency assignments*	*Channels*
225-400 MHz	Mobile	100%	1	1	1 half duplex
	Transportable	50%	20	20	10 duplex
2.5 GHz	Fixed program	50%	20	40	20 duplex 2 simplex

In conjunction with the Design Authority and considering the 1977 time frame for implementation, it was decided to design to the projected Thor-Delta launch vehicle capability of 1890 pounds in transfer orbit. This study was performed during the interval when NASA was proposing to develop the Thor-Delta to an 1890 pound launch capability in transfer orbit. The present objective of 2000 pounds being developed by the McDonnell Douglas Company for the U.S. Domsat program, was proposed at a later date.

The 1890 pound capability was considered to have a high probability of being available without an excessive nonrecurrent cost penalty to the program. After appropriate allowances for interstage adaptor, apogee motor fuel, *etc.* this resulted in designs to an initial on-station-weight of 963 pounds.

System concepts

While the program constraints indicated a geostationary orbit, the specific operating frequencies and dual-band nature of the requirements, coupled with the statistical nature of the major portion of the traffic (telephony) gave the

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possibility of having several new modes of operation, and in turn permitted application of unique spacecraft techniques. To prevent major economic and/or technological penalties to the implementation program, additional design objectives were established. These objectives were:

- All flight spacecraft to be identical,
- Operational use of in-orbit spares,
- Operational use of spacecraft early-life resources,
- Non-tracking ground stations, and
- Maximum reliability of system.

To meet these objectives, the conceptual design work normally carried out at the single spacecraft level was carried out instead on the total space segment level normally existing at various times in the mission, *i.e.* single-operational spacecraft, two spacecraft in orbit, early-life power, end-of-life power, single-point failures, and eclipse vs sunlight operation. The traffic model quoted was considered to be the minimum acceptable for a viable service, and design emphasis was placed on protecting the minimum traffic in all foreseeable circumstances but exceeding it to the greatest extent possible under "normal" operational conditions.

The opportunities for application of new concepts result from the statistical nature of the major portion of the traffic coupled with the requirement that the ground-station antennas be of small diameter (4-6 feet). Thus at the lower band, the ground-station beamwidths are such that spacecraft situated at quite widely separated orbital stations can be simultaneously illuminated by the up-link beam. As a result, with only slight signal loss, the low-band services can be split between two spacecraft spaced about 18° apart in longitude. Thus, the two spacecraft are never eclipsed simultaneously and, in principle, communications traffic can be maintained without secondary (battery) power. This *sequential eclipse* offers savings in weight which can be applied to increased communications, and additional fuel.

However, the two spacecraft cannot operate at the same frequencies simultaneously when in the view of a common source. Thus it is necessary that the identical satellites exhibit different frequency plans, preferably without major hardware penalties; this objective has been achieved by introducing a switchable local oscillator source.

In principle, it is also possible to split service, with each spacecraft operating in only one frequency band (although supplied with transponders at both frequencies) and carrying no redundancy. Then, in the case of a transponder failure, the functions of the two satellites are reversed to maintain service. This *criss-cross redundancy* provides high protection against transponder failures although obviously not against failures of the spacecraft supporting subsystems.

At the higher band (2.5 GHz), the ground-station directivity is such that time-spaced eclipse cannot be utilized; however, the spacecraft can be illuminated adequately by a fixed pointing-antenna over reasonable excursions from its station. Thus *reduced inclination control* when coupled with a technique of *biased inclination insertion* provides additional savings in fuel weight. The antenna directivity also demands that this traffic be through a single satellite.

To make use of the early-life power available in the spacecraft yet avoid substantial hardware difficulties *e.g.* in signal combining, the concept of *non-identical substitution* is incorporated providing a variable communications capability (fitting the available power) and also fulfilling the redundancy requirements. Where identical substitution is required, as might occur near the end of spacecraft life, it is available through the criss-cross redundancy feature.

By appropriate allocation of hardware and functions, it has proven possible to develop design concepts which incorporate these features yet fulfill the single satellite requirements. Thus the practical system fulfills the traffic model requirements for a single satellite and greatly exceeds it for the full system.

Spacecraft alternatives

In a previous study[2] it was found that low-band services tended to be maximized in a 3-axis spacecraft configuration while the high-band services were optimized in a dual-spin configuration. For a dual-band system, it was considered necessary to examine a variety of spacecraft configurations to arrive at an optimum. Four basic concepts were examined as to feasibility with two detailed to a greater extent.

Electrically despun—dual spin

The design was developed as a hybrid arrangement utilizing, at the lower band, electrical despin of an antenna array over the surface of the cylindrical solar array, with the high-band services provided through a mechanically despun erectable antenna at the top of the spacecraft. The low-band antenna was a more complex and higher gain version of the LES6 antenna but still failed to provide sufficient gain (when coupled with the power available at the end of life) to fulfill the single-satellite minimum traffic model. The design concept was developed to the stage of basic configuration and budgets, but not pursued in the absence of more detailed predictions of antenna performance.

3-axis, rigid deployable solar array

This concept was considered of interest where the prime power demand is in excess of that available from dual-spin concepts but somewhat less than the power available from a flexible array such as the one used by the Communications Technology Satellite (CTS). The design developed was based on the ITOS/TIROS designs adapted by RCA Astro-Electronics Division and earlier proposed for the U.S. Domestic Program. Again basic budgets were developed though not pursued as detailed design-and-costing information was not available at the time of the study. The concept is considered a valid candidate for this mission.

Dual spin

Dual-spin concepts were examined in depth for this mission, with several differing designs traded off as to lifetime, inclination control, and eclipse capability. The general conclusion is that the dual-spin concept offers a wide range of design options which fulfill the general mission requirements, and allow incorporation of the features developed in the course of the study. Further, this concept appears to be the one which could most readily encompass changes in launch capability should they occur; and in particular, the dual-spin concept would revert most readily to a 1550-lb transfer orbit weight should the higher capability Thor-Delta not be available.

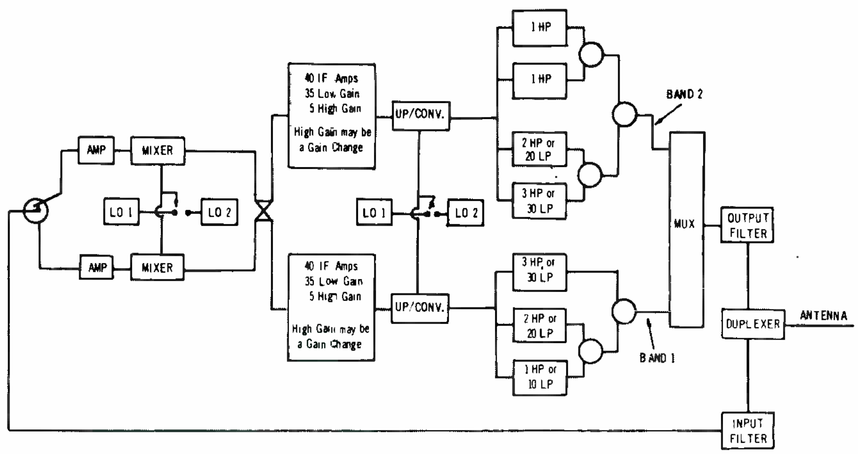

Fig. 1 — Block diagram for the 300 MHz transponder.

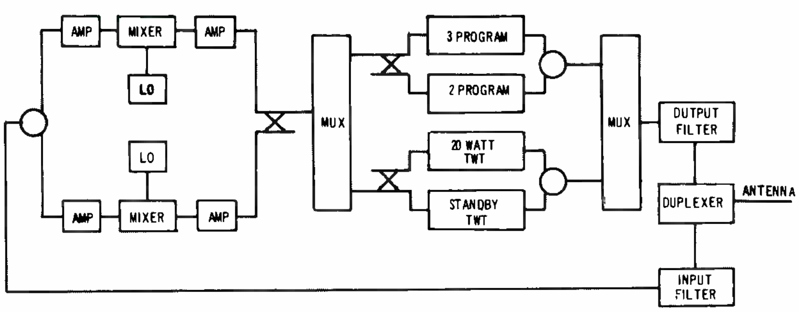

Fig. 2 — Block diagram for the 2.5-GHz transponder.

The design limitation for the dual-spin configurations tends to be available power although both the power and weight margins tend to zero out almost simultaneously. This means the design makes full use of both resources. A basic implementation margin equal to 5% of transfer orbit weight is carried separately in accordance with good design practice.

3-axis, flexible solar array

A 3-axis concept utilizing a large extensible solar array was developed based on the extensive CTS data available. The general concept of such configurations is applicable where the mission demands on power are large considering the launch vehicle involved (as for CTS). In the present mission, the tradeoffs tend to become weight limited by virtue of the secondary power demands in eclipse (if extensive use is made of the available primary power) and because of the large weight assignments to solar array extension and orientation.

This 3-axis configuration is considered viable for this mission although there is somewhat less range of tradeoffs than for the dual-spin design, and it is also somewhat more sensitive to launch vehicle capabilities.

Communications

The transponder portion of the communications subsystem is the key to the operational flexibility of the overall system. As shown in Figs. 1 and 2 there are two completely separate transponders, one at each band. In fact, in the dual-spin designs the only element of commonality is the antenna reflector; while in the 3-axis design, there is no point of dual function.

The low-band transponder (Fig. 1) shows the broadband low-level receiver followed by a local oscillator mixer unit. The local oscillator is designed to put out either of two frequencies as determined by ground command. This allows the incoming signals from either one of two bands to be down converted to a set of 80 channelized i.f. strips. Thus two identical spacecraft can utilize a maximum of 160 frequency assignments (*i.e.* 80 each) without carrying additional hardware or violating the requirement to be identical. A number of these i.f. amplifiers have a gain change of 10 dB available, to provide the high EIRP down-link signals.

After i.f. limiting and amplification, the signals are up converted and sent to one of two power amplifiers selected by command from an assortment of different types. As shown, there are broadband power stages carrying up to three high-power carriers or up to 30 low-power carriers. It must be noted that only one of the power amplifiers in each of the multiplexer input arms can be powered up at one time, but because of their differing capabilities the demand on spacecraft resources can be varied.

The 2.5-GHz transponder (Fig. 2) is more conventional in concept. It is a single translation, all-rf repeater having two channels. Program material is carried in a transistor power amplifier capable of either two or three carriers. The telephony traffic is carried through a 20-W travelling-wave tube amplifier (1-for-1 redundancy). The TWT proposed is an adaptation of a tube developed for S-band operation in the Apollo mission. It features dual-mode operation (10 or 20 W) and thus the demand on spacecraft resources can be reduced for eclipse or similar purposes.

The transponder specifications are summarized in Table II.

The antenna portion of the subsystem differs according to the spacecraft configuration under consideration. In a dual-spin design (Fig. 3) the antenna consists of an erectable rib and mesh parabolic reflector 130 inches, diameter. This is about the largest diameter which can be carried in the fairing without complex mechanical arrangements. The feed is a structural amalgamation of a horn-type linear feed at 2.5 GHz with a reflector-backed crossed-dipole feed providing circularly polarized low-band illumination.

Table II — Specifications for the dual-frequency transponder (single satellite service).

2.5 GHz SUBSYSTEM		
Type	Single Frequency Conversion	
Operation	F.D.M.A.	
Input	Uncooled Paramp	
Multiplexing	Graphite Fiber Epoxy Composite Waveguide Filters	
Weight	20 lbs.	
Services	Telephony	Broadcast
Number of Carriers	90	3
Output Device	TWT	Transistor
Output Power (dBW)	9.2	3.9
Eclipse	50 %	67 %

300 MHz SUBSYSTEM		
Type	Dual Frequency Conversion Fully Channelized at I.F.	
Operation	F.D.M.A.	
Input	Low Noise Amplifier	
Multiplexing	Interdigital Filters	
Weight	70 lbs.	
Services	Mobile	Transportable
Number of Carriers (Max.)	3	30
Number of Carriers (E.O.L.)	1	20
Output Device	Transistor	Transistor
Output Power (dBW) (Max.)	16.1	16.1
Eclipse	1	10

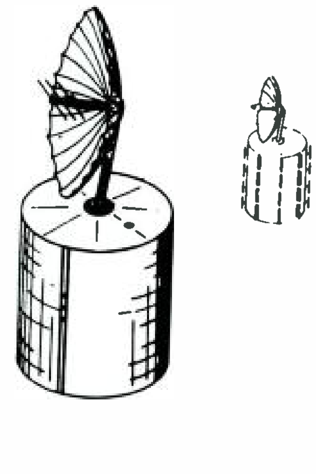

Fig. 3 — Dual-band, dual-spin spacecraft.

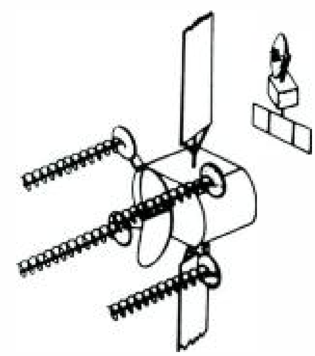

Fig. 4 — 3-axis stabilized spacecraft—CTS based.

Table III — Traffic capability channels.

		300 MHz		2.5 GHz	
		High Power	Low Power	Broadcast	Low Power
Single Satellite	Sun BOL	3	30	3	90
	Sun EOL. S.S.	1	30	3	90
	Min. Eclipse	-	-	2	45
Dual Satellite System	Sun	4	60	3	90
	Min. Eclipse	1	30	2	45

		300 MHz		2.5 GHz	
		High Power	Low Power	Broadcast	Low Power
Single Satellite	Sun BOL	3	30	3	90
	Sun EOL. S.S	1	20	3	90
	Eclipse	1	10	2	45
Dual Satellite	Sun	3	50	3	90
	Eclipse	3	30	3	90

Table IV — Spacecraft characteristics.

Spin stabilized configuration

Diameter: 86 in., Height 157.5/227.5 in.
1820 lbs. in transfer; Initial on orbit 963 lbs.; End of Life: 813 lbs.
Dual-band transponder
Canadian coverage
Power: 360 W E.O.L. (S.S); Eclipse: 243 W
8-Year Life

3 Axis configuration

Diameter: 71 in., Height: 116 116 in.
1820 lbs. in transfer; Initial on orbit 948 lbs. End of Life: 800 lbs.
Dual-band transponder
Canadian coverage
Power: 437 W E.O.L. (S.S.); Eclipse: 160 W
8-Year Life

For the 3-axis design, the antennas are separate at high and low bands. The high band is a simple parabola with horn feed; however, at 300 MHz the antenna is a quad helix array (Fig. 4).

Conclusions

On the basis of the study, it was concluded that a dual-band spacecraft is feasible within the constraints of this mission, and that, by unique spacecraft design, attractive operating modes can be incorporated in the system, improving the cost effectiveness. Table III summarizes the traffic model achieved for the two design concepts detailed in the course of the study, while Table IV gives their respective *top level* specifications.

The dual-spin configuration (Fig. 3) shows the greatest range of viable tradeoffs of the two concepts examined in detail and thus the greatest adaptability to other mission constraints that might be developed. The design presented comes close to limiting simultaneously across all constraints imposed by the launch vehicle (weight, fairing, limits on power, antenna height *etc.*) and thus appears to be simultaneously close to an optimum and an upper limit under the chosen and given constraints.

The 3-axis CTS-based configuration (Fig. 4) also fulfills the basic mission requirements but lacks some of the dual-spin flexibility in design; it is basically weight limited — and only limited advantage can be taken of the large power per pound coefficient (for power increases) made possible by the flexible solar array.

For the other configurations examined, the electrical despin configuration shows antenna-gain limitations, while the 3-axis ITOS configuration showed promise especially at the higher launch weight.

Because of the proposed system operating modes, all the designs have more severe thermal problems than normally encountered in communications spacecraft, since the thermal subsystem must maintain the appropriate equipment environment despite a highly variable heat load developing at different locations within the spacecraft. This problem, particularly in the 3-axis configurations may require application of active thermal control techniques.

Acknowledgment

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Television-compatible generation of eight-color alphanumerics

R.J. Clark | Dr. F.G.R. Warren

The broadcast quality Video IV display controller described in this paper can produce large elaborately formed characters that can be broadcast along with standard programming and displayed on home tv receivers. The hardware/software tradeoffs have been chosen to provide flexible operator control of the color of characters, edges, and backgrounds; font selection and size; placement and number of characters; and character movement.

During the 1964 Presidential Election, the National Broadcasting Company used, for the first time over the air, a system for electronically generating television-compatible alphanumeric symbols developed by RCA Limited in Montreal. Shortly thereafter, a model was delivered to the Canadian Broadcasting Corporation, and the system was used subsequently by numerous other broadcasting authorities in North America and Europe.

The same principles were later adapted for other television display systems such as those found in airports and stock-exchange information systems. These systems could produce reasonably complex graphics, block diagrams, bar charts, etc., and could be addressed from keyboards, with controllers to handle many keyboard inputs and display outputs.

A new generation of broadcast alphanumeric controller — called Video IV — is being developed, based on a modular, programmable concept. Again, the first application is in the broadcast field.

Video IV has vastly improved performance, including excellent formation of characters; control of character fonts; availability of non-Roman alphabets, accents and graphic symbols; full control of eight colors for individual characters and background; and edging and blinking of characters. Editing, erasing, centering, and roll and crawl of selected data are available.

R.J. Clark

Dr. F.G.R. Warren

R.J. Clark, Mgr. Applied Research, Digital and Information Technology Laboratory, RCA Limited, Montreal, Quebec, graduated from McGill University in 1957 with the BE in Electrical Engineering (communications option). During the years 1957 to 1960, he worked for Canadair Limited (Montreal) and Boeing Aircraft Company (Seattle) developing tactical telemetry systems for SPARROW and BOMARC missiles. In 1960 he joined RCA Limited and worked on a variety of digital systems, ranging from aircraft radar simulators to antenna steering systems for ground stations. In addition, he was involved in the development of the first tv compatible CRT display system and has since received several basic patents in this field. From 1963 to 1972, he worked as a specialist engineer on furthering the development of CRT displays in the areas of color and graphics, designing airport display systems, and developing special data entry and retrieval systems for telephone companies, hospitals, power companies and CATV networks. In the period 1972 to 1973, as a staff engineer, Mr. Clark developed the basic concept of the equipment discussed in this article. Recently he was appointed to his present position.

Dr. F.G. Ross Warren, Associate Director of Research and Director of Digital Information Technology Laboratory, RCA Limited, Montreal, Quebec obtained the BSc (hons.) from the University of Manitoba in 1941. After working for four years with Defence Industries Limited and the Aluminum Company of Canada, he entered McGill University in 1945 to study nuclear physics. He was awarded a National Research Council Studentship in 1946 and Fellowship in 1947, and received the PhD in 1948 with a thesis on a cold cathode proton source for the synchrocyclotron. Before joining RCA Limited in 1949, Dr. Warren worked for a year with Bell Telephone Laboratories in New Jersey on dielectrics and their application to wire coating and to capacitors. With RCA Limited he has done research and development on scanning antennas, on aircraft detection systems, and on system aspects of radar, communications and aerial navigation. From 1954 to 1956, he was loaned to the Department of National Defence as Head of the Radar and Navigation Aids Section of the RCAF Systems Engineering Group, the design authority for the Mid-Canada Line. On his return to RCA Limited he became Manager, Systems Engineering in the Defence Systems Division and, in 1960, Director of the Systems Research Laboratory, one of four sections of the RCA Research Laboratories in Montreal. In 1965 he was appointed to his present position. Dr. Warren is a member of Sigma Xi, and of the Canadian Association of Physicists, and a registered member of the Corporation of Professional Engineers of Quebec. He is a member of the Canadian committee of Commission VI of URSI. He was organizer and first chairman of the Montreal Joint Chapter of the IEEE Groups on Microwave Theory and Techniques and on Antennas and Propagation, was Chairman of the Technical Program Committee for the 3rd Canadian IEEE Symposium on Communications, held in September 1964, was a member of the Executive Committee of the 7th International Quantum Electronics Conference held in Montreal in May 1972, and Vice-Chairman (Communications) of the Technical Program Committee for the IEEE Canadian Communications & EHV Conference, November 1972, in Montreal. He was a member of the Administrative Committee of the IEEE Group on Microwave Theory and Techniques from 1963 to 1970, was chairman of its Chapter Activities subcommittee for 1965-66, and was Associate Editor for Abstracts of the *IEEE Transactions on Microwave Theory and Techniques*. He is a member of the National Research Council's Associate Committee on Instructional Technology.

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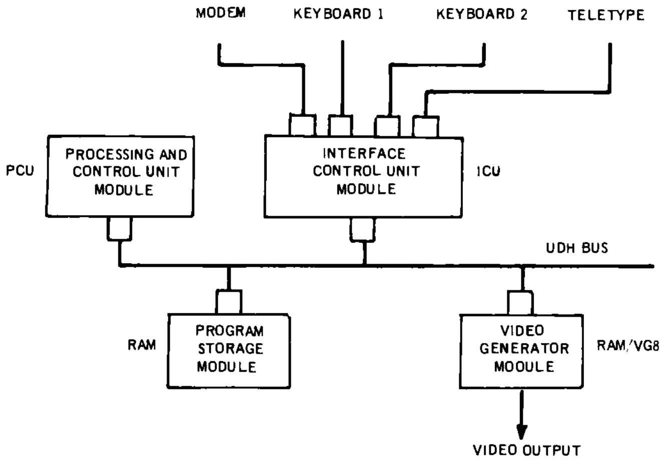

Fig. 1 — Simple display controller unit.

Two prototype models of Video IV have been delivered to the Canadian Broadcasting Corporation and one model to CHAN-TV in Vancouver. These models have been used in over-the-air programming (*e.g.*, in Manitoba and Quebec elections).

Basic techniques

The basic requirements for a tv-compatible display controller (Fig. 1) are 1) to receive digital messages from a variety of sources such as keyboards, computers, or teletype lines; 2) to store the messages in a display refresh memory; and 3) to convert the digital messages stored in refresh memory into video for standard tv sets. The data input operation, shown in Fig. 2, is performed as follows:

1) A number of discrete character locations are designated on the CRT screen; *e.g.* there might be 250 locations disposed in 10 lines of 25 characters each on a broadcast-type display (Fig. 3). A section of memory (display refresh memory) is designated containing one word location for each of these potential character positions.

2) The incoming signal codes (words) identifying the characters, and perhaps additional information concerning them, are stored in memory locations corresponding to the designated positions on the screen.

3) The signal controlling the intensity of the electron beam in the tv display tube is produced in the following manner. As the beam is scheduled to enter one of the designated positions on the CRT screen, at which a character may appear, the memory location corresponding to that position is consulted to determine what character, if any, should be there. If a character identity is stored, the character generator is consulted to determine what the signal intensity variation should be on that particular line of the tv scan to produce the required character. Thus, on each tv scan line, the character generator is consulted once for each character position in the row (if a character is stored in the memory location corresponding to that position). A character generator contains, in its memory, the shape of each character or other symbol that the system may be called on to display. The information is stored in a matrix format, identifying which positions in the matrix should be *on* and which *off* to produce the required character. See Fig. 4 for several character formats of different matrix sizes.

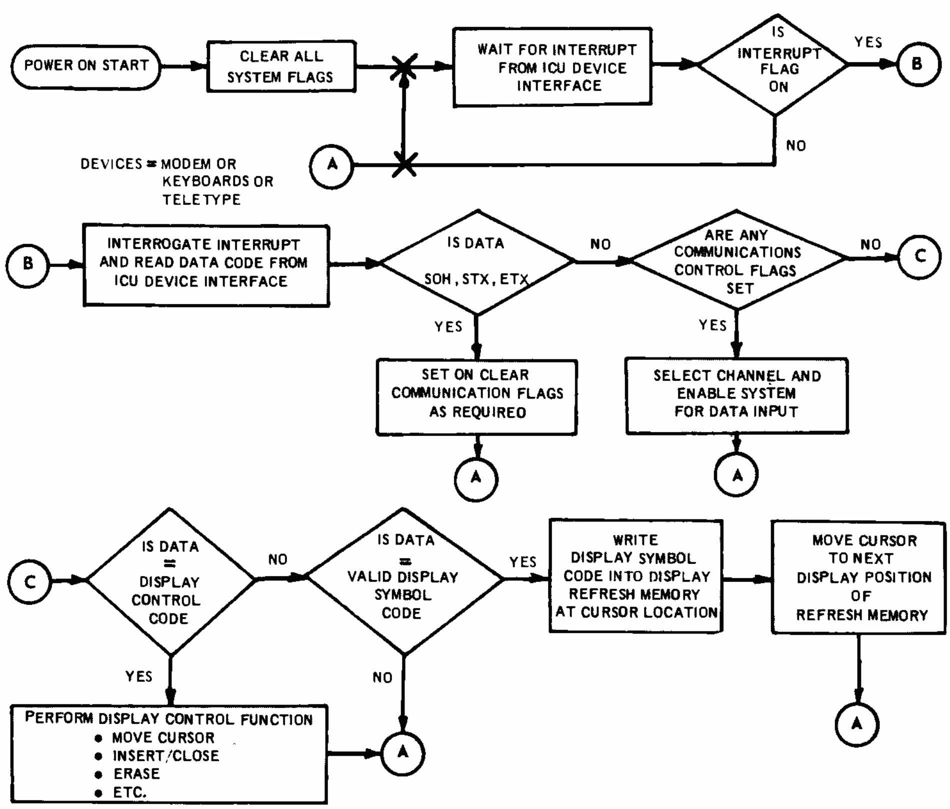

Fig. 2 — Flow diagram for data input, processing, and control operation.

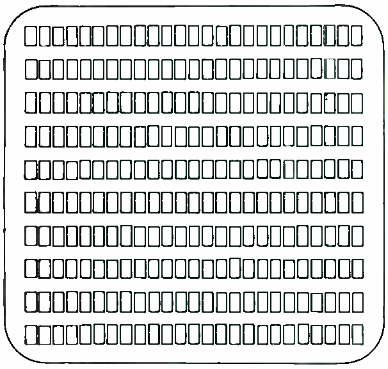

Fig. 3 — Predesignated potential character positions.

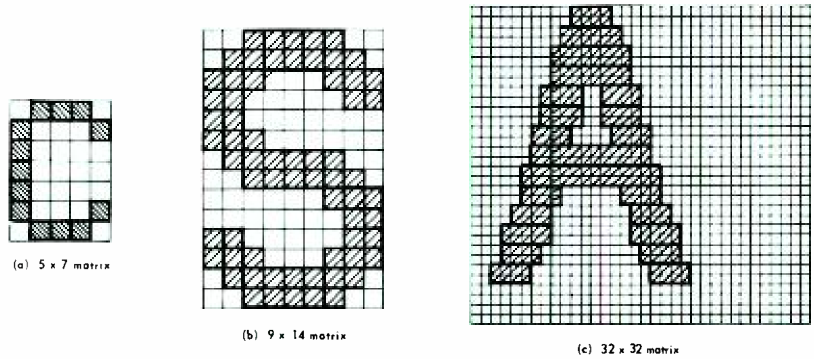

Fig. 4 — Matrix storage of character shapes.

In general, each horizontal row of the matrix corresponds to one (or sometimes two) horizontal lines of the tv raster.

The character-generation technique was first developed by RCA in 1962 and is in general use by industry. It provides tv compatible video from digitally stored data as described in Figs. 5 and 6. As the beam scans across and down the tv screen, data codes are read from a display-refresh memory. These codes are combined with a tv-line counter code to provide an address code by which symbol dot-pattern codes are read from the character generator memory. The symbol dot pattern codes corresponding to a particular symbol and tv line scan are then transmitted serially to the final video amplifier stages.

Special features

Other functional performance features of the Video IV display controllers include:

1) Ability to type messages into refresh memory, verify them on the display, then transmit them to a remote computer for processing.
2) Special keyboard operator editing aids to improve typing efficiency and accuracy.
3) Special display effects (*i.e.* color, edging, etc.) to highlight displayed data.

Programmability

Display controllers generally have been hard-wire programmed to perform most of the above functions. This involves wiring logic gates, registers, and counters in different ways to meet the various customers' requirements. However, certain typical features can vary from customer to customer, including number of characters displayed per row, number of display rows, character size, and keyboard-edit functions.

In prior controllers, these features were usually provided by modifying existing hardware modules with wiring changes, links, or additional logic. This made such custom units expensive and often economically impractical. The controllers discussed here are programmable by software and not hardware changes. Thus, only one hardware design of each module will be produced, and custom requirements will be accommodated by changes made to the controller's software operating system, stored on a replaceable disk cartridge unit. It will also be possible to enhance or modify a customer's controller, in the field, by simply replacing the old disk cartridge with a new cartridge having operating software with different and additional features.

Interface flexibility

Connecting a hard-wired controller to a data processing facility usually involves

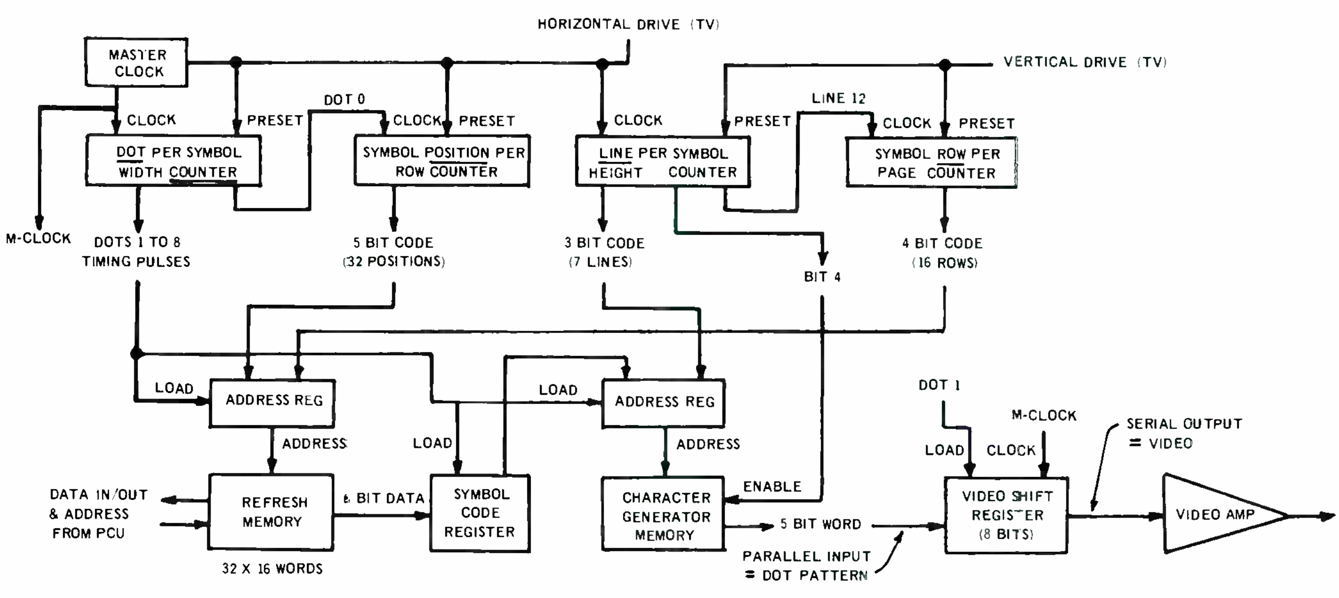

Fig. 5 — Simplified block diagram of video generator module.

special and costly interface software and hardware. On the other hand, these new intelligent controllers can transmit messages to, or receive messages from, external devices under software and not hardware program control. Thus, by changing or adding I/O-handler software, it is possible to transmit or receive messages using virtually any user-oriented communications control procedures and codes (such as ASCII, EBCDIC, BAUDOT). It is also possible for a single controller to communicate simultaneously with a variety of external devices (such as computers, printers, keyboards or cassettes) where each device requires a different data input/output handling procedure. Data input/output to external devices is provided by EIA RS232 C interface connections. Each asynchronous interface can be programmed separately in terms of data-word size (5-, 6-, 7-, or 8-bit data), odd or even parity, data speed (110, 1200, 2400, or 4800 b/s) and number of stop bits (1 or 2). Both synchronous and asynchronous RS232 C interface connections are provided. The synchronous interface operates in eight-bit ASCII code.

Video generators

Available with the new generation of display controllers will be a series of tv-compatible video generators believed to be the most powerful and flexible units of their kind on the market. The combined capabilities of these modules make them unique in the industry. The use of random-access memory (RAM) instead of read-only memory for the character generator makes it possible to store a variety of symbol fonts on the disk unit for loading into any display channel (character-generator memory) on command. Broadcast controllers will, therefore, be capable of transmitting messages to the home in many languages on any channel for international events, news, and motion picture subtitling.

The video generators incorporate programmable x-y format/font display-control counters which allow the user to vary, under software control:

- Number of characters per line,
- Number of lines per page,
- Size of symbols,
- Vertical roll rate up the screen, and
- Horizontal crawl rate across the screen.

The capacity of the character generator memories, together with the programmable counters, enables the user to compose displays having more than one size of symbols. Another interesting feature is the use of touching-symbol dot matrices which make it possible to produce exotic language symbols (Arabic, Hebrew, *etc*); to draw graphics such as bar charts, line graphs, block diagrams, and maps; and to create animation. The character video generators can be driven from an internal (or external) 525-line or 625-line tv sync source, and since each generator is independently synchronized, it is possible to run different display channels from separate tv sync sources or even switch sync sources for a particular channel while on line.

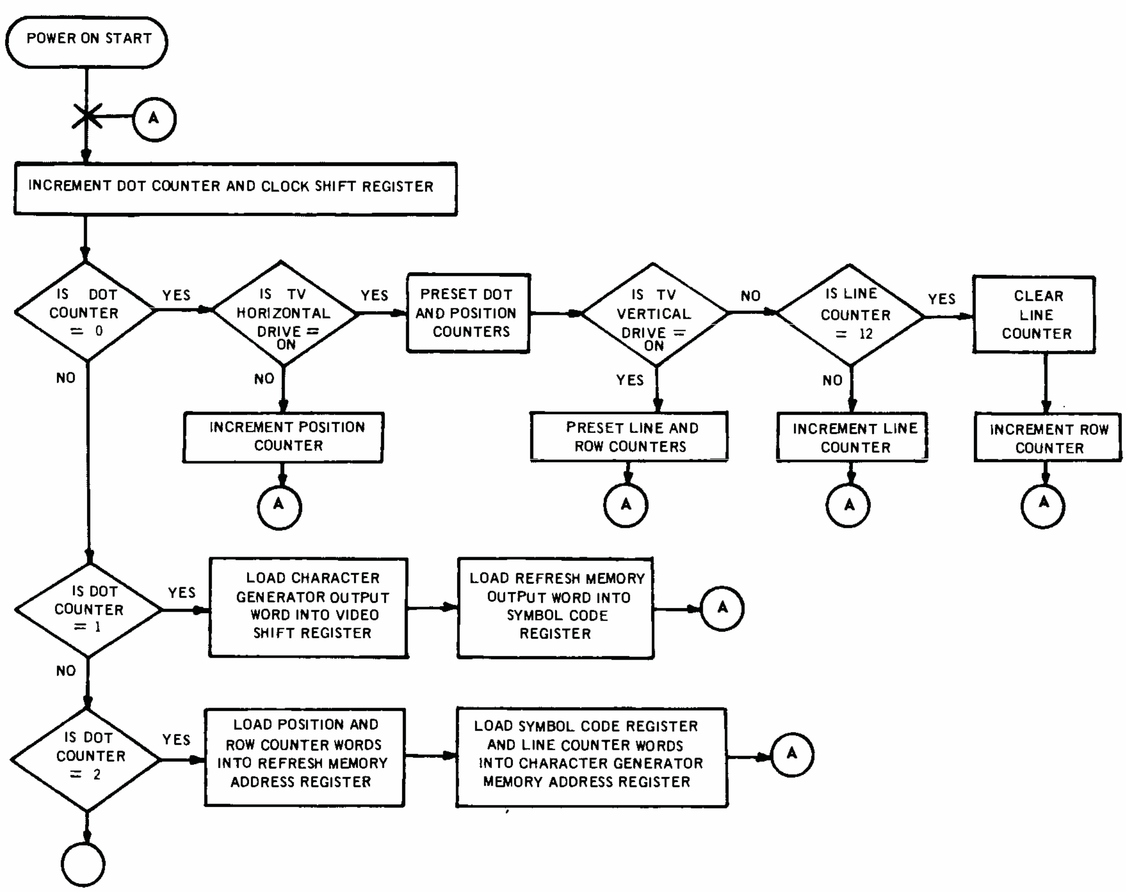

Fig. 6 — Flow diagram for tv-compatible generation of alphanumerics.

Display color control

Color control bits are stored with the symbol codes in refresh memory to provide the necessary color control logic in the final video amplifier stages. Color bits are controlled by the software system such that a keyboard operator (or computer) can write symbols in any one of eight colors, symbols with edging in any one of eight colors, and symbols with background in any one of eight colors.

Edging for symbols

The broadcast-quality video generator produces symbol edging on command by inserting horizontal and vertical time-base delays in the output video signal. The various combinations of horizontally and vertically delayed signals are *or*'ed logically to provide a final output video signal and an edge key video signal for use by the broadcast system.

Data roll and crawl

The broadcast-quality video generator is capable of rolling messages vertically up or horizontally across the tv screen on command, as these messages are received from a disk storage unit. This effect is produced by the software operating system by continuously writing control words into the programmable display control counters provided in the video generators.

Color graphic displays

The video generators also produce high quality graphic displays, in color, for such purposes as bar graphs, block diagrams and schematic drawings, line graphs, and simple maps or cartoons. Future developments will improve and extend this capability greatly.

These graphic displays will be made possible through the use of variable-font RAM character generators having continuous touching-symbol dot matrices.

Editing and display control features

Software can also be provided which causes the controller to perform special custom keyboard edit or display control features such as:

- Insert a new item in a list (*i.e*, new flight data insertion);
- Delete an item in a listing (*i.e.*, flight data cancellation);
- Delete a letter or word in a sentence and close up the blank space;
- Insert a letter or word in a sentence;
- Center data on the display;
- Protect the display field;
- Vary the tab;
- Transmit selected data fields only.

Multichannel displays capability

Each controller can generate up to 16 channels of tv compatible video simultaneously. Each channel has associated with it a video-generating module (or modules) providing the refresh memory and character generator.

Applications

The first application for the Video IV broadcast alphanumeric controller is the generation of signals to be mixed with the normal video broadcast signal to produce high quality, alphanumeric messages superimposed on the normal television picture (or occupying the screen by themselves). Typical uses might be in broadcasting news flashes, election results, sport statistics, weather bulletins or providing graphical illustrations or simple cartoons. Ultimately, the additional processing and control capabilities of the controller may be used to perform a variety of other control functions in the broadcast studio.

The salient features of Video IV may be summarized as follows:-

- High quality characters produced using up to a 32x32 matrix. Character fonts may be specified by the customer.
- Upper and lower case, accents and special symbols included in a 64-, 96-, or 128-character set.
- Choice of eight colors available for character, for edging and for background.
- Line formats programmable from 1 to 12 lines of 8 to 30 characters or 1 to 20 lines of 25 to 50 characters.
- Four character sizes selectable by program control.
- Roll, crawl, blink and editing features.
- Diskette (floppy disc) storage for source material and previously composed material, and for operating programs.
- Generation of bar graphs, simple block diagrams.
- Control through keyboard, stunt box, computer or communications line (RS232 C).

Some experimental Video IV presentations are shown on the cover of this publication.

Future Developments

Early display generators created only a limited repertoire of small, simple monochrome characters in fixed non-touching rectangular areas on the screen. The display generators described in this article make it possible to produce large elaborately formed characters, with flexible control of character color, edge color and background color, in upper and lower case, if required, and with a variety of accents and special symbols for use with foreign alphabets and for limited graphic application. Touching characters can be made available; these will be required for some non-Roman alphabets, as well as for improved graphic capability. Proportional spacing can also be provided for different characters; *i.e.* narrower than normal letters for *i*'s and wider for *m*'s and *w*'s. A wide variety of character fonts will be available on any machine through the use of diskette storage.

Future developments will provide even greater display flexibility, with a series of video generators capable of generating complex line graphs, dot graphs, maps, block diagrams, cartoons, and a variety of other graphic display effects in color. The present limited capability for repetitive animation will be extended to a more flexible capability through more extensive use of disk memory. Also, additional use will be made of the intelligence of the controller to provide signals to control other functions as well as the display.

Acknowledgment

It is a pleasure to acknowledge the valuable contributions made by R. H. Colt as Manager of the group charged with development of the experimental model of Video IV and by R. C. Graham, who, among other tasks, did much of the design on the processing module and established its instruction set, as well as the essential contributions of the other members of the development group.

Design criteria for high-data-rate terrestrial communications systems

J.M. Keelty

Society's increasing reliance on data communications can be expected to make increasingly greater demands upon the capacity of communications transmission systems. Terrestrial radio-relay systems transmitting hundreds of megabits per second per rf channel in the 10- to 20-GHz portion of the frequency spectrum are logical contenders to supply the required capacity. This paper discusses the factors limiting the performance of such systems and estimates the form into which they may evolve.

PROPAGATION in the 10- to 20-GHz frequency band is generally affected by the same factors as propagation in other bands — albeit to a greater or lesser degree. Attenuation by rain is much greater than in the band from 2 to 10 GHz. On the other hand, multipath fading does not appreciably affect performance, if certain path-length selection criteria are followed.

Attenuation by atmospheric precipitation

Attenuation caused by rain has been investigated theoretically and experimentally for over twenty years. A great deal of effort has been devoted to establishing the precise relationship between point rainfall rates and signal attenuation. Many measurements on terrestrial test links have been required because of the difficulty of accurately establishing the fine structure of the rainfall along a path.

Some of the best known results are those of Ryde and Ryde[1] and Medhurst[2]. The results of the latter are shown in Fig. 1.

The author has found that the following equation, adapted from ones presented in NBS Technical Note 101, provides a prediction of attenuation close to that measured experimentally:

$$y = KR^{\alpha} \qquad \text{(dB/Km)}$$

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where R = rainfall rate (in mm/hr); $K = 4.0f^{2.5} \times 10^{-5}$; $\alpha = [1.14 - 0.07\,(f-2)^{1/3}][1 + 0.085\,(f - 3.5)\exp(-0.006f^2)]$; and f = frequency (in GHz).

Attenuation resulting from the presence of fog or snow is small compared to that resulting from rain and will not be discussed here.

Effect of multipath fading

Frequency selective fading due to multipath effects is often a performance-limiting factor in microwave communications because it can reduce signal strength to unusable levels and limit system bandwidth. In S-, C-, and X-band systems, some form of diversity is usually employed to combat the effect.

The most troublesome type of reflection that can cause multipath is that from atmospheric layers associated with negative gradients in the atmospheric refrative index. Ruthroff[3] has analyzed propagation under such substandard atmospheric conditions and calculated path lengths for various frequencies, which, if not exceeded, will result in a situation in which the magnitude of fades resulting from multipath is negligibly small. These path lengths will nearly always exceed the path-length limits established by rain attenuation.

Path geometry selection

The data presented in the previous section indicates that the path attenuation introduced by rainfall can be enormous. For example, Fig. 1 indicates that, at 18 GHz, 100 mm/hr of rain introduces 10 dB/km of excess attenuation into a path. Fig. 2 depicts point rainfall rates versus cumulative time for New Jersey and Quebec. It indicates that rainfall can be 100 mm/hr for significant periods of the year and, therefore, that performance of a high-data-rate system will be precipitation-limited. This section assesses what effect such attenuation would have on system availability and how this affects selection of path geometry.

Tandem and path-diversity transmission systems

A tandem transmission system consists of a series of radio-relay repeaters in cascade. A path-diversity system is designed by duplicating an entire transmission system and placing the two paths some distance apart, with intervening switching nodes. If rainfall severely degraded the performance on one or more hops of a path, the traffic would be switched to the other path. Work by Osborne[4], who compared the two systems on the basis of performance and the numbers of repeaters required, has indicated that the path-diversity system is not meritorious. We will therefore confine our attention to tandem systems.

Criterion for establishing performance levels of tandem transmission systems

In this discussion, tne performance of a tandem-repeater data-transmission system is assumed to be precipitation-limited. The bulk of precipitation that will degrade error rates of a digital radio-transmission system can be assumed to be associated with storms.

The model shown in Fig. 3 represents the worst perturbation conceivable: A long line of thunderstorms that may cross the path of the hops at any angle. Assuming that the crossing angles are all equiprobable, the relationships between the error rate on one hop affected by rain, the overall error rate on all hops affected by rain, and the system outages can be derived.

Let n be the number of links affected by a rain storm; y be the resulting error rate on the n affected links; x be the error rate at one regenerating repeater due to one rain-affected link ($y=nx$); and $p(r)$ be the probability density function of variable r.

Letting $w = n$, the transformation

$$y = nx \qquad w = n$$

permits us to write

$$p(y,w) = \frac{p(x,n)}{|J|}$$

where J is the Jacobian of the transformation which is equal to n:

$$p(y) = \int_{-\infty}^{\infty} \frac{p(x,n)}{|n|} dw$$

$$= p(x) \int_{-\infty}^{\infty} \frac{p(n)dn}{|n|} \qquad (1)$$

$p(n)$ can be estimated by referring to the situation geometry shown in Fig. 3

$$l = w/\sin\theta$$

$$n = l/R$$

$$= w/R\sin\theta$$

$$= K/\sin\theta$$

The distribution $p(n)$ must be estimated from that of θ. Here we assume that the storm-approach angles are equiprobable.

$$p(\theta) = \tfrac{1}{2}\pi$$

$$p(n) = p(\theta)\,|\,f'(\theta)\,|$$

$f'(\theta)$ and $p(n)$ are easily found as

$$f'(\theta) = -[K/n^2]\,[1-(K^2/n^2)]^{-1/2}$$

and

$$p(n) = K/\{2\pi n^2[1-(K^2/n^2)]^{1/2}$$

Therefore, from Eq. (1),

$$p(y) = [p(x)K/2]\int dn/[n^2(n^2-K^2)^{1/2}]$$

After integration and insertion of appropriate limits of integration,

$$p(y) \div \frac{Rp(x)}{2\pi w}$$

if

$$l/R >> w/R$$

i.e., if the storm is much longer in one dimension than in the other. The probability that the error rate on the links affected is equal to or greater than Y may be obtained as follows:

$$\int_{Y}^{\infty} p(y)dy = \frac{R}{2\pi w} \int_{Y}^{\infty} p(x)dy$$

$$= \frac{RY}{2\pi w X} \int_{Y}^{\infty} p(x)dx$$

where X is the error rate due to a single hop affected by the storm. Therefore

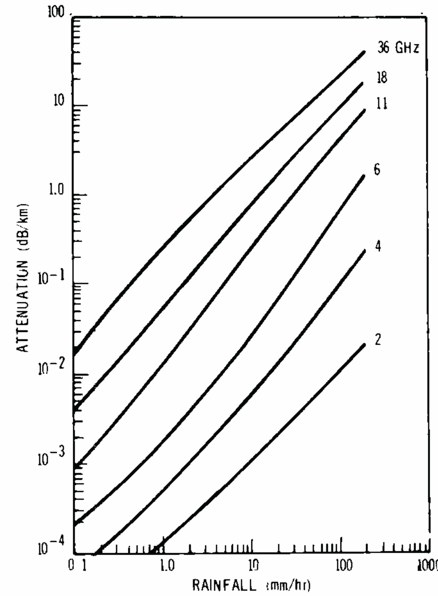

Fig. 1 — Theoretical rainfall attenuation at various frequencies.[2]

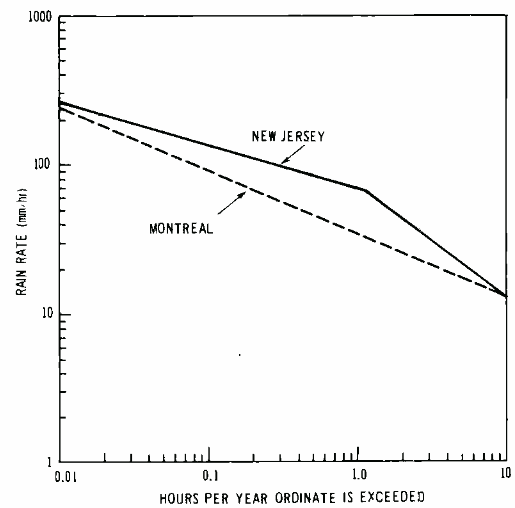

Fig. 2 — Point rainfall rates.

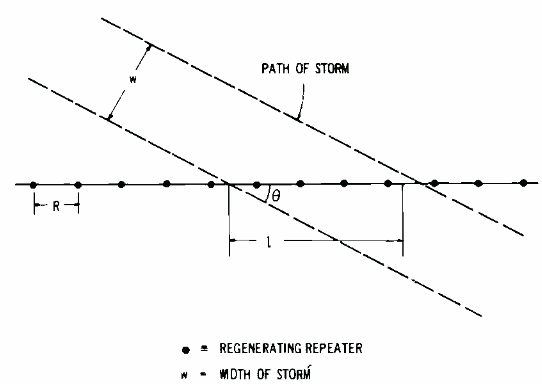

Fig. 3 — Tandem-repeater relay system/rain-storm configuration.

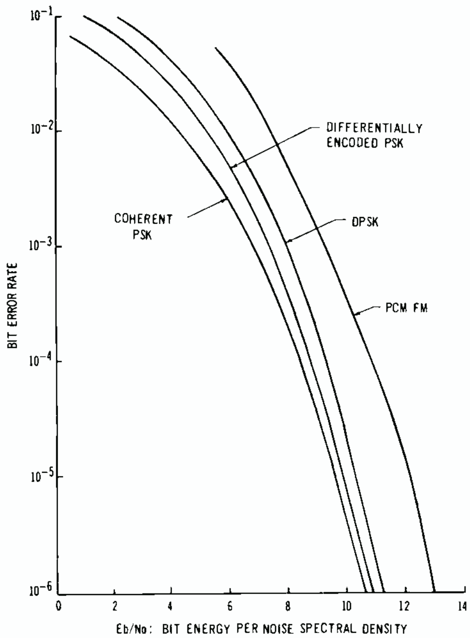

Fig. 4 — Bit-error-rate performance of various modulation systems.

$$\int_Y^\infty p(x)\,dx = \frac{2\pi w X}{RY}\int_Y^\infty p(y)\,dy$$

where the integral on the left-hand side is the probability that the single-hop error rate $\geqslant Y$. The factor $\int p(y)\,dy$ is that portion of the total system outage that can be apportioned to the section of the system affected by a single rainstorm. Since we will ultimately employ yearly point rainfall rates to calculate outages we can calculate this as follows:

$$\int_Y^\infty p(y)\,dy = \frac{\textit{system yearly outage}}{\textit{system length}/RY/X}$$

The denominator of the expression on the right hand side is the number of possible sections in the system that can be affected by rain, each section being of equal length to the section affected by the model rainstorm.

The procedure may be illustrated by calculating the single-hop outage rate permissible for a 2500-km link when the overall error rate must not exceed 10^{-6} for more than one hour per year (10^{-4} outage).

$$X = \frac{Y}{2\pi w/R}\,\frac{\int p(x)dx}{\int p(y)dy}$$

where the integrals are evaluated between Y and ∞.

$$\int_Y^\infty p(x)dx = \frac{2\pi w/R}{Y}\,(10^{-4}X)/(2500X/10^{-6}R)$$

$$= \frac{2\pi w}{Y}\;\frac{10^{-10}}{2500}$$

$$= \frac{2\pi w\;10^{-4}}{2500}\text{, since } Y = 10^{-6}$$

$$\int_Y^\infty p(x)dx = 10^{-6}\text{, if we assume } w = 4\text{ km}$$

That is to say, the error rate on one hop must not exceed 10^{-6} for more than 0.0001% of the time if the error rate on the entire system is not to exceed 10^{-6} for more than 0.01% of the time.

Table I — Characteristics of radio-relay system.

Parameter	*Value*
Antenna gain	18 GHz: 47 dB 11 GHz: 42.7 dB
Receiver noise figure	10 dB
Receiver bandwidth	250 MHz
Modem implementation margin	4.8 dB
Composed of:	
Intersymbol interference	2.4 dB
Differential encoding loss	0.3 dB
Sundry	2.1 dB
Carrier-to-interference ratio (C/I)	23.5 dB

Table II — Repeater interference budget.

Parameter	*Values* (dB)
Adjacent channels	− 30
Reach-through	− 40
Back radiation	− 36
Back reception	− 30
T_x to R_x	− 35
Other digital systems	− 33
Analog systems	− 33
LO noise	− 40
C/I	23.5 dB

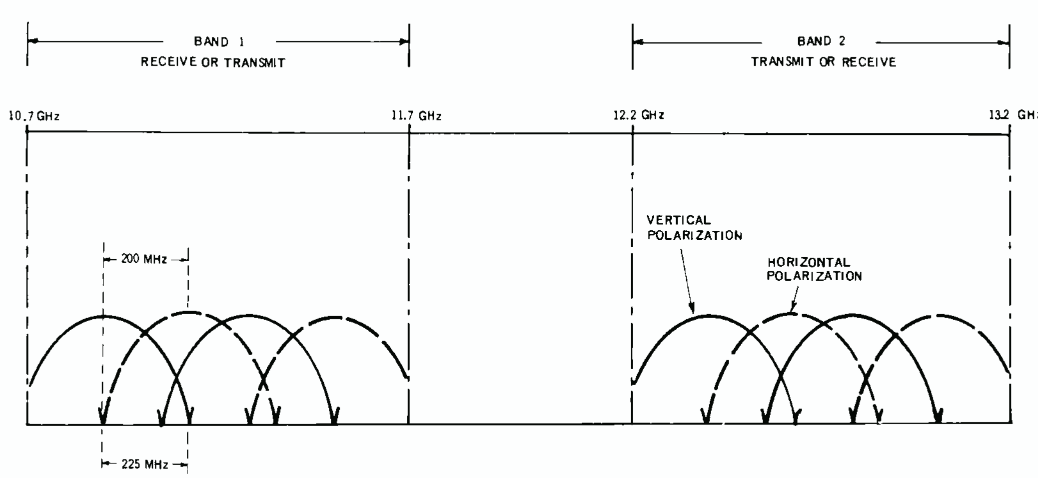

Fig. 5 — 11-GHz frequency plan for four duplex 550 Mb/s channels.

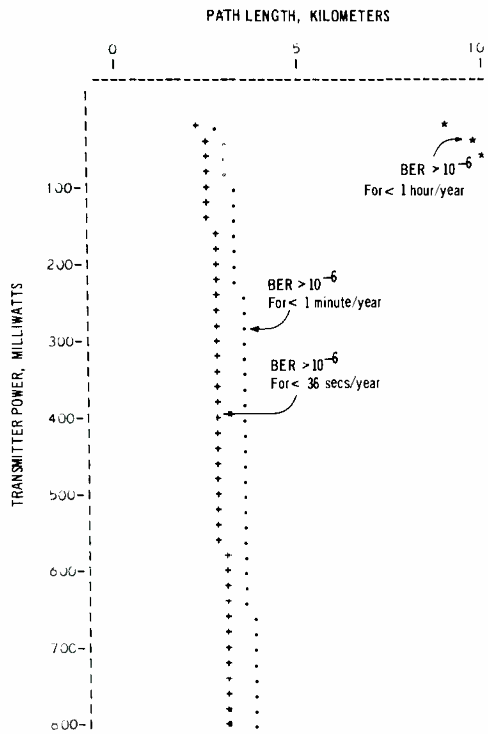

Fig. 6 — Single-hop performance at 11 GHz.

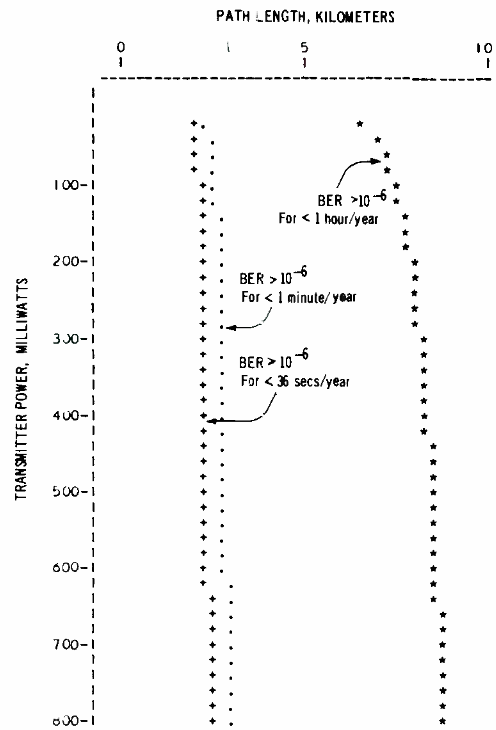

Fig. 7 — Single-hop performance at 18 GHz.

Implications to signalling system

In the 10- to 20-GHz frequency range, the power output of wave-launching devices is limited, and the most efficient modulation system in terms of transmission energy per bit is required. PSK with NRZ-L data is this system. The use of four-phase PSK permits one to double the amount of information carried in a given bandwidth. (With respect to two-phase PSK). The error-rate characteristics of various modulation systems are summarized in Fig. 4.

Path design

The method of design using the criteria established in the previous sections for evaluating the effect of precipitation on the system error rate can be illustrated by considering the design parameters of a system which must support 550 Mb/s on each of four duplex rf channels with an overall error rate that must not exceed 10^{-6} for more than 0.01% of the time. Results are calculated for 12- and 18-GHz carriers. A suitable frequency plan is shown in Fig. 5. This shows polarization multiplexing which permits adjacent channels to be placed very close together without adding too much interchannel interference. The arrangement shown is centered at 12 GHz. A plan for 18 GHz could be identical.

Calculations in the previous section indicated that the single-hop error rate must not exceed 10^{-6} for more than 0.0001% of the time (~36s/yr) if the system-outage objective is to be met.

The calculations to predict the path lengths allowable with PSK modulation to meet the 10^{-6} BER are straightforward and will not be reproduced here. They were based on radio-relay system characteristics shown in Tables I and II, and New Jersey rainfall data.

The results are shown in Figs. 6 and 7 for a series of transmitter powers. They indicate that the appropriate path lengths are 2.5 and 3 km, respectively, to meet the single-hop outage objective of 10^{-6} (36 s/yr).

Conclusions

A new method of relating the overall BER (bit-error rate) system performance of 10- to 20-GHz terrestrial high-data-rate communications systems to single-path performance has been presented. An example calculated for a typical North American locality indicated that the path lengths permissable are surprisingly short: 3 km or less.

These results agree well with those reported by the Nippon Telephone and Telegraph Public Corporation.[5] However, the prediction method used by the authors of Ref. 5 was not disclosed. It is believed that the approach reported herein is well suited for use in areas where only a minimum amount of rainfall-rate data is available — a few point measurements plus some meteorologically derived radar data on rainstorm cell widths.

It is also of interest to note that considerable economy can be achieved if the lowest possible frequency allocation is available to support the traffic.

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Carbon-dioxide laser development at RCA Limited

Dr. R. A. Crane

A capability for producing highly efficient, long-life sealed carbon-dioxide lasers for communications applications has been developed at the Research Laboratories of RCA Limited. Both the status in laser development and a currently available product line, based on these lasers, are described.

RESEARCH AND DEVELOPMENT programs in CO_2 lasers have been prominent features at the Research Laboratories of RCA Limited for several years. An important part of this effort has been the development of reliable, sealed-off CO_2 lasers for a wide range of communications applications. The committment to the CO_2 laser for these applications is based primarily on three factors inherent in this device:

1) A high laser radiation conversion efficiency ($\sim$15%) which results in relatively small system sizes and weights,
2) A superior atmospheric window at its operating wavelength of 10.6 μm, and
3) The wide bandwidths possible at optical frequencies.

Although initially very high, support for the development of CO_2 laser communications systems had declined somewhat over the past few years, basically because of the short operating lifetimes and poor reliability of the lasers then available. Interest, however, is presently steadily increasing. This is attributed to the availability of long-life sealed-off lasers of the type discussed in this paper. These lasers have achieved an operational life in excess of 26,000 hours (about 3 years) which is about 15,000 hours greater than the best claims made by other sources.[1,2] As RCA's approach to this problem is fundamentally different from that of other laser manufacturers, the company stands in a unique position as a supplier of both sealed-off CO_2 laser tubes and laser systems.

To take advantage of this status, a production facility is being set up for the large-scale manufacture of laser tubes, ancillary components, and packaged laser systems. Since the key element is a consistently long-life laser tube, the following discussion is mainly concerned with this component.

Basic considerations

For CO_2 laser communications applications, a basic and most important requirement is that the laser have a long operational life and as high an efficiency as possible. In addition, each particular application has to be carefully considered as environmental conditions can impose restrictions on tube and window materials, fabrication techniques, cooling methods, and overall design that may affect the primary requirements. Fortunately, there is an adequate range of tube and Brewster window materials available that can be used for long sealed-off life lasers. These materials and som eof their relevant properties are displayed in Tables I and II. Output power requirements vary from about 0.5 to 20 W so that these lasers assume relatively small dimensions ranging from about 10 to 100 cm in length.

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Dr. R. Anthony Crane, Research Laboratories, RCA Limited, Canada, received the BASc (honors) in Engineering Physics from the University of Toronto in 1957. At the same university, he also obtained the MA in 1961 and PhD in 1965 for his work on the induced absorption of solid hydrogens. During the period 1958-1960, he was a lecturer in the Department of Mathematics at the University of Waterloo. In June 1965, Dr. Crane joined the staff of the Research Laboratories of RCA Limited, where he is presently engaged in the study of the properties and applications of gaseous lasers. This has included projects such as manufacturing processes, emission, and impedance properties of carbon-dioxide laser plasmas and studies of ultra-high power CW and pulsed carbon-dioxide laser systems. Dr. Crane was responsible for the development of space-qualified carbon-dioxide lasers to be used in the laser communications experiment for the NASA ATSF satellite. This work involved optimization of the laser power efficiency and development of long term sealed-off operating life. In attaining these goals, a considerable capability was acquired in the Laboratories for developing rugged leakproof sealing methods and fabrication techniques using ceramic materials. During 1968, Dr. Crane developed the software for the millimeter PCM Test Link Study Phase of Project Mallard. Dr. Crane is a member of the Canadian Association of Physicists and of the IEEE.

The design requirements can be broadly divided into two classes: ground-based and space-qualified systems. A spaceborne CO_2 laser is the most demanding in design as these lasers must be designed for minimum weight, minimum total input power requirement, ruggedness necessary to withstand the vibrational and thermal shocks associated with the launch and the environment of outer space, and yet must operate reliably for at least three years. As a result, designers are turning more to the use of alumina and beryllia ceramics as these materials have the highest shock resistance, have a high thermal conductivity that facilitates passive cooling techniques and, in addition, offer the highest bakeout temperature necessary for ultra-clean systems. However, due to near-future market limitations for such systems and their higher cost, a larger part of the development work at RCA has been addressed to a potentially greater market where glass laser structures are more than adequate.

For ground-based laser applications, tube replacement would, in most cases, be neither difficult nor disruptive provided this occurs at a rate not greater than once annually, the tube design is readily adaptable to such a feature, and the laser tubes are reliable and reproducible with respect to their performance characteristics. This entails, for 24-hour per day operation, a sealed-off tube life of 8760 hours. Consequently, less costly tube material, such as glass, can be used. Glass CO_2 laser systems are currently on the market featuring a one-year warrantee, but these items are geared to a laboratory style market where customer

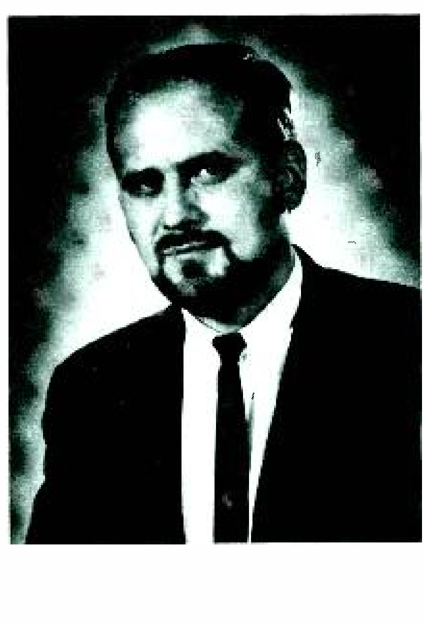

Table I — Properties of some laser tube materials.

Material	Thermal Conductivity (cal/cm cm sec °C)	Thermal Expansion /°C (0–100°C)	Melting Point (°C)	Young's Modulus (psi)	Approximate Cost Factor for an Assembled Tube
Glass	0.0026	3.3×10^{-6}	~800	9×10^{6}	1
Silica	0.0032	5.5×10^{-7}	1670	10×10^{6}	1.5
Cervit	0.004	0.2×10^{-7}	~800	13×10^{6}	~4
Alumina	0.09	8.0×10^{-6}	2040	51×10^{6}	4
Beryllia	0.52	5.4×10^{-6}	2573	50×10^{6}	6

Table II — Properties of some optical materials for 10.6 micrometers.

Material	Index of Refraction	Absorption Coefficient (cm^{-1})	Melting Temperature (°C)	Remarks
NaCl	1.49	0.005	801	Hygroscopic, fractures easily
KCl	1.46	0.0005	776	Hygroscopic, fractures easily
AgCl	2.06	0.01	455	Cold flows, reacts to UV
AgBr	2.25	0.01	432	Better than AgCl
TI Glass 1173	2.60	0.03	326	Poor thermal characteristics low power applications
TI Glass 20	2.49	0.02	474	Poor thermal characteristics, low power applications
Ge	4.00	0.03 to 0.06	936	Thermal runaway above 40°C
GaAs	3.2	0.02	400*	Best all round material
CdTe	2.64	0.002	1041	Best all round material
ZnSe	2.40	0.006	1520	Newer material in polycrystalline form

* Sublimation Temperature

usage is not expected to exceed 1000 hours during this time and the warrantee replacement rate is unknown. By contrast, the laser tubes under discussion could allow warrantees up to the 12,000-hour level and in a variety of tube designs that are readily adaptable for existing systems or for inclusion in RCA's own laser cavities.

The importance of the tube life factor is basically economic. Tube life is usually defined as the operational time during which the output power drops to half its initial value. This means that the system must be performing to minimum specifications at the power level just prior to end of life so that the original output and tube length would be about twice (assuming linear degradation) that required with power wastage over most of the operational life of the system. Consequently, systems with poorer life characteristics must be scaled accordingly, to meet the operational goal, with poorer overall efficiency and cost. If tube life is greater than that required, then the initial requirements can be scaled down commensurately for a more compact and efficient system; or the operational period can be extended with fewer tube replacements. In either case, the economic benefits accruing from a long-life laser are clear. It is also essential that the life characteristics of the laser not be enchanced at the expense of output efficiency.

Sealed-off carbon-dioxide laser development

The development of a sealed-off CO_2 laser capability was initiated at RCA Limited in mid-1968 with a modest, but at the time difficult objective for 1000 hours of sealed-off operation. As time progressed, this goal was greatly increased, primarily to meet the needs for space-borne applications, until the present status (as depicted in Table III) was achieved. In this type of development work, a tube life of 26,000 hours implies that this capability already existed some three years ago.

The CO_2 laser operates with a gas mixture consisting of CO_2, N_2 and He, with Xe and/or H_2O added in small amounts to enhance tube life and efficiency.[3,4] Tube life is limited by loss of the primary gas component, CO_2, through decomposition and irreversible reactions in the discharge and at the electrodes, as well as gas cleanup due to sputtering and absorption. These deleterious effects are largely eliminated by the use of suitable electrode materials and design and by electrode and tube processing procedures.

For long, necessarily sealed-off operation, glass can be used as a structural material. This was established early in the program when glass tubes were used primarily for problem solving for ceramic alumina structures and now formed the basis of RCA Limited's current CO_2 laser product line. This is fortunate, as glass is relatively inexpensive, is easy to work and assemble, and facilitates design modifications that may be dictated by market trends. To maintain a favorable gas component balance under discharge conditions and over long periods of time, the laser tube must be subjected rigidly to a process-control procedure that was developed during the program — this includes, under controlled specifications, acid bath cleaning, a number of bakeouts prior to and after assembly, and a final discharge conditioning.

Another critical area is the electrode material and design. Gas cleanup by cathode sputtering is a basic problem with all cathodes and is minimized by designing the electrodes in the form of hollow cylinders with a guard ring at the open end. In this way, the discharge is confined to the inside region of the electrode and away from sharp edges. Some of the materials tested early in the program were nickel (No. 270) and platinium. With Ni as a cathode material, "cold cathode" life of about 500 hours is typical, the limitation being due to chemisorption of gas constituents at the cathode. However, by proper gas ballasting and adjustments of the gas mixture, this life can be regularly extended from 1200 to 2000 hours. The chemisorbed products can be released and tube life greatly extended by heating the cathode to about 300°C either externally or internally. Such techniques have achieved operational sealed-off life up to

Table III — Carbon-dioxide laser development status.

Longest tube life (glass)		– 26,000 hours
Reliability (glass)		– 12,000 hours
Output power (TEM_{00})		– 0.5 to 20 + watts
Output efficiency		– 11 to 15%
Stabilization:	FM	– 1 in 10^9 (short term) – 3 in 10^9 (long term)
	AM	– < 0.2%
Cathode design		– Patent pending
Ceramic laser design		– Comprehensive – Assembly facility – Modular construction (any size)
In-house capacity		– Complete fabrication – Quality control

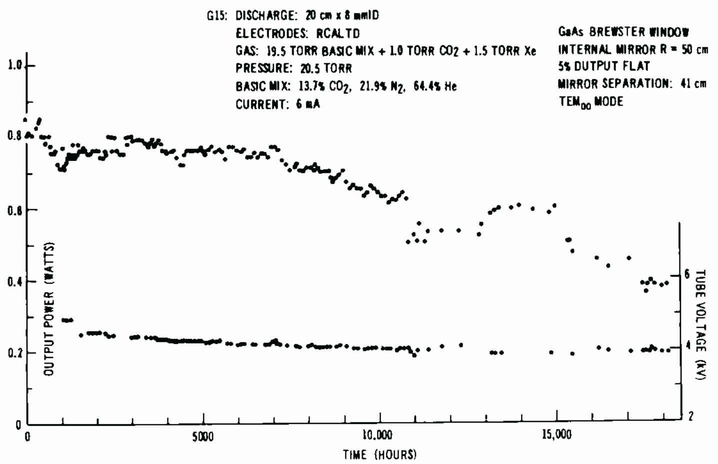

Fig. 1 — Life characteristic of a sealed-off carbon-dioxide laser.

11,000 hours; but the undesirable features of this type cathode are that the life extension techniques produce unreliable and erratic performance, loose chemical deposition in the tube, and the process is largely dependent on tube design. *Pt* can also be used, but this material sputters severly and limits tube life to about 1500 hours.

As the above electrodes (and a few others) were not suitable for long reliable tube life, a more detailed study of the problem was made[5] and a predicted list of materials and processing was determined for trial. Of those tested, the most successful was a specially developed (patent pending) cathode, coded as RCALTD. This material is reliable, does not require the life enhancement procedures such as with *Ni*, and is independent of the tube design or the gas mixture used. As with the tube, the electrodes must also be subjected to a process control. Fig. 1 shows the operational life characteristic on the output power and tube voltage to be about 20,000 hours with 75% of the initial output at the 15,000-hour level. (The laser is still operating at 26,000 hours.) The laser under this test (see Fig. 2) does not contain a gas reservoir, which is a common feature of most commercially available CO_2 lasers. The results with this laser are supported by other larger and more modern versions to the 12,000-hour level. The use of this cathode is currently standard practice at RCA.

Most of the CO_2 lasers in the development program have been in configurations featuring two Brewster windows. This configuration minimizes the number of different components internal to the system, renders the tube independent of the optical cavity for separate study, and facilitates tube replacement in existing cavities. The basic and standard laser tube design that has evolved from this program is shown in Fig. 3. To utilize Brewster windows stress-free, leak-proof seals were developed in order to minimize stress-induced birefringence, which for thermally mismatched materials (the case here), can degrade the output power by more than an order of magnitude. The success of these seals is demonstrated in the output characteristic for a 50 cm (active length) standard tube shown in Fig. 4. Laser output efficiencies from 11 to 15% are routine with lasers of this size, and the results are comparable with internal mirror configurations. Of the Brewster window materials tested to date (see Table II), *GaAs* and *CdTe* are the best and most commonly used; *CdTe* gives slightly better performance but is more fragile than *GaAs*. However, in both of these cases, the material quality (crystalline structure, dislocation density, and polishing specifications) have to be closely controlled for optimum performance.

Fig. 5 shows the TEM_{oo} mode output and efficiency capability for the standard, two-Brewster window, sealed-off CO_2 lasers in terms of active length. Longer tubes, and hence greater output powers, can be fabricated, simply by extending the cleaning facility to accomodate the larger tubes. The above results are expected to be improved using the new facilities, especially for the smaller lasers.

The development of a sealed-off ceramic (Al_2O_3) laser tube capability has been essentially a parallel effort using the results obtained from the glass-tube program. With the aid of RCA Laboratories, Princeton, N.J., simple ceramic-to-ceramic, high-temperature seals have been developed which allow easy assembly on a modular basis. Only a few of these lasers have, to date, been life-tested, and the current status is at 2000 hours. Fig. 6 shows a conduction-cooled Al_2O_3 laser tube, which for an active length of 20 cm, produces 3W (TEM_{oo}) of output power. In addition to a more rugged structure and the convenience of passive cooling, ceramic tubes generally produce better output performance than that obtained with water-cooled glass systems.

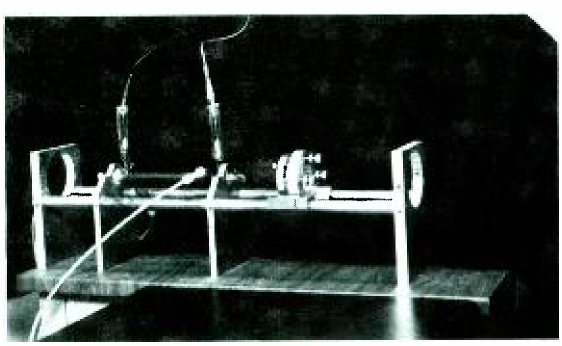

Fig. 2 — Sealed-off laser under life test.

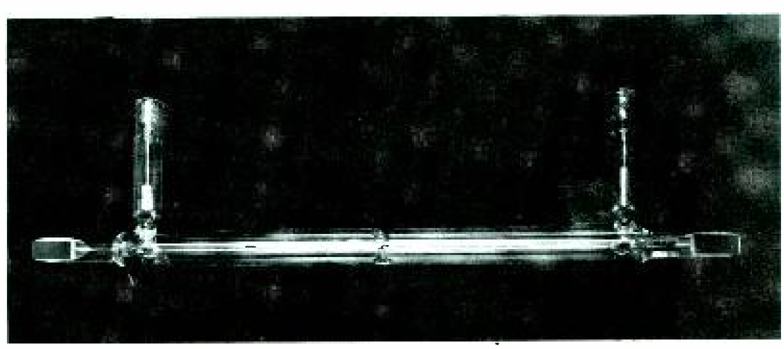

Fig. 3 — Standard carbon-dioxide laser tube.

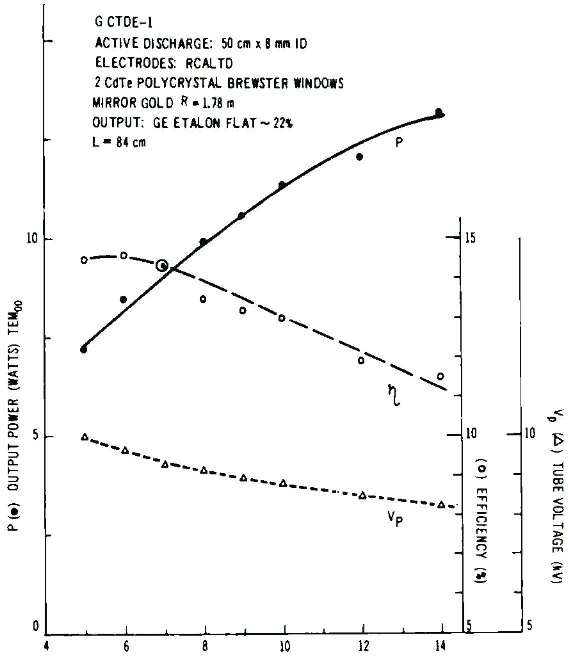

Fig. 4 — Output power, efficiency, and tube voltage vs discharge current.

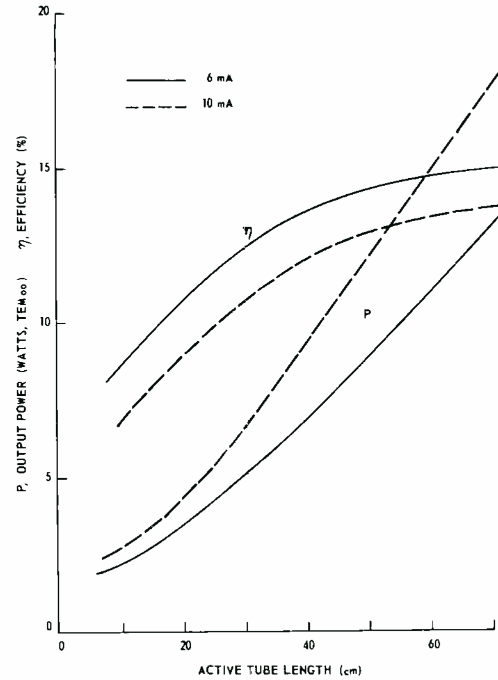

Fig. 5 — Output and efficiency capability vs tube length for standard, two-brewster window lasers.

Carbon-dioxide laser products

Sealed-off CO_2 laser tubes, out of the Research Laboratories of RCA Limited, have primarily been supplied to parties requiring high quality laser tubes for insertion into systems and to researchers looking for state-of-the-art performance. To take advantage of the apparent technical lead, a production facility has been set up for the pilot plant manufacture of a family CO_2 laser products. The products currently and commercially available include sealed-off laser tubes; stabilized CO_2 laser oscillators; and components such as optical cavities, mirror translators, and control electronics. In development are waveguide lasers, both CO and CO_2, power supplies, and system-oriented accessories. This is part of a long term program to develop and broaden the product line and includes marketing effort to make the products better known and to assess future requirements.

Some of the laser tube configurations that have been and currently are commercially available are displayed in Fig. 7. All of these, except for the alumina structure E, are simple modifications of the standard laser tube (see Fig. 3). Tube B features a gas reservoir mounted on the side, and C has a more rugged reservoir configuration concentric with the discharge tube. A reservoir is presently a customer option as there is no evidence, as yet, that this leads to enhanced tube life. In laser tube D, the water jacket is removed for a design modeling that of the alumina tube E. Thus, tube cooling can be provided by conduction to a heat sink via an aluminum support block. The laser A, shown in a 20-W size, has an internal mirror configuration and is offered to satisfy requirements for a raw laser-beam power source.

All of these lasers can be fabricated in sizes to suit most power level requirements and are amenable to further design modifications. With two Brewster windows, the laser tube is relatively independent of the optical cavity; consequently, it offers a simple and convenient tube replacement capability for most existing systems. The status of this configuration is such that RCA could warrantee reliability up to 12,000 hours of operational life.

Fig. 8 shows a 5-W stabilized, single frequency oscillator system that was developed to incorporate RCA's sealed-off laser tubes and is now commercially available. The optical cavity structure is modular, based on lightweight aluminum support sections, so that any tube size as well as other components such as modulators and Q-switchers and gratings can be easily accomodated. Stabilization

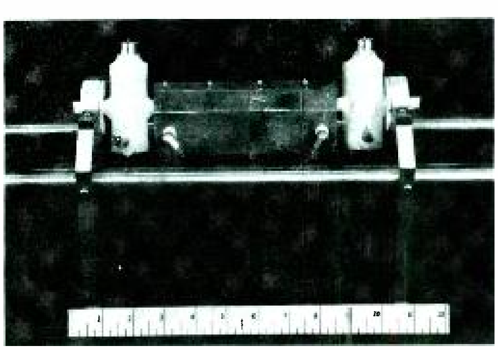

Fig. 6 — Alumina laser tube.

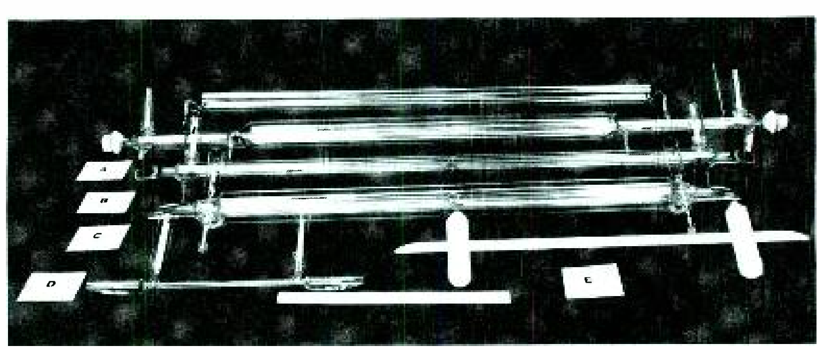

Fig. 7 — Carbon-dioxide laser tube configurations.

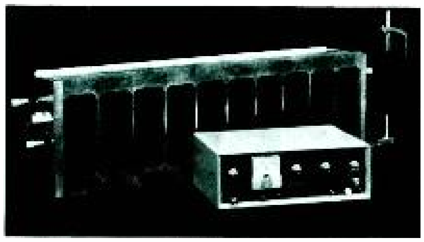

Fig. 8 — Stabilized, sealed-off, Carbon-dioxide laser system.

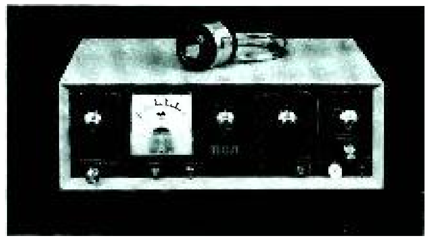

Fig. 9 — Electro-mechanical mirror translator and electronic stabilizer control.

by feedback, and locking to a single laser transition, from any one of several that can be selected, is provided by cavity tuning through an electronically controlled electromechanical mirror translator using a center-line dither at 100 Hz. The short-and long-term frequency stabilities of this laser system are particularly suitable for communications applications, being of the order 1 and 3 parts in 10^9, respectively, with amplitude fluctuations less than 0.2%. The mirror translator and the stabilizer electronics package, shown in Fig. 9, are presently being produced for individual sale. The translator, which was originally designed for space applications, is a rugged device that operates in a voltage regime of ±6V and has a scanning range of about 200 μm. The system also features a ramp scanning capability over several half-wavelengths so that output signatures and individual line contours can be monitored. To expand the capability of the laser system a variety of ancillary components such as modulators, Q-switch subsystems, pulsed and dc power packs, and gratings are under development.

Recent developments

The sealed-off CO_2 waveguide and CO laser are two relatively new devices currently under development at RCA that have attractive commercial prospects. In the usual CO_2 laser, the continuous frequency tunability is limited by the low gas pressure to about 25 MHz. By operating at much higher gas pressures the bandwidth is increased — pressure broadening increases the gain linewidth at a rate of approximately 5 MHz/torr — with the implication, for stable discharges, of ever decreasing tube diameters.[6] Sealed waveguide lasers, with tube bores of 1-mm diameter, have been constructed of glass and tested, in the laboratories, at gas pressures in excess of 200 torr. Because of the higher pressure and the waveguide action of the discharge capillary tube, which completely utilizes the plasma volume, these devices produce significantly greater output per unit active length than the previous low-pressure CO_2 lasers. For example, about 2W is typical for a 10-cm waveguide tube. An operating pressure of 300 torr is a primary goal as this implies a tunability of about 1.5 GHz, a regime attractive for mode-locking applications and as a wide-band local oscillator for doppler tracking of satellites.

The CO laser also holds considerable promise for optical communications, opening up another wavelength region in the infrared and offering some relief in the selection of optical materials and the detection problems associated with the CO_2 laser at 10.6 μm. However, it finds a more immediate application (and also with the CO_2 laser) in pollution monitoring and control. For example, its operational range from about 5 to 6 μm, with over eighty transitions, is in a particularly sensitive absorption region for a number of nitrogen oxides found in the exhaust of combustion engines. The development of the CO laser is based on the standard CO_2 laser tubes so that its incorporation into RCA's commercial optical cavity is straightforward. Sealed-off CO laser operation, with room-temperature cooling, has already been achieved in the laboratory.

Under these conditions, the output power from a 50-cm tube, with two Brewster windows (BaF_2) is about 4W (TEM_{00} mode). Both the CO laser and the waveguide laser are slated for inclusion into the product line as soon as formal life testing, which is currently underway, is completed.

Conclusion

The development of sealed-off CO_2 lasers to the present status of proven long life and reliability has been outlined above. It should be pointed out that this was achieved as a result of original developments at the Research Laboratories of RCA Limited, and consequently an advantageous position has been attained for commercial exploitation. Several items, including laser tubes and a versatile stabilized laser system are already available as products. The expansion of the product line — in particular, the waveguide and CO laser — is part of a continuing development program. A systematic approach has been sought so that , coupled with systems technologies available at RCA, a leading position for supplying complete laser communication systems may be attained in the near future.

Acknowledgments

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Development of a high-intensity light source

S.Y.K. Tam | B.W. Gibbs

An efficient 160-kW vortex-stabilized light source has been successfully developed. Laboratory tests have shown that it is feasible for practical applications. Although designed originally to withstand a chamber pressure of 10 atm and a gas flow of 0.05 lb/s, it gave excellent performance at much lower pressures (2 to 4 atm) and gas flows (0.01 to 0.025 lb/s). There was no apparent deterioration in the transparent jacket and the electrodes after an accumulated operation of a few hours at high power levels. At 160 kW, the radiation efficiency is typically 40%, and the light source spectrum is peaked in the visible region giving a measured luminous efficiency of 90 lm/input W.

Sebastian Y.K. Tam of the Physical Electronics Group, RCA Limited Research Laboratories, Montreal, Canada, graduated with the BSc Honors in Physics in 1962 from the University of Hong Kong where he held a Government Bursary Grant and Mrs. Eng Wong Yuk Mui's Scholarship. In 1965, he received the MSc from the University of British Columbia and the PhD in 1967 from the same university with a thesis on the problem of current density measurements in pulsed discharges using a magnetic probe. For his post-graduate work in U.B.C., he has been awarded a Research Fellowship and a National Research Council Studentship. In 1967, Dr. Tam joined the Plasma and Space Physics Group of RCA Limited Research Laboratories in Montreal, where he has developed a large-volume, high-density, quiescent magnetoplasma suitable for antenna and wave propagation experiments. He has done extensive experimental work on plasma diagnostics, plasma resonances, wave propagation and antennas in plasmas. For the antenna studies, he has developed techniques that enable him to investigate the impedances of different types of antenna in an electrically large laboratory magnetoplasma. In theoretical work, he has conducted studies on the interaction of a satellite with the ionosphere, energy relaxation processes in multicomponent plasmas and impedances of antennas in magnetoplasmas. Recently, he has developed an efficient 150-kW high-intensity light source using a high-pressure vortex stabilized arc. He is presently engaged in the development of high energy lasers. Dr. Tam is a member of the American Society and of the Canadian Association of Physicists.

Brian W. Gibbs of the Physical Electronics Group, RCA Limited Research Laboratories, Montreal, Canada; attended Queen's University during 1951-1953. In 1953 he joined the technical staff of the Pure Physics Division of the National Research Council. During the next seven years Mr. Gibbs was involved in the construction and operation of microwave spectrometers extending into the millimeter region. This work provided extensive experience in many phases of vacuum technology and ultra-clean gas handling techniques. In 1960 he became a member of the RCA Limited Research Laboratories and was appointed Research Associate in 1963. He is the co-author of six scientific reports and eleven publications relating to the interaction of electromagnetic waves with plasmas — including measurements of transmission, reflection, antenna radiation pattern and strong field em wave phenomena for isotropic and anisotropic plasma conditions. During 1971 he was responsible for co-ordinating the relocation of the RCA Limited Research Laboratories as well as the design and specifications of the new lab facilities. More recently Mr. Gibbs was engaged in the successful engineering and testing of a high-power, vortex-stabilized light source. In his present position, he is in charge of a program to develop a production facility for the fabrication of carbon dioxide lasers and related equipment.

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Ed. note: Recently the system described in this paper was tested to obtain more complete results under extended operating conditions. A nine hour endurance test was conducted. The first five hours was continuous operation. During the next four hours, the VSLS was turned on and off 30 times. No significant deterioration of any of the components was detected.

THE CONVENTIONAL METHOD of supplying illumination over a large area such as a park, a football stadium, or a hockey rink relies on the use of hundreds or thousands of high-power halide lamps. We report here the development and test results in RCA Ltd., Montreal of an unconventional, compact, high-intensity vortex-stabilized light source (VSLS) that will replace hundreds of halide lamps and will be most suitable for illuminating large areas.

A vortex-stabilized arc differs from a conventional arc in having a stabilizing vortex of gas around its arc column. It performs better than the conventional arc because it can maintain a much longer, collimated, high-pressure arc column at a much higher input power over a wide range of power levels. As a result, it has become a useful device for producing high-intensity radiation.

Prior work on VSLS

Pioneering work of vortex-stabilized arcs was done by Plasmadyne Corporation and Union Carbide in the late fifties and early sixties after they had developed plasma torches for arc welding, and metal spraying. Work on vortex-stabilized radiation sources became active in the early sixties when such sources were developed to simulate solar radiation.

An earlier model developed by Plasmadyne (Denis et al, 1965)[1] consists of a fused-silica cylinder and two water-cooled conical electrodes aligned on a common axis. The working gas is introduced tangentially to the inside circumference of the fused silica cylinder and forms a vortex as it spins to the central axis, exhausting through a drilled hole at the anode tip. At 17 atm the vortex-arc source in argon had a typical input power of 25 kW and a total radiant output efficiency of 31% including the visible, near infrared and ultra-violet regions. But its comparatively poor luminous efficiency, at 17 lm/W, made it an inefficient light source — compared with the mercury-vapor lamp which has a typical luminous efficiency of 45 lm/W.

Later development of vortex-stabilized light sources resulted in essentially the same configuration with comparable efficiencies but higher power inputs. The behavior of such systems became better understood when Anderson, Eschenbach and Troue (1965)[2] conducted a systematic experimental study on their 20-kW input power source; they obtained a useful empirical equation

$$N = AI^{1.6}\ P^{0.4}\ G^{0.35}\ D^{-2.6}$$

where N, I, P, G and D are the radiance, arc current, pressure, gas flow rate, nozzle diameter, respectively and A is a constant which depends upon the design of the arc system. About the same time Stresino and Eschenbach (1966)[3] were able to produce an argon VSLS with 180-kW input and 60-kW output powers

Table I — Actual characteristics of the 100-kW VSLS.

Dimensions of Arc Chamber	Specification
Length	15 in.
Diameter	5 in.
Weight	20 lbs.
Quartz Envelope	
Inner tube (I.D.)	1.5 in.
Length	10 in.
Wall thickness	0.070 in.
Outer tube (O.D.)	20 in.
Length	12 in.
Wall thickness	0.070 in.
Power dissipation	20 kW
Anode	
Material	OF copper
Nozzle O.D.	1.125 in.
Straight I.D.	0.375 in.
Power dissipation	10 kW
Cathode	
Material	2% Thoriated tungsten
Tip diameter	0.5 in.
Power dissipation	2 kW
Typical Arc Characteristics	
Length	8 in.
Voltage	200V
Current	500 A
Pressure	3 atm
Flow	Argon, vortex injection 0.02 lb/s
Input power	100 kW
Radiation output	38 kW
Radiation efficiency	38 ± 5%
Luminous efficiency	80 lm input W

respectively with a radiant efficiency of about 30%.

Electrode erosion became a severe problem when attempts were made to further increase the input power. Effects of gas pressures P and arc current I on electrode erosions were then investigated experimentally by Tuchman and Enos (1976).[4] It was found that at a given pressure, the cathode tends to erode catastrophically as the current increases beyond a critical value. The same was true when the pressure was increased and the current kept constant. The product PI apparently should not exceed a maximum value determined by experimental conditions.

With more information about the performance of vortex arcs, Malliaris, John and Enos (1970)[5] were able to develop the laboratory model of a 250-to 500-kW arc lamp with about 40 ± 5% radiant efficiency. The essential achievements of this model were its longer arc length (5 to 8 in.) compared with a maximum of 4 in. for previous models (Anderson *et al.* 1965)[2], high power (250- to 500- kW input power), high efficiency (40 ± 5%), and a useful long lifetime of 12 hours for an overnight continuous operation. Despite its comparatively higher power and efficiency, the quartz jacket in the arc lamp of Malliaris *et al*[5] was subject to high radiation power density and had to withstand high pressure (10 atm). As a result, it became opaque from devitrification after a few hours' operation and it failed catastrophically several times within an accumulated operation of 50 hours. The combined effects of high discharge pressures and currents were found to cause significant cathode erosion and the cathode could only last for 20 to 30 hours. Moreover, since the arc extended far into the anode nozzle, up to 20% of the total arc radiation was wasted. Much improvement was therefore required before such a device could be put in practical use.

RCA Limited Research Laboratory study

After studying the prior test results, we were confident that most of the existing problems could be solved or greatly reduced. For example, a quartz tube of smaller radius might be used to withstand higher chamber pressures. Devitrification of the quartz jacket might be eliminated by using a longer arc for the

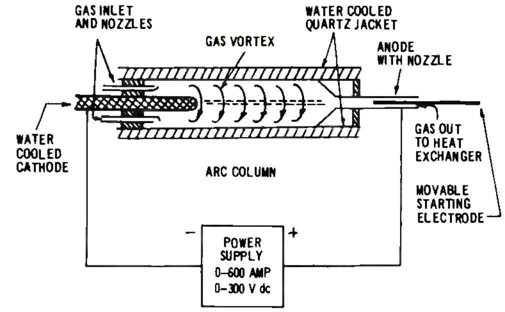

Fig. 1 — Arrangement of laboratory model of vortex-stabilized light source.

same power output so as to reduce the radiation per unit arc length. Cathode erosion would be reduced if we could reduce the discharge current but maintain a longer arc at a higher voltage. Fortunately, we had the opportunity to explore such problems under a project sponsored by the Defense Research Establishment Valcartier, Canada. The project turned out to be highly successful and rewarding since within a period of eight months we were able to develop a high-intensity light source with much less severe requirements but better efficiency. The following is a brief description of our design and test results. More details are given in Tam and Gibbs (1972)[6]

Design of vortex-stabilized light source

Although arc physics has been a subject of extensive investigation, a great part of the physics and experimental techniques are still based on intuition and empirical experimental results. This is especially the case in high-pressure vortex-stabilized arcs. We therefore chose a design close to the VSLS developed by Malliaris et al (1970)[5] but aimed at achieving the following:

a) Long arc
b) Good collimation, and
c) High current density.

Since the power loss in the electrodes and the external circuit to the VSLS depends largely on the discharge current while the power input increases with the arc length, it is important to have a long arc for better efficiency. Good collimation enables simpler focusing with a comparatively smaller reflector. A high current density is required to produce a high temperature

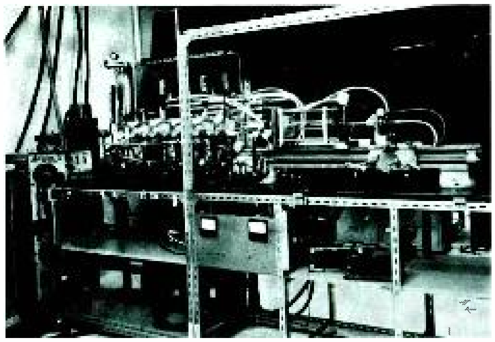

Fig. 2 — Photo of the laboratory model VSLS with accompanying measuring instruments for studying arc characteristics. The VSLS is mounted on a lathe bed for experimental convenience.

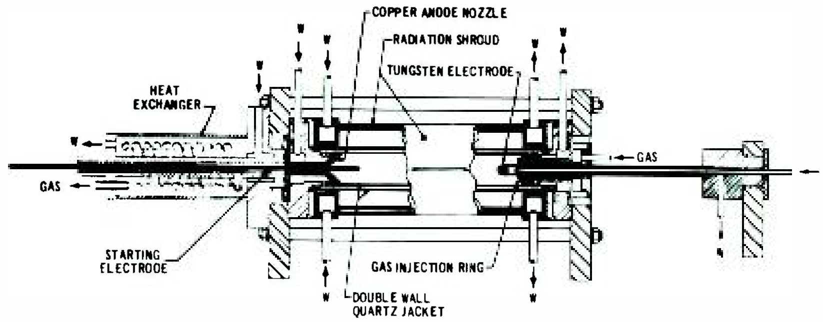

Fig. 3 — Arc chamber assembly for VSLS W indicates water cooling.

arc column for more efficient radiation in the visible region.

The design of our laboratory model of VSLS consists essentially of an arc chamber, a water cooling system, a gas flow system, and a power supply (see Figs. 1, 2, and 3).

The cylindrical arc chamber consists of a 1.5 in. i.d. water-cooled quartz jacket, a 0.5 in. o.d. water-cooled thoriated-tungsten cathode at one end and a water-cooled copper anode at the other. Gas enters the chamber tangentially through a set of nozzles around the cathode to provide a vortex and heat insulation between the arc column and the quartz jacket. It leaves the arc chamber through the nozzle at the center of the anode. The cathode is movable axially so that its distance from the anode can be adjusted. A starting electrode which may be moved from the anode to the cathode is included to facilitate starting of the arc. In the laboratory model, we have also added a detachable water-cooled shroud which not only shields and absorbs radiation from the discharge, but also allows calorimetric measurements of the total radiance. The shroud has two slits to allow spectroradiometric measurements of the source. The VSLS is maintained by five dc-welder supplies in series with a maximum input power of about 150 kW. Table 1 gives the actual dimensions and arc characteristics of our 100-kW arc lamp.

The integrated experimental system proved to be extremely versatile. Modifications and adjustments were accomplished quickly. The starting electrode, the anode nozzle, the vortex injection ring and the electrode assembly could each be removed for examination or replacement in 10 or 20 minutes. The entire arc chamber assembly could be removed, disassembled and the quartz tubes replaced within two hours. For a quick visual inspection of the arc chamber, the upper half of the shroud could be removed, exposing the quartz jacket.

To start an arc, the cathode is brought close to within about 0.5 cm from the position where it touches the anode nozzle. With water and gas flowing the safety interlock is activitated. The power supply is now turned on. The starting electrode which feeds through the anode nozzle is pushed against the cathode momentarily and then pulled back immediately until its tip is completely out of the arc chamber. As soon as it is separated from the cathode, a small arc with a current of about 10 A is struck between them. When the tip of the starting electrode recedes back into the anode nozzle, an intense arc, initiated by the small arc between the anode and the cathode, takes over. The cathode is then pulled away from the anode until an arc of a required length is obtained. The whole procedure is in fact very simple and is chosen because of the simplicity of the circuit and the operation. Since the current flow between the starting electrode and the cathode during starting is small (below 10 A), and the cathode is never in contact with the anode at any time, such a procedure does not allow electrode erosion due to shorting (between the anode and the cathode).

To protect the arc chamber from damage, protecting switches are installed at proper places and connected in such a way that the power supply will be turned on only when there are adequate water and gas flows through the cooling systems. The electrodes are protected from severe overcurrents by fast reacting fuses.

The electrical system consists of five welder power supplies in series. Their limited duty cycle prevents us from continuous operation at full power (150 kW) for more than a few minutes. However, such a length of time is enough to give conclusive information about the operations of different parts of the system. In particular, the great doubt about cathode erosion due to high-current operations at high pressure can be clarified.

General behavior

The VSLS was found to be very reproducible, easy to start and very stable in output radiation. Although there were many variable parameters such as the gas flow rate, the chamber pressure, discharge current and voltage, an arc of a given characteristic could be reproduced with no difficulty. The starting electrode easily initiated an arc under all conditions instantaneously. Observation of the arc through a filter showed that the arc was dynamically stable. Under normal operating conditions, its output radiation did not show any significant fluctuation. There was no sign of deterioration in the quartz jacket due to devitrification, deposition of material, or mechanical failure as a result of pressure imbalance. The cathode showed no sign of erosion even after many high-power discharges (over 100 kW) with a cumulative time over several hours. The whole design of the VSLS is therefore considered a significant success.

As a laboratory model, the VSLS is extremely flexible. Since it has been assembled with "O" rings, nuts and bolts, it can be dismantled or assembled in a short two hours. Change of parts such as the anode nozzle, gas injection nozzle and the cathode can be done in a matter of minutes. With a shroud which is separable into two halves, the arc chamber can be examined visually. The present design has enabled us to conduct systematic scientific investigation yielding valuable information for further development.

Calorimetric and spectral measurements

We studied the performance of the VSLS by obtaining calorimetric and spectral measurements since the former tells us about the power dissipations on various parts of the system and the latter gives us information about the quality and the luminous efficiency.

We determined the power dissipations in the cathode, the quartz jacket and anode, the shroud, and the heat exchanger respectively by measuring the temperature rises in the water flowing through the corresponding cooling loop in each component. The radiated power was calculated from the rate of heat absorbed by the shroud. The precision of the measurements was checked by comparing the total power dissipation in all the loops calculated from calorimetric measurements with the electrical input power. In all our measurements, the two agreed within 5%. Typical results are given in Table II.

From Table II, we find that the radiation efficiency n increases considerably with the input power. Typically at input powers of 30 kW, 50 kW, 100 kW and 160 kW the respective efficiencies are approximately 19%, 28%, 37% and 40%. Besides, n increases significantly with the arc current and is still increasing at 150 kW. Unfortunately, our power input has been limited by the power supply to 160 kW and we have not been able to try an arc at higher input powers to achieve higher efficiencies. Yet the potential capabilities of the system have been clearly demonstrated.

Table II — Typical operating conditions of VSLS at varying input power, gas flow and chamber pressure.

Electrical Input power(kW)	*Argon flow rate* (lb/s)	*Arc length (cm)*	*Chamber pressure* lbf/in^2*(gage)*	*Power radiated (% of input)*
32.5	0.0146	8	12.5	19
50	0.0132	8	11	28
100	0.0219	20	30	37
160	0.0321	20	70	40

To obtain the radiation spectrum of the VSLS, we analyzed the radiation emitted through one of the two slits on the shroud with the help of a 1.0 meter Czerny-Turner Spectrometer and an RCA 7102 photomultiplier. Typical radiation spectra are given in Fig. 4. The high radiation efficiency of the VSLS is evident since the radiated power is peaked within the visible region in each of the spectral curves. In fact, about 60% of the total continuum radiation falls within the visible region taken between 4000Å and 7000 Å. Intense spectral lines occur between 6500 Å and 9000 Å, but no attempt has been made to obtain their total radiation.

We determine the luminous efficiency K of the VSLS using the measured radiation spectrum P_λ versus λ and the absolute luminosity K_λ of a photopic eye (see RCA Electro-Optics Handbook)[7]. A curve of K_λ P_λ versus λ is then plotted. The luminous efficiency is then obtained as

$$K = \int_0^\infty K_\lambda \, P_\lambda \, d_\lambda \; / \; \textit{Total input power}$$

The numerical values of the numerator are obtained with the help of a planimeter. K is typically around 90 lumens/W for the higher power experimental runs in Table II.

Summary of results

We have successfully developed the laboratory model of a high-intensity VSLS. It has been tested under open-loop operating conditions at input powers up to 160 kW. Results of the tests show that all our design objectives have been achieved and mostly exceeded. All the initial estimates of the mechanical strength and heat transfer in various parts of the system have been adequate. The laboratory model has proved to be extremely flexible, stable, reproducible and compact for its power. Since it operates satisfactorily at much lower chamber pressures and gas flow rates with even better luminous efficiency, it proves to be a significant improvement over all previous VSLS models and to our knowledge the best system to date. To present a comprehensive summary of its performance we have given results at typical operating conditions in Table II and the typical radiation spectra in Fig. 4. Typically at a 160 kW input power, the luminous efficiency is about 90 lm/input W.

Although no endurance test has been made, the VSLS is expected to give a continuous operation over a long duration since there is no sign of deterioration in any part of the system after numerous runs with a cumulative period of a few hours.

Results of the present phase of development show that a high-power plasma illumination device is feasible. Our laboratory model is ready for the next phase of development to make it a practical unit for actual applications.

Practical features of the VSLS

The VSLS has many advantages over the conventional high-intensity lamps because of its compactness, flexibility and above all its extremely high power. Its high intensity has potential capabilities in a wide variety of applications. The following will discuss VSLS advantages.

Compactness

The most efficient and most widely used light sources for illuminating large areas have been the conventional mercury vapor lamp and multivapor metal halide lamps. The luminous efficiency is typically 45 lm/W, for the mercury vapor lamp, 90 lm/W for the multivapor lamp and the VSLS we have built. For comparison, a 100-W tungsten filament lamp has a luminous efficiency of about 17 lm/W.

Such lamps have been used for illuminating city parks, hockey rinks, football and baseball fields. Since each of such lamps can handle a maximum input power typically between 1 and 3 kW, an inconveniently large number (usually a few hundred to thousands) is required to provide enough lighting. This problem may be avoided when a few compact high-power VSLS are used instead.

Instantaneous starting

Unlike the halide lamp that takes a warm up period of up to half an hour, the VSLS gives its full power immediately after it is started. This makes it even more useful as an emergency high-power light source.

Flexibility

Another significant advantage of the VSLS is its flexibility. Since it operates satisfactorily over a range of voltage or current, it can be adjusted slightly to maintain the same quality of lighting, *i.e.* brightness and color temperature, after repeated use. In comparison with the halide lamps whose light output deteriorates with time, the VSLS maintains its quality throughout its life.

There is therefore no definite limit to the life of a VSLS. In fact, after a long period of operation, a completely new set of transparent jacket and electrodes may be replaced to obtain a new VSLS. The replacement takes only a few hours and costs much less than the replacement of 180 halide lamps.

Typical applications

A VSLS will be extremely useful in illuminating large areas during emergencies, illumination of a stadium, and laser pumping. We now consider these applications in more details.

Illumination over large areas

Typical applications are for night-time operations in emergencies such as rescue operations during shipwrecks, plane crashes, oil spills, landslides, storms, floods or power blackout in thickly populated areas. A 180-kW VSLS emits approximately 1.6×10^7 lumens with an efficiency in beam formation of 50% — enough to illuminate an area of about 3 sq. miles at 10 full moonlights (*i.e.*, about 0.1 lm/ft^2) or 9000 sq. yards at 1000 full moonlights (comparable to the lighting during sunset). The VSLS may be carried by an airplane, a helicopter or fixed on top of a tall building.

Illumination of a stadium

As a practical example let us consider the main stadium at Munich for the 1972 Olympic games. It used 550 mercury-halide floodlights that drew 2,000 kW and required a 60,000 V surge for ignition.

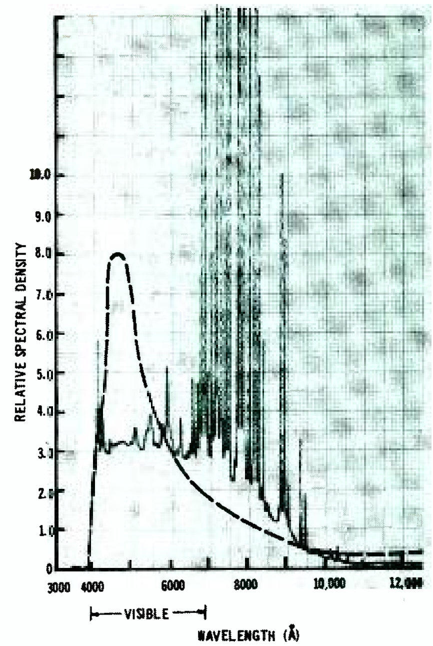

Fig. 4 — Radiation spectrum of VSLS at higher powers: Gas flow 0.03 lb/s; arc length 20 cm; chamber pressure 55 lbf/in^2 (gage); arc voltage 275 V; arc current 500 A. Solid line is photomultiplier output; dashed line is continuum corrected for S-1 response. Relative spectrum is practically unchanged provided arc current remains approximately the same.

Most of the floods were in batteries mounted on two masts, 210 ft. high. The lighting was maintained at 1500 lm/m^2 (about 150 lm/ft^2 or 1.5×10^4 full moonlights) and a color temperature of 6000°K for color tv. To give the same illumination, one may use six VSLS units of 180 kW each. The VSLS requires a much smaller supporting framework. The cost of installing the supports will be greatly reduced. Besides, one needs only six VSLS units whose total cost including all the supporting facilities such as water and gas pumps will compete favorably with the halide lamp. The VSLS will eventually find its use in the future illumination of parks and stadia.

Laser pumping

The VSLS will be a very efficient pumping source for laser rods such as the *Nd/YAG*. In fact, the Nd^{3+} (0.5%) = *YAG* has strong absorption between 7400 and 8200 Å (Kaminskii 1967)[8] where the VSLS has strong emission lines (see Fig. 4). The only problem at present is to provide *Nd/YAG* rods that could handle high powers without damage.

Other applications

In addition to what we have discussed the VSLS has important uses in many other applications. A compact unit of 30-kW input power carried on a car or a small truck will find important uses for the police, the firemen, for riot control, prison breaks, for the golf course, the ski hills, as an illumination source for color tv, or a night-time navigation help on the St. Lawrence Seaway. For the military it is the most suitable device for night-time reconnaisance and surveillance. With slight modification, it may be used as an ultra-violet source or an infrared source. In fact less efficient VSLS sources have been used in solar simulation experiments. Since the Canadian arctic is at night for half of the year, natural daylight may be simulated, with the help of a VSLS. For the Canadian Defense, it will be extremely useful for Arctic surveillance. There are many other useful applications for a high-power VSLS and we do not intend to exhaust the list here. However, we must bear in mind one important aspect. The conventional halide lamps have their practical limit and are no practical solution for very-high-intensity radiation sources. Eventually halide lamps will have to be replaced by new power sources of 100 kW to a megawatt merely because it is impractical to use the thousands of halide lamps needed. The VSLS we have developed is so far the most promising source available. It is ready for the next phase of development to make it more reliable and commercially available.

Acknowledgments

The authors thank Dr. A.K. Ghosh for his initial efforts in making such a program materialize. His continued interest and helpful discussions have contributed to the success of this work.

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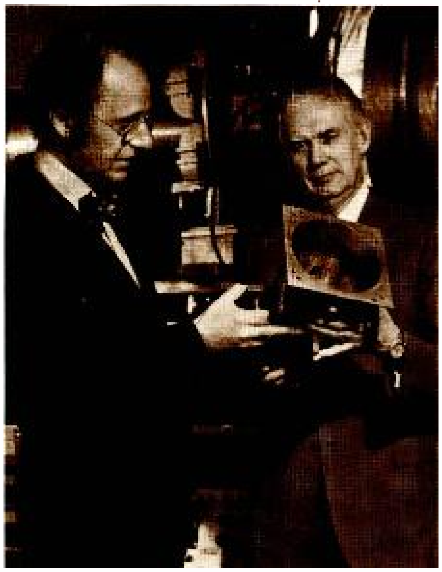
The 1974 David Sarnoff Awards for C



Peter Foldes with G. Denton Clark, President, RCA Ltd.

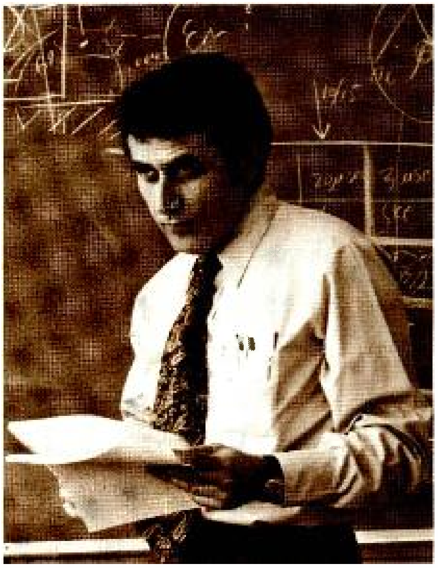
For sustained outstanding achievement in antennas for satellite communications.

Peter Foldes

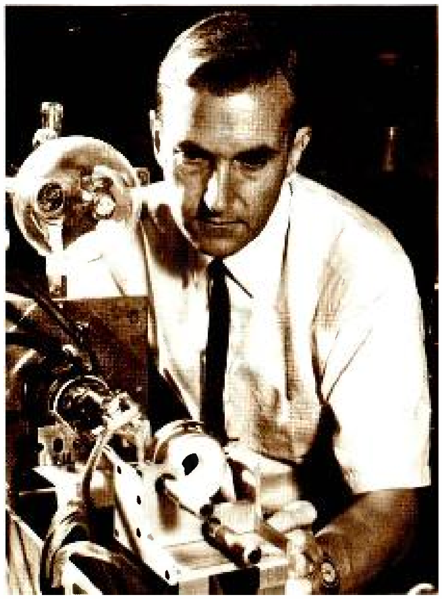
Mr. Foldes of Government and Commercial Systems Division, RCA Limited, Montreal, Quebec, has a long record of outstanding technical innovation and leadership in the field of satellite communication antennas. His technical and business leadership has been a key factor in the success of RCA Limited's earth station and satellite business. Among his accomplishments, Mr. Foldes has pioneered the use of Cassegranian antennas for communications systems and has developed a number of state-of-the-art rf optics and feed systems for the INTELSAT network, which have been installed in various countries. He designed the earth antennas for the world's first domestic satellite communications sytems, the Canadian Telesat Network, and the first U.S. domestic system. He has been a leader in the development of spectrum re-use feed systems for earth stations. He has led the development of the first 24-channel spectrum re-use antenna system for RCA Globcom's domestic satellite. He has published numerous papers and reports, has several patents, and has become a recognized authority in the antenna field.

For outstanding research and leadership in the development and advancement of semiconductor devices.

Henry Kressel



Dr. Kressel of RCA Laboratories, Princeton, NJ, has provided basic scientific achievements, management direction, and leadership in the field of injection lasers at RCA. As a result of his efforts over the past five years, RCA is presently the recognized leader in this field, and is a pre-eminent commercial supplier of these semiconductor devices. As head of a small research group, Dr. Kressel succeeded in developing a sophisticated product — bringing it all the way from a laboratory curiosity to commercial viability in a very short time. His work in improving the reliability and reducing the operating current density of these devices is particularly noteworthy. He has published about 80 papers, has six issued patents, and ten disclosures filed on the metallurgy, luminescent properties, reliability, and fundamental laser properties of injection luminescent materials and devices; he has six issued patents and ten disclosures filed.



For innovative contributions to the development of gas lasers and for his ability to shorten the time cycle between research and commercial application.

Karl G. Hernqvist

Dr. Hernqvist of RCA Laboratories, Princeton, NJ, has made major contributions to all of RCA's commercially viable gas lasers: the ion lasers, argon, krypton, zenon; the metal vapor lasers, helium-selenium and helium-cadmium; as well as the ubiquitous helium-neon laser. However, his most significant contributions to the RCA laser product line have been in two areas: helium-neon and helium-cadmium. Both these lasers have the potential of very large markets and RCA's present and future market position depend on Dr. Hernqvist's development of a low-cost long-lived cold-cathode helium-neon laser, and a low-noise, low-cost helium-cadmium laser. The first laser has permitted Electronic Components to compete in the highly competitive helium-neon market; the second laser has given RCA a unique advance on the entire industry. Dr. Hernqvist's prolific technical accomplishments include 45 technical publications and 24 patents. This award recognizes Dr. Hernqvist's numerous research and development successes in the laser field since 1963, as well as his unique ability to rapidly transfer advanced technology to a product division.

Outstanding Technical Achievement

RCA's highest technical honors, the annual David Sarnoff Awards for Outstanding Technical Achievement, have been announced for 1974. Each award consists of a gold medal and a bronze replica, a framed citation, and a cash prize.

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

For outstanding conception, design, analysis, development, and installation of an array of television and fm antennas on a single tower serving the San Francisco Bay area.

John W. Barbour, Douglas J. Frank, Ralph J. Pschunder, Richard L. Rocamora, Matti S. Siukola, and Henry H. Westcott

Messrs. Rocamora, Westcott, Frank, Dr. Siukola of Commercial Communications Systems Division, Gibbsboro, NJ, Mr. Barbour of CCSD, Camden, NJ, and Dr. Pschunder of Missile and Surface Radar Division, Moorestown, NJ, were responsible for the development, design, fabrication, and installation of the Mt. Sutro multiple antenna system. This system centralizes the eleven tv broadcast stations assigned to the San Francisco Bay area. The end result is a cluster of three 210-ft stacks of antennas on one triangular platform, 977 ft above ground with eight stations now operational and three scheduled for a later date. Each tv station can radiate its signal with no discernible degradation as a result of the intermixing of uhf and vhf antennas. The entire project took three years to complete; it was erected on schedule, within cost, and without engineering changes. The resulting system is one of the most unique and technically sophisticated antenna installations in the world.

J. W. Barbour / D. J. Frank — R. J. Pschunder / R. L. Rocamora — M. S. Siukola / H. H. Westcott

For major contributions and leadership in the development of high-voltage power transistors for automotive ignition and other applications.

Wilfred P. Bennett, Eugene J. Chabak, Larry J. Gallace, Gilman A. Lang, Sandy J. Mattei, and Ural Roundtree, Jr.

Messrs. Lang, Bennett, Gallace, and Roundtree of Solid State Division, Somerville, NJ, and Messrs. Chabak and Mattei of SSD, Mountaintop, PA, were responsible for the basic design, process development, reliability engineering, applications engineering, and volume manufacture of high-voltage pi-nu (nearly intrinsic p- and n-type) power transistors specifically for automotive ignition systems. This team was responsible for much of the basic innovative effort on pi-nu structures and thick high-resistivity low-cost epitaxy materials and processes. In addition, they provided the reliability engineering and circuit development work leading to feasible ignition system designs for Chrysler, Ford, and American Motors. Two full years of high volume experience and field history with Chrysler shows the achievement of extremely low field-failure rates, indicative of the effective characterization, rating, and reliability efforts of this team. A major part of the accomplishment was the rapid factory introduction and volume production to the levels necessary to support this high volume application with good reproducibility.

W. P. Bennett / E. J. Chabak — L. J. Gallace / G. A. Lang — S. J. Mattei / U. Roundtree, Jr.

Dual-beam earth station antennas

P. Foldes

In commercial communication satellite systems, multiple satellites are often used for a variety of reasons (e.g., to ensure reliable service in the event of satellite failure or sunspot interference). Thus, each earth station must be capable of communicating, simultaneously and independently, with each satellite. This paper examines the two-beam two-satellite earth-station antenna system and analyzes the various parameters involved in deciding whether one or two reflectors are needed and in determining optimum reflector size and shape.

Peter Foldes, Mgr, Antenna Laboratories, Government and Commercial Systems Division, RCA Limited, received the diploma of electrical engineering from the Technical University of Budapest in 1950. He did his Post Graduate work at the Telecommunication Research Institute and Academy of Science in Budapest between 1953 and 1956. Early in his career, he was involved in the design of airborne radio and radar transmitters and antennas; he also performed propagation studies and system design of radar and microwave communication systems at the Army Research Institute and at the Telecommunication Research Institute of Budapest. In 1957, he joined RCA Limited in Montreal, where he became involved in the rf multiplexer, waveguide, and antenna system design for the Alaska and Trans-Canada microwave communication systems. During this period, he was pioneering in the use of Cassegrainian antennas for communication systems, which led to a participation various NASA-JPL programs. On the basis of this work, JPL built the first 85-ft Cassegrainian antenna for space communication and his rf optics design was adopted for JPL's 210-ft-diameter antenna. Since 1962, he has led RCA Limited's Antenna Laboratory and in this capacity, he designed a number of rf optics and feed systems for the Intelsat network. These are now in operation or being built in Canada, U.S.A., Panama, Brazil, Argentina, India, Pakistan, Bangladesh and China. During the same period he designed rf optics and feed systems for various domestic satellite system earth stations with 24-, 33- and 51-ft diameters used by the Telesat, Western Union, and American Satellite Corporation networks. He was also involved in various spacecraft antenna studies and designs. He has lectured widely and has published over thirty papers; has three books and has five patents to his credit. He recently won the 1974 David Sarnoff Award for Outstanding Technical Achievement "for sustained outstanding achievement in antennas for satellite communications."

DURING the first decade of commercial satellite communication, the technically and economically feasible satellite had relatively limited EIRP (effective isotropic radiated power) capability, and it had a relatively large movement around its nominal "stationary" position relative to earth. These features demanded a high G/T earth station antenna with a steering and tracking capability on its main beam. For such situations, the antenna structure as well as its rf feed system was relatively complex and expensive. Furthermore, the multiple utilization of such systems for simultaneous operation toward more than one satellite was technically only marginally feasible, and was economically not attractive.

With the increasing satellite EIRP and improved station-keeping accuracy, it was possible to decrease G/T and eliminate the tracking requirement, as was demonstrated by the Canadian Telesat system. In such systems, the cost of the earth station antenna is considerably less. However, it is still characterized by a communication coverage that is restricted to the vicinity of the electro-mechanical axis of the antenna. For such systems, the available maximum antenna gain (G_M) is, by and large, arbitrarily selectable and is proportional to the aperture area. On the other hand, the available effective gain, G_e, is restricted by the satellite station-keeping accuracy, and it differs from G_M by an amount inversely proportional to the square of the station-keeping accuracy.

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When more than one satellite is used in a system and each earth station must provide simultaneous, independent communication via these satellites, then the earth station must provide a number of beams corresponding to the number of satellites. The following discussion will be restricted to two satellites and two beams. Such a configuration requires two feeds, a corresponding set of rf equipment, and either one or two main reflectors. The presented data will refer to the 4-GHz band downlink, 6-GHz band uplink system, although the results can be easily modified to other frequency bands.

The selection between one or two reflectors has to be made on the basis of reliability, rf performance and cost. In the following, it will be assumed that the reliability of non-tracking reflectors is ideal, and that the secondary rf characteristics, such as antenna noise temperature and isolation between beams, can be made equivalent from the system's point of view whether one or two reflectors are used. If, for such a situation, a maximum gain, G_M, and maximum satellite separation, α, are specified, then the selection between one or two reflectors can be made strictly on the basis of cost. As the required G_M or α increases, the achievable saving with a single reflector relative to two reflectors decreases until a crossover point characterized by equal cost is reached. Beyond that point, a lower cost can be achieved by two separate reflectors. In the following, it will be assumed 1) that the minimum value for α is 3°, for which at least 25 dB isolation has to be achieved between copolarized beams and 2) that the maximum α is 6°, corresponding to the nominal 5° orbital slot separation with some safety margin.

Symbols used

a—reflector vertical dimension

b—reflector horizontal dimension

C—system cost

D—minimum diameter (height) of the spherical reflector

d_e—effective aperture diameter

$EIRP$—effective isotropic radiated power

F/D—ratio of antenna focal distance to antenna diameter

f—frequency

G—antenna gain

G_e—effective antenna gain (for a satellite that is not perfectly stationary)

G_M—max. antenna gain

G_o—available practical gain for a single-beam antenna

G/T—gain to noise-temperature ratio

K—aperture aspect ratio ($K=a/b$ for paraboloid reflector; $K=b/D$ for the spherical reflector).

R—radius of the spherical reflector

RBW—scanning angle of the beam normalized to the 3-dB beamwidth of the antenna

α—satellite separation angle

α/θ_3—normalized scanning angle

δ_x—x-axis displacement from reflector center along the **E** vector

δ_n—variation in satellite position from nominal, as viewed from the earth station (station-keeping accuracy)

η—antenna efficiency

λ—wavelength

θ_3—3-dB beamwidth

ϕ—running angle measured in the direction of the **E** vector

ψ_m—aperture angle

In finer details, the cost of the system also depends on how the variation of G_M within the coverage range ($3° \leqslant \alpha \leqslant 6°$) is selected. From this point of view, the "low-gain" (for the present discussion, G_M=43.5 dB at 4 GHz) and "high gain" (for the present discussion G_M=51.5 dB at 4 GHz) antennas have to be treated separately. For the low-gain case the beam separation, α, in terms of 3-dB beamwidths, θ_3 is small, thus the "scanning loss" associated with the separate beams is also small. This allows the use of dual (shaped) reflector optics with their associated high antenna efficiency in the order of $\eta = -1.7$ dB), or focal-point-fed systems (paraboloid or spherical type) with an antenna efficiency of approximately $\eta = -2.7$ dB. Since scanning loss is small for such a case, the dual reflector system has an economical and mechanical configuration advantage, at least for the 4-GHz operation.

Reflector selection

The high-gain case is not realizable with a dual reflector for a satellite separation angle, α, of 5° to 6°. This leaves only focal-point-fed systems. There are only three practical variations available for the main reflector shape:

1) Segment of a revolutionary surface of paraboloid;
2) Parabola profile in the plane perpendicular to the orbital plane and circular profile in the plane of orbit (paraboloid torus); or
3) Segment of a sphere.

The first reflector has an elliptical aper-

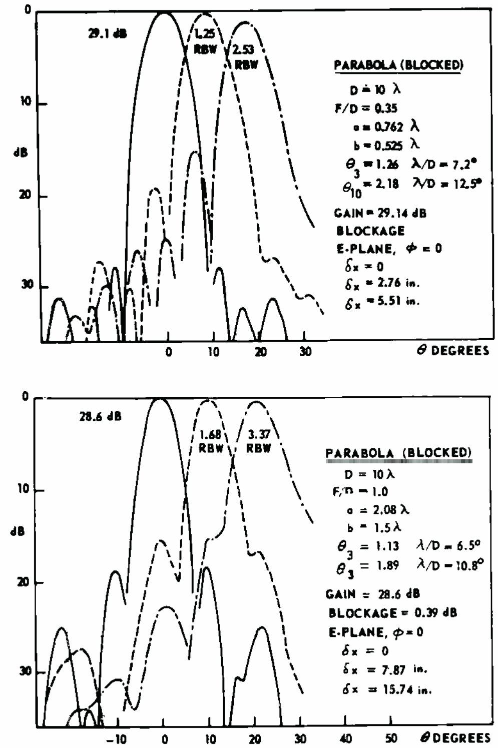

Fig. 1 — Pattern of a focal-point paraboloid *vs* various scanning angles and *F/D* ratios.

ture shape with the major axis in the vertical plane, good efficiency for small α values, and reasonable efficiency for the transmitter frequency band. The third reflector has an elliptical aperture with the major axis in the plane of orbit; a reasonably flat, compromise efficiency for the range of α; and a poor transmitter-band efficiency. The second reflector is between the two limiting cases.

The final reflector probably has to be chosen on the basis of the cost of transmit power. For $\alpha \leqslant 4.5°$, the paraboloid geometry seems to be more economical. For the $4.5° < \alpha \leqslant 6°$ satellite separation range, the spherical reflector geometry has better efficiency.

It must be noted that the above summary neglects some secondary, but still important, considerations. For instance, the paraboloid system produces an elliptical beam cross-section which has its major axis in the orbital plane; thus, such beam geometry is less sensitive for the daily apparent satellite position variations in this plane. Furthermore, the paraboloid system can be offset fed; this reduces the blockage of the dual-feed-horn unit and necessary tower height to support the package at the expense of some vertical-plane frequency-dependent beam squint. For such a system, the waveguide loss to a

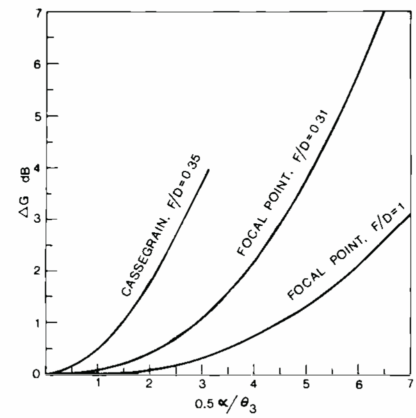

Fig. 2 — Scanning loss of paraboloid antennas *vs* normalized scanning angle for various *F/D* ratios.

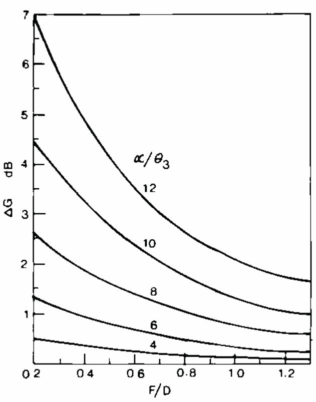

Fig. 3 — Scanning loss of focal-point-fed paraboloids *vs* *F/D* for various normalized scanning angles.

ground-mounted paramp can be made very small. A disadvantage of the paraboloid-shaped reflector is that it requires a large-aspect-ratio horn, which increases the difficulties in obtaining a simultaneously optimum primary pattern for the 4- and 6-GHz band.

On the other hand, the spherical reflector system produces an elliptical beam cross-section with smaller aspect ratio and with a minor axis in the orbital plane. Such a system is less sensitive for the daily apparent satellite-position variations in the orthogonal plane to the orbit and provides more isolation between two beams for a given α. At the same time, pure spherical reflectors are more sensitive to offset feeding, require slightly higher feed tower, and have more loss and blockage.

The intermediate compromise case (paraboloid torus) is probably the optimum for rf coupling, but it requires double curvature surface panels with the associated higher tooling cost.

It follows from the above discussion that the differences between the three above-mentioned reflector variants are small and, once an overall compromise is considered, negligible. The final selection is not particularly cost sensitive and has to be made on the basis of one or another of the preferred system characteristics.

System analysis

In order that a system analysis can be performed, a series of charts will be presented showing interesting relationships between G_M, G_e, α, effective aperture diameter d_e, aperture aspect ratio K, *etc.* for 4- and 6-GHz frequency bands and for dual-reflector, focal-point-fed paraboloid- and spherical-reflector optics.

The results are based on the following three major related programs, which have been completed by RCA Limited:

1) Factory and field test results for the 33⅓-ft.-diameter "NTV type" antenna system used in the Telesat network and elsewhere;[1]
2) Multiple-beam isolation study performed for Intelsat-Comsat;[2] and
3) Non-tracking antenna study performed fo CRC[3].

The first program verified the antenna efficiency of practically achievable wide-band, dual-reflector-type "shaped" optics. The second project resulted in the development of an extensive computer program for general multiple-beam antennas and also very detailed experimental results directly applicable for the "low gain" antenna. The third program was restricted to computer analysis only, but its results, for area coverage antennas, proved to be mostly useful for the present problem.

Basic relationships between antenna characteristics

The data presented in this section is based mostly on the work previously mentioned. Wherever it was available, the experimental verification of the computer-calculated data was also utilized. The data is presented in the form of charts to facilitate tradeoff analysis between parameters.

The graphically presented data covers five different optical configurations, namely:

1) Dual-reflector (Cassegrain) optics with $F/D = 0.35$.
2) Focal-point-fed paraboloid with $F/D = 0.35$.
3) Focal-point-fed paraboloid with $F/D = 1.0$.
4) Spherical reflector with $F/D = 0.816$.
5) Spherical reflector with $F/D = 1.0$.

The calculations are made for 4 and 6 GHz; the range of satellite separation covers $0 \leqslant \alpha \leqslant 6°$; aspect ratio of the apertures is analyzed for $1 \leqslant K \leqslant 3$. For the shaped dual-reflector-type optics, $\eta = -1.7$ dB is assumed for $\alpha = 0°$ at 4 GHz(as it was verified for Telesat's NTV antenna). For the focal-point-fed paraboloid at $\alpha = 0°$ and $f = 4$ GHz, $\eta = -2.7$ dB is assumed (probably somewhat pessimistically).

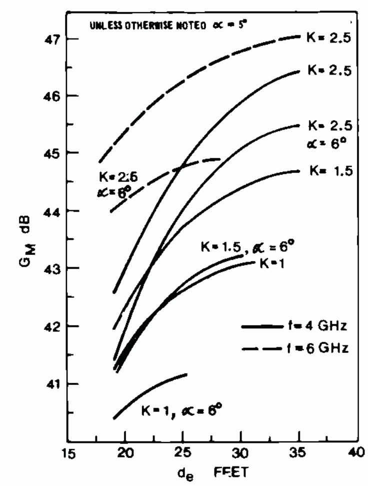

Fig. 4 — Achievable gain with a dual-reflector, shaped antenna at 4 GHz, 5° and 6° satellite separation angles, *F/D* = 0.35, and -1.7 dB efficiency for various aperture aspect-ratio (assuming 0.05° satellite position variation in the "vertical" plane).

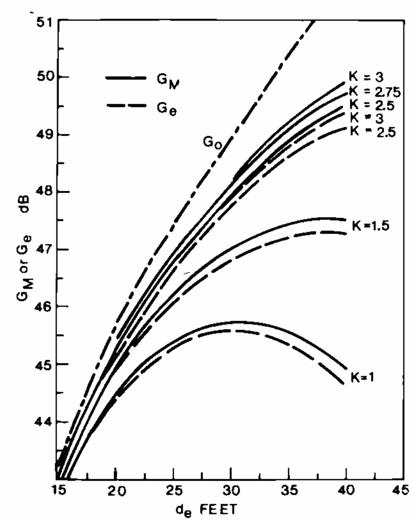

Fig. 5 — Achievable gain with a focal-point-fed paraboloid *vs* equivalent antenna diameter at 4 GHz for 5° satellite separation angle, *F/D* = 0.35, an efficiency of -2.7 dB vertical station-keeping accuracy = 0.05°, and *K* =1, 1.5, 2.5, 3.

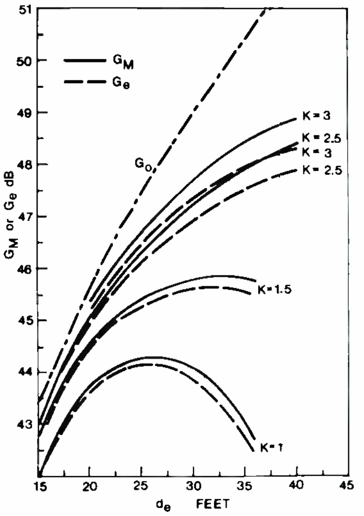

Fig. 6 — Achievable gain with a focal-point-fed paraboloid *vs* equivalent antenna diameter at 4 GHz for satellite separation angle of 5°, F/D = 1, an efficiency of -2.7 dB vertical station-keeping accuracy = 0.05°, and K =1, 1.5, 2.5, 3.

For the spherical reflector, η is nearly independent of α, but starts off at a lower value at α=0° determined by the spherical aberration — and, therefore, by R/D, where R is the radius of the spherical reflector and D is its minimum diameter (height). For the present widely separated beams, the antenna aperture is not circular. In the case of the paraboloid reflector, a non-unity aspect ratio $K = a/b$ (where a is the vertical, b is the horizontal dimension) is necessary to widen the horizontal beamwidth and thus reduce the scanning loss. In the case of the spherical reflectors, a non-unity $K = b/D$ aspect ratio (where b is the horizontal dimension) is necessary to avoid spillover loss when the beam is scanned.

The scanning loss for the Cassegrainian case is based on measurements made in RCA Limited's Antenna Laboratory on a 45-dB-gain antenna at 11 GHz. The scanning loss for the focal-point antenna is based on computer calculations and measurements made as part of the aforementioned multiple-beam isolation study. The gain degradation of the spherical reflector is based on the data published in the literature.[4,5]

In the following charts, two gain figures are calculated. G_M is the maximum gain on the axis of the main beam, which generally does not coincide with the mechanical axis of the aperture. G_e is the effective gain in the vertical plane, 0.05° away from the axis of the beam. G_e takes into account the effect of the satellite station-keeping accuracy for the above assumption.

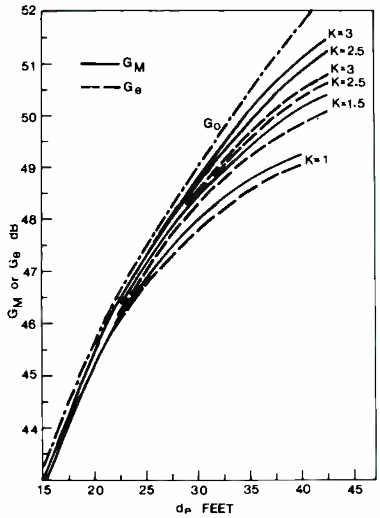

Fig. 7 — Achievable gain with a focal-point-fed paraboloid *vs* equivalent antenna diameter at 4 GHz for satellite separation angle of 5°, F/D = 1, an efficiency of -2.7 dB, vertical station-keeping accuracy of +0.05°, and K = 1, 1.5, 2.5, 3.

The presented charts are not complete; *i.e.*, they do not cover all possible combinations of the above listed ranges of parameters. However, they cover adequately the range of variables in order that the basic system tradeoff can be made.

Fig. 1 shows the pattern of focal-point-fed paraboloids *vs.* scanning angles for F/D = 0.35 and 1. It can be seen that the pattern deterioration can be greatly reduced by increasing F/D. This reduces scanning loss and coma sidelobe (on inside slope of scanned beam) at the expense of the increased feed size and increased separation between reflector and feed. For such systems, the feed has to be withdrawn from the center of the aperture and can be placed most conveniently on a feed tower, particularly for antennas having low operational evaluation-angle requirements. Figs. 2 and 3 show the scanning loss of paraboloids *vs.* α or F/D.

It is obvious that for scanning loss $\Delta G \geqslant$ 3 dB, it is cheaper to realize a dual-beam reflector than to use one main reflector. Thus, the curves show practical cases only for $\Delta G < 3$ dB. For a given α and G, the scanning loss can be reduced by increasing the beamwidth in the horizontal plane and reducing it in the vertical plane until the tracking loss caused by δ_v (vertical-plane satellite movement) becomes limiting. Assuming δ_v=0.05° and a 0.2° vertical-plane beamwidth, the tracking loss is 0.75 dB. If the scanning loss is selected as 1 dB, then for F/D = 1.2, α/θ_3 = 10 can be obtained. When α = 5°, this determines a horizontal beamwidth of θ=0.5°, an aspect ratio of K=2.5, and an equivalent circular beam-cross-section of $\theta_3{}^* = \theta_3/K^{1/2}$ = 0.325° on the mechanical axis of the aperture. It can also be seen from Fig. 2 that, for a given maximum scanning loss and α/θ_3 ratio, F/D has to be above a certain value. For the presently interesting "low gain" antennas, F/D can be around the conventional 0.35 value, but for the high gain case, where $\alpha/\theta_3 \approx 10$, the F/D has to be 1 or more.

Fig. 4 shows the achievable gain *vs.* equivalent (effective) antenna diameter at 4 GHz for shaped Cassegrainian optics at α = 5° and 6°, respectively. It can be seen that in the vicinity of the required G = 43.5 dB, considerable improvement of gain can be achieved by making the aperture shape elliptical by using an aspect ratio of $K \approx 2.5$. The use of larger K makes the feed design considerably more difficult and requires an undesirable increase of the larger dimension of the aperture, while the gain improvement is small The figures also show the large increase in aperture size associated with the increase of α from 5° to 6°. For instance, if α = 5° with K=2.5 then G_M = 43.5 dB at 4 GHz requires d_e = 16 ft; however G_M = 46.5 dB at 6 GHz requires d_e = 21.6 ft.(From this, it follows that the G_M = 47.5 dB at 6 GHz is already impractical with a Cassegrain system.) On the other hand, for α=6° and G_M = 43.5 dB at 4 GHz, d_e must be 18.4 ft diameter, and it is not practical to achieve more than 45 dB of 6-GHz gain. Thus, the

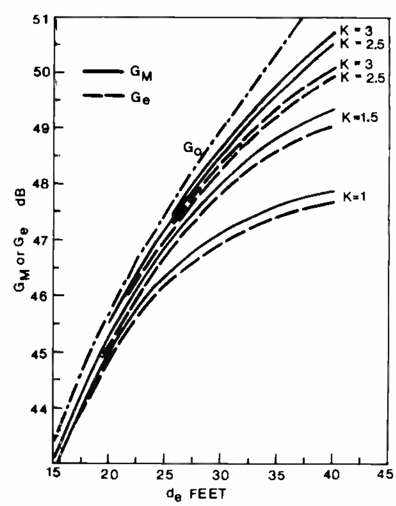

Fig. 8 — Achievable gain with a focal-point-fed paraboloid *vs* equivalent antenna diameter at 4 GHz for satellite separation angle of 6°, F/D = 0.35, an efficiency of -2.7 dB, vertical station-keeping accuracy of 0.05°, and K =1, 1.5, 2.5, 3.

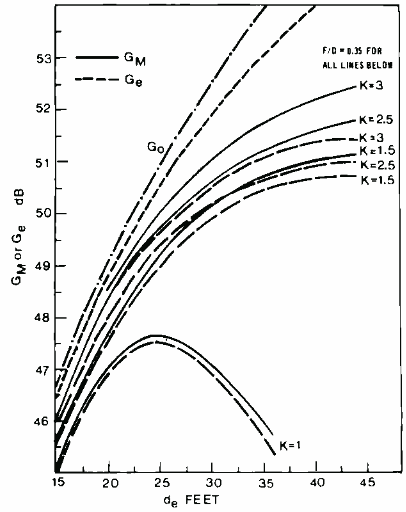

Fig. 9 — Achievable gain with a focal-point-fed paraboloid *vs* equivalent antenna diameter at 6 GHz for satellite separation angle of 5°, F/D = 0.35 and 1, an efficiency of -2.7 dB, vertical station-keeping accuracy of 0.05°, and K = 1, 1.5, 2.5, 3.

Cassegrain system is attractive only up to $\alpha = 5°$, and for systems where lower transmit-band gain is adequate.

Figs. 5 through 8 show the characteristic gain curves of dual-beam, focal-point-fed paraboloids at 4 GHz as a function of equivalent antenna diameter for $K = 1$, 1.5, 2.5 and 3, $F/D = 0.35$ and 1, $\alpha = 5°$ and 6°. Each diagram shows G_M (which is the gain on the axis of the main beams separated by the angle α) and G_e (which takes into account a 0.05° vertical-plane misalignment relative to the position of the satellite). The curves also show G_e which is the available practical gain for a single-beam antenna.

The following conclusions can be drawn from these curves:

- For a given F/D, α, and K, there is an optimum d_e for which the gain is optimum.

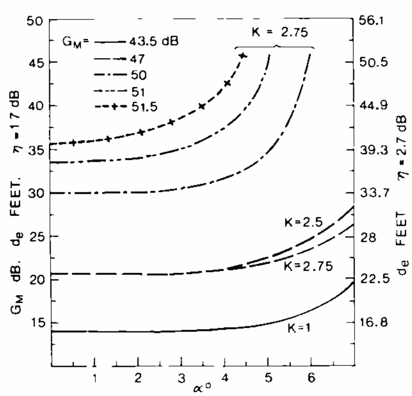

Fig. 10 — Equivalent antenna diameter of focal-point-fed paraboloid *vs* satellite separation for maximum antenna gains at 43.5, 47, 50, 51 51.5 dB and -1.7 dB and -2.7 dB efficiencies at 4 GHz, F/D = 0.35.

- Both G_M and G_e increase with increasing F/D and K and with decreasing α.
- The required gain for the "low gain" antenna at 4 GHz can be achieved even for $\alpha = 6°$ with $K = 1$. (Circular aperture, conventional $F/D = 0.35$ and aperture diameter $d_e = d = 19$ ft, assuming $\eta = -2.7$ dB.) Such a design may represent a practical "optimum" because of the commercial availability of such reflectors.
  A more sophisticated design, which also works better in the 6-GHz band can be obtained by using $K = 2.5$ and $F/D = 1$. With these parameters, $G_M = 43.5$ dB can be achieved at 4 GHz by selecting $d_e = 16$-ft. diameter. The $G_M = 47.5$ dB, 6-GHz gain with such a configuration can be achieved by $d_e = 18$-ft diameter. Thus, the above geometry, although commercially not presently available, meets the gain requirements of the "low gain" antenna.
- The required gain for the "high gain" antenna at 4 GHz can be achieved only by large F/D. For $\alpha = 6°$, $K=3$ results in $G=51.5$-dB gain with $d_e = 46$ ft. If the satellite separation can be reduced to $\alpha = 5°$, then $d_e = 42.5$ ft is adequate. Although with a further increase of F/D and more sophistication in the feed design ($\eta \cong -2.2$dB), the equivalent antenna diameter can probably be reduced to $d_e \cong 40$ ft; the maximum dimension, a, of this antenna aperture remains considerable on account of the large K.

On the basis of reading out the differential gain between $F/D = 0.35$ and 1 from Figs. 5 and 7, about a 1-dB gain increase can be obtained, if F/D is increased to unity.

Fig. 9 shows the available gain with focal point paraboloids at 6 GHz for $\alpha = 5°$ and $F/D = 0.35$ and 1 respectively. The gain behavior is similar to the 4-GHz case; but to come close to the specified gain, only large K and F/D values are interesting.

Fig. 10 shows the relationship between d_e and α for $\eta = -1.7$ and -2.7 dB for constant G_M values. This figure illustrates how a rapid increase of antenna size is necessary once α is beyond a certain value.

Fig. 11 shows the relationship between a and α for $\eta = -2.7$ dB, $F/D = 0.35$; this Figure also shows the variation of the cost of the antenna reflector normalized to the cost of two reflectors producing the same gain on the axis of the dual beams. Obviously, one is interested in a single-reflector, dual-beam antenna, if there is a sizeable potential cost saving. For this purpose, probably the $C = 79\%$ curve can be used since smaller cost savings are approaching the accuracy of calculations. On the basis of this curve for $F/D = 0.35$ and $G_M = 50.5$ dB, a cost reduction to 79% can be achieved only to $\alpha = 3.6°$. On the

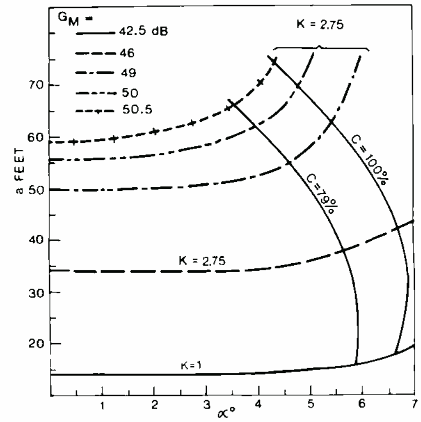

Fig. 11 — Maximum (elevation-plane) antenna dimension of focal-point-fed paraboloid *vs* satellite position for antenna gains of 42.5, 46, 49, 50, 50.5 dB, at -2.7 dB efficiency (f= 4 GHz, F/D = 0.35). Figure also shows cost of reflector, C relative to equivalent-gain, two-antenna reflector system.

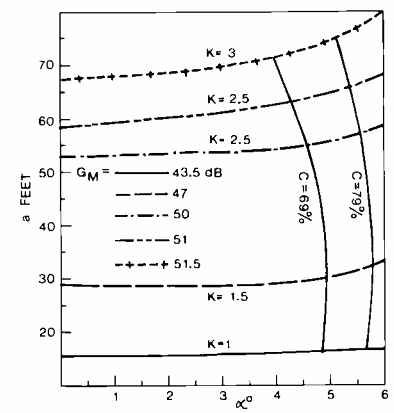

Fig. 12 — Maximum (elevation-plane) antenna diameter of focal-point-fed paraboloid *vs* satellite position for antenna gains of 43.5, 47, 50, 51.5 dB at -2.7 dB efficiency (f = 4 GHz, F/D = 1).

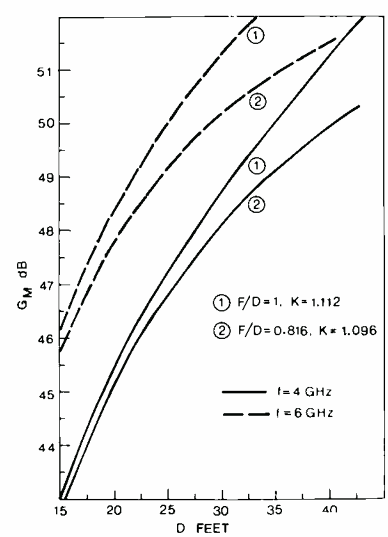

Fig. 13 — Maximum antenna gain *vs* minimum (elevation-plane) dimension of spherical reflector for F/D = 0.816 and 1 at = -2.7 dB antenna efficiency (f =4 and 6 GHz, K = 1.112, F = 0.5R, and aperture angle of 26.56.

other hand, for $F/D = 1$ and $G_M = 51.5$ dB, the same cost saving can be achieved up to α=5.1° (see Fig. 12). For the same case, the cost of the reflector can be reduced to 69%, if α is reduced to 4°.

Fig. 13 shows the maximum on-axis gain achievable with a spherical reflector geometry at 4 and 6 GHz, respectively, using F/D = 0.816 and 1. As a first approximation, the spherical reflector, for large F/D, behaves similarly to the paraboloid. To avoid large spillover loss, the horizontal size of the antenna has to be increased relative to the vertical although for the presently required small scan angle, the resulting aspect ratio is small. For instance, if $F/D = 1$, the total aperture angle is $2\ \psi_M = 63.7°$; thus for $\alpha = 6°$, the aspect ratio is $K = 69.7/63.7 = 1.11$. Since the antenna has better spillover efficiency for the central location of the beam, there is a scanning loss even in this case, but this is much smaller than for the paraboloid. It can be seen from Fig. 13 that at 4 GHz, $G_M = 51.5$ dB requires $D = 39.5$ ft and b = 43 ft or d_e = 41.6 ft.

This is nearly equal to the d_e = 42.5 ft. calculated for the paraboloid case at α = 5°. Obviously, as α is increased, the spherical reflector develops an advantage. On the other hand, for smaller α, the paraboloid produces larger gain.

This situation is particularly noticeable at 6 GHz, as it is shown in Fig. 14, which compares the gain of the paraboloid and spherical reflectors on the same graph as a function of α. The gain crossover in the 4-GHz band is at α=2.7°; while in the 6 GHz band it is at α = 5.4°. It can be concluded from Fig. 14 that, if α can be restricted to 5°, then the paraboloid and spherical reflectors are equivalent in the

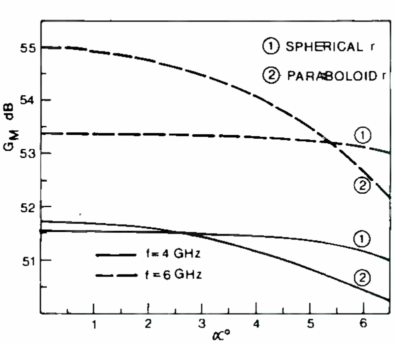

Fig. 14 — Variation of maximum gain vs satellite separation angle for focal-point-fed paraboloid and spherical reflectors at 4 and 6 GHz for an effective antenna diameter of 40 ft., (F/D = 1). For paraboloid reflector, K = 2.5; for spherical reflector, K = 1.11.

Table I — Summary of typical dual-beam antenna characteristics.

	Low-gain focal-point-fed paraboloid	High-gain focal-point-fed paraboloid	High-gain focal-point-fed spherical
K	2.5	2.5	1.11
d_e(ft)	18	42.5	45.3
a(ft)	11.4	67.2	43 ($a=D$)
b(ft)	28.5	26.9	47.3
R(ft)			90.6
F/D	0.938	1	1
F(ft)	10.68	26.9	43
ψ_m			26.56
G_M at 4 GHz (dB)			
α=5°	44.5	52.2	52.2
α=6°	44.4	51.9	52.0
G_M at 6 GHz (dB)			
α=5°	47.8	54.2	54.0
α=6°	47.6	53.8	53.8
T (°K at 5° elevation)	49	47	49(α=5°) 50(α=6°)
θ_a } at 4 GHz	0.54	0.23	0.40
θ_e } at 4 GHz	1.35	0.58	0.38
θ_a } at 6 GHz	0.36	0.17	0.27
θ_e } at 6 GHz	0.90	0.42	0.25
Feed-horn dimension (in.)	3.38 × 8.45	3.38 × 8.45	8.45 × 9.38

4-GHz band for all practical purposes, while the paraboloid has about 1 dB more average gain in the 6-GHz band over the range of α. For this latter reason, the paraboloid seems to be more advantageous. However, if $\alpha = 6°$ is mandatory and represents the typical operational position of the satellite, then the 0.7-dB higher receiver-band gain is more valuable than the better transmitter average gain, and the use of a spherical reflector could be preferable.

Summary and conclusion

On the basis of the previous discussion, Table I summarizes the most important characteristics of some selected low gain and high gain antennas. It can be seen that, for the high gain case, the spherical reflector requires 13.6% larger area for approximately the same G_M. On the other hand, its maximum linear dimension is considerably smaller than for the equivalent paraboloid. In practice, these two effects approximately cancel each other insofar as cost is concerned. Thus, the choice between the two can be made on the basis of which one provides a beam cross-section that conforms better to the daily variation of the satellite position.

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Integrated up and down converters and dividers for earth stations

G. Kadar | F.J. Labelle | R.L. Ernst | S. Yuan

A joint program by the Government Communications and Automated Systems Division in Somerville, N.J. and RCA Limited in Montreal, Canada led to the development of a new generation of commercial earth station equipment — double-conversion up- and down-converters and microwave dividers. By using microwave-integrated-circuit and hybrid technologies, size was reduced significantly, manufacturing cost lowered, and reliability improved.

SINCE the beginnings of satellite communications, evolutionary design work has continued at RCA Ltd in Montreal, Canada, towards reducing the size and cost of satellite earth stations. The results have been manifested in such innovations as "wheel-and-track" and "step-tracking" antenna systems, beam-waveguide microwave optics, and spectrum re-use feeds. The latest innovation is a new generation earth station ground communication equipment.

With extensive application of microwave integrated circuits and stripline techniques, this equipment requires one quarter of the space of the previous system. Further improvements include lower cost, a smaller control building which houses the equipment, greater ease of maintenance, more convenient expansion capability, and higher reliability.

The program was a joint effort of two RCA divisions, one located in Montreal, the other in Somerville, N.J. The development activity was started and completed in an unusually short time and in a highly cost-effective way.

Joint work program

In establishing this development program, several unique approaches were developed to foster inter-divisional cooperation. Hopefully, the success of this program will encourage and accelerate other joint developments.

The initial contacts and discussions were performed at the senior working engineering level, where a great deal of flexibility exists to carry out quick and drastic trade-offs among performance, cost, and schedule. Once these preliminary, "unofficial" · discussions showed clearly that the joint program was viable, higher levels of Management became fully involved, and after further investigation, decided on the program.

There are four ingredients of such a joint venture. First, the systems engineer must

George Kadar, Aerospace Systems, RCA Limited, Montreal, received his diploma of electrical engineering from the Technical University of Budapest in 1951. He has been employed at RCA Limited since 1961 where he worked on a variety of telecommunications problems, including design and and development of heavy route microwave radio equipments and systems and satellite Earth station equipment. He has participated in numerous analog and digital communication system studies and proposals related to Earth stations and satellites for the Canadian and U.S. Domestic Satellite Systems, including the conceptual and project definition phase of the Anik Satellite. Currently he is an Engineering Specialist dealing with communications topics related to RCA Globcom's Domestic Satellite System. Prior to joining RCA Limited he was employed at Philips Limited in Toronto, Canada, (1957-61) dealing with radio tube and ionospheric sounder development. Between 1951-57 he was employed in Budapest developing a.m. and fm transmitters and microwave tubes. Mr. Kadar is a member of the Association of Professional Engineers of the Province of Ontario.

Robert L. Ernst has authored anotner paper in this issue; his biography and photograph appear there.

John J. Labelle, Technical Development, RCA Limited, Montreal, has been with RCA since 1950, and has been involved in the design of rf and i.f. equipment for microwave communications and for satellite Earth Stations. In 1961-2, he was responsible for the design of the Beacon transmitter used in the Relay satellite and, later, for the design of the mixer-preamplifier used in 9102 and 9202 microwave systems. From 1964 to 1972, he worked on equipment design with the Earth Station Equipment Engineering group. At present, he is working on the new generation of Earth Station equipment, making full use of microwave integrated circuitry.

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S. Yuan, Ldr., Advanced Communications Laboratory, Government Communications and Automated Systems Division, Somerville, N.J., received the BSEE from the University of California at Berkeley in 1952 and the MSEE from Columbia University in 1956. Mr. Yuan is currently involved in the fabrication of thin-film circuits and the design and development of microelectronic microwave circuits for use in an X-band transmitter and receiver. Since becoming a leader (1966) he has been responsible for the development of circuits such as uhf rf amplifiers, uhf/vhf VCOs, phase comparators, and crosspoints using beamlead diodes for switching matrices. From 1963 to 1966 his work assignment was in the area of solid-state rf techniques; his responsibilities were interference reduction, frequency multipliers, and signal detection in the presence of noise. He is the co-inventor of a balanced mixer circuit which can alleviate high-order intermodulation and crossmodulation distortion. His work on frequency multipliers has resulted in a theoretical analysis for predicting the efficiency of a X8 multiplier as a function of the nonlinear coefficient and an an experimental model of the multiplier which yields a 20% efficiency octupler (500 MHz to 4 GHz). From 1957 to 1963 he was a senior engineer with the electronics division of Curtis Wright Corporation and a member of the electronic research laboratory staff at Columbia University. From 1953 to 1955, he worked with RCA on the development of broadcast equipment. Mr. Yuan is a member of the Chinese Institute of Engineers, Tau Beta Pi, Eta Kappa Nu, and Phi Tau Phi. He has published more than ten papers and has a pending U.S. patent.

be sufficiently discontent with the existing in-house product(s) to initiate the development, preferably with the encouragement of the Management. Second, a group of engineers of another division must be ready to accept the technical challenge, usually given informally and on short notice. Third, an engineer (in our case a senior engineer from Montreal) must be willing and able to work alongside the development group, to arrange the orderly and efficient transfer of technology. Finally, the Management teams on both sides must be listening to the advice of their engineers and be ready to act and make decisions on short notice.

Development program

In the autumn of 1972, RCA Ltd in Montreal was preparing a technical proposal for the delivery of small Earth Stations to operate within the Canadian Satellite System. It quickly became obvious that the existing communication equipment had to be replaced by devices occupying smaller space, while satisfying the requirements for cost reduction and reliability.

For the ground communications equipment part of the station, it was clear that microwave integrated circuits and hybrid structures would provide the ideal solution. In-house development was first considered. However, the manpower, cost, and schedule implications of such an in-house program (*i.e.*, in Montreal) were forbidding, as our own design and production ability of microwave integrated circuits and hybrid devices was not very advanced at that time.

Thus, other alternatives were examined. Scanning the various RCA divisions, we learned that engineers at the Government Communications and Automated Systems Division in Somerville, under the guidance of Dr. Pan, were developing various state-of-art microwave integrated circuits and hybrid devices for the military frequency bands.

While the electrical and mechanical performance requirements of those devices were quite different than those required in commercial Earth Stations, the commonalities were sufficient to indicate that the conversion of those devices and units was practical.

Thanks to the very direct manner by which Dr. Pan handled RCA Ltd's challenge from the beginning, the initial discussions resulted in the quick establishment of technical requirements and budgetary and schedule estimates, while keeping the contacts at all times at the working engineering level.

A mild element of competition — always helpful to keep cost in line — was introduced when, during the initial search for development support, we got in touch with a capable engineering group at the Missile and Surface Radar Division in Moorestown, N.J., who also seemed eager to take up the technical challenge.

However, it seemed that the Somerville group's work more closely suited our needs. All these facts were given to the appropriate Managements at RCA Ltd. and in Government Communications and Automated Systems. The decision and the agreement between the two Managements was rather swift and the development program commenced in the winter months of 1972.

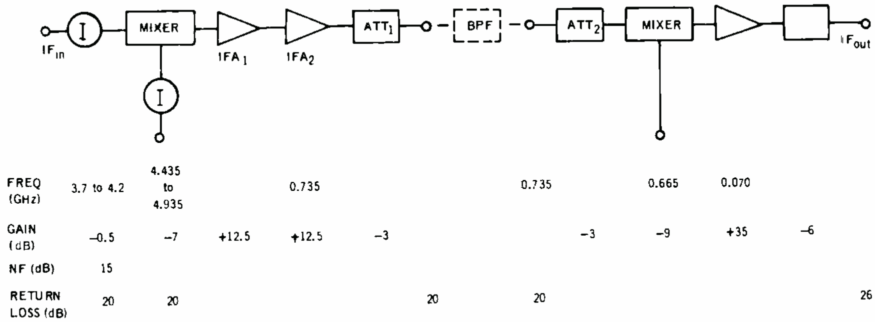

Fig. 1 — Down-converter block diagram and requirements.

Technical requirements

The major tasks given to the Government Communications Systems group at Somerville were to design:

1) A frequency-agile double-conversion down-converter (block diagram and requirements in Fig. 1) which, by mixing with a local oscillator, converts the carrier located in the 3.7- to 4.2-GHz band, to an intermediate frequency of 735 MHz, where a preliminary carrier selection is made using a filter with a 50-MHz bandwidth. After a second frequency conversion to 70 MHz, the carrier is further amplified in a linear i.f. amplifier.
2) A frequency-agile, linear double-conversion up-converter (block diagram and requirements in Fig. 2) which, by mixing with a local oscillator, converts the signal to an intermediate frequency of 735 MHz, and then, by further mixing, converts the signal to the required rf carrier frequency in the range of 5925 to 6425 MHz, at a maximum output level of −10 dBm.
3) A four-way microwave signal divider (3.7- to 4.2-GHz range) to serve as a building block for a 32-way divider supplying up to 32 receivers (Fig. 3).

These items were designed by a group under Dr. Y. Pan, working to rather stringent specifications supplied by RCA Ltd. in Montreal.

The program was two-fold: Finished working models were to be delivered, and all information was to be provided to enable successful production run in Montreal.

System description

Five modules have been developed for the system. Three modules are made completely from microwave integrated circuits: A 4-GHz to 735-MHz down-converter, a 735-MHz to 6-GHz up-converter, and a 4-GHz four-way power divider. The remaining two modules are custom made from commercially available components; these include a 70-MHz to 735-MHz up-converter and a 735-MHz to 70-MHz down-converter. Both converters include identical band-pass filters with 735 MHz center frequency. These filters are compact nine pole types, with excellent gain flatness, that were commercially available.

4-GHz to 735-MHz down-converter (Fig. 1)

In this microwave integrated circuit module, the range from the lowest local-oscillator frequency (2.965 GHz) to the highest rf (4.2 GHz) represents a bandwidth of more than 30%.

Bandwidths of microstrip circulators are typically greater than 50%, therefore a single design was used for both rf and local-oscillator isolators in the prototype.[The LO isolator was later redesigned in Montreal, to accommodate a change in LO frequency.]

The design utilizes a combination of a ferrite three-port microstrip circulator with a 50-ohm chip resistor. The circulator, including the needed impedance transformers, is deposited on an all-ferrite substrate. The direction of circulation in the two circulator units is opposite, to minimize permanent-magnet field interaction. However, since a steel casing is used for the isolator portion of the module (to satisfy the specification for magnetic shielding), the precaution of designing adjacent circulators with opposite directions of rotation is unnecessary.

The mixer uses a pair of newly available microstrip packaged Schottky barrier diodes (HP 5082-2216) in a single-balanced configuration. To insure adequate bandwidth, the diodes are coupled to the local-oscillator and rf signals through a 3-dB interdigitated coupler having a one-octave bandwidth. The i.f. outputs of the two diodes are combined in a Wilkinson type combiner.

The i.f. amplification is done with a wideband (600 to 800 MHz) linear amplifier. The amplifier incorporates a microstrip packaged transistor (HP 35821) with chip resistors and capacitors as microstrip tuning elements. The exact design has been determined by computer optimization techniques. A 3-dB attenuator, built into the coaxial connector, is used on this and all other converter modules to provide a good match to the 735-MHz bandpass filter used in the converter.

The measured performance of the module is summarized below:

Parameter	*Measured*
RF input frequency	3.7 to 4.2 GHz
Input return loss	>25 dB
Output frequency	735 ± 18 MHz
Output return loss	22 dB (min)
Frequency response	± 0.2 dB (max)
L.O. return loss	20 dB (min)
Gain	17.2 dB (max)
Noise figure	12.2 dB (max)
3rd-order intermodulation	53 dB

735-MHz to 70-MHz down-converter (Fig. 1)

These low frequency (less than 1-GHz) modules were assembled from commercially available components. At these frequencies, the commercial components are available at prices and delivery times which make in-house development, to achieve the same performance, highly impractical. Detailed specifications published by the manufacturers enabled component selection. The most significant parameters to consider are gain, system intermodulation ratio, overall flatness, and size.

The selected components, ANZAC Mixer Model MD 113 and Avantek Amplifiers Model UA 152 and VA 305, are interconnected in a package to result in a compact module having few external connections. The input return loss is a function of the double-balanced mixer, and the result—a vswr of about 1.5:1—represents a typical value. The slightly lower gain of this module is offset by the correspondingly higher gain for the 4 GHz down converter module. The measured performance for this module is summarized below:

Parameter	*Measured*
Input frequency	735 ± 18 MHz
Input impedance	50 ohms
Input return loss	14.3 dB (min)
Output frequency	70 ± 18 MHz
Output impedance	75 ohms
Output return loss	24.8 dB (min)
Gain	15.6 dB
Frequency response	± 0.2 dB
L.O. signal	665 MHz
L.O. return loss	8.9 dB
Output spurious	≪−60 dB
Second harmonics	−43 dB

735-MHz to 6-GHz up-converter (Fig. 2)

The microstrip transistor amplifier is similar to the one used in the down converter; however, it is slightly modified to insure a low input vswr centered at 735 MHz. The vswr is further improved by the 3-dB attenuator built into the input connector. The frequency converter is essentially a scaled version of the 4-GHz unit. Pill-packaged diodes (HP 5082-2707) are used here, because the higher frequency microstrip packaged diode was not readily available at the time of this development program.

The isolators are also scaled designs of the 4-GHz units. They are laid out in opposite circulation directions to minimize magnetic interaction, but, as it was noted earlier, this precaution is unnecessary due to the shielding provided by the steel housing. The measured performance of the module is summarized below:

Parameter	*Measured*
Input frequency	735 ± 18 MHz
Input return loss	22.8 dB (min)
Output frequency	5.925 to 6.425 GHz
Output return loss	17 dB (min)
Gain	−2 dB
Spurious	<−60 dB
Frequency response	± 0.5 dB
L.O. return loss	19 dB (min)

70-MHz to 735-MHz up-converter

This is the simplest module of the system. It is merely a packaging of a commercial double-balanced mixer with an impedance transforming resistive pad and a 3-dB connector pad. The measured performance is summarized below:

Parameter	*Measured*
Input frequency	70 ± 18 MHz
Input impedance	75 ohms
Input return loss	29.4 dB (min)
Input level	+5 dBm
Output frequency	735 ± 18 MHz
Output impedance	50 ohms
Output return loss	18.7 dB (min)
Gain	−12.8 dB
Frequency response	±0.2 dB
L.O. signal	665 MHz
L.O. impedance	50 ohms
L.O. return loss	5.8 dB

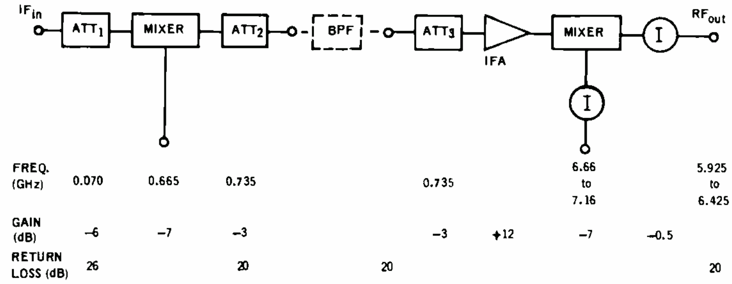

Fig. 2 — Up-converter block diagram and requirements.

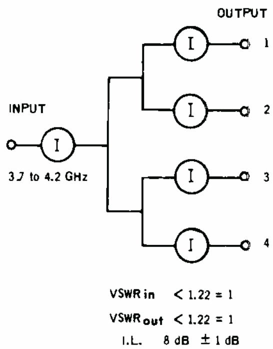

Fig. 3 — Four-way divider block diagram.

Four-way power divider (Fig. 3)

This module is designed to divide an input signal of 3.7- to 4.2-GHz between four output ports. At least 40-dB isolation is required between any two output ports while 20-dB isolation is needed between any output and the input port.

The basic divider is laid out on a single 2× 1 inch alumina substrate. Additional substrates were used to provide transmission lines to bring the outputs of the divider to the respective isolators. Ferrite circulators were used to provide the required isolation performance. As with the other modules, the direction of circulation for the five isolators was not critical because of the steel casing used to achieve magnetic shielding. Measured performance of the four-way divider is summarized below:

Parameter	*Measured*
Input frequency	3.7 to 4.2 GHz
Input impedance	50 ohms
Input return loss	20 to 25 dB
Output impedance	50 ohms
Output return loss	20 to 25 dB
Isolation between output ports	35 to 40 dB
Loss from input to output	8 ± 0.5 dB

Mechanical design criteria

Ground plane

One of the most common problems encountered with microwave integrated circuit modules is the gradual degradation of module performance characteristics due to poor soldering of the ground plane, or too much solder which causes uneven spacing between the substrate and the chassis. A good ground is essential to eliminate performance instabilities and stray radiation. Therefore, the chassis for the modules were machined out of a solid block of brass and then gold plated, thus maintaining a continuous ground plane from the connectors to the ceramic substrate.

For the same reason, the ceramic substrate and the chassis ground plane were completely tinned with solder before the ground plane was soldered to the chassis.

Easy repair

Where many circuit functions are integrated into one microwave integrated circuit (MIC) module, cost effectiveness plays an important role. Although these modules can be manufactured at a cost that is competitive with conventional circuits, even in small quantities, one must consider the cost of repair in case one of the circuits within the module malfunctions. If indeed all the circuits are designed on a single substrate, the replacement of a single transistor means reworking all the other components. Furthermore, it would be extremely difficult to troubleshoot the devices. Therefore, to provide the maximum flexibility in repair, each individual circuit function (such as the isolator, the mixer and the i.f. amplifiers) is self contained. That is, each circuit has an individual substrate and is mounted in its own chassis with connectors for inputs and outputs. Thus, each MIC can be tested, checked, or repaired individually. These circuits are then joined together mechanically as well as electrically.

Magnetic shielding

The MIC isolators contain magnets which could detune other circuits. To prevent this, steel chassis were used in the isolator parts of the modules. This provided magnetic shieldings and also allowed the use of much weaker magnets which were considerably less expensive (Indox V versus Semarian Cobalt). However, this is done at the expense of increased weight.

Metallization

When these MIC modules were developed originally, the metallizations on the substrate were chrome-seated gold. Sometimes, this led to electrical instability caused by migration of gold. The gold layer gets scavaged easily if improper solder is used, for example. The metallization was subsequently changed to chrome-copper-gold. By doing so, good electrical properties are still maintained through the copper layer even if the gold surface is destroyed. The brass chassis were gold plated and the steel chassis, for the isolators, were nickel plated. These metal interfaces all seemed to work out satisfactorily.

MIC development in Montreal

An RCA Montreal engineer was working alongside the Somerville group during the last stages of the development. Thus, when it became necessary — subsequent to the delivery of the units to Montreal — to introduce some changes into the design, the Montreal engineers already had the confidence and expertise to carry out those developments.

The following tasks were completed in Montreal:

- Redesign of the input isolator in the 4-GHz to 735-MHz down-converter, to accommodate change in the local oscillator frequency.
- Design of an MIC two-way microwave divider (3.7- to 4.2-GHz band).
- Design of an MIC bandpass filter covering the 3.7- to 4.2-GHz range, including an input isolator.
- Redesign — jointly with Somerville — the mechanical packaging of the devices in a modular form, for versatile interconnection and ease of test and repair.

After the development was completed, the devices went into regular production at the expanded MIC facility in Montreal. These state of art modules are now forming an integral part of our new generation of Earth Station communications equipment. The dialoge between the two engineering teams is continuing, and we are already discussing plans for a new joint state-of-the-art development program.

Acknowledgments

The authors acknowledge the technical leadership of Dr. Pan, Somerville, and the foresight of Mr. J.R.G. Cox, Chief Engineer in Montreal, who encouraged and promoted this joint-development activity.

Silicon photosensors and their application

T. Doyle | H.C. Sprigings

RCA Limited is one of the leaders in the development and production of silicon photosensors. The authors discuss the characteristics of various photosensors, their operation, and their application in military and industrial systems.

THE basic solid state photodetector made at RCA Limited consists of a semiconductor p-n junction. In this type of photodetector, the absorption of radiation and the collection of the charge generated takes place most efficiently in the depletion region of the junction. The two parameters which determine the spectral characteristics of the photodetector are the width of the depletion region and the thickness of the dead layer on the surface on which the radiation is incident. The dead layer occurs because of the high concentration of dopant required to form the p-n junction. The depletion layer width determines the spectral characteristics at the long wavelength (λ>900nm) end of the response curve, while the dead-layer thickness determines the spectral characteristics at the short

Howard C. Sprigings, Mgr., Engineering and Development, Electro-Optics Department, Electronic Components Division RCA Limited, Canada, received the BSc in 1962 from Sir George Williams University. In 1956, he joined the Northern Electric Company's Materials Inspection Laboratory where he carried out chemical and metallurgical analysis on metals. He was transferred to the Research and Development Laboratories in 1959 and assisted in development work on the npn planar transistor. Mr. Sprigings joined the Research Laboratories of RCA Limited in April 1960. Initially, he was engaged in doing research and development on various types of silicon nuclear particle detectors using oxide passivation techniques. He has been involved in the development of a high-power, high-frequency transistor and has been doing research and development of multi-element photodiodes for the detection of 1.06-micrometer radiation. He has also examined various methods for passivating devices fabricated from ultra high-resistivity silicon. In 1971, he joined the Electro-Optics Department of Electronic Components Division as Manager of Engineering and Development and has since been engaged in directing programs related to the development of silicon photosensors. He is a member of the IEEE and the Canadian Association of Physicists.

Thomas Doyle, Adm., Applications Engineering, Electro-Optics Department, Electronic Components Division, RCA Limited, Canada, received the BSc with honors in Natural Philosophy from the University of Edinburgh in 1960 That year, he joined the Royal Aircraft Establishment at Bedford, England, where he was engaged in researching the automatic landing of aircraft. He has worked in the field of atmospheric propagation of radiation at wavelengths from the visible to the microwave region. He also has worked with analog computors simulating the landing of different aircraft under different atmospheric conditions and with different control equations. In 1964, Mr. Doyle joined the Research Laboratories of RCA Limited. Since then, he has worked on a variety of problems in infrared physics, involving measurements in the range of 0.6μm to 30μm. He has designed, developed, and tested infrared detectors which have been sold to researchers in Canada, the U.S., and Britain. He has also designed very low noise, very high impedance preamplifiers (which operate at 77K) to go with the improved detectors. He has invented a novel form of Dewar flask which allows access to the cooled specimen without disturbing the Dewar vacuum. A patent is being applied for by RCA for this design. In August 1971, he transferred to the Electro-Optics department.

wavelength ($\lambda < 500$ nm) end of the response curve (see Fig. 1).

Photodetectors are generally used in the fully depleted mode. This means that the depletion layer width is the thickness of the silicon wafer. To operate a detector in the fully depleted mode, the p-n junction has to be reverse-biased, and the thicker the wafer the larger the bias that has to be applied. N-type substrate material is used for wafer thicknesses up to about 250 μm while p-type substrate material is used for wafer thicknesses up to 700 μm as it is easier to make high breakdown voltage devices with p-type material than with n-type material. Therefore, long-wavelength detectors are generally made using high-resistivity p-type material, and short-wavelength detectors are made using n-type material.

Photodetector types

The photodetectors are characterized geometrically into single element, quadrant, and special geometry detectors.

Single-element photodetectors

These types of photodetectors can be divided up into those which use p-type starting material and those which use n-type material.

N-type photodetectors — The term "n-type" denotes the impurity-type of the base starting material. A cross section of the device is shown in Fig. 2. N-types are normally used for the detection of wavelengths below 950nm, and when optimized at 900nm with an anti-reflection coating they have quantum efficiencies close to 95%. Because the silicon diode is thin the speed of response is very fast. At 50 V, rise times are of the order of 2 to 3 ns.; at 100 V, rise times are less than 1 ns. A typical response-time curve as a function of bias is shown in Fig. 3 for a 1-mm^2 photodetector. These photodetectors are sealed hermetically behind a flat glass window. They are made in sizes which range from 0.2 mm^2 to 1 cm^2. The wavelength at which the response peaks coincides exactly with the wavelength of emission of GaAs emitters and lasers.

P-type photodetectors — These devices are normally used for detecting radiation above 900nm and particularly radiation at 1.06μm, which is the wavelength of the YAG laser, the importance of which will be discussed later. Before these detectors are designed for a system, a trade-off between responsivity and speed of response must be made. The wider the depletion region of these detectors, the more efficiently will they detect longer-wavelength radiation; however, the transit time of electrons and holes across the wide depletion region determines the rise time of the photodetector which is a key parameter because charge will recombine before collection. These detectors are anti-reflection coated on the entry surface and reflection coated on the back surface. They can be mounted so that the radiation enters either at the p$^+$ side or the diffused junction side of the diode. Photodetectors are usually provided with a guard ring which assists in minimizing surface leakage current which contributes to the device noise. Fig. 4 shows the cross section of a single element p-type photodetector.

Multi-element photodetectors

Quadrant photodetectors — Fig. 5 shows the cross section of a fully depleted quadrant photosensor with radiation entering the common junction surface. The active area of a quadrant photodiode is divided into four segments, each with its own output. In this way, the position on the detector surface where the radiation is incident can be determined by operating the four outputs of the photodetector. These detectors are made with n-type or p-type starting material, and they have the same general characteristics as those of the single element n-type or p-type photodetector. Quadrant photodetectors have special characteristics relating to the transition region between adjacent quadrants and also crosstalk between quadrants (see Fig. 6). Typical values for crosstalk are 0.1% to 5% and for transition (which is measured as the distance between the 90% signal in one quadrant to the 90% signal in the next quadrant), typical values are 0.008 to 0.020 in.

Special geometries — The most popular multi-element photodetector is the quadrant 4-element structure; however, almost any geometrical division of the active area can be made. Detectors have been made using from 2 elements to 64 elements, with individual elements from

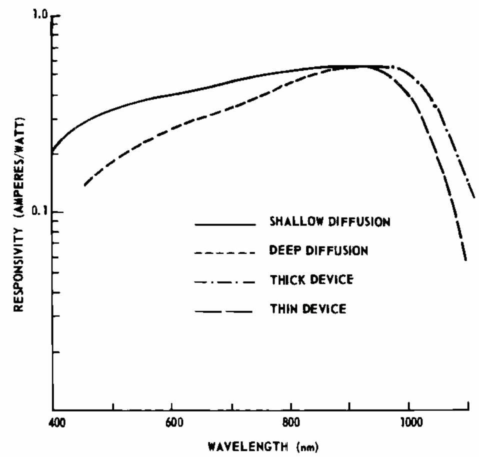

Fig. 1 — Spectral response.

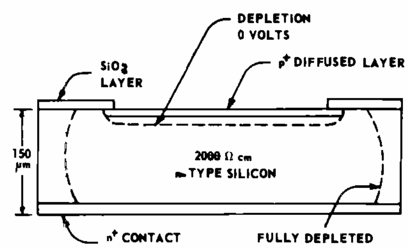

Fig. 2 — N-type photodetector.

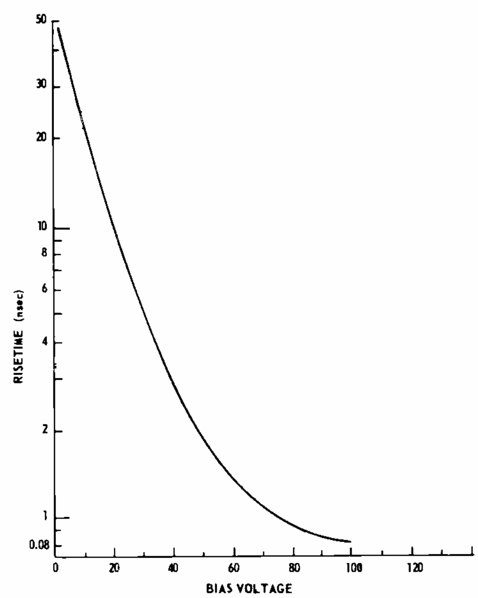

Fig. 3 — Typical rise time *vs* bias voltage for the C30807 photodetector 1mm^2.

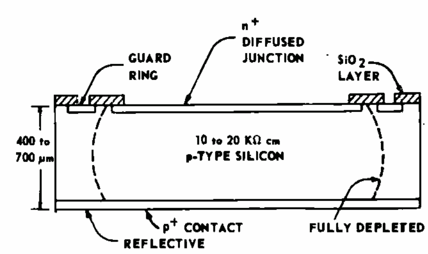

Fig. 4 — P-type photodetector.

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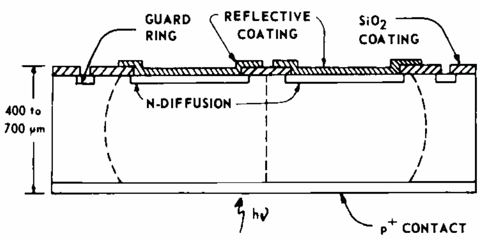

Fig. 5 — Quadrant photodetector.

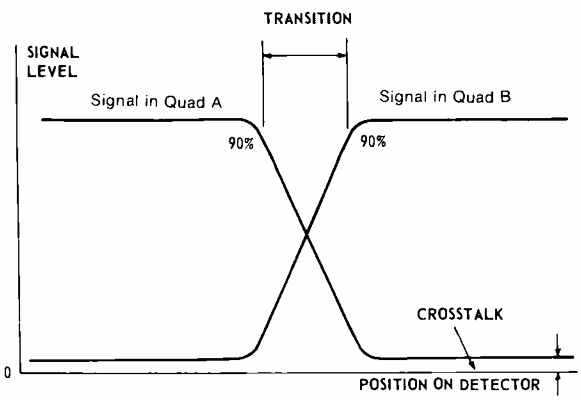

Fig. 6 — Signal variation with position on a quadrant photodetector.

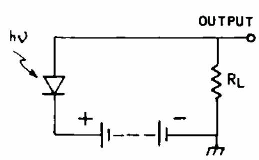

Fig. 7 — Operation of photodetector with bias.

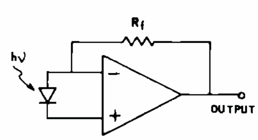

Fig. 8 Operation of photodetector photovoltaically.

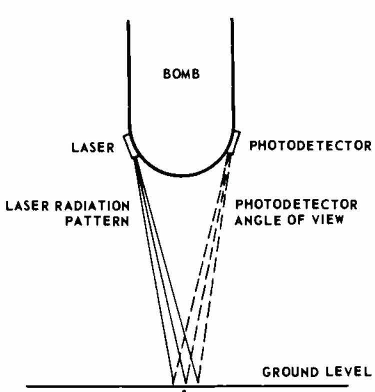

Fig. 9 — Bomb fuse system.

0.1 mm^2 to > 1 cm^2 in area. Individual elements within one photodetector need not be all the same shape but can take any shape required for their intended application.

Avalanche photodetectors

In all the photodetectors described above, one absorbed photon generates one electron-hole pair and one electron-hole pair is collected. With the avalanche photodiode, one absorbed photon generates one electron-hole; but before this is collected, it enters a region of high field and through the avalanche process it generates more charges. The total charge collected is then much more than that generated by the photon. The responsivity of the avalanche photodetector (A/W) is much higher than the responsivity of the regular photodetector. The avalanche photodetectors, made at RCA Limited have responsivities at 900 nm of about 80 A/W and at 1060 nm about 16 A/W. Response times are in the order of a few nanoseconds. More information on avalanche photosensors can be obtained from the paper by R.J. McIntyre in this issue.

Hybrid opto-electronic assemblies

To extend the potential of these photodetectors, some units built incorporate, in a single package, a single element photodetector and a hybrid preamplifier. A trade-off is reached in these units between noise equivalent power (NEP) and speed of response. Typical values are:

	C30815/16	C30847
Rise time	35 ns	7 ns
NEP (W Hz$^{-1/2}$)	3×10^{-12}	8×10^{-12}

A silicon avalanche photodetector and a hybrid preamplifier have also been incorporated in a single package with a rise time of 10 ns and an NEP of 5×10^{-14} W Hz$^{-1/2}$.

Modes of operation

There are basically two ways to operate photodetectors — biased mode and photovoltaic mode.

Biased mode — In this mode, a bias is applied across the photodetector and the depletion width is increased to fill the total thickness of the silicon wafer. In this region, a high field exists and the capacitance is minimum. This mode is best suited for detection of very fast pulses. The operating circuit is shown in Fig. 7. The photocurrent flows through R_L and develops a voltage across R_L. This voltage can then be amplified and processed as required.

Photovoltaic mode — In this mode, no external bias is applied to the detector. The operating circuit is shown in Fig. 8. The operational amplifier maintains the voltage across the photodetector close to 0 V and also makes the detector appear to be working into a small load resistance. The output voltage of the operational amplifier is:

$$E_{OUT} = I_\Phi R_f$$

where I_Φ is the photocurrent generated, and R_f is the feedback resistor.

Applications

Solid state silicon photodetectors find applications in a large number of systems including military and industrial and commercial.

Military systems

Target designator — In this type of application, a laser illuminates the target. A quadrant detector in an aircraft or missile has the target imaged on its surface. The signals from the four


Fig. 10 — Quadrant photodector (wire quided missile system).

quadrants indicate the position of the image of the target on the detector surface which is a measure of the location of the target in the field of view. These signals are used to control and direct the weapon system.

Bomb Fuse — Silicon photosensors in conjunction with *GaAs* lasers have proven to be an extremely efficient way of presetting the altitude at which a bomb will explode. This is performed with the system shown in Fig. 9. The laser and the detector have very narrow fields of views, and they can only see each other when their point of intersection coincides with the ground.

Wire guided missile systems — The photodetector sits in the focal plane of the optics and "sees" the target and the missile. The operator sees the same field, and he attempts to keep the target on the cross hairs which coincides with the detector quadrant division lines. In this way, he keeps the image of the target on the center of the detector. The missile signal generates an error signal which is fed back via the wire system to the missile and brings the missile on course to the target. Fig. 10 shows the photodetector used in this type of system.

Industrial and commercial applications

Pattern analysis and recognition — A 64-element photodetector has been developed for analyzing radiation defraction patterns. Fig. 11 depicts the 64-element array on a silicon wafer with a diameter of 1½ in. A typical application of this system is shown in Fig. 12. Other applications include color TV shadow-

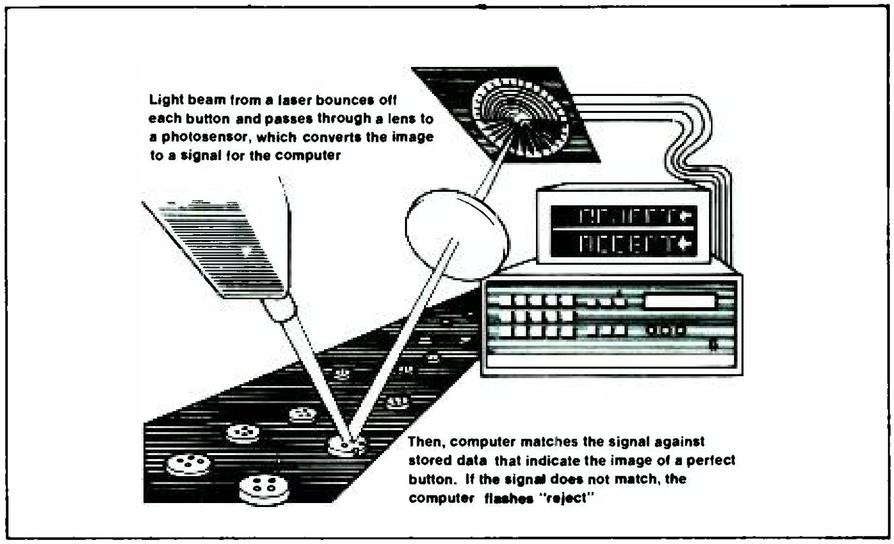

Fig. 12 — Pattern recognition on the assembly line.

mask defect detection, precision alignment, and pattern defect and X-ray analysis.

Auto refractor — This instrument has been designed to measure the refraction of the eye objectively. Normally, in prescribing corrective lenses for visual defects, a subjective examination is performed with the patient noting what he observes on a chart. In the auto refractor, invisible radiation (930-nm wavelength) is introduced into the eye through a 2-mm area in the center of the patient's pupil. The instrument has a quadrant photodetector which monitors the retinal image centered on the forea to provide continuous output data concerning the state of the eye. This instrument enables children's eyes to be examined accurately and considerably reduces the time required to perform eye measurements.

Range finder — This system operates like a radar system. A pulse of radiation, with a fast rise time, is emitted from the instrument and is reflected from an object. The returning reflected pulse is detected using a silicon photodetector, and the time between the emission and the return of the pulse is measured. This time is a measure of the distance to the object. This system has found use in military applications. However, many commercial and industrial applications, such as surveying, are being developed.

Conclusions

The silicon photosensor is now accepted as a most efficient and economical method of detecting radiation in the 300- to 1100-nm range. Potential applications for this device are numerous and new applications are continuously being discovered. Figs. 13 and 14 illustrate the versatility available in making custom multi-element photosensors.

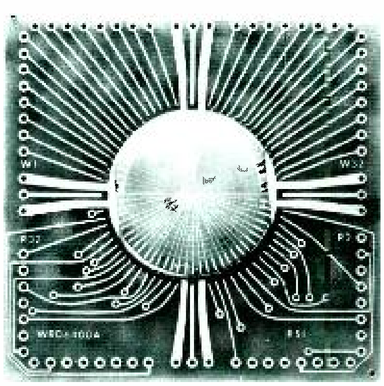

Fig. 11 — 64-element photodetector.

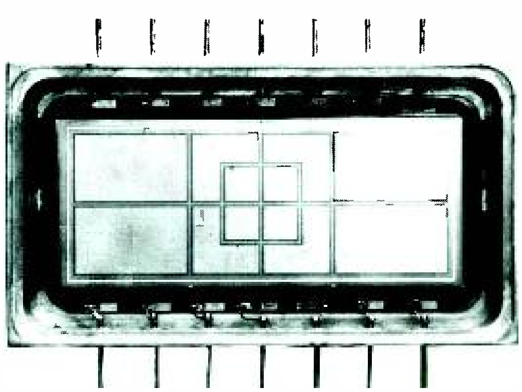

Fig. 13 — Special geometry quadrant.

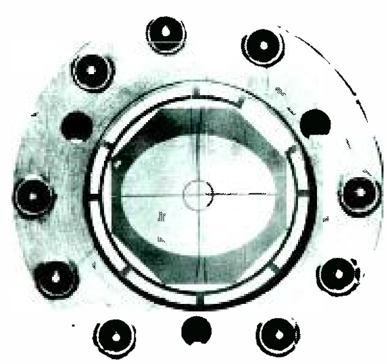

Fig. 14 — Special purpose octant.

K-band MIC technology

Robert L. Ernst

The realization of microwave integrated circuits (MIC's) usable throughout the K-band frequency range, i.e., up to 40 GHz, requires a refinement in technology. Particular attention must be paid to the selection of substrate material, the coaxial-to-microstrip launcher, the package, and the variation of microstrip characteristics with frequency. At higher frequencies, inverted microstrip lines and waveguide-to-microstrip launchers can provide simpler circuits and improved performance.

As MICROWAVE integrated circuit (MIC) technology develops, the need for ever higher frequency circuits is constantly generated. Now that MIC's are commonly used up through X-Band frequencies, i.e., up to 12.4 GHz, techniques are presently being developed for Ku- and Ka- band circuits, *i.e.*, up to 40 GHz. Working at these higher frequencies demands a careful examination of many fundamental design techniques and fabrication methods to insure proper circuit performance. The important topics to be considered are:

1) the limitations of scaling with frequency;

2) the use of alternate substrate materials;

3) methods of launching a wave from a coaxial cable into the various MIC transmission lines;

4) packaging of the completed circuit;

5) dispersion or variation of microstrip transmission line properties with frequency; and

6) transmission line configurations other than microstrip.

The principle of designing a high-frequency circuit by reducing the dimensions of a properly working lower-frequency circuit inversely with the frequency is as old as microwave circuitry. Many K-band circuits can be successfully generated with this method; most matching networks, filters, and ferrite circulators fall into this category. Certain other types of circuits cannot be designed by this technique because of other high-frequency effects. The 3-dB quadrature coupler used in many frequency converters, amplifiers, and phase shifter circuits is one such circuit. In Fig. 1, three

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Table I — Properties of substrates

Material	Surface Roughness Δ (Microinch)	*Tan*δ× 10^4 at 10GHz	ϵ_r	K in watts cm^2-°C	MIC Applications
Alumina (99.5%)	2-8	1-2	10	0.3	Microstrip, suspended substrate
(96%)	20	6	9	0.28	
(85%)	50	15	8	0.20	
Sapphire	1	1	9.3-11.7	0.4	Microstrip, lumped element
Glass	1	20	5	0.01	Lumped element, quasi-monolithic MICs
Quartz (fused)	1	1	3.8	0.01	Microstrip, lumped element
Beryllia	2-50	1	6.6	2.5	Compound substrates
Rutile	10-100	4	100	0.02	Microstrip, slot-line coplanar
Ferrite/Garnet	10	2	13-16	0.03	Microstrip, coplanar compound substrates non-reciprocal components
GaAs (High-resistivity)	1	16	13	0.3	High-frequency microstrip, monolithic MICs
Si (High-resistivity)	1	10-100	12	0.9	Monolithic MICs

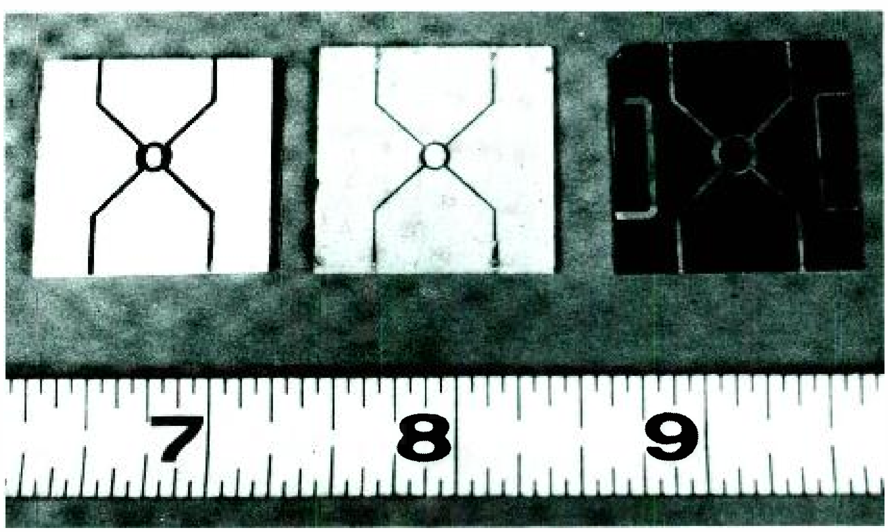

Fig. 1 — Ku-band 3-dB quadrature couplers.

different hybrid couplers designed to operate at a center frequency of 13.8 GHz are shown. The coupler on the left is fabricated on a 25-mil thick alumina substrate using a design based on scaling a well-performing unit at 7.5 GHz. The performance of this unit is disappointing due to several effects. Significant undesired coupling occurs across the center hole because it has about the same dimensions as the transmission line widths which make up the ring. The width of the 35-ohm transmission lines approaches one-quarter wavelength at these frequencies. In addition, the three microstrip transmission lines which meet at the junctions of the hybrid are so wide compared to a wavelength, that the junction is very poorly defined.

The center hybrid in Fig. 1 represents an attempt to obtain improved quadrature coupler performance by using a thinner 10-mil thick alumina substrate. The resulting thinner transmission lines will minimize the high-frequency effects of the 25-mil thick alumina substrate. Unfortunately, the fact that a 50-ohm line is only 10 mils wide causes difficulty in making a low-VSWR transition from a coaxial connector. It is also very difficult to make a high-characteristic-impedance transmission line on this substrate. For example, a 5-mil width line has an impedance of about 90 ohms on 25-mil thick alumina, while the impedance is only 65 ohms on a 10-mil thick alumina. This represents a severe design limitation for MIC's.

Alternate substrate materials

By using a different substrate material, in this case, a 10-mil thick quartz, a 13.8 GHz MIC quadrature hybrid with good electrical performance results (Fig. 1).

The properties of several substrate materials suitable for MIC applications are given in Table 1. By comparing fused quartz with 99.5% alumina, it is seen that the only major difference is in the relative dielectric constant. The surface roughness and loss tangent for these two materials is comparable.

By taking advantage of the lower dielectric constant of quartz, microstrip line widths can be made approximately the same as those found on commonly used 25-mil alumina substrates; at the same time, the length of the distributed components can be increased. The result is that line widths do not approach a significant portion of a wavelength over a 60 percent greater frequency range. Therefore, circuits which work well on 25-mil alumina up to 12.4 GHz can be readily extended to 20 GHz by using 10-mil thick quartz.

Coaxial-to-microstrip transitions

Launchers or transitions from a coaxial connector to microstrip can be divided into two general categories. They can be mounted flush with the edge of the substrate, or they can be mounted on a circuit frame which encloses the substrate.

The simplest flush-mounted connectors use an air dielectric on the side of the microstrip tab. When these connectors are used at K-band frequencies, care must be taken that the distance between the center conductor and the metallic sleeve is not a significant fraction of a wavelength. A launcher compensated for high-frequency performance will have reduced inner and outer diameters while maintaining the proper 50-ohm characteristic impedance.

A novel flush-mounted launcher with good high-frequency performance has been developed by the RCA Laboratories.[1] This launcher is made by modifying a commercially purchased unit. When two of these units are tested together as shown in Fig. 2, the VSWR up to 18 GHz is less than 1.25 as shown in Fig. 3. These connectors are very useful for testing prototype circuits mounted on a simple metal block.

A launcher configuration used to connect to an MIC substrate through the wall of a circuit frame is shown in the left side of Fig. 4. The transmission-line section through the wall is formed by the center conductor and dielectric shield of the connector, with the ground conductor being formed by the wall of the circuit frame itself. This connector shows poor performance at K-band frequencies because of the comparatively large cross sectional area of the dielectric insulator A compensated connector designed for use at these frequencies would have a reduced-diameter center conductor and dielectric sleeve as shown in the right of Fig. 4.

Packaging

The packaging of deliverable MIC's must be carefully designed to maintain good circuit performance at K-band frequencies. The typical package used at lower frequencies has a three-piece construction. The substrate is soldered onto a base block which has an overlapping lip, typically 1/8 inch wide. A four-sided frame is then placed over the substrate and base block, and attached to the overlapping lip by two 0-80 screws. A cover is then attached to the top of the circuit frame by two more 0-80 screws.

When this three-piece construction is used at higher frequencies, it is found that the performance of the enclosed circuit is severely degraded. This is the result of excessive ground current paths required to go from the ground conductor of the launcher to the ground plane of the substrate. In the worst case, the ground currents from the connector are forced to go down through half the thickness of the circuit frame, through the two screws attaching the frame to the base block, and up through the entire thickness of the base block to reach the substrate ground plane. Such a condition leads to poor VSWR's, increased losses, and radiation.

A practical solution to the problem of excessive ground current paths is to make the base block and circuit frame as a single piece. This guarantees the shortest possible distance for ground currents from the launcher to the substrate ground plane. The resulting performance is equivalent to or even better than that of lower-frequency MIC's assembled in a separate base block and circuit-frame construction.

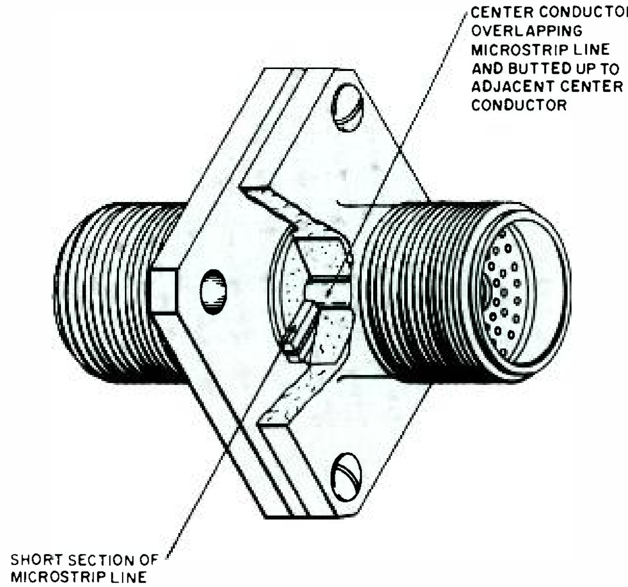

Fig. 2 — Coax-microstrip adapter test configuration.

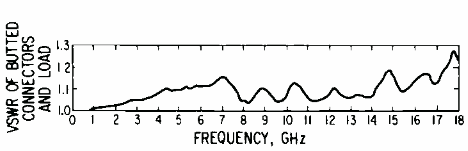

Fig. 3 — VSWR of butted microstrip-coax adapters.

Dispersion in microstrip

Much analytical and experimental work has been done by many workers to determine the variation of the velocity of propagation and the characteristic impedance of microstrip transmission lines with increasing frequency. A study of this work[2] shows that the normalized velocity (relative to C_0) of propagation in microstrip is given by:

$$V_p = \frac{1}{(\epsilon_r \epsilon_{eff})^{1/2}} \; \frac{(\epsilon_{eff})^{1/2} f_n^2 + (\epsilon_r)^{1/2}}{f_n^2 + 1}$$

where ϵ_r is the relative dielectric constant of the substrate and the normalized frequency f_n is given by

$$f_n = \frac{f}{f_c} = \frac{4h\,(\epsilon_r - 1)^{1/2}}{\lambda_o}$$

with h being the substrate thickness. The cutoff frequency f_c is given by

$$f_c = \frac{C_0}{4h\,(\epsilon_r - 1)^{1/2}}$$

and C_0 is the velocity of light in free space. One expression for the effective dielectric constant is given by:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \; \frac{1}{[1 + (10h/w)]^{1/2}}$$

where w is the width of the strip.

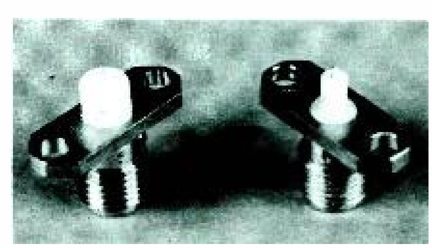

Fig. 4 — Coax-microstrip launchers.

The characteristic impedance Z_0 of the microstrip line is determined by the simple expression:

$$Z_O = Z_{01} * V_r$$

where Z_{01} is the characteristic impedance of the same structure with $\epsilon_r = 1$. The variation of Z_0 with frequency for 25-mil thick alumina and 10-mil thick quartz substrates is shown in Fig. 5. It can be seen that the impedance change for the alumina line is significant at the higher frequencies, while the variation in the quartz line over the same frequency range is practically non-existent. An examination of the expression given above for f_c shows that this result is to be expected. It shows that f_c increases when the substrate dielectric constant and the substrate thickness are reduced.

A high-frequency alternate microstrip

Even with thin quartz substrates, the use of microstrip lines at the higher K-band frequencies can be limited by dimensions which are too short to be practical. What is needed is an MIC transmission line in which the effective dielectric constant is as low as possible. One configuration which meets this requirement is the inverted microstrip.

With the inverted microstrip, a strip-center conductor is supported above a ground plane by being suspended from a thin substrate such as quartz. There is no dielectric placed between the strip conductor and the ground plane. The configuration of inverted microstrip and its effective dielectric constant is shown in Fig. 6. It is seen that ϵ_{eff} is typically less than 1.7 over a very wide range of line parameters.

An illustration of the application of inverted microstrip is the Impatt oscillator cavity shown in Fig. 7. This circuit, which operates at 28.5 GHz[3], requires no drilling of holes to mount the diode, and is capacitively coupled to an output line of inverted microstrip.

At these higher frequencies, the performance from even compensated coaxial launchers would be poor. A better method is to use a transition from waveguide. Such a transition usable at 30 GHz is shown in Fig. 8[3] Basically a transition is first made from waveguide to a very short section of microstrip and then to inverted microstrip.[4]

Summary

By using the proper substrate materials, coaxial-to-microstrip launchers, and proper packaging techniques, MIC's can readily be extended to frequencies of around 18 GHz. With the correct selection of transmission line and waveguide input launchers, MIC techniques can be utilized throughout the K-band frequency range.

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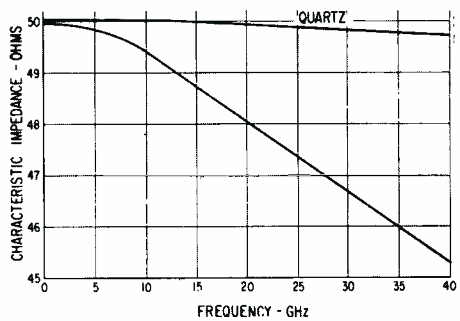

Fig. 5 — Variation of microstrip impedance with frequency.

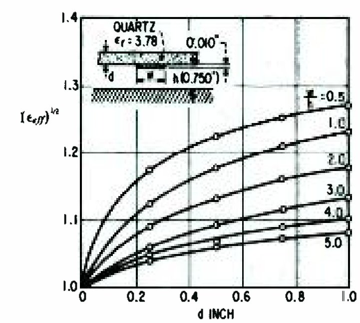

Fig. 6 — Square root of effective dielectric constant for inverted microstrip.

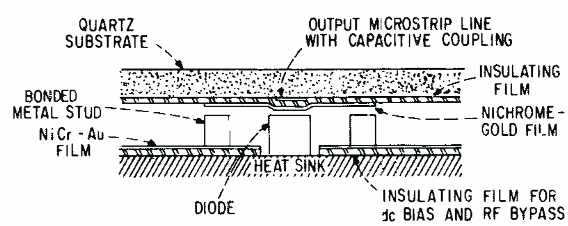

Fig. 7 — Impatt oscillator cavity with output on inverted microstrip.

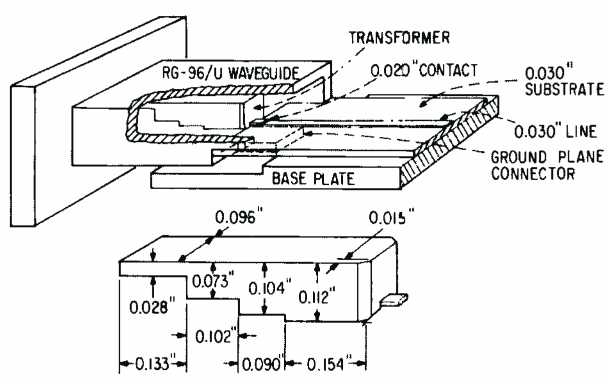

Fig. 8 — Dimensions of 30-GHz waveguide-to-microstrip transition: (a) mechanical design, (b) ridgeline transformer.

Variable-data-rate multimode quadriphase modem

R.W. Allen | B. H. Batson

A versatile modulator and demodulator has been developed to facilitate the evaluation of various digital communications links. The modem is capable of either PSK or QPSK operation and can accommodate a wide range of continuously tunable data rates (1 kb/s to 30 Mb/s in each of two channels). In the QPSK mode, operation is possible using either a single serial data stream (single-channel operation) or using two mutually independent, unrelated, and asynchronous data streams (dual-channel operation). Integrate and dump detectors are used at the demodulator for regeneration of the data stream(s). The measured performance of the system (including the bit detectors) is within 2 dB of the theoretical optimum for either PSK or QPSK at any rate within the range of rates provided by the modem, and is within 1 dB of theoretical over most of the range of rates.

PHASE-SHIFT KEYING (PSK) is a highly efficient modulation technique for transmission of information in digital form. In general, a PSK signal can assume one of M phase states over any particular signaling interval and is, therefore, sometimes referred to as an MPSK signal. From a decision theory

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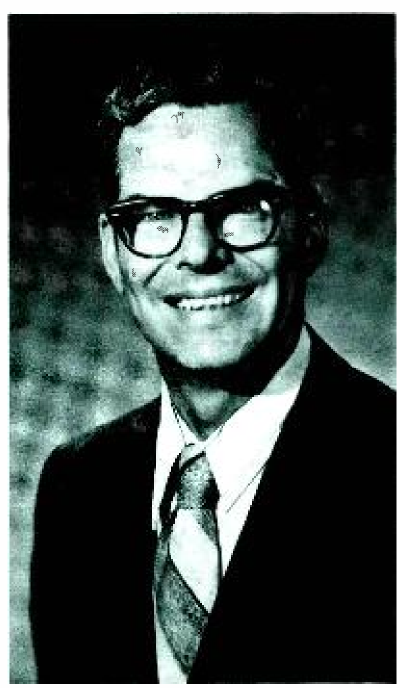

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viewpoint, binary PSK (the particular case of MPSK for $M = 2$) fulfills the requirements for an optimum signaling set. Such a signal can be generated by DSB—SC (double-sideband—suppressed-carrier) modulation of a carrier by a bipolar rectangular waveform, as well as by direct phase modulation of a carrier,[1] and is optimum in the sense that the probability of error is minimized for a given signal-to-noise ratio. The probability of error for ideal coherent binary PSK is given by

$$P_e = \tfrac{1}{2}\,\mathrm{erfc}\,(E_b/N_o)^{1/2} \qquad (1)$$

where E_b/N_o is the ratio of energy per bit to receiver single sided noise spectral density.

Since the input and output of an MPSK system are commonly binary data, it is usual to restrict the number of phase states M to an integral multiple of 2, such as 4 or 8, to keep the translations simple.[2] For $M = 4$, each signaling interval or symbol represents 2 bits of information; for $M = 8$, each symbol represents 3 bits; and so forth. Thus, if the transmission bandwidth required for transmission of R bits/second (using binary PSK modulation) is B Hz, then the bandwidth required for transmission of R bits/second (or $R/\log_2 M$ symbols per second) is $B/\log_2 M$. Fig. 1 illustrates MPSK bit-error probability performance for various values of M.[3]

The case of MPSK for $M = 4$, usually referred to as QPSK or *quadriphase*, is of particular importance for several reasons, the most notable of which is that the bit error probability (not symbol error probability) for ideal QPSK is exactly the same as for ideal binary PSK. Hence Eq. 1 applies to QPSK as well as to binary PSK. This is significant because MPSK bit error performance for $M > 4$ is considerably degraded over that for $M = 2$; and such signaling sets, while more conservative of bandwidth, are not generally practical for communications links having moderate or severe power limitations.

The quadriphase modem described herein was designed and fabricated to facilitate the experimental evaluation of QPSK over a wide range of data rates under both ideal and non-ideal operating conditions and to verify and demonstrate the various modes of operation to be subsequently described.

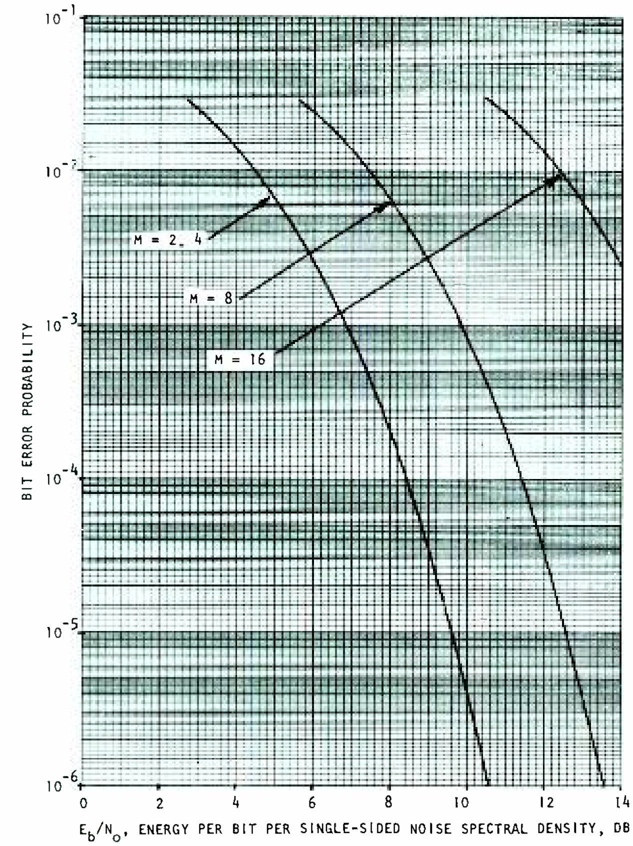

Fig. 1 — Error probability for MPSK signaling.

QPSK fundamentals

A QPSK signal can be generated by several different methods, including a) addition of two quadrature carriers, each of which is phase-modulated by a separate binary sequence; b) addition of two quadrature carriers, each of which is amplitude-modulated (DSB-SC) by a separate bipolar binary sequence; and c) phase modulation of a single carrier by a 4-level digital sequence. Fig. 2 illustrates the mechanization of these three methods of QPSK signal generation.

For methods a) and b), the two binary sequences could be derived from a single input data stream by means of a serial-to-parallel converter; or they could be obtained from separate sources which possibly could be independent, unrelated, and asynchronous. The former case (single-input data stream) will henceforth be referred to as the *single-channel* mode while the latter case (separate-input data streams) will be referred to as the *dual-channel* mode. By means of the dual-channel mode, QPSK can effectively be used as a multiplexing technique (in *phase*, rather than time or frequency) for two channels of information. Another interesting feature of the dual-channel mode is that if a zero input is supplied to one of the channels, the modulator output is simply a binary PSK signal. Because of these features and because of inherent difficulties in maintaining an accurate modulation index for phase modulation by a multilevel sequence, method b) above was selected as the signal generation for the quadriphase modem under consideration here. The QPSK signal which results from use of method b) is given by

$$\begin{aligned} S_2(t) &= A a_n(t)\cos(\omega_c t) + B b_n(t)\sin(\omega_c t) \\ &= (A^2 + B^2)^{1/2} \cos\{\omega_c t - \tan^{-1}[B b_n(t)/A a_n(t)]\} \end{aligned} \qquad (2)$$

where $a_n(t)$ is the input binary sequence (± 1) to the upper, or in-phase, channel; $b_n(t)$ is the input binary sequence (± 1) to the lower, or quadrature, channel; and A and B represent the amplitude states of the two channels. Note that the QPSK signal

$S_2(t)$ can assume only a single amplitude state but one of four possible phase states. For the case when $A = B$, the four phase states are 90° apart and the QPSK signal is said to be *balanced*. Should the sequences $a_n(t)$ and $b_n(t)$ be of unequal rate, however, and should equal performances (error probabilities) be required for the two channels, then it is necessary to allocate a large percentage of the transmitted power to the higher-rate channel. For this case, which is referred to as the *unbalanced* mode, $A \neq B$ and the phase states are symmetrically spaced in pairs but are no longer 90° apart.

Just as several methods exist for generation of a QPSK signal, so do several techniques exist for QPSK demodulation. Regardless of the method used to generate the QPSK signal, the coherent detection scheme shown in Fig. 3 is the optimum means of recovering the two sequences $a_n(t)$ and $b_n(t)$. The received QPSK signal is input in parallel to two coherent binary PSK demodulators, one corresponding to the in-phase (I) channel and the other corresponding to the quadrature (Q) channel. For the ideal case, in which the reference phase error $\Phi = 0$, the upper half of the quadriphase demodulator is a correlation detector for $a_n(t)$ and the lower half is a correlation detector for $b_n(t)$. As pointed out previously, the bit-error probability for ideal QPSK is the same as for ideal binary PSK. Note that, when the reference phase error $\Phi \neq 0$, an undesirable crosstalk term appears in each of the two channels. Thus, the problem of coherent carrier reference recovery is an important one.

The coherent carrier references for the I and Q channels could be obtained by any of a number of techniques, including: a) transmission of a residual I or Q carrier component and narrowband tracking at the receiver, b) transmission of a coherently related separate carrier reference, c) use of a "quadrupling loop" or Costas-type loop for regeneration of a carrier component from the QPSK signal itself,[4] or d) remodulation of the QPSK signal by the demodulated data streams. Approach d) was selected for incorporation into the quadriphase modem of interest here and will be described in a subsequent section of this paper.

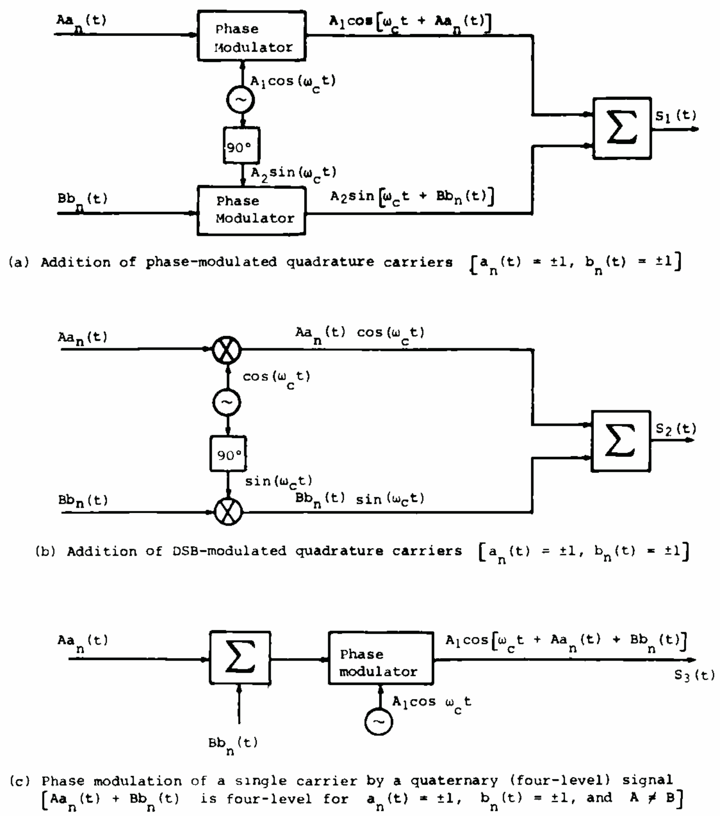

Fig. 2 — Generation of QPSK signals.

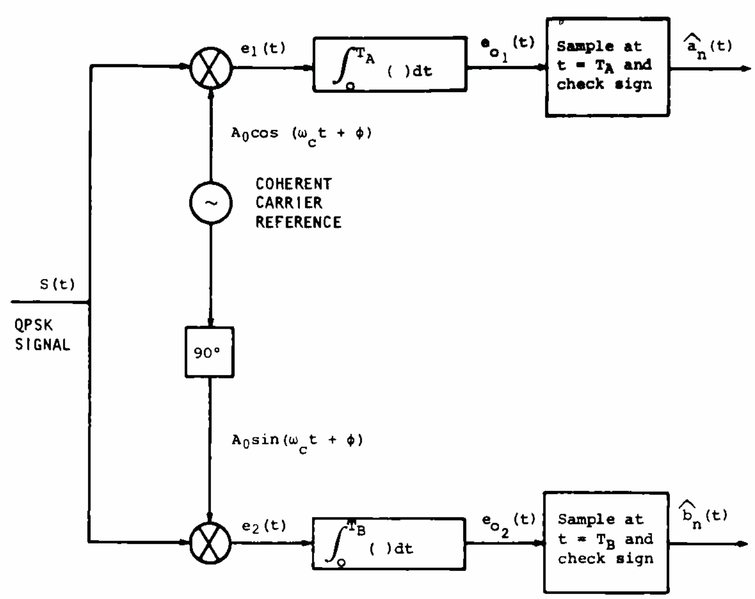

Fig. 3 — Detection of a QPSK signal.

Modem design

To achieve performance approaching theoretical, each transmission element and timing function must be near optimum. For this reason, the design approach for the modem incorporated the following features:

1) High-speed logic elements (Schottky and ECL).
2) Broadband linear amplification with adequate dynamic range in all i.f. or rf and baseband analog signal circuits.
3) Coherent demodulation, using a local carrier extracted from phase modulated signal-plus-noise.
4) Matched filter data detection, using integrate, sample, and dump techniques. Timing is extracted from the demodulated baseband data-plus-noise.

The discussion that follows describes how these key characteristics were obtained with a single design that can operate at any arbitrary data rate from 1 kb/s to 30

Mb/s in each of two independent channels or in a single-channel quadriphase mode.

Modulator design

The block diagram of Fig. 4 represents the principal modulator functions. Since several distinct modes of operation are possible, the signal flow for each mode of interest will be briefly described.

The simplest mode, conceptually, is single-channel biphase (binary PSK). In this mode, a single data input passes through the channel-A interface circuits, which translate the input signal to TTL levels and provide accurately related timing for later processing steps. Depending on operator selection, the data is either forwarded directly to the modulator or is first differentially encoded. Differential encoding for PSK operation results in the conventional algorithm, *i.e.*, and input data logic 1 causes a change in state at the encoder output, while an input data logic 0 causes no change in state at the encoder output. Either the "direct" or the encoded signal, depending on operator selection, is applied to the switching port of the in-phase (*I*) balanced modulator. The *I* component of a stable 70-MHz local oscillator drives the L.O. port of the balanced modulator. A ±90 modulation is thus obtained at the modulator output. This signal is passed unattenuated to an output mixer. If desired, the center frequency of the signal may be offset up to 300 MHz by means of an external L.O. For 70-MHz operation, the mixer is biased so that the signal passes through unattenuated. In PSK operation, the quadrature signal is disabled and all circuits associated with it are unused.

Dual-channel quadriphase modulation is obtained by adding a data input to channel B. Processing is identical to that for channel A, except that the quadrature (*Q*) component of the 70-MHz L.O. is applied to the channel-B modulator. A direct or differential mode may be selected for channel B independently of what has been selected for channel A. The data rates for the two channels are completely independent and may be either synchronous or asychronous. Linear summing of the channel A and channel B modulated outputs provides a quadriphase signal. The relative energy allocated to transmission of information in each channel is adjustable by means of variable attenuators in each channel preceding the linear summing function. Examples of output signal phase states for biphase and dual-channel QPSK modes are shown in Fig. 5.

Single-channel QPSK operation requires a data input on channel A only. As in the other modes, direct and differential encoding options are available. In the direct mode, the incoming data is split into two half-rate signals by steering the input alternately to one path and then to the other. One signal path then modulates the *I* component while the other modulates the *Q* component. Summing of these results in a single-channel quadriphase output. Normally, the components will be adjusted for balanced operation, since equal information content is expected in each component.

A differentially encoded option is available for single-channel QPSK operation. The algorithm is as follows:

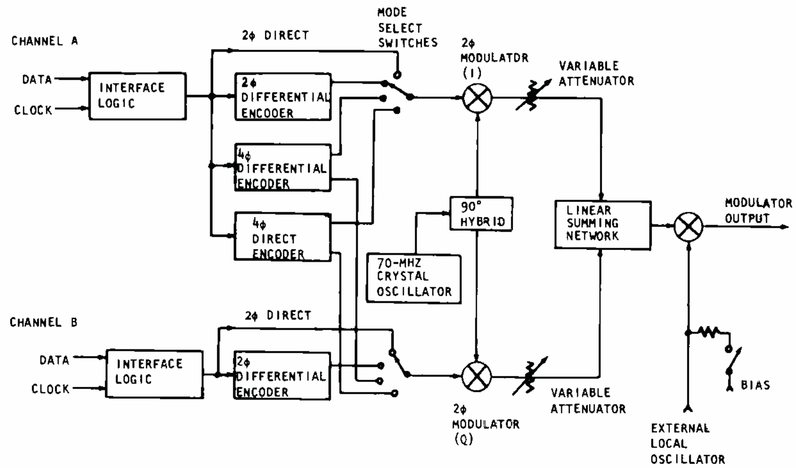

Fig. 4 — Quadriphase modulator.

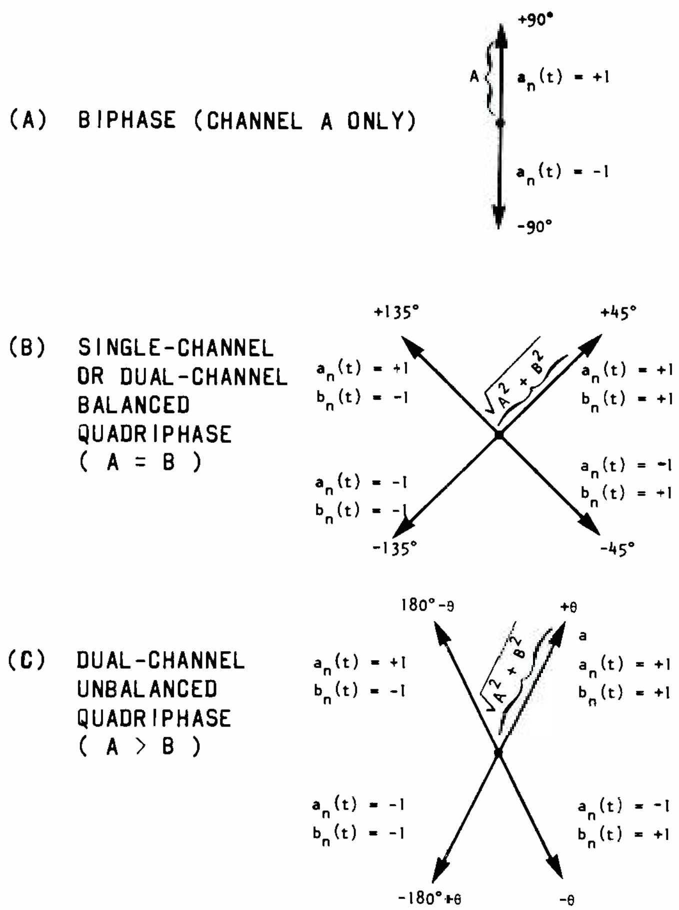

Fig. 5 — Signal characteristics at modulator output.

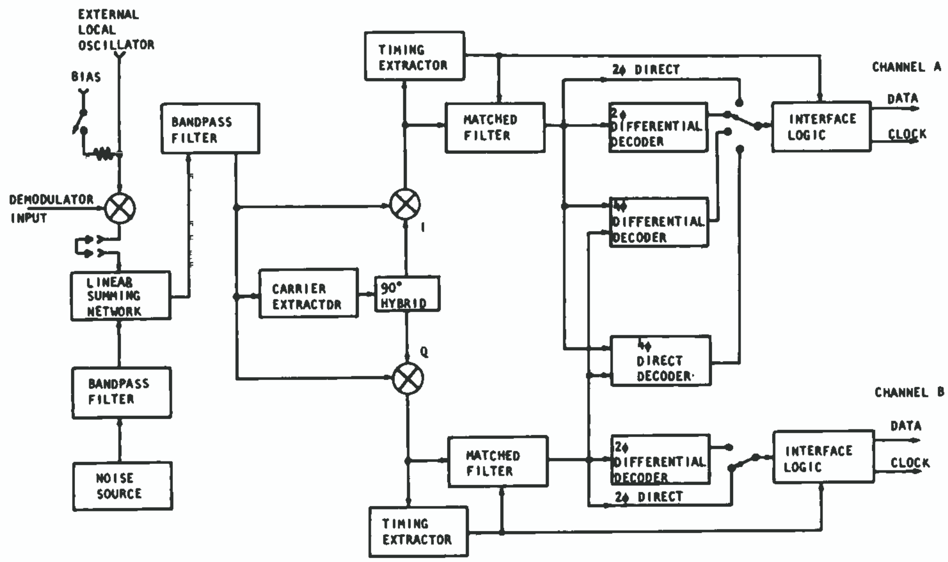

Fig. 6 — Quadriphase demodulator.

Data	*Phase change in output*
00	0°
01	+90°
10	+270°
11	+180°

A Gray code is used so that an error of ±90° in received phase will cause no more than a one-bit error in the decoded data.

Demodulator design

The demodulator functions are depicted in the block diagram of Fig. 6. If the input signal is at 70 MHz, it is passed unattenuated through the input mixer by biasing the mixer diodes fully *on*. For any other input frequency, an appropriate external L.O. signal is applied, offsetting the signal to 70 MHz for further processing.

The output of a wideband noise source (1 MHz to 150 MHz) is summed with the 70-MHz signal to simulate link and receiver noise. The relative levels of signal and noise are adjustable over a wide range. Selectable band-pass filter in the noise and i.f. paths permit experimental evaluations related to any desired data rates.

The first step in recovering data from the input $S+N$ is extraction of a carrier, for use in coherent (optimum) demodulation. The data-aided technique that is used will be described in detail in a subsequent section.

The extracted carrier is passed through a 90° hybrid to obtain the orthogonal components which are applied to in-phase (I) and quadrature (Q) mixers for coherent demodulation of the respective components of the incoming signal. Two baseband data signals with noise are thus obtained. If the input signal is PSK, only one demodulator is used.

The next step in the optimum recovery process is timing extraction. A combined analog/digital extraction technique will be described that covers the wide range of rates (15 octaves).

Data-plus-noise and timing signals are applied to the matched filters, which operate on the integrate, sample, and dump principle over the same 15-octave range of data rates. Techniques used will be described further.

A "hard" decision is made at the end of the integrate period for each received symbol, converting the two integrated data-plus-noise signals into two binary data streams having error rates commensurate with the E_b/N_o, as given in Eq. 1, existing at the signal-plus-noise summing point.

Depending on the modes selected by the operator, the demodulator performs functions complementing those of the modulator, *i.e.*, PSK direct, PSK differential decode, QPSK direct (recombines two half-rate data streams into a single full-rate data channel) and QPSK differential decode.

Demodulator carrier extractor

Since a continuous signal appears at the input, lock-up time of the carrier extractor is not critical. Two limiting factors are the high loop gain required to obtain a low static phase error for practical values of initial frequency offset, and the narrow loop bandwidth required to reduce noise modulation of the reference carrier to an acceptably low value for the lowest data rate. A further requirement on the carrier-extraction technique is that it must provide high performance in PSK, balanced QPSK, and unbalanced QPSK modes. It can be shown that frequency multiplication (quadrupling) yields a "wandering" carrier reference phase when unbalanced QPSK modulation is used and the modulation in either channel has long runs with no transitions. The data-aided technique to be described here does not have this disadvantage if true multiplication of linearly derived data and input signals is performed. The linearity restriction can be removed by a manual adjustment technique if the unbalance is fixed at a known ratio.

The block diagram of Fig. 7 may be used to understand the operation of the data-aided carrier extractor. It is easiest to begin by assuming that a 70-MHz carrier reference is available at the VCXO output and then to follow the signals through the carrier extraction circuits to see how this reference is obtained. For the initial discussion, it will also be assumed that the data intended for channel A is being received in Channel A and that the "Ambiguity resolving" electronic switches remain connected in the positions shown in Fig. 7. Orthogonal components of the carrier reference are obtained with a 90° hybrid and applied to the I and Q demodulators. Data (plus noise), corresponding to the two modulation components of the QPSK input signal, appear at the demodulator outputs. These data signals, which are forwarded to the matched filters to produce output data, are also used in the carrier extraction process. For this purpose, they are first passed through simple RC lowpass filters having time constants of approximately one-tenth of the corresponding data periods. A comparator in each channel provides binary output levels. To reestablish the relative amplitudes of the two channels in accordance with the power allocated to each data stream at the transmitter, the binary signal corresponding to the lower power channel (normally the lower data rate signal) is appropriately attenuated.

The 70-MHz QPSK input signal (plus noise) is separately re-modulated with these two level-adjusted data signals. When the two resulting interdependent modulated 70-MHz signals are combined in the proper phase (by shifting one 270° relative to the other), all modulation components are cancelled and a strong carrier reference signal is produced. The phase-locked VCXO acts as a very narrowband self-tuning filter, providing a carrier reference having the necessary spectral purity to give near optimum coherent demodulation.

A summary treatment of the carrier extractor action is given in Table I, with signal identifiers referenced in Fig. 7. Delays through the circuits are omitted for simplicity. Intentional addition of delays in lines D_1 and D_2, corresponding to delays in the remodulation loops, will improve the carrier extractor performance. Phase delays in the hybrids and combiners used for ambiguity resolution are equalized by using identical components in symmetrical branches of the circuit. Table I assumes no insertion phase delays through the circuits, including the phase-locked VCXO. Actual delays are compensated with a fixed delay in the VCXO output link. In Table I, only the desired modulation products are listed; other products are removed with filtering.

Note that the derived carrier reference (9) always has the same phase as the assumed signal (2), regardless of the initial lockup phase relation, thereby resulting in a stable lockup condition. However, channels A and B may be interchanged and/or the data may be inverted at the demodulator outputs. Therefore, some form of ambiguity resolution is needed.

Table I — Carrier-extractor process.

Signal identifier	Ambiguous lockup conditions 1	2	3	4
(1) Modulated input	$A\cos wt + B\sin wt$	$A\cos + B\sin wt$	$A\cos wt + B\sin wt$	$A\cos wt + B\sin wt$
(2) L.O. (I)	$\cos wt$	$\sin wt$	$-\cos wt$	$-\sin wt$
(3) L.O. (Q)	$\sin wt$	$-\cos wt$	$-\sin wt$	$\cos wt$
(4) Channel A	A	B	$-A$	$-B$
(5) Channel B	B	$-A$	$-B$	A
(6)	$A^2\cos wt + AB\sin wt$	$B^2\sin wt + AB\cos wt$	$-A^2\cos wt - AB\sin wt$	$-B^2\sin wt - AB\cos wt$
(7)	$B^2\sin wt + AB\cos wt$	$-A^2\cos wt - AB\sin wt$	$-B^2\sin wt - AB\cos wt$	$A^2\cos wt + AB\sin wt$
(8)	$-B^2\cos wt + AB\sin wt$	$-A^2\sin wt + AB\cos wt$	$B^2\cos wt - AB\sin wt$	$A^2\sin wt - AB\cos wt$
(9) Extracted carrier	$(A^2 + B^2)\cos wt$	$(A^2 + B^2)\sin wt$	$-(A^2 + B^2)\cos wt$	$-(A^2 + B^2)\sin wt$

frequently the case for dual-channel QPSK operation, the modem provides automatic switching to assure that data appear in the correct channel by prescribing that the nigher level signal shall always appear in channel A, any incorrect relationships of levels may be detected and used to reverse the "ambiguity resolution" switches in the carrier extraction loop. This has the effect of interchanging channels A and B at the demodulator outputs, and is accomplished rapidly, so that the carrier extractor phase-locked loop does not lose lock. When the power levels in the two channels are the same, any convenient external means for recognizing the content of the data streams (or lack of correct information therein) could be used to initiate this switchover of channels.

The remaining ambiguity affects data polarity. By using differential encoding, this ambiguity is removed at the expense of a small penalty in error rate. Finally, if one wishes to use the "direct" modes (no differential encoding), the output data may be inverted by a manual operation. This function could also be electronically actuated by external sensing.

Ambiguity resolution

When the powers allocated to the signals in channels A and B are different, as is

Bit-timing extractor

The bit-timing extractor utilizes a simple RC filter followed by a digital synchronizer for data rates from 1 kb/s to 4 Mb/s in four selectable 8:1 ranges. The digital synchronizer operates from a continuously variable reference frequency of 32 to 256 MHz. As shown in Fig. 8, the variable reference frequency is first applied to a digital divider with four selectable division ratios from 1 to 4096 in 8:1 steps. The reference frequency is set so that the divider output frequency is approximately equal to 64 times the data rate (within 0.1%). This is followed by a

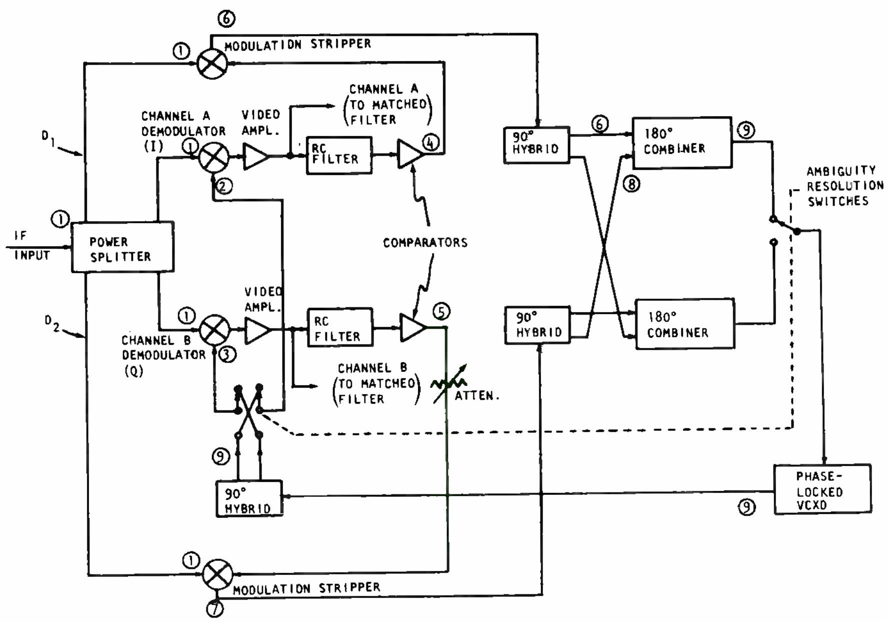

Fig. 7 — Carrier extractor.

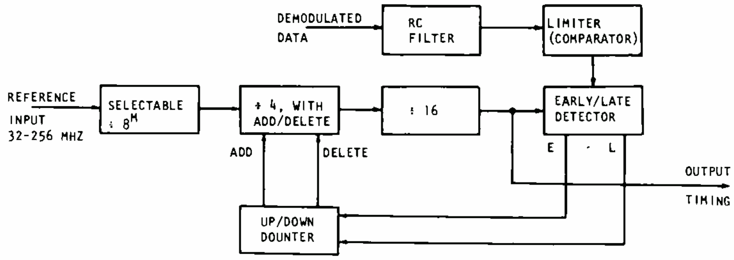

Fig. 8 — Digital-bit-timing extractor.

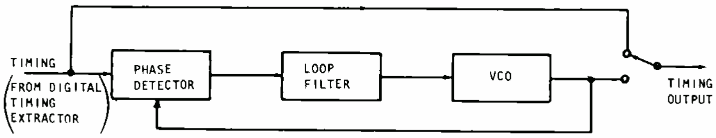

Fig. 10 — Analog phase-locked loop.

high-speed ECL synchronous divide-by-4 counter. Add/delete logic connected to this counter permits the counter output to behave as if an extra pulse has been added to the input or as if a pulse has been deleted, on command. The divide-by-4 output is further divided by 16 to provide an output frequency nearly equal to the data rate. Data transitions are compared to this signal in an early/late detector, which generates an "early" pulse if a data transition occurs before the reference transition, and a "late" pulse if the data transition is late. The early/late pulses are applied to a 16-state up-down counter which acts as a loop filter by averaging the early and late pulses, applying add/delete commands only when the accumulated difference between the number of early and late pulses equals the counter capacity. The overall action of the synchronizing loop is to provide a timing output that is essentially derived by binary division of the reference input, except that pulses are added to or deleted from the divider input if the timing deviates from that of the data transitions. Since the add/delete function occurs at a point in the circuit where the reference is 64 times the data rate, timing to ±1/64 data period is obtained. The critical portion of this timing extractor is the divide-by-four with associated add/delete logic, which must operate up to 256 MHz. To obtain the required performance, ECL logic elements were mounted on the fired-film hybrid circuit shown in Fig. 9. The hybrid technology provides short lead lengths, controlled characteristic impedances, and good line terminations for high frequency circuits.

It was not feasible to use reference frequencies higher than 256 MHz to accommodate rates above 4 Mb/s. Therefore, it was necessary to reduce the division ratio of the digital synchronizer for rates from 4 Mb/s to 30 Mb/s, which yields a corresponding increase in the timing error. For example, at 16 Mb/s, a division ratio of 16 can be used, but this results in a timing error of ±1/16 data period.

To reduce this timing error, an analogy cleanup loop was added in tandem with the digital loop, covering ranges of from 4 to 8, 8 to 16, and 16 to 30 Mb/s. A conventional phase-locked loop, as shown in Fig. 10, was used for this purpose.

Data-matched filter

A matched filter is utilized that provides near-optimum performance for any bit rate from 1 kb/s to 30 Mb/s. The filter operates on the integrate, sample, and dump principle. Incoming data-plus-noise is amplified in a wideband amplifier. The amplifier output is simultaneously applied to two active integrators. At the start of a bit interval, one integrator is enabled, while the other is held at zero level. At the end of the interval, a sampling strobe pulse causes the integrator outputs to be compared. This comparison results in a "hard" decision as to whether a data 1 or 0 was received. In the next bit interval, the first integrator is dumped and held at zero level while the second integrator is enabled to follow the same sequence of events. The two integrators thus operate on alternate bits. Their two comparator outputs are sequentially sampled in conventional logic circuits to provide a recovered data output. Nine selectable ranges for the active integrators provide piecewise continuous coverage of the 15-octave data range.

Fig. 9 — Fired-film hybrid divide-by-four and add/delete.

Modem physical characteristics

The modulator and demodulator functions of the modem are contained in separate enclosures to permit evaluation over real communications links. Although size was not of special concern for this laboratory equipment, reasonable dimensions were obtained.

The modulator and its power supply are contained in a standard 19-inch-wide chassis, having a height of 5 ¼ inches and a depth of 13 inches. A photograph of the unit is shown in Fig. 11. Digital circuitry for the modulator is comprised of TTL logic elements in DIP's, mounted on four PC boards, each having dimensions of 4 ½ inches by 4 inches. The rf/i.f. circuits occupy one additional PC board of the same size, plus an oven-controlled stable 70-MHz oscillator module. Space is provided in the modulator enclosure for a bit-timing extractor, in the event that a timing reference for the incoming data is not available from the data source.

The demodulator occupies an enclosure with the same dimensions as the modulator, as shown in Fig. 12. The demodulator power supply, not shown, is also in a case of the same size. A total of 24 printed-circuit boards are used in the demodulator as follows:

rf/i.f. input	1
Carrier extractor	5
Bit-timing extractor	6 ½ (each channel)

Matched filter	1 (each channel)
Digital (decoders and interface circuits)	3

In addition, a built-in wideband noise source and selectable i.f. bandpass filters are provided.

Experimental results

Fig. 13 summarizes the results of a series of bit-error-rate performance tests obtained using the multimode quadriphase modem described herein. The degradation in performance from that theoretically attainable for coherent binary PSK or QPSK ranged from less than 1 dB (direct encoding) at the higher transmit rates. Although Fig. 13 indicates only the bit-error-rate performance for the single-channel QPSK mode, additional tests performed for dual-channel balanced and dual-channel unbalanced modes verified operation for those modes and provided results consistent with those obtained for the single-channel mode.

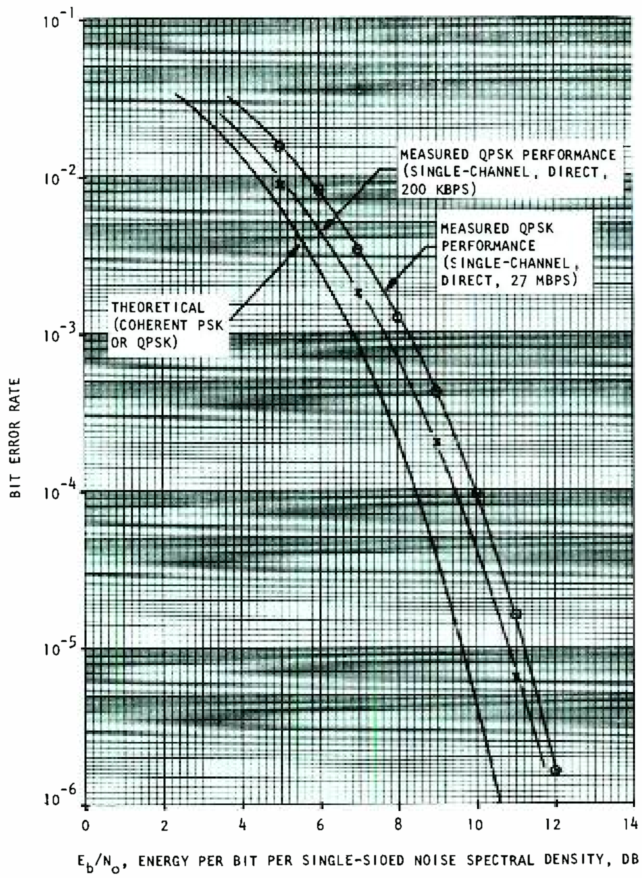

Fig. 13 — Experimental results.

Summary and conclusions

The multimode QPSK modem described in this paper is of interest because of its extreme flexibility and because of its near-optimum performance over a very wide range of input data rates. Since the desired flexibility was achieved by providing for selectable or continuously variable parameters, the resulting hardware tends to be somewhat complex both in circuitry and in operator controls. Circuits or parameters that are either continuously adjustable or selectable include the following:

- Predetection filter bandwidth.
- Carrier extractor RC filter in two remodulation loops. Gain in one remodulation loop.
- Bit-timing extractor — Input RC filters in each channel. Analog PLL offset in each channel.
- Matched filter — Integrator slope.

For field and/or flight use, the number and complexity of operator adjustments would have to be reduced. However, the basic approaches and technology used in this modem could be applied advantageously to field and/or flight hardware.

Two methods for accomplishing a reduction in the number and complexity of operator adjustments are 1) provide automatic circuitry to replace manual controls, and 2) reduce the user requirements to a finite number of data rates. The latter method is, of course, preferable in terms of the resulting size, weight, power, reliability, and cost of the hardware. As an example of savings that could be realized, consider the bit-timing extractor. If a simple relationship can be established between the desired operating rates and a single reference frequency, the timing can be synthesized from a fixed, stable source. In the simplest case, this could be done by selection of rates that are related by powers of two, which can be obtained by simple binary division. Modest increases in circuitry can provide many more finite choices of operating rates. The operator function could then be reduced to a single data-rate-select control, which could select appropriate values for all the variables listed above.

Fig. 11 — Quadriphase modulator.

Fig. 12 — Quadriphase demodulator.

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An active product specification file on microfiche

A.J. Bianculli| L.H. Urdang

To overcome the many disadvantages of a hard-copy system for dynamic updating of product specifications, RCA Solid State Division developed and implemented a microfilm system. The Solid State Division's Engineering Specification microfilm system has demonstrated that microfilm is not limited to storage of information for archival purposes but, in application to an active data system, it is superior to the system it supplants.

THE RCA Solid State Division maintains an active listing of thousands of its devices available for sale. To efficiently manufacture this broad spectrum of products, accurate and detailed specifications of all the parts, materials, processes, and tests employed in the production process are essential. At the time the microfilm system was initiated, the basic specification file consisted of 60,000 8½ × 11-in. size pages of information. This basic file was actively updated to keep the information current via a change control system. File maintenance resulted in the processing of over 3,000,000 pages of hard copy per year.

The need for a dynamic file system

The disadvantages of the hard-copy system were many:

- 50 five-drawer file cabinets were needed to store the printing masters and extra copies of the specifications.
- A complete master set of specifications occupied 52 ft of shelf space.
- Mailing costs alone to distribute updated information to plant locations in the United States and overseas exceeded $10,000 per year.
- The time required to print, sort, handle, and collate individual hard-copy sheets was excessively long. This delay impaired the usefulness of updated information.
- Interfiling of updated information into 150 different user files was a time-consuming, onerous chore, disliked by clerks. As a result, filing at user locations fell behind, further contributing to a lack of timeliness of specification data.

To overcome these disadvantages, a microfilm system was developed and instituted.

Early decisions—microforms

A preliminary investigation revealed a bewildering array of hardware, microforms, and software available to implement a microfilm system. A number of basic decisions were required. Most elemental was the choice of microform.

Three basic types of microform are available and widely used: 35-mm film mounted on tab-size cards; 16-mm roll film; and index-card-size microfiche. The 35-mm form is most suited and generally used to microfilm engineering drawings or other materials where copy size may vary and is usually larger than 8½×11 in. Roll film (16-mm) is a suitable medium for an archival or relatively inactive file where copy is oriented chronologically. The problem of retrieving information that is located deep in the roll of film is apparent. The most suitable form for a dynamic specification system is microfiche. A microfiche is a small card containing a number of separate images of pages of copy. Because the capacity of each fiche is limited, it is the best form to use for a total communication system that is fragmented into many categories. Frequent updating is easier to accomplish because the fiche can be revised individually—an essential element of an active system.

Microfiche

There are several microfiche formats in use, but the Solid State Division specification system employs the National Microfilm Association (NMA) standard (Fig. 1). This standard specifies fiche dimensions of 105×148.75 mm. The copy is reduced twenty-four times (24X) and filmed in an array of 14 columns by 7 rows, thus providing a maximum packing density of ninety-eight 8½X11-in. pages of copy. The top row is reserved for a fiche title that can be read without magnification.

Microfiche may be generated completely automatically, via a computer, and this method will be described later. At this point, the essentially manual production

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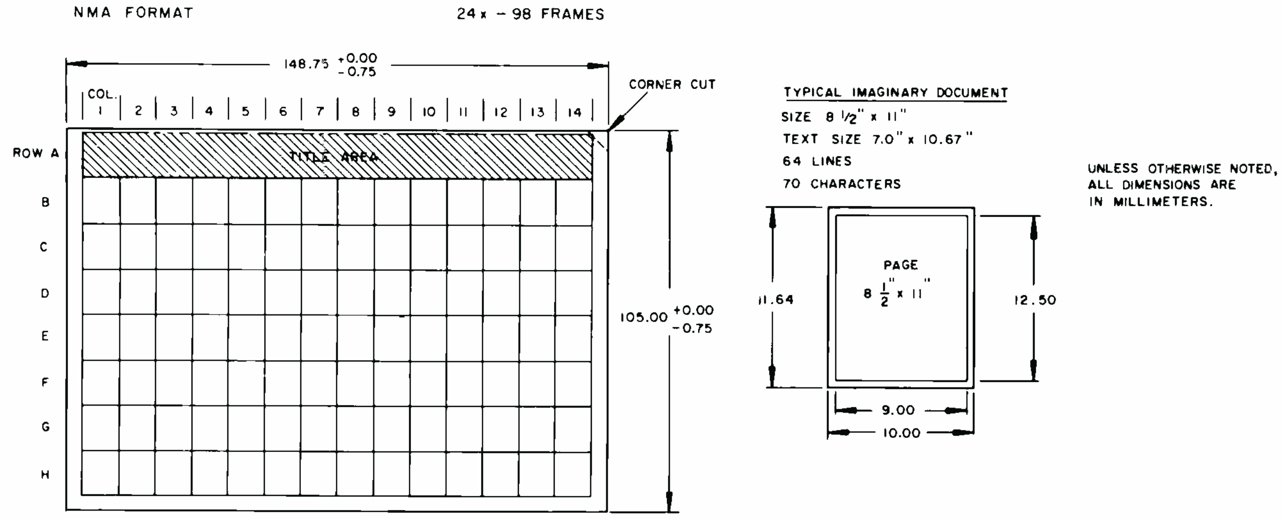

Fig. 1 — National Microfilm Association microfiche format.

method employed for preparing microfiche of Solid State engineering specifications will be delineated: In general, the copy is prepared on a typewriter (a draftsman may add graphics, if required) and filmed page-by-page; the film is then developed and cut into fiche-size negativzs that become the microfiche masters. Title strips are applied to the masters and the masters are contact-printed on fiche-size copy film. The copies are then developed and are now ready for collation and distribution. A flow chart that describes this procedure is shown in Fig. 2. Extensive evaluation of hardware available to produce microfiche was made before choosing the modules necessary for our application.

Early in the investigation, it was recognized that a high level of readability was necessary for a successful system. Readability is directly traceable to copy quality and type size and style; therefore, electric typewriters with interchangeable type fonts were dedicated to the microfilm production system. A highly readable type style was selected for the application.

Microfiche masters may be prepared by either of two methods. The individual documents may be filmed sequentially on 16-mm film which is then cut into short lengths (each containing 14 frames) that are mounted in rows. Addition of a title row completes a "stripped-up" fiche master. Alternately, the 16-mm film can be inserted into special transparent envelopes, called "jackets". The jackets serve the function of orienting and holding the strips during fiche filming. To avoid these obviously laborious procedures, a "step and repeat" microfilm camera, (see Fig. 3) was acquired. This camera employs a 105-mm-wide roll film supported on a structure that is capable of x-y motion. The structure locates and frames the position of the first image on the film, the first page of copy is positioned below the camera, and the shutter is manually actuated. While the operator is positioning the second piece of copy, the film is automatically moved to the next frame position and the operation is repeated. Upon completion of filming, the film is developed in an automatic developer, Fig. 4, and cut into individual fiche-size negatives. Pressure sensitive, transparent title strips that are readable by the naked eye and which describe the contents of the fiche are typed and affixed to the title row of the master.

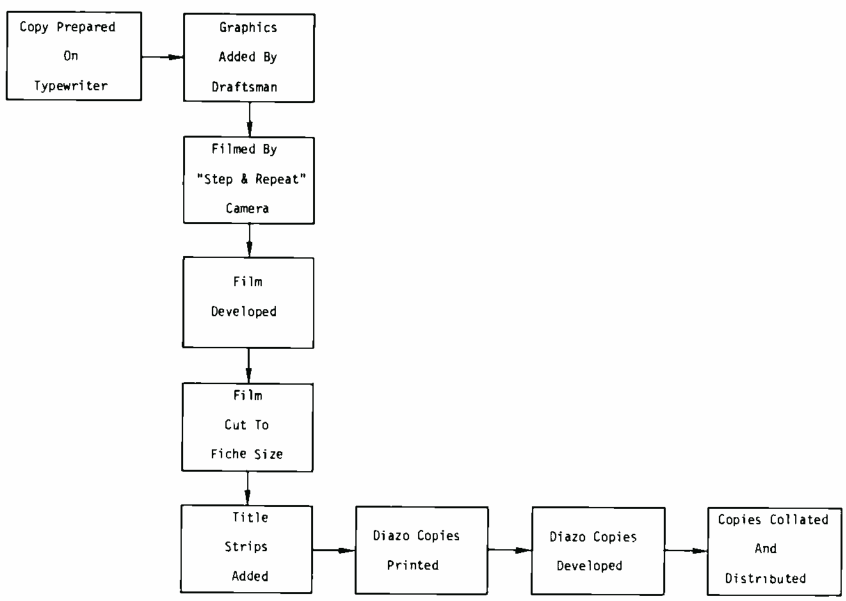

Fig. 2 — Microfilm production flowchart.

Two types of copy film are available — diazo, which is ammonia sensitive, and vesicular, which is heat sensitive. Solid State Division engineering specifications are published on diazo copy film. The master and diazo copy film are placed in intimate contact in a printer (see Fig. 5). Exposure to ultra-violet light prints the image which is then developed in a small ammonia developer, as shown in Fig. 6. Sufficient copies are made to distribute one to each specification user, and the master is filed for future use or reference.

Microfiche reader

Probably the most important single item of hardware that required evaluation and selection was the microfiche reader. The reader is needed to enlarge the microfilm image to eye-readable size. It was felt that the success or failure of the microfilmed engineering specifications system was, in large degree, dependent upon the ease of use and clarity of the enlarged image. Forty-six different readers were evaluated; their cost spread ranged from $75 to over $500. The reader that was finally selected, as shown in Fig. 7, was chosen as the most cost-effective equipment that provided the desired resolution quality. Reader-printers, machines that enlarge a microfilm image and reproduce it in hard copy, were also made a part of the system (see Fig. 8). Capital funds for all equipment were justified by the Engineering Standards Department, and readers and reader-printers were transferred to the specification users as the need arose. (The number of reader-printers was severely restricted intentionally. It was felt that the indiscriminate availability of reader-printers would encourage the making of more relatively expensive hard copies than might be really necessary.)

Data retrieval

Data retrieval from the microfiche file can be accomplished in several ways, ranging from a simple inexpensive manual system that is employed in the Solid State Division to sophisticated, expensive, computer-controlled retrieval devices. The latter are justifiable in applications where look-up of information must be accomplished in seconds (as in responding to a telephone inquiry from a customer) and/or where a clerk must retrieve information almost continuously for extended periods of time. For the engineering specifications system, it was established that quick, but not necessarily instantaneous, retrieval was required. Special looseleaf binder filler pages were obtained with pockets to hold fiche, as shown in Fig. 9. Each filler page holds 16 fiche on each side, and a 1½-in. notebook can hold 5 filler pages. Thus, assuming 100% packing density, over 15,000 frames, or 8½ × 11-in. page equivalents, of information can be accomodated in the binder. This 1½-in. binder has the potential of replacing 50 three-inch binders holding the equivalent hard-copy pages; a 100 to 1 reduction in shelf space.

An important consideration must be emphasized at this time. Without minimizing the importance of good hardware, system implementation is more highly dependent upon the organization of the filmed material. Unlike a hard-copy system, the user can have displayed before him only one page at a time. He does not enjoy the ability to scan back and forth between fiche conveniently. Therefore the fiche should be organized with this thought in mind. References should be avoided, indices must err on the side of over-listing, and fiche subjects must be divided logically.

A basic fault of the exisiting hard-copy specification system was its arrangement of data. Throughout its evolution, efforts

Fig. 7 — Microfiche reader.

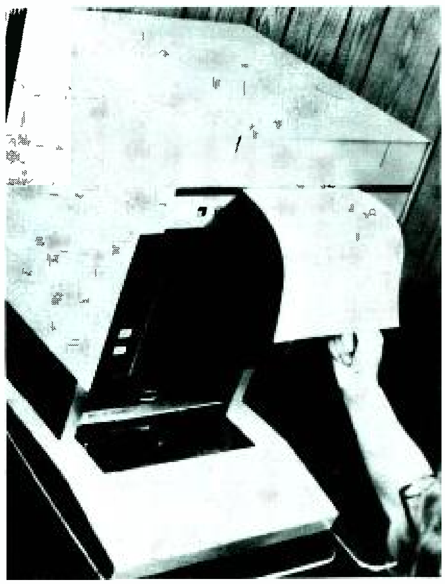

Fig. 8 — Microfiche reader/printer.

Fig. 3 — "Step and repeat" microfiche camera.

Fig. 5 — Microfiche copy printer.

Fig. 4 — Silver film developer.

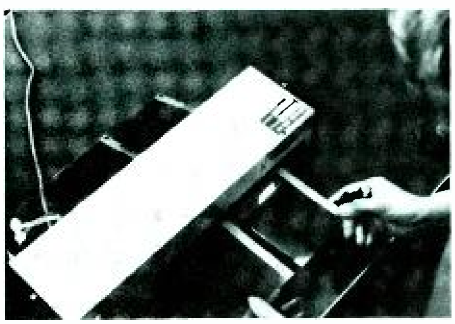

Fig. 6 — Microfiche copy developer.

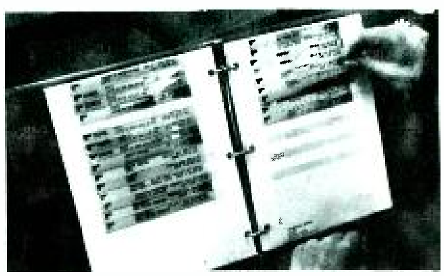

Fig. 9 — Microfiche filing system.

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Issue	Issue	Issue	Issue
1 August 14, 1972			

TYPE	DEVEL. NUMBER TA----	SEE-XXX-101-FAMILY	PRODUCT LINE	DESCRIPTION
40750	7563	453-101-40752	Thyristor	SCR
40751	7564	453-101-40752	Thyristor	SCR
40752	7565	453-101-40752	Thyristor	SCR
40753		453-101-40756	Thyristor	SCR
40754	7570	453-101-40756	Thyristor	SCR
40755	7571	453-101-40756	Thyristor	SCR
40756	7572	453-101-40756	Thyristor	SCR
40757		453-101-40760	Thyristor	SCR
40758	7599	453-101-40760	Thyristor	SCR
40759	7600	453-101-40760	Thyristor	SCR
40760	7601	453-101-40760	Thyristor	SCR
40761		453-101-40530	Thyristor	Triac
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40766		453-101-40530	Thyristor	Triac
40767		453-101-40530	Thyristor	Triac
40768		453-101-TA7661	Thyristor	SCR
40769	7654	453-101-40530	Thyristor	Triac
40770	7655	453-101-40530	Thyristor	Triac
40771	7656	453-101-40530	Thyristor	Triac
40772	7657	453-101-40530	Thyristor	Triac
40773	7671	453-101-40486	Thyristor	Triac
40774	7672	453-101-40486	Thyristor	Triac
40775	7642	453-101-2N5572	Thyristor	Triac
40776	7643	453-101-2N5572	Thyristor	Triac
40777	7644	453-101-2N5574	Thyristor	Triac
40778	7645	453-101-2N5574	Thyristor	Triac
40779	7614	453-101-2N5572	Thyristor	Triac
40780	7615	453-101-2N5572	Thyristor	Triac
40781	7616	453-101-2N5574	Thyristor	Triac
40782	7617	453-101-2N5574	Thyristor	Triac
40783	7618	453-101-2N5572	Thyristor	Triac
40784	7619	453-101-2N5572	Thyristor	Triac
40785	7620	453-101-2N5574	Thyristor	Triac
40786	7621	453-101-2N5574	Thyristor	Triac
40787	7646	453-101-2N5442	Thyristor	Triac
40788	7647	453-101-2N5442	Thyristor	Triac
40789	7648	453-101-2N5445	Thyristor	Triac

Fig. 10 — Typical specification page.

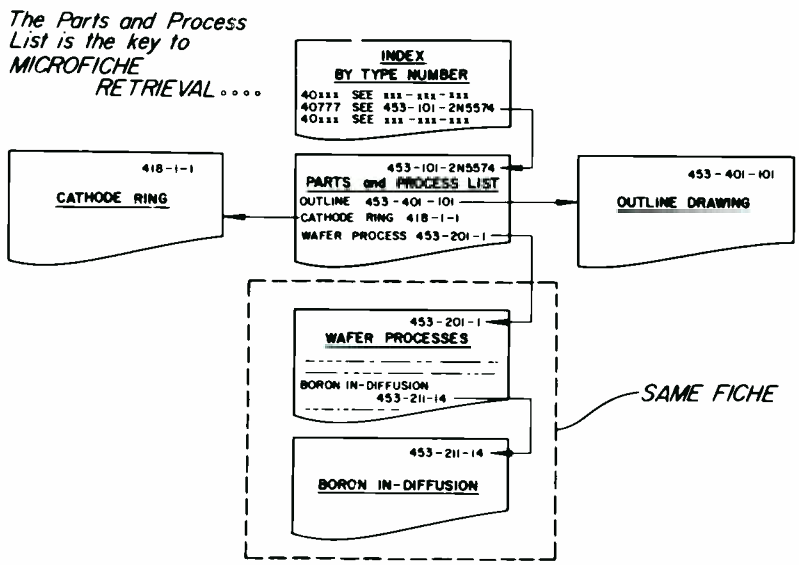

Fig. 11 — Retrieval procedure.

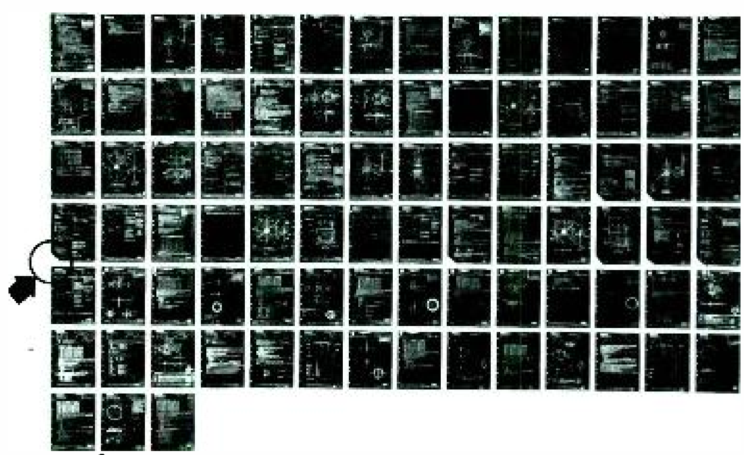

Fig. 12 — Frame revision technique.

were directed toward economizing space, *i.e.*, if the number of specification pages were reduced, the cost of reproducing and distributing the engineering specifications would likewise be lowered. As a consequence, very small type was employed for the specifications, data was tabulated and centralized in specific sections of the notices, thereby necessitating multitudinous references throughout the standards, and, generally, the entire set of specifications was divided by function (*i.e.*, by testing specification, parts specifications, processing specifications, etc.) rather than by product line. This latter idiosyncrasy meant that a product-line user was required to consult a number of different sections in order to piece together a complete story for each product in which he was interested. Furthermore, this arrangement demanded that each specification be coded (essentially, by type of product to which it applied) in order to avoid indiscriminately distributing all specifications pertaining to all product lines to all users.

From hard copy to microfiche

When the hard-copy system was analyzed with an eye toward applying it to a microfilm system, it quickly became obvious that it was unwieldy and would not work on microfiche. First, the type size was too small to display with a high degree of resolution. Second, the proliferation of references, directing the user hither and yon, would involve the constant insertion and removal of fiche at a reader to reach the data sought—an unthinkable situation if the stated goal is to provide a more convenient reference sytem. Finally, with fiche, individually coded sheets could not be accomodated because, short of multiplying the number of fiche required—one for each code—there was no way to separate differently coded frames. A user would be required to take all or nothing.

All of these problems were overcome. As mentioned earlier, typewriters were replaced by machines with interchangeable type spheres and a highly legible type font was selected, as shown in Fig. 10. The specifications were rearranged by product line and rewritten to eliminate as many references as possible. Two new indices were devised to make data retrieval more rapid. The first of these, an alpha-numeric listing, by type number, of all current products made by the Solid State Division, directs the user to the proper product-line section of the notices for the data he desires. The other is a specific index, type by type, of each specification pertaining to that type. File numbers are arranged so that a user familiar with the product line in question can bypass the first index and go directly to the specific index for the device type in which he is interested. An outline of this procedure is shown in Fig. 11.

Fiche division by product line obviated the need for elaborate distribution codes. However, within product lines, fiche are sub-divided by function (testing, processing, etc.). In this manner, it is possible to provide a fairly precise distribution, geared to a user's need, without a complicated, involved collation routine. For example a user charged with broad product-line responsibility, say, a manufacturing engineering leader, would receive all of that product-line's specification (perhaps 25 fiche). On the other hand, a user charged with specific functional responsibilities that cut across product lines, a test superintendent, for instance, can receive the test specification fiche from each product line.

Revised microfiche

In addition to these basic system improvements, a number of lesser, but yet important, features were devised for the microfiche system. One of these provides an effective means of "eye-balling" a fiche to immediately determine which frames of the fiche were revised since the last issue. The Solid State Division engineering specifications system is very dynamic—as many as 300 pages are revised every week. Although it would be a relatively simple matter to film and distribute revisions on an "addenda" fiche, such a procedure would require the user to study the addenda fiche before going to the specification directly. Rather than inconvenience the user this severely, revisions are made to the system by refilming the original fiche specifications and substituting the revised pages for the superseded material. Fiche issue numbers are updated and the user, when he receives the updated fiche, replaces the old issue with the new. Maintenance of current, active specifications becomes a simple matter. However, many users expressed a need to be able to scan a fiche quickly (preferably without using a reader or enlarger) in order to establish which frames were revised since the previous issue. This was accomplished by folding back a triangular corner on each sheet of revised copy. Even after photographing at a 24X reduction, it is easy to distinguish the revised frames (see Fig. 12).

Future system improvements

Experience to date shows that the microfilm system has been well accepted. Many improvements remain to be made, however. In particular, three obvious upgradeable areas are:

1) Reduction of turn-around time (time span between submission of a specification to the Standards department and its distribution to users);
2) Reduction of labor required to produce specifications on microfiche; and
3) Further improvement in specification organization and data retrieval.

All of these areas can be satisfied to some extent by the application of the computer to the microfilm system. Equipment is available today that marries the two technologies and the Solid State Division engineering specifications system was designed to accomodate COM (Computer Output on Microfilm) both in hardware and in content.

By using COM techniques, it is possible to completely eliminate the preparation of hard copy. Data is inputted directly to a computer, manipulated or stored, then outputted via magnetic tape. This tape can be fed into a COM recorder wherein the data is displayed on the face of a cathode ray tube. A camera is arranged to photograph the CRT directly. Filming can be on 16-mm roll film or 105-mm film for fiche production. A schematic of the COM technique is shown in Fig. 13. The following comparison dramatizes the enormous reproduction capability of COM. An electric typewriter can type up to 15 characters per second or 6 pages per hour. An impact printer can output 4,400 characters per second or 2,000 pages per hour. But a COM recorder can generate 70,000 characters per second or 30,000 pages per hour.

In the Solid State Division system, certain specification data are now entered into a computer data base as a matter of routine. This data becomes accessible "on-line" for inquiry by an individual with a terminal and the proper coded access passwords. Of special importance to the microfilm system is the fact that this data can be outputted (via COM equipment) without the need for elaborate reorganization of data, typing, proofreading, or printing.

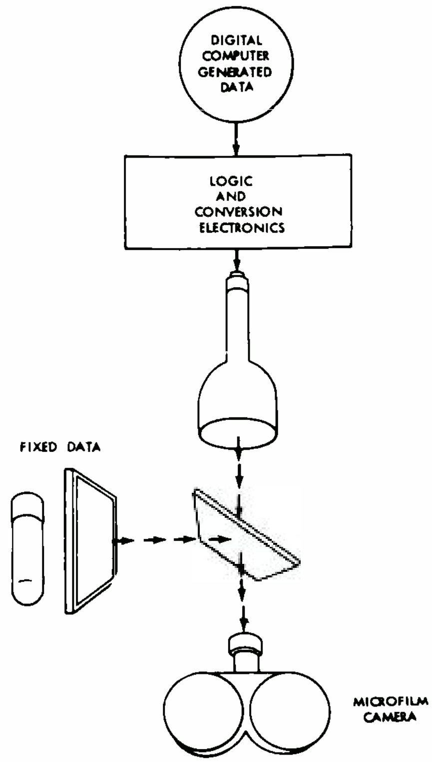

Fig. 13 – Computer output on microfilm (C)

Conclusion

The widespread acceptance of the Solid State Division's engineering specification microfilm system is definitely attributable to the following facts:

- Shortcomings of the hard-copy system were recognized and overcome by the microfilm system.
- Preliminary and continuing education was provided to all users in order to acquaint users with microfilm, in general, and to surface his unique problems and to provide solutions for them.
- Every effort was made to provide high-quality, convenient, and reliable hardware.

Acknowledgment

The authors wish to acknowledge the contribution made by R.E. Brown toward the conception and development of an active specification file on microfilm. Mr. Brown was one of the earliest champions of the use of microfilm for Solid State Divison product specification, and he helped to lay the groundwork for the acceptance of the system.

Fast frequency-hopping synthesizer

Edward J. Nossen

In this paper, the author describes the RCA frequency synthesizer developed and tested at discrete frequencies; it was hopped at a 100-kilohops/s rate between many frequency pairs, and over the entire band by means of a pseudo random-code generator. Settling time (determined as no further phase change relative to a fixed reference frequency) was well within a microsecond for each trial. Spectral purity of -60 dB close-in was traceable to reference frequency noise; further out, spurious outputs were -70 dB or better. It is concluded that frequency hopping can provide optimum anti-jam performance with fast synchronization and satisfactory multiple access.

THE NEEDS of providing security for future tactical communication systems may be satisfied by the frequency-hopping approaches described in this article (the name, "frequency hopping" derives from the fact that a signal dwells on a specific frequency for a period of time and then rapidly switches to a new frequency and remains there for another period of time).

Such frequencies can be anywhere within a 100-MHz bandwidth; in the RCA frequency synthesizer, new frequencies are selected pseudo-randomly by a relatively complex code generator. Thus, adequate complexity provides practical solutions to the threat of enemy jamming, the near-far multiple access problem, and the synchronization problems present in direct-sequence pseudo-noise systems of equal bandwidths. To accommodate the high data rates, such as multiple digitized voice signals, and to protect against sophisticated repeat jammers, a fast hopping rate and settling time are essential in any system. To satisfy the multiple-user near-far requirements, imposes severe spectral purity constraints on the design engineers. In the past, there has been considerable development in the area of pseudo-noise-spread-spectrum communication equipments. Relatively little development effort has gone into anti-jam frequency-hopping techniques. Table I compares some of the features of direct-sequence pseudo-noise modulation and frequency hopping.

For some applications, pseudo-noise modulation will certainly be the preferred approach; however, it is realized that there are many other systems in which frequency hopping can provide equivalent anti-jam performance with faster synchronization and improved multiple access.

Design goals

Therefore, RCA set out to develop a fast-hopping frequency synthesizer system to overcome problems such as enemy jamming, near-far multiple access, and synchronization problems existing in direct-sequence methods. The following design goals were adopted for the fast hopping frequency synthesizer:

1) Settling time—1 microsecond maximum
2) Spurious outputs—80 dB below selected frequency
3) Bandwidth—13 MHz
4) Number of frequencies—4096

System considerations

The anti-jam performance of a direct-sequence pseudo-noise system and a properly designed frequency-hopping system are similar. The threats that are the most effective against each are different but for the worst-case threat, approximately the same jam-to-signal ratio can be handled by each for equal bandwidth.

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Edward J. Nossen Ldr. Communications Systems, Government Communications Systems, Camden, New Jersey, received the BSEE from Newark College of Engineering in 1953, and the MSEE from Drexel Institute of Technology in 1956. He has also completed graduate courses at the University of Pennsylvania. From 1953 to 1955, Mr. Nossen worked for Minneapolis-Honeywell in the instrumentation and process control field. After joining RCA in 1955, he participated in the modernization of the missile control auxiliaries of the MG3 airborne fire control system, design of the antenna and feedhorn, nutation servos of the TALOS missile guidance radar, and special-purpose digital computers for airborne fire control and navigation. Mr. Nossen was responsible for system analysis and technique development in the field of electronic reconnaissance and electronic countermeasures. His study responsibilities have also included operations analysis and evaluation of military systems in an ECM environment. Mr. Nossen was responsible for system studies and the development of several spread-spectrum anti-jam communications systems. Studies and hardware development involved a number of classified programs in tactical communications. Subsequently he has been responsible for studies and technique development of pseudo-random noise and tone ranging systems for communications and navigation applications. He conceived the Apollo VHF ranging system, which permitted astronauts to communicate and range simultaneously by means of narrow-band voice radios. Other programs wherein he played an active role include (ICNI) (Integrated communication, navigation and identification), and frequency hopping communications. In recent years he has had systems responsibility for the Apollo 17 Lunar Sounder's Coherent Synthetic Aperture Radar. He also participated in many Shuttle studies of the communications and tracking subsystem for North American Rockwell, Grumman, and NASA. Most recently he was responsible for the communications tradeoffs and configuration for secure anti-jam drone (RPV) communication system handling command, telemetry, and video information. Mr. Nossen is a member of Tau Beta Pi, Eta Kappa Nu, and the IEEE. He was awarded RCA's 1969 David Sarnoff Outstanding Achievement Award in Engineering for his conception of and contributions to the Apollo VHF Ranging program. He holds three U.S. Patents. He is a licensed Professional Engineer in the State of New Jersey.

Table I — In many applications, frequency hopping offers advantages over pseudo-noise modulation of equal bandwidths.

Characteristic	Pseudo noise	Frequency hopping
Anti-jam performance	Similar, although different threats are optimum against each.	
Detectability	Similar when radiometric intercept receivers are used.	
Multiple access (without time division)	For typical bandwidth ratios	
Near-far margin	20dB	60dB
Range ratio	10	1000
Synchronization time	3×uncertainty × processing gain	10 data bits to prevent false lock
Long code serial search	several seconds typical	milliseconds typical
Matched filter correlator	same as frequency hopping	
Current technology developments at RCA	CMOS/SOS LSI correlator 1024 stages keyed up to 50 Mb/s from long code generator	1200 MHz bandwidth at X-band 1 kHz resolution

Detectability

In the detectability column, direct-sequence pseudo noise has generally been considered to be superior; however, this is only true when conventional intercept receivers are used. With radiometric intercept receivers, the enemy depends only on the transmitted energy rather than the particular signal structure. Since both modulation forms require nearly the same energy per bit, the detectability with an optimum intercept receiver does not differ significantly.

Multiple access

In the multiple access area, without resorting to time-division techniques, frequency hopping is considerably superior to pseudo-noise modulation. The latter suffers from the near-far problem where a nearby friendly or a jamming transmitter of small power can disrupt the signal coming from a far-off transmitter. A 30-dB spread-spectrum system using pseudo-noise modulation could only tolerate about 20 dB of near-far margin (which is equivalent to a 10-to-1 range ratio). With frequency hopping, the near-far margin is a function of the filter characteristics and skirt selectivity rather than the processing gain of the system. Consequently, 60-dB attenuation of in-band signals is a realistic average value; this would produce a range ratio of 1000-to-1.

Synchronization of direct-sequence, pseudo-noise modulation has always been a difficult problem. Many development efforts have gone into special matched-filter correlators. These have included delay lines of all varieties including electromagnetic delay lines, acoustic delay lines, surface wave devices, digital delay lines in the form of magnetic drums, shift registers and of course most recently LSI technologies. Normal synchronization with pseudo noise is obtained by a sequential search procedure requiring an acquisition time about three times the period of uncertainty multiplied by the processing gain of the system. Since the keying rate is generally high, many chips have to be searched sequentially before synchronization is achieved. Several seconds is a typical number for serial search. Frequency-hopping signals can often be acquired in milliseconds since the keying rate is several orders of magnitude lower than the direct-sequence rate.

RCA is currently doing development work in both pseudo-noise modulation and frequency-hopping techniques. LSI correlators potentially provide fast acquisition of direct-sequence, pseudo-noise modulation—and frequency-

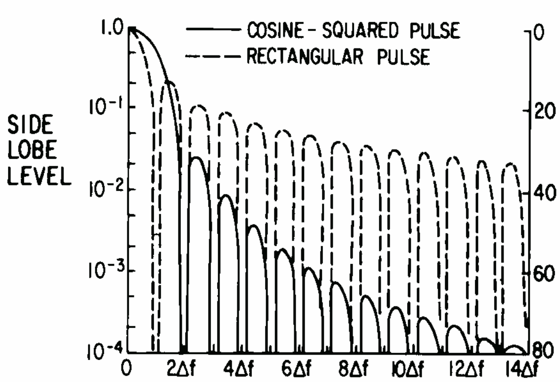


Fig. 1 — Transmitter sidelobe.

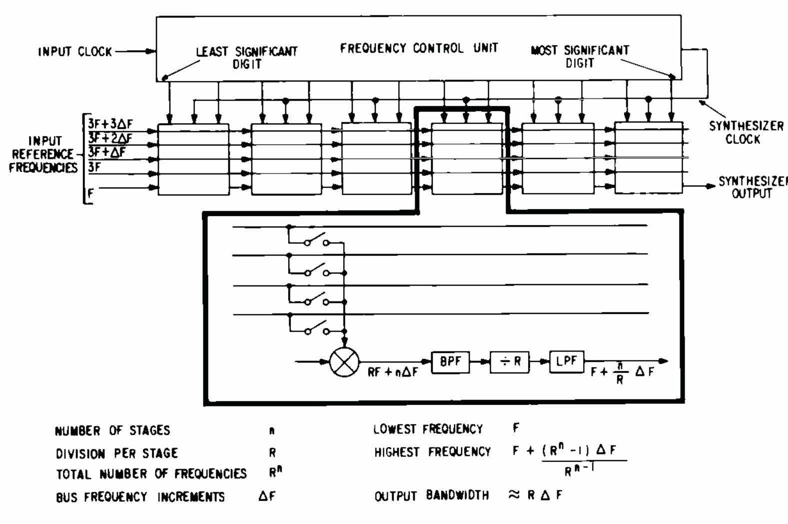


Fig. 2 — Iterative synthesizer configuration.

hopping synthesizers provide extremely wide bandwidth capabilities in the microwave region.

System requirements

The major requirement is the need for a fast settling time. This permits rapid frequency hopping to accommodate high data rates with little off time. It also defeats repeat jammers which have no time available to intercept a signal, analyze it, and respond on that frequency. By the time the jammers respond, the communications system would be operating on a new frequency.

Error correction

Error correction coding is extremely important with frequency hopping, since it corrects for bursts and jamming errors. It also corrects for friendly frequency coincidences which occur when frequency hopping is used as a multiple access modulation scheme. Some of the more powerful coding techniques used today, such as Reed-Solomon codes are extremely effective.

Multiple access control

Low inband spurious output is important to minimize the jamming vulnerability and also to minimize mutual interference in a multiple-access system. Transmitter sidelobe control is equally important in permitting multiple users to share the band with minimum interference. This reduces the energy in adjacent channels and therefore allows a greater near-far capability. Transmitter sidelobe control is illustrated in Fig. 1. Theoretical curves are shown for sidelobe characteristics: one is for the rectangular pulse for each data bit, or transmission bit in the case of coding; the other is the sidelobe level that will be realized with a cosine square pulse. As can be seen from the curves, the rectangular-pulse spectrum falls off rather slowly while the cosine-square-pulse spectrum falls off very rapidly at the expense of a somewhat increased mainlobe width. Experimental sidelobe control has been achieved with carefully balanced mixers which provide carrier suppression of close to 70 dB. The experimental results show very close correlation with the theoretical curve for a cosine square pulse.

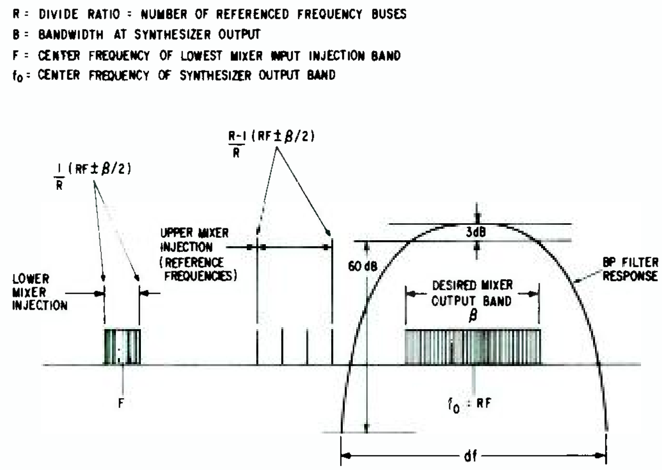


Fig. 3 — Filter requirements.

Amplitude modulation

In some operational systems, it may not be convenient to use amplitude modulation to achieve the cosine-square weighting. However, there is no need to use linear amplitude modulators and amplifiers since the relatively old ampliphase transmitter technique could readily provide amplitude modulation. RCA's Broadcast a.m. transmitters, including those operating in the shortwave bands have used this technique. Amplitude modulation is obtained by combining two phase modulated channels of constant envelope signals.

Synthesizer design approach

The synthesizer design approach employs a mix-and-divide technique having wideband filters and high-speed, emitter-coupled logic dividers.

To avoid spurious multiplication, direct synthesis of the desired 13-MHz bandwidth was accomplished at a 200-MHz center frequency. Fig. 2 illustrates the iterative synthesizer configuration selected for implementations; it shows the input reference frequencies applied to six identical stages, each controlled by a digital command. For each stage, one of four bus frequencies is selected and applied to a mixer receiving an injection from the preceding stage. The sum frequency is filtered, divided and filtered again, before being applied to the next stage.

Spurious output analysis

A tradeoff determined the optimum number of synthesizer stages in a typical 2^{12} frequency capability. Table II shows parameters for division ratios of 2,4,8, and 16.

Table II — Parameters resulting from various division ratios

	Division Ratio Per Stage			
Parameters	2	4	8	16
Reference frequencies	2^1	2^2	2^3	2^4
Number of stages for 2^{12}	12	6	4	3
Number of mixers	12	6	4	3
Number of crosspoint switches	24	24	32	48
Nominal frequencies				
Mixer inputs				
lower	f	f	f	f
upper	f	$3f$	$7f$	$15f$
Mixer outputs				
lower (image)	0	$2f$	$6f$	$14f$
upper (desired)	$2f$	$4f$	$8f$	$16f$
Lowest desired frequency	$2f - \beta/2$	$4f - \beta/2$	$8f - \beta/2$	$16f - \beta/2$
Highest undesired frequency	$f + \beta/2$	$3f + (3/8)\beta$	$7f + (7/16)\beta$	$15f + (15/32)\beta$
Guard space	$f - \beta$	$f - (7/8)\beta$	$f - (15/16)\beta$	$f - (31/32)\beta$

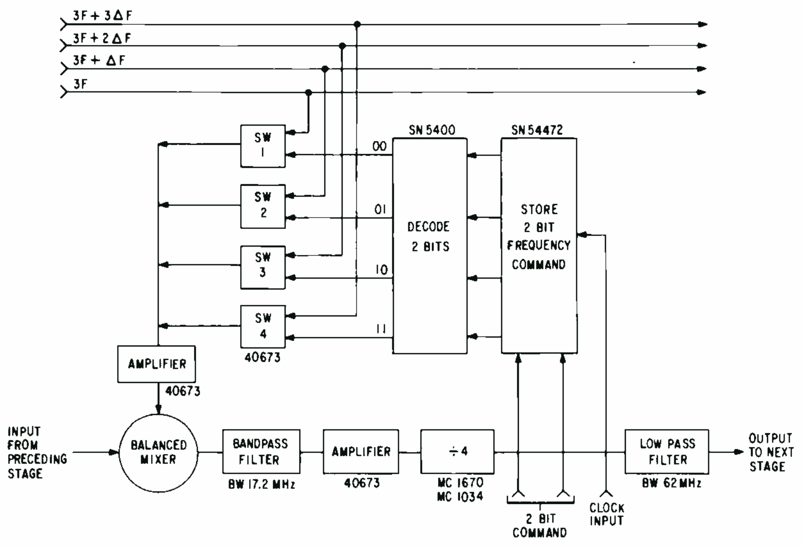


Fig. 4 — One stage of frequency hopping synthesizer.

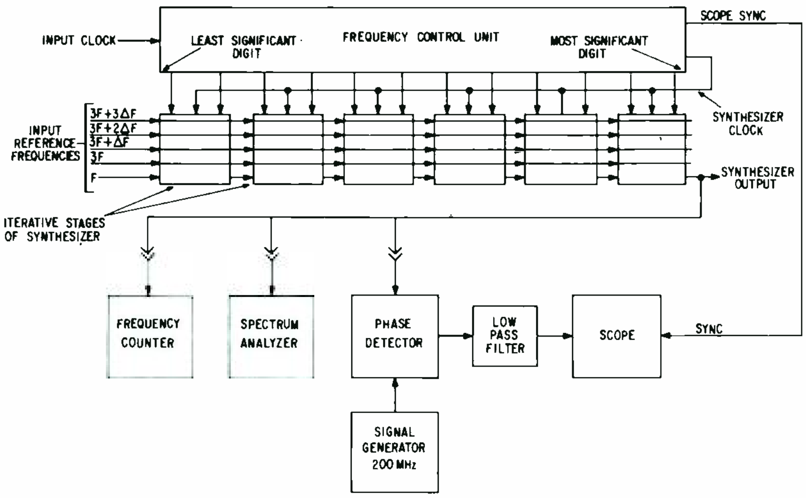


Fig. 5 — Frequency synthesizer test configuration.

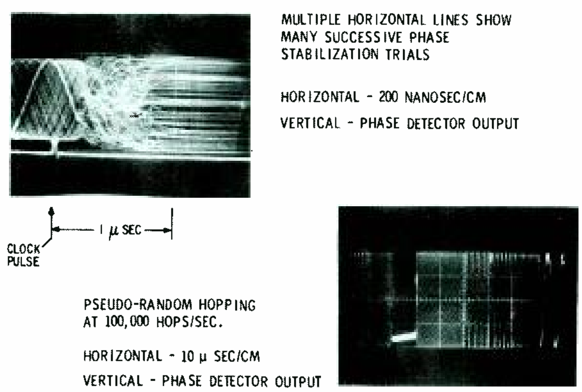


Fig. 6 — Setting time.

A spurious analysis was performed for the divide-by-two, divide-by-four and divide-by-eight configurations. Based on typical balanced-mixer characteristics, the divide-by-two combination has an *unacceptable* fourth-order spurious output only 13-dB below the desired signal. The divide-by-four configuration has an *acceptable* output, 70-dB spurious of eighth order. However, in applications requiring very high spectral purity, a divide-by-eight approach is preferable: its first objectionable spurious product would be an eighth-order output, 96-dB below the desired signal.

Filter requirements

Filter requirements are a critical design parameter in an iterative synthesizer (see Fig. 3). On the right, the desired mixer output band is shown; on the left is the lower mixer injection frequency which has some bandwidth from the preceding stages.

In the center are the four or eight selected bus frequencies. The filter must attenuate these by 60 dB or more to minimize spurious outputs. Various types of filters have been considered and one critical parameter is the delay introduced by the filter. Analysis has shown that, for various types of Chebishev and Butterworth filters, the envelope delay depends more on the spurious attenuations than on the particular filter implementation. The filter can therefore be selected for ease of implementation and tuning.

A synthesizer stage

A single stage of the iterative synthesizer implemented by RCA is shown in Fig. 4. Four bus frequencies are used with four switches to select one of these. A 2-bit command is stored in a pair of flip-flops which are decoded and used to drive the switches. The switches use FET's and have achieved 90 dB isolation. An FET amplifier provides adequate drive for the balanced mixer. The input from the preceding stage is mixed with the selected frequency, the sum frequency is filtered in the bandpass filter, amplified, and then divided by four from approximately 200 MHz down to 50 MHz. A low-pass filter with a bandwidth of 62 MHz removes unwanted high-frequency components. The resulting signal is applied to the next stage.

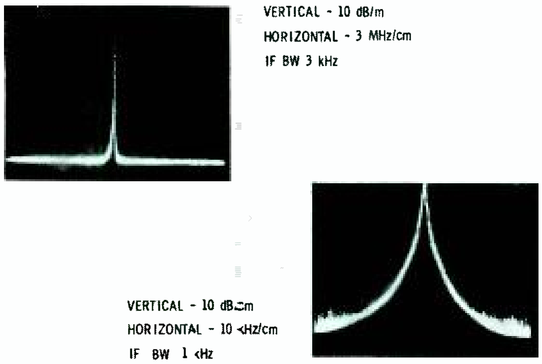


Fig. 7 — Spectral purity.

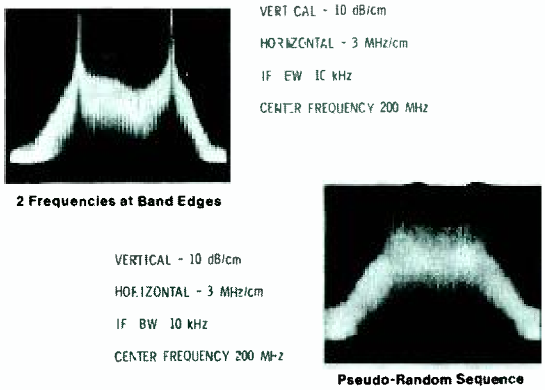


Fig. 8 — Frequency hopping at 100 kilohops/s.

Performance tests

To test the frequency synthesizer, as shown in Fig. 5, a frequency counter measured actual frequency, a spectrum analyzer showed spectral purity and a phase detector driven from a stable oscillator provided an output suitable for indicating final settling of the synthesizer.

The phase detector could thus detect when phase changes of the synthesizer output are no longer present for an accurate measurement of the synthesizer settling time. The output frequency at 200 MHz could be changed from 193.5 MHz to 206.5 MHz in 3.2 KHz steps. The transition from one frequency to another was completed in less than a microsecond. The spurious response was 60 dB or better, in many cases it exceeded 70 dB.

Settling time

Test results of the settling time of the synthesizer are shown in Fig. 6. In this test, the synthesizer was commanded to select a specific frequency in the 13-MHz band. It was subsequently commanded to select the 200-MHz reference frequency for coherent detection of the phase of the synthesizer. As can be seen, from the time of the clock pulse commanding a frequency change to the point where the output of the phase detector is a steady signal, no more than one microsecond elapsed. Many trials starting from different frequencies were made and superimposed in the photograph. All show complete settling in a microsecond. The settling time is further illustrated by the pseudo random hopping pattern at 100,000 hops/s. The phase detector output shows the beat frequency between the output frequency and the 200-MHz reference. Each "frequency dwell" was 10 microseconds. As can be seen, one of the selected frequencies was exactly the 200-MHz reference frequency. Other frequencies were either close by or at a considerable distance thereby resulting in substantial beat frequencies. In any case the transition time is small compared to the 10 microsecond dwell on each discrete frequency.

Spectral purity

The spectral purity of the signal is shown in Fig. 7. The entire band is shown in the top photograph, where the spurious signals are generally 70 dB below the desired frequency. A blowup of the desired frequency region shows some spurious components within a few kilohertz, which are only 60 dB down. These have been traced to the phase noise of the reference oscillator rather than to contributions by the frequency synthesizer. In any case the "close-in" spurious would in all likelihood be masked by the spectrum of the switching wave form. Even with cosine-square pulse shaping, the sidelobes would be far in excess of the "near-in" spurious level. Fig. 8 shows the spectrum seen when the frequency synthesizer is hopped between two discrete frequencies at a 100 kilohop/s rate. Since pulses were not shaped in amplitude, the spectrum around each of the selected frequencies contains the familiar $(sin\ x/x)^2$ components. This is also apparent when a pseudo random sequence was used to select the synthesizer frequency at a 100 kilohop/s rate. If the sidelobe levels are objectionable in a particular application, amplitude weighting can be applied.

Final construction

Fig. 9 shows the front and back views of one stage of the iterative frequency synthesizer. A combination of discrete and integrated circuits were used in the construction. A considerable amount of compartmentalized shielding minimizes leakage and resulting spurious. Six synthesizer packages are stacked to form a synthesizer for 2^{12} frequencies. Thick-film hybrid construction would permit reduction from the present synthesizer size to approximately 15 cubic inches for production applications.

Acknowledgment

The author wishes to thank R. Allen, J. Feller, and A. Jackson for their contributions to the successful development of the frequency-hopping synthesizer.

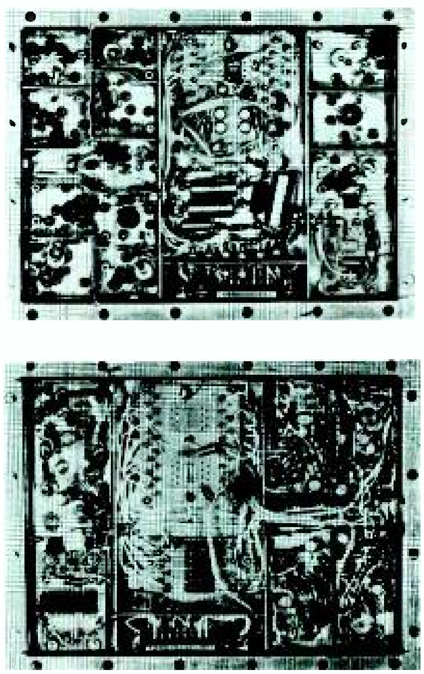
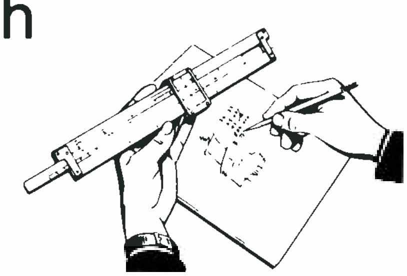


Fig. 9 — One iterative stage frequency hopping synthesizer.

Engineering and Research Notes



Electro-optical digital-to-analog converter

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Government and Commercial Systems
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The optical integrated circuit shown in Fig. 1 is a digital-to-analog converter which emits an analog light beam from a digital input electrical signal. It can operate at bit rates much higher than previously obtained by electrical output digital-to-analog conversion used in conjunction with analog light modulators for image recording, digital communication demodulation, *etc.*, and requires only an extremely small space. This is possible because the D-to-A conversion is performed directly on the light source. The device makes use of a monolithic array of incoherent stripe electrode light emitting diodes[1] formed on a semiconductor laser material[2] with epitaxial layers shown in Fig. 2. Electrons flowing across the p-n junction combine with holes in the very narrow recombination region to emit light directly beneath each current-driven electrode. The other three layers which make up the large optical cavity (LOC) shown in Fig. 2 have optical indices of refraction which serve to confine and guide the generated light to the edge of the device where it is emitted as an incoherent light beam. The electrodes for each striped LED are spaced so that the light which is guided to the emitting edge from each subsequent electrode is related to the next electrode by a factor of ½ due to attenuation in the waveguide cavity. The output light intensity is described by the equation.

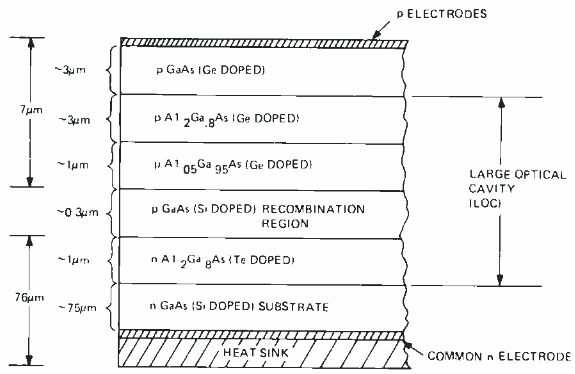

Fig. 2 — Electro-optic converter construction.

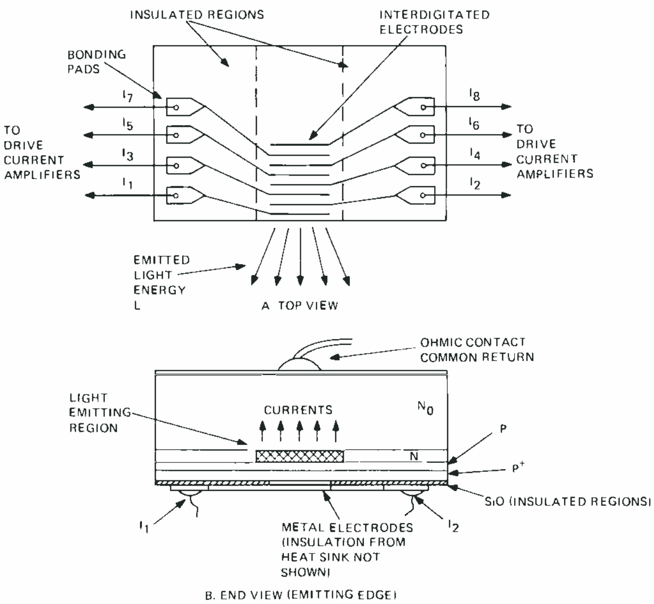

Fig. 1 — Electrode arrangement and connections.

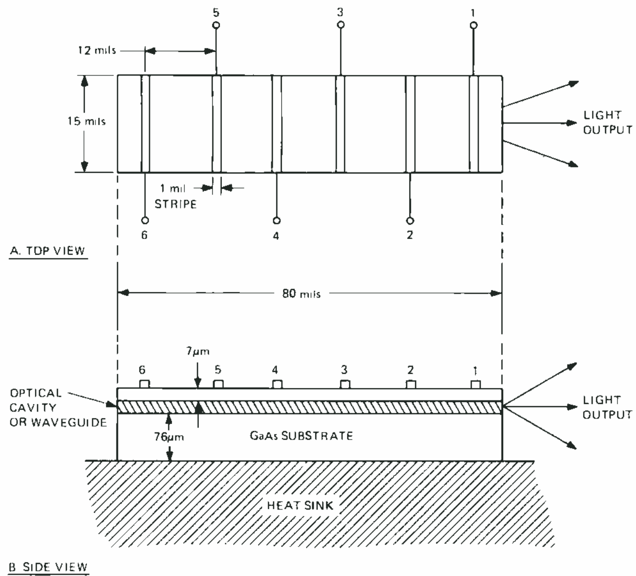

Fig. 3 — Feasibility model of electro-optic converter structure.

$$L = K\sum_{n=1}^{n=8} a_n 2^{-n}$$

where a_n is one or zero depending on whether or not drive current exists at the n^{th} electrode. All drive currents are equal.

Some light from all the driven-stripe-electrode LEDs is conducted to the entire periphery of the structure shown in Fig. 1a, but this is attenuated by the much longer distance to the unused edges which can be coated with black absorbing wax. The attenuation in the inactive surrounding semiconductor material (shown as insulated regions in Fig. 1a) can be increased by ion implantation. Ion implantation and annealing can also be used to adjust the attenuation constant of the active waveguide region.

A feasibility model of this device with six electrodes was fabricated and tested. This is shown in Figs. 3a and b, with the dimensions of the semiconductor chip and electrodes. The header on which this device was mounted is shown in Fig. 4. All edges except the light output edge were coated with absorbent black wax to eliminate the effect of leakage light and reduce the effect of nearby wall reflections. In the preferred embodiment of Fig. 1a, these walls would be removed far from the stripe-electrode LEDs.

Measurements made of the light output of the device in Fig. 3 indicate that the attenuation of the light from the various LED sources was 204 dB/cm (or $\alpha = 47\ cm^{-1}$). A smaller attenuation is not desirable since it would require the device to be too large. The measured attenuation indicates that the electrode spacing should be 5.8 mils instead of 12 mils as fabricated.

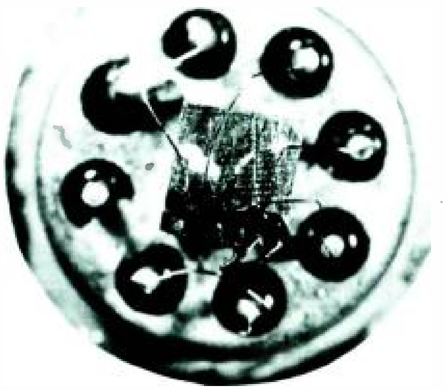

Fig. 4 — Mounting of D/A converting light source.

It would probably be advantageous in future fabrication to place the electrodes closer together than required for the given type of material and then ion bombard (implant) and anneal until the proper attenuation value is obtained in the active waveguide region. A much higher attenuation in the inactive regions could be obtained by a different ion implantation procedure. This would eliminate the effect of reflection from the walls without making the device larger.

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Reprint RE-19-6-30| Final manuscript received January 3, 1974.

Simple, efficient, clean-steam generator for oxidation of semiconductor wafers

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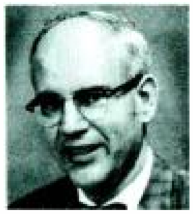

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In the fabrication of silicon semiconductor devices, a key process often repeated many times is the thermal growth of a generic oxide, *e.g.*, SiO_2. This is normally accomplished by passing oxygen and/or water vapor across the wafers in heated furnaces. The use of steam at atmospheric pressure is a widely used process because of the high growth rate of the oxide (compared to a dry O_2 oxidation process), and because of convenience and reproducibility.

The fabrication of many silicon devices, specifically MOSFETs, requires a highly clean oxide growth process, *i.e.*, oxidation should not introduce foreign impurities such as alkali metals into the silicon or into the SiO_2 as it grows. Impurities such as sodium are particularly troublesome, and result in a driftable charge (Q_o) and unstable operation.[1]

It is common practice to use a high-purity quartz furnace tube and a high-purity alumina mullite or silicon carbide liner to isolate the tube from impurities usually found in the furnace elements and in the insulation. A baffled boiler made of fused silica filled with triple-distilled water serves as the source of steam. This system is used to obtain clean steam-grown oxides and indeed, by controlling the boiling rate and the addition of water and by maintaining extreme cleanliness, oxides which are clean and free of driftable charge can be produced. Unfortunately, such a system is quite variable and easily contaminated, and it requires constant care and periodic cleaning. Use of HCl gettering[2-5] has been proposed and used by some to overcome the variabilities of the conventional steam oxidation process; however, the continuous use of large quantities of HCl in the system presents severe safety and maintenance problems.

Determination of steam oxidation system variables

A series of experiments was conducted to determine the major variables in a conventional steam oxidation system. A well-cleaned system was assembled in a standard wire-wound furnace, with a new alumina furnace liner, virgin quartz tube and boiler filled with triply-distilled water. Fittings provide for the possible introduction of oxygen or nitrogen along with the steam. The system was operated at 1050°C. As the variables were changed, system cleanliness was evaluated through the use of MOS capacitors, *i.e.*, C-V and bias-temperature tests.[6] The test slices of (100) silicon were well etched and cleaned and split into test and control half slices; storage areas, annealing furnaces, and metallization equipment were continuously monitored for cleanliness.

The following conclusions can be drawn from these experiments:

1) A virgin system will produce dirty oxides. Continuous passage of

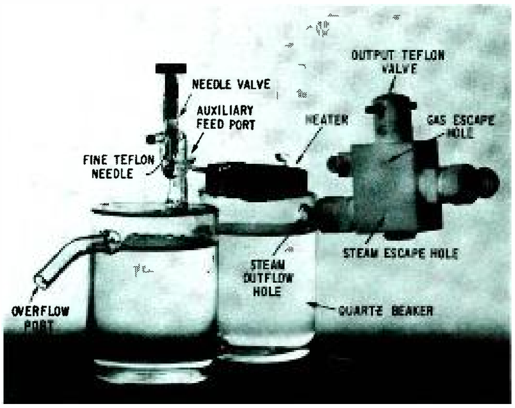


Fig. 1 — Surface evaporator (steam generator).

clean steam through the tube for several days at 1200°C will bring the system to a clean equilibrium state. Thereafter, a *continuous* flow of clean steam produces oxides with very low values of flat-band voltage shift (>0.2V/1000Å).

2) Addition of O_2 or N_2 to the steam has no effect on oxide cleanliness unless steam generation accidentally slows down or ceases. It then acts to reduce back diffusion of the "dirty" outside air.

3) Rapidly boiling water results in "dirtier" oxides than those obtained from a gently rolling boil.

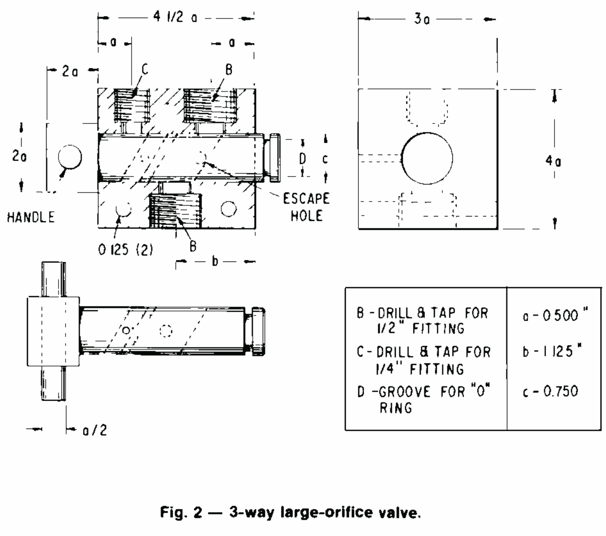
4) In a given furnace, clean oxides may be grown in dry O_2, yet steam oxides prove impure. However, a furnace that produces clean-steam oxides also produces highest quality dry O_2 oxides.

The above results suggest that in a clean system with aged quartz and liners, the continuous passage of *clean* steam produces oxides low in driftable charge contamination.

The following system meets these objectives.

Continuous surface evaporation system

The surface evaporator shown in Fig. 1 consists of two connected fused-quartz containers. One serves as the cold reservoir in which the water level is determined by means of continuous feed and overflow. The other is the boiler—and uses a small heater directed at the top surface of the water. Since the heater produces large quantities of infra-red radiation which is strongly absorbed in water, and because still water is a poor thermal conductor, intense heating of the water surface liberates large quantities of clean steam *without motion or agitation of the water.*



B - DRILL & TAP FOR 1/2" FITTING	a - 0.500"
C - DRILL & TAP FOR 1/4" FITTING	b - 1.125"
D - GROOVE FOR "O" RING	c - 0.750

Fig. 2 — 3-way large-orifice valve.

The evaporator shown in Fig. 1 is very simple, and its size can be tailored for any particular need. The heater is a 110V/200W ceramic solderpot element, and the containers are sealed 400cc quartz beakers. An auxiliary feeding port doubles as a pressure equalizer and prevents siphoning. By properly adjusting the input needle-valve, constant water level and evaporation rate are easily maintained. To change the evaporation rate, the heater's supply voltage can be changed.

In many cases, the outflow of steam must be controlled. For this purpose a simple three-way all-Teflon large orifice valve, as shown in Fig. 2, is used. The valve allows either steam or some other gas to be fed to the furnace. Two small escape holes in the back allow the bleeding of excess gas or steam into the air from the unused input, to prevent buildup of pressure in lines or the boiler. The holes are 0.125 inch in diameter and are drilled on the back face of the valve housing, and on two opposite sides in the circular revolving valve. Thus, only one hole faces the escape opening in the back wall at any one time.

Experimental results

The continuous-feed surface evaporator has been in use in the fabrication of discrete and integrated bipolar transistors and MOSFETs. Operation is essentially trouble free and flawless, unless heavy contamination is accidentally introduced. Measurements of SiO_2 growth rates at various temperatures indicated that the growth was never limited by the lack of steam. The steam generators were fed from either a common source of deionized water or distilled water.

Capacitance-voltage and 300°C bias-temperature tests[6] indicated negligible shifts due to oxide charge instability. Excellent SiO_2-Si interface properties in wafers oxidized at 875°C were verified by C-V measurements,[7] and breakdown voltage on oxides thinner than 800 Å consistently exceeded 10^7 V/cm. Helium annealing of the wafers was carried *in-situ*, utilizing the valve described in Fig. 2. More results of steam oxidation using our system are described elsewhere.[8]

Conclusions

The system proved to be eminently suitable for clean-steam generation. It is simple, and can be adapted for many different uses where clean steam is important. It can further be compacted by omitting the reservoir tank, and utilizing Pyrex parts (*e.g.*, valve) where no hot water or steam are in contact with the glass. Stable MOSFETs were made by use of the surface steam generator, and *C-V*, *b-T* tests indeed indicate that extremely clean oxides can consistently be grown by utilizing steam generated by this surface evaporator.

Acknowledgment

The authors are indebted to Marcellus Green and D. W. Flatley for early testing of the system, and to other members of RCA Laboratories and RCA's Solid State Division for valuable comments. Thanks to C.W. Mueller and J.H. Scott for encouraging the use of surface evaporation. J. Murr assisted in the design of the three-way valve.

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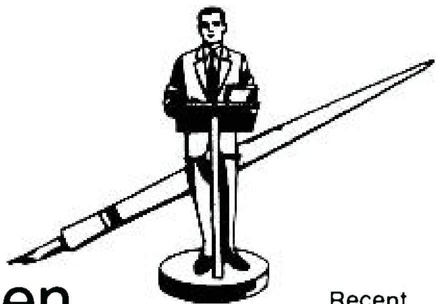
*Since this article was written, Mr. Ronen has left RCA.



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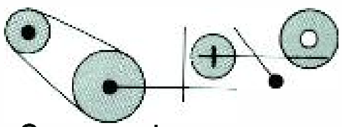

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Cross-Mounted Mask Changer with Thickness Monitoring — A. Harel (Labs. Pr.) U.S. Pat. 3747558, July 24, 1973

Process for Fixing Holographic Patterns in Electro-Optic Crystals and the Crystals Produced Thereby — J. J. Amodei, D. L. Staebler (Labs. Pr) U.S. Pat. 3773400, November 20, 1973

Cathodochromic Image Screen and Method for Preparing Cathodochromic Sodalite for Said Image Screen — I. Shidlovsky (Labs. Pr) U.S. Pat. 3773540, November 20, 1973

Electron Beam Addressable Memory System — F. J. Marlowe, C. M. Wine (Labs. Pr.) U.S. Pat 3774116, November 20, 1973

Method of Producing a Window Device — J. A. Van Raalte, V. Christiano (Labs. Pr.) U.S. Pat. 3788892, January 29, 1974

Bucket Brigade Scanning of Sensor Array — P. K. Weimer (Labs. Pr.) U.S. Pat. 3789240, January 29, 1974

Double-Sided Holographic Replicas — W. J. Hannan, J. R. Frattarola (Labs. Pr.) U.S. Pat. 3790245, February 5, 1974

Optical System for Orthogonalizing Image Field of Protection — E. G. Ramberg (Labs. Pr.) U.S. Pat. 3790267, February 5, 1974

System for Recording and Playing Back Color Encoded Holograms — I. Gorog (Labs. Pr.) U.S. Pat. 3790701, February 5, 1974

Semiconductor Light Ray Deflector — J. I. Pankove (Labs. Pr.) U.S. Pat. 3790853, Feburary 5, 1974

Fabrication of Monolithic Integrated Circuits & E. J. Boleky, 111 (Labs. Pr.) U.S. Pat 3791024, February 12, 1974

Coaxial Magnetic Slug Tuner — L. S. Napoli, J. J. Hughes (Labs. Pr.) U.S. Pat. 3792385, February 12, 1974

Novel Liquid Crystal Electro-optic Devices — C. S. Oh, E. F. Pasierb (Labs. Pr.) U.S. Pat. 3792915, February 19, 1974

Circuit for Operating an Avalanche Diode in the Anomalous Mode — A. S. Clorfeine (Labs. Pr.) U.S. Pat. 3793539, February 19, 1974

Gated Flip-Flop Employing Plural Transistors and Plural Capacitors Cooperating to Minimize Flip-Flop Recovery Time — E. K. Yu (MTC, Som.) U.S. Pat. RE27928, February 26, 1974

Pal-Type Color Signal Processing Apparatus — P. E. Haferl (Labs. Zurich, Switz.) U.S. Pat. 3794754, February 26, 1974

Voltage Induced Optical Waveguide Means — D. J. Channin (Labs. Pr.) U.S. Pat. 3795433, March 5, 1974

LSI Array and Standard Cells — T. R. Mayhew (MTC, Cam.) U.S. Pat. RE27935, March 5, 1974

Holographic Recording on Photochromic Lithium Niobate — W. Phillips, D. L. Staebler (Labs. Pr.) U.S. Pat. 3799642, March 26, 1974

Cathodochromic Cathode Ray Tube and Method for Preparing Cathodochromic Sodalite for Said Tube — I. Shidlovsky (Labs. Pr.) U.S. Pat. 3799881, March 26, 1974

Niobium-Gallium Superconductor — G. W. Webb (Labs. Pr.) U.S. Pat. 3801378, April 2, 1974

Method of Depositing Electrode Leads — R. S. Ronen, E. A. James (Labs. Pr.) U.S. Pat. 3801477, April 2, 1974

111-V Compound on Insulating Substrate and Its Preparation and U'SE — I. Ladany, C. C. Wang (Labs. Pr.) U.S. Pat. 3802967, April 9, 1974

Electroluminescent Film and Method for Preparing Same — J. J. Hanak (Labs. Pr.) U.S. Pat. 3803438, April 9, 1974

Electron-Beam Pumped Laser with Extended Life — F. H. Nicoll (Labs. Pr.) U.S. Pat. 3803510, April 9, 1974

Method for Eliminating Degradation of Crossed-Field-Amplifier Performance — B. Goldstein (Labs. Pr.) U.S. Pat. 3795432; Assigned to U. S. Government

Manufacture of Video Discs — R. M. Mehalso, D. I. Harris (Labs. Pr.) U.S. Pat. 3795534, March 5, 1974

Metal Vapor Laser Discharge Device — K. G. Hernqvist (Labs. Pr.) U.S. Pat. 3798486, March 19, 1974

Microwave Transmission Line and Devices Using Multiple Coplanar Conductors — R. E. Debrecht, L. S. Napoli (Labs. Pr.) U.S. Pat. 3798575, March 19, 1974

Computer System with Program-Controlled Program Counters — J. A. Weisbecker (Labs. Pr.) U.S. Pat. 3798615, March 19, 1974

Page Composer Translating Information from Electrical to Optical Form — L. S. Cosentino (Labs. Pr.) U.S. Pat. 3798620, March 19, 1974

An Active Twin T Filter with a Positive Feedback Q Control — W. E. Barnette (Labs. Pr.) U.S. Pat. 3602833, August 31, 1974

Process of Making Acousto-optic Devices — G. A. Alphonse, G. E. Bodeep (Labs. Pr.) U.S. Pat 3798746, March 26, 1974

Electronic Components

Electron Tube Having Internal Glass Member Coated with Crystalline Ceramic Material — J. A. Powell (EC, Lanc.) U.S. Pat. 3787780, January 22, 1974

Method for Producing Evaporation Inhibiting Coating for Protection of Silicon-Germanium and Silicon-Molybdenum Alloys at High Temperatures in Vacuum — P. J. Chao (EC, Hrsn.) U.S. Pat. 3783031, (no issue date given); Assigned to U. S. Government

Method for Printing Negative Tolerance Matrix Screen Structure for a Cathode-Ray Tube — E. E. Mayaud, S. Pearlman (EC, Lanc.) U.S. Pat. 3788846, January 29, 1974

Methods of Manufacture of Color Picture Tubes — R. H. Godfrey (EC, Lanc.) U.S. Pat. 3788847, January 29, 1974

Methods of Manufacture of Color Picture Tubes — A. M. Morrell (EcC, Lanc.) U.S. Pat. 3788848, January 29, 1974

Cathode-Ray Tube Having Conductive Internal Coating Comprised of Iron Oxide and Graphite — J. J. Maley, D. W. Bartch (EC, Lanc.) U.S. Pat. 3791546, February 12, 1974

Means for Ensuring Starting of Gas Laser — J. T. Mark (EC, Lanc.) U.S. Pat. 3792372, February 12, 1974

Amplifier Protection Circuit — J. C. Sondermeyer (EC, Som.) U.S. Pat. 3796967, March 12, 1974

Thermo-Electric Modular Structure and Method of Making Same — N. S. Freedman, C. W. Horsting, W. F. Lawrence and J. J. Carrona (EC, Hrsn.) U.S. Pat. 3787958, January 29, 1974; Assigned to U. S. Government

Self-conversing Color Image Display System — J. Gross, W. H. Barkow (EC, Pr.) U.S. Pat. 3800176, March 26, 1974

Multi-Indicia Display Device — P. L. Farina (EC, Som.) U.S. Pat. 3800178, March 26, 1974

Thermoelectric Generator — M. E. Pryslak (EC, Hrsn.) U.S. Pat. 3794526, March 26, 1974; Assigned to U. S. Government

Method of Making a Directly-Heated Cathode — R. A. Lee, A. Bazarian, Jr. (EC, Lanc.) U.S. Pat 3800378, April 2, 1974

Heater-Cathode Insulation Leakage Test Method and Apparatus — EC, Hrsn.) U.S. Pat. 3801892, April 2, 1974

Shadow Mask Mounting Assemblies — A. M. Morrell (EC, Lanc.) U.S. Pat 3803436, April 9, 1974

Insulated Dual Gate Field-Effect Transistor Signal Translator Having Means for Reducing its Sensitivity to Supply Voltage Variations — J. O. Preisig, A. Presser (EC, Som.) U.S. Pat. 3789246, January 29, 1974

Electron Beam and Deflection Yoke Alignment for Producing Convergence of Plural In-line Beams — R. L. Barbin (EC, Lanc.) U.S. Pat. 3789258, January 29, 1974

Focus-Grill Cathode-Ray Tube Image Reproducer Modulation with Grill Voltage — F. J. Campbell (EC, Pr.) U.S. Pat. 3790845, February 5, 1974

Consumer Electronics

Switchable Antenna Circuit for Television Providing for Reception of UHF and VHF Signals Utilizing a Single Built-in Monopole Antenna or Two External Antennas — E. E. Janson, M. W. Muterspaugh (CE, Indpls.) U.S. Pat. 3787773, January 22, 1974

High Voltage Protection Circuit — P. R. Ahrens (CE, Indpls) U.S. Pat 3789260, January 29, 1974

High Frequency Automatic Gain Control Circuits — D. J. Carlson (CE, Indpls.) U.S. Pat. 3792359, February 12, 1974

Method of Controlling Resistance Values of Thick-Film Resistors — R. S. Degenkolb, T. R. Allington, Y. H. Wang and M. Oakes (CE, Indpls.) U.S. Pat. 3793717, February 26, 1974

Jitter Immune Transistorized Vertical Deflection Circuit — L. E. Smith, D. L. Neal (CE, Indpls.) U.S. Pat. 3794877, February 26, 1974

Plural Operating Mode Television Receivers — D. H. Willis (CE, Indpls.) U.S. Pat. 3795762, March 5, 1974

High Voltage Protection Circuit — R. K. Waltner, M. N. Norman (CE, Indpls.) U.S. Pat. 3795767, March 5, 1974

Thick Film Inductor with Ferromagnetic Core — B. Astle, J. M. Guiot (CE, Indpls.) U.S. Pat. 3798059, March 19, 1974

Multiplex Decoding System — A. L. Limberg (CE, Som.) U.S. Pat. 3798376, March 19, 1974

Instant-on Circuit for a Television Receiver — D. F. Griepentrog, R. J. Gries (CE, Indpls.) U.S. Pat. 3801856, April 2, 1974

Television Deflector Circuit with Transformerless Coupling between the Driver and Output Stage — D. W. Luz (CE, Indpls.) U.S. Pat. 3801857, April 2, 1974

RCA Ltd

Multiple Terminal Display System — R. J. Clark (Ltd, Montreal, Canada) U.S. Pat. 3774158, November 20, 1973

Electronic Time Measurement — P. L. Chapman (Ltd, England) U.S. Pat. 3789600, February 5, 1974

Low Noise Detector Amplifier — M. J. Teare (Ltd, Montreal, Canada) U.S. Pat 3801933, April 2, 1974 (assigned to RCA Limited, Canada)

Patent Operations

Apparatus for Distinguishing Between Various FM Broadcast Multiplex Transmissions — A. L. Limberg (Pat. & Lic., Pr.) U.S. Pat 3787629, January 22, 1974

Solid State Division

Control Circuit Employing Digital Techniques for Loads such as Balance Wheel Motors — S. S. Eaton, Jr. (SSD, Som.) U.S. Pat. 3787715, January 22, 1974

Circuit for Supplying Regulated Power Upon Demand — A. C. N. Sheng (SSD, Som.) U.S. Pat. 3787757, January 22, 1974

Electronic Firing Circuit — R. P. Fillmore, R. C. Heuner (SSD, Som.) U.S. Pat. 3788226, January 29, 1974

Differential Amplifier and Bias Circuit — C. F. Wheatley, Jr. (SSD, Som.) U.S. Pat. 3790897, February 5, 1974

Signal Detection in Noisy Transmission Path — D. K. Morgan, R. C. Heuner (SSD, Som.) U.S. Pat. 3795823, March 5, 1974

Dates and Deadlines

As an industry leader, RCA must be well represented in major professional conferences . . . to display its skills and abilities to both commercial and government interests.

How can you and your manager, leader, or chief-engineer do this for RCA?

Plan ahead! Watch these columns every issue for advance notices of upcoming meetings and "calls for papers". Formulate plans at staff meetings—and select pertinent topics to represent you and your group professionally. Every engineer and scientist is urged to scan these columns; call attention of important meetings to your Technical Publications Administrator (TPA) or your manager. Always work closely with your TPA who can help with scheduling and supplement contacts between engineers and professional societies. Inform your TPA whenever you present or publish a paper. These professional accomplishments will be cited in the "Pen and Podium" section of the *RCA Engineer*, as reported by your TPA.

Dates of upcoming meetings —plan ahead

Ed. note: Meetings are listed chronologically. Listed after the meeting title (in bold type) are the sponsor(s), the location, and the person to contact for more information.

JUNE 20-22, 1974 — **Topical Conference on Radio Frequency Plasma Heating,** NPS, AIP, Texas Tech. Univ., Lubbock, TX **Prog info:** M. Kristiansen, Plasma Lab., Texas Tech. Univ., Lubbock, TX 79409

JUNE 20-22, 1974 — **Conference on RF Plasma Heating,** APS, IEEE, Texas Tech. University Campus **Prog info:** Dr. M. Kristiansen or Dr. M. O. Hagler, Dept. of Electrical Engineering, Texas Tech. University, Lubbock, TX 79409

JUNE 27, 1974 — **America's Federated National Standards System - Challenges and Opportunities - 1974,** ANSI, AI of Mass., Marriott Motor Hotel, Newton, Mass. **Prog info:** Mr. Claude H. Burns, American National Standards Institute, 1430 Broadway, New York, NY 10018

JUNE 24-28, 1974 — **ASME Conference on Pressure Vessels, Nuclear Reactor Containments, Education,** ASME, Eden Roc Hotel, Miami Beach, FL **Prog info:** Paul Drummond, Mgr., Industry Dept., ASME, 345 E. 47th St., New York, NY 10017

JULY 1-5, 1974 — **Precision Electromagnetic Measurements Conf.,** Royal Society, IEE, IERE, IM et al, IEE, London, England **Prog info:** 1974 CPEM Secretariat, c/o The Conf. Dept., IEE, Savoy Pl., London W.C. 2 R OBL England

JULY 8-10, 1974 — **AIAA 8th Aerodynamic Testing Conference,** Bethesda, Md. **Prog info:** AIAA, 1290 Avenue of the Americas, New York, NY 10019

JULY 14-19, 1974 — **Power Engineering Soc. Summar Meeting and Energy Resources Conf.,** PE, Disneyland Hotel, & Anaheim Conf. Ctr., Anaheim, Calif. **Prog info:** S. H. Gold, Southern Calif. Edison Co., POB 800, Rosemead, CA 91770

JUNE 16-19, 1974 — **Int'l Conference on Communications,** COMM., Twin Cities Section, Leamington Hotel, Minneapolis, Minn. **Prog info:** M. S. Ulstad, POB 35366, Minneapolis, Minn. 55435

JUNE 17-19, 1974 — **Design Automation Workshop,** C, ACM, SHARE, Holiday Inn, Denver, Colo. **Prog info:** S. P. Krosner, IBM Corp., POB 1328, Boca Raton, FL 33432

JUNE 18-21, 1974 — **Joint Automatic Control Conference,** Austin, TX **Prog info:** AIAA, 1290 Avenue of the Americas, New York, NY 10019

JUNE 19-21, 1974 — **Fault Tolerant Computing Conference,** C, Univ. of Illinois, Champagne, IL **Prog info:** H. Y. Chang, Bell Labs., Naperville, IL 60540

JUNE 19-21, 1974 — **Joint Automatic Control Conference,** CS, AIAA, SIAM, ASME, AIChE, et al, Univ. of Texas, Austin, TX **Prog info:** M. Denn, Dept. of Chem. Engrg., Univ. of Del., Newark, Del. 19711

JULY 15-18, 1974 — **Nuclear & Space Radiation Effects Conference,** NAP, Colorado State Univ., Fort Collins, Colo. **Prog info:** R. H. Stahl, Intercom Rad. Tech., POB 80817, San Diego, CA 92138

JULY 15-19, 1974 — **Int'l Conference on Frontiers in Education** - Education, IEEE UKRI Section, IEE, ASEE et al, City University, London, England **Prog info:** 1974 Frontiers in Educ. Secretariat, IEE, Savoy Pl., London W.C. 2R OBL Eng.

JULY 16-18, 1974 — **Electromagnetic Compatibility Symp.,** EMC, San Francisco Hilton Hotel, San Francisco, CA **Prog info:** Alan Johnson, 439 Molino Ave., Sunnyvale, CA 94086

JULY 23-26, 1974 — **Circuit Theory and Design,** IEE, IEEE UKRI Section, IERE, IEE, London, England **Prog info:** IEE, Savoy Place, London, W. C. 2R OBL England

JULY 24-26, 1974 — **Summer Computer Simulation Conference,** SMC et al, Shamrock Hilton Hotel, Houston, TX **Prog info:** B. Chandrasekaran, Ohio State Univ., 2024 Neil Ave., Columbus, OH 43210

JULY 29-AUG. 1, 1974 — **Intersociety Conference on Environmental Systems,** AIAA, Seattle, Wash. **Prog info:** AIAA, 1290 Avenue of the Americas, New York, NY 10019

AUG. 5-9, 1974 — **AIAA Mechanics and Control of Flight Conference** (with cooperation of AAS), Anaheim, CA **Prog info:** AIAA, 1290 Avenue of the Americas, New York, NY 10019

AUG. 12-14, 1974 — **Computer Communications Int'l Conference,** C, ICCC Int'l Council, Stockholm, Sweden **Prog info:** E. Boyer, Int'l Council for Computer Comm., 8803 Stonehaven Ct., Potomac, MD 20854

AUG. 12-23, 1974 — **Photoelectronic Imaging Devices,** The University of Rhode Island, Kingston, RI 02881 **Prog info:** Photoelectronic Imaging Devices, Dept. of Electrical Engineering, University of Rhode Island, Kingston, Rhode Island 02881, Attn: Professor G. Sadasiv

AUG 13-15, 1974 — **Pattern Recognition Int'l Conference,** C, Hotel Eremitge, Lyngby-Copenhagen, Denmark **Prog info:** E. Backer, EE Dept., Delft Univ. of Tech., Delft, The Netherlands

AUG. 21-23, 1974 — **Engrg. in the Ocean Environment Int'l Conference,** IEEE Oceanography Coor. Comm. et al, Nova Scotian Hotel, Halifax, Nova Soctia **Prog info:** J. Brooke, The Bedford Inst. of Oceanography, Dartmouth, N.S., Canada

AUG. 26-30, 1974 — **National Elec. Conf. New Zealand (NELCON NZ),** New Zealand Sec. New Zealand, Nat'l Soc., et al, Univ. of Auckland, Auckland, New Zealand **Prog info:** D. R. Hutt, IEEE N. Z. Section, POB 6291, Auckland, New Zealand

AUG 26-30, 1974 — **Intersociety Energy Conversion Engrg. Conference,** ED, AES, ASME, et al, Jack Tar Hotel, San Francisco, CA **Prog info:** Hsuan Yeh, Univ. of Penna., Sch. of Elec. & Mechanical Engrs., Phila., PA 19104

AUG. 26, 27, 1974 — **Engineering in the Service of Society: New Education Programs,** IEEE's Committee on Social Implications of Technology and the Education Group, Carnahan House, University of Kentucky, Lexington **Prog info:** Prof. John S. Jackson, College of Engineering, University of Kentucky, Lexington, Kentucky 40506

Calls for papers —be sure deadlines are met.

Ed. note: Calls are listed chronologically by meeting date. Listed after the meeting title (in bold type) are the sponsor(s), the location, and the deadline information for submittals.

OCT. 9-10, 1974 — **1974 Conference on Display Devices and Systems,** IEEE, Society for Information Display, Advisory Group on Electron Devices, Statler Hilton Hotel, New York, NY **Deadline info:** (abst) 6/24/74 **to** Thomas Henion, Palisades Institute, 201 Varick Street, New York, NY 10014

OCT. 14-17, 1974 — **1974 USN/URSI - IEEE Meeting,** IEEE Groups, Geoscience Electronics, Information Theory, Instrumentation and Measurement, Antennas and Propagation, Circuits and Systems, and Microwave Theory and Techniques, University of Colorado, Boulder, Colorado **Deadline info:** (abst) 7/19/74 **to** Dr. C. Gordon Little, Secretary USNC/URSI, Wave Propagation Laboratory, National Oceanographic and Atmospheric Administration, Boulder, Colorado 80302

NOV. 18-20, 1974 — **Fourth IEEE International Semiconductor Laser Conference,** IEEE Joint Council on Quantum Electronics, Atlanta, GA **Deadline info:** (abst) 8 copies 8/1/74 **to** A. R. Calawa, Chairman Program Committee, MIT Lincoln Laboratory, P.O. Box 73, Lexington, MA 02173

NOV. 20-21, 1974 — **1974 IEEE Specialty Conference on the Technology of Electroluminescent Diodes,** IEEE Electron Devices Group, Atlanta GA **Deadline info:** (abst) 8 copies 8/1/74 **to** P. E. Greene, Program Committee Chairman, HP Laboratories, Hewlett-Packard Co., 1501 Page Mill Road, Palo Alta, CA 94304

DEC. 3-4, 1974 — **Compatibility of Energetic Materials with Plastics and Additives,** Materials Div., American Defense Preparedness Association; Picatinny Arsenal, Dover, NJ **Deadline info:** (abst) 7/1/74 **to** Frank D. Swanson, Honeywell, Inc. - Mail Station H2480, 600 Second Street North, Hopkins, MN 55343

DEC. 3-6, 1974 — **Magnetism & Magnetic Materials Conference,** IEEE-MAG, AIP, et al; Jack Tar Hotel, San Francisco, CA **Deadline info:** (papers) 8/16/74 **to** H. C. Wolfe, A.I. P., 335 E. 45th St., New York, NY 10017

DEC. 9-11, 1974 — **1974 IEEE International Electron Devices Meeting,** Electron Devices Group, Washington Hilton Hotel, Washington, DC **Deadline info:** (abst) 8/12/74 and late-news papers (200-word abst) before 10/28/74 **to** Dr. William C. Holton, 1974 IEDM Technical Program Chairman, Texas Instruments Inc., M/S 145, POB 5936, Dallas, TX 75222

DEC 12-14, 1974 — **Nuclear Sci. & Scintillation Counter Symp.,** NAP, Nasa, NBS, Shoreham Hotel, Washington, DC **Deadline info:** (abst & sum) 6/3/74 **to** G. L. Miller, ID440, Bell Labs, Murray Hill, NJ 07974

JAN. 21-22, 1975 — **Vehicular Technology Conference,** VT, Royal York, Toronto, Ontario, Canada **Deadline info:** (sum.) 6/1/74 **to** A. J. Dinnin, Bell Canada, 393 Univ. Ave., Rm. 701, Toronto, Canada

JAN. 26-31, 1975 — **1975 IEEE Power Engineering Society Winter Meeting,** Statler Hilton Hotel, New York, NY **Deadline info:** (ms) 9/1/74 **to** IEEE Headquarters, 345 East 47th Street, New York, NY 10017

JAN. 28-30, 1975 — **Reliability & Maintainability Symposium,** R, ASQC et al, Sheraton Park Hotel, Washington, DC **Deadline info:** (papers) 5/1/74 **to** J. M. Wiesen, Sandia Labs., Dept. 1750, Sandia Base, Albuquerque, N. Mexico 87115

APRIL 21-23, 1975 — **1975 International Radar Conference,** IEEE, S-AES, and the Washington Section, Washington, DC **Deadline info:** (MS) 3 copies 11/15/74 **to** Dr. Merrill Skolnik, Naval Research Laboratory, Code 5300, Washington, DC 20375

JUNE 23-27, 1975 — **Pressure Vessels & Piping for Energy Systems,** ASME, San Francisco, CA **Deadline info:** (abst) 9/2/74 **to** R. E Nickell, Div. 1541, Sandia Labs., P.O. B. 5800, Albuquerque, NM 87115

AUG. 24-30, 1975 — **International Federation of Automatic Controls (IFAC/75),** AIAA, Cambridge, MA **Deadline info:** (papers) 9/1/74 **to** AIAA, 1290 Avenue of the Americas, New York, NY 10019

Engineering News and Highlights

RCA wins Emmy Award

RCA Broadcast Systems, Camden, N.J., has received an Emmy Award for developing the first video tape cartridge system to automate tv station breaks and broadcasts of other tv program sequences recorded on tape. RCA was cited by the National Academy of Television Arts and Sciences "for its leading role in the development of the quadruplex video tape cartridge equipment."

RCA now has six Emmy's for engineering and technical achievements. This latest Emmy is for a major advance in automating television station operations. The RCA system, called the TCR-100, holds 22 video tape cartridges each capable of three minutes of playing time. The desired cartridge playback sequence is entered into the machines memory and, at the touch of a button, an uninterrupted series of commercials, promotional announcements and other programming is broadcast automatically.

The RCA Emmy was accepted at the Emmy Award ceremonies in Hollywood by **Andrew F. Inglis,** Division Vice President and General Manager, RCA Commercial Communications Systems Division of which RCA Broadcast Systems is a part.

While RCA has produced audio cartridge systems for radio stations for many years, the idea of using the cartridge method for video tape broadcasts was first broached in 1967. A design team headed by **Arch C. Luther,** now Chief Engineer of Broadcast Systems, was formed and an engineering prototype machine built and demonstrated at the National Association of Broadcasters convention in March 1969.

Awards

Government Communications and Automated Systems Division (Burlington Operations)

Hugo Logemann has received a Technical Excellence Award for March 1974 for his work on the Analogue Moving Target Indicator Study.

The Automatic Test Programming Team of **Robert A. Lindley, William C. Newmann,** and **Steven M. Schlosser** received a Technical Excellence Award for March 1974 for the successful development of concepts for automatic test program generation.

Electronic Components

P. D. Strubhar and **C. H. McKee** were instructors in a Basic Metals course given at the Lancaster plant. The course consisted of 12 lectures and it was completed in April 1974.

Thomas F. Deegan of Receiving Tube Engineering has advanced to Senior Member of IEEE.

The System Analysis Team of **Francis J. Chaples, Ralph F. Gerenz, Robert A. Monat,** and **Jack B. Nance, Jr.** received a Technical Excellence Team Award for April 1974 for the development of a method to improve the timeliness and credibility of the assessment of incoming data in a control system.

Government Communications and Automated Systems Division (Camden)

Norm Hovagimyan has received a Technical Excellence Award for the development and design of an all-electronic private automatic branch exchange (PABX).

Professional Activities

Government Communications and Automated Systems Division (Camden)

G. G. Zappasodi and **J. E. Dowd** were first-place winners in the 1974 National Packaging and Handling Competition of the Society of Packaging and Handling Engineers. Their entry, a new method of packaging a broadcast transmitter cabinet, won first place in the General Category sponsored by Better Packages, Inc. of Shelton, Conn.

Don Schnorr was Chairman of the session on "Flexible Composites in Printed Circuitry" at IEEE INTERCON this year.

Government Communications and Automated Systems Division (Burlington Operations)

Ben Piscopo received the Outstanding Article Award from the Society for Technical Communications. His article, "Word Processing" was selected from among all articles that appeared in the Society's Publication, *Technical Communication,* during 1973.

Research and Engineering

Engineering

Dr. William J. Underwood has been elected a charter member of the International Association of Applied Social Scientists in recognition of his work in internal organizational development at RCA. As Manager, Engineering Professional Programs, Dr. Underwood is responsible for several professional development programs at RCA, including Continuing Engineering Education, Technical Information Services, and Technical Communications.

Harry Kleinberg, Manager, Corporate Standards, recently discussed the problems and attitudes inherent in dealing with metrication, at a combined meeting of the Delaware Valley Chapter, Society for Technical Communication, and the Group on Professional Communications, IEEE.

Laboratories

Dr. Jan A. Rajchman, Staff Vice President, Information Sciences, has been named to the National Inventors Council by Secretary of Commerce Frederick B. Dent. The Council, an advisory committee of the Department of Commerce, is concerned with the processes of invention and serves as a forum for the discussion of issues relating to creativity and the development of inventions to meet the needs of society.

Dr. Thomas Tipton Hitch received the John A. Roebling award of the Delaware Valley Chapter of the American Society for Metals. The award is given annually for outstanding contributions to the science of metals.

Commercial Communications Systems Division

The second Meadow Lands Technology Seminar, organized by **Karl Neumann** and **Roger Wolf,** attracted a capacity attendance of 250 personnel. Presentations by **A. F. Inglis, J. Leer, A. Luther, D. Reinert, Dr. J. Hillier,** and **Dr. H. Woll** highlighted the morning and afternoon sessions.

Promotions

Electromagnetic and Aviation Systems Division

R. C. Hayes from Mgr., EW Engrg. to Mgr., Elec. Des. & Dev. Eng. (F.C. Corey, EASD, Van Nuys)

R. L. Reed from Mgr, Govt. Support Progs. to Mgr., Prod. Support Eng. (F.C. Corey, EASD, Van Nuys)

Solid State Division

T. Athanas from Ldr., Technical Staff to Mgr., MOS Integrated Circuit Technology (D.R. Carley, SSD, Som.)

M. Blumenfeld from Member, Technical

Staff to Ldr., Tech. Staff (D.R. Carley, SSD, Som.)

C. Knudsen from Assoc. Member, Tech. Staff to Ldr, Tech. Staff (D. E. Burke, SSD, Som.)

M. Oakes from Ldr., Tech. Staff to Mgr., Hybrid Programs (R.R. Giordano, SSD, Som.)

P. Roman from Member, Tech. Staff to Engrg. Ldr. (J. Assour, Mountaintop)

W. VanWoeart from Member, Tech. Staff to Ldr., Tech. Staff (SSD, Som.)

Electronic Componets

J. A. Stankey from Engrg. Ldr., Product Develop. to Mgr., C & P Laboratory (R. E. Salveter, EC, Marion)

Consumer Electronics

P. Berg from Sr. Member, Engrg. Staff to Ldr., Engrg. Staff (B. L. Dickens, CE, Indpls.)

R. D. Clubb from Engr. to Mgr., Shipboard Sys. (T. J. Barry, SvCo, Springfield)

Staff Announcements

Service Company

Edgar H. Griffiths, Executive Vice President has announced the appointment of **Julius Koppelman** as President, RCA Service Company. Mr. Koppelman will continue to be responsible for the Computer Systems on-going organization.

Government Communications and Automated Systems Division Burlington Operations

Stanley S. Kolodkin, Division Vice President, Burlington Operations, RCA Government Communications and Automated Systems Division has announced the appointment of **F. Ralph Shirak** as Manager, Automatic Test Equipment Programs.

Eugene M. Stockton, Chief Engineer, Engineering Department has announced the appointment of **Harry K. Schlegelmilch** as Manager, Radiation Systems Engineering.

John F. Currier, Manager, Tactical and Space Systems Programs has announced the appointment of **Gerald T. Ross** as Manager, Radar Program Operations.

Arthur J. Barrett, Plant Manager, Camden Plant has announced the appointment of **George H. Laning** as Manager, Materials.

Astro-Electronics Division

Abraham Schnapf, Manager, Program Management has announced the appointment of **George K. Martch** as Manager, Atmosphere Explorer Project.

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