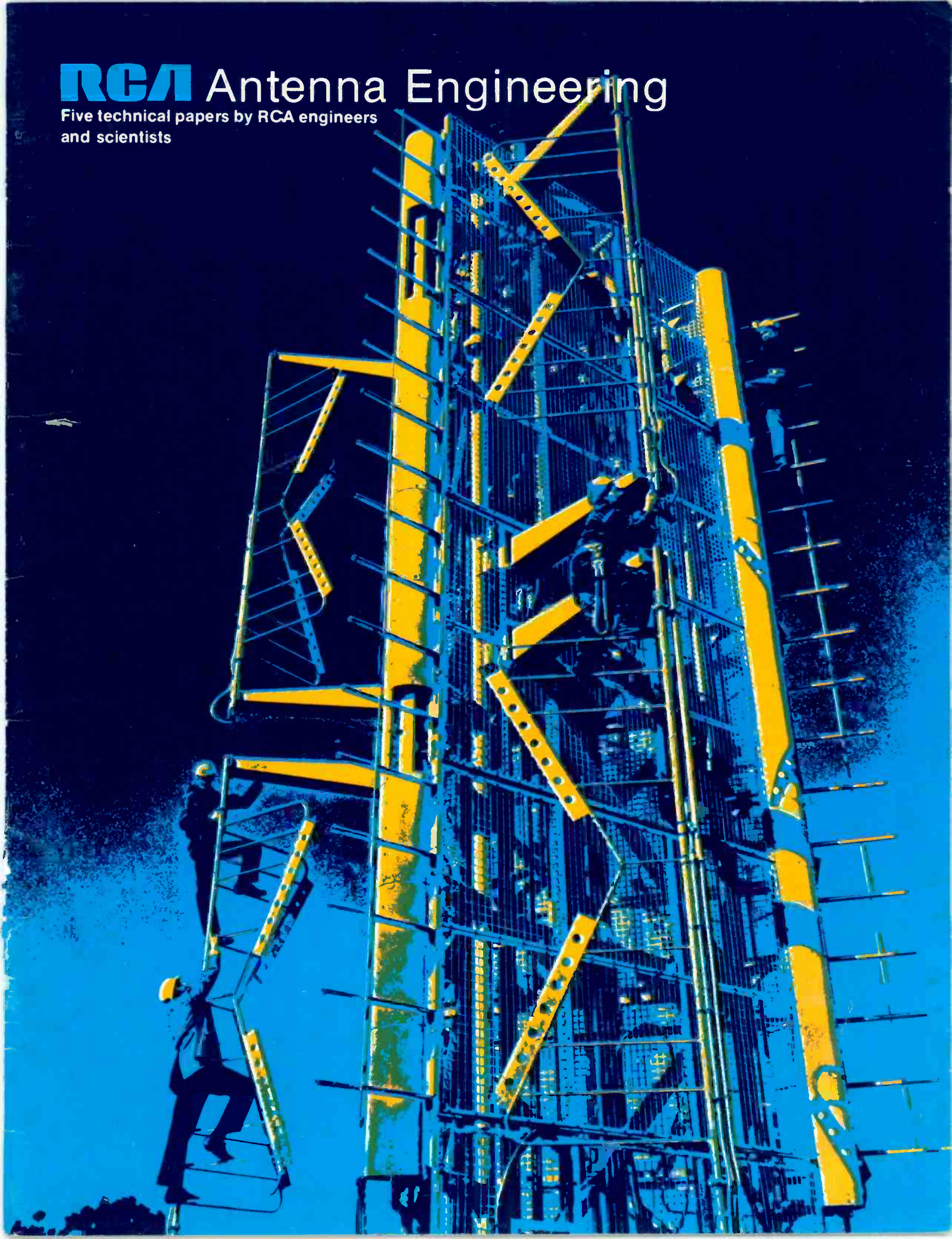
RCA Antenna Engineering

Five technical papers by RCA engineers and scientists



Antenna engineering

This booklet includes five papers that provide a sample of the wide-ranging antenna engineering design and development work carried on at RCA for broadcasting and television stations throughout the world, for military systems and for home television receivers.

The Broadcast Antenna Engineering Center is solely concerned with engineering of Antenna systems and the provision of equipment for broadcast and television purposes. Therefore, I have written an article (beginning on page 2) which describes the activities of the Broadcast Antenna Engineering Center.

This facility is staffed with dedicated broadcast antenna engineers, scientists and technicians who are devoted to the creation of antenna systems and products not only for general broadcast and television applications — but also customized antenna arrays to satisfy individual station needs ... or the needs of several broadcast and television stations where each has a distinct coverage contour requirement. The Broadcast Antenna Engineering Center also designs and furnishes compatible transmission-line equipment, filter-matching networks, and miscellaneous accessories that are designed to work together in transmitting the signal from the transmitter to the antenna.

RCA is in a unique position to act as a single responsible source for all components required in a complete transmitting system, thus simplifying the work of the broadcast station chief-engineers and consultants who must secure and maintain reliable transmitting systems.

The RCA technical broadcast field representatives listed on the inside back cover of this booklet are capable of working with the broadcast and television engineers and consultants in planning and solving problems of any complexity; these technical representatives are backed up by the services of the RCA engineers and technicians of the Broadcast Antenna Engineering Center described in this booklet.

You are invited to contact the RCA broadcast field representative serving your territory when planning your broadcast station needs. You will find these men eager to serve you not only in providing sophisticated broadcast antenna systems but in the provision of all types of a.m., fm, and television broadcast equipment.

Richard L. Rocamora

R. L. Rocamora, Manager
Antenna Engineering and Product Management
Broadcast Systems
Communications Systems Division
RCA GCS, Gibbsboro, NJ

Our cover

... features part of a new broadcast antenna complex being planned for the World Trade Center (New York City) installation. Climbing the antenna are engineer Frank Chwieroth (lower left) and wiremen Richard Carver (top left), Harold James (center), and Harry Crowthers (top right) **Photo credit:** Bill Eisenberg, GCS, Camden.

Report to the Engineering Consultant

Report No. 76

February 15, 1974

RCA ANTENNA ENGINEERING PAPERS

The enclosed booklet contains a collection of five technical papers by RCA engineers on various antenna subjects.

E. N. Luddy

Enc. PE-604

RCA Communications Systems Division

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RCA Antenna Engineering

Five technical papers by RCA engineers and scientists

Contents

RCA's broadcast antenna engineering center

R. L. Rocomora

This paper describes RCA's Broadcast Antenna Engineering Center where 70 engineers and associated technicians combine their talents to design, build, and produce about 20 basic types of fm and tv transmitting antennas in addition to custom-engineered antenna systems. Such products vary from the timeproven RCA Superturnstiles to complex multi-station antenna arrays that satisfy unique coverage requirements for a variety of viewer area contours. By employing modern computer-aided design techniques, plus full-scale horizontal- and vertical-radiation-pattern field testing ... upwards of 2000 fm and tv antenna structures and systems have been designed and produced in cooperation with engineers and consultants of the television broadcast industry. Several of RCA's antenna designs are reviewed in this article, and performance criteria and measurement techniques are described.

Richard L. Rocamora, Manager, Antenna Engineering Center, Broadcast Systems, Gibbsboro, New Jersey, received his degree in electronics from New York University in 1946. He also attended graduate courses at the Polytechnic Institute of Brooklyn and the Moore School of Engineering at the Universtiy of Pennsylvania Mr. Rocamora joined RCA in 1952 with an engineering background which included design experience in relay logic, power control systems and test instrumentation. His work at RCA included the development and design of transistorized digital communications equipment. In 1959, Mr Rocamora was made a leader of this activity. He was subsequently promoted to Manager, Digital Equipment Engineering of the Communications Systems Division, a position he held until 1964, when he assumed his present duties.

THE RCA ANTENNA Engineering Center at Gibbsboro, N. J., started in 1954 with a single building and one antenna-test-positioner (turntable) on a few acres of ground. At that time, only two or three types of broadcast antennas were being produced.

Today, the Gibbsboro complex encompasses 135 acres. It includes three large antenna test sites, two scale-model test sites, and more than 20,000 square feet in modern engineering labs, machine shops, offices and assembly buildings. The Center is now the design, development and production site for up to 20 basic fm and tv antenna types, associated transmission lines, filters, and complete custom-designed equipment systems for linking transmitter and antenna.

An organization chart of the Antenna Engineering Center and a picture of the engineering staff are shown in Figs. 1 and 2. The Center employs approximately 70 people of which about 25 are engineers. An aerial view of the center is shown in Fig. 3.

Final manuscript completed October 26, 1973.

Fig. 1 — Gibbsboro staff - from left to right: D.G. Hymas, R.L. Rocamora, Dr. M.S. Siukola, H. H. Westcott, and N. Nikolayuk.

Antenna design evolution

Early tv antenna designs were omnidirectional vhf types with gains of less than 10; a few stacked dipoles were produced, but by far the bulk of deliveries were RCA Superturnstiles.

Superturnstiles

The Superturnstile antenna is constructed with batwing shaped radiators stacked one above the other. Because of its simplicity and superb performance, this pioneer vhf antenna remains today the standard of comparison world-wide. Some 700 RCA Superturnstiles have been placed in service.

As tv allocations began to escalate in frequency, the need for new designs in high-gain antennas became apparent. On vhf channels 7 to 13, for example, the complex mechanical feed system of the Superturnstile tended to limit reliability of the antenna. Thus, a simple design with lower wind load was indicated.

TW antennas for vhf

The low wind load need led to the development of the Traveling Wave (TW) antenna and the new feed system for which it was named.[1] The rugged,

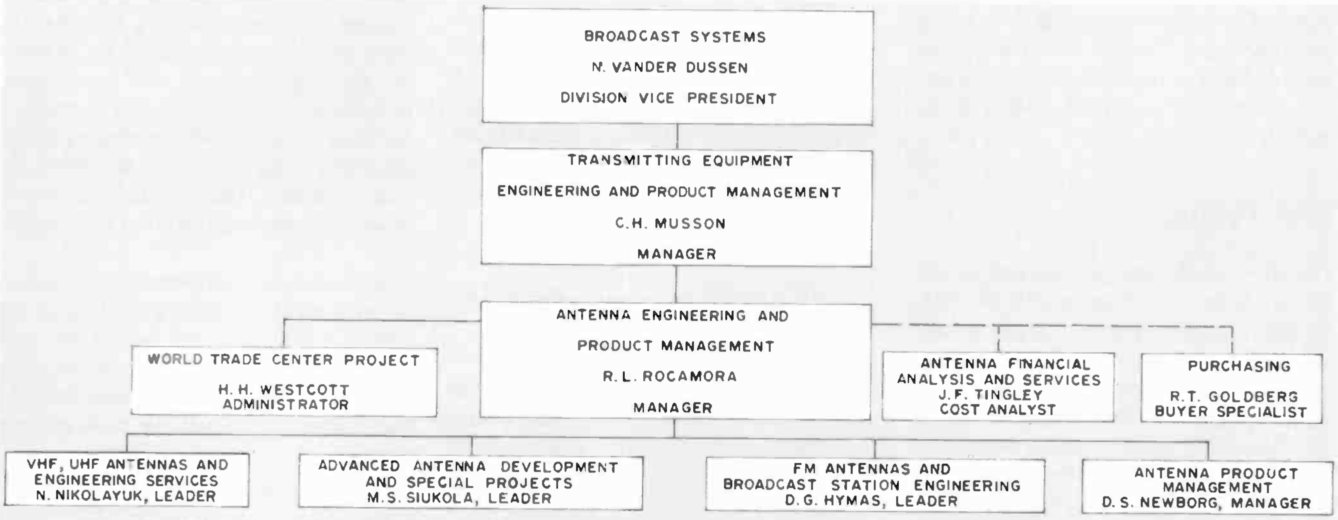


Fig. 2 — Gibbsboro antenna engineering and product management organization.

Fig. 3 — Gibbsboro Antenna Engineering Center.

enclosed feed system, connected at the base of the antenna, consists of a single inner conductor which sets up a traveling wave between it and the supporting outer conductor. Pairs of slots on opposite sides of the cylinder are fed by capacitive pick-up probes. The Traveling Wave antenna not only provides gains of 9 to 18, but gives smoother vertical patterns and better circularities than the Superturnstile. With RCA's 25-kW transmitter, the system achieves the FCC maximum 316-kW effective radiated power (ERP) for vhf channels 7 to 13 with power to spare. The TW is still one of the most popular of the vhf high-band antennas. Over 110 have been built and installed.

UHF Pylons

Gibbsboro continued its high-gain antenna development program and, in 1954, scored a major breakthrough in uhf design. This antenna, the first ultra-gain Pylon for uhf, is a slotted-cylinder type, 100 feet high, with nominal gains of up to 60.[2] Again, the radiator is an integral part of the structure, the slots being energized by a standing wave on the inner conductor. The feed system is a simple design with built-in provisions for beam-tilt adjustment. The Pylon antenna made possible the first uhf station with one million watts ERP. As a measure of broadcast industry acceptance, RCA Pylons are in use by the majority of uhf stations in this country; approximately 400 have been delivered.

Trends of the "fifties"

Beginning late in the '50's, Gibbsboro engineers sensed a changing market and responded with new products to meet its needs. The new market needs included:

- Increases in ERP and tower heights.
- Increases in use of directional antennas.
- More sharing of towers and antennas by broadcasters or sharing of common tower structures with individual antennas.

The station owner's bid for signal dominance (as reflected by the demand for increases in ERP) resulted in much original design work by RCA on antennas, transmission-line components and supporting structures. Requirements were usually for radiating the maximum power from towers ranging in height up to 2,000 feet. Several installations were made.

Zee, VeeZee, and Butterfly types

Although many directional applications were filled by the slotted cylinder antennas, the radiation patterns of these types were not optimum in some cases. This problem was met with the development of a series of uhf and vhf panel antennas known as the "Zee", "Vee-Zee" and "Butterfly." Zee and Vee-Zee panels utilize zig-zag elements.[3] The Butterfly panel[4] is based on the hardware of the Superturnstile. Panels can be face-mounted from one to five around the tower to provide omnidirectional as well as directional patterns of any desired shape. Panel antennas, with their tower-like mainframes, are advantageous in multiple antenna systems since they can be used alone or as supports for other antennas.

To meet the requirements of multiple station systems, it was necessary to develop new antennas as well as modify existing designs so they could be stacked side by side, one above the other, or both.[5] Auxiliary equipment was also introduced to permit stations to share antennas and antenna apertures.

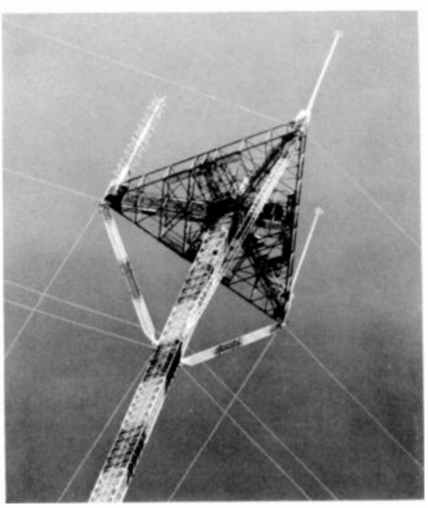
Broadband fm antennas

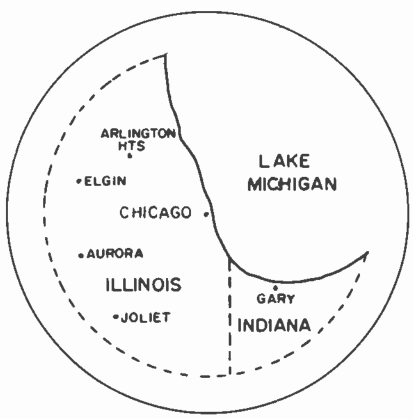
With the move to multiple-station systems and their ancillary services, the need arose for a broadband fm antenna design. Development of a broadband, circularly polarized antenna[6,7] made it possible to radiate both horizontally and vertically polarized fm signals from the same antenna. This design became the basis for future multi-station fm systems.

The mechanical and electrical constraints of stacking antennas on a platform at the top of a tall tower are numerous. And where broadcast groups form to share facilities, individual preferences must be met, sometimes under the most adverse conditions.

Multi-station arrays and candelabra designs

All broadcasters in a multi-station system vie for the same audience. Thus each is vitally interested in, among other things, his coverage and the position of his antenna on the tower. Since matters of this kind are often decided by other than engineering considerations, the antenna, which for obvious technical reasons should be at the top of the tower, may actually wind up at the bottom. But the designer must still satisfy the requirement





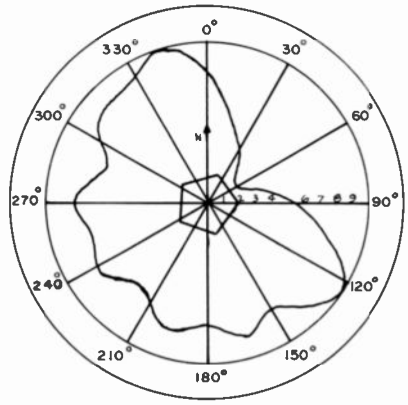


Fig. 4 (left) — Side-by-side Candelabra antenna system on tower at Sacramento, California. Fig. 6 (above) — Directional patterns of John Hancock Polygons.

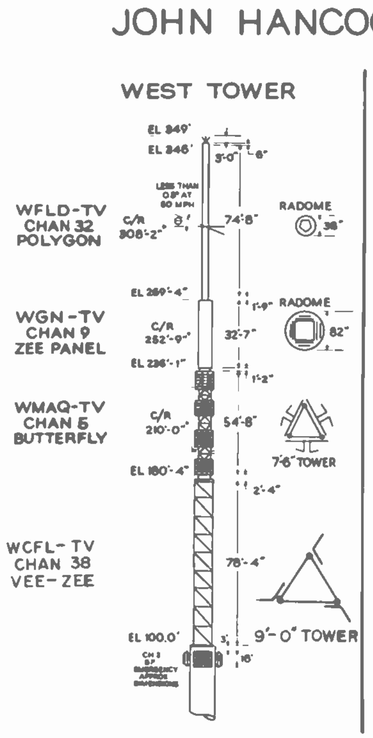


Fig. 5 — John Hancock multi-station antenna system.

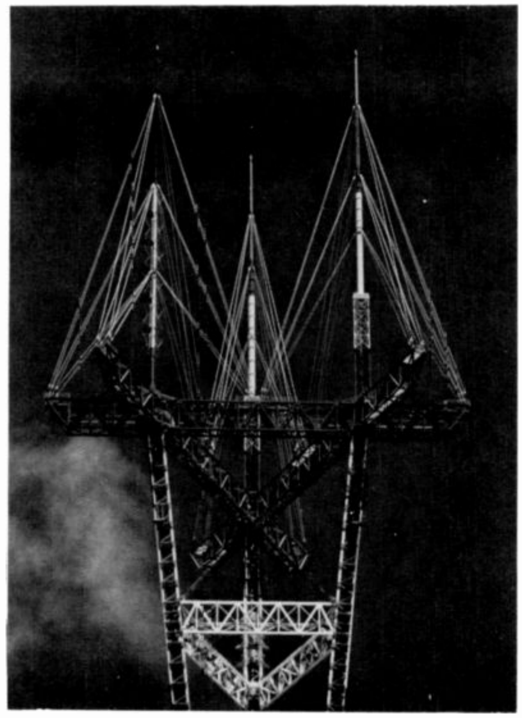


Fig. 8 — Mt. Sutro antenna system.

for a solid structure and provide antenna designs that assure good performance characteristics. This part explains the need for the wide variety of antenna types and system combinations.

Obviously the design of multiple-station tv antenna systems calls for considerable experience in analyzing the effects of scattering on the patterns of antennas operating in close proximity to each other. This was the subject of intensive study[8] as early as 1957, and the findings were used for several candelabra designs that were to follow.

In early installations, specifications of pattern circularity were verified and demonstrated by means of scale models. Subsequently, however, equally accurate theoretical methods of determining gain were formulated.[9] For several years now, these computer-based techniques have been used in design and cost estimating calculations, and most recently to provide customized vertical patterns for antenna arrays.[10]

Typical multi-station systems

The first of the multiple-station systems, following the historic Empire State Building array, were the candelabras consisting of two or more tv antennas horizontally stacked on the same platform at the top of a tower (Fig 4). RCA has equipped about 10 of these "side-by-side" systems in this country, using Superturnstiles, Pylons and Traveling Wave antennas.

Typical of more sophisticated designs are the RCA multi-station systms on John Hancock Center Building in Chicago, and on Mt. Sutro near San Francisco (Figs. 5 and 8).

Both the 6-station John Hancock system and the 11-station (7 tv, 4 fm) Mt. Sutro system combine horizontally and vertically stacked antennas. The John Hancock system employs five types, one of which is the new 5-mW uhf Polygon. There are two Polygons on John Hancock (channels 32 and 44) with patterns tailored to direct radiation around Lake Michigan (Fig. 6). This is the first use of the Polygon, a 5-sided self supporting structure consisting of zig-zag panels. The Polygon has a gain capability of 60, and can be designed for power inputs up to 200 kW.

Antenna performance criteria

All antenna types (Fig. 7) are adjusted for proper input impedance before delivery to the customer. As to other tests required, RCA broadcast antennas are categorized as follows:

1) *Product-line types* requiring no pattern or gain tests. These are the omnidirectional, medium-gain tests. These are the omnidirectional, medium-gain Superturnstile, Traveling-Wave and Butterfly types which have a history of strict adherence to calculated radiation patterns and gain figures. Proof-of-performance tests are conducted only at customer request and at extra charge.
2) *Product-line types* for which verification of vertical pattern and gain is recommended. These are the omnidirectional high-gain antennas such as the uhf Pylon and Polygon. Tolerances in the manufacture of these antennas usually contribute to some deviations from the calculated patterns, making measurement with pattern trimming advisable.
3) *Directional vhf and uhf types*. Pattern and gain tests are required for all directional antennas which, in addition to their directivity, may have a variable beam-tilt design in the azimuthal plane.
4) *Multiple-station systems*. Scale models are used to determine the effects of adjacent antennas.
5) *Circularly polarized antennas*. Special test-procedures include measurements of axial ratio and certain other parameters.[11]

Superturnstile	Zee panel
Butterfly	Vee-Zee panel
Traveling Wave	Polygon
Pylon	Mark 3 panel
FM	

Fig. 7 — Antennas in production at Gibbsboro.

Measurement techniques

Vertical patterns are recorded with the antenna lying horizontally on a rotating positioner. Azimuthal patterns are recorded on the vertical pattern positioner by rotating the antenna on its longitudinal axis, spit fashion. Azimuthal patterns can also be recorded with the antenna mounted vertically on a positioner. Where size or complexity make it impractical to mount an antenna system on standard test facilities, scale models are fabricated and tested in free space. Gain is determined by mechanical integration of the recorded patterns.

Throughout pattern measurements, the antenna under test is used as a receiving antenna in accordance with the reciprocity principle. Source antennas are selected and located so as to provide illumination of the antenna test range. Upon delivery and erection of an antenna at the customer's site, field-service engineers conduct antenna system performance tests. Since all antennas have been adjusted at the factory for proper input impedance, field tests should be minimal.

Systems must be checked after installation of transmission lines to assure that there are no excessive discontinuities, a minimum of reflections and low mutual coupling in the case of multiple installations. An rf pulse technique[12] using a vestigial sideband signal to simulate the television signal is used for reflection tests. Impedance transformers are employed when required to achieve optimum reflection levels.

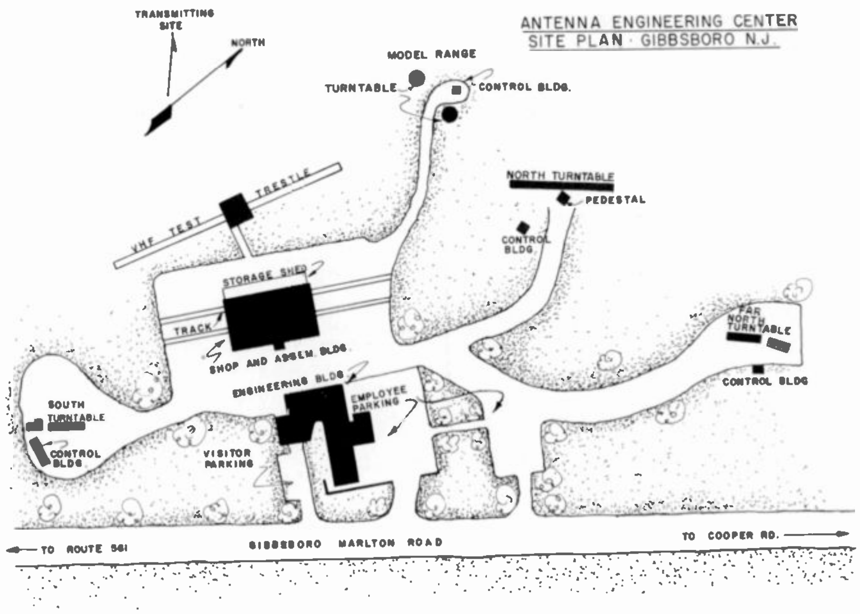
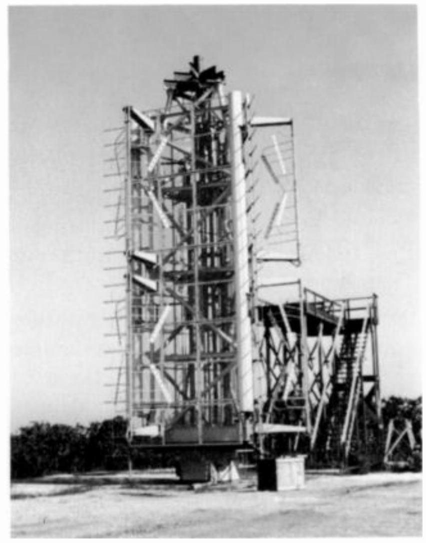


Fig. 9 — Gibbsboro facility layout.



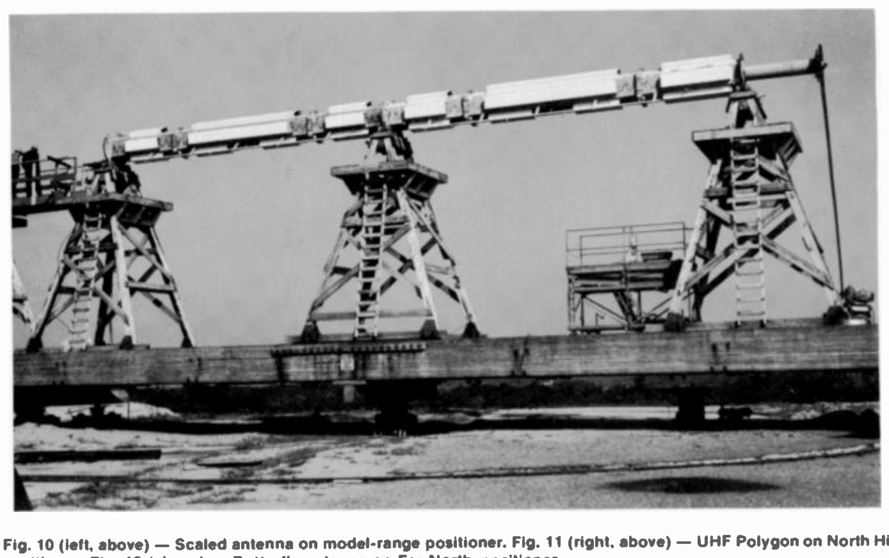


Fig. 10 (left, above) — Scaled antenna on model-range positioner. Fig. 11 (right, above) — UHF Polygon on North Hill positioner. Fig. 12 (above) — Butterfly antenna on Far North positioner.

Antenna center facilities

The 135-acre facility is laid out to provide the best possible conditions for efficient antenna handling and testing (Fig. 9). Included is a model range for design and development of antennas and filter equipment.

The Center is built around two antenna ranges, one 18,000 and the other 10,000 feet in length. Supplementing the ranges are four antenna positioners, each tailored for special requirements. Each of the following facilities (Figs 10, 11, and 12) has its own control building equipped with the most modern measurement equipment available:

1) *North Hill* is the site of the largest positioner. This facility resembles a 130-foot long barge located diametrically on a 90-foot circular rail track. Positioner capability

was recently extended to handle antennas as long as 150 feet and weighing up to 45 tons. Antennas for all tv frequencies can be supported horizontally up to 25 feet above the barge, which has an automatic spit turning system. Also at North Hill is a pedestal type positioner which is used for azimuthal pattern measurements and impedance testing of low band vhf antennas.

2) *South Hill* is the oldest facility at the Center. The positioner at this site is used primarily for uhf Pylons and high band vhf (Traveling Wave) antennas up to 120 feet long and weighing 15 tons. Panel antennas are also tested on the South Hill.

3) The *Far North* facility was added in 1967 to accomodate increased uhf business, starting with the Kentucky Educational System. The basic equipment is a pedestal-type positioner. A support trestle is normally used to measure horizontally positioned Pylon and panel antennas up to 80 feet long and weighing 10 tons. The main pedestal positioner also serves for impedance and azimuthal pattern testing of vertically mounted massive antennas such as those recently tested for the World Trade Center project.

4) The *Model Range* incorporates two multi-axis positioners for scale model antenna and system measurements.

Filters and transmission line

An equally important assignment of skills at Gibbsboro is the design of various high power filters and coaxial transmission line for use with fm and tv transmitters operating over the broadcast range of 54 to 890 MHz.

Harmonic filters are necessary to reduce harmonic output of fm and tv transmitters to the stringent levels prescribed by the FCC. Another type of filter, a combiner, is commonly used today to combine the signals from two or more transmitters for higher output power. A filter of this type was recently developed to combine the output of three 15 kW vhf transmitters into a single antenna.

The vestigial sideband filter is a single shaping filter used at the output of the television transmitter to attenuate a portion of the visual lower sideband while maintaining the passband within a fraction of a dB. The diplexer is a form of filter that must be used to combine the visual and aural transmitter outputs for vhf antennas (such as Traveling Wave antennas) onto a single transmission line feeder.

The functions of vestigial sideband filtering and diplexing have been combined in a vhf filterplexer recently introduced for the RCA TT-50FH 50 kW transmitter.[13] Filterplexers have been designed to handle power as high as 220 kW at uhf.

To meet the requirements of voltage, power and efficiency at these frequencies, filtering elements must be made of coaxial transmission line secitons or waveguide cavities, rather than of less bulky lumped constants. Even so, the heat developed often requires some form of built-in temperature compensation to eliminate filter detuning. One example is the new high power Filterplexer,[13] where cavity probes were compounded of Invar and steel to maintain proper length with temperature change.

New filter designs are assisted by computer analysis of mathematical models. They are now air cooled rather than water cooled. The capability of coaxial tv line has been increased by the use of Freon to accelerate heat transfer from the inner to the outer conductor. Proper exploitation of Freon, therefore, may be expected to increase present power ratings of coaxial transmission lines and components.

Custom designed systems

Frequently the fm and tv broadcaster desires a transmitting system different from the standard and tailored to his specific needs. To meet this requirement experienced Gibbsboro engineers work closely with the customer and Broadcast Sales to first define the optimum system and to set system specifications. A proposal is then drafted and presented to the customer.

Upon approval by the customer, the custom system is then finalized in design, fabricated and tested at Gibbsboro. On site installation guidance is often offered with the more complex systems.

The custom system engineering ranges in complexity from transmitting room installation plans showing equipment placement and transmission line routing, to RF output switching and logic circuitry for multi-transmitter parallel operation. Typical systems can be found in the Empire State Building, John Hancock Building in Chicago, Mt. Sutro in San Francisco, New Jersey Educational Broadcast Facilities, and in most major cities of the U.S. as well as some overseas.

Several custom systems originally designed by Gibbsboro are now being offered as standard items with current transmitters. For instance, approximately the first 20 paralleled tv transmitters were designed on a custom basis; a standard paralleled transmitter is currently offered as a catalog item. A circuit to sense transmitter exciter output and automatically switch to a spare in event of failure is now standard with the "F-Line" tv transmitters, while custom packaging of rf output switches in unitized cabinets led to the standard "OPTO Switch" design for vhf-tv transmitting systems.

Conclusion

The need for new types of broadcast antennas and associated equipment has grown substantially in the last two decades. The quest for higher power, the desire of broadcasters to share antenna structures, increased use of directionals, extensive activity in UHF, all have placed new emphasis on design integrity. RCA engineers at Gibbsboro have kept abreast of these requirements by carrying out the following programs:

1) Initiating state-of-the-art solutions to system problems,
2) Maintaining a sophisticated test range to verify concepts, and most importantly,
3) Continuing to provide antenna equipment with a performance and acceptance record that is unmatched anywhere in the industry.

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New VHF filterplexer

D. G. Hymas | J. J. Matta | P. C. Noll | A. N. Schmitz

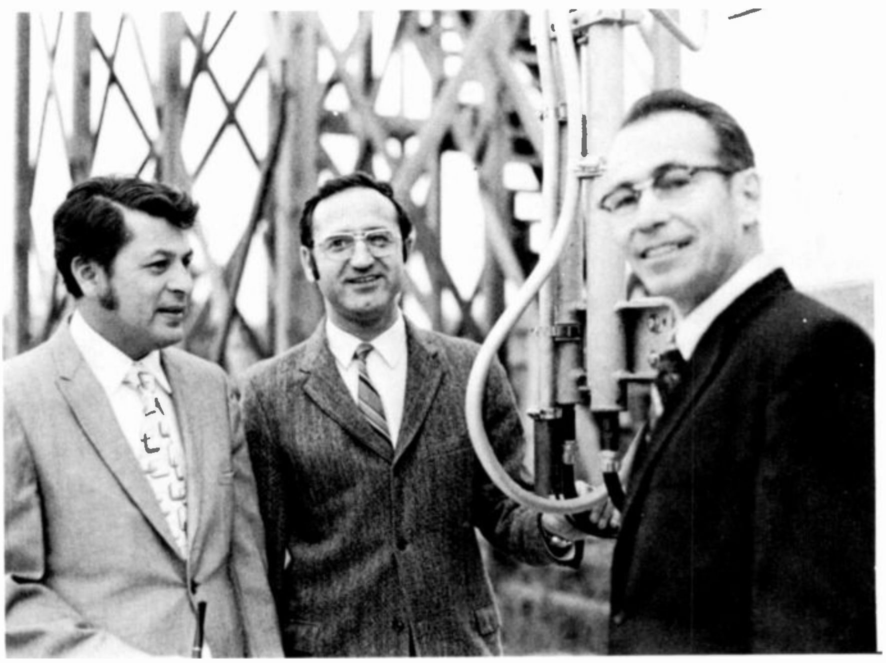
The recently introduced RCA TT50FH television transmitters for Channels 7 through 13 have a new filterplexer at the output shaping the lower sideband visual signal (50kW peak) and combining the aural signal (10kW) into a single coaxial transmission line. More stringent transmission standards have been introduced with increasingly more emphasis on idealized performance in all parts of the transmitter including the filterplexer.

Anthony N. Schmitz, Antenna Engineering Center, Broadcast Systems, Gibbsboro, New Jersey, received the BSME from California State Polytech in 1959. From 1959 to 1963, Mr. Schmitz was with the Missile and Surface Radar Division where he worked on the design of bandpass filters, temperature stabilized klystrons and high power RF loads. Since joining the Antenna Engineering Center, he has been engaged in the design of filterplexers, cavity temperature compensation systems, transmission-line components, 3-dB. couplers, notch diplexers, sidebased filters, antennas and RF load systems. He has a patent for a method to improve the average power capability of coaxial transmission lines and a patent pending on a heat resistant ferrite coating.

Joseph J. Matta, Antenna Engineering Center, Broadcast Systems, Gibbsboro, New Jersey, received the BS in Physics from St. Joseph's College in 1951. He subsequently completed post-graduate courses in Advanced Math from the Moore School of Engineering. His experience includes development of high power RF loads and transitions for the BMEWS project and includes a patent in conjunction with this project. In Commercial Broadcast TV Systems, he was project engineer for the first high power UHF waveguide filterplexer, also FM and VHF notch diplexers, triplexers, UHF hybrid filterplexer and the VHF coaxial filterplexer

Donald G. Hymas, Ldr., Antenna Engineering Center, Broadcast Systems, Gibbsboro, New Jersey, received the BSEE from the University of Alberta, Canada in 1949 and the MSEE from Moore School, University of Pennsylvania in 1960. Following graduation, he worked for Canadian General Electric from 1949 to 1953 in radio receiver design and on various communication systems projects, the principal one of which was one linking Pinetree early warning radar sites. Since 1954 he has been with RCA working in the microwave communications field involving message, data, and television relaying, and since 1970 as Leader in Filter Products, Transmission Line and FM antennas at Gibbsboro, New Jersey. Mr. Hymas is a Registered Professional Engineer of the Province of Ontario and a member of the IEEE.

Authors (left to right) Schmitz, Matta, and Hymas.



MODERN television transmitting antennas for the VHF high-band channels (such as the RCA traveling-wave antennas) employ a single coaxial line as the feeder from the television transmitter to the tower-mounted antenna. The visual and aural transmitter outputs must be diplexed onto the single transmission-line feeder and in addition the double sideband visual signal from the transmitter must be filtered forming a vestigial sideband signal to confine the radiated modulation components within a 6-MHz channel assignment (see Fig. 1). A *filterplexer* combines the functions of vestigial sideband *filter* and *diplexer*.

The electrical operation of the filterplexer may be visualized by reference to the equivalent circuit (Fig. 2). Here, the resonant coaxial cavities actually used in the filterplexer are represented by lumped circuits. The 3-dB coaxial couplers used

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Phillip C. Noll, Antenna Engineering Center, Broadcast Systems, Gibbsboro, New Jersey received the BSEE from Purdue University in 1952 and MSEE from Drexel Institute of Technology in 1965. He continued with additional post-graduate study at the University of Pennsylvania . He joined RCA in 1952, working in the Vacuum Tube Division at Cincinnati, Ohio. In 1953, he transferred to the Antenna Engineering Center. Since that time, he has participated in design projects on sideband filters, filterplexers, and other high power circuit components. Mr. Noll's recent projects include Television and FM multiplexing equipment for the new World Trade Building in New York City. He is a member of Eta Kappa Nu, and IEEE.

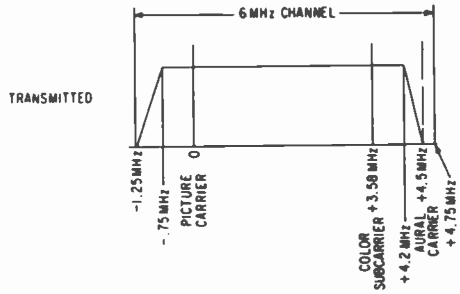

Fig. 1 — Idealized transmission characteristics.

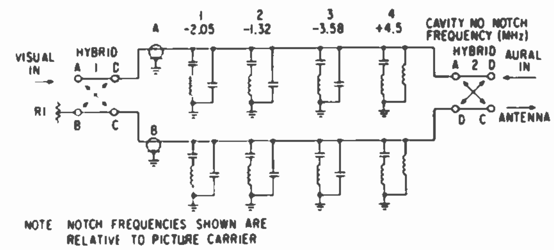

Fig. 2 — Filterplexer equivalent circuit.

at input and output are identified as hybrid 1 and hybrid 2. These 4-port devices may be visualized as tightly coupled directional couplers that have the following properties:

Power splitting
a) A signal applied at port *A* divides with half the power delivered to port *C* and half to port *D* and little or none at port *B*. The signals at ports *C* and *D* are in phase quadrature.

Combining
b) If equal-power quadrature-phase signals are applied at port *A* and *B*, the signals add at port *C* and little or none appears at port *D*.
c) The bandwidth is 30 to 40 MHz. Despite the physical length of λ/4, the quadrature phase relationship holds for frequencies far off band center.

Diplexing
d) From b) above since port *D* is effectively isolated from port *A*, a second signal may be applied at port *D* and this signal from the symmetrical property of this device will be divided with half delivered to port *A* and half to port *B* with little or none to port *C*. The signals at port *A* and port *B* will be in phase quadrature.

Consider now the visual signal applied at port *A* of hybrid 1. The signal splits (quadrature phase, equal power) to feed the two coaxial lines (*A* and *B*), each with four cavities, series resonated at the following frequencies (referenced to picture carrier):

Cavity No.	*Resonant freq. (MHz)*
1	-2.05
2	-1.32
3	-3.58
4	+4.5

The four cavities are parallel resonated near picture carrier. Each cavity places a low impedance across the line at the series-resonant frequency so the energy at this frequency is almost totally reflected back to hybrid 1. The spacing of cavities on line *A* with respect to hybrid 1, port *D*, are the same as those on line *B* with respect to hybrid 1, port *C*. Therefore, the reflected signal from cavity 1*A*, for example, adds in phase with that from cavity 1*B* at hybrid 1, port *B*, where the unwanted signal is absorbed in load R1. Very little of this reflected signal is returned to hybrid 1, port *A*. The portion of the visual signal between -0.75 MHz and +4.18 MHz, relative to the picture-carrier frequency, passes through branches *A* and *B* with little attenuation and is delivered to the antenna at hybrid 2, port *C*.

The aural signal is applied to port *D* of hybrid 2 and is split (quadrature phase, equal power) to feed the two coaxial lines —*A* and *B*. Most of this signal is reflected by cavities 4A and 4B and returned to the antenna via hybrid 2, port *C*. Leakage of the aural signal past cavities 4A and 4B is absorbed in the terminating load R1 connected to hybrid 1.

Design program

The initial design was assisted by analysis of a mathematical model using a computer program developed in Fortran IV. A 2x2 matrix was formed for each of the parallel coaxial lines with cavities. These were combined into a 4x4 matrix which was then analyzed in tandem with a 4x4 matrix for each hybrid. Cavity slopes, resonant frequencies, and spacings were then varied to establish required production tolerances for the required transmission performance specification.

The next phase of the program was the development of the resonant cavities with the required parameters. Particular attention at this phase was directed to designing safe voltage margins into the product. Each of the parallel lines of the filterplexer must handle 25 kW, peak visual power. Thus the peak voltage is given by

$$V_{peak} = \sqrt{2 \times 25{,}000 \times 50}$$
$$= 1580 \text{ V}$$

The cavities were successfully tested with a transmitter at these peak powers. Tests were not extended to actual breakdown, as the transmitter power was not available at this time.

A most critical part of the design was the frequency stabilization of cavities against ambient temperature variation. The principle used is discussed in the next section.

Principle of cavity temperature compensation

The resonant frequency of a cavity can be represented by a series LC circuit where the resonant frequency is a function of the inductance and capacitance of the cavity. The inductance L is a function of the length the probe protrudes into the cavity and the capacitance C is a function of the gap between the probe tip and the cup. As the ambient temperature rises, the outer shell of the cavity and the probe increases in length causing the cavity to detune.

The problem then becomes one of controlling the probe length so the product LC remains constant. This was accomplished by making a compound rod with a portion of the length of invar and the remaining portion steel. Typical frequency shift curves are shown in Fig. 3.

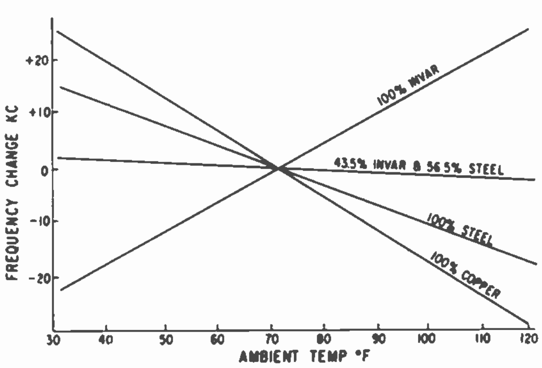

Fig. 3 — Frequency drift *vs.* ambient temperature.

Table I — Filterplexer specifications.

	New Filterplexer	*Previous product*
Visual amplitude response (dB normalized)		
-4.25 to -1.25 MHz	-20	-20
-3.58 MHz	-42	-42
-0.75 to 4.0 MHz	-0.6	—
-0.5 MHz	—	-0.75
0 to +4.0 MHz		+0.3 to -1.0
+4.18 MHz	-1	-1.5
Input return loss (dB)		
Visual		
-4.25 to -1.25 MHz	20.9	20.9
-1.25 to +4.0 MHz	31	26.5
+4.0 to -4.18 MHz	26.5	23.2
Aural	20.9	20.9
Efficiency (%)		
Visual	95.5	94
aural	90	92
Size LxWxH (in.)	96x47x34	90x87-1/2x29
Cooling	Forced air	Water

All cavities are cooled from a single forced-air blower and manifold distribution system properly portioning the flow to cavity pairs in relation to the heat dissipation requirements.

The probe is designed so that the power losses (due to heating of the probe assembly) influence the compensation. Air that is heated in proportion to power losses is circulated around the compound rod. Thus stabilization is optimized for varying power input level to the cavity as well as varying ambient temperatures.

This portion of the design program was accomplished in the following sequence:

1) Analysis of mathematical model of each cavity which included the temperature distribution along the cavity axis and radial distribution.
2) Synthesis of a model in breadboard form, using suitably placed heaters to achieve the temperature distribution postulated in the model.
3) Temperature compensation of the breadboard.
4) Power tests on the cavity model.
5) Selection of air–cooling system with proper manifolding for the complete filterplexer.
6) Power tests on the complete filterplexer.

Performance standards

What are the ideal standards for filterplexer performance and how closely are they approched with the new model? The standards are based on transmission characteristics for visual and aural channels and effective isolation between these channels.

The Federal Communications Commission, the regulatory body governing domestic broadcast transmission, specifies that the shape of the transmitted visual channel shall be in accordance with Fig. 1. This illustrates the lower sideband shaping of the amplitude modulated visual signal required to confine the radiated modulation components in the assigned 6-MHz television channel band.

In addition to the amplitude shaping requirements, the filterplexer must provide a good impedance match throughout the modulation band to the transmitter and must have low attenuation (high transmission efficiency) at the visual channel carrier frequency.

The aural channel requires no amplitude shaping; however, a good impedance match and low attenuation must be provided across a band of ±50 kHz centered at picture carrier frequency plus 4.5 MHz. The standards on isolation between visual and aural channels are set by the transmitter designer to:

1) Control level of intermodulation products that may be generated in the transmitter output amplifiers if such isolation is not provided. These products may be radiated if not properly attenuated in the design.
2) Minimize effect on the output metering circuits of visual and aural transmitters particularly those monitoring output load VSWR.

Table II — Filterplexer measured data.

Frequency (MHz) *Rel. to pix carrier*	*New product, chan. 8* Normalized Atten. *(dB)*	*VSWR*	*Previous product, chan. 8* Normalized *Atten. (dB)*	*VSWR*
−4.5	21.7	1.03	25.6	1.03
−3.58	54.8	1.02	51.6	1.03
−3.2	31.1	1.01	21.6	1.025
−2.75	26.5	1.02	21.1	1.025
−2.05	57.2	1.035	20.6	1.02
−1.42	—	—	42.6	1.01
−1.6	21.7	1.050	42.6	—
−1.32	36.0	1.070	—	—
−1.25	21.0	1.065	21.6	1.01
−1.0	2.7	1.040	10.4	1.02
−0.75	0.3	1.040	3.6	1.03
−0.5	0	1.035	0.4	1.02
0	0	1.035	0	1.02
0.75	0	1.035	0	1.04
1.75	0.1	1.045	0.6	1.06
2.75	0.28	1.045	0.8	1.09
3.25	0.32	1.040	0.8	1.10
3.75	0.21	1.035	0.6	1.10
4.0	0.47	1.020	0.2	1.08
4.18	0.95	1.035	1.0	1.14
4.5	25.6	1.125	31.7	1.24
4.75	6.4	1.092	10.5	1.11
Isolation (dB)	36.4		31	
Visual to Aural	36.41		31	
Aural to Visual	50		47	
Efficiency (%)				
Aural	90		91	
Visual	95.5		95.5	
Aural VSWR	1.02		1.17	

A comparison of specifications for the new filterplexer and those for the predecessor are shown in Table I. Measured performance data on a production unit are shown in Table II together with corresponding data for the previous product.

Principal differences in this design from previous units are the following:

1) Addition of pair of cavities in the lower sideband to improve the response at −0.75 MHz.
2) Improved passband response.
3) Use of 3-dB coaxial coupler instead of bridge diplexer. This resulted in a more compact assembly despite the two additional cavities.
4) Forced-air cavity cooling instead of water.
5) Cavity temperature compensation.

Conclusions

Some of the design considerations of a television transmitter filterplexer have been described. Emphasis in the development program was placed on performing full power tests on cavity models as early in the program as possible to verify calculated voltage margins and temperature compensation requirements. Full power tests were also performed on a complete filterplexer prior to production for customer orders.

Future improvements in the design are under review. Significant product cost reduction might be achieved with the advent of high power circulators to isolate transmitter output amplifier from the filterplexer. With the consequent possible relaxation of input impedance requirements three visual cavities might be eliminated in the present eight cavity design. Improvements in material plating technology are being studied for possible lower cost substitutes for copper presently used in the cavities for high electrical and thermal conductivity as well as structural strength.

Acknowledgment

This development program was initiated under the direction of Roger E. Wolf now Manager Television Transmitter Engineering Meadow Lands, Pa.

Computer-aided design of vertical patterns for TV antenna arrays

Dr. Krishna Praba

A method for filling nulls in the vertical pattern of a broadcast TV antenna has been developed and applied. This computer-based technique, now being used by the Communication System Division, compares favorably with other methods. The computer program is versatile and the synthesis technique has been especially successful since the designer is in the decision loop. However, further work is needed to improve the optimization methods.

SEVERAL METHODS of synthesizing the vertical patterns of antenna arrays for television broadcasting have been developed.[1,2,3,4] All of them refer to arrays having identical elements. In arrays consisting of panels that are themselves several wavelengths long, the vertical pattern of the panel itself may have, in effect, a null in the region of interest. To avoid such a null, the array can be made up of shorter panels, but the number of feed points is increased thus reducing reliability. Another method for overcoming the problem is to combine one short panel with several longer panels to make up the aperture. This combination of short and long panels established a need for a general method of solving a variety of null-filled patterns with simplified illumination currents. A computer-aided design technique was developed a few years ago to assist in the synthesis of such arrays. The program, now available on a time-sharing terminal, allows the user to fill the nulls to the desired extent and also to reduce side lobes. When necessary, constraints may be imposed on the amplitude or phase of the currents in one or several panels.

The magnitude of the unfilled array pattern around the main beam is, of course, considerably greater than that at other angles. Further, the main beam may be tilted to any desired location by progressively phase-shifting the currents of the panels. A null-filled pattern can be considered to be made up of an unfilled primary pattern whose main beam is located at the desired angle and one or several more unfilled patterns whose main beams are located at the primary pattern nulls to be filled. The illumination currents for the final pattern are the sum of all these illuminations. Adjust-

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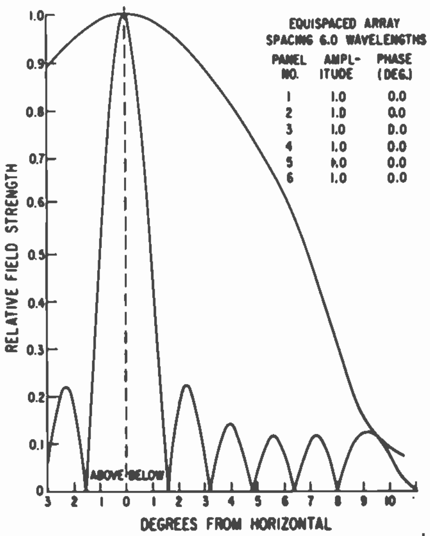

Fig. 1—Uniformly illuminated equiphase array.

ment of the phase of the secondary illuminations results in reducing or increasing the magnitude of the pattern at the desired angle, thus accomplishing null fill or side-lobe reduction. In general, the starting point is not restricted to unfilled array illumination. Thus, previous solutions can be improved upon, reducing the solution time considerably.

The technique compares favorably with all the other methods and has been extensively used in antenna array synthesis. When the current in a panel is constrained in magnitude or phase, that particular panel current is readjusted to the constrained value. The method is faster in that the null filling is restricted to the desired nulls only, instead of specifying the entire range. In addition, no gradient calculations are necessary, as is the case in steepest descent techniques.

General considerations

The vertical pattern $P(\theta)$ of an antenna consisting of N panels, at a depression angle θ is given by

$$P(\theta) = \sum_{i=1}^{N} p_i(\theta) A_i \exp(j\phi_i) \exp[j(2\pi/\lambda)]\, d_i \sin\theta \qquad (1)$$

where $p_i(\theta)$ is the vertical pattern of the i^{th} panel; A_i is the amplitude of the current in the i^{th} panel; ϕ_i is the phase of the current in the i^{th} panel; and d_i is the location of the i^{th} panel. In TV applications, only the normalized magnitude of the pattern is of interest.

For an array consisting of N identical panels spaced uniformly apart and carrying identical currents, the expression of the vertical radiation pattern is given by

$$|P(\theta)| = |p(\theta)|\,|\sin[(N\pi d/\lambda) \sin\theta]/N \sin[(\pi d/\lambda)\sin\theta]| \qquad (2)$$

where $p(\theta)$ is the vertical radiation pattern of the panel and d is the spacing. When $p(\theta)$ is a constant (unity since it is a relative field pattern), the function $P(\theta)$ repeats itself for every λ/d in $\sin\theta$ and has nulls at $(Nd \sin\theta/\lambda = \pm m$, for $m = 1, 2, \cdots)$. A plot of Eq. 2 for $p(\theta) = 1$ is available in many texts.[5] The unfilled pattern for a six-layer Zee-panel array is shown in Fig. 1.

To provide adequate coverage for television broadcasting, the nulls in the radiation pattern in the coverage area cannot be tolerated. In most cases, the customer specifies the extent to which the nulls are to be filled. The desired amount varies with the type of coverage area, their distances from the antenna, the height of the antenna, its effective radiated power, *etc.* The desired pattern to achieve a 100-mV/m signal in the coverage area, is shown in Fig. 2, based on the FCC data.[6]

Any specified tilting of the beam below the horizontal is easily achieved by progressive phase shifting of the currents in each panel by an amount equal to $-2\,(\pi/\lambda)\, d_i \sin\theta_T$, where θ_T is the required amount of tilt. Minor corrections, necesssary to account for the panel pattern, can be easily determined by iteration.

When the nulls of a pattern are filled, the directivity of the pattern is reduced. This reduction in gain is to be kept as low as possible. A typical gain loss of 1 to 2 dB is generally encountered.[7] A good approximation of the gain reduction is the ratio of the beam maximum of Eq. 1 to that of an array in which the beam maximum is maximized for the same power input. In a uniformly spaced array with identical elements, the beam maximum is maximized when all the currents are equal in magnitude and the beam is tilted to coincide with the maximum of the element pattern.

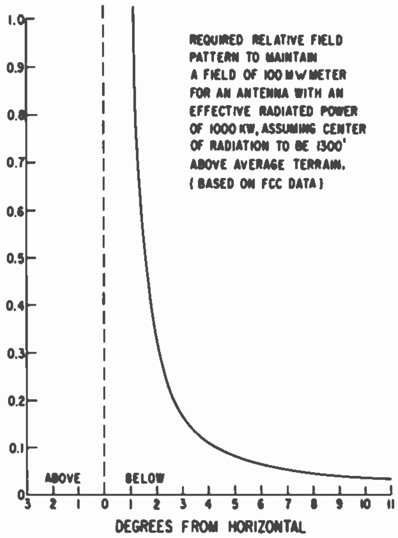

Fig. 2—Desirable relative field pattern.

In the case of an array with two different element patterns, the power into the panels is to be proportional to the gain of the panel pattern, assuming that the panel beam tilts are the same and mutual coupling between panels can be neglected.

In some cases, it is not only necessary to fill the nulls, but it is also desirable to reduce the levels of the sidelobes, so as to increase the gain of the pattern.

Null-filling methods

The variables available for pattern null filling are the spacings of the panels and the amplitudes and phases of the exciting currents. The spacings are generally chosen for the full utilization of aperature and the gaps between the panels are just sufficient to reduce mutual coupling between adjacent panels. Hence, the only variables available are the $2(N\text{-}1)$ amplitudes and phases.

In split-feed systems, one of the simple methods of null filling is by power division between the panels. For example, a 70:30 power division between each half of the array produces a 13% fill of the first null, but the even nulls are not filled. If this method is extended to fill all the nulls, the resultant power division is not acceptable in practice. But power division is usually employed where only the first null is to be filled. A typical pattern is shown in Fig. 3.

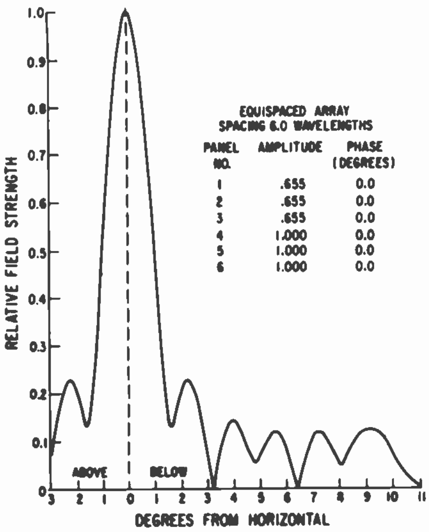

Fig. 3—Equiphase array with power division.

A similar approach to null filling by changing the phases of the currents is very useful, since the power fed to the antenna is maximized. In an array are equal for maximum power input; in some other arrays, the amplitudes are adjusted in proportion to the power ratings. For example, if the bottom and the top layers of an N-layer array differ in phase by ϕ from the rest, the first $[(N/2)-1]$ nulls are filled. The amount of null fill is ap- of identical elements, the amplitudes proximately

$$(4/N)\sin(\phi/2)\cos[\pi N d \sin\theta/\lambda]$$

The side-lobe levels tend to be high.

One of the classical methods of null filling in which both phases and amplitudes are modified, is the "Woodward Quadrature Method."[2] The successive nulls are filled by the elementary uniform array which is shifted by progressive phase to the required null location and is in quadrature with the main illumination. The solution is the algebraic sum of all such elemental illuminations. The method has been used successfully in the design of antenna arrays.[3] Generally, one has no control on the side lobes and constraints are not applicable. Equal amplitude constraint can also be imposed by correcting the amplitudes of the current back to unity.[9]

Computer-aided design

The following method is similar to "Woodward's" procedure except that the quadrature requirement for the null filling part of the illumination is removed. A plot of the array pattern, as in Fig. 1, indicates that the magnitude around the main beam is considerably greater than that at other angles. The panel element pattern further enhances this effect by reducing the secondary main lobes as well. The main beam is shifted to any depression angle θ by progressively phasing the panel current by an amount equal to $(-2\pi d_i/\lambda)\sin\theta$. If the pattern is to be raised or lowered at any angle θ_M, a second illumination of the array with a progressive phase shift in the current and an additional constant phase is added to the primary illumination. In this case, the current I in the panel i is modified to

$$I_i = A_i \exp(j\phi_i) + \sum_{M=1}^{L} k \exp \left\{ j[(-2\pi/\lambda) d_i \sin\theta_M + \alpha] \right. \quad (3)$$

If α is in phase with the pattern corresponding to all the A_i and ϕ_i, the resultant pattern due to the new currents is increased by an amount proportional to k at θ_M. If α is out of phase, the resultant pattern is reduced. If k is proportional to A_i, the normalization is accomplished. Minor variations in the pattern around the angle θ_M can be accounted for by successive iterations. If the currents are to be fixed in any of the panels (for example, in the case of power constraint), the magnitude of the current is readjusted to the original value. In such a case, the resultant pattern improvement is reduced and more than one iteration is necessary. It has been found that the number of iterations to arrive at the final solution are reduced considerably if a partially filled pattern is chosen as a starting point. Hence, most of the derived solutions are generally stored for future use as a starting point.

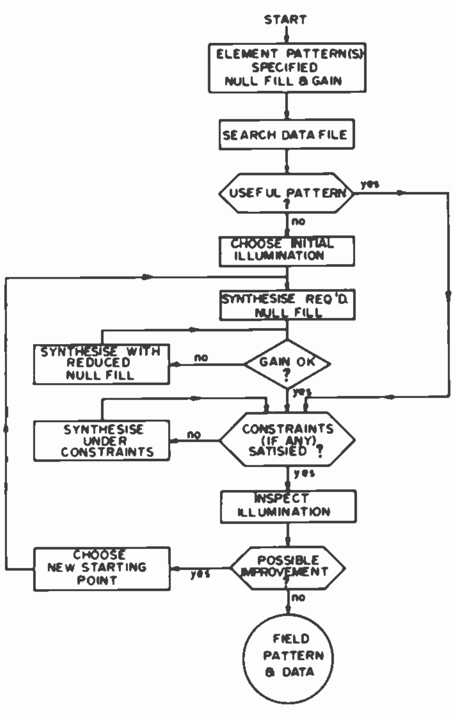

Fig. 4—Computer aided pattern synthesis, flow chart.

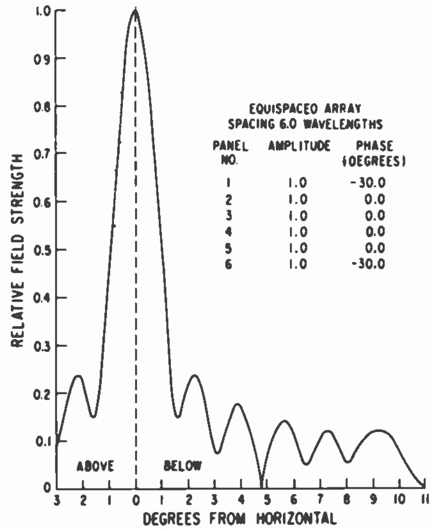

Fig. 5—Uniformly illuminated array with variable phasing.

Results

A computer program (Fig. 4) using the above method has been in use for several years. The following examples are illustrative of the results that have been obtained.

Example 1 (Fig. 5): With all the amplitudes equal, the first two nulls are filled by phase perturbation of the top and bottom panels of a six-layer antenna. This solution is often used as a starting point, as is the case for examples given below.

Example 2 (Fig. 6): The third null is filled by shifting the pattern to the depression angle where it occurs with an in-phase illumination. Two iteration steps were required to achieve 5% null, since all the amplitudes were constrained to be equal.

Example 3 (Fig. 7): From the above pattern, all the nulls were raised by removing the amplitude constraint. A second iteration was needed to raise the fourth null to 7.5% from 4.7%. The maximum power in any panel is

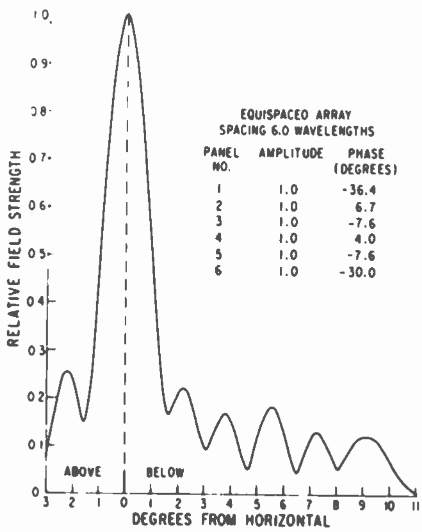

Fig. 6—Uniformly illuminated array with variable phasing, improved.

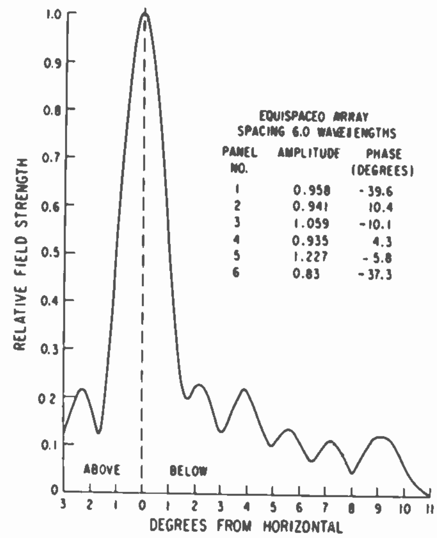

Fig. 7—Array with power division under phasing.

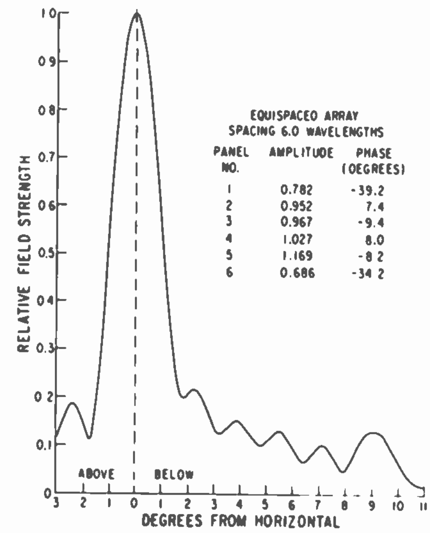

Fig. 8—Array with power division under phasing, improved.

24% instead of 16.7% in the equal-amplitude case.

Example 4 (Fig. 8): The second lobe at 3.7° below the horizontal in *example 3* is almost equal to the first lobe at 2.2°. This was reduced to produce a smoother pattern. Two iterations were required to keep the nulls filled to the same level.

Example 5 (Fig. 9): In this high gain antenna consisting of eleven panels, one of the middle panels is shorter than the other panels. The longer panels have a null at 9°. The array is tilted to 0.75° and the coverage is compared with 100-mv/mm curve derived from FCC data.

Only simple examples have been shown. The pattern shaping is not necessarily restricted to a null or side lobe. The computer program is quite versatile and the synthesis technique has been especially successful since the designer is in the decision making loop.

Further work

One of the major problems in antenna arrays is pattern stability across the channel bandwidth. The problem is more severe in the case of multiplexed antennas. Simplified feed-system compensation is not economical. In such cases, the compensation for phase changes in the feed system has to be accounted for. Work has been done on the optimization of antenna illumination taking into account the feed system of the array.[10] Another problem is to determine whether any particular solution of the antenna array synthesis is the optimal one or whether a higher gain could still be obtained. An extension of the earlier work is underway.

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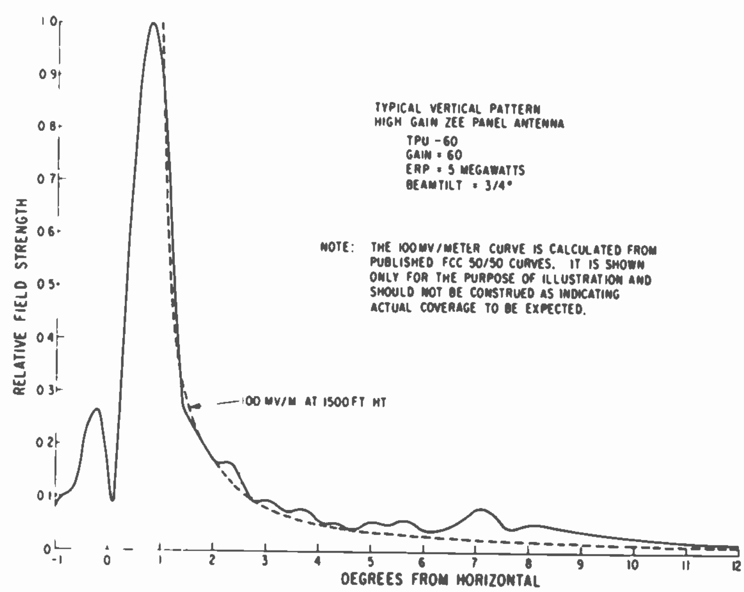
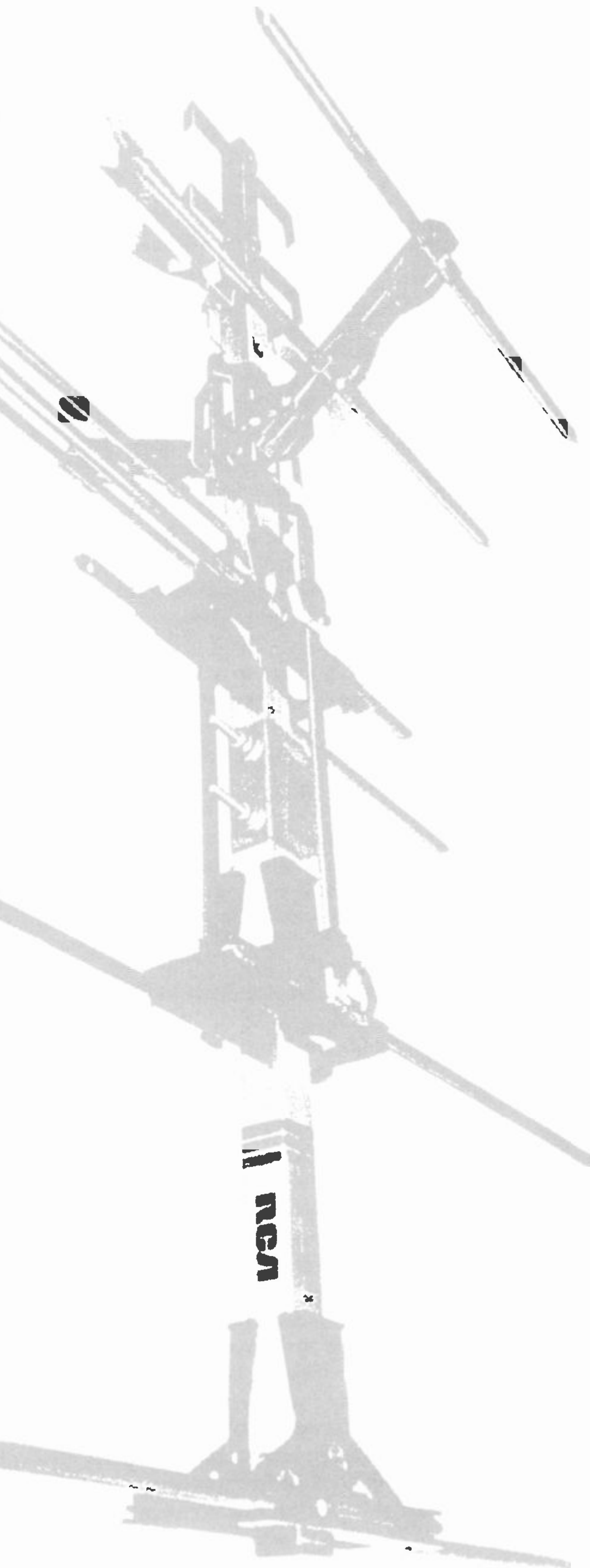


Fig. 9—Typical antenna patterns.

Television receiving antennas in blue and gold

J. D. Callaghan | D. W. Peterson

The profitable television receiving antenna product-line, being designed and produced by RCA Parts and Accessories, demonstrates the success that can be obtained by entrepreneurship within divisional boundaries of a large corporation. The necessary elements of such success are the recognition of a viable market, the ability to reach it, and the talent to produce product at a competitive cost. Add a management team with the wisdom and foresight to identify and exploit these elements and the courage to make the necessary investment and the result is a new area of profit where none had previously existed. This paper describes the engineering effort behind the development of the current RCA product line of "blue and gold" TV receiving antennas and how its success has paved the way for the introduction of other product lines into market areas previously untouched by RCA.



RCA PIONEERED in the design and sale of television receiving antennas. However, the antenna business was only an adjunct to the home instrument business and, as such, was isolated from the mainstream of television receiver design and manufacture. Consequently, RCA was an early dropout.

In 1966, the RCA Parts and Accessories Division at Deptford, New Jersey, re-entered the receiving antenna business and, in 1970, introduced a new line of RCA-designed antennas; this new line has proven to be an outstanding success. The "Permacolor" antenna line illustrates how RCA may profitably enter well-established small markets.

The television receiving antenna industry produces a national aggregate gross income of about $50-million annually and is dominated by several relatively small manufacturers who have been in existence from the early days of TV. For most of the major manufacturers, antennas represent a substantial proportion of their total business. This means that they must organize their manufacturing along quite simple and efficient lines to make their product highly cost competitive. To re-enter this business, RCA had to implement an effective plan which would entail full control of engineering, manufacturing, and marketing—a plan that would equal or exceed the efficiency of major competitors.

This was accomplished through several phases. The first phase involved specifying and procuring a line of antennas from

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a competitor for exclusive sale by RCA. There are many drawbacks to buying from a competitor; but there was no other practical way since, at the outset, it had been decided that marketing, engineering, and manufacturing organizations were to be established on a pay as-as-you-go basis utilizing profits from antenna sales. There are several major drawbacks to this approach:

1) A necessary economy in marketing antennas is the drop shipping of finished goods from factory to distributor. Thus, the competitor knows at all times who the RCA customers are; he knows their level of purchases; and can approach the more attractive accounts on the sale of their own "original" brand.
2) The antennas are easily recognized in the marketplace as the competitor's product, a decided product identity disadvantage.
3) RCA, as an intermediary between manufacturer and distributor, must mark up the cost whereas a merchandising manufacturer can sell directly to distributors without this additional mark up. This cost disadvantage is probably the most serious drawback.

Nevertheless, Parts & Accessories established an aggressive marketing organization which has been able to build sales to an attractive level.

Once the ability to achieve a significant share of this market was established, the next step was to develop a highly distinctive line of antennas that could be produced by a non-competitive manufacturing source or by an RCA production facility. To accomplish this next phase, additional engineering and support personnel were hired and an engineering facility was designed and constructed.

Antenna development facility

Antenna development and design requires a special facility which must include outdoor antenna testing ranges. Such a facility was planned and built at Deptford, N.J., in 1968. Radio-wave reflections from an adjacent building can seriously limit the capabilities of an antenna range, so the antenna building was designed to minimize these reflections. Since television broadcasting employs horizontally polarized radiation, transverse horizontal wiring and plumbing in the building was avoided. Radio-frequency measurements of building materials were made as the basis for choosing non-reflecting materials. The sidewalls of the frame structure made use of vinyl siding with Celotex sheathing and interior walls, materials with far lower reflection coefficients than most building materials. The roof material was corrugated fiberglass sheet. The net result was a building unusually free of radio-wave reflections.

Fig. 1—Antenna development facility at Deptford. The curved radio-transparent wall used for "indoor" testing of antennas is at this end of the building.

Fig. 2—This end of the antenna development facility shows the tower at one end of the radiation-pattern measurement range.

Special laboratory accommodations were incorporated in the design of the building to enable antenna development and design work to be carried on indoors despite inclement weather which often hinders antenna work on a conventional outdoor range. This "indoor" laboratory is a room 20 ft high by 30 ft wide by 20 ft deep. It is situated at one end of the building and has a 20x30-ft radio-transparent window in one wall facing an outdoor radiating source. The window was designed "in house" and is considered unique. It consists of dacron-reinforced vinyl sheeting stretched across a sturdy wood frame. The vinyl sheet is edge supported with heavy elastic ties to produce a natural tautness. The top and bottom edges curve outward while the side edges curve inward. The resulting compound curvature imparts stability to the sheet, even in high winds (see Appendix A). After four years of service, the radio window shows no deterioration. An outside view of this radio-transparent wall is shown in Fig. 1.

The indoor test room is ideal for gain and VSWR measurements. The room is part of a 100-ft antenna test range and is used for gain measurement at all TV frequencies. An x-y plotter makes it possible to

Donald W. Peterson, Mgr., Product Development Engineering, RCA Parts and Accessories, Deptford, N.J., joined RCA as an engineering trainee in 1936 and started in the radio receiver Service Department in 1937 as a technical writer. He transferred to the RCA Research Laboratories in Camden, N.J. in 1940, where his activities included development and research in antennas and radio wave propagation. As a member of the original technical staff of the Priceton Laboratories, he received a laboratory award and the IRE Scott Helt award for the development of time domain reflectometry for television transmitting antenna testing. He also received a laboratory award for concepts in UHF broadcasting. In 1961 he transferred to the Missile and Surface Radar Division as an antenna development and design engineer. Projects included development of a circularly polarized feed for the lunar excursion erectable TV antenna. He received a citation for work on the "two pound radar" antenna. In 1967 Mr. Peterson joined Parts and Accessories where he was responsible for the development of the RCA line of TV receiving antennas.

J. D. Callaghan, Mgr., Engineering, RCA Parts and Accessories, Deptford, N.J., was employed by RCA in 1946 as a member of the RCA Service Company Home Instruments Engineering Department. His responsibilities included the development and approval of TV receiving antennas and antenna systems. He also engaged in the development of color TV test equipment, TV technician training and liaison between the TV service activity and Consumer Electronics Engineering. In addition, he received the RCA Award of Merit in 1951. In 1959 he joined the RCA Service Company BMEWS project where he became Engineering Manager with responsibility for on-site installation check-out and test of all BMEWS equipment. Mr Callaghan came to RCA Parts and Accessories in 1964 and organized the present Engineering group which develops accessory products such as TV antennas, rotators, signal distribution systems, color TV test jigs, and automobile stereo tape players. During the course of his employment with RCA, Mr. Callaghan has been granted nine U. S. patents.

Authors Peterson (left) and Callaghan.

plot antenna gain over the entire TV spectrum automatically in minutes. Equipment is also available in the room for automatically plotting VSWR measurements *vs.* frequency. The entire new RCA "Permacolor" outdoor line of antennas was developed and initial tests were performed in this room.

The opposite end of the antenna building houses the operating terminal of a 250-ft antenna test range set up primarily for radiation pattern measurement. The tower for the range is shown in Fig. 2. This tower can be lowered onto the building deck by remote control for access to the antenna mount. The range is instrumented with a polar pattern plotter which operates with a bandwidth of only 5 Hz to eliminate extraneous interference.

The antenna under test is operated as a signal source. The range receiving antenna may thus be situated at the remote end of the Range where its directional characteristics are used for minimizing local TV station interference to the extent that patterns may be measured between picture and sound carrier frequencies of the local TV stations if desired.

Product development and design

Having planned and built the antenna facility, the first activity was development of a complete line of outdoor TV receiving antennas. This meant that new electrical and mechanical design concepts were needed in an art which had been thoroughly worked over for many years by experienced competitors.

It was clear at the outset that the new RCA line would, of necessity, be electrically similar to competitive lines. All competitors were using an end fire array for the VHF portion of the antenna with a 54-to-88-MHz and a 174-to-216-MHz band. Fortunately, most of the basic electrical design ideas came from early RCA work on HF antennas. Common array elements for the low VHF and high VHF bands were obviously desirable for economy. This required creativeness and, similarly, the means of incorporating a UHF antenna for an all-channel line required new concepts.

Existing competitive antenna designs were examined early in the program to assess both their weaknesses and their strengths. A significant weakness that was common to all of the popular existing designs was soon discovered. In each of these designs, the antennas are packaged in a folded condition to facilitate storage and shipment. This requires them to be unfolded by the installing technician. In the usual design, each dipole element is folded by use of a rivet acting as a hinge pin. The contradiction in concept of setting the rivet loose enough for hinging and at the same time tight enough for reliable electrical conduction makes it almost inevitable that RF noise will develop when weathering causes corrosion at the hinge joint. Here was an opportunity for design improvement. An electrical design was developed which separated the hinge function from the electrical connecting function. This made it possible to accomplish a permanent electrical connection that is immune to atmospheric deterioration. The strap which permanently connects the dipole to the transmission line is solidly riveted and is shown in Fig. 3. Permanent electrical connection is further assured by the use of special, fluted aluminum rivets which cut into the sides of the holes in the material being riveted.

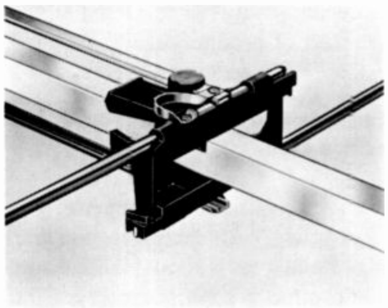

Fig. 3 — Antenna unfolding and interlocking apparatus.

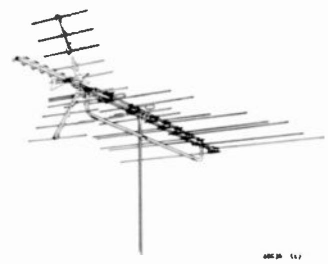

Fig. 4 — Model 4BG36 "Permacolor" antenna.

A new feature was to overlap the dipoles at their insulating support. This overlap provided an easy means of transmission line transposition by simply reversing the overlap on successive dipoles. In the final product, the two halves of the insulator were designed to unfold and interlock as shown in Fig. 3, thus providing a noise-free dipole supporting structure of great strength.[1] The overlap also provided a new means for separating low-VHF and high-VHF antenna functions.[2] The shunt capacity needed to accomplish separation was provided inexpensively by merely lengthening the element overlap at the appropriate place in the array.

Another electrical feature introduced in the design provided for a novel means of placing low-VHF directors in front of the high-VHF antenna without degrading high-VHF performance. This feature was accomplished by the bugle-shaped members seen as part of model 4BG36 of the "Permacolor" line illustrated in Fig. 4. The UHF antenna was incorporated into the total configuration by placing a corner reflector type of antenna in front of the VHF antenna and tuning the reflector members to act as directors for the high VHF band.[3]

Of economic necessity, the antennas are fabricated using the same kinds of parts and material as the competitors use: sheet metal stampings, butt-seam tubing, welded tubing, and plastic moldings. These are all parts that can be fabricated with high-speed automatic machines to make them cost competitive. A kit of about 75 common parts was designed for this project. From this kit, all of the antennas needed for a complete line of six VHF, three UHF, one FM and nine all-channel antennas could be made. There are also seven of these models packaged complete with all installation material and several types of transmission line for the do-it-yourself market.

Colors for the new antenna line, predominately blue with gold support booms, were adopted by merchandising to add "eye appeal." The color choice also represented innovation since all-gold finish had become standard with the industry.

Even the package size of the product is a significant cost factor because warehousing and shipping represent cost just as surely as do materials and labor. The antenna was, therefore, designed to be the ultimate in compactness when folded. All but four antennas of the 19-antenna product line are packaged in standard long, slender cartons that are only 5¼ inches square. Despite their folded compactness, the antennas unfold with ease and lock positively and permanently into their functioning configuration.

The antennas are marketed by the Parts and Accessories Division located at Deptford, N.J. The salesmen reach RCA Consumer Electronics distributors, as well as many other independent outlets throughout the entire nation. Sales volume has grown to the point where single distributors often order tractor trailer-size deliveries.

The advertising of this product has been both straightforward and effective. The forthright character of the RCA advertising makes it stand out in an industry which has often grossly exaggerated in their advertising copy.

The RCA product has strong and easily recognized sales features which give both the Advertising Department and the salesmen a story for their customers.

All of the RCA antenna laboratory products and components are fully documented within the RCA drawing system. The general excellence of this system has permitted both precision and flexibility in dealing with vendors as well as tight control of the product in the antenna factory.

Antenna factory

Most of the metal parts used in production are fabricated "in-house". The factory employs high-speed stamping machines, rolling mills, piercing machines, swaging machines, and other similar equipment. All aluminum sheet metal is pre-finished before stamping, rolling, or piercing. Even welded tubing, which is purchased, is finished before forming and welding. A tube-bending machine is shown in Fig. 5. Stamped parts are produced with automatic machines at a high rate with progressive dies. Plastic parts are produced from RCA molds by suppliers who specialize in these items.

Antennas are assembled with automatically fed riveters along a 200 ft moving belt as shown in Fig. 6. Quality is assured by inspection of vendor-supplied parts, and by assembly line inspection. Antenna quality has remained high from the start of production.

Entrepeneurship—Parts and Accessories style

As a business enterprise, RCA engineering, manufacturing, and marketing of antennas is an unqualified success. The product is good, the price is right, the customers are pleased, and RCA shows a respectable profit. The entire undertaking has been carefully tailored to fit the product with no room for frills. Every member of the team plays a vital role and every member knows how he relates to the overall effort. Morale is high among the participants because everyone sees tangible results from his individual efforts. Business success becomes personal success.

The antenna activity is integrated as part of RCA Parts and Accessories. Marketing, Advertising, Sales, Accounting, Purchasing, and Engineering activities are located in Deptford, N.J. The sales organization operates throughout the entire United States.

The RCA investment in a sales organization, an engineering facility, the design effort, tooling, and the manufacturing facility, along with successful production and promotion, has convinced even the most skeptical that RCA is in this business to stay.

RCA's superior position in marketing home instruments has, of course, helped in marketing RCA antennas. The RCA name and reputation have been of significant value in opening customer doors for this new product line. For growth to continue at a healthy rate, however, it has been necessary that the antenna line measure up to the name. Along with the relationship to the Corporation, at large, the new antenna activity has been able to create its own way of life—a way that is highly efficient in the production and sales of a product in an established and competitive market.

After successfully launching the manufacture of the "Permacolor" outdoor line of antennas in the RCA antenna factory, other products were examined for possible addition. Similarly, a highly distinctive line of indoor antennas was also developed; these antennas are now produced in our manufacturing facility. In both cases, the advantages of in-house manufacture proved to be a substantial factor in achieving planned business results.

The future

The RCA antenna laboratory building at Deptford also provides for an engineering activity engaged in investigating a variety of other potential products. There is a complete model shop, a design and drafting room, and general engineering laboratories.

Other product items that have been developed by P. & A. Engineering include a TV-antenna-system accessories line of 45 items. These consist of amplifiers and passive devices required for small home type MATV, (master-antenna TV) systems, a few of which are shown in Fig. 7. There is an antenna rotator line with three models, plus a complete line of antenna-installation hardware. RCA Parts and Accessories also engages in other diversified product design. One of these is car stereo tape players, some items of which are shown in Fig. 8. The RCA engineering contribution to the design of these products varies from complete product design to critical review and modification. Careful factory production control is exercised on all product lines. It

Fig. 5—Tube-bending machine.

Fig. 6—Automated riveting operation.

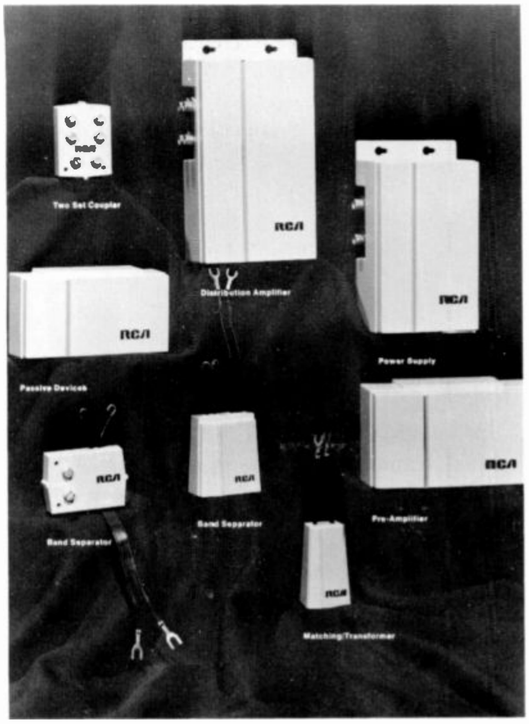

Fig. 7—Some of the accessories-line for master-antenna TV systems.

Fig. 8—Some of the car stereo-tape line.

is expected that some of these products will eventually go the full way from outside procurement to RCA manufacture along the same lines patterned by the antenna business.

The Deptford engineering group has already had substantial experience with antenna rotator and RF amplifier design. There has also been an advanced development project in cooperation with the David Sarnoff Research Center.[4] This has resulted in the creation of a new concept of a miniature transistorized, rotatable, outdoor antennas which is enclosed in a weatherproof housing. This product will be introduced early in 1973. The development of this antenna will be fully described in a future issue of the *RCA Engineer*.

Acknowledgments

Neil Burwell and Frank DiMeo were responsible for the mechanical design and the product design of the "Permacolor" antenna line. Mr. Burwell died shortly after conclusion of the mechanical design phase of the antenna line.

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2 Peterson, D. W. (RCA), *Combined VHF-UHF dipole antenna array*, U. S. Patent 3,653,056.
3 Callaghan, J. D. (RCA), *Multi-frequency antenna*, U.S. Patent 3,683,391.
4 The new antenna concept was developed at Deptford under the leadership of Dr. James Gibson of the David Sarnoff Research Center

Appendix A—Design of the radio-transparent window for the antenna development facility at Deptford, N.J.

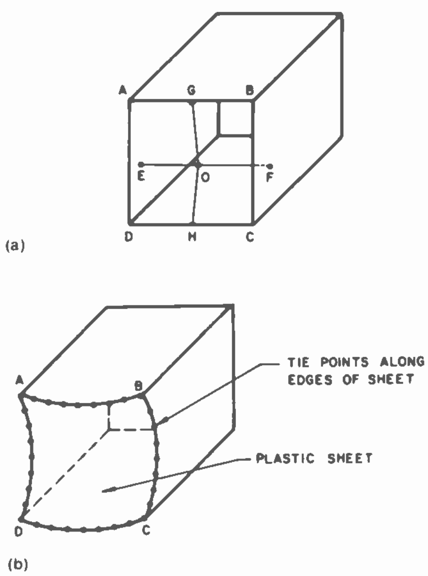

Fig. 9—Sketches of radio transparent window.

The radio-transparent window consists of an edge-suported, single plastic sheet 600 ft^2 in area. A sheet of this size will be exposed to approximately 14,000 lbs of air pressure in a 90 mi/h wind. It is not difficult to design a wood structure for the static load that this imparts to the supporting frame. However, if such a sheet is drawn taut to a flat surface, it tends to oscillate in the wind. It is the oscillation which makes the sheet self-destructive and adds substantially to the stresses imparted to the support members.

A method for minimizing wind-induced oscillation was conveived by Neil Burwell. If ABCD of Fig. 9a represents the open end of a box, a vertical string attached to top and bottom can be rendered incapable of oscillation in its fundamental mode by pulling it toward the inside of the box at point 0 at the center. A second string stretched horizontally across the opening can be similarly rendered non-oscillating by pulling its center outward from the box. If the ends of the horizontal string are moved inward, EOF and GOH become a stable system with neither string capable of fundamental-mode oscillation. A similar balance of forces may be accomplished in a sheet attached to points ABCD by curving the top and bottom outward and the sides inward as shown in Fig. 9b.

The outside wall of the antenna laboratory is such a compound curved sheet, made of polyvinyl chloride reinforced with a dacron fibers. The sheet constitutes the entire end wall of the building shown in Fig. 1. It was drawn taut and permitted to be self-equalizing by use of heavy elastic ties along the edges.

Prior to the erection of the full-scale wall, a scale model of the plastic sheet and the elastic supports was constructed over a vacuum chamber. The behavior to be expected in high winds was studied by partially evacuating the chamber and measuring tension in the elastic ties.

G&CS antenna range

W. C. Wilkinson

The antenna is a major element in most of the systems produced by the various divisions of G&CS. The development and measurement of these antennas requires increasingly sophisticated facilities and controlled conditions. A new RCA antenna test range for this work has been planned and is being implemented. Special attention has been paid to the problems of mutual and external interference from systems both in operation and under test. Management as well as technical design will play an important role in the solution of these everpresent problems.

SINCE THE COMPANY was formed more than 50 years ago, RCA has had a major role in antenna research, design, and manufacture. One of the earliest was the Beverage[1] or wave antenna consisting of two horizontal wires 9 miles long. One of the latest is the AN/SPY-1 antenna,[2] consisting of 4480 electronically steered elements. The types, sizes, and frequencies have been as varied and as extreme as the electronic communications art itself.

A necessary adjunct to any antenna development is a test or measurement capability. In RCA, these measurement facilities have taken many forms in numerous locations: building roofs, vacant lots, unused baseball fields, specially designed buildings, and elaborately graded terrain. In the past (and to some extent even at present), the test locations and facilities represented the narrow needs of a single division or product line. Although such parochialism limited the resources that could be used for capital equipment, a competitive position could generally be maintained.

However, the great strides made in electronics during and since the World War II, and the pressing requirements for communication by the world's increasing population have enormously increased the complexity and necessary capability of antennas. In addition, labor costs and schedule needs make high-data-rate test equipment mandatory. The result is that test facilities have increased manyfold in sophistication and cost. Hand-turned positioners and point-by-point hand-plotted data points exist only in the reminiscences of not-so-old engineers.

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graduated from Purdue University in 1941, with the BSEE. Since then, he has been employed by RCA; in 1941-1942, at the Manufacturing Co., Camden, N. J.; in 1942-1961 at the RCA Laboratories, Princeton, N.J.; and since March 1961 at the Missile and Surface Radar Division, Moorestown, N.J. His experience has been in applied research and advanced systems development, RF transmission and components, and in antennas. Particular areas of experience are: narrow-beam rapid-scanning antennas at microwave and millimeter waves; airborne high-resolution radar; and ground-space communication antennas. At present, he is engaged in developmental programs on antenna systems. Mr. Wilkinson is a member of Sigma Ki, Eta Kappa Nu, and a Senior Member of the IRE.

History

Somewhat over ten years ago, the defense group of RCA divisions consolidated the antenna personnel at Moorestown in the Missile and Surface Radar Division for the purpose of enhancing the development and design capability. The commonality of antenna experience would improve and cross-feed designs for the various divisions; the DEP Antenna Skill Center came into being. In the years since its formation, the grouped antenna skills have served all five divisions in many programs, and have contributed materially to the needs of the commercial divisions. (An antenna range is operated by CSD at Gibbsboro, N.J. for development and production test of FM and TV broadcast transmission antennas.[3] Another range for TV receiver antennas is operated at Deptford.[4]

At about the same time that the Antenna Skill Center was instituted, the range facilities at Moorestown were seriously affected by operation of the prototype of the BMEWS tracker, the AN/FPS-49, a nearby very high power radar. A number of the antenna test programs were moved to the just previously relinquished Home Instruments receiver test site at Medford, N.J., approximately nine miles from the M&SR plant. This small site has been in continuous use since, for programs which could not tolerate the ambient electrical noise level at Moorestown. However, the site was only an expedient and never became a complete permanent range.

The need for a consolidated permanent range has been recognized, but the apparent requirement for more suitable land became a stumbling block. As noted, the pressing needs for better facilities triggered an evaluation of previous range plans in light of existing constraints. The difficulties of obtaining land located sufficiently close and situated such that it would be in a noise-free enivronment for the reasonable future, forced a re-examination of the potential usefulness of the Moorestown property itself. Two conclusions were reached:

1) This property could be used if a full program of noise control were carried out; and
2) No other location would be markedly better.

The particular and general range needs were assessed and a master plan developed for an orderly implementation over a 4- to 5-year period. This plan has been approved, and periodic reviews and assessments will modify the plan details, if necessary, as time goes on.

Requirements

As noted, the types and sizes of antennas developed at MSRD have spread over a large span. It is expected that this will continue. Thus a broad general capability must be met, recognizing of course that there will always be sizes and types so extreme that special techniques and facilities will be required. The general requirements for a range site are:

Size	adequate for developmental tests
Interference	minimal or within control
Accuracy	permanent calibrated ranges
Support	shop, laboratory, housekeeping
Location	convenient to the MSRD main plant
All-weather	sufficient to maintain schedules

Fig. 1 shows the relationship of minimum required range length, antenna size, and frequency. Various representative antenna developments are spotted, illustrating that most of the programs can be satisfied with a range length of 3000 to 4000 ft.

Interference is of two kinds, passive and active. Passive relates to those effects which prevent the antenna from being tested in a free-space environment: multi-path or unwanted scattering effects of ground reflections, buildings, and natural vegetation. Active interference includes all undesired radiation.

The ever-present ground is handled by either of two techniques:[5] the test antenna and source are elevated to minimize ground reflections, or the two end points are located close to the ground and the ground reflection controlled and used. The former is called an elevated range and the latter a ground-level range. In some instances advantage has been taken of two elevated points separated by a valley. South Jersey, unfortunately, does not boast such features. More generally one or both terminals are placed on towers and residual spectral ground reflections broken up or absorbed to some tolerable level. This is a type of range employed at MSRD for many programs.

The ground-level range requires carefully graded and controlled terrain between the test antenna and the source antenna to maintain a stable addition of the ground-reflection signal with the direct-link signal over the area of the test antenna aperture. This type of range is useful for certain sizes and frequencies.

Active interference is generated by many sources: some are licensed transmitters, others are incidental noise generators. The ever-increasing number of radar and communication stations puts almost any test site in an interference area. In addition, MSRD itself has a continuing number of radar and high-power transmitters under test. Source radiation of multiple ranges themselves may cause intra-range problems. Tolerable levels can be reached and maintained only by an across-the-board attack:

1) Elimination or reduction of the interference
2) Discrimination against the interference

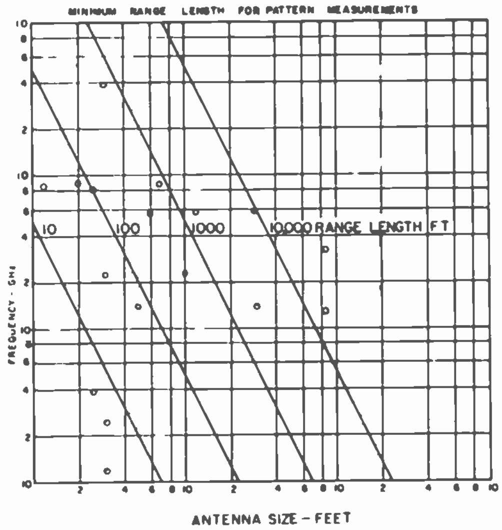

Fig. 1—Relationship of minimum range length, antenna size, and frequency.

The first works on the interference source, the second on the test antenna receiver.

Range plan

General

The general plan consists of four elements:

1) Location and layout
2) Building modifications
3) Interference control
4) Facilities and equipment

The major location of the range and its parts will be on the RCA Moorestown property, a triangular-shaped 400-acre piece of land (Fig. 2). The nucleus or hub of the range will be an existing building (Fig. 3); this can be used with only minor interior modifications. The interference control will extend to all phases, from prevention of interference generation to the op-

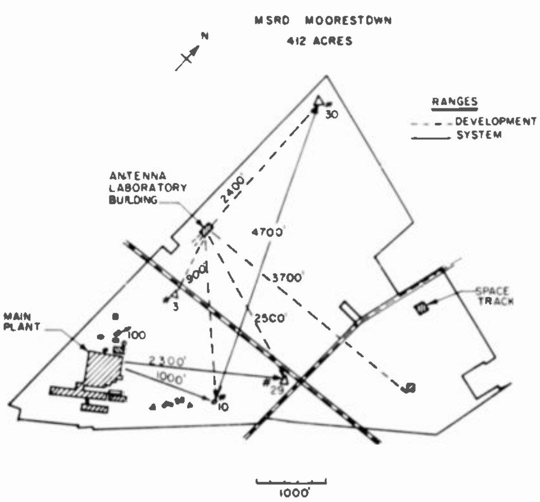

Fig. 2—Radar test ranges, MSRD.


Fig. 3—Antenna laboratory building.

eration in interference using sophisticated discrimination equipment. It includes technical management as well as techniques. The facilities and equipment consist of anechoic rooms, source towers, test equipment, surveyed and calibrated test ranges, and the accessory shop, laboratory, and computer support.

Location

The antenna laboratory building (Fig. 3) is located about ½ mile north of the main plant buildings and is surrounded by more-or-less open fields. It formerly housed the equipment used for outdoor backscatter and signature analysis measurements. After lying almost idle for some years, it was recently put into service for the AN/SPY-1 antenna measurements. This latter equipment and its arrangements, a major capital investment itself, will be incorporated into the overall range plans. Fig. 2 shows the relationship of the building to the property.

All but one of the ranges will have their terminus here. A short range is tentatively planned to be located on the existing RCA Gibbsboro site.[3] This is about 14 miles, or 18 to 20 minutes, from Moorestown. The need and use for this range will depend on particular interference problems at Moorestown. Plans also include the use, if needed, of a small piece of land suitable for a source tower located at Arney's Mount, about 13 miles northeast of Moorestown. Activity at the leased Medford test site is to be phased out and terminated.

The plan includes renovation of the antenna laboratory building and some modifications. The basic building layout and major supporting walls fit into the range needs quite well. Fig. 4 shows the layout and planned use of the building interior.

Interference control

The interference control plan includes those areas of activity which will permit antenna measurements to be made throughout the Moorestown ranges with a minimum of interference. It is clear that there is no single solution, that there will be some periods of unavoidable conflict, and that the problems will require continual attention and periodic activity. On the other hand, there is probably no location which is either completely free or could be sheltered from similar kinds of interference for any long period of time.

The interference control consists of two kinds of activity: technical investigation and control, and range management and control. The first has these steps:

- Interference measurement and analysis
- Development of techniques for discrimination
- Construction or modification of test equipment

Existing and potential interference sources have been defined by measurements and by tabulation of licensed transmitters. This data will be used to influence location and orientation of ranges as well as allocation of individual ranges to programs. It will pinpoint excessive levels and identify those which can be reduced.

Range management will include the establishment of a Range Control Board which will guide and control:

- all planned range use
- all range modifications
- all MSRD land use
- all range capital equipment

By these means, potentially serious conflicts can be averted, planned time sharing can be influenced, major interference sources can be prevented, and undesirable interacting activity can be minimized. This board will seek to optimize solutions for short-term problems while maintaining the long term integrity of the range capability and capital investment.

Radar-type Interference

One particularly troublesome type of interference is that from nearby radars, both operational and experimental or in test. These are located both off and on RCA property and naturally tend to be in the same general frequency bands as antennas to be developed. While frequency discrimination and modulation coding can do much, it cannot handle all situations. The pulse nature of the interference suggests that a blanking technique can have value. The low duty cycle of most antenna measurements will allow, in effect, time sharing of the same spectrum.

An experimental evaluation and equipment development for this technique is underway and initial results are quite promising. Synchronization with the interference pulse is obtained from the leading edge for equipments off-property and beyond control. Those on-property can be synchronized likewise, or, for extreme high-level problems and pulse-rate-agile systems, hard-wired video or RF links can be used to completely blank the pulse. It is unlikely at a given frequency and situation, that more than one to three interfering equipments will be operational simultaneously. Thus the potential reduction in measurement data rate does not appear severe.

Description of ranges

The various existing and planned ranges are listed in Table I and their locations delineated in Figs. 2 and 5. Two important guidelines are being used in their design and construction:

1) Ranges will have permanent calibrated capabilities using dedicated equipment; and
2) Operating equipment and procedures will incorporate labor-saving and time-saving features.

A major portion of the required equipment is already owned and in general use. This will be rearranged and supplemented. Ranges 1 and 2 exist in part. Forms of ranges 5, 6, and 7 exist at other locations. Ranges 3 and 4 are in process of being built. The remaining three will be implemented as their need becomes more imminent.

All the ranges consist of the receiving end where the antenna under test is rotated through its various look angles, and the transmitting or source end from which a test signal is radiated. The receiving end will have a pad and pedestal with a drive system for rotating the antenna, a receiver, and recording equipment for sensing and documenting variations in the antenna performance. The transmitting source will generally be located on a tower and will be remotely controlled in orientation, polarization, and frequency. The use of phone lines and digital circuitry for control is planned. Some receiving sites will be enclosed for all-weather operation and to allow tests on antennas with particular environmental limitations, such as those for space. A capability down to 200 MHz will be available in these chambers.

Range No. 1 is already in existence and in use. It was designed to test the AN/SPY-1 antenna—a high data-rate, wide-coverage, broad-band, electronic scanning antenna. This is a 900-ft-long elevated range, operating between a 150-ft-source tower and a 50-ft-high tower-mounted pedestal. The measurement and data requirements of this program dramatically illustrate the magnitude of modern antenna testing. This array has a 100 × 90° coverage with a less-than 2° beam. For each beam position, three monopulse patterns must be assessed: one sum and two difference patterns, and these at several frequencies. Gain, beamwidth, lobe level, beam position, and error slope are only some of the data that must be gathered.

The pedestal and signal source as well as the antenna beam steering are controlled by a programmed computer (Digital Equipment Corp., Model PDP-11, with 18k core memory). Measured data is stored on magnetic tapes for evaluation and reprocessing for presentation. The computer also analyzes and presents spot data in real time to validate measurements being taken.

Ranges 3 and 4 are being built as a pair, using a common control room and source tower. Certain specialized recording and control equipment will also be shared. The two ranges have different but over-lapping frequency ranges. Likewise Ranges 1 and 2 will share a common control room and some equipment.

Conclusion

The complement of ranges as proposed will give RCA an antenna development and measurement facility fully suitable to the needs of the foreseeable future. These will support the product lines (other than broadcast) of the other four G&CS divisions as well as MSRD.

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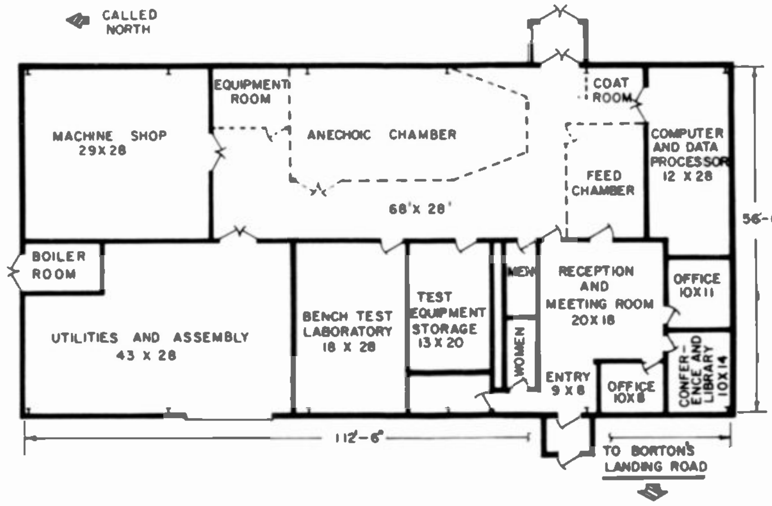

Fig. 4—Floor plan of antenna laboratory building.

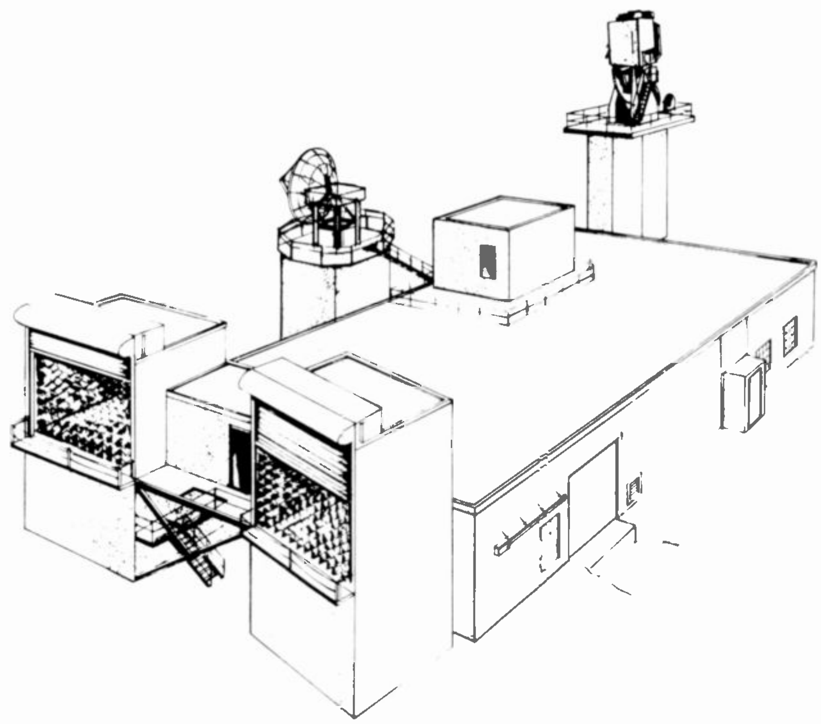

Fig. 5—Configuration of antenna laboratory facility.

Table I—Developmental ranges.

No.	Type	Height (ft) Transmit	Height (ft) Receive	Length (Ft)	Min. freq. (MHz)	Remarks
1	Elevated open	150	50	900		
		150	50	2500		
		200	50	3700		
2	Elevated open	150		2400		
		200		3700		
3	Ground level and elevated semi-anechoic	0 to 40	26	0 to 300	1000	
		200	26	2400	1000	
4	Ground level and elevated semi-anechoic	0 to 40	26	0 to 300	400*	
		200	26	2400	400*	
5	Anechoic room	—	—	10	1000	Feed and element tests
6	Shielded anechoic room	—	—	40	1000	Feed and element tests
7	Ground plane	0 to 150	0			HF scale model tests
8	Elevated range	Various	75	Variable		For high front-to-back and main-to-minor lobe ratios.
9	Elevated	25	25	0 to 100		Located at Gibbsboro for specal interference problems.
10	Line of sight	300	50	70,000		Potentially useful.

* Useful to 200 MHz at some performance accuracy reduction.

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