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RCA

Founded 1909

In Memoriam

JACOB JOHN ROBERT POPPELE

1898 - 1986

Founded 1909, New York, U.S.A.

The Radio Club of America, Inc.

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Price $2.50

Organized for the interchange of knowledge of the radio art, the promotion of good fellowship among the members thereof, and the advancement of public interest in radio.

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Jack Poppele — A Man For Tomorrow

One definition of a prophet is: "a person regarded as a leader, or a spokesman of some doctrine or cause." Jack Poppele certainly fits that description.

But the old adage: "A prophet often is without honor in his own country" certainly doesn't apply.

The Newark (NJ) **Sunday Star Ledger** of May 23, 1982 featured the story of Jack Poppele in the article "Pioneer Turns U.S. On to Radio". Let's read a bit of what it had to say.

"On the two-and-a-half-inch disc appeared a black and pink image of Felix The Cat. It was the first crude picture transmitted electronically into a receiver. The year was 1926 and Allen B. DuMont was developing television in a Jersey City shop called Jenkins Radiovisor.

"The production of radiovisor receivers began in September 1926. The second set off the production line was a gift from DuMont to his friend Jack Poppele, Jr., a native of Newark and a pioneer in radio broadcasting in New Jersey. Radio's origins in the Garden State go back to February 1922. The station was WOR, now one of the nation's largest and most lucrative outlets.

"Poppele, then 24, was regarded by his electrical engineering peers as a visionary in the broadcasting industry. In those days, television was nonexistent and radio was a novelty with no commercial value."

Now, more than six decades later, Poppele still fits the definition of a pioneer and a prophet. He serves as Chairman of the Board of Tele-Measurements, Inc. and a Director of The Radio Club of America, Inc. amongst his other activities. His services to The Radio Club have long been documented through his serving as Chairman of the annual Awards Banquet, and his generosity in providing a meeting site for the monthly meetings of The Club's Executive Committee.

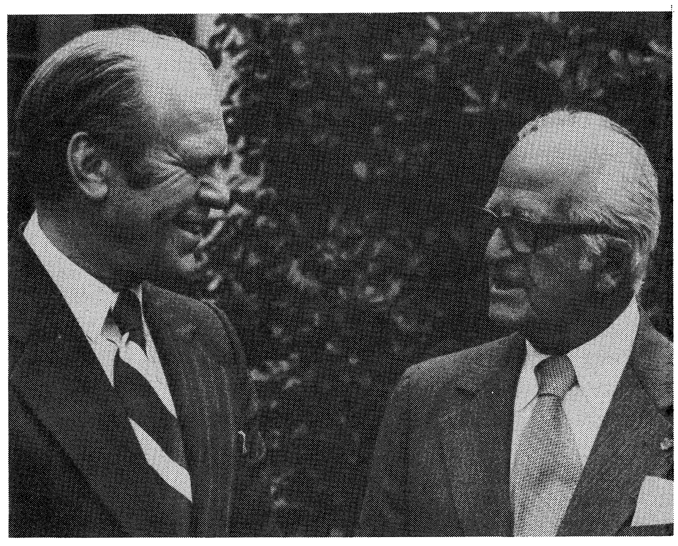
He founded Tele-Measurements in 1961 as an engineering and communications contractor, specializing in radio and television broadcasting. Over its life span, Tele-Measurements has moved into allied video, data and sound fields. Its notable achievements are represented by the recent installation of a Local Area Network at the West Point Military Academy, video surveillance systems at the gambling casinos in Atlantic City, and in the design and installation of Mobile Television Vans for the broadcast and cable markets.

The company, began in a small garage in the home of its President William Endres, has now grown into its own 14,000 square foot building in Clifton, NJ, and is one of the best equipped modern contracting and support facilities in the East, providing complete design, installation and service for RF and Data system communications, Television studios, Production Vans, Teleconferencing, and Graphic Presentation Facilities.

Tele-Measurements provides complete design, implementation, installation, certification, documentation and on-going technical support services for these advanced systems.

Poppele's career spans the entire history of broadcasting and he was an early advocator of AM-radio stereo broadcasting. He has known all of those legendary personages of the emerging electronic era: Thomas A. Edison, Guglielmo Marconi, Edwin H. Armstrong, Lee de Forest, David Sarnoff, Allen B. DuMont, and Samuel F.B. Morse.

His work brought him into the presence of seven successive presidents — from F.D. Roosevelt to Gerald Ford. In 1954, President Eisenhower appointed Poppele to the position of Director of the Voice of America, U.S.I.A. The job's responsibilities were those of directing broadcasts in 43 languages over 83 transmitters located through-out the world.



Poppele's fascination with radio communications began in 1912 when he assembled a wireless set at his home in Newark. Then 14 years old, he quit school to work in a machine shop at wages of five cents a hour. After a ten-hour workday, he studied the theory of electricity at Newark Tech and, later, traveled by trolley-car and ferry to New York City to study code and radio theory at the Marconi Wireless School.

In 1915, he obtained a commercial operator's license and got a job as a wireless operator aboard the S.S. Iroquois. During World War I, he served in the U.S. Army Transport Service.

As radio broadcasting took root in the years immediately following the war, Poppele was amongst the first to recognize its potential. By 1922, the federal government had issued only 13 licenses. Poppele was persuasive and convinced L. Bamberger & Company department store in Newark, NJ to set up a station and WOR became the 14th licensee. Its antenna was a piece of wire strung between two poles on the roof top; the home-made transmitter had a power output of 250 watts. It was enough to broadcast the songs of a local piano player who worked without pay.

A few weeks after turning on the switch, Poppele became the station's chief engineer at a salary of $23 a week. The station operated from 10 to 10:30 in the mornings, from 2-2:30 and 5-5:30 in the afternoons, and from 8 to 9 in the evenings.

"There wasn't much to do so I sold radios in the store between broadcasts," Poppele recalls "I was selling so many radios that they cut my commission from two percent to one percent. To make up the loss, I sold twice as many radios."

Christmas arrived and Bamberger's would be closed on the bigget holiday of the year. That meant that WOR also would be off the air. Poppele went to his boss and told him the customers would have nothing to hear on Christmas Day.

"He wanted to know who would give up their Christmas to operate the station," Poppele related. "I said there'll always be other Christmases." And WOR became the first station to broadcast on Christmas Day. Poppele played phonograph records from 7 in the morning until 10 at night. There were listeners as far away as Asbury Park.

During April 1923, Poppele was summoned to the office of Louis Bamberger. It was a top level meeting on the future of WOR.

"Mr. Bamberger informed us that we had been in the broadcasting business for 14 months and had spent $20,000," Poppele recounted. "He believed Bamberger's had gotten all the promotion out of WOR that it could and he was going to turn in the broadcast license."

Poppele saw his radio future abruptly ending. "I said, 'Mr. Bamberger, you're making a great mistake; radio will be big business.' " Felix Fuld, president of Bamberger's, wanted to know how Poppele knew that radio would be commercially successful.

"I told them that radio can reach all the people on the air; that those people didn't have to buy records when they could listen to music off the air," Poppele remembered. Harry Hattrey, vice president of clothing, sided with Poppele and suggested that WOR stay on the air for at least another two years.

One day, Poppele met Bamberger's china buyer, Pauline Bacmeister. He impressed her that day in 1924 by going on the air and promoting dishes that were not selling in her department. Poppele doubled the price per set from 75 cents to $1.50 and sold two truckloads of china. "I didn't get in trouble because they sold out," Poppele grinned. He married the china buyer the following year.

With WOR assured of a future, Poppele stayed on as Chief Engineer for three decades, eventually heading a staff of 150 engineers and technicians and reaching the positions of Vice President and Director of the Mutual Broadcasting System.

In the early days, many milestones were set by WOR. There was the first trans-Atlantic broadcast between New York and London in 1923, the first play-by-play broadcast of a football game and, in 1927, the transmission of radio pulses toward Mars to help scientists ascertain whether an advanced form of life might respond— a feat that gained national attention more than a quarter century before men began to probe space with satellites. Poppele's job was to arrange and technically supervise those events.

In a sketch published in 1945 by **Broadcasting News**, the WOR engineer was credited with rigging up what was probably the first portable receiver. After buying seats for the Dempsey-Tunney heavyweight championship in Philadelphia in 1926, Poppele discovered his tickets were for the last row in the mammoth stadium. Undeterred, he built a small radio receiver and brought it with him to the stadium. He put a couple of batteries in his pocket, hung an aerial from his seat, and listened to the fight while watching it from a quarter of a mile away.

An early convert to frequency modulation (FM) broadcasting, Poppele was one of the first broadcasters to inaugurate commercial FM programs. These included experiments with transmission of home facsimile programs in association with John V.L. Hogan (HM).

Perhaps Poppele's most important contribution to radio was the directional signal patterns that he developed with two teams of research scientists at Bell Laboratories. Working only with theoretical data, Poppele had to convince his new employer, R.H. Macy & Co., which acquired Bamberger's a few years earlier, that a supertransmitter of 50 kW costing $350,000 plus a directional antenna would give the station exceptional coverage. Winning approval, the world's first super-station was built in 1935. With the new directional antenna beaming a strong signal at population centers and not over the ocean or westerly woodlands, WOR's income rose from $385,000 to $1.2 million, the first year, and to $1.7 million, the second.

Television had its advent long before World War II. In 1926, Jenkins Radiovisors were being built in Jersey City by the de Forest Radio Company. On July 2nd at 8:00 P.M. Eastern Standard Time, the Jenkins Laboratories began broadcasting radiomovies on 46.72 m. (6.42 KHz.) over amateur radio station W3XK and, simultaneously, on 186.92 m. (1.605 KHz.) for Washington, DC viewers. The broadcasts were repeated every Monday, Wednesday and Friday nights.

The programs began with the transmission of simple subjects, then more elaborate subjects, and still later a picture story. Each subject was proceeded by an announcement in the International Morse Code and voice, and each picture story finished with "END" directing the viewer to switch to sound for the next announcement.

The picture standards were 48 lines per picture and 15 pictures per second. The camera consisted of a Nipkow disc having 48 small lenses mounted in holes equally-spaced over a 2½ inch spiral which rotated at 900 rpm in front of a photocell. The lenses transmitted the scanned images of the silhouettes used for the picture subjects. These were relatively easy to pick up and permitted the use of a narrow-picture-frequency band.

The Radiovisor picture receiver units used similar spinning discs, usually of 12 inch diameter, which spaced pulsations of a neon glow tube in synchronization with the pulses generated by the photocell of the camera. While the Radiovisor would produce pictures when attached to any good radio receiver, the manufacturer recommended resistance-coupled amplifiers for better pictures.

The principal problem was in the synchronization of the Radiovisor to the camera. Usually this was accomplished by supporting the disc of the picture receiver unit on a bearing-supported shaft such as that of an idle motor, and using a separate fractional-horsepower motor as a planetary driver. Synchronization was achieved by changing the distance of the driving motor from the center of the scanning disc. An occasional fault occurred when the sides of the disc were reversed; then the picture appeared upside down.

The radio output at about 180 volts was connected through a switch to the neon lamp. The cathode electrode continuously glowed pink in the absence of a pulsed signal, and cutoff or went black when the signal was received to make up black silhouettes on a pink ground.

Jenkins Laboratories' literature forecast:

"This is the beginning of a new industry; a new form of radio entertainment. With these motion picture broadcasts we are hoping to contribute to its rapid development. Ultimately this pantomine story-teller will come to all our firesides as a fascinating teacher and entertainer, without language, literacy, or age limitation; a visitor to the homestead with photoplays, the opera, and a direct vision of world activities, without the hinderance of muddy roads or snow blockades."

This disc scanning system was introduced to the general public at the Bell Telephone exhibit during the 1933-34 World's Fair in Chicago. The picture transmission plus two-way telephone conversation took place between adjacent telephone booths, via telephone lines.

At the New York World's Fair in 1939-40, RCA introduced the all-electronic TV system but the shadows of World War II prevented its exploitation. The advent of electronic television found Poppele amongst the vanguard advancing the art of visual broadcasting. He was responsible for the establishment of WOR-TV in New York City and WOIC-TV (now WTOP-TV) in Washington, DC.

Again anticipating the potential of television, Poppele helped found the Television Broadcasters Association and served as its president for six terms from 1944 through 1950. As the association's chief executive officer, he participated in drafting the engineering rules and channel allocations that serve as the basis of today's TV broadcasting.

Poppele has been honored for his pioneering by being elected a Fellow of both The Radio Club of America and the IRE (now IEEE); he has received the gold medal of the Veteran Wireless Association, and an award from the American Television Society.

A busy man, he finds time to have served four terms on the Grand Jury; as an officer of the county Red Cross; as president of the local Republican Club; as a member of the Board of Directors of Upsala College; and as an active member of his church.

Jack Poppele has been a member of The Radio Club of America since 1942; he served with distinction as Vice President in 1967 and 1968 and as a Director in 1965-67 and 1969-83; he was elected to Director Emeritus for Life in 1983. He was awarded the Club's Sarnoff Citation in 1974 "for Significant Contributions to the advancement of Electronic Communications."

With an active lifetime devoted to the growth of America and with the vision and foresight to help its young people to become the best, all that Poppele has asked in return is — "Just a few kind words."

REPRINTED FROM THE RADIO CLUB OF AMERICA'S *DIAMOND JUBILEE YEARBOOK.*

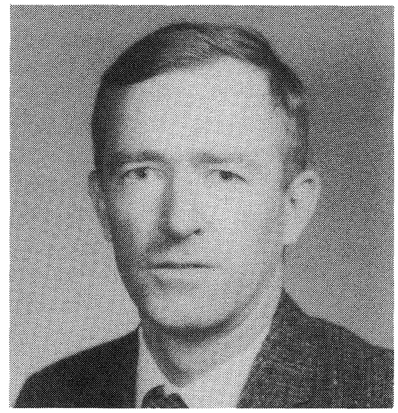
I've lost a friend. Early in the morning of October 7th, Jack Poppele died. For most members, he needs no introduction nor my soliloquy. He was, of course, a Director Emeritus of the Club at the time of his death, and he had spent much time on this year's Award Banquet as he has done on many in the past. His membership covered a period of 45 years and this was paralleled with almost as long leadership as president of the deForest Pioneers. He gave, too, to the other organizations with which he was prominently identified: Society of Motion Picture & Television Engineers, American Physics Society, Acoustical Society of America, FM Broadcasters Association (President), Veteran Wireless Operators Association (President), Broadcast Pioneers (President), IEEE (Fellow), Essex County Chapter of the American Cancer Society, his church, and many other groups.

So Jack's death is not my loss alone. As he used to say: "There are only three things you are free to take through life — good health, good memories, and good friends." And he always believed that each of the members of The Radio Club was a friend. My loss is yours, too.

His friendship is his legacy to all of us.

Fred M. Link

THE MAGNETRON AND THE BLACK BOX: SOME REFLECTIONS ON THE EARLY HISTORY OF MICROWAVE SYSTEMS



by James E. Brittain, Ph.D. (M 1983, F 1985)

In September 1940, a British technical mission arrived in the United States with a black trunk that contained, amongst other things, an electronic device that was destined to have far-reaching consequences.

Two British physicists, Henry A. Boot and John T. Randall, had invented the highly-secret device, a cavity magnetron, that was capable of producing powerful pulses of microwave energy.James P. Baxter in his book *Scientists Against Time,* described the Boot and Randall magnetron as being "the most valuable cargo" ever brought to the United States.

The British disclosure of the remarkable properties of the cavity magnetron stimulated the creation of the famous Radiation Laboratory at the Massachusetts Institute of Technology. Scientists and engineers at the Radiation Laboratory, and at several other university and industrial laboratories, developed a variety of magnetrons during the war years and incorporated them into diverse radar and electronic countermeasures systems. The United States invested more than two billion dollars in the development and production of these systems. This created a momentum and a knowledge base that led to numerous post-war applications of the magnetron that was to include the microwave oven.

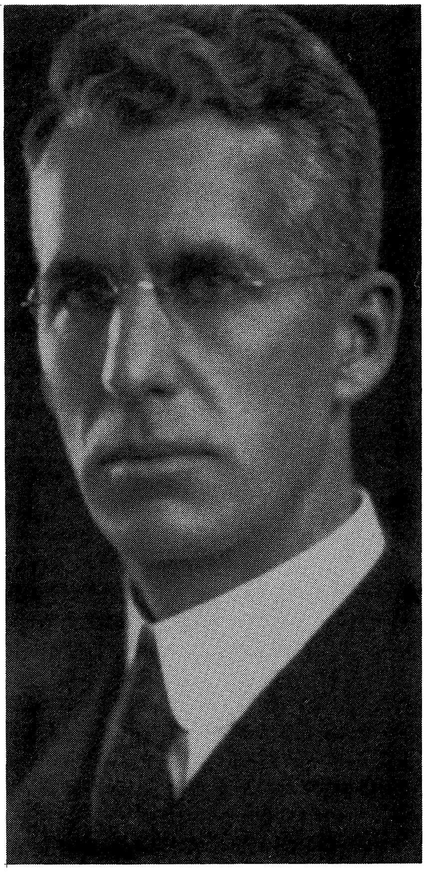
The cavity magnetron brought over by the British mission had a long prehistory that may be traced back to a low-frequency magnetron invented for possible use in radio communication by Albert W. Hull at the General Electric Research Laboratory (GERL). Hull and his colleagues at GE also investigated the use of the magnetron as an electronic power converter during the early 1920s. Investigators in Europe and in Japan independently discovered that the Hull magnetron, under certain conditions, would generate oscillations at centimeter wave lengths. The discovery that relatively short waves could be used effectively for radio communication led to a simultaneous effort to modify conventional vacuum tube devices for higher frequency capability.

Short-wave research also revealed that the presence of ships and airplanes could be detected by reflected energy. Inherent limits in the high-frequency performance of conventional tubes led to interest in the magnetron as an alternative source both for short-wave communication and for experimental radio-detection systems.

Magnetron research took place in at least twelve countries prior to 1939 when Boot and Randall began the work that culminated in their invention of the resonant-cavity magnetron. More than 170 research papers dealing with the theoretical or experimental properties of the magnetron were published during the period from 1920 to 1940, with a steep climb in publication frequency after 1935. The remainder of this paper will review the history of the magnetron up to 1940, and conclude with some details of the "black box" mission and its extraordinary impact.

The Invention and Early Application of the Magnetron

Albert W. Hull (1880-1966) invented the first device to be called a magnetron. Born in Connecticut, he graduated from Yale and taught physics at the Worcester Polytechnic Institute. In 1913, he joined the staff at the GERL that had just begun to explore the field of electronic tubes. In 1914, Hull invented the dynatron, an electronic tube with a negative resistance characteristic. When the grid-controlled vacuum tube became the subject of patent litigation, he began to experiment with magnetic control as an alternative. In November 1916, he applied for a patent on the use of a variable magnetic field to control the flow of electrons between cathode and anode. During these experiments he devised what he called a pliodynatron that could be controlled by a grid, a magnetic field or a combination.



Albert W. Hull, who developed the first magnetron in 1916, is also known for his research with vacuum tubes and x-ray crystallography.

Hull resumed his research on magnetic control in 1919 when the patent situation again posed a threat to the GE position in radio-electronics. Initially, terms such as the *comet valve, boomerang valve,* or the *ballistic electron valve,* were used at GE to describe Hull's experimental tubes intended for use in a radio receiver with no grid-controlled tubes. But by early in 1920, the term *magnetron* was coined reportedly at the suggestion of Laurence A. Hawkins, executive engineer at the GERL. Hull's first magnetrons used a cathode surrounded by a cylindrical anode with a magnetic field produced by an external electromagnet. He filed five patent applications on tubes with magnetic control during 1920-21.

In 1925, Frank R. Elder of the GERL published a paper in *The Proceedings of the Institute of Radio Engineers* on the use of the Hull magnetron in radio. Elder reported that they had used a four-stage magnetron amplifier to receive signals from a transmitter located in Germany. He included data on eight magnetron tubes with different design characteristics. Elder disclosed that one of the GE magnetrons that employed a control coil weighing 125 lbs., had generated power of up to 15 kw, at a wave length of 15 km, when connected as an oscillator. [1]

A resolution of the patent threat had the effect of lessening the interest in the magnetron at GE for a few years although some consideration was given to the possibility of using high-power magnetrons to replace rotary converters in the electric power field. Hull and his associates at GE did not observe high-frequency oscillations in the magnetron until they were reported elsewhere.

The Discovery of High-frequency Oscillations in the Magnetron

Two European scientists, August Zacek and Erich Habann, reported in 1924 that they had observed very-high-frequency oscillations in magnetrons with a constant magnetic field. Their important discovery escaped the attention of researchers at the GERL until 1928. Zacek, a physicist in Czechoslovakia, detected magnetron oscillations at a wave length of about 29 cm while Habann, of the University of Jena in Germany, reported oscillations at around 100 MHz with a magnetron operating in the negative resistance mode.

In 1927, a young Japanese electrical engineer, Kinjiro Okabe, independently detected oscillations at about 60 cm with a magnetron tube. He subsequently carried out an exhaustive study of the effect and tried more than fifty different electrode configurations. He found that the split-anode magnetron was a more efficient generator than a single anode type that Hull had used. Okabe learned of the work of Zacek and Habann during 1928.

Okabe's mentor, Hidetsugu Yagi, a professor at Tohoku University, carried news of the Okabe magnetron investigations to the United States in 1928, where he gave several lectures and published a paper in *The Proceedings of the IRE.* By then, Okabe had produced magnetron oscillations at 12 cm and he extended the limit to 5.6 cm by 1929. While in the U.S., Yagi visited the GERL in Schenectady, N.Y. where his disclosure of Okabe's magnetron research led to an immediate resumption of work on the magnetron. [2]

Magnetron Research in the United States: 1928-1940

Several GE researchers investigated the theory and application of the high-frequency magnetron following Professor Yagi's visit. William C. White and E.S. Darlington participated in tests of a split-anode magnetron that produced up to 10 watts at 400 MHz, beginning in 1928. In a paper published in *Electronics* in 1930, White included a description of an experimental magnetron with a water-cooled anode that could generate 2.5 kw at 75 MHz. Another GE engineer, Chester W. Rice, published a paper in 1936 in which he gave the results of experiments with a magnetron operated at a wave length of 4.2 cm in conjunction with a parabolic-reflector antenna.

Rice used an alnico permanent magnet to achieve a more compact design and communicated over a distance of six miles. Rice mentioned that he had been able to detect the presence of an automobile and a Waco biplane by means of the Doppler effect. He speculated that a similar microwave-beam system might be used to relay television signals between stations located 15 to 20 miles apart.

John P. Blewett and Simon Ramo, both employed at GE at the time, undertook a theoretical analysis of the high-frequency behavior of a space charge subjected to a magnetic field in the late 1930s. Blewett had received a Ph.D. from Princeton in 1936, and Ramo had received his doctorate at the California Institute of Technology, the same year. A paper that Dr. Blewett and Dr. Ramo published in the *Physical Review* in 1940 not only explained some of Rice's observations but also predicted an effective space-charge dieletric-constant of less than unity, a prediction verified by 1941. Dr. Blewett worked for about ten years at the GERL and also spent some time at the Cavendish Laboratory in England.[3]

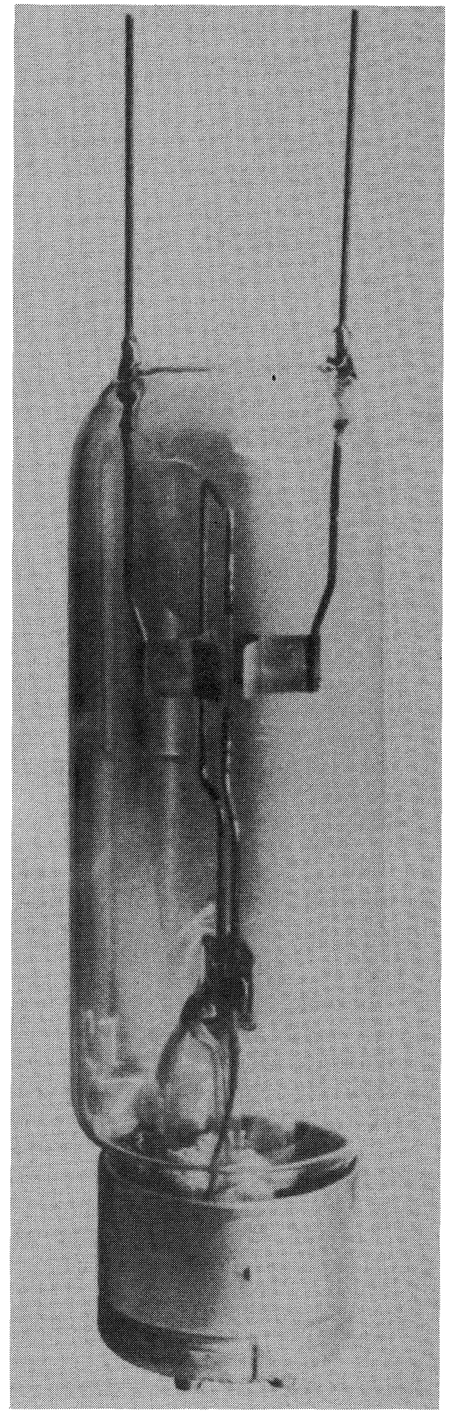
G. Ross Kilgore investigated the magnetron as a high-frequency source at the Westinghouse Research Laboratory in Pittsburgh, from 1929 to 1934 when the project was terminated. Kilgore graduated with a degree in EE from the University of Nebraska in 1928,and joined a group headed by Ilia L. Mouromtseff at Westinghouse. Kilgore recently described Mouromtseff as "a brilliant man and an ideal boss, providing his people with ideas, encouragement, and considerable freedom."

Initially, Kilgore attempted to replicate the magnetron experiments reported by Okabe but encountered difficulty with instability. Kilgore then discovered that tilting the magnetic field slightly with respect to the magnetron axis resulted in greater stability and power. He published an IRE paper on his research in 1932, but used the term "magnetostatic oscillator" rather than magnetron since Mouromtseff regarded the latter as a GE trade name.

Kilgore later developed a magnetron that generated about one watt at 3000 MHZ and used it for communication tests at a distance of about 1.5 miles. He also noticed Doppler-effect reflections from moving automobiles and railroad cars in the vicinity. (The Westinghouse Company installed the Kilgore apparatus at the Century of Progress exposition held in Chicago in 1933-34.) The Company sold two of the 9 cm magnetrons to the Army Signal Corps Laboratory at Fort Monmouth where they were used in radio detection experiments by W. Delmar Hershberger in 1933.

When Westinghouse ended its support of the magnetron research in 1934, Kilgore joined the RCA research group in Harrison, NJ and continued work on magnetrons under the direction of Browder J. Thompson. Kilgore constructed a magnetron that generated up to 100 watts at 500 MHz and RCA made them commercially available by 1938.[4]

By the time Kilgore came to RCA, other investigators there already had begun research on high-frequency magnetrons. Ernest G. Linder, who received his doctorate at Cornell in 1931, joined RCA in 1932 and began magnetron research soon afterward. Linder and Irving Wolff demonstrated a split-anode magnetron transmitter operating at about 10 cm for representatives of the Army Signal Corps in the Fall of 1934. The following year, Wolff, Linder and R.A. Braden published an IRE paper in which they described an end-plate magnetron that generated about 2.5 watts at 9 cm. They stated that the new design eliminated the need to tilt the magnetic field as Kilgore had found beneficial. (Linder published several other papers on the microwave magnetron prior to 1940.)



Split-anode magnetron built at GE. Tubes of this design have produced power outputs of 100 to 400 W at 50 cm.

Claud E. Cleeton and Neil H. Williams, physicists at the University of Michigan, extended the frequency limit of the magnetron and used the magnetron to investigate the absorption spectrum of ammonia gas during the early 1930s. Initially, they employed a split-anode magnetron obtained from the Westinghouse Research Laboratory. By 1933, they constructed a new magnetron that generated signals in the range of 1-3 cm. They then tried to determine the highest frequency that could be generated and, in 1936, reported producing magnetron oscillation at 0.64 cm wave length. Cleeton continued his research on magnetrons at the Naval Research Laboratory where he worked with A. Hoyt Taylor and J.P. Hagen. They used a 10 cm magnetron in ship-detection experiments during 1936 but the results proved so erratic that the Navy decided to use high-power vacuum tubes at lower frequency for the first radar system installed on a ship, in 1938.

Cleeton went on to help develop a pulse radio recognition system (IFF) designed to assist ships in the identification of friendly aircraft. According to Kilgore, the tube designers did not learn of the urgent need for a magnetron intended for pulse operation until after the arrival of the British cavity magnetron.

Magnetrons in Europe in the 1930s

Considerable research on magnetrons took place in French industrial laboratories during the 1930s. A group headed by Maurice H.H. Ponte at the laboratory of the Compagnie Generale de Telegraphie sans Fil (GTSF) investigated split-anode magnetrons beginning in 1932. In 1934, Ponte reported tests of magnetrons over a range of 7 to 500 cm in wave length, and at power levels up to 40 watts. Henri Gutton of the GTSF laboratory designed a microwave iceberg detection system using a magnetron operated at 16 cm, that was installed on the *Normandie* in 1935.

Andre G. Clavier and a group at the LMT, the International Telephone and Telegraph laboratory in Paris, also experimented with magnetrons for possible use in microwave communication. In 1939, Clavier reported that his group had experimented with magnetrons at wave lengths down to 1.2 cm. Clavier managed to continue research in occupied France during the war using short-wave transmitters hidden near the coast and in a fishing boat. The French engineers experimented with multi-segment anodes of up to 18 segments, and developed larger diameter oxide-coated cathodes that served to increase magnetron current ratings substantially. The latter innovation was adopted by the British for the high-power cavity magnetron in 1940.

K. Posthumus, who worked for the Philips company in the Netherlands, contributed to magnetron theory during the 1930s. He published a paper in *Nature* in 1934, reporting the discovery of a new-type oscillation in magnetrons where the magnetic field intensity was well above the theoretical cut-off point. He stated that the output frequency doubled if four anode segments were used instead of two, and predicted still higher frequencies if more than four were used.

Posthumus interpreted his observations by means of a rotating-field theory that he disclosed in a paper published in the *Wireless Engineer* in 1935. Adapting a technique used in the analysis of induction motors, he resolved the electric field in an oscillating magnetron into two components rotating in opposite directions. His theory indicated that electrons in a magnetron tended to travel in synchronism with a component of the rotating field. The rotating-field theory later proved important to Boot and Randall in their analysis of the cavity magnetron.

Posthumus' investigation of the magnetron was in the context of an effort to develop a practical microwave communication system at Philips. In 1937, the Philips engineers reported using a magnetron at 1200 MHz to communicate over a distance of 50 km.

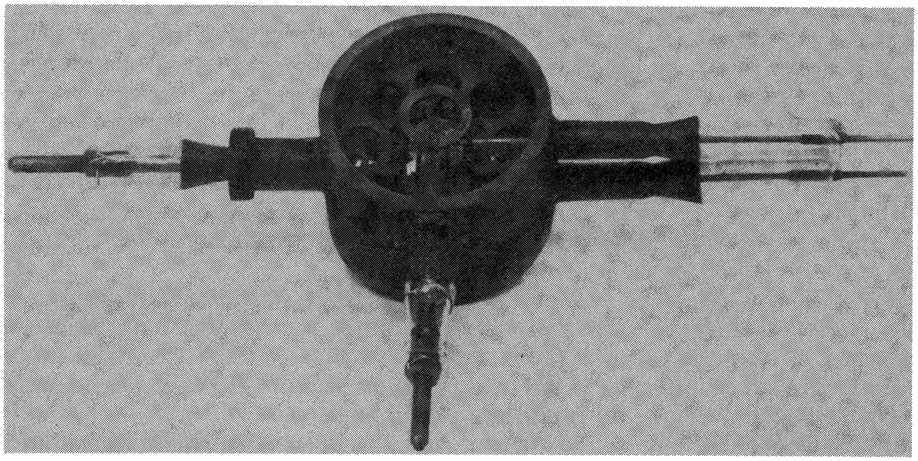
German industrial and university laboratories also initiated research on magnetrons during the 1930s. Experiments with a microwave aircraft detection system at the Telefunken company were reported in 1935. The system used a split-anode magnetron operating at 10 cm. Several doctoral candidates at the University of Jena and the University of Freiburg studied the behavioral of magnetrons and numerous papers on the magnetron appeared in German periodicals during the years from 1933 to 1939.

Magnetron research also began in the Soviet Union during the 1930s. Several papers dealing with the effect of gases in magnetron tubes and the causes of anomalous heating of magnetron cathodes were published by a group located at the Ukranian Physico-Technical Institute, in Kharkow. N.F. Alekslov and D.D. Malairov of the University of Leningrad published an important paper on magnetrons in the Soviet *Journal of Technical Physics* in 1940. This paper later was translated into English and published by the IRE in 1944. They described an experimental magnetron constructed with cylindrical cavities drilled in a copper block. This design helped overcome limits on magnetron output due to anode heating and they reported getting 300 watts at about 10 cm. This innovation apparently did not become known outside the Soviet Union until Boot and Randall independently developed a cavity-resonator magnetron.

British Magnetron Research and the Invention of the Cavity Magnetron

E.O.S. Megaw began research on the magnetron at the Wembley laboratory of the British General Electric Company and became a recognized authority on the subject. In 1933, he reported his discovery of secondary cathode emission in a split-anode magnetron and also published a paper that summarized theoretical and experimental work on magnetrons since Hull's first papers. Subsequently, he engaged in a friendly exchange with Posthumus over the validity of the rotating-field theory but came to accept it by 1935. E.W.B. Gill and K.G. Button also investigated the magnetron at Oxford University and reported their findings in 1936.

The final stimulus that led to the invention of a cavity magnetron suitable for use in microwave aircraft-detection systems came from British concern over the potential threat of German bombers. In 1939, a microwave research team headed by Mark Oliphant and including Boot and Randall was formed at the University of Birmingham.



Early copy of the British cavity magnetron. At the center is the anode block with eight resonant cavities. On the right are the leads for the current supply to the cathode. The lead for power extraction is on the left; it is connected to the coupling loop placed inside the outmost left resonant cavity. "Straps," visible in the middle of the anode structure, interconnect alternate resonators for a more stable operation.

Randall had received his doctorate at the University of Manchester and had spent a year at the Wembly laboratory of British GE where he gained practical experience in vacuum-tube techniques. Boot had graduated in physics in 1938 and later received a doctorate at Birmingham in 1941.

Boot and Randall initially experimented with Barkhausen-effect tubes but found the power inadequate for the needs of a transmitter and turned to the magnetron late in 1939. They lacked the time to conduct a comprehensive review of the magnetron literature but did encounter the rotating-field theory of Posthumus. A key idea came from their background in physics and they thought of the advantage of changing from a Hertzian loop resonator to a cylindrical cavity resonator. They estimated the dimension needed for a resonator of about 10 cm. [5]

For their first microwave magnetron, Boot and Randall drilled six cavities in a copper block with the cavities arranged symmetrically around the cathode. They conducted a successful test on February 21, 1940 and achieved a continuous power output of about 400 watts at 9.8 cm. The rather cumbersome experiemntal magnetron used in this first test quickly was converted into a compact unit suitable for manufacture by engineers at the British GE laboratory at Wembley.

Megaw had just learned the details of the French magnetrons including the large diameter cathodes and these were adopted for the new cavity magnetron to further increase its power. The Wembley engineers also reduced the length of the magnetron so that it would fit between the poles of a compact permanent magnet. They adopted a gold ring seal instead of the wax seal used initially by Boot and Randall. Reportedly, the Wembly group employed a Colt revolver as a drilling jig for the first few six-cavity magnetrons made there. Finally, they integrated the new cavity magnetron into an airborne radar set and, by May 1940, used it to detect a submarine periscope at a distance of seven miles. [6]

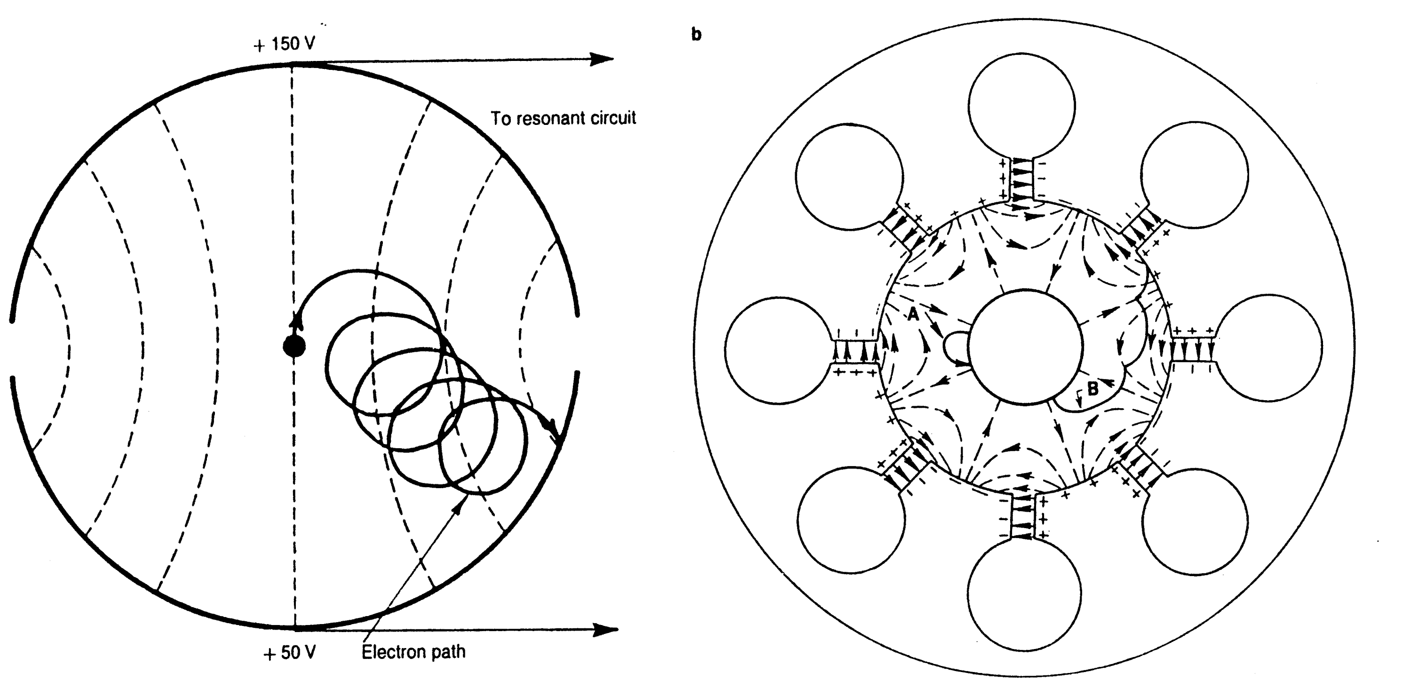
The Tizard Mission and its Impact

Henry Tizard (1885-1959), Chairman of the British Air Ministry committee on defense against aircraft, proposed in the Spring of 1940 that the British should arrange to share certain military secrets with the United States in order to take advantage of American production capabilty. The proposed mission to the U.S. received approval in July 1940, and Tizard was selected to head the mission that included three military officers and three civilians. Edward G. Bowen, a physicist who had done cosmic ray research before heading a group assigned to develop an airborne microwave radar system, was a member of the mission.

They collected various documents including circuit diagrams, manuals and photographs and packed them in a black deed box that was kept under guard at the Savoy House in London. Also included in the box was one of the first of twelve cavity magnetrons constructed at British GE, at Wembly. Bowen went to Wembly in early August 1940 to observe tests of the magnetron by Megaw and the best one was selected to take to the U.S.

Bowen was assigned to take the black box to Liverpool, and kept it under his bed in a London hotel on the night before departure when it proved too large to fit in the hotel safe. The next morning he took the valuable box, strapped to the top of a taxi, to the train station and travelled to Liverpool with one civilian escort. The Atlantic crossing was made aboard the *Duchess of Richmond.* John Cockroft, a Cambridge physicist who was another member of the mission, calculated that the black box filled with secrets would float even if the ship sank.

They landed at Halifax, Nova Scotia where a contingent of American soldiers provided security for the rest of the trip to Washington, D.C. There, the British mission was housed at the Shoreham Hotel. Meetings began with American military officers and others on September 12, 1940. The British produced the cavity magnetron at a meeting attended by Harold Loomis and Karl Compton of the National Defense Research Council (NDRC), and the American scientists were understandably impressed when they heard that such a small device could generate 10 kw pulses at 10 cm.



Electron paths in magnetrons. In the split-anode magnetron **(a)** the electrons emerging from the cathode follow spiraling paths toward the anodes because of the crossed magnetic and electrostatic fields. The electrons always drift towards the anode with the lowest voltage; this explains the negative-voltage characteristic of the tube. If the two anodes are connected to a resonant circuit, the electron path alternates between the two anodes with a frequency determined by the resonant circuit. In the cavity magnetron **(b)** each cavity forms a resonant circuit. During oscillation the displacement charges shown in the figure alternate at the operating frequency and the path of spiraling electrons rotates from one anode segment to the next as a traveling wave. Electrons **(A)** slowed down by the rf field return to the cathode, while electrons **(B)** accelerated by the rf field reach the anode quickly. (From *Microwave Magnetrons*, George B. Collins, ed. McGraw-Hill, New York, 1948.)

Alfred Loomis (1887-1975) had become wealthy as a lawyer and investment banker and had established a private laboratory in Tuxedo Park, NY. He became interested in microwaves during the 1930s and was selected to chair the Microwave Committee of the NDRC. He had strong connections to MIT and several MIT people had worked at the Loomis Laboratory. Bowen and Cockcroft spent a weekend at Loomis' home in Tuxedo Park late in September 1940 where they met Edward Bowles, an EE professor at MIT, and Hugh Willis, research director of the Sperry Company. The group decided that the Bell Telephone Laboratory should be asked to manufacture copies of the British magnetron. A few days later, Brown went to Bell Labs to disclose the design details of the magnetron and to demonstrate its performance.

Bowen was delighted when the magnetron he had brought from Wembley still worked and produced even more power than expected. He returned to Washington but received an urgent call from Bell Labs the next day. He learned that the BTL scientists had taken an X-ray photograph of the magnetron and found it to have eight holes instead of the six shown on the drawings that Bowen had brought from England. He then placed a call to Megaw at Wembley and discovered that only ten of the first twelve magnetrons had been made with six holes but that one had seven holes and another eight. He had selected the only one with eight holes. Since it worked so well, the BTL group decided to duplicate the eight-hole magnetron. They fabricated 30 cavity magnetrons within a month, with the first five going to the newly formed Radiation Lab. Meanwhile Bowen and other members of the British mission visited various centers of microwave research in the U.S. and acquired samples of apparatus such as klystrons and lighthouse tubes to send to Britain.

In mid October, Bowen and Cockcroft spent another weekend at Loomis' house in Tuxedo Park where they discussed research projects with Loomis, Bowles, E.O. Lawrence, and Carrol Wilson. The top priority was given to development of an airborne radar set, an anti-aircraft gunlaying set and a long-range radio navigation system. They also decided that a new laboratory should be formed to develop and test radar systems and that it would be staffed by civilians, but would be linked closely to military and industrial labs. The British representatives pointed out that they had been able to make effective use of people trained in disciplines other than physics and engineering, in radar research and development. The same weekend, the group worked out a preliminary design of 10 cm radar based on the magnetron, that would be the first project of the new laboratory.

The following day Loomis called a meeting of the NDRC Microwave Committee, at his New York City apartment. This important meeting was attended by Loomis, Bowen, Bowles, Lawrence and by Marvyn Kelly from Bell Labs, Ralph Beal from RCA, and Hugh Willis from Sperry. Because of the short notice of the meeting, representative from GE and Westinghouse were not present. The Committee proceeded to allocate contracts to BTL, GE, RCA, and Sperry for the manufacture of various components that would be needed for the first microwae radar system. After the formal meeting ended, Loomis, Lawrence and Bowen discussed the design of a long-range navigation system that became known as LORAN. (Lawrence agreed to take on the assignment of recruiting people for the new laboratory and began immediately using the telephone in Loomis' apartment.)

The next meeting of the Microwave Committee took place October 18, 1940 at the Carnegie Institution, in Washington. In addition to Loomis, Bowen and Bowles, this meeting was attended by Vannevar Bush, Chairman of the NDRC, and MIT President Karl Compton. Others at the meeting represented GE, RCA, Sperry, Westinghouse, the Navy, and the Army Signal Corps. Final contract arrangements, including deadlines, were decided. For example, Bell Labs promised to deliver five magnetrons in thirty days, and RCA promised delivery of two to four cathode ray display tubes in thirty days.

Various sites for the proposed laboratory were considered including the Carnegie Institute and Bolling Field near Washington, but an offer from MIT to provide 10,000 square feet of laboratory space was accepted by the NDRC. Lee DuBridge was recruited by Lawrence to head what became known as the Radiation Laboratory. The Microwave Committee met at MIT October 30, 1940 to inspect the facility and it began operation in November.

The first microwave radar set built at the Radiation Laboratory was tested from the roof of the Lab early in January 1941, and it picked up aircraft reflections over Boston Airport in February. The prototype was then modified for installation in an aircraft and underwent its first flight test on March 21. In June 1941, less than a year after the arrival of the cavity magnetron in the U.S., the Radiation Lab sent a working 10 cm radar to Britain. [7]

Although the nucleus of the Radiation Lab staff was an elite group of physicists recruited by Lawrence, the staff expanded to a peak of 3897 people having many disciplines and backgrounds. About 350 were from industry, 1050 from universities, and the rest from diverse occupations. The staff included about one fifth of the leading physicists in the country, and approximately two billion dollars was spent on systems designed or developed at the Lab — approximately the same amount spent on the atomic bomb during the same period.

More than forty scientists and engineers were assigned to work on magnetrons at the Rad Lab during the period from 1940-1945, and more than twenty types were produced. They ranged in frequency from 30 to 30,000 MHz and in output power from 30 to 3,000,000 watts (peak). Generalized methods of analysis were developed so that a magnetron could be designed quickly with predictable characteristics. Magnetron magnets were made ranging in weight from a few ounces to 100 lbs. The magnetron group at the Rad Lab was headed by George B. Collins, a physicist from the University of Rochester, and who edited the classic book *Microwave Magnetrons* published in 1948.

Other centers of magnetron research and development during the war included the Radiation Lab at Columbia University, the Radio Laboratory at Harvard University, the Bell Labs, the GE Research Laboratory, the Westinghouse Research Laboratory, and the Raytheon Company. The groups at GE and Harvard concentrated on the development of tunable magnetrons that could be used in radar countermeasures equipment. Lewi Tonks headed the effort at GERL that included John P. Blewett and Joseph L. Hull amongst others. Early experience with split-anode magnetrons there during the 1930s contributed to their success in the design of broad-band jamming transmitters. David H. Sloan, of the Westinghouse Research Lab, also developed a tunable magnetron for use in a countermeasures transmitter.

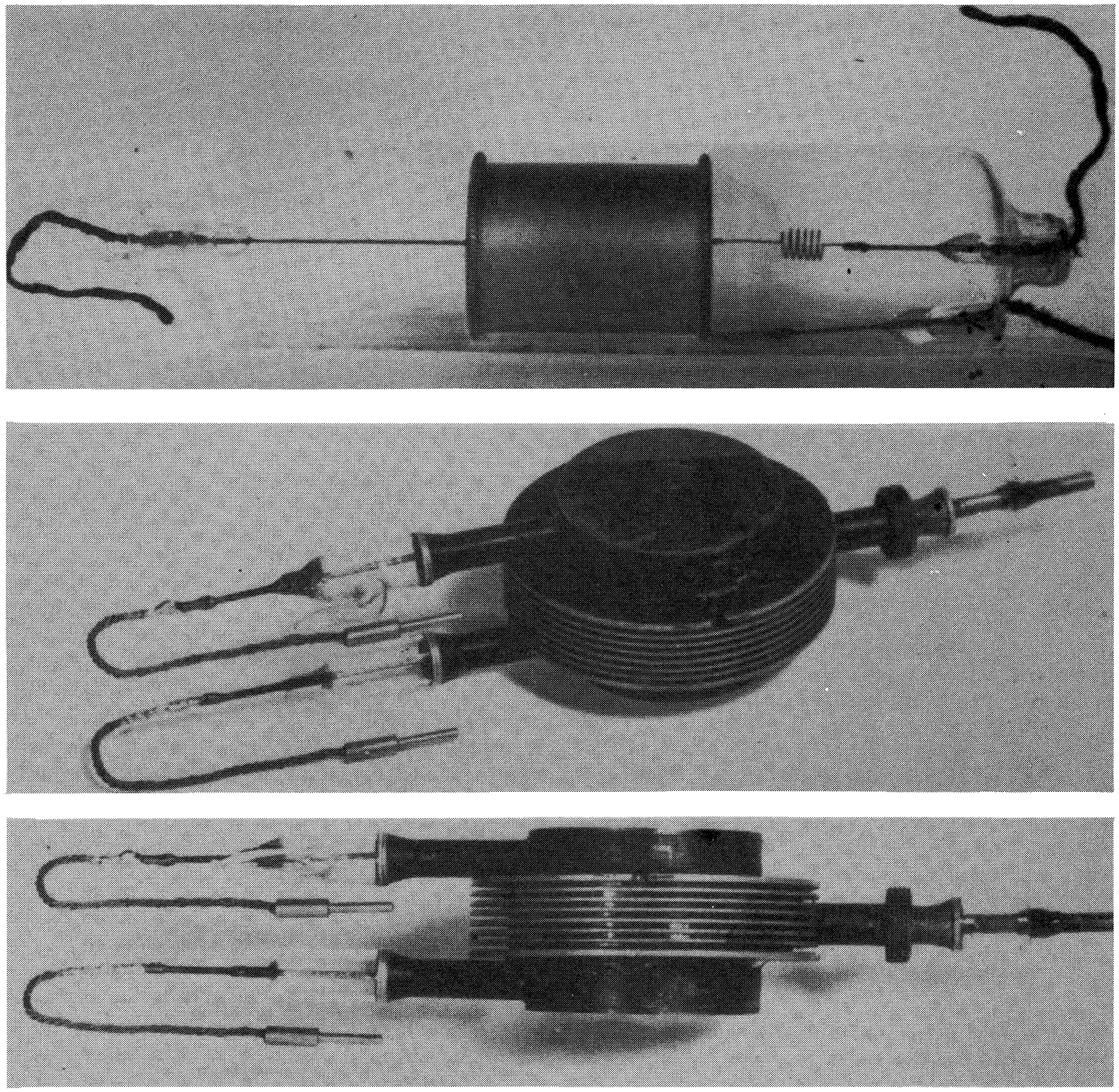
The problem of "mode jumping" that limited the performance of the first resonant-cavity magnetrons was solved to a large extent by an innovation known as "strapping" proposed by J. Sayers at the University of Birmingham in England, in 1941. This involved connecting alternate anode segments with copper straps to cause greater separation between the desired mode and unwanted modes of oscillation. This enabled a dramatic increase in magnetron output power and efficiency.

Percy L. Spencer of the Raytheon Company introduced the ring-in-groove method of strapping in the U.S. He also introduced a novel method of producing magnetron anodes by using punched laminations from copper sheet that then were brazed during assembly. The conventional strapping was unsuitable for magnetrons designed for use at around one cm (K band) and researchers at the Columbia Radiation Lab introduced the so-called "rising-sun" magnetron that used alternating cavities of different size to get mode separation. They found it necessary to use a hobbing technique in which precision-ground hobs and blocks were used at high pressure to produce the rising-sun anode pattern in copper cylinders. [8]

Conclusion

The cavity magnetron that arrived in the black box in 1940 is a remarkable example of the sharing of secrets at a time when the U.S. was not yet at war. The barriers to technology transfer that exist in normal times can be overcome in a crisis sitution such as the British experienced at the time. Even so, the common language and cultural heritage of the two countries served to facilitate this technological exchange that benefitted both parties. Although the magnetron and the black box tended to overshadow the broader exchange, there also was a substantial transfer of related microwave technology from the U.S. soon after the British initiative.

Perhaps the most remarkable impact of the black box mission was its role in the creation of the Radiation Laboratory at MIT, an institution that existed for less than five years and will celebrate its 50th anniversary in 1990. It taught many lessons in what highly-motivated people from diverse backgronds could achieve in a short time especially when communication barriers amongst military, industrial, and university centers having common interests and goals, were lowered for the duration of the war. It became the paradigm of the kind of institution that can bring rapid technological change and its "graduates" carried the doctrine elsewhere when the Lab disbanded in 1945. The magnetron found many uses in civilian as well as military applications and eventually entered many homes by way of the microwave oven. The descendant of Albert Hull's original magnetron has come to have far-reaching effects in the socio-cultural sphere as well as in scientific instruments and technological hardware.



a GE

b AT&T BELL LABS

c AT&T BELL LABS

Magnetrons. a: Albert W. Hull's first magnetron. It consists of a straight wire cathode surrounded by a cylindrical anode. The British cavity magnetron **(b and c)** was brought to the US by the Tizard mission and demonstrated for the first time in the US at Bell Labs on 6 October 1940.

Notes

1. Frank R. Elder, "The Magnetron Amplifier and Power Oscillator," *Proceedings of the IRE,* 13,(1925):145-188.

2. See my paper on the Yagi-Uda antenna in the *Proceedings* of the Radio Club of America, 59(November 1985): 7-10.

3. Personal communication from John P. Blewett, June 13, 1985.

4. G. Ross Kilgore, "Recollections of Pre-World War II Magnetrons and their Applications," IEEE *Transactions on Electron Devices,* ED-31 (November 1984): 1593-95.

5. Copy of a memorandum by John T. Randall dated May 1, 1984. I am indebted to Dr. E.G. Bowen for providing me with a copy.

6. Henry A.H. Boot and John T. Randall, "Historical Notes on the Cavity Magnetron," IEEE *Transactions on Electron Devices,* ED-23(July 1976):724-29.

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HONORS AND AWARDS 1986

ARMSTRONG MEDAL
Dr. George H. Brown

Awarded for major contributions to the design of broadcast antennas — and particularly those used in television broadcasting; also for leadership in the establishment o the NTSC color television standards, and in the inventions of the vestigal sideband filter and the shadow-mask kinescope.

RALPH BATCHER MEMORIAL AWARD
Donald K. deNeuf

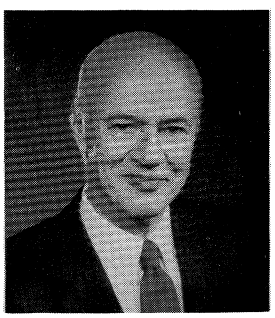
Awarded for contributions in preserving the history of radio communications through his writings and publication of articles, and for his early work as a shipboard radio operator.

FRED M. LINK AWARD
Fred M. Link

Established and initially awarded in recognition of pioneering work in the development of FM landmobile radio, and for worldwide activities in supporting its use in public safety, governmental, commercial and private services.

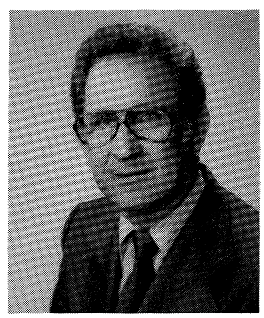
PIONEER CITATION
O. James Morelock

Awarded in recognition of outstanding services to the Radio Club as President, Corresponding Secretary, Director, and Chairman of the Publications Committee, and for his pioneering contributions to test instrumentation.



SARNOFF CITATION
Kenneth M. Miller

Awarded for major contributions in radio communications and in the applications of electronics to aviation, instrumentation, and computers; also for his leadership of the Radio Club's Grants-in-Aid scholarship program.

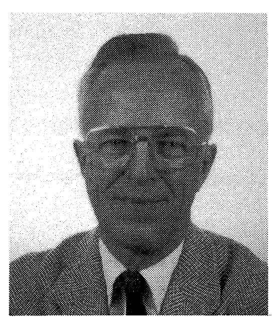


SPECIAL SERVICES AWARD
Mal Gurian

Awarded in recognition of outstanding service to the Radio Club in the Office of Vice President and coordinator of the Awards Banquets; also, for leadership in the development of cellular radiophone services.

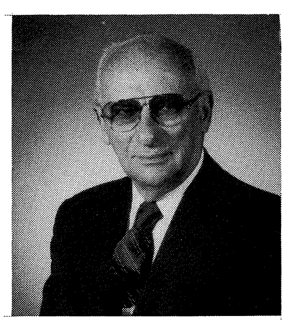
ALLEN B. DuMONT CITATION
William H. Sayer

Awarded for pioneering work in UHF television transmitter design with applications of klystron tubes; also, for application of the kylstrons to tropospheric scatter communication systems.



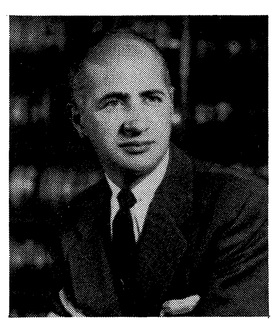
PRESIDENT'S AWARD
Archibald C. Doty, Jr.

Awarded for contributions in developing a computerized program for the storage and retrival of the Radio Club's records, and in recognition of continuing work in antenna research.



HENRI BUSIGNIES MEMORIAL AWARD
Frank A. Gunther

Awarded for pioneering work in the design of two-way police radio systems and for the development of FM transmitters and receivers, LORAN, and tropospheric scatter systems.



LEE deFOREST AWARD
Maurice Zouary

Awarded for contributions in the preserving of early sound motion pictures made by Dr. Lee deForest, and for leadership in recognizing Dr. deForest as the Father of Modern Talking Pictures.

FELLOWS — 1986

The following Members are elevated to the Grade of Fellow in The Radio Club of America in recognition of their achievements in furthering the goals of the Club, and are here Cited:

Roy E. Anderson, Vice President — Mobile Satellite Corp., King of Prussia, PA, for achievements in satellite navigation and communication systems.

Edward F. Barnhart, Senior Engineer (Retired) — Columbia Gas Transmission System, Charleston, WV., for systems development in use of microwave and landmobile radio services in communications.

John C. Beaman, Vice President & General Manager — Larsen Electronics Inc., Vancouver, WA., for engineering development of specialized landmobile antenna products.

Emil J. Beran, Vice President — Bell Atlantic Mobile Systems. Basking Ridge, NJ, for contributions in the development of cellular radio services.

Robert E. Bloor, Engineer (Retired) — Ohio Bell Telephone Company, Westlake, OH., for early work in developing Amateur radio services in public emergency communications, and activity in vehicular communications.

Robert C. Corwin, Vice President Marketing — Decibel Products, Inc., Dallas, TX, for contributions in the development and distribution of antenna systems.

Dr. John H. Davis, Executive Director — AT&T Consumer Products, Holmdel, NJ, for contributions in the field of digital technology in the research and development of cellular mobile radio.

Sam L. Dawson, President — Component Engineering Company, Culver City, CA, for contributions associated with the field performance of key military communication systems in World War II, and subsequent industry work.

Norman E. Fowlkes, Supervisor of Technical Operations — ARAMCO Services Co., Houston, TX., for pioneering work in VHF radio control systems and in network control centers.

Don L. Fox, Microwave Communications Supervisor — Florida Highway Patrol Tallahassee, FL., for advanced technical work in design, installation and maintenance of Florida's largest law enforcement communication system.

Dr. Roger E. Fudge, Chief Engineer — British Telecom Ltd., London, England for contributions in satellite communications systems and emergency services communications.

Gary M. Frederick, Supervisor — Collins Div., North American Rockwell, Marion, IA., for technical and management leadership in the activitie of the Collins Radio Division.

Weldon P. Hale, Superintendent of Communications — Maryland State Police, Owings Mill, MD., for leadership in communications associated with law enforcement groups in Maryland.

Leland F. Heithecker, Executive Director — QCWA, Springtown, TX., for leadership in Amateur radio organizations and contributions in the field of broadcast antenna systems.

Herbert Hoover III, Investor — San Marino, CA., for leadership and support of Amateur radio sponsored programs on an international basis.

John B. Johnston, Chief - Personal Radio Branch FCC, Washington, DC., for contributions in the development and revision of rules in the general mobile, personal communications, and Amateur radio services.

Dr. William C.Y. Lee, Vice President — PacTel Mobile Corp., Costa Mesa, CA., for achievements in mobile communications engineering and early leadership in cellular systems development.

Byron O. McCollum, Director of Technology — Bucks County Dept. of Communications, Penns Park, PA., for leadership in the advancement of Bucks County Police Radio network and contributions as a key committee member of APCO Projects Committee.

Scott R. McQueen, Sales Representative — Campbell, CA., for development and implementation of cellular systems.

Richard L. Miller, President — APCO, Palmdale, CA., for technological and organizational contributions in the field of public safety communications.

Louis Perlmutter, Sales Executive (Retired) — SONAR Corporation, Hallandale, FL., for contributions in the field of communications equipment design and distribution.

Evan B. Richards, Vice President — Ameritech Mobile Communications Inc., Schaumburg, IL., for leadership in the pioneer Bell System cellular installation and for leadership within the IEEE VTS programs.

Dan L. Roszelle, Regional Manager — Celwave R.F. Inc., Marlboro, NJ., for industry leadership in the application of specialized antenna designs in landmobile communications.

Byron G. Ryals, Ryals Communications Engineering, Sunnyvale, CA., for introduction and distribution of advanced technological equipment.

Robert Simkins, Superindendent (Retired) — T.O.B., Oyster Bay, NY., for industry leadership in use of mobile communications in public utility maintenance and for activities in Amateur radio.

David S. Simmonds, President — Lenbrook Industries, Ltd., Pickering, Ont., Canada, for leadership activities in commercial and technical organizations.

George K. Starace, Supervising Engineer (Retired) — New York Telephone Co., Plano, TX., for activities in early development of AMTS, IMTS, and cellular radio systems for Bell System companies and private radio services.

Leland W. Smith, Brig. General — U.S.M.C. (Retired), Jasper, AR., for contributions in military communications and leadership in QCWA and other Amateur radio organizations.

Harry Tarbell, Owner/Manager — Pacific Paging, Beaverton, OR., for leadership in the field of two-way communications in the Pacific Northwest.

Marguerite E. Warshaw, Moderator — Rockland Cablevision Inc., Valley Cottage, NY, for activities in educational radio and television, authorship of educational programs, and active support of deForest Pioneer projects.

David E. Weisman, Attorney — Newrath, Meyer & Faller, P.C., Washington, D.C., for expertise in the field of filings before the Federal Communications Commission, and counsel to NABER.

Amandus G. Wentzel, Jr., Supervisor (Retired) — Princeton University, Trenton, NJ., for contributions in remote control telemetering and communications for U.S. Navy.

David W. Winter, Retired, for long time activities in Amateur radio organizations.

A NOTE ON NORTON'S THEOREM

by Col. James F. Scoggin, Jr. (U.S. Army Signal Corps. - Ret.), Ph.D., P.E. (M 1975, F 1984)

In a typical introductory circuit analysis course, a college sophomore may encounter the name of only two Americans — Joseph Henry and Edward L. Norton. Henry, of course, is the unit of inductance. Norton (and the 19th-century French engineer Thevenin) are the originators of twin theorems, so useful in linear network simplification and so often mystifying to the young student.

Who was Edward L. Norton, and what was the genesis of Norton's Theorem? Norton is very much a 20th-century American, having been named an IEEE Fellow in 1962, for "fundamental contributions to circuit theory."

Because Mr. Norton's career was in the technical staff of the Bell System, his original paper announcing the Theorem naturally appeared in the *Bell System Technical Journal.* It didn't. There was no "original paper."

In 1979, the author was able to get the story, through the assistance of Dr. W.H. Doherty, IEEE Fellow 1944, and Mrs. Blanche L. Norton, the wife of Edward Norton. [1] At various times prior to 1979, curious engineers — unable to locate the original paper — had written to Norton, and copies of some of her husband's replies were graciously provided by Mrs. Norton, to the author.

The relation was originally worked out in a mechanical form to allow for the compliance of record material when driving a phonograph needle. It was not until several years later, when the use of transconductance in place of voltage gain became customary in vacuum tube circuit studies, that the relation appeared to have value in electrical work. The first to use it in this field is believed to have been E.B. Ferrell, but there was apparently no publication at the time.

Mr. Norton's earliest written record was in a memorandum dated November 3, 1926, to the patent department of the Bell Telephone Laboratories. The theorem was not regarded as particularly important at that time, and the material did not appear in any patent papers. The first published statement was apparently in the second edition (1937) of Professor W. K. Everitt's *Communication Engineering.* Professor Everitt had visited the Laboratories and talked with R.V.L. Hartley, who mentioned the relation and gave Norton credit for originating it.

Professor Everitt stated Norton's Theorem as follows:

> "The current in any impedance Z_R, connected to two terminals of a network, is the same as if Z_R were connected to a constant-current generator whose generated current is equal to the current which flows through the two terminals when those terminals are short-circuited, the constant-current generator being in shunt with an impedance equal to the impedance of the network looking back from the terminals in question."

E.L. Norton joined the Bell System technical staff from M.I.T. in 1922. A major specific contribution of his was the invention of impedance transformation in band-pass filters. [2] Indeed, to his associates in the Bell Laboratories,

> Norton was something of a legendary figure in network theory work who turned out prodigious numbers of designs armed only with a slide rule and his intuition. Many anecdotes survive. On one occasion, T.C. Fry called in his network theory group, which included at that time Bode, Darlington and R.L. Dietzold among others, and told them: "You fellows had better not sign up for any graduate courses or other outside work this coming year because you are going to take over the network design that Ed Norton has been doing single-handed." [3]

Soon after the end of World War II, Norton became heavily involved in solving the most difficult equalization circuits for the Nike missile control system.[4] He retired in 1963 as a department head in the High Speed Data Terminals Department, Holmdel. [5]

Edward L. Norton was born on July 28, 1898, in Rockland, Maine. He earned the S.B. at M.I.T. and the M.A. at Columbia University, and for 41 years had a productive career in the Bell System. He died January 28, 1983, after several years as an invalid.

References

Background Note: The Citadel's Electrical Engineering Department, of which the author is an emeritus professor, is proud to display a diagram of the magnificently simple Norton equivalent circuit, autographed by the originator.

1. Private communications, Dr. W.H. Doherty — Mrs. Blanche L. Norton — J.F. Scoggin, Jr., 1979.

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3. E.F. O'Neill, ed., *A History of Engineering and Science in the Bell System: Transmission Technology (1925-1975),* AT&T Bell Laboratories, 1985, p210.

4. M.D. Fagen, ed., *A History of Engineering and Science in the Bell System: National Service in War and Peace (1925-1975),* Bell Telephone Laboratories, Inc., 1978, p.375.

5. *Bell Labs News,* February 14, 1983, p.4.

WEATHER, RADIO, AND THE THIRD WORLD

by Edward Rich, Jr. (M 1980, F 1985)

Smoke signals, flags, horns and lights were widely used to communicate thoughts long before radio was invented. The invention of radio certainly brought about great changes but, strangely, the primitive means of communications still flourish in many developing countries.

Tradition defines communication as a transfer or exchange or intelligence between points or parties. But to the people of third-world countries, communication has a much deeper and often very personal meaning. In these countries, all communications have three major dimensions: where something is happening as related to their home or country; what is happening and how it impacts their lives; and who is involved and whether they themselves will be personally affected.

The third-world's communications normally involve politics, disasters, people, food and the day-to-day happenings that are the very core of their existence. This is not to say that these people are not interested in world affairs or what happens to other people, but it must be accepted that in their countries, survival is on a day-to-day basis, making their concerns considerably different than ours.

There are over 300 countries in the world today; the majority are poor, poorly-educated and underprivileged. Most of these countries are located in the warmer parts of the world and are collections of thatched-roof huts arranged in villages near sources of water, food and work. Illiteracy runs high, as does overpopulation. Natural disasters such as floods destroy people, villages and what food there is, and continual food shortages create a constant struggle for survival.

The attempted solution — training people to help themselves — is without end, and has been a worldwide organized effort ever since the United Nations was formed. The nations that support the U.N. also support direct aid programs in the less fortunate countries. Aid is provided in agriculture, communications, science, education and manufacturing, to name a few. In the area of science, one of the heavily-endowed areas include meterology and hydrology.

Weather Forecasting

In today's modern world, the business of weather forecasting relies on numerous electronic devices: radar, radio communications, automated observations, and complementary studies and activities provided by neighboring countries. A great deal of information is developed and distributed on a global basis, and to support local activity. Where then does the little developing country fit into this highly-technical and sophisticated scheme of things?

It has been my good fortune to be involved in improving a particular kind of radio communication for weather forecasting and natural disaster warnings that currently links the most modern digital-satellite systems to pre-Marconi flag-wavers. Although the experiences narrated in this article focus on Bangladesh, I have had the opportunity to work in dozens of countries and am convinced that most developing countries are similar — sharing both the problems and solutions. To understand how a more sophisticated form of radio transmission can best be utilized in a country like Bangladesh, it's important to explore their history and weather patterns.

The Republic of Bangladesh, once a part of India and later known as East Pakistan, achieved its independence more than a dozen years ago. The country is situated at the northern end of the Bay of Bengal with India to its west and north, and Burma to its east. It is essentially a great flood plain, carrying off the rain and melting snows from India, Nepal and China. The country is about the size of Illinois, yet it has a population of some 94 million people. About 20 percent of the country is always under water and when the rains come almost 40 percent of the land is submerged.

The Weather Cycle

The Banglasdesh weather cycle is typically tropical. Winter starts in January and lasts six to eight weeks. Then come the annual Northwesterlies. Gale-force winds and lashing rain combine with the melting snows to swell the rivers to unknown boundries.

Then the weather gets bad. The Monsoons begin. Temperatures soar to the 100-degree plus mark, rivers rise as much as 55 feet sweeping away houses, animals, crops, and people. Cities are inundated by endless seas for weeks, while mildew and rot attack whatever is left on high ground.

When the rains are finished and the lower ground starts to reappear, the Bay of Bengal makes itself known. Vicious cyclones — or hurricanes as we call them — whip up the Bay, driving walls of water over the southern part of the country. People by the thousand lose their lives. Survivors lose their homes, animals and crops.

"Why do the people remain in these life-taking areas?" The answer is simple: "There is no other place to go — no high ground — no way to get there, and no place to live if you could move!"

Where do radio and high-tech communications fit into this utterly austere form of existence?

The rapidly advancing state of those arts in the developed countries had to have an effect on Bangladesh and other developing countries. Two of the most significant areas of progress were in electrical power generation and distribution, and television.

The Power System

The distribution of power was and still is somewhat of a problem. A 250,000-volt main was run across Bangladesh bridging rivers and lowlands. Towers 350 feet high support the huge strands of cable. The bases of the towers — to provide some idea of the problem — are reinforced concrete 40 feet in diameter and extend downward through 80 feet of silt before reaching bedrock, thence into the rock by additional boring. In some areas, the water is 40 feet above the top of the silt bed.

The power mains are reliable and good. Distribution through the branches and sub-branches remains a problem. The more local the service, the more unreliable it becomes. Villages often are served by a single drop of 20 amperes capacity, which is shared by all who can attach to it. Frequent connects and disconnects degrade the service so that, in time, it is a service in name only.

The distribution of power throughout the country served as a basis for the establishment of a modern FM repeater network to permit organized maintenance of the power grid.

Along with the distribution of power, television receivers were installed in each village that had a power drop, allowing many people to see television for the first time. Most of the larger villages have only one television receiver, but it is a start. Television does not reach everyone — hundreds of thousands have never seen it.

The application of TV technology was very much due to developments in solid-state devices. The generation and distribution of power took on a new meaning, as did the development of high-reliability television transmitters and receivers capable of surviving in the high-humidity environment of Bangladesh. The Bangladesh television system was expanded by networking and provided two channels of simulcast programming from the capital. It permitted television signals to reach every part of the country with good signal strength.

Broadcast radio — very popular in a few of the largest cities — is at a disadvantage in the rest of the country because of the lack of power in homes, and the lack of resources to obtain portable radios or the batteries to run them. Indeed, the nights in the Bangladesh countryside are very dark and very quiet . . .

The Weather Bureau

Bangladesh has had a weather bureau for many years. The organization collected and still collects environmental data by mail: river stage, rainfall and temperatures. From the global networks that provide large-area forecast information and from local measurements, weather forecasts and warnings of impending storms were issued. These often were in error or too late. Picture a hurricane driving a wall of water 40 feet high and 50 miles wide — with no way to predict it or to warn the population — that happened in the early '70s and took 500,000 lives.

The United States launched its very successful TIROS weather satellite series in the early '60s. This satellite orbited the earth in a polar orbit every 100 minutes or so and transmitted the scanned information simultaneously. It was sent in both a complex, high-resolution form and a simple low-resolution form. When displayed on cathode-ray tube terminals or by collecting the scan lines on Polaroid film, the users had magnificent pictures of the Earth's cloud cover. This formed an extremely useful tool, when combined with global network information, to provide realistic forecasts of coming weather.

The United States Agency for International Development (USAID) saw, in this, a way to help countries that were prone to environmental disaster and began — along with several other nations — a program to equip the meterological services with simple stations to monitor, visually, the Earth's cloud cover and their own weather patterns.

From 1969 to 1979, approximately 40 countries around the world were equipped with these simple automatic picture-taking stations.

Placing tethered weather buoy in Bay of Bengal.

An advanced series of satellites were launched starting in 1978. Picture quality became 100 fold better, but formats were more complex and new equipment was needed. The U.S. National Weather Service was responsible at that time for implementing such new programs. Commercial sources came up with costs that far exceeded budgets for the replacement of the old equipment. The solution was one for which Radio Club Members are famous: "When all else fails, do it yourself."

And so we did! With the help of one of NASA's engineers, we designed a really low cost satellite ground station and throughout a period of a year, assembled 26 for use around the world. The real satisfaction out of this program was in doing what industry couldn't do, what government wasn't supposed to be capable of doing, and in a shorter time than was supposed to be possible. We save Uncle Sam and the taxpayers about a million dollars, received our due rewards from Juanita Kreps, Secretary of Commerce — and traveled around the world three times in the process. And they say "Never volunteer!"

The first station went to Bangladesh and was completed in October 1978. The first picture displayed was of a cyclone no one knew had formed, starting in the Bay of Bengal. The Bengali engineers learned a great deal in the two years that followed.

USAID, through NASA, initiated the next program phase. This provided the equipment needed to process more complex data format. It also added the imagery transmitted by the Japanese geostationary meterology satellite which we know as GMS.

Satellites became more complex as the digital data processing and communication technology emerged. It became time again for Bangladesh to grow — and this time to the rank of a number one forecast facility. Fortunately, budgets grew with the times and USAID underwrote a $5 million program for this last step.

Agro Climate Environmental Monitoring Program

It took two years hard work by ten engineers to assemble this final station complement. It was completed and installed by June 1985. When packed for sea shipment, it occupied three containers with no room to spare. Containers are 8x8x20 feet and weigh about 44,000 pounds when loaded. Only the computers were shipped by air. The support equipment included an 85-kW natural-gas diesel generator for back-up power, a 45-kW uninterruptable power supply to provide power to the computers without glitches or spikes, and a 20-ton filtered air-conditioning system — all to manage the operating environment for the processing center.

The electronic processing system serves three satellites: the original TIROS series, the Japanese geostationary, and an Earth resources satellite known as Landsat. The Landsat is new in this discussion but has been in orbit for some years. It provides multi-spectral imagery of the Earth, with resolution in the 100-meter range as contrasted to the low resolution of weather satellites which are, at best, in the range of 1 km. Dual computers are used — providing independent processing or handling of all types of data should one system fail.

While the same basic data are transmitted by the satellites, data now are enhanced by computer techniques to highlight weather and environmental changes that were never seen before. That data are used by teams of meterologists, hydrologists, agronomists, and economists to look at weather patterns, flood conditions, land use, crop diseases, planting efficienty and a host of new parameters that provide the warnings, advice, national work schedules and priorities.

A series of automatic data collection stations located at critical points on the rivers and Bay supply additional data input to the processing system.

Monitoring water level parameters to permit prediction of maximum rise, spread and crest time is of maximum importance. The solution to this is to implant a "stilling well" — a steel cylinder — in the bank of a critical water body with feeder pipes going out into the water itself. In theory, the water rises and falls in this stilling well and, by using shaft encoder techniques, the position of a float is recorded and transmitted on a programmed basis. Other measurements including temperature, salinity, wind speed and direction, solar radiation, humidity and pressure are also recorded and transmitted. These data are combined in digital form in a data burst which is released every 140 seconds.

When the orbiting TIROS satellite passes within range, it receives this burst of UHF and transmits it on microwave frequencies multiplexed with the imagery. Thus it acts like a repeater, but without additional receivers; instead simple software derives and prints the measured parameters in engineering units.

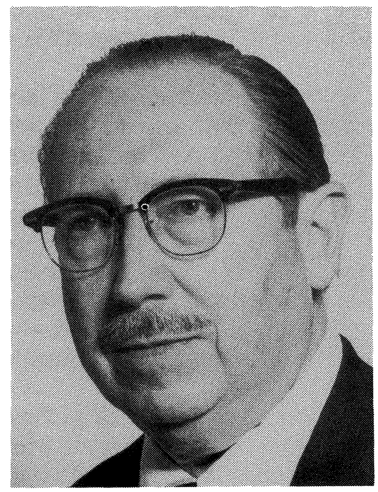
Bangladesh has ten data collection platforms and one tethered buoy at critical river points. All stations are powered by storage batteries charged by 10-watt solar panels. Microprocessors are used to collect and buffer the data, and perform on-board processing to conserve bit space in the data bursts which are limited to 256 bits.

Today, the center — which has the elegant name SPARRSO, the Space Research and Remote Sensing Organization — operates at all hours of the day and night. Extra shifts are active when the sky goes black in the Spring and Fall. Workers look forward to January and February with mixed emotions. For while the ground is dry, crops are flourishing, and work can be done on antennas, it is still Winter; the temperature falls at 50° at night and rises only to 80° in the daytime. For most, this is pure misery.

The story of weather radio is far from being over. Bangladesh — like every other country in the world — cannot be legislated into the role of a smooth-running, trouble-free, high-tech machine. Like the rest, it must wrestle with changes in management that can cope with the technology, the vast amount of data and the monumental problem of keeping things going. There are problems of maintenance, inventories, procurement and other such items. Communication between people also is a problem, and it's with people who are not a part of this high-tech age that progress slows to the pace of willingness to teach and be taught.

Our adventure in Bangladesh will be extended for two years, starting again in a few months. The job of maintaining hardware and software, and originating solutions to other problems will be a full-time task. If we are successful at blending in some of the American ingenuity, initiative and logic, we will indeed have made a major contribution to the technical development of this third-world country.

THE FIRST RADAR FOR COMMERCIAL AIRLINES



by Frederick G. Suffield, P.E. (M 1978, S 1984)

In 1945, four young engineers who had worked for Westinghouse in Baltimore on military radar systems, determined that there would be a need for airborne radar in commercial aircraft for the improvement of safety. These engineers, Aubrey W. Vose, Albert H. Palmes, James P. Westcott, and the author, packed everything they owned into two old automobiles and headed for California. Working out of their savings, they conceived and built a radar of a new design.

Military radars, at that time, were bulky and heavy. The AN/APS-6, for example, was designed for the F6F Gruman Hellcat and was a 40 KW, X-band search and short-range fire-control radar. It was not packaged for installation in commercial aircraft and it was complex in operation.

At that time, the airlines did not foresee a need for airborne radar; however, American Airlines was experimenting with a modified AN/APS-10 military radar. The other airlines adopted a "wait-and-see" attitude. A major cause of accidents with their DC-2 and DC-3 aircraft seemed to be the running into mountain tops.

The needs of a commercial aircraft radar were established as follows:

Design Goal

Weight under 75 pounds
Minimum number of units
Minimum number of cables
Simple displays
Simple controls
Minimum power consumption
Maximum reliability
X-Band
Forward looking only
Fit into a DC-3

Prototype Attained

Weight: 58 pounds
Two units
Two cables and one flexible shaft
5 inch offset PPI sector display
On-off, range, sensitivity, and brillance controls
Less than 500 watts, 400 Hz. power
200 flight hours reliability
2J55 Magnetron
180° forward scan
Flown in a DC-3

A few innovative design features contributed to the success of the radar.

The Antenna

In 1946-47, there were few sources of radar technical data or components on the West Coast. Gilfillan, in Los Angeles, was doing some radar work, and Dalmo Victor, in San Carlos, was doing some work with antennas.

It was the opinion of the four engineers that a conventional, forward-looking, mechanically-driven antenna with left-right-left-right-etc. 180° scan would be heavy, complex, and subject to maintenance problems.

The solution was to mount two 18-inch paraboloidal reflectors back to back on opposite sides of a round waveguide that supplied an azimuth drive as well as RF to and from the antenna reflectors. Transitions from round to rectangular waveguides provided the feeds for each antenna.

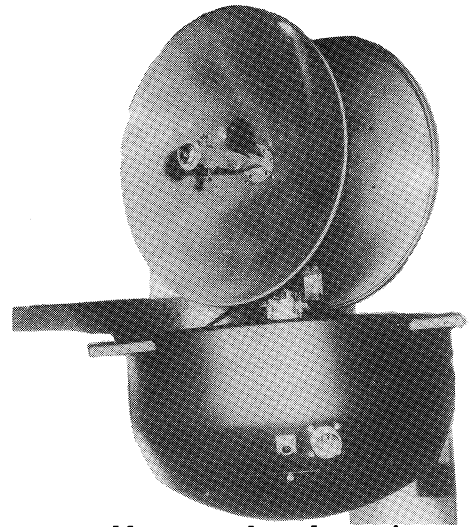
Supported above the rectangular guides was a center-mounted lever arm attached to two pins that were inserted throuch chokes into the rectangular guides at the base of each feed. As the lever arm was pivoted at its center, it inserted a pin through one choke as the other pin was being withdrawn; thus, it was essentially a waveguide switch. With the antenna pair being rotated continuously in one direction and the cam operating the switch as each antenna started its 180° scan looking forward, there was a smooth and continuous one-direction rotation through the 180° scan.

The drive system consisted of a 400 cycle, two-phase motor and a gear train that drove the round waveguide (and thus the antenna reflectors) in one direction, with no intermittent motion to cause wear on the gears, or backlash. The design was improved by using a double-ended motor to drive the assembly and to cool it with a fan blade on the top shaft. Rather than use two identical feeds, a small spoiler was added to one feed to give some ground paint; thus, dead-ahead targets were seen on all scans and a lighter paint of the area below the aircraft appeared on alternate scans.

The Electronics

The general electronics — mixer, duplexer, IF, transmitter, power supply, trigger circuits and automatic frequency control — were built on a pie shaped chassis and located around the central gear box. Thus, the fan directed air over the heat-producing items. The external structure was a spun aluminum can.

The mixer and duplexer were conventional; a Magic T mixer later was added to improve performance. The receiver IF strip was a circuit with a possible alignment problem. Instead of using 6AK5 tubes, the Western Electric 403-B long-life, close-tolerance tubes were used. After initial adjustment, one could change tubes without the need for realignment. In the drive circuits for the display and the AFC, the same philosophy with respect to tube choice was maintained: WE 403-B and 2C51 tubes were used.



The antenna assembly mounted on electronics structure.

The Modulator

A decision was made to utilize Westinghouse strip-wound, grain-oriented type 'C' cores with the Westinghouse Fosterite compound for all iron-core items to minimize size and weight. No transformer manufacturer on the West Coast was familar with these items, and there were none who knew anything about high-voltage pulse transformers. So it became necessary to train them.

The conventional basic modulator circuit had a power transformer feeding a pair of high-voltage rectifiers, a well-insulated filament transformer, and an input high-voltage filter capacitor The output went through a hold-off diode thence through a charging choke to the pulse line. All items were heavy and bulky, and most were heat producing. Now came the need for an invention and we took a radical approach.

Having 400 Hz. primary power, it was decided to set the pulse repetition rate to 400 Hz. synchronous with the input power frequency. A decision was made to eliminate the rectifier tubes and their filament transformer, and to eliminate the input high-voltage filter capacitor. By grounding one end of the high-voltage power transformer and running the other end directly to the hold-off diode and triggering the thyratron at the positive swing of the AC, the modulator thought it was seeing DC. It worked great but had a by-product: each time it fired, it put a tremendous pulse on the plane's power line. This caused a buzzing on all radio and intercom equipment. The problem was resolved with a separate, small inverter feeding the radar and isolating it from the remainder of the aircraft electronics and power circuits.

As the 2J55 magnetron was run with a one microsecond pulse at the 400 Hz. (repitition) rate, it was operating on the lower side of its rating and its life was greatly extended. In as much as the antenna switching produced some transients in the output of the magnetron, the running at the reduced power input also helped minimize potential reliability problems.

The Indicator

This had to be small because of the limited cockpit area and panel space of the DC-3. The 5FP-7A magnetically-focused and deflected cathode ray tube was selected as the indicator, and packaged in a box slightly larger than the tube outline. A TV permanent-magnet focus unit was selected to save power. To obtain high voltage for the CRT, a selenium stack 1/4 inch in diameter and about 4 inches long was used thereby eliminating another tube and its filament transformer. As in other units, the small tubes were W.E. 403-B and 2C51 types.

Since only the forward 180° was to be scanned and displayed, the permanent magnet focus assembly was modified to offset the center of the display to the bottom of the screen. To eliminate more circuitry, range lines were engraved on the face of the Plexiglass overlay. Controls were a bare minimum: an off-on switch, a range selection switch, gain, and brilliance. The philosophy was that if trouble developed, the pilot would do better to shut down the unit rather than attempting to adjust dozens of controls.

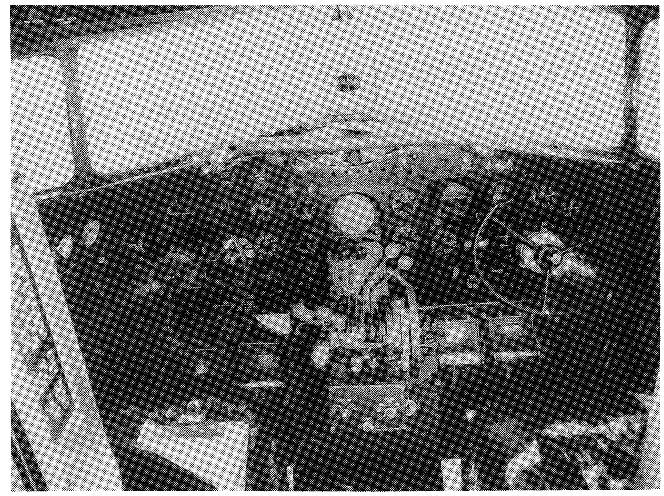
The beam was deflected by a rotating magnetic assembly. To synchronize it with the 180° scan of the antenna, two microswitches and a cam were added to the deflection assembly to reverse the coil terminals. As one antenna scanned its forward 180° sector, the beam also scanned a synchronous 180°. When the continuous-rotation antennas were switched, the cam on the deflection-coil assembly tripped the microswitches and the reversed coil connections resulted in the beam re-starting at the left side of the screen rather than going through 360° as would be normal.

Coupling the rotating deflection coil to the antenna scan as done on most military radars would have required a servo system. This would involve added weight, power consumption, and complexity. As the antennas ran continuously in one direction and the deflection coil also ran in one direction, they were coupled together with a length of flexible shaft. When the coil axis and the antenna pointing direction were aligned and the flexible shaft coupled, the two rotating elements were in alignment; there was no backlash and no circuitry to fail.

Proximity Warning

Since the use of radar was new in so far as airline crews were concerned, it was felt that some sort of warning device to alert the crew to a target of possible hazard would be a good idea. A simple circuit was built using a type 546 miniature, dual control grid thyratron. One grid was driven positive by a trigger pulse from the modulator, and held positive for a time representing a range of five to ten miles. The second grid was driven by the video target output of the receiver. Thus, the tube would fire only when both signals were present, representing a target within the five to ten mile interval. The plate of the thyratron was fed B+ through a resistor and was connected to ground through a capacitor. Essentially, a saw tooth signal was generated.

The plate was coupled through a transformer to a speaker. When a target appeared in the range gate, a raucous buzz resulted, alerting the pilot to a danger ahead.



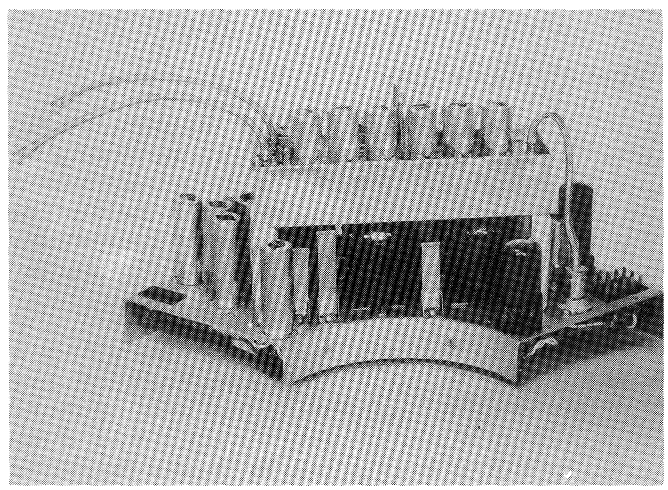
Installation of radar indicator in DC-3 aircraft.

The Installation

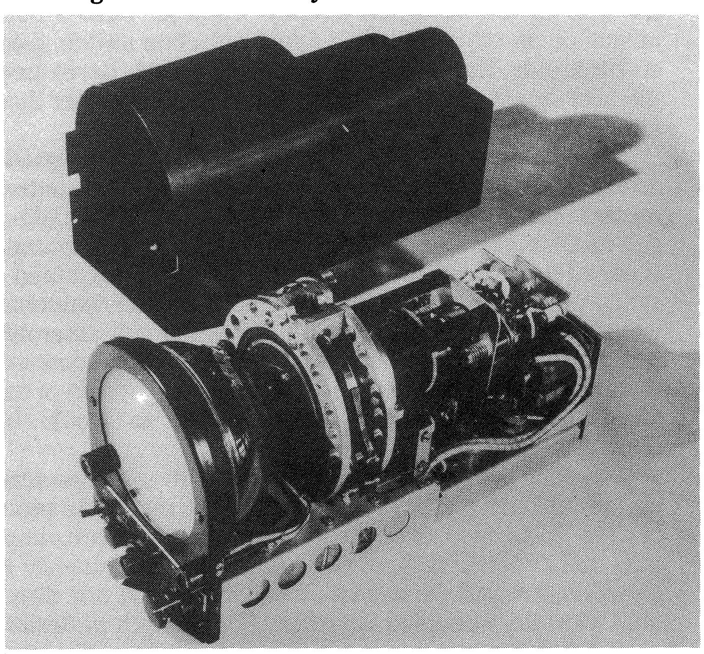
Southwest Airlines was willing to test the radar and made available one of their DC-3 aircraft. It then was found that there were no sources of radomes in the area. To make a radome, we pulled the aluminum nose cap from the DC-3 and hot-formed a sheet of 1/2 inch Plexiglass over it, and then sand-blasted the interior. The plane became the only white nose DC-3 in the state.

The experimental radar was tested on regularly scheduled flights between San Diego and Medford, OR. for over 200 passenger-carrying flight hours before the first failure — that of a TR tube.

The smaller airlines such as Southwest were busy trying to obtain money to buy aircraft and to develop a customer base. Much as they wanted radar, they could not afford it. The larger airlines did not yet see the need for radar.



Electronics assembly.



Indicator assembly and housing.

Five years later, such larger airlines as United and American began to be interested, and two of the original four engineers — at that time working for the Houston Corporation, of West Los Angeles — started the development of a second version of the commercial airlines radar. At that time, RCA wanted to get into the airborne radar field and purchased the Houston Corporation. The two engineers, having started design work on the newer radar with Houston, continued their work with RCA. The resulting unit, the type AVQ, became the first commercial airlines radar to go into production; it was followed by Bendix and Collins units for commercial aircraft, and by Collins and King equipment for general aviation.

The satisfaction remains with the four engineers with respect to the pioneering work done and the resultant wide use of radar for the safety of commercial aircraft. While the original need was to avoid running into mountains, the development of aircraft with higher cruising ceilings, better navigational aids, and improved weather data, resulted in a gradual change in the use of airborne radar away from obstacle detection and towards the determining and avoiding of areas of heavy rainfall and turbulence.

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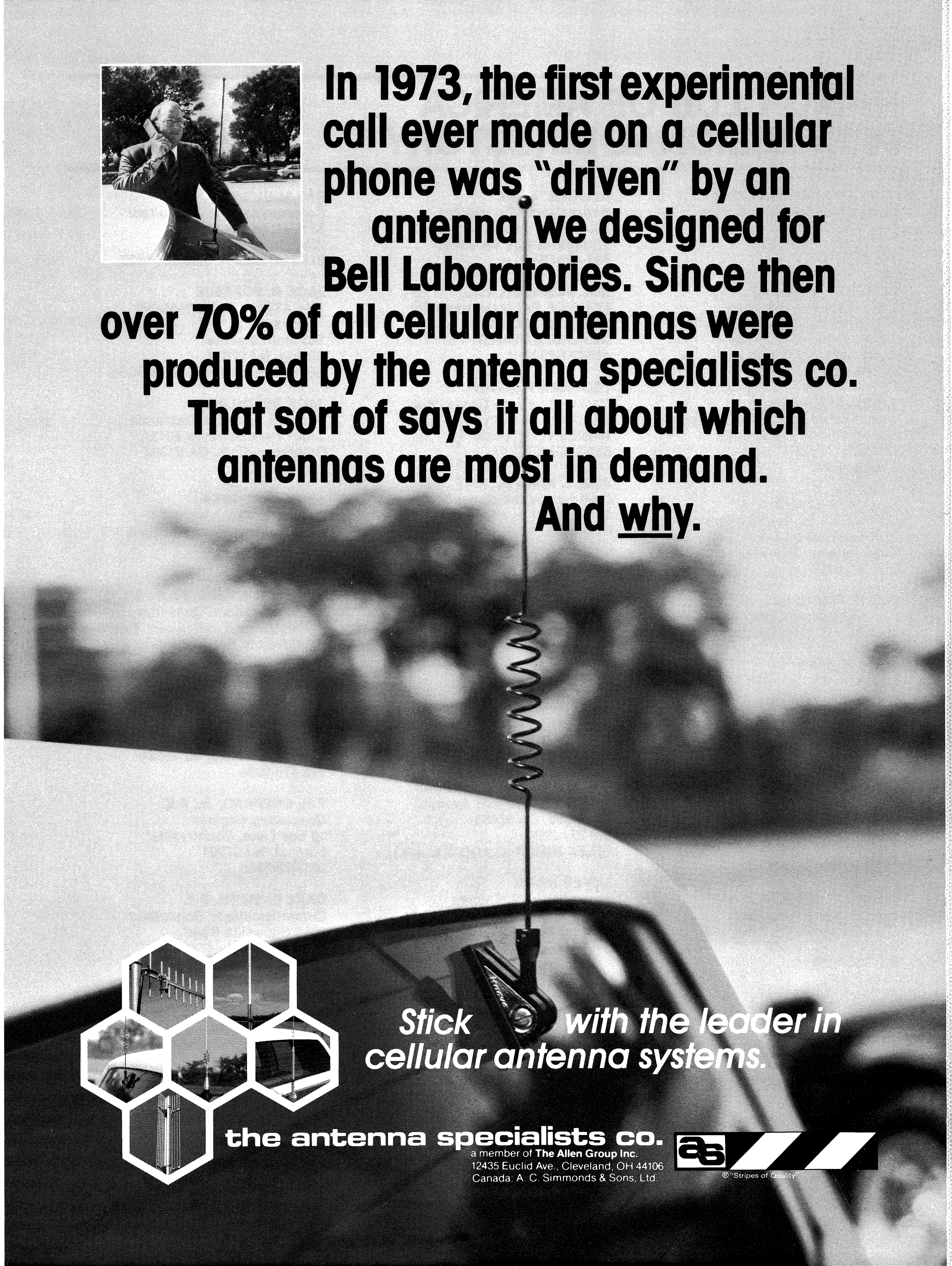
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