Report of Advances in Microwave Theory and Techniques—1957*

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THIS report is devoted to advances in theory, experiment, and application of microwave sources, amplifiers, circuits and circuit elements, transmission lines, and detectors. The radiation, propagation, and reception of microwaves are mentioned only indirectly. An attempt is made to provide coverage of foreign as well as domestic advances.

Advances in 1957 continue to be dominated by extensions in the use of gyromagnetic media. Recent developments include the ferromagnetic amplifier and various nonlinear devices. Much attention has been given to such devices as the nonreciprocal phase shifter, the resonance isolator, the field displacement isolator, and circulators which depend upon the Faraday rotation phenomenon. This attention has been directed towards increasing the operation power level of the devices and the operating bandwidth. Ferrites with narrow resonance line widths are needed for both linear and nonlinear devices.

Sources of microwave energy continue to receive considerable study. Advances in this area include extensions in the use of direct stimulation of radiation emission from uncharged matter for amplifiers and sources of microwave energy. Three and four-level solid-state masers appear to be especially noteworthy because they amplify in a continuous manner and because their high permissible spin concentration leads to large gain-bandwidth products. Extensions of traveling-wave-type tubes in various ways, however, have dominated the activity in the realm of microwave sources. The introduction of a crossed-field type of amplifier or oscillator which utilizes a reentrant electron flow and a non-reentrant and nonresonant interaction circuit is noteworthy.

Transmission lines *per se* continue to be important. Activity seems to be dominated by such needs as wider operating bandwidths, higher power handling capabilities, lower attenuation, and miniature size, and by more esoteric considerations of a military or an application nature. Strip and planar transmission lines have continued to be of interest because of their compactness and broad-band transmission characteristics. Interest in large, circular hollow pipes as transmission lines of low attenuation has been sustained. Much of the interest is in maintaining purity of the TE_{01} mode and elimination or control of coupling of this mode with other TE modes and with the TM_{11} mode in curved sections and serpentine bends. Surface waveguides and miscellaneous types of uniform and nonuniform lines or waveguides account for much activity in tota. Foreign interest in surface waveguides appears to be greater than domestic.

Almost all phases of microwave theory and techniques have advanced. In most phases, the advances have been in the nature of refinements and extensions of developments of the past.

The individual work on the subjects mentioned above is listed in three sections: I. Sources and Detectors, II. Transmission Lines, and III. Measurements. Ferrite and other microwave component developments are listed under the various headings.

I. Sources and Detectors

The portion of the microwave spectrum which is usable is determined by the sources and detectors available. Sources continue to be the principal limitation. Activity in the field of sources of microwave energy has been great. Most of the well-established types have been improved, altered, extended, and combined in sundry ways. In addition, the direct interaction of electromagnetic energy with matter as a source of microwave energy is increasing in importance.

Much of the activity has been stimulated by practical needs for:

1) Higher output powers,
2) Wider tuning ranges,
3) Better frequency stability,
4) Higher operating frequencies,
5) Greater ease of tuning,
6) Higher signal-to-noise ratios,
7) Improved mechanical features from the operational and/or manufacturing point of view.

Molecular types of sources will be reviewed first because they are recent in origin. They are promising as sources with low noise levels.

Molecular Types

Microwave fields can interact with the molecules in uncharged matter. In such interactions the internal energy of molecules is directly converted into microwave energy. This conversion is induced by placing the molecules in a microwave field. The emission induced is phase-related to the inducing field.

One of the methods of inducing emission of internal molecular energy is by use of masers (microwave amplifiers by stimulated emission of radiation). Masers may

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be of a molecular-beam type in which a beam of ammonia molecules is separated into upper and lower energy-state beams by utilizing a quadratic Stark effect. If the upper energy beam is passed through an appropriate resonant cavity, the basis for a microwave amplifier of very narrow bandwidth results. By adequately increasing the beam density the power emitted by the molecules may exceed the losses in the walls and load. In this case oscillations build up until saturation effects produce equilibrium. As an oscillator, such a maser produces microwave energy of high spectral purity; as an amplifier, it yields a very narrow bandwidth.

The basic physical properties of molecular amplifiers and several types of amplifiers are described in the following paper which serves as an excellent general introduction to the subject:

[1] J. P. Wittke, "Molecular amplification and generation of microwaves," PROC. IRE, vol. 45, pp. 291–316; March, 1957.

Solids as well as gases may yield molecular amplification. Three- and four-level solid-state masers were proposed last year.

[2] N. Bloembergen, "Proposal for a new type solid state maser," *Phys. Rev.*, vol. 104, pp. 324–327; October, 1956.
[3] M. W. P. Strandberg, "Quantum mechanical amplifiers," PROC. IRE, vol. 45, pp. 92–93; January, 1957.
[4] A. Javan, "Theory of a three level maser," *Phys. Rev.*, vol. 106, pp. 1579–1589; September, 1957.
[5] W. V. Smith, "Microwave amplification by maser techniques," *IBM J. Res. Dev.*, vol. 1, pp. 232–238; July, 1957.
[6] G. Feher and H. E. D. Scovil, "Electron spin relaxation times in gadolinium ethyl sulphate," *Phys. Rev.*, vol. 105, pp. 760–762; January, 1957.
[7] H. E. D. Scovil, G. Feher, and H. Seidel, "Operation of a solid state maser," *Phys. Rev.*, vol. 105, pp. 762–763; January, 1957.
[8] H. Heffner, "The maximum efficiency of the solid-state maser," PROC. IRE, vol. 45, p. 1289; September, 1957.
[9] K. D. Bowers and W. B. Mims, "Three level maser without a magnetic field," paper presented at Conference on Electronic Tube Research, Berkeley, Calif.; June, 1957.
[10] P. F. Chester and D. I. Bolef, "Super-regenerative masers," PROC. IRE, vol. 45, pp. 1287–1289; September, 1957.

Under certain conditions of operation a three-level system appears to be closely related to a parametric-type amplifier. Parametric amplifiers utilize the negative resistance introduced into a circuit by a nonlinear reactance which is driven by a strong high-frequency field. Parametric amplifiers were treated theoretically.

[11] J. P. Wittke, "New approaches to the amplification of microwaves," *RCA Rev.*, vol. 18, pp. 441–457; December, 1957.
[12] S. Bloom and K. K. N. Chang, "Theory of parametric amplification using nonlinear reactances," *RCA Rev.*, vol. 18, pp. 578–593; December, 1957.
[13] B. Salzberg, "Masers and reactance amplifiers—basic power relations," PROC. IRE, vol. 45, pp. 1544–1545; November, 1957.
[14] M. T. Weiss, "Quantum derivation of energy relations analogous to those for nonlinear reactances," PROC. IRE, vol. 45, pp. 1012–1013; July, 1957.

Ferromagnetic amplifiers were proposed for the microwave range and were later operated at 4500 mc. Such amplifiers consist of a cavity which contains a ferrite sample and which can support two resonant modes. A local oscillator excites the cavity in one of the resonant modes and causes the magnetization of the ferrite to precess uniformly. This precession results in a time-varying coupling between the two modes. If the local oscillator frequency is equal to the sum of the resonant frequencies, the local oscillator power is converted through nonlinear effects to signal frequency power.

[15] H. Suhl, "Proposal for a ferromagnetic amplifier in the microwave range," *Phys. Rev.*, vol. 106, p. 384; April, 1957.
[16] M. T. Weiss, "A solid-state microwave amplifier and oscillator using ferrites," *Phys. Rev.*, vol. 107, p. 317; July, 1957.
[17] J. Itoh, "Proposal for a solid-state radio-frequency maser," *J. Phys. Soc. Japan*, vol. 12, p. 1053; September, 1957.

Interest in maser and parametric types of amplifiers initially stems from their promise as low noise devices. Noise figures as low as 1.0 db have been reported for masers. Their limitations include: low power-handling capability, narrow bandwidth, and tuning difficulties. It should be noted, however, that the solid-state microwave amplifiers can be expected to offer advantages with respect to power output, tunability, bandwidth, and simplicity when compared with gaseous types.

[18] J. P. Gordon and L. D. White, "Experimental determination of the noise figure of an ammonia maser," *Phys. Rev.*, vol. 107, p. 1728; September, 1957.
[19] R. V. Pound, "Spontaneous emission and noise figure of maser amplifiers," *Ann. Phys.*, vol. 1, pp. 24–32; April, 1957.
[20] M. W. P. Strandberg, "Inherent noise of quantum-mechanical amplifiers," *Phys. Rev.*, vol. 106, pp. 617–620; May, 1957.
[21] K. Shimoda, H. Takahasi, and C. H. Townes, "Fluctuations in amplification of quanta with application to maser amplifiers," *J. Phys. Soc. Japan*, vol. 12, pp. 686–700; June, 1957.
[22] L. E. Alsop, J. A. Giordmaine, C. H. Townes, and T. C. Wang, "Measurement of noise in a maser amplifier," *Phys. Rev.*, vol. 107, pp. 1450–1451; September, 1957.
[23] M. W. Muller, "Noise in a molecular amplifier," *Phys. Rev.*, vol. 106, pp. 8–12; April, 1957.
[24] A. E. Siegman, "Gain, bandwidth and noise in maser amplifiers," PROC. IRE, vol. 45, pp. 1737–1738; December, 1957.
[25] M. L. Stitch, "Maser characteristics for one and two iris cavities," 1957 IRE WESCON CONVENTION RECORD, pt. 3, pp. 175–181.

Work closely related to that on masers was reported.

[26] L. E. Norton, "Coherent spontaneous microwave emission by pulsed resonance excitation," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 262–265; October, 1957.

Self-induced coherent emission was found to continue to 10 μsec after removal of a 1-μsec excitation pulse.

Related to the work on molecular amplifiers and oscillators is that on the use of ferrites for frequency multiplication, mixing, detection, and amplitude modulation. As an indication of the possibilities, if second-order effects are included in treating the behavior of the magnetic moments of unbalanced electron spins in ferromagnetic materials under the action of an RF field, the possibility of using ferrites to detect an amplitude-modulated microwave signal becomes apparent.

[27] D. Jaffe, J. C. Cacheris, and N. Karayianis, "Ferrite microwave detector," 1957 IRE NATIONAL CONVENTION RECORD, pt. 1, pp. 242–249.

When two microwave signals of different frequencies are applied to a magnetized ferrite in a waveguide, sum and difference frequencies are generated. The sum-frequency output has been found to be quite linear with respect to variations in signal or local oscillator power levels.

[28] P. H. Vartanian and E. N. Skomal, "Mixing in ferrites at microwave frequencies," 1957 IRE WESCON CONVENTION RECORD, pt. 1, pp. 52–57.

At high peak powers it has been concluded that frequency doubling in ferrites can be made more efficient than low-power doubling in crystals. The frequency conversion is sensitive to sample shape and dimensions as well as to position in the waveguide. Frequency multiplication, especially doubling, promises to be a practical means of generating high-frequency microwave power.

[29] J. L. Melchor, W. P. Ayres and P. H. Vartanian, "Microwave frequency doubling from 9 to 18 kmc in ferrites," Proc. IRE, vol. 45, pp. 643–646; May, 1957.
[30] H. Suhl, "The theory of ferromagnetic resonance at high signal powers," *J. Phys. Chem. Solids*, vol. 1, pp. 209–227; January, 1957.

By inserting a tube of ferrite of low saturation level over the center conductor of a coaxial cable, a high modulation percentage over an 8 per cent bandwidth at *L* band has been achieved by alternately biasing the ferrite into and away from gyromagnetic resonance.

[31] B. Vafiades and B. J. Duncan, "An L-band ferrite coaxial line modulator," 1957 IRE National Convention Record, pt. 1, pp. 235–241.

Microwave single-sideband modulators using ferrites have received further consideration.

[32] G. Kemanis, "On the Cotton-Mouton effect in ferrites," Proc. IRE, vol. 45, pp. 687–688; May, 1957.
[33] K. I. Khoury, "On the use of ferrites for microwave single-sideband modulators," Proc. IRE, vol. 45, p. 1418; October, 1957.

Gaseous discharges also show promise as sources and detectors. It has been found that in a microwave discharge, the frequencies contained in the output are integral multiples of the applied field frequency. The possibility of utilizing this new phenomenon for developing a high-power and high-efficiency frequency multiplier for the sub-millimeter-wave region has been discussed.

[34] M. Uenohara, M. Uenohara, T. Masutani, and K. Inada, "A new high-power frequency multiplier," Proc. IRE, vol. 45, pp. 1419–1420; October, 1957.

Other investigations of the effect of microwaves on gaseous conductors and of the spectral distribution of the thermal noise of such conductors were reported. Among the results reported were the effects of incident microwave power on the various parts of a hydrogen glow discharge. When incident on the positive column or upon the region adjacent to the cathode, the discharge current increased slightly. When incident on the Faraday dark space, a large decrease in discharge current was noted.

[35] B. J. Udelson, "Effect of microwave signals incident upon different regions of a dc hydrogen glow discharge," *J. Appl. Phys.*, vol. 28, pp. 380–381; March, 1957.
[36] B. J. Udelson, J. E. Creedon, and J. C. French, "Microwave measurements of the properties of a dc hydrogen discharge," *J. Appl. Phys.*, vol. 28, pp. 717–723; June, 1957.
[37] M. Bayet, J. L. Delcroix, and J. F. Denisse, "Theory of the interaction between two electromagnetic waves in an ionized gas," *Ann. Télécomm.*, vol. 12, pp. 140–141; May, 1957.
[38] S. M. Bergmann, "Spectral distribution of thermal noise in a gas discharge," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 237–238; October, 1957.

Crystals as harmonic generators, mixers, and detectors continue to receive attention. The noise figures obtainable from low-noise mixer crystals approach fundamental theoretical limits. The desire for better noise figures has led to physical cooling of the mixer crystal.

[39] J. M. Richardson and R. B. Riley, "Performance of three-millimeter harmonic generators and crystal detectors," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 131–135; April, 1957.
[40] A. C. Macpherson, "An analysis of the diode mixer consisting of nonlinear capacitance and conductance and ohmic spreading resistance," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 43–51; January, 1957.
[41] J. M. Richardson and J. J. Faris, "Excess noise in microwave crystal diodes used as rectifiers and harmonic generators," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 208–212; July, 1957.
[42] G. C. Messenger, "Cooling of microwave crystal mixers and antennas," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 62–63; January, 1957.

Traveling-Wave Devices

Traveling-wave tubes are emerging from the laboratory to become elements of microwave systems. However, many improvements and refinements are desirable. Their great promise for practical application has caused studies of traveling-wave devices to dominate the activity in the field of microwave sources. The results of many such studies are frequently applicable, of course, to other types of microwave sources.

Traveling-wave tubes were reviewed from the point of view of the user and procedures in selecting the proper operating performance and circuit design most suited for his application were discussed.

[43] A. H. Nielsen and N. W. Hansen, "The selection and application of traveling wave tubes," 1957 IRE National Convention Record, pt. 3, pp. 49–56.

A new microwave repeater system which uses a traveling-wave tube for the combined purpose of power amplification and local oscillator action was developed. No automatic frequency control was required.

[44] H. Kurokawa, I. Someya, and M. Morita, "New microwave repeater system using a single traveling-wave tube as both amplifier and local oscillator," Proc. IRE, vol. 45, pp. 1604–1611; December, 1957.

One of the needed improvements for practical application of traveling-wave tubes is that of smaller size. A description was given of a 100-mw, all metal, *S*-band tube which had a minimum gain of 25 db, a weight of less than 3 pounds including solenoid, a maximum solenoid diameter of 2 inches, and a length under 1 foot.

[45] J. O. Bramick, "A light-weight, low-level traveling-wave tube for S-band," 1957 IRE National Convention Record, pt. 3, pp. 66–70.

Another metal tube of rugged design for use with a compact solenoid or with periodic focusing was described.

[46] R. McClure, "A high-gain traveling-wave tube for *X*-band," 1957 IRE Wescon Convention Record, pt. 3, pp. 143–149.

Traveling-wave tubes as tunable oscillators with external feedback and as limiting amplifiers were studied.

[47] V. G. Price and C. T. Anderson, "*X*-band traveling wave tube feedback oscillator," 1957 IRE National Convention Record, pt. 3, pp. 57–65.
[48] F. B. Fank and G. Wade, "Traveling-wave tube limiters," IRE Trans. on Electron Devices, vol. ED-4, pp. 148–152; April, 1957.

The power output of a one-watt tube was held constant with $\pm\frac{1}{2}$ db for a 20-db range of input power.

Power and gain considerations were of interest in the medium and high power class of traveling-wave tubes. A pulsed power output of 3 megawatts at an efficiency of 34 per cent was among the results reported.

[49] J. F. Gittins, N. H. Rock, and A. B. J. Sullivan, "An experimental high power pulsed travelling wave tube," *J. Electronics Control*, vol. 3, pp. 267–286; September, 1957.
[50] M. Chodorow and R. A. Craig, "Some new circuits for high-power traveling-wave tubes," Proc. IRE, vol. 45, pp. 1106–1118; August, 1957.
[51] C. W. Barnes, "Power and gain limitations of helix-type travelling wave tubes," *Vide*, vol. 12, pp. 43–48; January–February, 1957.
[52] P. K. Tien and J. E. Rowe, "The backward-traveling power in the high power traveling-wave amplifiers," Proc. IRE, vol. 45, pp. 87–88; January, 1957.
[53] J. L. Putz and G. C. Van Hoven, "Use of multiple helix circuits in 100-watt cw traveling wave amplifiers," 1957 IRE WESCON Convention Record, pt. 3, pp. 138–142.
[54] L. W. Holmboe and M. Ettenberg, "Development of a medium power L-band traveling-wave amplifier," IRE Trans. on Electron Devices, vol. ED-4, pp. 78–81; January, 1957.

Backward-wave amplifiers have a very narrow pass band characteristic which can be shifted over a wide range of frequencies by varying the beam voltage; hence these types of tubes may be used as electronically tunable band-pass amplifiers. Gain fluctuations are being minimized so that practical application of backward-wave amplifiers is feasible.

[55] M. R. Currie and D. C. Forster, "The gain bandwidth characteristics of backward-wave amplifiers," IRE Trans. on Electron Devices, vol. ED-4, pp. 24–34; January, 1957.

As local oscillators, backward-wave oscillators show promise even at millimeter wavelengths.

[56] J. A. Noland and R. E. Lepic, "Backward-wave oscillators for the 17 to 41 kmc band," *Sylvania Technologist*, vol. 10, pp. 13–16; January, 1957.
[57] A. Karp, "Backward-wave oscillator experiments at 100 to 200 kilomegacycles," Proc. IRE, vol. 45, pp. 496–503; April, 1957.
[58] C. F. Hempstead and A. R. Strnad, "A versatile source of millimeter waves," *Bell Labs. Record*, vol. 35, pp. 241–245; July, 1957.
[59] F. L. Vernon, "The behavior of a backward-wave oscillator with external feedback," 1957 IRE National Convention Record, pt. 3, pp. 91–102.
[60] R. D. Weglein, "Backward-wave oscillator starting conditions," IRE Trans. on Electron Devices, vol. ED-4, pp. 177–179; April, 1957.
[61] H. R. Johnson and R. D. Weglein, "Backward-wave oscillators for the 8000–18,000-megacycle band," IRE Trans. on Electron Devices, vol. ED-4, pp. 180–184; April, 1957.
[62] R. Olivier, "Use of an O-type carcinotron as a uhf generator for wide-band measurements," *Onde Élect.*, vol. 36, pp. 992–996; November, 1956.
[63] P. Palluel, "Experimental study of the characteristics of O-carcinotrons with interdigital lines," *Onde Élect.*, vol. 36, pp. 962–965; November, 1956.

For frequencies below 500 mc, a major design problem is that of obtaining a tube of reasonably small size. Hollow electron beams were used in preference to solid beams for uhf tubes because the size of the tube can be reduced by permitting operation at a lower voltage and greater gain per wavelength for a specified beam power.

[64] D. A. Dunn, "Traveling-wave amplifiers and backward-wave oscillators for uhf," IRE Trans. on Electron Devices, vol. ED-4, pp. 246–264; July, 1957.

Microwave frequency mixing and frequency division have been accomplished in traveling-wave tubes by employing the nonlinearities of an overmodulated beam. Frequency conversion to microwave intermediate frequencies as well as to frequencies as low as 30 mc with conversion gains as high as 30 db were attained.

[65] R. W. DeGrasse, D. A. Dunn, R. W. Grow, and G. Wade, "Microwave frequency mixing and frequency division with beam-type tubes," 1957 IRE WESCON Convention Record, pt. 3, pp. 163–168.
[66] R. W. DeGrasse and G. Wade, "Microwave mixing and frequency dividing," Proc. IRE, vol. 45, pp. 1013–1015; July, 1957.

A traveling-wave tube which employs two helices in cascade to produce frequency multiplication as high as forty was described. Output powers in the range of 20 to 100 mw for beam powers of 2 to 4 watts at output frequencies between 2 and 4 kmc were obtained.

[67] D. J. Bates and E. L. Ginzton, "A traveling-wave frequency multiplier," Proc. IRE, vol. 45, pp. 938–944; July, 1957.
[68] G. Mourier, "Contribution to the large-signal theory of traveling-wave tubes," *Onde Élect.*, vol. 36, pp. 929–936; November, 1956.

Crossed-field devices such as the traveling-wave magnetrons received attention. Small- and large-signal theories and space-charge-effect studies were dominant.

[69] J. Feinstein and G. S. Kino, "The large signal behavior of crossed-field traveling-wave devices," Proc. IRE, vol. 45, pp. 1364–1373; October, 1957.
[70] B. Epsztein, "Effects of space charge in crossed-field tubes," *Compt. Rend. Acad. Sci., Paris*, vol. 244, pp. 2902–2905; June 12, 1957.
[71] R. W. Gould, "Space-charge effects in beam-type magnetrons," *J. Appl. Phys.*, vol. 28, pp. 599–605; May, 1957.
[72] H. A. Haus and D. L. Bobrooff, "Small-signal power theorem for electron beams," *J. Appl. Phys.*, vol. 28, pp. 694–704; June, 1957.
[73] O. Bunemann, "A small-amplitude theory for magnetrons," *J. Electronics Control*, vol. 3, pp. 1–50; July, 1957.
[74] L. Gold, "Space charge in the relativistic magnetron," *J. Electronics Control*, vol. 3, pp. 87–96; July, 1957.

The theory of noise in traveling-wave and related tubes and the practical realization of high signal-to-noise ratios continue to stimulate much activity.

[75] R. Knechtli and W. R. Beam, "Validity of traveling-wave-tube noise theory," *RCA Rev.*, vol. 18, pp. 24–38; March, 1957.
[76] J. Labus, R. Liebscher, and K. Pöschl, "Condition for minimum noise factor of traveling-wave tubes," *Arch. Elekt. Übertragung*, vol. 10, pp. 486–490; November, 1956.
[77] W. W. Rigrod, "Noise spectrum of electron beam in longitudinal magnetic field. I. The growing noise phenomenon," *Bell Sys. Tech. J.*, vol. 36, pp. 831–853; July, 1957.
[78] W. W. Rigrod, "Noise spectrum of electron beam in longitudinal magnetic field. II. The u.h.f. noise spectrum," *Bell Sys. Tech. J.*, vol. 36, pp. 855–878; July, 1957.
[79] H. D. Allen and J. M. Winwood, "A low noise travelling-wave tube amplifier for the 4000 mc/s communications band," *J. Brit. IRE*, vol. 17, pp. 75–85; January, 1957.
[80] F. B. Fank and F. M. Schumacher, "Development and operation of broad-band low noise traveling wave tubes for *X*- and *C*-bands," 1957 IRE WESCON Convention Record, pt. 3, pp. 150–155.
[81] J. C. Twombly, "Shot noise amplification in beams beyond critical perveance," 1957 IRE WESCON Convention Record, pt. 3, pp. 156–162.
[82] W. R. Beam, "Noise wave excitation at the cathode of a microwave beam amplifier," IRE Trans. on Electron Devices, vol. ED-4, pp. 226–234; July, 1957.
[83] L. D. Buchmuller, R. W. DeGrasse, and G. Wade, "Design and calculation procedures for low-noise traveling-wave tubes," IRE Trans. on Electron Devices, vol. ED-4, pp. 234–242; July, 1957.
[84] M. R. Currie and D. C. Forster, "Experiments on noise reduction in backward-wave amplifiers," Proc. IRE, vol. 45, p. 690; May, 1957.

The size and weight of focusing structures for traveling-wave tubes have been limiting factors on the application of traveling-wave tubes. Periodic systems and light-weight permanent magnets as focusing structures were studied and some design procedures were outlined.

[85] M. S. Glass, "Straight-field permanent magnets of minimum weight for twt focusing—design and graphic aids in design," PROC. IRE, vol. 45, pp. 1100–1105; August, 1957.
[86] F. Sterzer and W. W. Siekanowicz, "The design of periodic permanent magnets for focusing of electron beams," *RCA Rev.*, vol. 18, pp. 39–59; March, 1957.
[87] K. K. N. Chang, "Confined electron flow in periodic electrostatic fields of very short periods," PROC. IRE, vol. 45, pp. 66–73; January, 1957.
[88] K. K. N. Chang, "Biperiodic electrostatic focusing for high-density electron beams," PROC. IRE, vol. 45, pp. 1522–1527; November, 1957.
[89] J. L. Palmer and C. Süsskind, "Injection of convergent beams focused by periodic magnetic fields," 1957 IRE WESCON CONVENTION RECORD, pt. 3, pp. 130–137.
[90] J. Labus, "Space charge waves along magnetically focused electron beams," PROC. IRE, vol. 45, pp. 854–861; June, 1957.
[91] D. C. Buck, "Stability of a cylindrical electron beam in non-sinusoidal periodic magnetic-focusing fields," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 44–49; January, 1957.
[92] J. S. Cook, R. Kompfner, and W. H. Yocum, "Slalom focusing," PROC. IRE, vol. 45, pp. 1517–1527; November, 1957.

Electron beam phenomena, including such topics as gun design and characteristics, oscillations in beams, and interaction of beams with electromagnetic waves, have received much attention.

[93] L. E. S. Mathias and P. G. R. King, "On the performance of high perveance electron guns," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 280–286; July, 1957.
[94] O. L. Hoch and D. A. Watkins, "A gun and focusing system for crossed-field traveling-wave tubes," 1957 IRE WESCON CONVENTION RECORD, pt. 3, pp. 122–129.
[95] K. Fujisawa and T. Kaneko, "Design of electron gun for strip beams," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 39, pp. 942–947; November, 1956.
[96] S. E. Webber, "Electron bunching and energy exchange in a traveling-wave tube," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 87–91; January, 1957.
[97] C. C. Wang, "Linear beam tube theory," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 92–106; January, 1957.
[98] G. R. Brewer and C. K. Birdsall, "Traveling-wave tube propagation constants," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 140–144; April, 1957.
[99] J. A. Mullen, "A power series solution of the traveling-wave tube equations," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 159–160; April, 1957.
[100] N. Rynn, "Analysis of coupled-structure traveling-wave tubes," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 172–177; April, 1957.
[101] V. N. Schevchik, "An analysis of the energy interchange between an electron stream and an electromagnetic wave," *Radiotekhnika i Elektronika*, vol. 2, pp. 104–110; January, 1957.
[102] P. V. Bliokh, "High frequency oscillations in electron beams with a periodically varying velocity," *Radiotekhnika i Elektronica*, vol. 2, pp. 92–103; January, 1957.
[103] R. L. Jepsen, "Ion oscillations in electron beam tubes; ion motion and energy transfer," PROC. IRE, vol. 45, pp. 1069–1080; August, 1957.
[104] N. C. Barford, "Space-charge neutralization by ions in linear-flow electron beams," *J. Electronics Control*, vol. 3, pp. 63–86; July, 1957.
[105] G. R. Brewer, "Some characteristics of a cylindrical electron stream in immersed flow," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 134–140; April, 1957.
[106] D. A. Dunn and W. R. Luebke, "Beam perturbations in confined flow electron beams with planar symmetry," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 265–270; July, 1957.

Reports of investigations of helices and other slow-wave structures for traveling-wave tube applications were given.

[107] G. Landauer, "The helix with a cylindrical coaxial attenuator," *Arch. Elekt. Übertragung*, vol. 11, pp. 267–277; July, 1957.
[108] P. Lapostolle, "Helices for traveling-wave tubes. Influence of the supports-attenuation-parasitic modes," *Ann. Télécomm.*, vol. 12, pp. 34–59; February, 1957.
[109] F. Paschke, "The reciprocity of coupling in traveling-wave tubes," *Arch. Elekt. Übertragung*, vol. 11, pp. 137–145; April, 1957.
[110] G. Al'tshuler, A. S. Tatarenko, and S. V. Gerchikov, "Design of a retarding system with double tandem rods," *Radiotekhnika i Elektronika*, vol. 2, pp. 609–617; May, 1957.
[111] K. Morita, M. Kawamura, and Y. Suematsu, "Slow-wave circuit of cascaded annular disks," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 40, pp. 454–460; April, 1957.
[112] J. C. Walling, "Interdigital and other slow wave structures," *J. Electronics Control*, vol. 3, pp. 239–258; September, 1957.

Klystrons

Velocity modulation tubes are of great practical importance. This fact motivates study of methods of improving such tubes. Greater operating bandwidths, higher efficiencies and output powers, lower noise levels, and better modulation methods are representative areas of improvement. One report indicated that efficiencies of 50 per cent for high-power klystrons are attainable. Another report indicated procedures by which the useful bandwidth of a high-power klystron can be doubled and that the maximum bandwidth obtained thus far was 5 per cent.

[113] W. J. Dodds, T. Moreno, and W. J. McBride, Jr., "Methods of increasing bandwidth of high power microwave amplifiers," 1957 IRE WESCON CONVENTION RECORD, pt. 3, pp. 101–110.
[114] W. L. Beaver, R. L. Jepsen, and R. L. Walter, "Wide band klystron amplifiers," 1957 IRE WESCON CONVENTION RECORD, pt. 3, pp. 111–114.
[115] K. H. Kreuchen, B. A. Auld, and N. E. Dixon, "A study of broadband frequency response of the multicavity klystron amplifier," *J. Electronics*, vol. 2, pp. 529–567; May, 1957.
[116] S. V. Yadavalli, "Application of the potential analog in multicavity klystron design and operation," PROC. IRE, vol. 45, pp. 1286–1287; September, 1957.
[117] M. S. Neiman, "Some basic relations in power klystron amplifiers," *Radiotekhnika*, vol. 12, pp. 3–12; April, 1957.
[118] E. D. Naumenko, "Wide-band reflex klystrons for millimeter waves," *Radiotekhnika i Electronika*, vol. 2, pp. 618–621; May, 1957.

The effect of reflector voltage, cavity voltage, reflector spacing, and loading on the output power and frequency of a klystron were discussed in detail.

[119] M. Kenmoku and S. Shitara, "Output control of reflex klystrons," *Onde Élect.*, vol. 37, pp. 102–115; February, 1957.

More detailed analyses of space-charge waves and methods of measuring and exciting them were made. It was shown that analyses restricted to the lowest order space-charge wave leads to incorrect results for optimum drift distances and other parameters.

[120] A. H. Beck, "Excitation of space-charge waves in drift tubes," *J. Appl. Phys.*, vol. 28, pp. 140–141; January, 1957.
[121] W. E. Walters, "Space-charge effects in klystrons," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 49–58; January, 1957.
[122] A. H. W. Beck, "High order space charge waves in klystrons," *J. Electronics*, vol. 2, pp. 489–509; March, 1957.
[123] D. Walsh, "The measurement of space charge wavelength in an electron beam," *J. Electronics*, vol. 2, pp. 436–440; March, 1957.

The mode of operation of multireflection klystrons was described and conditions for maximum efficiency established.

[124] B. Meltzer, "Notes on the multi-reflection klystron," *Electronic Radio Engr.*, vol. 34, pp. 109–112; March, 1957.

An investigation of noise in a high-power klystron indicated that the principal source of noise was in the tuning mechanism.

[125] R. A. LaPlante and G. A. Espersen, "A low-noise klystron with high power output," *Philips Tech. Rev.*, vol. 18, no. 12, pp. 361–368; 1956–1957.

A three-resonator, pulsed-grid klystron amplifier was described which could reliably produce a very narrow frequency spectrum. Another method of modulation used a modulating anode.

[126] J. D. Swearingen and C. M. Veronda, "The SAL-89 a grid controlled pulsed klystron amplifier," 1957 IRE WESCON CONVENTION RECORD, pt. 3, pp. 115–121.
[127] G. M. W. Badger, "A new method for modulating electron beams for pulse applications and linear amplitude modulation systems," 1957 IRE NATIONAL CONVENTION RECORD, pt. 3, pp. 82–90.

An investigation of a klystron in which the electron transit angle through the resonator is large indicated that efficiencies which are greater by a factor of two or three than those of conventional klystrons were possible.

[128] V. N. Shevchik, S. A. Suslov, and Y. D. Zharkov, "Investigation of a special type of reflex klystron," *Zh. Tekh. Fiz.*, vol. 27, pp. 377–386; February, 1957.

A klystron design which yields a wide frequency range of operation for constant reflector voltage was described.

[129] M. Kenmoku, "Constant-reflector-voltage klystron," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 40, pp. 981–988; September, 1957.

The nonlinear behavior of klystrons was studied. A nonlinear space-charge-wave equation was derived and by using third-order successive approximations was split into three simultaneous linear equations which were solved for klystrons. Equations for gain and efficiency of two cavity klystrons were given.

[130] F. Paschke, "On the nonlinear behavior of electron beam devices," *RCA Rev.*, pp. 221–242; June, 1957.
[131] K. Fukisawa, T. Kaneko, and T. Namekawa, "General treatment of millimeter-wave klystron cavities," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 40, pp. 556–563; May, 1957.

Magnetrons

Work on magnetrons was quite limited compared with that on traveling-wave tubes. A number of the de-developments listed under traveling-wave devices might have been listed under klystrons or magnetrons. This is especially true of some of the developments in crossed-field traveling-wave devices.

A new microwave device of the crossed-field type known as the "platinotron" which might have been reported under traveling-wave devices is reported here. This device looks like a magnetron. It has a reentrant beam as does the magnetron but a nonreentrant interaction network which is matched at both ends over the frequency band of interest. Power outputs of almost 2 megawatts at 69 per cent efficiency, and 10 per cent bandwidths at efficiencies greater than 50 per cent were obtained.

[132] W. C. Brown, "Description and operating characteristics of the platinotron—a new microwave device," PROC. IRE, vol. 45, pp. 1209–1222; September, 1957.
[133] W. C. Brown, "Platinotron increases search radar range," *Electronics*, vol. 30, pp. 164–168; August, 1957.

Work reported on magnetrons *per se* seemed to emphasize high power, high efficiency, better tunability characteristics, and better performance under pulsed conditions.

[134] J. Ninerailles, B. Vallantin, and P. Stern, "Power magnetrons, MC 1053 and MCV 1053," *Onde Élect.*, vol. 37, pp. 274–281; March, 1957.
[135] Z. Fraenkel, "The development of a tunable cw magnetron in the *K*-band region," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 271–280; July, 1957.
[136] T. R. Bristol and G. J. Griffin, Jr., "Voltage-tuned magnetron for f-m applications," *Electronics*, vol. 30, pp. 162–163; May, 1957.
[137] E. Petrasco and I. I. Vasilesco, "A frequency-modulated magnetron," *Compt. Rend. Acad. Sci., Paris*, vol. 244, pp. 2296–2298; April 29, 1957.
[138] E. C. Okress, C. H. Gleason, R. A. White, and W. H. Hayter, "Design and performance of a high power pulsed magnetron," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 161–171; April, 1957.

For certain cylinder voltages when a beam of electrons is injected tangentially into the space between two coaxial cylinders, it was reported that the electrons describe circular paths without a magnetic field being necessary. Power outputs of some tens of milliwatts were obtained at operating wavelengths in the 70–130 cm range.

[139] A. Wersnel, "Magnetless magnetron," *Vide*, vol. 13, pp. 59–63; January–February, 1957.

The effect of cathode eccentricity, space charge theory, and signal theory of magnetrons are other topics which were discussed.

[140] G. E. Becker, "Dependence of magnetron operation on the radial centering of the cathode," IRE TRANS. ON ELECTRON DEVICES, vol. ED-4, pp. 126–131; April, 1957.
[141] L. Gold, "Kinetic theory of space charge: part 1—Cut-off character of the static magnetron," *J. Electronics Control*, vol. 3, pp. 97–102; July, 1957.
[142] R. W. Gould, "Space charge effects in beam-type magnetrons," *J. Appl. Phys.*, vol. 28, pp. 599–605; May, 1957.
[143] L. Gold, "Space-charge in the relativistic magnetron," *J. Electronics Control*, vol. 3, pp. 87–96; July, 1957.
[144] O. Bunemann, "A small amplitude theory for magnetrons," *J. Electronics Control*, vol. 3, pp. 1–50; July, 1957.

II. TRANSMISSION LINES

In accord with IRE standards, the definition of transmission lines is here considered to encompass ordinary transmission lines, hollow waveguides, and surface-wave structures. Developments in microwave circuit components based on the various types of transmission lines are reviewed after transmission line developments.

TEM Lines

The inherently broad bandwidth characteristics, small size, light weight, and mechanical simplicity of many types of TEM lines continued to stimulate considerable efforts to improve their performance. The interest in filters and other microwave components was sustained by the trend to broad-band systems.

Various aspects of the several types of strip or planar lines were treated theoretically and design methods were further developed.

Higher order mode limitations on the dimensions of symmetrical strip line were used to derive the permissible dimensions at any given frequency and characteristic impedance. Conclusions were reached regarding the best ratio of strip thickness to ground-plane spacing.

[145] K. S. Packard, "Optimum impedance and dimensions for strip transmission lines," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 244–247; October, 1957.

A theoretical method was given for computing the capacitance of certain electrostatic-field geometries which previously has proved intractable because the determination of such fields required the evaluation of hyperelliptic integrals. The method was applied to the calculation of the characteristic impedance of a strip line.

[146] J. D. Horgan, "Coupled strip transmission line with rectangular inner conductor," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 92–99; April, 1957.

A procedure involving successive approximations to determine the current distribution was applied to a microstrip line to determine the fields associated with the lowest order mode.

[147] T. T. Wu, "Theory of the microstrip," *J. Appl. Phys.*, vol. 28, pp. 299–302; March, 1957.

Unidirectional strip lines utilizing ferrite elements with magnetic fields applied in a transverse sense relative to the direction of a propagation to produce resonance or field displacement were described. Such circuits are useful for phase shifters, modulators, switches, etc.

[148] S. Yoshido, "Microwave transverse magnetic type unidirectional strip circuits," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 40, pp. 30–33; January, 1957.

Several aspects of coaxial and open-wire transmission lines were studied. In one study it was found that it was advantageous to disperse the supporting beads for the inner conductor of a coaxial cable according to a progressive dispersal formula which was derived.

[149] D. Dettinger, "The optimum spacing of bead supports in coaxial line at microwave frequencies," 1957 IRE NATIONAL CONVENTION RECORD, pt. 1, pp. 250–253.

Related studies were concerned with random spacing of discontinuities and with statistical prediction of voltage standing-wave ratios for many randomly spaced discontinuities.

[150] R. K. Moore, "The effect of reflections from randomly spaced discontinuities in transmission lines," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 121–126; April, 1957.

[151] J. A. Mullen and W. L. Pritchard, "The statistical prediction of voltage standing-wave ratio," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 127–130; April, 1957.

Singly and multiply braided outer conductors of coaxial cables were investigated experimentally. It was reported that the studies led to the use of large interweaving angles and thin wires for the braids. Ferromagnetic intermediate layers were tried and were found to introduce practical difficulties.

[152] L. Krugel, "Multiple screening of flexible coaxial cables," *Telefunken Ztg.*, vol. 30, pp. 207–214; September, 1957.

The problem of distortion of waveforms of durations of the order of a millimicrosecond by the high frequency loss in a coaxial cable was analyzed. Generalized curves were presented by which the response of any length of coaxial cable can be predicted if one point on the attenuation vs frequency curve is known.

[153] R. L. Wigington and N. S. Nahman, "Transient analysis of coaxial cables considering skin effect," PROC. IRE, vol. 45, pp. 166–174; February, 1957.

The theory of exponential and other nonuniform lines was the subject of several reports.

[154] R. Codelupi, "Theory of nonuniform lines," *Alta Frequenza*, vol. 26, pp. 226–282; August, 1957.

[155] B. G. Kazansky, "Outline of a theory of non-uniform transmission lines," *Proc. IEE*, Monogram 261R; October, 1957.

[156] Laszlo Solymar, "On higher order approximations to the solution of nonuniform transmission lines," PROC. IRE, vol. 45, pp. 1547–1548; November, 1957.

[157] E. F. Bolinder, "Study of the exponential line by the isometric circle method and hyperbolic geometry," *Acta Polytech.*, Elec. Eng. Ser., vol. 7, no. 8; 1957.

The coupling of a multilayer laminated transmission line to other lines was discussed and the problem of minimizing losses caused by mode conversion was investigated.

[158] H. E. Martin, "Mode-conversion phenomena in multi-layer transmission lines and their effects on transmission along singly and tandem-connected lines," *Arch. Elekt. Übertragung*, vol. 11, pp. 7–16, 81–96; January/February, 1957.

Tape ladder lines of the single-ridge, double-ridge, single T-section, and double T-section types in which the rungs of the ladder are thin tapes were studied. Dispersion curves and coupling impedances were calculated.

[159] P. N. Butcher, "A theoretical study of propagation along tape ladder lines," *Proc. IEE*, vol. 104, pt. B, pp. 169–176; March, 1957.

[160] P. N. Butcher, "The coupling impedance of tape structures," *Proc. IEE*, vol. 104, pt. B, pp. 177–186; March, 1957.

Hollow Waveguides

The high power-handling capacity, wide bandwidth, and low attenuation characteristics of large hollow pipes, excited in the circular TE_{01} mode, continue to attract considerable attention directed towards the eventual practical utilization of such waveguides.

Transmission through straight sections of aluminum tubing manufactured and installed to British commercial tolerances for standard-production, solid ground tubes resulted in attenuations which were 30 per cent above the theoretical value and stable conditions of propagation.

[161] H. E. M. Barlow and E. G. Effemey, "Propagation characteristics of low-loss-tubular waveguides," *Proc. IEE*, vol. 104, pt. B, pp. 254–260; May, 1957.

Bends and curves in TE_{01}-mode waveguides cause mode conversion. Several analyses of such mode conversions were made and methods of preventing or reducing them were proposed.

[162] S. P. Morgan, "Theory of curved circular waveguide containing an inhomogeneous dielectric," *Bell Sys. Tech. J.*, vol. 36, pp. 1209–1252; September, 1957.
[163] H. E. M. Barlow, "Propagation of the circular H_{01} low-loss wave mode around bends in tubular metal waveguide," *Proc. IEE*, vol. 104, pt. B, pp. 402–409; July, 1957.
[164] H. G. Unger, "Circular electric wave transmission in a dielectric coated waveguide," *Bell Sys. Tech. J.*, vol. 36, pp. 1253–1278; September, 1957.
[165] H. G. Unger, "Circular electric wave transmission through serpentine bends," *Bell Sys. Tech. J.*, vol. 36, pp. 1279–1291; September, 1957.
[166] H. G. Unger, "Normal node bends for circular electric waves," *Bell Sys. Tech. J.*, vol. 36, pp. 1292–1307; September, 1957.
[167] S. Kumagai, Nobuaki Kumagai and Hirotaro Ohba, "Mode conversion losses in transmission of TE_{01} modes through conically tapered waveguides," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 40, pp. 1203–1209; November, 1957.
[168] Shin-ichi Iiguchi, "Mode conversion in transmitting TE_{01} wave through a slightly tilted guide," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 40, pp. 870–876; August, 1957.
[169] Shin-ichi Iiguchi, "Mode conversion in transmission of TE_{01} wave through a slight off-set of the guide," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 40, pp. 1095–1102; October, 1957.
[170] M. V. Persikov, "Directional coupler for the H_{01} wave in a waveguide with circularly cross-section," *Radiotekhnika i Electronica*, vol. 2, pp. 65–74; January, 1957.
[171] B. Z. Katsenelenbaun, "Long symmetrical circular waveguide junction for H_{01} waves," *Radiotekhnika i Electronika*, vol. 2, pp. 531–546; May, 1957.

The TE_{01}-mode losses in a waveguide with walls of alternate rings of conducting and insulating material and in one with walls of helically wound wire were studied.

[172] G. Comte, F. de Carfort, A Ponthus, and J. M. Paris, "Utilization of circular waveguides for the long distance transmission of centimeter and millimeter waves," *Cables and Transmission*, vol. 11, pp. 342–355; October, 1957.

High-power waveguide systems of rectangular cross section have been studied. Results show that multimegawatt power levels bring with them adverse effects of harmonics.

[173] M. P. Forrer and K. Tomiyasu, "Effects and measurement of harmonics in high-power waveguide systems," 1957 IRE NATIONAL CONVENTION RECORD, pt. 1, pp. 263–269.

Rectangular waveguides with slight deformations into hexagonal shape have been analyzed by variational methods to determine suitability of such a structure as an approximation for a rectangular guide. Deflections of a rectangular guide subject to internal pressure were also investigated.

[174] T. Humphreys, "Waveguide design for die-casting," *Electronic Radio Eng.*, vol. 34, pp. 441–447; December, 1957.
[175] L. G. Virgile, "Deflection of waveguide subjected to internal pressure," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 247–250; October, 1957.

Miscellaneous types of waveguides which received attention include waveguides wound into a helix, septate waveguides, and ridge waveguides.

[176] R. A. Waldron, "Theory of the helical waveguide of rectangular cross-section," *J. Brit. IRE*, vol. 17, pp. 577–592; October, 1957.
[177] B. Valtersson, "Phase velocity in helical waveguides," *Onde Élect.*, vol. 37, pp. 843–849; October, 1957.
[178] R. G. Mirimanov and G. I. Zhileiko, "Analysis of some types of septate waveguides," *Radiotekhnika i Electronika*, vol. 2, pp. 172–183; February, 1957.
[179] T. S. Chen, "Calculation of the parameters of ridge waveguides," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 12–17; January, 1957.
[180] J. van Bladel and O. von Rohr, Jr., "Semicircular ridges in rectangular waveguides," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 103–106; April, 1957.

Losses in the walls of waveguides and their effect on propagation have received further study. One approach was similar to that used by Sommerfeld in treating surface waves on a single solid conductor.

[181] A. Turski, "Calculation of losses in smooth walls of circular waveguides on the basis of Maxwell's equations," *Arch. Elektrotech. Warsaw*, vol. 5, pp. 567–568; 1956.

Another approach was a surface-impedance one which was applied to parallel plane, rectangular and circular waveguides.

[182] A. E. Karbowiak, "Waveguide characteristics," *Electronic Radio Engr.*, vol. 34, pp. 379–387; October, 1957.

The effects on losses of parallel semicircular grooves in waveguide walls, of utilizing ferrous materials, and of surface finish were studied.

[183] E. A. Marcatili, "Heat losses in grooved metallic surface," PROC. IRE, vol. 45, pp. 1134–1139; August, 1957.
[184] J. J. Allison, F. A. Benson, and M. S. Seaman, "Characteristics of some ferrous and non-ferrous waveguides at 27 Gc/s." *Proc. IEE*, vol. 104, pt. B, pp. 599–602; November, 1957.
[185] J. Allison and F. A. Benson, "Surface finish and attenuation of aluminum waveguides," *Electronic Eng.*, vol. 29, pp. 36–38; January, 1957.

Transient and pulse propagation characteristics of waveguides were investigated.

[186] A. E. Karbowiak, "Propagation of transients in waveguides," *Proc. IEE*, vol. 104, pt. C, pp. 339–348; February, 1957.
[187] R. S. Elliott, "Pulse waveform degradation due to dispersion in waveguides," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 254–257; October, 1957.

A magnetized gyromagnetic medium is birefringent. The effect of birefringence has been studied. It is evident that new methods and techniques of model synthesis are needed when ferrite-loaded structures are considered.

[188] H. Seidel, "The calculation of waveguide modes in gyromagnetic media," *Bell Sys. Tech. J.*, vol. 36, pp. 409–426; March, 1957.
[189] H. Seidel, "Viewpoints on resonance in ideal ferrite slab-loaded rectangular waveguides," 1957 IRE WESCON CONVENTION RECORD, pt. 1, pp. 58–69.
[190] I. A. Monosov, "Characteristics of the Faraday effect in a cylindrical waveguide with a ferrite rod," *Radiotekhnika i Elektronika*, vol. 2, pp. 547–556; May, 1957.
[191] A. K. Stoliarov, "Use of ferrites in waveguide design," *Electrosviaz*, vol. 1, pp. 34–45; May, 1957.
[192] H. Seidel, "Ferrite slabs in transverse electric mode waveguide," *J. Appl. Phys.*, vol. 28, pp. 218–226; February, 1957.

Tapered transitions and gradual changes of cross section were investigated.

[193] B. J. Migliaro, "Designing tapered waveguide transitions," *Electronics*, vol. 30, pp. 183–185; November, 1957.
[194] D. J. Leonard and J. L. Yen, "Junction of smooth flared waveguides," *J. Appl. Phys.*, vol. 28, pp. 1441–1448; December, 1957.
[195] A. L. Gutman, "The calculation of waveguide with gradual change of section," *Radiotekhnika*, vol. 12, pp. 20–28; August, 1957.
[196] G. Piefke, "Reflection at the transition from rectangular waveguide to sectoral horn," *Arch. Elekt. Übertragung*, vol. 11, pp. 123–135; March, 1957.

Surface-Wave and Periodic Structures

Interest in surface-wave transmission lines of the Goubau type has continued. Additional performance data have been obtained and aspects of the theory of excitation and propagation have been treated.

[197] G. Goubau and C. E. Sharp, "Investigations with a model surface wave transmission line," IRE Trans. on Antennas and Propagation, vol. AP-5, pp. 222–227; April, 1957.
[198] S. N. Contractor and S. K. Chatterjee, "Propagation of microwaves on a single wire, part 2," *J. Indian Inst. Sci.*, vol. 39, sec. B, pp. 52–67; January, 1957.
[199] T. Berceli, "Surface wave propagation along coated wires," *Acta. Tech. Acad. Sci. Hungary*, vol. 17, pp. 219–251; 1957.
[200] A. L. Cullen, "A note on the excitation of surface waves," *Proc. IEE*, vol. 104, pt. C, pp. 472–474; September, 1957.
[201] O. Zinke, "Cables and radio paths at microwave frequencies," *Nachricht. Z.*, vol. 10, pp. 425–430; September, 1957.
[202] Hiroshi Kikuchi, "Electromagnetic fields on infinite wire of high frequencies above plane earth," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 40, p. 721; June, 1957.
[203] B. Chiron, "The influence of external agents on the propagation of a surface wave," *Cables and Transmission*, vol. 11, pp. 237–244; July, 1957.
[204] C. Jauquet, "Transverse-magnetic surface wave on an infinitely conductive cylinder," *Bull. Acad. Roy. Belgique Cl. Sci.*, vol. 43, pp. 1178–1183; November, 1956.

Closely related to the Goubau line are numerous other "open" or surface wave structures. Among these structures are dielectric rods and cylinders and related maze structures, disk structures, helical wires, and dielectric slabs.

[205] C. Jauquet, "Excitation of a transverse magnetic surface-wave propagated on a dielectric cylinder," *Ann. Télécomm.*, vol. 12, pp. 217–233; June, 1957.
[206] D. D. King and S. P. Schlesinger, "Losses in dielectric image lines," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 31–35; January, 1957.
[207] G. Piefke, "Wave propagation in the disk line," *Arch. Elekt. Übertragung*, vol. 11, pp. 49–59; February, 1957.
[208] D. Marcuse, "On a novel surface waveguide with bandpass properties," *Arch. Elekt. Übertragung*, vol. 11, pp. 146–148; April, 1957.
[209] G. Schiefer, "The attenuation constant of the helical-wire conductor," *Arch. Elekt. Übertragung*, vol. 11, pp. 35–40; January, 1957.
[210] R. C. Hansen, "Single slab arbitrary polarization surface wave structure," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 115–120; April, 1957.
[211] M. A. Miller and V. I. Talanov, "Electromagnetic surface waves guided by a boundary with small curvature," *Zh. Tekh. Fiz.*, vol. 26, pp. 2755–2765; December, 1956.
[212] R. E. Plummer and R. C. Hansen, "Double-slab arbitrary-polarization surface-wave structure," *Proc. IEE*, vol. 104, pt. C, pp. 465–471; May, 1957.

Junctions

The analysis of a discontinuity or a junction in a transmission line or waveguide is a field problem. The results of the analysis are expressed in an equivalent network form for convenience in dealing with the effect of such a discontinuity or junction on a single mode transmission system.

To solve the field problem of a discontinuity in cross section of a rectangular waveguide, the Wiener-Hopf method for solving a certain class of integral equations was applied in one paper. In another paper the Rayleigh-Ritz method was used to obtain approximations for the eigenfunctions and eigenvalues for a dielectric step in a rectangular waveguide.

[213] W. E. Williams, "Step discontinuities in waveguides," IRE Trans. on Antennas and Propagation, vol. AP-5, pp. 191–197; April, 1957.
[214] R. E. Collin and R. M. Vaillancourt, "Application of Rayleigh-Ritz method to dielectric steps in waveguides," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 177–184; July, 1957.

The four-terminal network for the junction of an empty rectangular waveguide with a rectangular waveguide partially filled with a dielectric was developed in another paper.

[215] C. M. Angulo, "Discontinuities in a rectangular waveguide partially filled with dielectric," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 68–74; January, 1957.

The determination of equivalent circuit parameters for discontinuities was discussed also in the following paper:

[216] R. E. Collin, "Determination of equivalent circuit parameters," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 266–267; October, 1957.

Other papers on linear two-port junctions which were presented include:

[217] G. Deschamps, "A variant in the measurement of two-port junctions," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 159–161; April, 1957.
[218] L. Breitenhuber, "The dielectric disk as a four pole transformation network to magnify the node displacement for measuring purposes," *Arch. Elekt. Übertragung*, vol. 11, pp. 223–226; June, 1957.
[219] E. F. Bolinder, "Graphical method of determining the efficiency of two-port networks," Proc. IRE, vol. 45, p. 361; March, 1957.
[220] E. F. Bolinder, "A note on the matrix representation of linear two-port networks," IRE Trans. on Circuit Theory, vol. CT-4, pp. 337–339; December, 1957.
[221] W. P. Ayres, "Broad-band quarter-wave plates," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 258–261; October, 1957.

Some papers on both linear and gyromagnetic two-port and multiport microwave components are listed under other headings.

Directional Couplers

Strip-line structures were used as the basis for several directional couplers. One paper described two 3-db strip-line couplers. One of these couplers was a quarter wavelength long at the center of its frequency band and had a variation in coupling of ± 0.3 db over a 2:1 frequency band. The other was three quarters of a wavelength long and had the same coupling variation but over a 4.5:1 band. Good directivity and low standing wave ratios were reported for these couplers.

[222] J. K. Shimizu, "Strip-line 3-db directional couplers," 1957 IRE WESCON Convention Record, pt. 1, pp. 4–15.

Bethe's small-slot coupling formulas were applied to the case of coupling between waveguide and strip line. Compact three and four element binomial-array couplers with flat coupling characteristics, good directivity, and high power-handling capacity were built for L band.

[223] H. Perini and P. Sferrazza, "Rectangular waveguide to strip-transmission-line directional couplers," 1957 IRE WESCON Convention Record, pt. 1, pp. 16–21.

A simple extension of Bethe's small-hole coupling theory for coupling through an aperture containing a ferrite was formulated.

[224] D. C. Stinson, "Coupling through an aperture containing an anisotropic ferrite," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 184–191; July, 1957.

The boundary value problem of multiple slot coupling between identical rectangular guides was treated in another theoretical investigation.

[225] J. A. Barkson, "Coupling of rectangular waveguides having a common broad wall which contains uniform transverse slots," 1957 IRE WESCON Convention Record, pt. 1, pp. 30–38.

A new design technique involving two strip transmission lines mounted back to back above the ground plane and coupled through slots which were graded in length was described. In one design an equal power split within 1 db over a frequency band of 2800–4300 mc was obtained.

[226] J. M. C. Dukes, "Broad-band slot-coupled microstrip directional couplers," *Proc. IEE*, Paper 2402R; August, 1957.

A forward-type coupler utilizing a multiplicity of capacitive coupling probes inserted in the base of a waveguide for coupling between a coaxial line and TE_{10} mode waveguide was described.

227] P. P. Lombardini and R. F. Schwartz, "A new type of directional couplers for coupling coaxial line to TE_{10} waveguide," 1957 IRE WESCON Convention Record, pt. 1, pp. 22–29.

The problem of many parallel waveguides with continuous and uniform coupling was solved by the application of normal modes and the solution was extended to an infinite number of lines.

[228] J. P. Shelton, Jr., "Multiple-line directional couplers," 1957 IRE National Convention Record, pt. 1, pp. 254–262.

In another paper, a multi-element directional coupler was considered as a cascaded set of two-element couplers, each of which is perfect in match and directivity at the design frequency.

[229] J. W. Crompton, "A contribution to the design of multi-element directional couplers," *Proc. IEE*, vol. 104, pt. C, pp. 398–402; April, 1957.

Hybrid Junctions

A number of papers have appeared on hybrid junctions. A new form of hybrid junction which utilizes the principle of the branch-waveguide directional coupler was described in one paper. The performance of such a hybrid junction was reported to be superior to that of the hybrid-T and rat-race and to compare favorably with that of the short-slot hybrid.

[230] P. D. Lomer and J. W. Crompton, "A new form of hybrid junction for microwave frequencies," *Proc. IEE*, vol. 104, pt. B, pp. 261–263; May, 1957.
[231] L. Young, P. D. Lomer, and J. W. Crompton, "A new form of hybrid junction for microwave frequencies," *Proc. IEE*, vol. 104, pt. B, p. 586; November, 1957.

The transmission properties of new 5, 6, and 10-arm hybrid rings were described in another paper. These should be useful as power dividers. The possibility of obtaining better conjugacy properties by connecting a five and a four-arm ring tandem was also suggested.

[232] H. T. Budenbom, "Transmission properties of hybrid rings and related annuli," 1957 IRE National Convention Record, pt. 1, pp. 186–190.

The development of a strip-line hybrid which maintains a high degree of isolation over a two to one frequency band was also reported.

[233] H. G. Pascalar, "Strip line hybrid junction," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 23–30; January, 1957.

Phase errors in a magic-tee were analyzed mathematically and measurements of linearity made.

[234] R. M. Vaillancourt, "Errors in a magic-tee phase changer," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 204–207; July, 1957.

Other papers involving hybrid junctions for specialized purposes are listed in other sections of this report.

Microwave Components

Gyromagnetic devices for use in microwave circuits and the theory and measurement of their characteristics received considerable attention.

An analysis of *n*-wire, ferrite-loaded transmission line having potential symmetry was given in one paper. The results are valid for thin wires and thin ferrite rods. An eight-wire-line *circulator* was evaluated on the basis of the theory.

[235] H. Boyet and H. Seidel, "Analysis of nonreciprocal effects in an *n*-wire, ferrite-loaded transmission line," Proc. IRE, vol. 45, pp. 491–495; April, 1957.

Another analytical paper developed the scattering matrices of cascaded two and four-port waveguide structures in terms of the scattering matrices of the component sections. Particular attention was given to ferrite-loaded directional couplers and to the conditions under which multi-element structures may function as circulators.

[236] B. Davison, "Multi-element ferrite devices," 1957 IRE WESCON Convention Record, pt. 1, pp. 39–51.

A high-power circulator and a broad-band circulator were described in two other papers.

[237] P. A. Rizzi, "High-power ferrite circulators," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 230–237; October, 1957.
[238] E. A. Ohm, "A broad-band microwave circulator," *Bell Labs. Record*, vol. 35, pp. 293–297; August, 1957.

Circle averaging techniques were suggested for application to the measurement of the scattering parameters of nonreciprocal two-ports.

[239] H. M. Altschuler, "Nonreciprocal two-port measurement based on an averaging technique," Proc. IRE, vol. 45, p. 1293; September, 1957.

Ferrite *isolators*, *phase shifters*, *switches* and *circular polarizers* were described in the following papers:

[240] S. Weisbaum and H. Boyet, "Field displacement isolators at 4, 6, 11, and 24 kmc," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 194–198; July, 1957.
[241] S. Hayasi, "Figure of merit of resonance-type isolator," Proc. IRE, vol. 45, pp. 1418–1419; October, 1957.
[242] B. J. Duncan, L. Swern, K. Tomiyasu, and J. Hannwacker, "Design considerations for broad-band ferrite coaxial line isolators," Proc. IRE, vol. 45, pp. 483–490; April, 1957.
[243] M. Sucher and H. J. Carlin, "Coaxial line non-reciprocal phase shifters," *J. Appl. Phys.*, vol. 28, pp. 921–922; August, 1957.
[244] S. Wenglin, "The principle of non-gyromagnetic ferrite phase-shifter," 1957 IRE National Convention Record, pt. 1, pp. 288–290.
[245] F. Reggia and E. G. Spencer, "A new technique in ferrite phase shifting for beam scanning of microwave antennas," Proc. IRE, vol. 45, pp. 1510–1517; November, 1957.
[246] S. Sensiper, "Microwave ferrite phase shifter," Proc. IRE, vol. 45, p. 359; March, 1957.

[247] G. S. Uebele, "High-speed ferrite microwave switch," 1957 IRE National Convention Record, pt. 1, pp. 227–234.
[248] J. P. Vinding, "Ferrite switches in radar duplexers," 1957 IRE WESCON Convention Record, pt. 1, pp. 71–76.
[249] H. S. Kirschbaum and S. Chen, "A method of producing broad-band circular polarization employing an anisotropic dielectric," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 199–203; July, 1957.

Fast-acting mechanical switches involving novel features were developed too.

[250] H. H. Weichardt, "Fast acting microwave switch," 1957 IRE National Convention Record, pt. 1, pp. 222–226.
[251] W. E. Fromm, S. H. Klug, and K. S. Packard, "Precision high-speed microwave switch," 1957 IRE National Convention Record, pt. 1, pp. 219–221.

Coaxial cable and waveguide *power dividers* investigations were reported. Broad-band response in a coaxial divider was obtained by making the input reflection coefficient and its derivative equal to zero. Any degree of power split was feasible by the design process which was outlined.

[252] J. Reed and G. Wheeler, "A broadband fixed coaxial power divider," 1957 IRE National Convention Record, pt. 1, pp. 177–181.

Two broad-band, short-slot hybrid junctions were used in a variable-ratio power divider for rectangular waveguides. This device may also be used to couple two frequencies into one output.

[253] W. L. Teeter and K. R. Bushore, "A variable-ratio microwave power divider and multiplexer," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 227–229; October, 1957.

A new type of power divider designed for use in antenna feeding systems was reported and four classes of dividers for various division ratios were discussed.

[254] T. G. Hame, "Waveguide power dividers," *Electronic Eng.*, vol. 29, pp. 368–373; August, 1957.

There are three principal types of *duplexers:* 1) branching, 2) polarization twist, and 3) balanced. The balanced type is inherently suited to broad-band use. The operation of balanced duplexers employing hybrid junctions as directional couplers was discussed in the following paper:

[255] C. W. Jones, "Broad-band balanced duplexers," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 4–12; January, 1957.

Other duplexers developed include a wide-band slab type and a high-power waveguide type utilizing 3-db directional couplers in cascade.

[256] P. Bouvier, "Wide-band duplexer for decimeter-wave aerials," *Ann. Radioélect.*, vol. 12, pp. 315–329; October, 1957.
[257] L. Milosevic, "High power duplexers," *Vide*, vol. 12, pp. 109–116; January/February, 1957.

Waveguide *loads* for high powers were studied too.

[258] V. Hlubuček, "Theoretical analysis of the design of a waveguide load for high powers," *Slaboproudý Obzor*, vol. 18, pp. 420–425; July, 1957.

Resonators and Filters

A number of papers appeared on the subjects of resonators and filters. The following are representaitve of the papers on resonators and related components.

[259] H. E. Bussey and L. A. Steinert, "An exact solution for a cylindrical cavity containing a gyromagnetic material," Proc. IRE, vol. 45, pp. 693–694; May, 1957.
[260] A. E. Karbowiak, "The concept of heterogeneous surface impedance and its application to cylindrical cavity resonators," *Proc. IEE*, Monogram 246R; June, 1957. Also *Proc. IEE*, vol. 105, pt. C, pp. 1–12; March, 1958.
[261] W. A. Gerard, "Reference cavity design considerations," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 148–152; April, 1957.
[262] C. M. Crain and C. E. Williams, "Method of obtaining pressure and temperature insensitive microwave cavity resonators," *Rev. Sci. Instr.*, vol. 28, pp. 620–623; August, 1957.
[263] G. N. Rapoport, "Measurement of the intensity of the electric field in cavity resonators by means of the resonant frequency-shift with insertion of a dielectric probe," *Radiotekhnika*, vol. 12, pp. 51–58; February, 1957.
[264] A. Redhardt, "An iterative process for the calculation of electromagnetic fields," *Arch. Elekt. Übertragung*, vol. 11, pp. 227–229; June, 1957.
[265] R. N. Ghose, "Excitation of higher order modes in spherical cavities," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 18–22; January, 1957.
[266] R. N. Ghose, "Exponential transmission lines as resonators and transformers," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 213–217; July, 1957.
[267] H. J. Riblet, "General synthesis of quarter-wave impedance transformers," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 36–43; January, 1957.

Ring type resonant circuits and re-entrant type filter circuits are increasing in importance. The ring circuit has the interesting capacity to resonate with unidirectional progressive waves when directionally coupled to the main guide. When nondirectionally coupled, the ring behaves like an ordinary cavity with standing waves.

[268] F. J. Tischer, "Resonance properties of ring circuits," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 51–56; January, 1957.
[269] K. Tomiyasu, "Effect of a mismatched ring in a traveling-wave resonant circuit," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, p. 267; October, 1957.
[270] J. M. C. Dukes, "Re-entrant transmission-line filter using printed conductors," *Proc. IEE*, Paper 2444R; November, 1957. Also *Proc. IEE*, vol. 105, pt. B, pp. 173–181; March, 1958.

A number of papers on other microwave filters appeared. The most noteworthy of those reviewed were probably those on circularly polarized microwave cavity filters.

[271] C. E. Nelson, "Circularly polarized microwave cavity filters," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 136–147; April, 1957.
[272] C. E. Nelson and W. L. Whirry, "Development of circularly polarized microwave cavity filters," 1957 IRE National Convention Record, pt. 1, pp. 191–196.
[273] H. Seidel, "Synthesis of a class of microwave filters," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 107–114; April, 1957.
[274] S. B. Cohn, "Direct-coupled-resonator filters," Proc. IRE, vol. 45, pp. 187–196; February, 1957.
[275] R. Bawer and G. Kefalas, "A modified equal-element band-pass filter," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 175–184; July, 1957.
[276] F. Shnurer, "Design of aperture-coupled filters," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 238–243; October, 1957.
[277] H. Yanai and J. Hamasaki, "*M*-derived waveguide filter," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 39, pp. 1029–1035; December, 1956.
[278] K. Kuroda, "An experiment on a wide-band coaxial filter," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 40, pp. 805–807; July, 1957.
[279] R. A. Van Patten, "Design of imposed low-pass filters using strip-line structures," 1957 IRE National Convention Record, pt. 1, pp. 197–207.

III. Measurements

Advances in microwave measurements were for the most part refinements and extensions of proven techniques and the application of these techniques to new situations. The areas of greatest advance appear to be those of absolute measurement of microwave power, the measurement of noise power, and the measurement of properties of ferromagnetic materials at microwave frequency.

Power Measurement

The absolute measurement of power was the subject of several studies. A new electron-beam technique for measuring either cw or pulse power flow in waveguides was described. The technique consisted of passing an electron beam transversely through an evacuated section of TE_{10}-mode waveguide. Electron transit time is adjusted so that the gain of energy of the electrons from the microwave field is a maximum. The energy gain is measured by means of a dc stopping potential which can be related to the field. The instrument appears to have considerable value for measuring or monitoring high power levels without disturbing the power being measured.

[280] H. A. Thomas, "Microwave power measurements employing electron beam techniques," Proc. IRE, vol. 45, pp. 205–211; February, 1957.

A similar technique for measuring or monitoring the microwave power in a coaxial structure was reported. Part of a coaxial line forms a diode. When power is fed along the line, the potential difference which is developed between the inner and outer conductors is a measure of the power.

[281] W. J. Hoskins, "Microwave power measurements employing electron beam techniques," Proc. IRE, vol. 45, p. 1285; September, 1957.

A new high-power wattmeter of the calorimetric type was developed. Superiority in accuracy, sensitivity, simplicity of construction, and operation to the conventional water-flow meter was claimed.

[282] A. Macpherson, "An absolute microwave wattmeter," Proc. IRE, vol. 45, pp. 688–689; May, 1957.

An instrument, consisting of a thin metallic rod suspended inside a rectangular TE_{011} cavity, was described for the absolute measurement of low-level microwave power. The oscillating system receives periodic impulses via the electromagnetic field by periodically interrupting the flow of power from the source. An error of less than ± 2 per cent in the 5–100 mw range was claimed.

[283] A. L. Cullen and H. A. French, "An instrument for the absolute measurement of low-level microwave power in the 3-cm band," *Proc. IEE*, vol. 104, pt. C, pp. 454–464; September, 1957.

Bolometers were the object of several studies.

[284] J. A. Lane, "Measurements of efficiency of bolometer and thermistor mounts by impedance methods," *Proc. IEE*, vol. 104, pt. B, pp. 485–486; September, 1957.
[285] E. Archbold, "An evaporated gold bolometer," *J. Sci. Instr.*, vol. 34, pp. 240–242; June, 1957.
[286] A. M. Bonch-Bruevich and Y. A. Imas, "Some problems in the application of semiconductor bolometers," *Radiotekhnika i Elektronika*, vol. 2, pp. 317–322; March, 1957.
[287] H. Rieck and F. Panniger, "A new thermistor power-measuring head for $\lambda = 9$–20 cm," *Nachr. Tech.*, vol. 7, pp. 101–104; March, 1957.
[288] V. N. Bogomolov, Y. V. Ilisavski, M. Kornfel'd, L. S. Sochava, and R. I. Strunin, "Low-inertia germanium bolometers," *Zh. Tekh. Fiz.*, vol. 27, pp. 213–215; January, 1957.

A very interesting combination of a cathode-ray type tube and a traveling-wave type tube to produce a wide-band display device was described. The brightness at the screen is a function of the microwave power input.

[289] D. E. George, "The wamoscope—a microwave display device," *Sylvania Technologist*, vol. 10, pp. 5–7; January, 1957.

A closely related study on high-frequency oscillography was reported in the following paper.

[290] H. Maeda, "Waveform observation of electron current using traveling-wave cathode-ray tubes," *J. Inst. Elec. Comm. Engrs. Japan*, vol. 40, pp. 1171–1177; November, 1957.

The measurement of noise in masers and the spectral distribution of thermal noise in a gas discharge were discussed in the following papers:

[291] J. C. Helmer, "Maser noise measurement," *Phys. Rev.*, vol. 107, pp. 902–903; August 1, 1957.
[292] S. M. Bergmann, "Spectral distribution of thermal noise in a gas discharge," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 237–238; October, 1957.

A rapid and simple means of measuring wide range of RF power was described.

[293] J. Swift, "A microwave power monitor," *Proc. IRE Australia*, vol. 17, pp. 424–428; December, 1956.

The radiometer, which is a receiving equipment designed to measure noise power to a high degree of accuracy, was the subject of several papers.

[294] G. R. Nicoll, "The measurement of thermal and similar radiations at millimetre wavelengths," *Proc. IEE*, vol. 104, pt. B, pp. 519–527; September, 1957.
[295] J. C. Greene, "Stability requirements and calibration of radiometers when measuring small noise powers," Proc. IRE, vol. 45, pp. 359–360; March, 1957.
[296] L. D. Strom, "The theoretical sensitivity of the Dicke Radiometer," Proc. IRE, vol. 45, pp. 1291–1292; September, 1957.
[297] R. N. Whitehurst, F. H. Mitchell, and J. Copeland, "A calibration procedure for microwave radiometers," Proc. IRE, vol. 45, pp. 1410–1411; October, 1957.
[298] W. H. Ward, "Two portable thermistor radiometers," *J. Sci. Instr.*, vol. 34, pp. 317–321; August, 1957.

A simple bridge method for the absolute calibration of attenuators at the frequency of operation was outlined. The method uses microwave and electronic apparatus which is usually available in microwave laboratories.

[299] E. Laverick, "The calibration of microwave attenuators by an absolute method," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 250–254; October, 1957.

The disadvantages of attenuators with transversely moved vanes and T-network attenuators were also discussed and a rotary attenuator was described which is not frequency sensitive and which has a constant phase shift up to a certain limit.

[300] R. Steinhart, "A microwave attenuator which is not frequency sensitive and has a constant phase shift within very wide limits," *Nachrich. Z.* vol. 10, pp. 294–297; June, 1957.

Impedance and Frequency Measurement

A number of papers appeared on impedance measurement with transmission lines. These papers were of the nature of refinements of established techniques. The following list is representative of those reviewed.

[301] L. Lewin, "A contribution to the theory of probes in waveguides," *Proc. IEE*, Monogram 259R; October, 1957. Also *Proc. IEE*, vol. 105, pt. C, pp. 109–116; March, 1958.
[302] D. R. Frankl, "Resistance of a partially short-circuited conducting slab," PROC. IRE, vol. 45, pp. 877–878; June, 1957.
[303] D. Dettinger, "Advantages of expressing standing-wave-ratio in decibels," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, p. 218; July, 1957.
[304] F. J. Charman, "V. H. F. line measurements," *Electronic Eng.*, vol. 29, pp. 499–503; October, 1957.
[305] E. M. Williams and J. H. Foster, "Standing-wave line for uhf measurements of high-dielectric constant materials," IRE TRANS. ON INSTRUMENTATION, vol. I–6, pp. 210–213; September, 1957.
[306] R. Mittra, "An automatic phase-measuring circuit at microwaves," IRE TRANS. ON INSTRUMENTATION, vol. I–6, pp. 238–240; December, 1957.
[307] R. Müller, "Measurement of the circuit impedance of slow-wave structures," *Onde Electr.*, vol. 37, pp. 128–135; February, 1957.
[308] R. W. Beatty, "An adjustable sliding termination for rectangular waveguide," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 192–194; July, 1957.

The measurement of the dielectric and/or magnetic properties of ferromagnetic and paramagnetic materials was a subject of considerable interest.

[309] L. A. Ault, E. G. Spencer, and R. C. LeCraw, "Circularly polarized traveling wave cavity for ferrite tensor permeability measurements," 1957 IRE NATIONAL CONVENTION RECORD, pt. 1, pp. 282–287.
[310] W. Von Aulock and J. H. Rowen, "Measurement of dielectric and magnetic properties of ferromagnetic materials at microwave frequencies," *Bell Sys. Tech. J.*, vol. 36, pp. 427–448; March, 1957.
[311] B. M. Bowie, "Microwave dielectric properties of solids for applications at temperatures to 300°F," 1957 IRE NATIONAL CONVENTION RECORD, pt. 1, pp. 270–281.
[312] G. Feher, "Sensitivity considerations in microwave paramagnetic resonance absorption techniques," *Bell Sys. Tech. J.*, vol. 36, pp. 449–484; March, 1957.
[313] H. K. Ruppersberg, "Method of measurement to determine the complex dielectric constant at wavelengths from 8 to 80 cm and temperatures to −150°C," *Z. Angew Phys.*, vol. 9, pp. 9–13; January, 1957.
[314] I. Brady, "Measurement of the complex dielectric constant of very-high-dielectric-constant materials at microwave frequencies," *Commun. and Electronics*, no. 30, pp. 225–228; May, 1957.
[315] A. G. Mungall and J. Hart, "Measurement of the complex dielectric constant of liquids at centimetre and millimetre wavelengths," *Can. J. Phys.*, vol. 35, pp. 995–1003; September, 1957.

Time and frequency measurements, and the frequency stabilization of sources received some attention. The molecular oscillator as a frequency or time standard is probably the most noteworthy development in this area.

[316] C. H. Townes, "Recent developments in measurement of time," *Nuovo Cim.*, vol. 5, supplement, No. 1, pp. 222–229; 1957.
[317] H. P. Raabe, "Measurement of instantaneous frequency with a microwave interferometer," PROC. IRE, vol. 45, pp. 30–38; January, 1957.
[318] R. C. Mackey and W. D. Hershberger, "Measurement and control of microwave frequencies by lower radio frequencies," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 64–68; January, 1957.
[319] I. Goldstein, "Frequency stabilization of a microwave oscillator with external cavity," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-5, pp. 57–62; January, 1957.
[320] M. Magid, "Broadband frequency stabilization of a reflex klystron by means of an external high *Q* cavity," 1957 IRE NATIONAL CONVENTIOON RECORD, pt. 1, pp. 208–218.

IV. CONCLUSION

In reviewing advances in microwave theory and techniques, one is impressed by the amount and quality of the published works. The field advances by the close interplay of physics with engineering. It is a field in which the lead-time between physical discovery and engineering use has approached zero. A bright and interesting future is the promise for those in this field.

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