Report of Advances in Microwave Theory and Techniques in Great Britain—1959*

JOHN BROWN†, SENIOR MEMBER, IRE

Introduction

THE continued research effort in the microwave field is reflected by the number of papers, which is as great as in any previous year. The single topic attracting the largest number of contributions has been that of waveguides for long-distance communication. This is partly the result of a very successful International Convention organized by the Institution of Electrical Engineers in London during January, 1959. To some extent it also indicates the amount of work which has been proceeding during the last few years and which now suggests that operational waveguide communication links may be in service within the foreseeable future.

Waveguides of the more conventional type have not been neglected, and the papers listed indicate a steady improvement in component design, methods of manufacture, and techniques of measurement. A somewhat surprising impression is given by the relatively small number of papers on solid-state microwave devices: this is certainly not representative of the effort devoted to this topic at present, and it is likely that there will be a marked increase in this number during the next year. Progress in microwave tube design and in microwave measurement techniques also continues.

1. Transmission Lines and Waveguides

In this section the properties of structures capable of transmitting electromagnetic waves are considered. During the period under review, papers have appeared on strip lines, waveguides operating with only one propagating mode, multimode waveguides, and artificial dielectrics.

1.1 *TEM Lines*

No original material has been published, but a useful survey of the properties of strip lines has appeared. This contains information on the basic properties of strip lines and on the design and manufacture of strip-line components and of transducers to waveguides or coaxial lines.

[1] A. F. Harvey, "Parallel plate transmission systems for microwave frequencies," *Proc. IEE*, vol. 106, pt. B, pp. 129–140; March, 1959.

1.2 *Waveguides*

The efforts made during the last few years to develop multimode waveguides for long-distance communication have been widely publicized as a result of the Convention referred to in the Introduction. The papers presented at this Convention have been published in Supplement No. 13 of volume 106, part B of the *Proceedings of the Institution of Electrical Engineers* and will be discussed in appropriate sections of this article. (This issue will be referred to throughout as IEE suppl. no. 13 B.) An authoritative review of this topic has been given by Prof. H. M. Barlow in this supplement, and other review articles have also appeared.

[2] H. M. Barlow, "Introductory survey," IEE suppl. no. 13 B, pp. 1–8.
[3] H. M. Barlow, "Long-distance transmission by waveguide," *Brit. Commun. & Electronics*, vol. 6, pp. 92–95; February, 1959.
[4] F. J. D. Taylor, "GPO interest in long distance transmission by waveguide," *ibid.*, p. 96.
[5] L. Lewin, "A long distance waveguide telecommunication system," *ibid.*, pp. 97–100.
[6] A. E. Karbowiak, "Assessment of waveguide performance as a long-distance transmission medium," *ibid.*, pp. 168–186. See also *Electronic Engrg.*, vol. 31, pp. 520–525; September, 1959.
[7] F. J. D. Taylor, "Some views on system application," IEE suppl. no. 13 B, pp. 186–187.

Propagation in overmoded waveguides is complicated by mode conversion, which can lead to the distortion of information, and experimental and theoretical results are reported for several types of low-loss guide.

[8] A. E. Karbowiak, "Distortion of information in non-uniform multimode waveguide," IEE suppl. no. 13 B, pp. 9–16.
[9] A. E. Karbowiak and V. H. Knight, "An experimental investigation of waveguide for long distance communication," *ibid.*, pp. 17–29.
[10] H. E. Rowe and W. D. Warters, "Transmission deviations in waveguide due to mode conversion: theory and experiment," *ibid.*, pp. 30–36.
[11] H. Larsen, "Delay distortion and equalization in H_0 waveguides for long range communication," *ibid.*, pp. 188–194.

A general analysis of the behavior of waveguides of arbitrary cross section has been carried out.

[12] G. Reiter, "Generalised telegraphist's equation for waveguides of varying cross-section," *ibid.*, pp. 54–57.

Further results on the H guide and new improved forms of this guide were reported.

[13] F. J. Tischer, "Properties of the H-guide at microwave and millimetre-wave regions," *ibid.*, pp. 47–53.

The properties of a waveguide consisting of spaced conducting disks with circular holes are claimed to compare favorably with those of solid guides.

[14] A. W. Gent, "The attention and propagation factor of spaced-disc circular waveguide," *ibid.*, pp. 37–46.

There is now general agreement that the most promising available waveguide for long-distance communication is that formed from a helical conductor covered by

* Received by the PGMTT, April 21, 1960.
† Elec. Engrg. Dept., University College, London, Eng.

a suitable insulating jacket. Detailed information on the design theory, properties, and methods of manufacture of such a guide has been given.

[15] H. G. Unger, "Helix waveguide design," *ibid.*, pp. 151–155.
[16] G. Piefke, "The influence of helix wire diameter on the modes in helix waveguide," *ibid.*, pp. 110–118.
[17] L. Lewin, "Winding and jointing helical wound waveguide," *ibid.*, pp. 156–158.
[18] A. C. Beck and C. F. P. Rose, "Waveguide for circular electric mode transmission," *ibid.*, pp. 159–162.

1.3 *Surface Waves*

Surface waves offer an alternative method of long-distance communication, and the experience gained from an operational system has been reviewed.

[19] G. Goubau, "Some characteristics of surface wave transmission lines for long distance transmission," *ibid.*, pp. 166–167.

Theoretical and experimental results are given for several types of reactive surface.

[20] K. P. Sharma, "The estimation of the reactance of a loss free surface supporting surface waves," *Proc. IEE*, vol. 106, pt. B, pp. 427–430; July, 1959.

A disadvantage of surface waves is the possible conversion of power to radiation, this being the equivalent of the excitation of unwanted modes in overmoded guide. Two aspects of this have been investigated, the first dealing with discontinuities such as changes in reactance or the presence of conductors in the path of the wave, and the second with the effect of curvature in the reactive surface supporting the wave.

[21] K. P. Sharma, "An investigation of the excitation of radiation by surface waves," *Proc. IEE*, vol. 106, pt. B, pp. 116–122; March, 1959.
[22] H. M. Barlow, "The power radiated by a surface wave circulating around a cylindrical surface," *ibid.*, pp. 180–185.

Interest in methods of launching surface waves continues and studies of slot launchers for both radial surface waves and single wire lines have been made. It is pointed out that although slot launchers can have a high launching efficiency, there is an inevitable restriction on the bandwidth of operation. A comparison is made with supergain antennas.

[23] J. Brown and K. P. Sharma, "The launching of radial cylindrical surface waves by a circumferential slot," *ibid.*, pp. 123–128.
[24] J. Brown and H. S. Stachera, "Annular slot launchers for single-conductor transmission lines," IEE suppl. no. 13 B, pp. 143–145.

An instructive comparison of problems involving surface waves, Çerenkov radiation, diffraction, and neutron scattering draws attention to the essential unity of the theoretical treatments.

[25] J. D. Lawson, "Electromagnetic wave problems," *Electronic and Radio Engr.*, vol. 36, pp. 332–338; September, 1959.

1.4. *Artificial Dielectrics*

Further results on the properties of artificial dielectrics have been presented and the possible use of these materials in dispersive prisms for frequency scanning and in radomes as low reflection materials is discussed.

[26] J. S. Seeley and J. Brown, "The use of dispersive artificial dielectrics in a beam scanning prism," *Proc. IEE*, vol. 106, pt. B, pp. 93–102; March, 1959.
[27] J. S. Seeley, "The quarter wave matching of dispersive materials," *ibid.*, pp. 103–106.
[28] A. Carne and J. Brown, "Theory of reflections for the rodded-type artificial dielectric," *ibid.*, pp. 107–115.

2. Waveguide Components

Work in components is largely directed to increasing the bandwidth over which satisfactory operation can be achieved, and to improving methods of manufacture. Tchebycheff functions have been used in the design of several waveguide components such as directional couplers and filters, and a guide to the use of such functions has been prepared. A useful bandwidth improvement can be obtained.

[29] R. Levy, "A guide to the practical application of Chebyshev functions to the design of microwave components," *Proc. IEE*, vol. 106, pt. C, pp. 193–199; September, 1959.

A stepped-waveguide transition between two rectangular waveguides of different cross section has been designed with steps in both guide height and width. The design and performance of such a transition connecting no. 11 and no. 12 waveguides is discussed, satisfactory results being achieved over the frequency range 3.7–4.3 gigacycles (gc).

[30] D. Wray, "Frequency compensation for simple stepped waveguide transforming sections," *Electronic Engrg.*, vol. 31, pp. 76–79; February, 1959.

The position of the short circuits on the arms of a hybrid junction used as a duplexer has been examined with a view to optimizing the bandwidth of operation.

[31] R. Levy, "Hybrid junctions," *Electronic & Radio Engr.*, vol. 36, pp. 308–312; August, 1959.

An interference-type two-hole directional coupler can be tuned by dielectric phase shifters between the coupling holes to give perfect directivity at any wavelength within a wide frequency range. Design details have been given.

[32] W. G. Voss, "Modified two-hole directional coupler," *Electronic & Radio Engr.*, vol. 36, p. 28; January, 1959.

The properties of waveguide switches of mechanical types have been compared with those using discharge tubes and ferrites.

[33] J. W. Sutherland, "Waveguide switches and branching networks," *Electronic Engrg.*, vol. 31, pp. 64–65; February, 1959.

Improvements in the design of cavity resonators which have been reported include the reduction of the effects of spurious modes in TE_{01n} resonators and an increase in the tuning range of TE_{11n} wavemeters for use in J and K bands.

[34] A. Cunliffe and R. N. Gould, "High Q echo boxes," *Electronic & Radio Engr.*, vol. 36, pp. 29–33; January, 1959.
[35] P. Andrews, "The design of broadband circular wavemeters," *Brit. Commun. & Electronics*, vol. 6, pp. 354–357; May, 1959.

The tuning range of X-band cavities designed for use with plug in klystrons has been increased to 30 per cent.

[36] R. Mather and J. Sharpe, "Wide range tuning cavities for reflex klystrons," *Electronic Engrg.*, vol. 31, pp. 390–393; July, 1959.

A simple acid-copper electroforming process suitable for laboratory use has been developed. Investment casting from frozen mercury patterns has proved to be suitable for the manufacture of components of normal commercial performance at frequencies around 10 gc.

[37] P. Andrews, "The electroforming of waveguide components," *Electronic Engrg.*, vol. 31, pp. 150-153; March, 1959.
[38] H. H. Scholfield, H. H. H. Green, and R. E. Gossett, "Manufacture of waveguide parts by investment casting from frozen mercury patterns," *Proc. IEE*, vol. 106, pt. B, pp. 431–434; July, 1959.

The development of the TE_{01} mode for long-distance communication has created the need for components designed for circular guides operating in this mode. Two new types of transducers which couple from rectangular guide to the TE_{01} mode in circular guide have been developed for operation at frequencies around 30 gc. The first uses slot coupling from a rectangular guide inserted along the axis of the circular guide and a bandwidth of 2 gc has been achieved. The second, which is designed specifically for narrow-band use, has the rectangular guide wrapped around the circumference of the circular guide, slot coupling again being used: the bandwidth obtained using 46 slots is of the order of 50 mc.

[39] B. Oguchi and K. Yamaguchi, "Centre-excited type of rectangular TE_{01} to circular TE_{01} mode transducer," IEE Suppl. no. 13 B, pp. 132–137.
[40] Y. Klinger and L. Lewin, "Channel insertion feed," *ibid.*, pp. 138–142.

Attention has also been given to transducers coupling circular guides of different radii, when both guides support the TE_{01} mode. The problem is to avoid conversion to other modes, and solutions involving either tapers or steps have been proposed.

[41] L. Solymar, "Design of a two-section conical taper in circular waveguide system supporting the H_{01} mode," *ibid.*, pp. 119–120.
[42] L. Solymar, "Monotonic multi-section tapers for overmoded circular waveguides," *ibid.*, pp. 121–128.
[43] L. Solymar, "Step transducers between over-moded circular waveguides," *ibid.*, pp. 129–131.

Estimates have been made of the transmitted mode amplitudes when a circular waveguide with an incident TE_{01} mode is connected to a guide whose cross section differs slightly from circular.

[44] L. Solymar, "Over-moded waveguides," *Electronic & Radio Eng.*, vol. 36, pp. 426–428; November, 1959.

It has been suggested that overmoded rectangular waveguides may be useful at millimetric wavelengths, and the problem of mode conversion again arises. Results have been derived for a pyramidal taper connecting two rectangular waveguides of different cross sections.

[45] L. Solymar, "Mode conversion in pyramidal-tapered waveguides," *Electronic & Radio Engr.*, vol. 36, pp. 461–463; December, 1959.

The possible excitation of unwanted modes at bends in a low-loss waveguide is one of the most difficult problems to be overcome, and several ingenious suggestions have been made. Two main lines of attack are being used. The first relies on modifying the surface reactance of the guide wall to inhibit the excitation of the unwanted modes and a general discussion of this possibility has been given. Results have been given for one particular configuration. The helix guide can also be considered from this point of view, and experimental values for the performance of a bend have been provided. Further information on bends will be found in several of the papers listed in Section 1.2.

[46] H. M. Barlow, "A method of changing the dominant mode in a hollow metal waveguide and its application to bends," IEE suppl. no. 13 B, pp. 100–105.
[47] P. Marie, "A bend for TE_{01} mode propagated in circular waveguide," *ibid.*, pp. 108–109.
[48] M. Thue, J. Bendayan, and G. Comte, "Researches on transmission of TE_{01} waves in circular waveguides in the vicinity of 25 and 35 gc/s," *ibid.*, pp. 94–97.

The second line of attack is to introduce an inhomogeneous dielectric into the waveguide with the object of preserving the field pattern of the wanted mode as it propagates around the bend.

[49] H. M. Barlow and D. C. Rickard, "Experiments on circular H_{01} wave propagation in a curved waveguide filled with an inhomogeneous dielectric," *ibid.*, pp. 106–107.

3. Solid-State Devices

The only papers published during 1959 on maser and mavar devices have been theoretical. The first gives a unified treatment of the noise properties of maser and mavar amplifiers by using the concepts of negative temperature and negative quality factor.

[50] E. D. Farmer, "The noise and gain properties of molecular and parametric amplifiers," *J. Electronics & Control*, vol. 7, pp. 214–232; September, 1959.

The effect of the series resistance of a variable capacity semiconductor diode on the performance of a variable reactance amplifier has been analyzed.

[51] P. Bobish and C. Sondhauss, "Einfluss des zeitabhangigen Serien-Wirkwiderstandes einer Kapazitätsdiode beim Mavar-Aufwärts mischer," *J. Electronics & Control*, vol. 7, pp. 344–366; October 1959.

Ferrite devices continue to attract considerable attention and progress has been reported in several directions. Further theoretical contributions on the properties of circular waveguides containing ferrites have appeared and the behavior at the interface between an empty rectangular waveguide and one completely filled with a ferrite has been analyzed.

[52] P. J. B. Clarricoats, "A perturbation method for circular waveguides containing ferrites," *Proc. IEE*, vol. 106, pt. B, pp. 335–340; May, 1959.
[53] R. A. Waldron, "Theory of mode spectra of cylindrical waveguides containing gyromagnetic media," *J. Brit. IRE*, vol. 19, pp. 347–356; June, 1959.
[54] L. Lewin, "A ferrite boundary value problem in a rectangular waveguide," *Proc. IEE*, vol. 106, pt. B, pp. 559–563; November, 1959.

A ferrite modulator, using Faraday rotation, has been designed to operate at high modulation frequencies. When used as a single-sideband modulator at X band, this device gives an output which is not more than 20 db below the input signal for modulation frequencies up to 10 mc.

[55] A. L. Morris, "Microwave ferrite modulator for high modulation frequencies," *J. Brit. IRE*, vol. 19, pp. 117–129; February, 1959.

The performance of a ferrite mixer has been analyzed and the conversion efficiency is shown to be 14 db worse than a conventional crystal mixer.

[56] L. Lewin, "The efficiency of ferrite as a microwave mixer," *Proc. IEE*, vol. 106, pt. C, pp. 153–157; September, 1959.

The possibility of using a ferrite rod in a circular waveguide as the basis of a traveling-wave amplifier has been examined theoretically. It is concluded that pulsed operation is necessary and that gains of up to 3 db/inch may then be obtained at X band, the bandwidth being of the order of 100 mc.

[57] P. J. B. Clarricoats, "The gain of travelling wave ferromagnetic amplifiers," *Proc. IEE*, vol. 106, pt. C, pp. 165–173; September, 1959.

4. Microwave Electronics

The emphasis has been on theoretical work designed to facilitate the construction of oscillators with higher power outputs and amplifiers with improved noise performance.

Expressions for the plasma frequency reduction factors in space charge waves have been obtained.

[58] D. H. Trevena, "On space charge waves," *J. Electronics & Control*, vol. 6, pp. 50–64; January, 1959. See also comments by R. H. C. Newton, *ibid.*, pp. 321–324; April, 1959.

An analysis of the effects of collisions on space charge waves has been made and leads to suggestions for reducing the noise in beam-type tubes and for measuring the collision frequency in a plasma.

[59] S. V. Yadavalli, "Collision damping of space charge waves in a plasma," *J. Electronics & Control*, vol. 7, pp. 261–267; September, 1959.

Further theoretical studies of coupling systems have been made.

[60] T. S. Chen, "Design and performance of coupled-helix transducers for travelling wave tubes," *J. Electronics & Control*, vol. 6, pp. 289–306; April, 1959.

[61] A. Ashkin, W. H. Louisell, and C. F. Quate, "Fast wave couplers for longitudinal beam parametric amplifiers," *J. Electronics & Control*, vol. 7, pp. 1–32; July, 1959.

A comparison of theoretical and experimental results on multistart helices intended for use in high-power traveling-wave tubes has been made.

[62] G. W. Buckley and J. Gunson, "Theory and behavior of helix structures for a high power pulsed travelling wave tube," *Proc. IEE*, vol. 106, pt. 5, pp. 478–486; September, 1959.

A method of focusing sheet beams by a periodic arrangement of magnetic fields has been suggested. This has possible applications in fast-wave traveling-wave tubes.

[63] P. A. Sturrock, "Magnetic deflection focussing," *J. Electronics & Control*, vol. 7, pp. 162–168; August, 1959.

A traveling-wave tube using a clover-leaf slow wave structure and a ferrite isolator has been shown to give an output power of 1 kw at X band. The gain is 22 db and the tube can be tuned over a 6 per cent range of frequency.

[64] M. O. Bryant, J. F. Gittens, and F. Wray, "An experimental C.W. power travelling wave tube," *J. Electronics & Control*, vol. 6, pp. 113–129; February, 1959.

The advantages of using a double tuned output circuit on a multicavity klystron have been demonstrated on an S-band tube. A power output of 2 Mw, for an input power of 25 watts and a beam power of 10 Mw, has been achieved over a 5.5 per cent frequency range.

[65] H. J. Curnow and L. E. S. Mathias, "A multi-cavity klystron with double tuned output circuit," *Proc. IEE*, vol. 106, pt. B, pp. 487–488; September, 1959.

The performance of a magnetron tuned by a waveguide has been examined. An equivalent circuit for the magnetron has been deduced from the form of the input admittance characteristic and has been used to predict the operating frequency as a function of the length of the tuning waveguide. Good agreement with measured values is reported.

[66] T. S. Chen, "Tuning and the equivalent circuit of multi-resonator magnetrons," *J. Electronics & Control*, vol. 7, pp. 33–51; July, 1959.

The cross-modulation which can arise in a frequency-modulated klystron as a result of frequency pulling has been examined theoretically. An idealized Rieke diagram is assumed and numerical results are given for the second and third harmonics produced.

[67] D. T. Gjessing, "A simple investigation of the cross-modulation distortion arising from the pulling effect in a frequency modulated klystron," *Proc. IEE*, vol. 106, pt. B, pp. 473–477; September, 1959.

A theoretical study of an electron beam parametric amplifier shows that the Manley-Rowe relations are satisfied.

[68] W. H. Louisell, "A three-frequency electron beam parametric amplifier and frequency converter," *J. Electronics & Control*, vol. 6, pp. 1–25; January, 1959.

A survey of particle accelerators has been prepared.

[69] A. F. Harvey, "Radio-frequency aspects of electronuclear accelerators," *Proc. IEE*, vol. 106, pt. B, pp. 43–57; January, 1959.

5. Measurements

Progress continues in improving measurement techniques for conventional waveguide systems and in developing methods for the rapid assessment of component performance. The interest in low-loss waveguides has shown the need for measurement techniques which are suitable for use in multimode guides and are capable of measuring very low attenuation.

5.1. *Standing-Wave Measurements*

Two new automatic standing-wave plotters have been developed. The first is based on a rotary standing-wave indicator, the need for mechanical rotation of the crystal detector being eliminated by the use of a ferrite polarization rotator. The VSWR is displayed directly on a meter. The second uses directional couplers, the signal being provided by a backward-wave oscillator which can be swept over the frequency range 7.5–11.0 gc. A cathode-ray tube presentation gives a plot of reflection coefficient against frequency.

[70] E. Laverick and J. Welsh, "An automatic standing wave indicator for the 3 cm band," *J. Brit. IRE*, vol. 19, pp. 253–262; April, 1959.
[71] J. C. Dix and M. Sherry, "A microwave reflectometer display system," *Electronic Engrg.*, vol. 31, pp. 24–29; January, 1959.

A reflectometer has been designed for use with strip lines in the frequency range 40–100 mc.

[72] G. H. Millard, "Triple V.H.F., reflectometer," *Electronic and Radio Engrg.*, vol. 36, pp. 11–13; January, 1959.

The reciprocity theorem has been applied to the problem of standing wave measurements and it is shown that there may be advantages in interchanging the oscillator and detector.

[73] G. D. Monteath, "Reciprocity in R.F. measurements," *Electronic & Radio Engr.*, vol. 36, pp. 18–20; January, 1959.

Waveguide circuits which are made in integral form cannot be tested by using conventional standing-wave indicators. A specially designed plug-in reflectometer overcomes this difficulty.

[74] G. Craven and V. H. Knight, "The design and testing of integrally constructed waveguide assemblies," *Proc. IEE*, vol. 106, pt. B, pp. 321–334; May, 1959.

Various problems related to standing-wave measurements have been discussed.

[75] J. R. G. Twistleton, "The transformation of admittance through a matching section and lossless waveguide junction," *Proc. IEE*, vol. 106, pt. B, pp. 175–179; March, 1959.
[76] L. Lewin, "Phase measurements through tapered junctions," *Proc. IEE*, vol. 106, pt. B, pp. 495–496; September, 1959.

5.2. *Measurements of Low-Loss Waveguides*

The attenuation in low-loss guide can be measured accurately by using a convenient length to form a resonant cavity. The Q values involved are of the order of 10^6 and special techniques have been developed to facilitate accurate measurements.

[77] J. A. Young, "Resonant-cavity measurements of circular electric waveguide characteristics," IEE suppl. no. 13 B, pp. 62–65.
[78] A. E. Karbowiak and R. F. Skedd, "Testing of circular waveguides using a resonant cavity method," *ibid.*, pp. 66–70.
[79] D. G. Keith-Wqlker, "An equipment for measuring the attenuation of low-loss waveguide transmission lines," *ibid.*, pp. 71–74.

Special methods have been developed to detect the presence of unwanted modes, and a survey of these has been given. A spinning dipole has been used to obtain a complete field pattern in a cross section of the waveguide.

[80] H. G. Effemey, "A survey of methods used to identify microwave fields or wave modes in cylindrical waveguides," *ibid.*, pp 75–83.
[81] H. M. Barlow & M. G. F. Wilson, "The spinning dipole technique applied to the measurement of waveguide modes," *ibid.*, pp. 84–88.

The magnitudes of the spurious modes exicited by a transducer from a single-mode to a multimode guide have been deduced from impedance measurements in the single-mode guide when the multimode guide is terminated by an adjustable short circuit.

[82] Y. Klinger, "The measurement of spurious modes in overmoded waveguides," *ibid.*, pp. 89–93.

5.3. *Miscellaneous Measurements*

A Hall effect wattmeter has been constructed to operate at a frequency of 4 gc for input powers in the range 30 mw to 20 watts. The semiconductor is mounted in a resonant cavity, less than 3.4 per cent of the incident power being absorbed. The accuracy is ± 3 per cent and is unaffected by the standing-wave ratio of the load, provided it exceeds 0.1.

[83] L. M. Stephenson and H. M. Barlow, "Power measurement at 4 gc by the application of Hall effect in a semiconductor," *Proc. IEE*, vol. 106, pt. B, pp. 27–30; January, 1959.

An incandescent filament lamp has been used as a noise source and is shown to have a higher noise temperature than a discharge tube but the bandwidth of operation is less.

[84] E. W. Collings, "A filament noise source for 3 gc," *Proc. IEE*, vol. 106, pt. B, pp. 97–101; March, 1959.

Phase differences between the side bands of an amplitude-modulated signal are used as the basis of a method for measuring high Q factors (see also [77]–[79]).

[85] F. H. James, "A method for the measurement of very high Q-factors of electromagnetic resonators," *Proc. IEE*, vol. 106, pt. B, pp. 489–491; September, 1959.

Details have been given of the frequency standard which is based on the cesium resonance in X band.

[86] L. Essen, E. G. Hope, and J. V. L. Parry, "Circuits employed in the N.P.L. caesium standard," *Proc. IEE*, vol. 106, pt. B, pp. 240–244; March, 1959.

A frequency standard covering the range 7–20 gc with a short-term stability better than 1 in 10^7 has been provided by multiplication from a 100-kc crystal.

[87] B. H. L. James and M. T. Stockford, "A microwave frequency standard," *Electronic Engrg.*, vol. 31, pp. 2–7, 82–87; January–February, 1959.

Optical techniques of measurement suitable for use at millimeter wavelengths have been surveyed.

[88] A. F. Harvey, "Optical techniques at microwave frequencies," *Proc. IEE*, vol. 106, pt B, pp. 141–157; March, 1959.