Interaction of Two Microwave Signals in a Ferroelectric Material*

A conventional degenerate mode parametric amplifier was used as a research tool to study the ferroelectric interaction with two microwave signals. Certain interesting results were obtained, namely, that there was an exchange of energy from the pump frequency to the signal frequency in the ferroelectric material via an idler frequency. Results are shown in Table I.

There was too much loss in the system at 1200 mc and 820 mc to obtain any gain; in fact, the insertion loss of the microwave circuit with material used was 7.5 db. Removing the pump frequency removes the idler and also lowers the amplitude of the signal frequency. The operation is very similar to a parametric amplifier with a low-cutoff frequency or lossy varactor.

TABLE I

f_s	f_p	Relative Amplitude of the Idler to the Signal Frequency	Pump Power
2600 mc	5200 mc	−31 db	1 watt
1200 mc	2400 mc	−6 db	120 mw
820 mc	1640 mc	−6 db	150 mw

The ferroelectric material was Barium Titanate of the polycrystalline type, Aerovox Body 90, operating at room temperature below its Curie point. A small chip, 0.005 inch thickness and 0.010 inch on a side, was used in a modified microwave crystal holder. The capacity of the sample was 2.2 $\mu\mu$f.

It does appear that the permittivity of the material can be varied at a microwave frequency rate; hence, the material becomes a variable capacity, thus making possible the basic element for a ferroelectric parametric amplifier.

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Contributors

Bruce B. Barrow (S'52–M'56–SM'59) was born on April 12, 1929, in Danville, Pa. He attended the Carnegie Institute of Technology, Pittsburgh, Pa., on a George Westinghouse Scholarship, and received the B.S.E.E. and M.S.E.E. degrees in 1950. He was awarded a Tau Beta Pi Fellowship for graduate study at the Massachusetts Institute of Technology, Cambridge, where he also taught in the Department of Electrical Engineering and worked on the staff of the Servomechanisms Laboratory. During this time, he was awarded a Fulbright Scholarship for a year of study at the Delft Institute of Technology in The Netherlands. In his last years at M.I.T. he worked in the Nuclear Instrumentation Group under the direction of Prof. T. S. Gray, and in 1955 he received the E.E. degree. His thesis was concerned with nuclear reactor instrumentation, and he has consulted for the General Electric Company in this field.

B. B. BARROW

In 1955, he joined Hermes Electronics Co., Cambridge, Mass., where he worked mainly on problems concerned with various communications systems, including the ACE High network now being constructed in Europe for SHAPE. Since 1958, he has been on leave with the SHAPE Air Defense Technical Center, The Hague, where he is studying improved methods of transmitting digital data over fading radio paths.

Mr. Barrow is a member of the Nederlands Radiogenootschap, Sigma Xi, and Tau Beta Pi.

Robert L. Carbrey (M'45) was born in Denver, Colo., on April 23, 1917. He received the B.S.E.E. degree with honors from the University of Colorado, Boulder, in 1940.

R. L. CARBREY

He joined the Bell Telephone Laboratories' outside plant department in 1940, where he engaged in work on coaxial and toll telephone cables. During World War II, he transferred to the radio research department where he worked on radar and pulse position modulation receivers, as well as single-sideband receivers. Since his transfer to the transmission research department at Murray Hill, N. J., in 1944, he has been engaged in work on a variety of pulse code modulation terminals and repeaters, except for an interval, during which time he worked on the design of time separation multiplexed speech interpolation systems.

Mr. Carbrey is a member of Tau Beta Pi and Eta Kappa Nu.

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Martin L. Cohen (M'60) was born in New York, N. Y., on May 20, 1929. He received the B.E.E. degree from Cornell University, Ithaca, N. Y., in 1952.

From 1952 to 1956, he worked for Raytheon Manufacturing Company, Newton, Mass., on the development of nonmicrophonic vacuum tubes and test equipment for microwave tubes. Before joining Arthur D. Little, Inc., Cambridge, Mass., in 1957 as a member of the Advanced Research Division, he studied applied mathematics and switching theory at Harvard University, Cambridge. His work at Arthur D. Little has been in the experimental development of superconductive computer elements, which has included research with the wire-wound cryotron and on the properties of vacuum-deposited superconductive films.

M. L. COHEN

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Sid Deutsch (A'46–M'55) was born in New York, N. Y., on September 19, 1918. He received the B.E.E. degree in 1941 from Cooper Union, New York, N. Y., and the M.E.E. and D.E.E. degrees in 1947 and 1955 from the Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

S. DEUTSCH

From 1935 to 1944, he was an electric motor technician and designer of electromechanical equipment and then served with the U. S. Navy until 1946. He was an electronics engineer from 1950 to 1954 at the Polytechnic Research and Development Company, Brooklyn, N. Y., and then joined

the Microwave Research Institute of the Polytechnic Institute of Brooklyn. At present, he is a consultant for the Budd Lewyt Electronics Company, Long Island City, N. Y.

Since 1943, he has also been teaching. He was a physics instructor at Hunter College, New York, N. Y. during 1943–1944, and was a radio and television instructor from 1946 to 1950. He taught at the College of the City of New York from 1955 to 1957, and since 1951 he has also taught at the Polytechnic Institute of Brooklyn, Brooklyn, N. Y., where he is now an associate professor of electrical engineering.

Dr. Deutsch is a member of Sigma Xi, Tau Beta Pi, and Eta Kappa Nu.

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A. Francis Dietrich was born in New York, N. Y., on November 24, 1909.

He joined the Bell Telephone Laboratories at Deal, N. J., in 1942. During 1942–1943, he worked on high-power radar transmitters. Since then, he has been engaged in experimental studies of broad-band microwave systems and terminal equipment. During the past ten years, he has specialized in high-speed millimicrosecond pulse techniques, including time separation return loss measuring sets and error-counting equipment for evaluating the performance of PCM microwave regenerative repeaters in the hundred-megabit range.

A. F. DIETRICH

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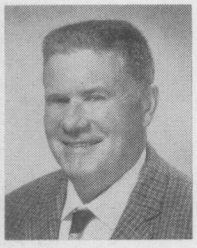
William M. Goodall (A'29–M'37–SM'43–F'51) was born on September 7, 1907 in Washington, D. C. He received the B.Sc. degree from the California Institute of Technology, Pasadena, in 1928. He joined the technical staff of the Bell Telephone Laboratories in 1928. He was located at Deal, N. J. until 1951, when he was transferred to Holmdel.



W. M. GOODALL

His early work included scale-model antenna studies of long-wave antennas, experimental ionosphere studies, and early radio-relay studies. During World War II, he worked on high-power pulse modulators for radar and PPM.

Later work included experimental PCM and broad-band microwave FM terminals, experimental studies of broad-band microwave PAM systems and broad-band microwave regenerative repeaters. More recently, he has been engaged in the field of high-speed short pulses including high resolution electrical stroboscopes.

Jack C. Greene was born in New York, N. Y., on May 11, 1928. He received the B.E.E. and M.E.E. degrees in 1947 and 1950, respectively, from the Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

J. C. GREENE

From 1947 to 1948, he designed digital computers and magnetic data-storage devices for the Teleregister Corporation, New York, N. Y. In 1948, he joined Airborne Instruments Laboratory, Melville, N. Y., where he performed research and development work on microwave countermeasure receivers, display and data handling devices, and novel uses of traveling-wave tubes until 1953. From 1953 to 1955, he served in the U. S. Army Signal Corps, where he was assigned to the Countermeasures Division of Evans Signal Laboratory, Belmar, N. J. In 1955, he rejoined Airborne Instruments Laboratory, and is presently a section head in the Department of Applied Electronics. He is currently concerned with radio astronomy receiver design, the development of solid-state devices for receiving systems, and theoretical studies in the countermeasures and low-noise receiving systems fields.

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Ralph E. Hiatt (M'47–SM'58) was born on April 12, 1910 in Portland, Ind. He received the B.A. degree in physics from Indiana Central College, Indianapolis, in 1932 and the M.A. degree in physics from Indiana University, Bloomington, in 1939. He later took several graduate courses in mathematics at Boston University, Boston, Mass. He taught mathematics and science in Indiana public schools until 1942.

R. E. HIATT

From 1942 until 1945 he was employed by the Radiation Laboratory of Massachusetts Institute of Technology, Cambridge. As a staff member in the Radiation Laboratory Antenna Group, he worked on microwave radar antennas; he organized the Ipswich Antenna Test Station and was Chief of this installation in 1944 and 1945.

He joined the Air Force Cambridge Research Center in 1945 and was Chief of the Ground Antenna Section until 1956. From 1956 until 1958, he was Chief of the Antenna Laboratory (later the Electromagnetic Radiation Laboratory).

In 1958, he joined the Radiation Laboratory of The University of Michigan, Ann Arbor, as associate head of the laboratory. He organized and now heads an experimental group in the Radiation Laboratory. He is currently engaged in work on radar scattering, in antenna research, and in experimental plasma studies.

Mr. Hiatt is a member of the American Physical Society and of Sigma Xi.

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William M. Kaufman (S'53–A'54–M'59) was born in Pittsburgh, Pa., on Dec. 31, 1931. He received the B.S.E.E. and M.S.E.E. degrees from Carnegie Institute of Technology, Pittsburgh, in 1953, and the Ph.D. degree in electrical engineering from the same institution in 1955.

W. M. KAUFMAN

In 1955 he joined the Semiconductor Department of the Westinghouse Electric Corporation, Youngwood, Pa., where he was engaged in performance evaluation and electrical ratings of semiconductor devices. Since 1957 he has been with the Westinghouse Research Laboratories, Pittsburgh, investigating digital system design and switching circuits. From 1956 through 1959, he was also a part-time faculty member of Carnegie Institute of Technology. He is currently a supervisory engineer responsible for studies in distributed circuitry and molecular electronics.

Dr. Kaufman is a member of Tau Beta Pi, Eta Kappa Nu, and Phi Kappa Phi, and an associate member of the AIEE. He has five patents pending in the fields of digital circuits and distributed circuitry.

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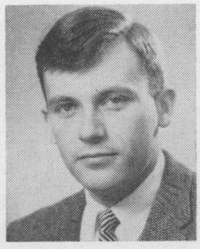
Norman H. Meyers (S'54–SM'59) was born in Buffalo, N. Y., on February 11, 1931. He received the B.E.E. degree from Rensselaer Polytechnic Institute, Troy, N. Y., in 1952; and the M.S. and D.Sc. degrees, also in electrical engineering, in 1954 and 1957, respectively, from the Massachusetts Institute of Technology, Cambridge.

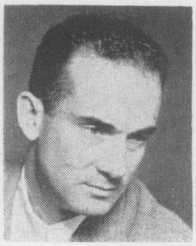


N. H. MEYERS

He remained at M.I.T. as an assistant professor of electrical engineering, from June, 1957 to June, 1958, during which time he also did research in the classical electrodynamics of moving media. Since that time, he has been on the staff of the research laboratory of the International Business Machines Corporation, in Poughkeepsie, N.Y. At IBM, he has been engaged in research and development of high-speed thin-film superconducting circuitry.

Dr. Meyers is a member of Tau Beta Pi, Eta Kappa Nu, Sigma Xi, and the Scientific Research Society of America.

Eugene W. Sard (A'49–M'55) was born in Brooklyn, New York, on December 21, 1923. He received the B.S.E.E. and M.S.E.E. degrees in 1944 and 1948, respectively, from the Massachusetts Institute of Technology, Cambridge.



E. W. Sard

From 1944 to 1946, he served in the USNR as a radar officer. From 1946 to 1948, he was a research assistant in the Center of Analysis and the Servomechanisms Laboratory of M.I.T., working on digital computers. Since 1948, he has been with Airborne Instruments Laboratory, Melville, N. Y., working at first in the Radar Department and more recently in the Applied Electronics Department, where he serves as a department consultant. For the past three years he has been working on the application of semiconductor diodes to various fields including fast switching, harmonic and subharmonic generation, and low-noise amplification. In the course of this work, he has made some fundamental theoretical contributions to the state of the art in these fields. Most recently he has been concerned with the analysis and implementation of tunnel diode amplifiers with very large bandwidths.

Mr. Sard is a member of Sigma Xi.

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Keeve M. Siegel (SM'57) was born in New York, N. Y. on January 9, 1923. He received the B.S. and M.S. degrees in physics from Rensselaer Polytechnic Institute, Troy, N. Y. in 1948 and 1950.

K. M. Siegel

He has been with The University of Michigan, Ann Arbor, since 1948, first as a research associate, then as a research engineer. He became head of the Upper Atmosphere Physics Section in 1949 and head of the Theory and Analysis Department in 1952. In 1957 he became head of the Radiation Laboratory. In 1957 he was appointed professor of Electrical Engineering. His work at The University of Michigan has been in the fields of electromagnetic theory (*e.g.*, scattering and diffraction), high-altitude research and work in thermodynamics and hydrodynamics (*e.g.*, incompressible ideal subsonic flow), and passage of plane waves of sound in air.

Professor Siegel is a member of the American Physical Society, American Institute of Physics, American Mathematical Society, and Sigma Xi. He is an Associate Fellow of the Institute of Aeronautical Sciences, a member of the USAF Scientific Advisory Board, and consultant to the Advanced Research Projects Agency and several major corporations. He is a member of the Editorial Boards of the *Journal of Research of the National Bureau of Standards* and the *Journal of Mathematical Physics*. He is a member of Commission VI of URSI. He is listed in *Who's Who in America*, *American Men of Science*, *Who's Who in World Aviation*, and *World Directory of Mathematicians*.

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Albert E. Slade was born in San Antonio, Tex., on September 14, 1923. He received the B.S. degree from the University of Maryland, College Park, in 1950, and then joined the National Security Agency, Washington, D. C., where he did research primarily in transistor circuits.

A. E. Slade

He joined Arthur D. Little, Inc., Cambridge, Mass., in 1956 as head of the Cryotron Research Program. His work at Arthur D. Little has been on research and development of superconductive computer components including vacuum evaporation of superconducting metals, design of circuits, and evaluation of devices.

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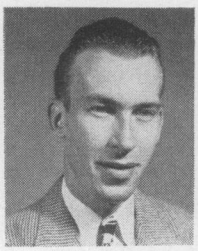
C. Russell Smallman was born in Quincy, Mass., on May 23, 1925. He received the B.S. degree in chemical engineering from Northeastern University, Boston, Mass., in 1947.

In 1947, he joined the staff of Arthur D. Little, Inc., Cambridge, Mass., where he has been active in infrared spectroscopic instrumentation and in electronic and electromechanical device development for meteorological research.

He has been associated with the cryotron project since its inception in 1955 by Dudley A. Buck and, as a member of the Advanced Research Division, has been active in the design of apparatus for vacuum deposition of superconductive circuits and in development of methods of fabrication and evaluation of superconductive circuits and devices.



C. R. Smallman

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Herschel Weil was born in Rochester, N. Y., on July 26, 1921. He received the B.S. degree in optics from the University of Rochester in 1943, and the M.S. and Ph.D. degrees in applied mathematics in 1945 and 1948, respectively, from Brown University, Providence, R. I.

H. Weil

During 1943–1944, he was employed as an optical engineer with the Bausch and Lomb Optical Company, Rochester. During 1946–1948, he was a research associate at Brown University working on theoretical problems in fluid mechanics. From 1948 to 1952, he was with the General Electric Company's General Engineering Laboratory, Schenectady, N. Y., where he worked on mathematical aspects of various engineering problems, becoming interested primarily in radar countermeasures work.

In 1952, he joined the staff of The University of Michigan Research Institute, Ann Arbor, where he has been mainly concerned with problems in electromagnetic theory with application to radar cross section computation. In February, 1960, he joined the faculty of the University of Michigan Electrical Engineering Department as an associate professor. He has continued his association with the UMRI through the Radiation Laboratory of The University.

Dr. Weil is a member of the American Mathematical Society, The Society for Industrial and Applied Mathematics, and Sigma Xi.