microstrip transmission lines—I: Coupled-mode formulation of inhomogeneous lines," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-18, pp. 217–222, Apr. 1970.
[9] L. A. Pipes, "Matrix theory of multiconductor transmission lines," *Phil. Mag.*, vol. 24, pp. 97–113, July 1937.
[10] H. Amemiya, "Time-domain analysis of multiple parallel transmission lines," *RCA Rev.*, vol. 28, pp. 241–276, June 1967.
[11] K. D. Marx, "Propagation modes, equivalent circuits, and characteristic terminations for multiconductor transmission lines with inhomogeneous dielectrics," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-21, pp. 450–457, July 1973.
[12] L. A. Pipes, *Matrix Methods for Engineering*. Englewood Cliffs, N. J.: Prentice-Hall, 1963.
[13] B. J. Orth and R. A. Speciale, "A solution of the coupled-mode equations in terms of redefined even- and odd-mode waves," *Electron. Lett.*, vol. 10, pp. 423–424, Oct. 3, 1974; also ——, "A solution of the coupled-mode equations in terms of redefined even- and odd-mode waves," Tektronix Lab. Rep. 006, July 24, 1974.
[14] R. A. Speciale, "The four-wave treatment of the coupled-line problem," Tektronix Lab. Rep. 004, May 11, 1974.
[15] ——, "S-parameters of the coupled line four port with different line terminations," Tektronix Lab. Rep. 004A, Apr. 11, 1975.
[16] ——, "Wideband, totally coupled directional transformers," in *1975 IEEE S-MTT Int. Microwave Symp. Dig. of Technical Papers* (IEEE Cat. No. 75CH0955-5), pp. 122–124; also ——, "Wideband, totally coupled direction transformers," *IEEE Trans. Microwave Theory Tech.*, to be published.
[17] N. R. Franzen, "A formal method for the inversion of 4 × 4 block matrices," Tektronix Lab. Rep. 005, May 11, 1974.

Annotated Literature Survey of Microwave Ferrite Control Components and Materials for 1968–1974

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(Editors)

***Abstract*—An annotated literature survey covering major development in the area of microwave ferrite control components and material primarily for the 1968–1974 period is presented.**

I-1. INTRODUCTION

AS PART of the responsibility for monitoring the field of microwave ferrite control components and materials the IEEE Microwave Theory and Techniques Society Ferrite Technical Committee (MTT-13) and the IEEE Magnetics Society's Technical Committee on High Frequency Materials have combined their resources to conduct a survey of the most significant papers that have appeared since the publication of the book by Lax and Button [I-1-1] in 1962, the 1968 survey article by Soohoo [I-1-2], and the 1969 book by Fay and Von Aulock [I-1-3]. The time for a new survey appears particularly appropriate in that this field has seen major advances in ferrite components and in materials. The field has matured and has reached a high level of sophistication in component optimization and in materials technology.

The emphasis in this article is on the ferrimagnetic control component and systems utilization of such components, although material aspects are considered also. A companion survey paper [I-1-4] has been published in the May issue of the IEEE TRANSACTIONS ON MAGNETICS. The article published therein has greater emphasis on materials and includes a section by C. E. Patton on the loss mechanisms in ferrimagnetic materials. A further companion paper by Knerr [I-1-5] covers the English language literature on circulators and isolators.

The survey was organized and pursued at joint meetings of the two technical committees with members of these committees accepting responsibility for the major topics. The section on nonlinear ferrite devices and filters was prepared by J. L. Allen, the sections on phase shifters and integrated circuits were contributed by L. R. Whicker, C. R. Boyd, Jr., R. Tang, and R. G. Roberts. P. de Santis and D. M. Bolle collaborated on the section on the edge-guided mode, and R. G. West and L. K. Wilson prepared the section on characterization and material properties of ferrites. The reviews of the foreign literatures were conducted by J. Nicolas and A. Priou (Materials/Devices,

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France), P. de Santis (Materials/Devices, Italy), and N. Ogasawara (Japan). No attempt was made to systematically survey the central and eastern European literature. Such a survey undoubtedly would have been useful but was beyond our capabilities at this time.

During the later part of the 1960's, ferrite component emphasis has been applied to the development of high-performance low-cost latching ferrite phase shifters for use in phased-array antennas. High-quality nonreciprocal and reciprocal phasers have been achieved. Circulator innovations have also occurred. The two major innovations include the development of the ferrite microwave integrated circuit (MIC) circulators and the development of the lumped-constant circulator.

In the materials technology area, the late 1960's and early 1970's have seen advances in the utilization of ferrite materials both at high frequencies, i.e., the nickel–zinc ferrites at K band and beyond, the use of narrow-linewidth garnets at UHF and VHF frequencies. The introduction of lithium–titanium ferrites of microwave quality should also be noted.

[I-1-1] B. Lax and K. L. Button, *Microwave Ferrites and Ferrimagnetics.* New York: McGraw-Hill, 1962.
[I-1-2] R. F. Soohoo, "Microwave ferrite materials and devices," *IEEE Trans. Magn.*, vol. MAG-4, pp. 118–133, June 1968.
[I-1-3] C. E. Fay and W. Von Aulock, *Linear Ferrite Devices.* New York: Academic, 1969.
[I-1-4] D. M. Bolle and L. R. Whicker, Ed., "Annotated literature survey on microwave ferrite materials and devices," *IEEE Trans. Magn.*, vol. MAG-11, pp. 907–926, May 1975.
[I-1-5] R. H. Knerr, "An annotated bibliography of microwave circulators and isolators 1968–1973," *IEEE Trans. Microwave Theory Tech.*, pp. 818–825, Oct. 1974. (This review is restricted to the English language literature only.)

II-1. NONLINEAR FERRITE DEVICES AND YIG FILTERS

[*prepared by J. L. Allen, University of South Florida*]

This section presents some of the principal papers on microwave nonlinear ferrite devices and yttrium iron garnet (YIG) filters for the period 1968–1973 and into 1974. Several important books and reviews have appeared in the literature during the past five years.

[II-1-1] J. Helszajn, *Principles of Microwave Ferrite Engineering.* New York: Wiley-Interscience, 1969.
Also consult [I-1-1], [I-1-2], [V-1-2], and [V-1-4].

II-2. NONLINEAR DEVICES

Much of the recent work on nonlinear ferrite devices has been concerned with YIG sphere-type devices used as limiters and harmonic generators. A good understanding of the basic nonlinear processes in ferrites is essential to the design of all the various types of nonlinear ferrite devices. Several papers are cited dealing with general characteristics of nonlinear effects in ferrite devices.

Device-Oriented Nonlinear Effects

[II-2-1] J. J. Green and F. Sandy, "A catalog of low power loss parameters and high power thresholds of partially magnetized ferrites," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Control Devices for Array Antenna Systems*), vol. MTT-22, pp. 645–651, June 1974.
[II-2-2] C. Borghese, "Longitudinal χ'' of polycrystalline and impurity-doped YIG in strong RF fields," *J. Appl. Phys.*, vol. 44, p. 3746, 1973.
[II-2-3] J. Helszajn and J. McStay, "First-order nonlinear theory in hexagonal ferrites with planar anisotropy under perpendicular pumping," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 437–446, July 1972.
[II-2-4] ——, "Parallel-pumping in hexagonal ferrites with the DC field off the easy plane," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-18, pp. 518–524, Sept. 1970.
[II-2-5] M. Weiner and S. Dixon, Jr., "Subsidiary resonance in planar hexagonal ferrites," *IEEE Trans. Magn.*, vol. MAG-6, pp. 397–399, June 1970.
[II-2-6] S. Dixon, Jr., M. Weiner, and T. R. AuCoin, "Ferromagnetic resonance and nonlinear effects in ferrites with uniaxial anisotropy," *J. Appl. Phys.*, vol. 41, p. 1357, 1970.
[II-2-7] C. Borghese and R. Roveda, "Grain-size average and distribution effects on the magnetic losses and threshold fields in nickel ferrites at microwave frequencies," *J. Appl. Phys.*, vol. 40, p. 4791, 1970.
[II-2-8] C. E. Patton, "Theory for the first-order spin-wave instability threshold in ferromagnetic insulators of ellipsoidal shape with an arbitrary pumping configuration," *J. Appl. Phys.*, vol. 40, p. 2837, 1969.
[II-2-9] C. E. Patton and J. J. Greene, "The first-order spin-wave instability threshold in saturated and partially magnetized spheres, rods, and disks of polycrystalline yttrium iron garnet at 9.1 GHz," *IEEE Trans. Magn.*, vol. MAG-5, pp. 626–631, Sept. 1969.
[II-2-10] D. R. Jackson and R. W. Orth, "Multiple subharmonic generation in YIG," *Proc. IEEE* (Lett.), vol. 57, pp. 1310–1311, July 1969.

Limiters

[II-2-11] S. Dixon, Jr., "Synchronously tuned ferrite power limiter for broad-band systems applications," *IEEE Trans. Magn.*, vol. MAG-9, pp. 529–531, Sept. 1973.
[II-2-12] J. L. Allen, "A compact subsidiary-resonance limiter," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-20, pp. 193–194, Feb. 1972.
[II-2-13] J. L. Carter and J. W. McGowan, "A laminar subsidiary-resonance limiter," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-18, pp. 652–654, Sept. 1970.
[II-2-14] ——, "X-band ferrite-varactor limiter," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-17, pp. 231–232, Apr. 1969.
[II-2-15] R. W. Orth, "Frequency-selective limiters and their applications," *IEEE Trans. Electromagn. Compat.*, vol. EMC-10, pp. 273–283, June 1968.

Harmonic Generation

[II-2-16] F. Bardati, M. Fossari, and G. Gerosa, "Second harmonic generation in ferrites," *Alta Freq.*, vol. 40, p. 147, 1971.
[II-2-17] J. D. Bierlein and P. M. Richards, "Harmonic generation and parametrically coupled spin waves in yttrium iron garnet," *Phys. Rev. B, Solid State I*, p. 4342, 1970.
[II-2-18] I. A. Deryugin, G. A. Milkov, and V. L. Grankin, "Excitation in ferrites of spin waves with the second magnetization harmonic frequency," *Radio Eng. Electron. Phys.*, vol. 15, p. 2281, 1970.

II-3. YIG FILTERS

Small polished samples of single-crystal YIG operated at ferrimagnetic resonance are used as resonators for tunable filters, for tuning oscillators, and for low-level limiters. Papers pertinent to filter applications are cited as follows.

[II-3-1] M. Igarashi and Y. Naito, "Theoretical analysis of magnetic resonance nonreciprocal circuits—Limitations of 3 dB bandwidth and available range," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-22, pp. 821–829, Sept. 1974.
[II-3-2] P. Röschmann, "Compact YIG bandpass filter with finite-pole frequencies for applications in microwave integrated circuits," *IEEE Trans. Microwave Theory Tech.* (Short Papers), vol. MTT-21, pp. 52–57, Jan. 1973.
[II-3-3] M. Igarashi and Y. Naito, "Properties of a four-port nonreciprocal circuit utilizing YIG on stripline—Filter and circulator," *IEEE Trans. Microwave Theory Tech.* (*1972 Symp. Issue*), vol. MTT-20, pp. 828–833, Dec. 1972.
[II-3-4] R. E. Tokheim and G. F. Johnson, "Optimum thermal compensation axes in YIG and GaYIG ferrimagnetic

spheres," *IEEE Trans. Magn.*, vol. MAG-7, pp. 267–276, June 1971.

[II-3-5] H. D. Rüpke, "Magnetodynamic modes in ferrite spheres for microwave filter applications," *IEEE Trans. Magn.*, vol. MAG-6, pp. 80–84, Mar. 1970.

[II-3-6] R. L. Fjerstad, "Some design considerations and realizations of iris-coupled YIG-tuned filters in the 12–40 GHz region," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-18, pp. 205–212, Apr. 1970.

[II-3-7] P. S. Carter, "Equivalent circuit of orthogonal-loop coupled magnetic resonance filters and bandwidth narrowing due to coupling inductance," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-18, pp. 100–105, Feb. 1970.

[II-3-8] J. Helszajn and J. McStay, "External susceptibility tensor of magnetized ferrite ellipsoid in terms of uniform-mode ellipticity," *Proc. Inst. Elec. Eng.*, vol. 116, p. 2088, 1969.

[II-3-9] S. Gaglione and M. Dydyk, "External Q_e of an ellipsoidally shaped ferrimagnetic resonator coupled to strip and microstrip transmission line," *Electron. Lett.*, vol. 25, p. 640, 1969.

[II-3-10] R. Grossbach, "Equivalent circuit for spherical planar-ferrite resonators," *Proc. IEEE* (Lett.), vol. 57, pp. 1236–1238, June 1969.

[II-3-11] ——, "Improved tunable ferrimagnetic filter using a magic-*T*," *Proc. IEEE* (Lett.), vol. 56, pp. 2077–2078, Nov. 1968.

[II-3-12] C. K. Greene, "A microstrip nonreciprocal tunable YIG filter," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Integrated Circuits*), vol. MTT-16, pp. 484–486, July 1968.

III-1. FERRIMAGNETIC PHASE SHIFTERS—AN OVERVIEW

[*prepared by Lawrence R. Whicker*]

During the past ten years need for phased-array antennas for radar, communications, and electronic warfare systems has prompted extensive effort in the development of fast-switching ferrite and diode phase shifters. This effort has resulted in a large number of technical papers describing such work. Some of the types or classes of ferrite-element phase shifters which have received attention include: waveguide nonreciprocal phase shifters, helical phase shifters, reciprocal and nonreciprocal strip-transmission-line phase shifters, microstrip phase shifters, latching Reggia–Spencer phase shifters, and reciprocal dual-mode phase shifters. Examples of such developments are described in [III-1-1]–[III-1-8]. For historical completeness, papers published prior to 1968 have been included. The paper by Blevins *et al.*, although not available in the open literature, has been included as it describes the first major industrial development in waveguide latching ferrite phasers [III-1-8].

For array applications, the waveguide nonreciprocal phaser and the reciprocal dual-mode phaser have proven electrically superior to the other types. General references on ferrite phase shifters are listed in [III-1-9]–[III-1-11]. The present status of ferrite phasers may be assessed by reviewing the June 1974 Special Issue on Microwave Control Devices for Array Antenna Systems of the IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES.

Historical Latching Ferrite Papers

[III-1-1] G. S. Blevins, J. A. Kempic, and R. R. Jones, "*C*-band digital ferrite phase shifter" (Classified Paper), in *1964 Symp. Dig. Electronically Scanned Array Techniques and Applications* [Rome Air Development Center (AF)].

[III-1-2] H. A. Hair, "Development of helical phase shifters," Final Rep. Contract AF19(628)-500, Sub 250, 1964.

[III-1-3] L. R. Whicker and R. R. Jones, "A digital latching ferrite strip transmission line phase shifter," *IEEE Trans. Microwave Theory Tech.* (*1965 Symp. Issue*), vol. MTT-13, pp. 781–784, Nov. 1965.

[III-1-4] J. S. Simons, W. K. Alverson, and J. E. Pippin, "A reciprocal TEM latching ferrite phase shifter," in *1966 G-MTT Symp. Dig.*, p. 241.

[III-1-5] L. R. Whicker, "Recent advances in digital latching ferrite devices," in *1966 IEEE Int. Conf. Rec.*, vol. 14, part 5, p. 49.

[III-1-6] G. T. Roome and H. A. Hair, "Thin ferrite devices for microwave integrated circuits," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Integrated Circuits*), vol. MTT-16, pp. 411–420, July 1968.

[III-1-7] I. Bardash and J. J. Maume, "A waveguide latching ferrite phase shifter," in *1968 G-MTT Symp. Dig.*, p. 274.

[III-1-8] C. R. Boyd, Jr., "A dual-mode latching reciprocal ferrite phase shifter," (*1970 Symp. Issue*), vol. MTT-18, pp. 1119–1124, Dec. 1970.

General Phase Shifter References

[III-1-9] W. J. Ince and D. H. Temme, "Phasers and time delay elements," in *Advances in Microwaves*, vol. 4, Leo Young, Ed. New York: Academic, 1969.

[III-1-10] L. Stark, R. W. Burns, and W. P. Clark, "Phase shifters for arrays," in *Radar Handbook*, M. Skolnik, Ed. New York: McGraw-Hill, 1970.

[III-1-11] L. R. Whicker, Ed., "Ferrite phasers and ferrite MIC components," in *Ferrite Control Components*, vol. 2. Dedham, Mass.: Artech Hse., 1974.

III-2. NONRECIPROCAL, TOROIDAL WAVEGUIDE PHASE SHIFTERS

[*prepared by Lawrence R. Whicker*]

As indicated in Section III-1, the nonreciprocal, toroidal waveguide phase shifter has proven to be one of the two types currently employed in phased-array developments. Historically, this type of phaser was first reported by Trenhaft and Silber in 1958. The early efforts were largely overlooked by the technical community for several years. Blevins *et al.* report on possibly the first industrially fabricated latching phase shifter.

In the mid-1960's several key papers dealing with the design relationship for toroidal phasers were published. These papers provide the basis for most present toroidal phaser designs. Experimental papers have appeared also which trace the development, optimization, and production of the toroidal phaser.

As the major experimental and analytical developments in this area have occurred just before the 1968–1974 time period, this section has been organized somewhat differently than the proceeding sections and attempts to point out some key papers over a longer time span. Three references on the behavior of partially magnetized ferrites are included for convenience as the results reported in these papers are used directly in the phaser designs.

Two references representative of switching considerations are included at the end of this section. These references describe partial switching techniques and the theory of "flux drive" circuits for providing phase shifter control.

Early Papers

[III-2-1] M. A. Treuhaft and L. M. Silber, "Use of microwave ferrite toroids to eliminate external magnets and reduce switching power," *Proc. IRE*, vol. 46, p. 1538, Aug. 1958.

[III-2-2] L. Levy and L. M. Silber, "A fast-switching *X*-band circulator utilizing ferrite toroids," in *1964 WESCON Conv. Rec.*, part 1, p. 11.

[III-2-3] L. M. Silber and A. Weis, "A fast switching high power *C*-band ferrite circulator," in *1964 IEEE Int. Conf. Rec.*, part 2, p. 32.

[III-2-4] G. S. Blevins, J. A. Kempic, and R. R. Jones, "C-band digital ferrite phase shifter" (Classified Paper), in *1964 Symp. Dig. Electronically Scanned Array Techniques and Applications* [Rome Air Development Center (AF)].

Analytical Papers

[III-2-5] E. Schlömann, "Theoretical analysis of twin-slab phase shifters in rectangular waveguide," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-14, pp. 15–23, Jan. 1966.

[III-2-6] W. P. Clark, K. H. Hering, and D. A. Charlton, "TE-mode solutions for partially ferrite filled rectangular waveguide using *ABCD* matrices," in *1966 IEEE Int. Conv. Rec.*, part 5, vol. 14, p. 39.

[III-2-7] W. J. Ince and E. Stern, "Nonreciprocal remanence phase shifters in rectangular waveguide," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-15, pp. 87–95, Feb. 1967.

[III-2-8] G. Klein, "Transient thermal behavior of latching ferrite phase shifters," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-15, pp. 429–430, July 1967.

[III-2-9] G. N. Tsandoulas, D. H. Temme, and F. G. Willwerth, "Longitudinal section mode analysis of dielectrically loaded rectangular waveguides with application to phase shifter design," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-18, pp. 88–95, Feb. 1970.

Experimental Papers

[III-2-10] J. A. Kempic and R. R. Jones, "A temperature stable high power C-band digital phase shifter," in *1965 IEEE NEREM Rec.*, p. 12.

[III-2-11] L. Dubrowsky, G. Kern, and G. Klein, "A high power X-band latching digital ferrite phase shifter for phased array application," in *1965 IEEE NEREM Rec.*, p. 214.

[III-2-12] R. R. Jones and J. A. Kempic, "Switching energy of a microwave polycrystalline ferrimagnetic toroid," in *1965 Proc. Nat. Electron. Conf.*, vol. 21, p. 1.

[III-2-13] L. R. Whicker, "Recent advances in digital latching ferrite devices," in *1966 IEEE Int. Conv. Rec.*, part 5, vol. 14, p. 49.

[III-2-14] J. K. Parks, B. R. Savage, L. J. Lavedan, Jr., and J. Brown, Jr., "A miniaturized C-band digital latching phase shifter," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-14, pp. 688–694, Dec. 1966.

[III-2-15] J. E. Degenford, L. R. Whicker, and E. Wantuch, "Millimeter wavelength latching ferrite phase shifters," in *1967 IEEE NEREM Rec.*, p. 60.

[III-2-16] E. Stern and W. J. Ince, "Design of composite magnetic circuits for temperature stabilization of microwave ferrite devices," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-15, pp. 295–300, May 1967.

[III-2-17] G. P. Rodrigue, J. L. Allen, L. J. Lavedan, and D. R. Taft, "Operating dynamics and performance limitations of ferrite digital phase shifters," *IEEE Trans. Microwave Theory Tech.* (*1967 Symp. Issue*), vol. MTT-15, pp. 709–713, Dec. 1967.

[III-2-18] R. A. Stern and J. P. Agrios, "A 500 kW X-band air-cooled ferrite latching switch," *IEEE Trans. Microwave Theory Tech.* (*1968 Symp. Issue*), vol. MTT-16, pp. 1034–1937, Dec. 1968.

[III-2-19] W. J. Ince, D. H. Temme, and F. G. Willwerth, "Toroid corner chamfering as a method of improving the figure of merit of latching ferrite phasers," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-19, pp. 563–564, June 1971.

[III-2-20] K. H. Hering, "A novel design of an X-band high-power ferrite phase shifter," *IEEE Trans. Microwave Theory Tech.* (Short Papers), vol. MTT-20, pp. 284–286, Apr. 1972.

[III-2-21] D. A. Charlton, "A low cost lithium ferrite phase shifter," in *1973 Int. Microwave Symp. Dif.*, p. 98.

[III-2-22] N. R. Landry, H. C. Goodrich, H. F. Inacker, and L. J. Lavedan, Jr., "Practical aspects of phase-shifter and driver design for a tactical multifunction phased-array radar system," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Control Devices for Array Antenna Systems*), vol. MTT-22, pp. 617–626, June 1974.

Partially Magnetized Materials

[III-2-23] E. Schlömann, "Microwave behavior of partially magnetized ferrites," *J. Appl. Phys.*, vol. 41, p. 204, 1970.

[III-2-24] J. J. Green and F. Sandy, "Microwave characterization of partially magnetized ferrites," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Control Devices for Array Antenna Systems*), vol. MTT-22, pp. 641–645, June 1974.

[III-2-25] ——, "A catalog of low power loss parameters and high power thresholds for partially magnetized ferrites," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Control Devices for Array Antenna Systems*), vol. MTT-22, pp. 645–651, June 1974.

Switching Techniques

[III-2-26] L. R. Whicker and R. R. Jones, "A digital current controlled latching ferrite phase shifter," in *1965 IEEE Int. Conv. Rec.*, part 5, p. 217.

[III-2-27] J. DiBartolo, W. J. Ince, and D. H. Temme, "A solid-state 'flux-drive' control circuit for latching ferrite-phaser applications," *Microwave J.*, vol. 15, p. 59, 1972.

III-3. RECIPROCAL PHASE SHIFTS

[*prepared by C. R. Boyd, Magnetics Applications Group, and Lawrence R. Whicker*]

Dual-Mode Phase Shifters

Although Faraday rotation phasers were described in the early ferrite literature, work on the present dual-mode configuration has been conducted largely in the last five years. Dual-mode phasers are Faraday rotation devices in which linearly polarized energy in a rectangular waveguide is converted to either left- or right-circularly polarized energy in fully loaded square or circular waveguide. The energy is phase shifted and then reconverted to linear polarization in a rectangular waveguide.

The design and operation of the dual-mode phaser is described in the references listed in this section. In general, dual-mode phasers are both performance and price competitive with toroidal, nonreciprocal phasers. They present an attractive alternative to the system design.

[III-3-1] C. R. Boyd, Jr., "Comments on the design and manufacture of dual-mode reciprocal latching ferrite phase shifters," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Control Devices for Array Antenna Systems*), vol. MTT-22, pp. 593–601, June 1974.

[III-3-2] A. M. Duputz and A. C. Priou, "Computer analysis of microwave propagation in ferrite loaded circular waveguide—Optimization of phase-shifter longitudinal field sections," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Control Devices for Array Antenna Systems*), vol. MTT-22, pp. 601–713, June 1974.

[III-3-3] W. E. Hord, F. J. Rosenbaum, and J. A. Benet, "Theory and operation of a reciprocal Faraday-rotation phase shifter," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 112–119, Feb. 1962.

[III-3-4] L. R. Whicker, "A comparison of two classes of ferrite phasers for use in phased arrays," in *1971 Proc. European Microwave Conf.*, Paper B/14, 4:1.

[III-3-5] L. R. Whicker and C. R. Boyd, Jr., "A new reciprocal phaser for use at millimeter wavelengths," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-19, pp. 944–945, Dec. 1971.

[III-3-6] R. G. Roberts, "An X-band reciprocal latching Faraday rotator phase shifter," in *1970 IEEE G-MTT Int. Symp. Dig.*, p. 341.

[III-3-7] C. R. Boyd, Jr., L. R. Whicker, and R. W. Jansen, "Study of insertion-phase variation in a class of ferrite phasers," *IEEE Trans. Microwave Theory Tech.* (*1970 Symp. Issue*), vol. MTT-18, pp. 1984–1089, Dec. 1970.

[III-3-8] C. R. Boyd, Jr., "A dual-mode latching reciprocal ferrite phase shifter," *IEEE Trans. Microwave Theory Tech.* (*1970 Symp. Issue*), vol. MTT-18, pp. 1119–1124, Dec. 1970.

[III-3-9] W. E. Hord, C. R. Boyd, Jr., and F. J. Rosenbaum, "Application of reciprocal latching ferrite phase shifters to lightweight electronic scanned phased arrays," *Proc. IEEE* (*Special Issue on Electronic Scanning*), vol. 56, pp. 1931–1939, Nov. 1968.

[III-3-10] W. E. Hord and F. J. Rosenbaum, "Propagation in a longitudinally magnetized ferrite-filled square waveguide," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-16, pp. 967–968, Nov. 1968.

Reggia–Spencer Phase Shifters

The Reggia–Spencer phase shifter has received little attention since 1968. Since this class of phaser has found considerable system usage, a few selected references are included in this section which trace the development and utilization of this phaser. Currently, Reggia–Spencer phasers are not performance competitive with dual-mode phasers.

[III-3-11] D. Bush, "Discussion on microwave apparatus," *Proc. Inst. Elec. Eng.*, vol. 104-B, suppl. 6, p. 368, 1957.

[III-3-12] 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, Nov. 1957.

[III-3-13] J. A. Weiss, "A phenomenological theory of the Reggia–Spencer phase shifter," *Proc. IRE*, pp. 1130–1137, June 1959.

[III-3-14] F. Reggia, "A new broad-band absorption modulator for rapid switching of microwave power," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-9, pp. 343–349, July 1961.

[III-3-15] W. P. Clark, "A high power phase shifter for phased-array systems," *IEEE Trans. Microwave Theory Tech.* (*1965 Symp. Issue*), vol. MTT-13, pp. 785–788, Nov. 1965.

[III-3-16] F. Reggia and T. Mak, "Reciprocal latching phase modulator for microwave frequencies," *IEEE Trans. Magn.* (*1966 INTERMAG Issue*), vol. MAG-2, pp. 269–273, Sept. 1966.

[III-3-17] W. E. Hord, F. J. Rosenbaum, and C. R. Boyd, Jr., "Theory of the suppressed-rotation reciprocal ferrite phase shifter," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-16, pp. 902–910, Nov. 1968.

[III-3-18] I. Bardash and J. J. Maune, "A waveguide reciprocal latching ferrite phase shifter," in *1968 IEEE G-MTT Int. Microwave Symp. Dig.*, p. 274.

III-4. HIGH-POWER PHASERS

[prepared by R. Tang, R. G. Roberts, Hughes Aircraft Company, Fullerton, Calif., and Lawrence R. Whicker]

Both reciprocal and nonreciprocal phasers which operate at high-peak- and high-average-power levels require special consideration in their design. The peak-power capacity of a phaser is determined by its cross-sectional geometry and various material properties such as saturation moment, gain size, and rare-earth doping. The average-power capacity is determined primarily by the geometry and loss tangent of the ferrimagnetic material used. An efficient thermal design with liquid cooling is required for phasers operating a power greater than a few hundred watts. The references listed in this section describe such designs and related materials problems.

[III-4-1] J. J. Green and F. Sandy, "A catalog of low power loss parameters and high power thresholds for partially magnetized ferrites," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Control Devices for Array Antenna Systems*), vol. MTT-22, pp. 645–651, June 1974.

[III-4-2] R. A. Moore, G. M. Kern, and L. F. Cooper, "High average power *S*-band digital phase shifter," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Control Devices for Array Antenna Systems*), vol. 22, pp. 626–634, June 1974.

[III-4-3] C. R. Boyd, Jr., and G. Klein, "A precision analog duplexing phase shifter," in *1972 G-MTT Int. Microwave Symp. Dig.*, p. 248.

[III-4-4] C. R. Boyd, Jr., L. R. Whicker, and R. W. Jansen, "Study of insertion-phase variation in a class of ferrite phasers," *IEEE Trans. Microwave Theory Tech.* (*1970 Symp. Issue*), vol. MTT-18, pp. 1084–1089, Dec. 1970.

[III-4-5] W. J. Ince, "The use of manganese doped iron garnets and high dielectric constant loading for microwave latching ferrite phasers," in *1970 IEEE G-MTT Int. Microwave Symp. Dig.*, p. 327, 1970.

[III-4-6] R. A. Stern and J. P. Agrios, "A 500 kW *X*-band air-cooled ferrite latching switch," *IEEE Trans. Microwave Theory Tech.* (*1968 Symp. Issue*), vol. MTT-16, pp. 1034–1037, Dec. 1968.

[III-4-7] G. P. Rodrigue, J. L. Allen, L. J. Lavedan, and D. R. Taft, "Operating dynamics and performance limitations of ferrite digital phase shifters," *IEEE Trans. Microwave Theory Tech.* (*1967 Symp. Issue*), vol. MTT-15, pp. 709–713, Dec. 1967.

III-5. OTHER PHASER GEOMETRIES

[prepared by Lawrence R. Whicker]

In attempting to find high-performance low-cost phaser elements for use in phased-array antennas, numerous phaser configurations have been investigated. Some of the more interesting references are listed in this section.

TEM Phasers

In this group, references are listed dealing with latching reciprocal and nonreciprocal strip-transmission-line phasers, helical phasers, slow-wave phasers, and an analog strip-transmission-line phaser.

[III-5-1] L. R. Whicker and R. R. Jones, "A digital latching ferrite strip transmission line phase shifter," *IEEE Trans. Microwave Theory Tech.* (*1965 Symp. Issue*), vol. MTT-13, pp. 781–784, Nov. 1965.

[III-5-2] R. Seckelmann, "Phase-shift characteristics of helical phase shifters," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-14, pp. 24–28, Jan. 1966.

[III-5-3] J. W. Simon, W. K. Alverson, and J. E. Pippin, "A reciprocal TEM latching ferrite phase shifter," in *1966 IEEE G-MTT Int. Symp. Dig.*, p. 241.

[III-5-4] R. R. Jones, "A slow wave digital ferrite strip transmission line phase shifter," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-14, pp. 684–688, Dec. 1966.

[III-5-5] T. Nelson *et al.*, "Small analog stripline *X*-band ferrite phase shifter," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. MTT-18, pp. 45–46, Jan. 1970.

Circular Polarized Phaser

A single reference is included here which describes a polarization-insensitive phaser. This phaser is closely related to the dual-mode phaser.

[III-5-6] M. C. Mohr and S. Monaghan, "Circularly-polarized phase shifter for use in phased array antennas," *IEEE Trans. Microwave Theory Tech.* (*1966 Symp. Issue*), vol. MTT-14, pp. 672–683, Dec. 1966.

Periodic Loading

Two references are included which describe the application of periodic loading in fabricating a group of ferrite nonreciprocal phasers.

[III-5-7] W. G. Spaulding, "The application of periodic loading to a ferrite phase shifter design," *IEEE Trans. Microwave Theory Tech.* (*1971 Symp. Issue*), vol. MTT-19, pp. 922–928, Dec. 1971.

[III-5-8] M. M. Z. Kharadly, "Periodically loaded non-reciprocal transmission lines for phase-shifter applications," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Control Devices for Array Antenna Systems*), vol. MTT-22, pp. 635–640, June 1974.

Fox Phasers

Two references are included which describe precision analog phase shifters. These phasers use construction techniques similar to dual-mode phasers.

[III-5-9] C. R. Boyd, Jr., "An accurate analog ferrite phase shifter," in *1971 G-MTT Int. Microwave Symp. Dig.*, p. 104.

[III-5-10] C. R. Boyd, Jr. and G. Klein, "A precision analog duplexing phase shifter," in *1972 Proc. G-MTT Int. Microwave Symp.*, p. 248.

III-6. FERRITE MICROWAVE INTEGRATED CIRCUITS

[*prepared by Lawrence R. Whicker*]

In this section, references describing microwave circuit functions formed on planar ferrimagnetic substrates are described. Four of the references are concerned with the performance of microstrip and slot-line circuits. Two additional references by Pucel and Massé provide means for accurately predicting the propagation characteristics for such circuits. Ferrite MIC circulators are covered in the companion paper by Knerr. To date, the performance of ferrite MIC components other than circulators has not been good when compared to waveguide components.

[III-6-1] F. J. Rosenbaum, "Integrated ferrimagnetic devices," in *Advances in Microwaves*, vol. 8, H. Sobol, Ed. New York: Academic, 1974, pp. 203–294.
[III-6-2] R. A. Pucel and D. J. Massé, "Microstrip propagation on magnetic substrates—Part I: Design theory," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 304–308, May 1972.
D. J. Massé and R. A. Pucel, "Microstrip propagation on magnetic substrates—Part II: Experiment," *ibid.*, vol. MTT-20, pp. 309–313, May 1972.
[III-6-3] G. R. Harrison, G. H. Robinson, B. R. Savage, and D. R. Taft, "Ferrimagnetic parts for microwave integrated circuits," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Integrated Circuits*), vol. MTT-19, pp. 577–588, July 1971.
[III-6-4] G. J. Buck, "Ferrite microstrip phase shifters with transverse and longitudinal magnetization," *IEEE Trans. Microwave Theory Tech.* (Corresp.), vol. 18, pp. 1170–1173, Dec. 1970.
[III-6-5] G. H. Robinson and J. L. Allen, "Slot line application to miniature ferrite devices," *IEEE Trans. Microwave Theory Tech.* (*1969 Symp. Issue*), vol. MTT-17, pp. 1097–1101, Dec. 1969.
[III-6-6] G. T. Roome and H. A. Hair, "Thin ferrite devices for microwave integrated circuits," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Integrated Circuits*), vol. MTT-16, pp. 411–420, July 1968.

IV-1. THE EDGE-GUIDED MODE

[*prepared by Pietro de Santis, University of Naples, Naples, Italy, and Donald M. Bolle*]

Devices were introduced in the period 1969–1971 which utilized the field displacement effect on planar geometries. Although this particular modal configuration on microstrip structures has not as yet led to extensive application, nevertheless, the inherent promise of broad-band operation and the increasing interest in devices using this edge-guided or peripheral mode have prompted the inclusion of the pertinent literature in this survey.

[IV-1-1] Y. S. Wu and F. J. Rosenbaum, "Wide band operation of microstrip circulators," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-22, pp. 849–856, Oct. 1974.
[IV-1-2] K. Araki, T. Koyoma, and Y. Naito, "A new type isolator using the edge-guided mode," *IEEE Trans. Microwave Theory Tech.* (Lett.), vol. MTT-23, p. 321, Mar. 1975.
[IV-1-3] P. de Santis, "Edge guided modes in ferrite microstrip with curved edges," *Appl. Phys.*, vol. 4, p. 167, 1974.
[IV-1-4] L Courtois, N. Bernard, B. Chiron, and G. Forterre, "A new edge mode isolator in the U.H.F. range," in *1974 IEEE S-MTT Int. Symp. Dig.* (Atlanta, Ga.).
[IV-1-5] L. Courtois, B. Chiron, and G. Forterre, "Propagation dans une lame de ferrite aimantée: Application a de nouveaux dispositifs nonreciproques à large bande," *Cables Telecommun.*, no. 4, p. 417, 1973.
[IV-1-6] P. de Santis, "Dispersion characteristics for a ferrimagnetic plate," *Appl. Phys.*, vol. 2, p. 197, 1973.
[IV-1-7] L. Courtois, "Propagation oblique les ondes electromagnetiques dans une lame de ferrite aimantée parallelement a ses faces," *Electron. Fis. Apl.*, vol. 16, p. 286, 1973.
[IV-1-8] G. Cortucci and P. de Santis, "Edge-guided waves in lossy ferrite microstrips," in *1973 Proc. European Microwave Conf.* (Brussels), vol. 2, p. B.9.
[IV-1-9] J. Puhhaubert, "Visualisation des ondes electromagnetiques hyperfrequence à l'aide des cristaux liquides," *Onde Elec.*, vol. 52, p. 213, 1972.
[IV-1-10] M. E. Hines, "Ferrite transmission devices using the edge-guided mode of propagation," in *Proc. 1972 IEEE G-MTT, Int. Microwave Symp.* (Chicago, Ill.), p. 236.
[IV-1-11] P. de Santis and F. Pucci, "Experiments on the optimization of a novel M.I.C. symmetrical three-port circulator," in *1972 IEEE G-MTT Int. Microwave Symp. Dig.* (Chicago, Ill.), p. 238.
[IV-1-12] M. Blanc, L. Dusson, and J. Guidevaux, "Études de dispositifs nonreciproques a ferrite à très large bande: Premiers realizations," *Rev. Tech. Thomson-CSF*, vol. 4, p. 27, 1972.
[IV-1-13] ——, "Etude de la fonction isolation à tres large bande utilisant des materiaux ferrites," in *Dig. 1ière Seminaire Int. Dispositifs Hyperfrequences à Ferrite* (Toulouse, France, 1972), p. 27.
[IV-1-14] B. Chiron and G. Forterre, "Emploi des modes de surface electromagnetiques pour la realization de dispositifs gyromagnetiques à très grande largeur de bandes," in *Dig. 1ière Seminaire Int. Dispositifs Hyperfrequences à Ferrite* (Toulouse, France, 1972), p. 27.
[IV-1-15] P. de Santis and F. Pucci, "Novel type of M.I.C. symmetrical three-port circulator," *Electron. Lett.*, vol. 8, p. 12, 1972.
[IV-1-16] L. Courtois, G. Declerq, and M. Peurichard, "On the nonreciprocal aspect of gyromagnetic surface waves," in *1972 Proc. 7th Annu. Conf. Magnetism and Magnetic Materials—Part 2* (Chicago, Ill.), p. 1541.
[IV-1-17] B. Chiron, G. Forterre, and C. Rannlu, "Nouveaux dispositifs nonreciproques à très grande largeur de bande utilisant des ondes de surface électromagnetiques," *Onde Elec.*, vol. 51, p. 816, 1971.
[IV-1-18] P. de Santis and R. Roveda, "Magnetodynamic boundary waves," in *1971 Proc. European Microwave Conf.* (Stockholm), C5/2:1.
[IV-1-19] M. E. Hines, "Reciprocal and nonreciprocal modes of propagation in ferrite stripline and microstrip devices," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-19, pp. 442–451, May 1971.
[IV-1-20] ——, "Ferrite phase shifters and multiport circulators in microstrip and stripline," in *1971 IEEE Int. Microwave Theory Tech. Microwave Symp. Dig.*, pp. 108–109.
[IV-1-21] R. Anderson, "Gyromagnetic device having a plurality of outwardly narrowing tapering members," U. S. Patent 3 555 459, Jan. 12, 1971.
[IV-1-22] M. E. Hines, "A new microstrip isolator and its application to distributed diode amplification," in *1970 IEEE Int. G-MTT Microwave Symp. Dig.* (Newport Beach, Calif.), p. 304.
[IV-1-23] "Peripheral mode isolator operates from 3.5 to 11 GHz," *Microwaves*, vol. 8, p. 64, 1969.

V-1. CHARACTERISTICS AND MATERIAL PROPERTIES OF FERRITES

[*prepared by R. G. West, Trans-Tech, Inc., Gaithersburg, Md., and Larry K. Wilson, Department of Electrical Engineering, Vanderbilt University, Nashville, Tenn.*]

During the past five years there have been several review papers that have appeared in the literature and a number of books on the characteristics and material properties of ferrites. Some of the more comprehensive or general works are cited as follows.

[V-1-1] J. Nicolas, A. LaGrange, R. Sroussi, and R.-L. Inglebert, "Some recent problems in the field of microwave ferrites," *IEEE Trans. Magn.*, vol. MAG-9, pp. 546–551, Sept. 1973.
[V-1-2] N. Ogasawara, "Device-oriented review of recent Japanese developments in magnetic materials for gyromagnetic

applications," *IEEE Trans. Magn.*, vol. MAG-9, pp. 538–545, Sept. 1973.
[V-1-3] M. Sugimoto, "Recent advancement in the field of high frequency ferrites," in *1972 AIP Conf. Proc.*, no. 10, pp. 1335–1349.
[V-1-4] E. E. Riches, *Ferrites: A review of materials and applications.* London, England: Mills and Boon, 1972.
[V-1-5] K. J. Standley, *Oxide Magnetic Materials*, 2nd ed. New York: Oxford, 1972.
[V-1-6] Y. Hoshino, S. Lida, and M. Sugimoto, Ed., *Ferrites.* Baltimore, Md.: University Park Press, 1971 (*Proc. Int. Conf. Ferrites*, Kyoto, Japan, 1971).
[V-1-7] J. Smit, Ed., *Magnetic Properties of Materials.* New York: McGraw-Hill, 1971.
[V-1-8] G. P. Rodrigue, "Magnetism in microwave devices," *J. Appl. Phys.*, vol. 40, pp. 929–937, Mar. 1969.
[V-1-9] E. C. Snelling, *Soft Ferrites: Properties and Applications.* London, England: Iliffe, 1969.
[V-1-10] W. J. Ince and D. H. Temme, "Phasers and time delay elements," in *Advances in Microwaves*, vol. 4, L. Young, Ed. New York: Academic, 1969, pp. 2–183.

V-2. MAGNETOSTATIC SURFACE WAVES

In 1961 Damon and Eshback predicted the propagation of magnetic surface waves in ferrite slabs. During the past five years several investigators have demonstrated the existence of these waves and have sought to apply this phenomenon to microwave delay lines and other applications.

[V-2-1] J. D. Adam, J. M. Owens, and J. H. Collins, "Studies of FMR linewidth in thick YIG films grown by liquid phase epitaxy," in *1973 Proc. AIP Conf. Proc.*, vol. 18, pp. 1279–1283.
[V-2-2] J. C. Sethares and M. R. Stiglitz, "Propagation loss and MSSW delay lines," *IEEE Trans. Magn.*, vol. MAG-10, pp. 787–790, Sept. 1974.
[V-2-3] J. D. Adam, J. M. Owens, and J. H. Collins, "Magnetostatic delay lines for group delay equalisation in millimetric waveguide communication systems," *IEEE Trans. Magn.*, vol. MAG-10, pp. 783–786, Sept. 1974.
[V-2-4] C. Vittoria and N. D. Wilsey, "Magnetostatic wave propagation losses in an anisotropic insulator," *J. Appl. Phys.*, vol. 45, pp. 414–420, Jan. 1974.
[V-2-5] A. K. Ganguly and C. Vittoria, "Magnetostatic wave propagation in double layers of magnetically anisotropic slabs," *J. Appl. Phys.*, vol. 45, pp. 4665–4667, Oct. 1974.
[V-2-6] J. B. Merry and J. C. Sethares, "Low loss magnetostatic surface waves at frequencies up to 15 GHz," *IEEE Trans. Magn.*, vol. MAG-9, pp. 527–529, Sept. 1973.
[V-2-7] W. L. Bongianni, "Magnetic wave devices for microwave applications," in *1973 Proc. AIP Conf.*, vol. 18, pp. 1005–1014.
[V-2-8] N. D. Wilsey and C. Vittoria, "Magnetic wave propagation in YIG and lithium ferrite slabs," in *1973 Proc. AIP Conf.*, vol. 18, p. 1278.
[V-2-9] D. F. Vaslow, "Group delay time for the surface wave on a YIG film backed by a grounded dielectric slab," *Proc. IEEE* (Lett.), vol. 61, pp. 142–143, Jan. 1973.
[V-2-10] N. D. Wilsey, C. Vittoria, and H. Lessoff, "Anisotropic excitations of magnetostatic modes in thin film disks," *Solid State Commun.*, vol. 10, p. 859, 1972.
[V-2-11] C. Vittoria, H. Lessoff, and N. D. Wilsey, "Induced inplane magnetic anisotropy in YIG films," *IEEE Trans. Magn.* (*1972 INTERMAG Conf.*), vol. MAG-8, pp. 273–275, Sept. 1972.
[V-2-12] W. L. Bongianni, "Magnetostatic propagation in a dielectric layered structure," *J. Appl. Phys.*, vol. 43, p. 2541, 1972.
[V-2-13] S. R. Seshadri, "Surface magnetostatic modes of a ferrite slab," *Proc. IEEE* (Lett.), vol. 58, pp. 506–507, Mar. 1970.
[V-2-14] W. L. Bongianni, J. H. Collins, F. A. Pizzarello, and D. A. Wilson, "Propagating magnetic waves in epitaxial YIG," *in 1969 Proc. IEEE G-MTT Int. Microwave Symp. D.*, pp. 376–380.

V-3. HEXAGONAL FERRITES

The increased utilization of millimeter wavelengths has continued to motivate work on hexagonal ferrites. The ability to obtain technically useful resonance-type device action at millimeter wavelengths with this class of ferrites, without large dc magnetic biasing fields, is the main feature of engineering interest.

[V-3-1] J. S. Reed and R. M. Fulrath, "Characterization and sintering behavior of Ba and Sr ferrites," *J. Amer. Ceram. Soc.*, vol. 56, pp. 207–211, Apr. 1973.
[V-3-2] J. P. Mahoney, A. Tauber, and R. O. Savage, "Low temperature magnetic properties in $BaFe_{12-x-y-z}An_xTi_yMn_zO_{19}$," in *1972 Proc. AIP Conf.*, no. 10, pp. 159–163.
[V-3-3] S. Dixon, Jr., T. R. AuCoin, and R. O. Savage, "Microwave resonance linewidths in substituted single-crystal barium ferrite," *J. Appl. Phys.*, vol. 42, pp. 1732–1733, Mar. 15, 1972.
[V-3-4] A. Tauber, R. O. Savage, Jr., and M. D. Grebenau, "Magnetic properties of a unique 18-layer hexagonal ferrite," *J. Appl. Phys.*, vol. 42, pp. 1738–1740, Mar. 15, 1971.
[V-3-5] ——, "Magnetic properties of single crystal $Ba_5Me_2Ti_3Fe_{12}O_{31}$, Me = Co,Du," in *1971 Proc. AIP Conf.*, no. 5, pp. 1547–1551.
[V-3-6] S. Dixon, Jr., M. Weiner, and T. R. AuCoin, "Ferromagnetic resonance and nonlinear effects in ferrites with uniaxial anisotropy," *J. Appl. Phys.*, vol. 41, pp. 1357–1358, Mar. 1970.
[V-3-7] A. Tauber, J. S. Megill, and J. R. Shappirio, "Magnetic properties of $Ba_2Zn_2Fe_{28}O_{46}$ and $Ba_2Co_2Fe_{28}O_{46}$ single crystals," *J. Appl. Phys.*, vol. 41, pp. 1353–1354, Mar. 1970.
[V-3-8] A. J. Kerecman, T. R. AuCoin, and W. P. Dattilo, "Ferromagnetic resonance in $Ba_4Zn_2Fe_{36}O_{60}$ (ZnU) and Mn-substituted ZnU single crystals," *J. Appl. Phys.*, vol. 40, pp. 1416–1417, Mar. 1969.
[V-3-9] A. J. Kerecman, A. Tauber, T. R. AuCoin, and R. O. Savage, "Magnetic properties of $Ba_4Zn_2Fe_{36}O_{60}$ single crystals," *J. Appl. Phys.*, vol. 39, pp. 726–727, Feb. 1968.

V-4. ION-SUBSTITUTION EFFECTS

Studies of rare-earth, manganese, and cobalt substitutions in YIG have been directed toward reducing the magnetostrictive effects in garnet materials and tailoring their peak power-handling capacity (spin-wave linewidth) for specific device application. Controlled rare-earth and cobalt-ion substitutions yield materials with predictable spin-wave linewidths. Manganese-ion substitutions have been found to reduce the magnetostriction and "square up" the hysteresis loop of YIG. These effects are particularly important in ferrite phase-shifter applications.

[V-4-1] J. J. Green and F. Sandy, "A catalog of low power loss parameters and high power thresholds of partially magnetized ferrites," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Control Devices for Array Antenna Systems*), vol. MTT-22, pp. 645–651, June 1974.
[V-4-2] R. L. Inglebert and J. Nicolas, "Relaxation of rare earth and cobalt ions in polycrystalline yttrium iron garnet," *IEEE Trans. Magn.*, vol. MAG-10, pp. 610–612, Sept. 1974.
[V-4-3] D. G. Scotter, "Wave-vector dependence of rare-earth relaxation in yttrium iron garnet," *J. Appl. Phys.*, vol. 43, pp. 4813–4816, Nov. 1972.
[V-4-4] G. F. Dionne and R. G. West, "Interpretation of rare earth ion effects on spin wave linewidths of iron garnets," in *1972 Proc. AIP Conf.*, no. 10, pp. 169–173.
[V-4-5] D. G. Scotter, "Effect of nonmagnetic inclusions on the spin-wave linewidth in polycrystalline YIG," *J. Appl. Phys.*, vol. 42, pp. 4088–4090, Sept. 1971.
[V-4-6] C. Borghese and R. Roveda, "Independent grain behavior of parametrically excited $\pi/2$ magnons in polycrystalline YIG," *Appl. Phys. Lett.*, vol. 19, pp. 156–158, Sept. 1971.
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[V-4-8] J. Nicolas, A. LaGrange, and R. Sroussi, "Some interesting properties of polycrystalline garnets containing Co^{2+} ions," *IEEE Trans. Magn.*, vol. MAG-6, pp. 608–610, Sept. 1970.
[V-4-9] C. E. Patton, "Microwave properties of fine grain poly crystalline yttrium iron garnet," *J. Appl. Phys.*, vol. 41, pp. 1355–1356, Mar. 1970.
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under oblique pumping," *J. Appl. Phys.*, vol. 40, pp. 172–177, Jan. 1969.

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[V-4-13] P. Hansen, J. Schuldt, and W. Tolksdorf, "Anisotropy and magnetostriction of iridium-substituted yttrium iron garnet," *Phys. Rev. B*, vol. 8, pp. 4274–4287, Nov. 1973.

[V-4-14] R. T. Lynch, Jr., J. F. Dillon, Jr., and L. G. Van Vitert, "Stress birefringence in ferrimagnetic garnet," *J. Appl. Phys.*, vol. 44, pp. 225–229, Jan. 1973.

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[V-4-16] G. F. Dionne, "Temperature and stress sensitivities of microwave ferrites," *IEEE Trans. Magn.*, vol. MAG-8, pp. 439–443, Sept. 1972.

[V-4-17] G. F. Dionne and J. B. Goodenough, "Effects of Co^{2+} and Mn^{3+} ion substitutions on the anisotropy and magnetostriction constants of $Y_3Fe_5O_{12}$," *Mater. Res. Bull.*, vol. 7, pp. 749–760, 1972.

[V-4-18] D. R. Mach, "Magnetostriction in silicon- and calcium-doped yttrium iron garnet," Master's thesis, Univ. Southern Calif., Los Angeles, 1972.

[V-4-19] G. F. Dionne, "On the origin of magnetic inhomogeneity in $Ca_2^{2+}V^5$-substituted garnets," *Mater. Res. Bull.*, vol. 7, pp. 1393–1401, Dec. 1972.

[V-4-20] P. Hansen, W. Tolksdorf, and J. Schuldt, "Anisotropy and magnetostriction of germanium-substituted yttrium iron garnet," *J. Appl. Phys.*, vol. 43, pp. 4740–4746, Nov. 1972.

[V-4-21] G. F. Dionne, "Elimination of stress effects on remanence ratios of cubic magnetic materials," *IEEE Trans. Magn.* (*1971 INTERMAG Issue*), vol. MAG-7, pp. 715–718, Sept. 1971.

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[V-4-24] G. F. Dionne, "Ferrimagnetic resonance measurement of the 2111 magnetostriction constant with the magnetic field along a ⟨111⟩ axis," *J. Appl. Phys.*, vol. 41, pp. 2264–2265, 1970.

[V-4-25] ——, "Molecular field coefficients of substituted yttrium iron garnet," *J. Appl. Phys.*, vol. 41, pp. 4874–4881, Nov. 1970.

[V-4-26] ——, "Effect of external stress on remanence ratios and anisotropy fields of magnetic materials," *IEEE Trans. Magn.*, vol. MAG-5, pp. 596–600, Sept. 1969.

[V-4-27] A. B. Smith, "A ferromagnetic resonance method of measuring magnetostriction constants," *Rev. Sci. Instr.*, vol. 39, pp. 378–385, Mar. 1968.

V-5. MAGNETOCRYSTALLINE ANISOTROPY

Considerable attention has been given to magnetocrystalline anisotropy in spinel and garnet materials during the past five years and an extensive literature exists dealing with both experimental and theoretical work. A recent paper has reviewed this literature and is included here as the only reference on this subject. This paper is thoroughly comprehensive and contains 309 references. It reviews the origins of magnetocrystalline anisotropy and discusses experimental data for spinels, garnets, metals of the 3*d* and 4*f* transition series, and some selected rare-earth compounds.

[V-5-1] M. I. Darby and E. D. Isaac, "Magnetocrystalline anisotropy of ferro- and ferrimagnetics," *IEEE Trans. Magn.*, vol. MAG-10, pp. 259–304, June 1974.

V-6. LITHIUM FERRITES

High Curie temperature and low intrinsic magnetic losses (implying improved device action) have provided the technical motivation for studying this ferrite system during the last five years. The wide range of ion substitutions undertaken and improvement in microstructure obtained during these studies have increased the technical usefulness and application potential of this system.

[V-6-1] G. F. Dionne, "Molecular-field coefficients of Ti^{4+} and Zn^{2+} substituted lithium ferrites," *J. Appl. Phys.*, vol. 45, pp. 3621–3626, Aug. 1974.

[V-6-2] G. M. Argentina and P. D. Baba, "Microwave lithium ferrites: An overview," *IEEE Trans. Microwave Theory Tech.* (*Special Issue on Microwave Control Devices for Array Antenna Systems*), vol. MTT-22, pp. 652–658, June 1974.

[V-6-3] D. W. Johnson, Jr., P. K. Gallagher, D. P Nitti, and F. Schrey, "Effect of preparation technique and calcination temperature on the densification of lithium ferrites," *Ceram. Bull.*, vol. 53, pp. 163–167, 1974.

[V-6-4] G. Bandyopadhyay and R. M. Fulrath, "Processing parameters and properties of lithium ferrite spinel," *J. Amer. Ceram. Soc.*, vol. 57, pp. 182–186, Apr. 1974.

[V-6-5] N. Rezlescu, D. Condurache, P. Petrariu, and E. Luca, "Resistivity and curie point of Li–Zn ferrites," *J. Amer. Ceram. Soc.* (Discussions and Notes), pp. 40–41, Jan. 1974.

[V-6-6] P. D. Baba *et al.*, "Fabrication and properties of microwave lithium ferrites," *IEEE Trans. Magn.*, vol. MAG-8, pp. 83–94, Mar. 1972.

[V-6-7] D. G. Wickham, "Reactions of lithium iron oxide ($LiFeO_2$) and the formation of spinels," *Mater. Res. Bull.*, vol. 7, pp. 339–344, 1972.

[V-6-8] T. Collins and A. E. Brown, "Low-loss lithium ferrites for microwave latching applications," *J. Appl Phys.*, vol. 42, pp. 3451–3454, Aug. 1971.

[V-6-9] D. H. Ridgley, H. Lessoff, and J. D. Childress, "Effects of lithium and oxygen losses on magnetic and crystallographic properties of spinel lithium ferrite," *J. Amer. Ceram. Soc.*, vol. 53, pp. 304–311, June 1970.

[V-6-10] R. W. Babbitt, G. Sands, and A. Dunlap, "Grain-size effects on switching properties of lithium ferrite," *J. Appl. Phys.*, vol. 40, pp. 1455–1457, Mar. 1969.

[V-6-11] A. J. Pointon and R. C. Saull, "Solid state reactions in lithium ferrite," *J. Amer. Ceram. Soc.*, vol. 52, pp. 157–160, Mar. 1969.

[V-6-12] R. F. Belt, "X-ray topography of lithium ferrite," *Mater. Res. Bull.*, vol. 2, pp. 919–927, Oct. 1967.

V-7. NARROW-LINEWIDTH MATERIALS

Reduction of the ferrimagnetic resonance linewidth in polycrystalline garnet materials has been investigated by a number of workers during the past five years. An order of magnitude decrease in ΔH has been obtained in the laboratory. The availability of polycrystalline garnets with narrower linewidths may result in new device applications for ceramic materials in the future.

[V-7-1] Y. Machida, H. Saji, T. Yamadaya, and M. Asanuma, "Gd- and Zr-substituted Ca–V garnets," *IEEE Trans. Magn.*, vol. MAG-10, pp. 613–615, Sept. 1974.

[V-7-2] H. Takamizawa, K. I. Yotsuyanagi, and T. Inui, "Polycrystalline calcium-vanadium garnets with narrow ferrimagnetic resonance linewidth," *IEEE Trans. Magn.* (*1972 INTERMAG Conf.*), vol. MAG-8, pp. 446–449, Sept. 1972.

[V-7-3] Y. Machida *et al.*, "Magnetic properties and resonance linewidths of Zr- and Ti-substituted Ca–V garnet," *IEEE Trans. Magn.* (*1972 INTERMAG Conf.*), vol. MAG-8, pp. 444–446, Sept. 1972.

[V-7-4] C. E. Patton and H. J. Van Hook, "Origin of the microwave loss in ultralow linewidth substituted garnets," in *1971 Proc. AIP Conf.*, no. 5, pp. 1565–1568.

[V-7-5] G. Winkler, "Substituted polycrystalline YIG with very low ferrimagnetic resonance linewidth and optical transparency," *IEEE Trans. Magn.* (*1971 INTERMAG Issue*), vol. MAG-7, pp. 773–776, Sept. 1971).

[V-7-6] H. J. Van Hook, "Microwave loss in low-magnetization polycrystalline garnets: A comparison of Ga and CA–V–IN-substituted YIG," *IEEE Trans. Magn.* (*1971 INTERMAG Issue*), vol. MAG-7, pp. 770–773, Sept. 1971.

[V-7-7] A. S. Hudson, "Substitution of gadolinium, aluminum, and indium in yttrium calcium vanadium garnets," *IEEE Trans. Magn.*, vol. MAG-5, pp. 610–613, Sept. 1969.

[V-7-8] G. Winkler and P. Hansen, "Calcium-vanadium-indium substituted yttrium-iron-garnets with very low linewidths of ferromagnetic resonance," *Mater. Res. Bull.*, vol. 4, pp. 825–838, 1969.

[V-7-9] H. J. Van Hook, J. J. Green, F. Euler, and E. R. Czerlinsky, "Linewidth reduction through indium substitution in calcium-vanadium garnets," *J. Appl. Phys.*, vol. 39, pp. 730–731, Feb. 1968.

V-8. RECENT INNOVATION IN FERRITE PROCESSING METHODS

Increased uniformity of technical properties and reduction of cost are the two major factors motivating study of the forming of ferrimagnetic materials by techniques deviating from the classical ceramic method.

[V-8-1] R. Roy, "New ceramic materials produced by novel processing techniques," *Powder Met. Int.*, vol. 6, pp. 25–28, Feb. 1974.

[V-8-2] R. L. Gentilman, "Chemical vapor deposition of epitaxial films of yttrium iron garnet and gallium-substituted yttrium iron garnet and a thermodynamic analysis," *J. Amer. Ceram. Soc.*, vol. 56, pp. 623–627, Dec. 1973.

[V-8-3] G. R. Blair, A. C. D. Chaklader, and N. M. P. Low, "Reactively hot-pressed yttrium iron garnets," *Mater. Res. Bull.*, vol. 8, pp. 161–169, Feb. 1973.

[V-8-4] D. H. Harris, "High remanent MgMn ferrite for microwave applications," in *1972 Proc. AIP Conf.*, no. 10, pp. 164–168.

[V-8-5] R. F. Belt and G. C. Florio, "Permeability and temperature coefficient changes in hot-pressed flame-sprayed nickel-zinc ferrites," *Amer. Ceram. Soc. Bull.*, vol. 51, pp. 523–526, June 1972.

[V-8-6] R. W. Babbitt, "Arc plasma deposition of nickel zinc ferrite," *Amer. Ceram. Soc. Bull.*, vol. 51, p. 646, Aug. 1972.

[V-8-7] C. G. Aumiller *et al.*, "Ferrite composite integrated microwave circuit development," in *1971 IEEE Int. G-MTT Microwave Symp. Dig.*, pp. 66–69.

[V-8-8] J. J. Mitchell, "Cryogenically crushed Ni–Zn ferrites," Army Electronics Command, Ft. Monmouth, N. J., Rep. ECOM-3399 (AD721587), Mar. 1971.

[V-8-9] T. Satō, "Formation and magnetic properties of ultrafine spinel ferrites," *IEEE Trans. Magn.*, vol. MAG-6, pp. 795–799, Dec. 1970.

[V-8-10] A. L. Micheli, "Preparation of lithium ferrites by coprecipitation," *IEEE Trans. Magn.*, vol. MAG-6, pp. 606–608, Sept. 1970.

[V-8-11] A. E. Paladino and C. R. Snider, "Ferrite-dielectric composites utilizing $MgO–MgA_2O_4$ mixtures to achieve thermal expansion matched substrates," *Ceram. Bull.*, vol. 49, pp. 280–285, 1970.

[V-8-12] J. G. M. de Lau, "Preparation of ceramic powders from sulphate solutions by spray drying and roasting," *Amer. Ceram. Soc. Bull.*, vol. 49, pp. 572–574, June 1970.

[V-8-13] F. J. Schnettler, F. R. Momforte, and W. W. Rhodes, "A cryochemical method for preparing ceramic materials," in *Science of Ceramics*, vol. 4, G. H. Steward, Ed. New York: Academic, 1968, pp. 79–90.

[V-8-14] D. H. Harris *et al.*, "Polycrystalline ferrite films for microwave applications deposited by arc-plasma," *J. Appl. Phys.*, vol. 41, pp. 1349–1349, Mar. 1970.

[V-8-15] A. I. Braginski and D. C. Buck, "Polycrystalline ferrite films for microwave applications," *IEEE Trans. Magn.*, vol. MAG-5, pp. 924–928, Dec. 1969.

[V-8-16] J. E. Mee, G. R. Pulliam, J. L. Archer, and P. J. Besser, "Magnetic oxide films," *IEEE Trans. Magn.*, vol. MAG-5, pp. 717–727, Dec. 1969.

V-9. OTHER INVESTIGATIONS OF SPINELS AND GARNETS

Investigations with a view toward the improvement and control of the microstructure and technical properties of a variety of ferrites in the spinel and garnet systems have been conducted during the last five years. The impetus for some of this work did not stem directly from the microwave industry, but in many cases it is directly applicable to problems of workers concerned with microwave materials.

[V-9-1] G. C. Jain, B. K. Das, R. S. Khanduja, and S. C. Gupta, "Effect of intragranular porosity on initial permeability and coercive force in a manganese-zinc-ferrite," in *1974 INTERMAG Cong. Dig.* (New York), Paper 9-8, (IEEE Pub. 74CHO 852-4-MAG).

[V-9-2] J. E. Knowles, "The origin of the magnetic loss induced by machining ferrites," in *1974 INTERMAG Conf. Dig.* (New York), Paper 9-5, (IEEE Pub. 74CHO 852-4-MAG).

[V-9-3] E. C. Snelling, "The effects of stress on some properties of MnZn ferrite," *IEEE Trans. Magn.*, vol. MAG-10, pp. 616–618, Sept. 1974.

[V-9-4] J. J. Green and F. Sandy, "Microwave characterization of partially magnetized ferrites," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-22, pp. 641–645, June 1974.

[V-9-5] C. E. Patton, "A review of microwave relaxation in polycrystalline ferrites," *IEEE Trans. Magn.*, vol. MAG-8, pp. 433–439, Sept. 1972.

[V-9-6] F. G. Brockman, "Nickel-zinc ferrites: IV, zero anisotropy in stoichiometric 50NiO/50ZnO ferrite containing 0.5 Mil % CoO—Relation between 60-Hz and 2.5-MHz magnetic losses," *J. Amer. Ceram. Soc.*, vol. 55, pp. 28–31, Jan. 1972.

[V-9-7] J. H. Magee, V. Morton, R. D. Fisher, and I. J. Lowe, "Relation between Fe_2O_3 particle size, spinel particle size and magnetic properties of Mn Zn Fe_2O_4 materials," *Ceram. Bull.*, vol. 50, pp. 966–970, Dec. 1971.

[V-9-8] I. Bady, "Temperature stability of ferrite substrates in microwave integrated circuits," *IEEE Trans. Magn.*, vol. MAG-7, pp. 276–280, June 1971.

[V-9-9] F. G. Brockman and R. P. White, "Nickel-zinc ferrites: III, dielectric properties of stoichiometric nickel-zinc ferrites," *J. Amer. Ceram. Soc.*, vol. 54, pp. 183–185, Apr. 1971.

[V-9-10] F. G. Brockman and K. E. Matteson, "Nickel-zinc ferrites: II, preparation and properties of stoichiometric 32NiO/68ZnO ferrite," *J. Amer. Ceram. Soc.*, vol. 54, pp. 180–183, Apr. 1971.

[V-9-11] R. Krishnan, "Anisotropy line broadening and related problems in polycrystalline $NiFe_2O_4$," *IEEE Trans. Magn.*, vol. MAG-7, pp. 202–204, Mar. 1971.

[V-9-12] G. R. Chol, "Influence of milled powder particle size distribution on the microstructure and electrical properties of sintered Mn–Zn ferrites," *J. Amer. Ceram. Soc.*, vol. 54, pp. 34–39, Jan. 1971.

[V-9-13] D. R. Secrist and H. L. Turk, "Electrical properties of high-density iron-deficient nickel-zinc ferrites," *J. Amer. Ceram. Soc.*, vol. 53, pp. 683–686, Dec. 1970.

[V-9-14] F. G. Brockman and K. E. Matteson, "Nickel-zinc ferrites: I, effect of composition on the magnetic properties of a nickel-zinc-(cobalt) ferrite," *J. Amer. Ceram. Soc.*, vol. 53, pp. 517–520, Sept. 1970.

[V-9-15] J. H. Magee, V. Morton, R. D. Fisher, and I. J. Lowe, "Factors affecting magnetic properties of linear ferrites," *Ferrites: Proc. of Int. Conf.* (July 1970), pp. 217–220.

[V-9-16] A. E. Paladino and E. A. Maguire, "Microstructure development in yttrium iron garnet," *J. Amer. Ceram. Soc.*, vol. 53, pp. 98–102, Feb. 1970.

[V-9-17] H. M. O'Bryan, Jr., P. K. Gallagher, F. R. Monforte, and F. Schrey, "Microstructure control in nickel ferrous ferrite," *Ceram. Bull.*, vol. 48, pp. 203–208, Feb. 1969.

[V-9-18] J. Verweel, "On the HF permeability of dense ferrites in polarizing fields," *IEEE Trans. Magn.*, vol. MAG-5, pp. 622–625, Sept. 1969.

[V-9-19] G. Chol, J.-P. Auradon, and F. Damay, "Influence of the sintering conditions on the densification of manganese–zinc ferrites," *IEEE Trans. Magn.*, vol. MAG-5, pp. 281–285, Sept. 1969.

[V-9-20] J.-P. Auradon, F. Damay, and G. Chol, "Modern investigation methods for the optimization of high-quality soft-ferrite manufacture," *IEEE Trans. Magn.*, vol. MAG-5, pp. 276–280, Sept. 1969.

[V-9-21] Q. H. F. Vrehen, H. G. Beljers, and J. G. M. DeLau, "Microwave properties of fine-grain Ni and Mg ferrites," *IEEE Trans. Magn.*, vol. MAG-5, pp. 617–621, Sept. 1969.

[V-9-22] P. Mossman, "The effects of processing conditions on the properties of polycrystalline $Bi_{3-2x}Ca_{2x}Fe_2Fe_{3-x}V_xO_{12}$ ferrites," *IEEE Trans. Magnetics*, vol. MAG-5, pp. 614–617, Sept. 1969.

[V-9-23] A. B. Van Groenou, H. G. Beljers, and F. C. M. Briessens, "Anisotropy and ferromagnetic resonance in $NiFe_2O_4$ with [111] texture," *J. Appl. Phys.*, vol. 40, pp. 1424–1426, Mar. 1969.

[V-9-24] D. C. Buck and F. Harris, "Quick evaluation method for microwave ferrites used in analog phase shifters," *J. Appl. Phys.*, vol. 40, pp. 1418–1419, Mar. 1969.

[V-9-25] S. Dixon, Jr., and D. C. Leo, "Nonlinear properties of magnesium manganese ferrite," *J. Appl. Phys.*, vol. 40, pp. 1414–1415, Mar. 1969.

[V-9-26] S. Natansohn and D. H. Baird, "Effect of synthesis parameters on the magnetic properties of manganese zinc ferrites," *J. Amer. Ceram. Soc.*, vol. 52, pp. 127–132, Mar. 1969.

[V-9-27] I. Bady, "Microwave properties of ferrites," *J. Appl. Phys.*, vol. 40, pp. 1420–1421, Mar. 1969.

[V-9-28] G. Chol, F. Damay, J. P. Auradon, and M. A. Strivens, "Recent developments in the manufacture of soft ferrites used in telephone equipment," *Electron. Commun.*, vol. 43, pp. 263–273, 1968.

[V-9-29] H. P. Peloschek and D. J. Perduijn, "High-permeability MnZn ferrites with flat μ–T curves," *IEEE Trans. Magn.*, vol. MAG-4, pp. 453–455, Sept. 1968.

[V-9-30] L. Courtois and F. Hoffmann, 'Initial permeability of ferrites at microwave and natural gyromagnetic resonance," *J. Appl. Phys.*, vol. 39, pp. 734–735, Feb. 1968.

[V-9-31] E. Ross, "Ferrites with initial permeabilities from 3,000 to more than 20,000; used in miniature transformers for nanosecond-pulse techniques," *Siemens Electron. Comput. Bull.*, vol. 5-66, pp. 138–142.

VI-1. LITERATURE OF FRANCE, ITALY, AND JAPAN

The following sections contain articles published in journals within France, Italy, and Japan which are felt to be of interest to the microwave magnetics community. Much of the work produced in these and other non-English speaking countries is published in the English language press and these listings have therefore been restricted to the non-English language journals.

VI-2. FRENCH LITERATURE ON MICROWAVE FERRITE MATERIALS 1969–1973

[prepared by J. Nicolas, Thompson-CSF, Gifsur, Yvettee, France]

[VI-2-1] R. L. Inglebert, "Étude de la relaxation d'ondes de spins dans des grenats polycristalline par resonance ferrimagnetique et par pompages parallèle et perpendiculaire," Thèse de 3ième cycle, Orsay, France, 1973.

[VI-2-2] J. Nicolas and M. Hildebrandt, "Hot pressed garnets: Study of sintering processes and of annealed materials," in *1973 Proc. 6th Int. Seminar Science of Ceramics*, Deut. Keramische Gesellschaft, vol. 30, p. 1.

[VI-2-3] J. Nicolas, A. LaGrange, and R. Sroussi, "Problème des pertes dan les ferrites hyperfrequences," presented at the 1ière Seminaire Int. Dispositifs Hyperfrequences à Ferrites, V (Toulouse, France, 1972), p. 1.

[VI-2-4] J. Nicolas and A. LaGrange, "Ferrites hyperfrequences pour dispositifs haute puissance de crète," presented at the 1ière Seminaire Int. Dispositifs Hyperfrequences à Ferrites, IV (Toulouse, France, 1972), p. 1.

[VI-2-5] D. J. Craik, A. D. Kitto, and D. P. Ross, "Magnetization precession in spinels and garnets" (in English), *J. Phys.*, suppl. vol. 32, p. C1-771, 1971.

[VI-2-6] E. Schlömann, "Behavior of ferrites in microwave frequency range" (in English), *J. Phys.*, suppl. vol. 32, p. C1-443, 1971.

[VI-2-7] L. Courtois and H. Pascard, "Materiaux ferromagnetiques feuilletés pour hyperfrequences," *J. Phys.*, suppl. vol. 32, p. C1-161, 1971.

[VI-2-8] K. A. Hempel and H. Kmitta, "Hysteresis of the microwave absorption of $BaFe_{12}O_{19}$ powder with various degrees of annealing" (in English), *J. Phys.*, suppl. vol. 32, p. C1-159, 1971.

[VI-2-9] Q. H. Vrehen and A. Broese Van Groenou, "Ferromagnetic relaxation in porous polycrystalline ferrites (in English), *J. Phys.*, suppl. vol. 32, p. C1-156, 1971.

[VI-2-10] J. Nicolas *et al.*, "Influence comparée de substitutions de cobalt dans des grenats polycristallins," *J. Phys.*, suppl. vol. 32, p. C1-153, 1971.
This paper shows the anomalous behavior of Co ions in garnets containing vanadium.

[VI-2-11] C. Borghese and R. Roveda, "Fine particles and fast relaxers influence on the magnetic RF threshold fields and losses in YIG" (in English), *J. Phys.*, suppl. vol. 32, p. C1-150, 1971.

[VI-2-12] R. Krishnan, "Magnetic anisotropy and resonance linewidth in rare earth doped Ni Fe O_4 crystals" (in English), *J. Phys.*, suppl. vol. 32, p. C1-148, 1971.

[VI-2-13] S. K. Barnejee, P. D. Baba, B. J. Evans, and S. S. Hafner, "On the relative efficiency of cobalt in the linewidth reduction of microwave ferrites" (in English), *J. Phys.*, suppl. vol. 32, p. C1-145, 1971.

[VI-2-14] A. J. Braginski, D. R. Buck, J. E. Degenford, and T. R. Oeffinger, "Thick ferrite films by chemical transport" (in English), *J. Phys.*, suppl. vol. 32, p. C1-142, 1971.

[VI-2-15] A. Deschamps, "Les ferrites en hyperfrequence," *Cables Transmission*, no. 4, p. 357, 1970.
This is a review paper. Some special points studied by the author pertain to the spinels containing titanium and hexagonal ferrites for millimetric-wave application.

[VI-2-16] A. H. Bono, "Contribution a l'etude de la mesure des caracteristiques dielectriques a 9 GHz," Thèse, Orsay, France, 1970.
In this thesis values of ϵ^1 and tan δ_ϵ are given for some series of microwave garnets. The influence of the stoichiometry and the temperature is studied.

[VI-2-17] J. Nicolas, R. Sroussi, A. LaGrange, and M. Hildebrandt, "Les ferrites presses à chaud en microelectronique hyperfrequence," presented at Colloq. Intern. Microelectronique Avancée (Paris, 1970), p. 6.

[VI-2-18] J. Nicolas, A. Lagrange, R. Sroussi, and M. Hildebrandt, "Preparation, proprietés et applications des ferrites pour hyperfrequence, presses à chaud," *Rev. Tech. Thomson-CSF*, vol. 1, p. 506, 1969.

[VI-2-19] G. Pircher, *Ferrites et grenats—Phonomènes Non Lineaires.* Paris: Dunod, 1969, p. 230.

VI-3. RECENT FRENCH LITERATURE ON MICROWAVE FERRITE DEVICES

[prepared by A. C. Priou, Department of Microwave Research, Aerospace Complex, Toulouse Study and Research Center, Toulouse, France]

Delay Lines

[VI-3-1] B. Desormière and C. Chauvin, "Étude et realisation de ligne à retard magneto-élastique à YIG," in *Proc. 1st Int. Seminar Microwave Ferrite Devices* (Toulouse, France, 1972).

[VI-3-2] J. F. Duputz, A., "Étude theorique de la propagation d'ondes magnetostatiques—Application aux lignes à retard," in *Proc. 1st Int. Seminar Microwave Ferrite Devices* (Toulouse, France, 1972).

Broad-banding a Ferrite Isolator

[VI-3-3] M. De Vecchis, L. Raczy, and P. Gelin, "A new slot line broadband isolator," in *European Microwave Conf. Dig.* (Brussels, 1973), vol. II, p. B.9.

[VI-3-4] L. Courtois, "Propagation oblique des ondes electromagnetiques dans une lame de ferrite aimantée parallelement à ses faces," presented at the 1st French-Spanish Microwave Symp. (Madrid, Spain, 1973); also ——, *Rev. Electron. Fis. Apl.* (*Special Issue on 1st Microwave Symp.*), vol. 16, p. 216, 1973.

[VI-3-5] L. Courtois, B. Chiron, and G. Forterre, "Propagation dans une lame de ferrite aimantée, application a de nouveaux dispositifs non-reciproques à large bande," *Cables Transmission*, vol. 27-A, p. 416, 1973.

[VI-3-6] B. Chiron and G. Forterre, "Emploi des ondes de surface electromagnetiques pour la realisation de dispositifs gyromagnetiques à très grande largeur de bande," in *Proc. 1st Int. Seminar Microwave Ferrite Devices* (Toulouse, France, 1972).

[VI-3-7] M. Blanc, L. Dusson, J. Guidevaux, "Étude de la function isolation à très large bande utilisant des materiaux ferrite UHF," in *Proc. 1st Int. Seminar Microwave Ferrite Devices* (Toulouse, France, 1972).

[VI-3-8] B. Chiron, G. Forterre and C. Raunou, "Nouveaux dispositifs non-reciproques à très grande largeur de bande utilisant des ondes de surface electromagnetiques," *Onde Elec.*, vol. 51, p. 816, 1971.

[VI-3-9] A. M. Duputz and A. Priou, "Modal analysis of ferrite slab loaded rectangular waveguide," in *1974 Proc. 5th Colloq. Microwave Communications* (Budapest, 1974).

[VI-3-10] ——, "Optimisation de dephaseurs à ferrite en guide TE_{11}," in *Proc. AGARD Congress* (Munich, Germany, 1973), 26th Meeting on Antennas for Avionics.

[VI-3-11] A. Delfour, E. Cazenave, and A. Priou, "Calcul des constantes de propagation complexes de tous les modes se propageant dans un guide d'ondes chargé de ferrite," presented at the 1st French–Spanish Microwave Symp. (Madrid, 1973); also ——, *Electron. Fis. Apl.*, vol. 16, p. 281, 1973.

[VI-3-12] A. M. Duputz and A. Priou, "Étude d'un dephaseur P.I.P. en bande KU," presented at the 1st French–Spanish Microwave Symp. (Madrid, 1973; also ——, *Electron. Fis. Apl.*, vol. 16, p. 300, 1973.

[VI-3-13] ——, "Étude des guides circulaires TE_{11} completement ou partiellement remplis de ferrite," in *Proc. 1st Int. Seminar Microwave Ferrite Devices* (Toulouse, France, 1972).

[VI-3-14] F. Gardiol, A. DelFour, and A. Priou, "Determination des modes de propagation dans un guide d'ondes rectangulaire charges de plaquettes de ferrite aimantées," in *Proc. 1st Int. Seminar Microwave Ferrite Devices* (Toulouse, France, 1972).

Theoretical and Experimental Design of Ferrite Phase shifters

[VI-3-15] J. Salmon, "Dephaseur à ferrite reciproque en bande KU," in *Proc. 1st Int. Microwave Seminar Ferrite Microwave Devices* (Toulouse, France, 1972).

High-Peak-Power Junction Circulator

[VI-3-16] A. Lagrange and B. R. Vallentin, "Materiau bande *X* à haute puissance: Application à un circulateur en *Y*," in *Proc. 1st Int. Seminar Microwave Ferrite Devices* (Toulouse, France, 1972).

Others

[VI-3-17] J. F. Duputz, C. Fournet, and A. Priou, "Microwave characterization of a ferrite below magnetic saturation," in *Proc. 5th Colloq. Microwave Communication* (Budapest, 1974).

[VI-3-18] J. R. Mahieu and Poinssot, "Exemples de realisations gyromagnetiques pour ondes millimetriques," in *Proc. 1st Int. Seminar Microwave Ferrite Devices* (Toulouse, France, 1972).

[VI-3-19] B. Chiron and A. Deschamps, "Nouveaux substrates heterogenes ferrite–ferrite et ferrite–dielectrique, utilisables dans les structures non-reciproques en microelectronique hyperfrequence," in *Proc. 1st Int. Seminar Microwave Ferrite Devices* (Toulouse, France, 1972).

VI-4. RECENT ITALIAN LITERATURE ON MICROWAVE FERRITE MATERIALS AND DEVICES

[prepared by P. de Santis, University of Naples, Naples, Italy]

[VI-4-1] F. Bardati, "Non-homogeneous plane waves in anisotropic media," *Alta Freq.*, vol. 40, p. 700, 1971.

[VI-4-2] F. Bardati, M. Fossati, and G. Gerosa, "Second harmonic generation in ferrites," *Alta Freq.*, vol. 40, p. 147, 1971.

[VI-4-3] G. Gerosa, "Ferrite-metal surface waves for lossy ferrites," *Alta Freq.*, vol. 39, p. 179, 1970.

[VI-4-4] N. Minnoja, "Ferromagnetismo nei film sottili," *Alta Freq.*, vol. 39, p. 493, 1970.

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VI-5. RECENT JAPANESE LITERATURE ON MICROWAVE FERRITE MATERIALS AND DEVICES

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