FUTURE DIRECTIONS FOR MICROWAVE FERRITE COMPONENTS

INVITED PAPER

Lawrence R. Whicker
Naval Research Laboratory
Washington, DC 20375

ABSTRACT

This paper reviews the present status of ferrite control components and attempts to predict areas for further work. The components considered here are primarily from the junction circulator or phase shifter groups. It is pointed out that while ferrite control component technology is reaching a mature state, the market for circulators and phase shifters is expected to be quite good for the next several years.

Introduction

The areas of application for ferrite control components are quite extensive. Such components are essential in the operation of radar, communication, and electronic warfare systems. A partial listing of ferrite components include:

- circulators
- isolators
- phase and amplitude modulators
- switches
- phase shifters
- magnetically tuned filters
- limiters
- duplexers

In a recent paper by Whicker and Young[1] the evolution of ferrite component technology was addressed. It was pointed out that from the mid-1950's until the early 1970's extensive effort has gone into the design and optimization of these components. Through the years, however, two types of components have received primary attention. These include the junction circulator[2-8] and phase shifter.[9-23] The circulator derives its importance from its wide range of applications while phase shifters are required for use in phased antenna arrays. At the present time these research and development efforts generally have been successful and the ferrite component technology is approaching or has reached a state of maturity.

In this paper, an attempt will be made to predict the future direction for this technology.

Junction Circulators

Over the years, the ferrite junction circulator has received more attention in the literature than any other ferrite control component. The range of system application for these components includes use as transmit-receive devices, as isolators and as switches. Table 1 lists characteristics of some commercially available circulators. Recent technical efforts have been concerned with design refinements and extending circulator operation to lower and to higher frequencies. Work on lumped element circulators have resulted in circulators at 200 MHz[2] and lower. Work on waveguide circulators by Piotrowski and Raue[8] have resulted in a high performance circulator for the 31-38 GHz frequency band. Circulators covering a 2% frequency band are commercially available at frequencies up to 100 GHz. Further work in circulator design to obtain broader bandwidth for ECM applications is expected in the future. Additional emphasis on designs for higher frequency operation are required. In particular, circulators suitable for use in various forms of millimeter wave integrated circuit format are needed. In general, major new innovations in circulators are not envisioned. On the other hand, the present level of systems usage is expected to remain stable or to show some growth. The large amount of competition for the circulator business has resulted in cost effective designs.

Reciprocal and Nonreciprocal Phase Shifters

a. Phase Shifters for Switches, Four-Port Circulators, and Phase Modulators.

Phase shifters find many uses in systems. They are used broadly in two areas. The first area consists of usage as a general control component. Examples here would include high and low power switches, four-port circulators or duplexers and in phase or amplitude modulators. In these applications hybrid couplers or magic tees are used along with phase shift sections to form control components. The second area consists of usage as elemental phase shifters in a phased array antenna.

In the general control area a variety of phase shifter types have been utilized, including Faraday rotation types, Reggia Spencer types, single slab and twin slab types, and latching toroidal types. As in the case of junction circulators, the present state of technology is rather mature. Specific modifications to existing designs are made to satisfy given system requirements. Figure 1 depicts a set of matched 4-port circulators (one port is terminated) which have been developed recently by the Raytheon Company for the Naval Research Laboratory. These circulators operate over a 15% frequency band at Ku-band. They operate at 10 kw peak and 400 watt average power levels. Figure 2 depicts a similar pair of matched Ku-band high speed switches which were developed by the Sedco Company. Efforts in this general control area should remain stable.

b. Phase Shifters for Phased Arrays.

As was pointed out in Reference 1, the need for phased array antennas for radar, communications, and electronic warfare systems has prompted extensive effort in the development of fast-switching ferrite elemental phase shifters. A partial listing of the types of structures investigated include

- Toroidal nonreciprocal phase shifters[14]
- Helical Phase Shifters[15]
- Reciprocal[16] and nonreciprocal[17] strip transmission line phase shifters
- Microstrip phase shifters[18]
- Latching Reggia-Spencer phase Shifters[19-20]
- Reciprocal dual mode phase shifters[21-23]

Of these types, the toroidal nonreciprocal phase shifter and the reciprocal dual mode phase shifter have proven electrically superior. Both types are commercially available.

Although high performance phase shifters have been around for almost ten years, only now are phased array systems nearing their production phases. During the last few years much effort has been extended in cost reduction programs for ferrite phase shifters and their associated driver circuits.

For the phased array application, ferrite phase shifters must compete with diode phase shifters and with the solid state active array approach. At frequencies below 2 GHz diode phase shifters and/or the active array approach are probably more cost effective than a ferrite phase shifter approach. For the 2-4 GHz range diode and ferrite phase shifter are quite competitive. For the 4-35 GHz range ferrite phase shifters are usually the best choice. At some future time, active arrays using GaAs FET transistors may challenge the ferrite phase shifter approach in the 4-10 GHz range.

Ferrite phase shifters employed in a new phased array are shown in Figure 3. The antenna is for the Air Force EAR (Electronically Agile Radar) program. This system is being developed by the Westinghouse Co. The antenna utilizes approximately 2,000 reciprocal dual mode phase shifter units. The phase shifter assembly includes the basic phase shifter, driver, polarization diversity switch and radiating element. The phase shifter shown on the left is manufactured by the Microwave Applications Group while the phase shifter on the right is manufactured by the Raytheon Co. The cost for the phase shifter-driver assembly is of the order of $100 when manufactured in large quantities. Other large phased arrays which are under development are the Navy AEGIS System and the Army Patriot System. The AEGIS system utilizes nonreciprocal phase shifters at S-band frequencies and is being developed by RCA Co. The Patriot system operates at C-band and is being developed by the Raytheon Co. Several other systems which utilize phase scanning in elevation use ferrite phase shifters in either a reciprocal or nonreciprocal format.

In light of the above developments, it appears that large quantities of phase shifters at S, C and X-band frequencies will be required over the next 5-10 year period. Design refinements and further effort on cost reduction procedures should follow. Research and development efforts to obtain high performance phase shifters for 60 and 94 GHz operation are needed. One possible approach to forming of small ferrite toroids for these frequencies uses are plasma spraying as a fabrication tool.[24] Materials research which might lead to higher saturation moment ferrite materials is desirable also.

Other Ferrite Control Components

Although somewhat less technical efforts have been expended in the development of other control components such as YIG filters and ferrite limiters, these components find important system usage. The YIG filter provides a nonmechanically tuned, narrow band filter which is tunable over a broad frequency range and has found wide application in microwave receivers. Limiters are universally found in receivers to provide receiver protection. There is expected to be a stable market for these products.

Conclusions

The ferrite control component field is becoming mature. In the phase shifter area, emphasis is switching from the research and development stage to the production stage. Emerging phased array systems will require several hundred thousand phase shifter units over the next few years. Development efforts are needed to obtain high performance phase shifters for use above 35 GHz. For circulators, the market is expected to remain stable or to experience some growth as system needs increase. Additional research and development efforts can be expected for higher frequency operation.

References

1. L.R.Whicker, C.W.Young, Jr., "The Evolution of Ferrite Control Components," Microwave Journal, Vol.21, No.11, pp.33-37, Nov.1978.
2. B.Lax, K.J.Button, Microwave Ferrites and Ferrimagnetics, McGraw-Hill,Inc., New York, 1962.
3. H.Bosma, "Junction Circulators," Advances in Microwaves, Vol.6, (Leo Young, Editor), Academic Press, New York, 1971.
4. H.N.Chait, T.R.Curry, "The Y or T-Junction-Type Circulator," J.Appl.Phys.,Vol.30, pp.152S-153S, 1959.
5. C.E.Fay, R.L.Comstock, "Operation of the Ferrite Junction Circulator," IEEE Trans.MTT-13, pp.15-27, Jan.1965.
6. J.W.Simon, "Broadband Strip Transmission Line Y-Junction Circulators," IEEE Trans.MTT-13, pp.335-345, May 1965.
7. Y. Konishi, N.Hoshino, "Design of a New Broadband Isolator," IEEE Trans.MTT-19, pp.260-269, Mar.1971.
8. W.S.Piotrowski, J.E.Raue, "Low-Loss Broadband EHF Circulator," IEEE MTT Trans.,Vol.MTT-24, pp.863-866, Nov.1976.
9. M.A.Truhaft, L.M.Silber, "Use of Microwave Ferrite Toroids to Eliminate External Magnets and Reduce Switching Power," IRE Proc., Vol.46, p.1538, Aug., 1958.
10. D.Bush, "Discussion on Microwave Apparatus," Inst. Elect.Engr.Proc.(London),Vol.104B, Suppl.6, p.368, 1957.
11. F.Reggia, E.Spencer, "A New Technique in Ferrite Phase Shifting for Beam Scanning of Microwave Antennas," IRE Proc., Vol.45, pp.1510-1517,Nov.1957.
12. J.A.Weiss, "A Phenomenological Theory of the Reggia Spencer Phase Shifter," IRE Proc., pp.1130-1137, June 1959.
13. W.E.Hord, F.J.Rosenbaum, C.R.Boyd, Jr., "Theory of the Suppressed-Rotation Reciprocal Ferrite Phase Shifter," IEEE Trans.MTT-16, pp.902-910, Nov.1968.
14. G.S.Blevins, J.A.Kempic, R.R.Jones, "C-Band Digital Ferrite Phase Shifter," (Classified Paper),Sympos. Digest on Electronically Scanned Array Techniques and Applications, RADC (Apr.1964).
15. H.A.Hair, "Development of Helical Phase Shifters," Final Report Contract #AF19(628)-500,Sub 250(Dec. 1964).
16. J.W.Simon, W.K.Alverson, J.E.Pippin, "A Reciprocal TEM Latching Ferrite Phase Shifter," 1966 G-MTT Symposium Digest (IEEE), pp.241-246.
17. L.R.Whicker, R.R.Jones, "A Digital Latching Ferrite Strip Transmission Line Phase Shifter," IEEE Trans. MTT-13, pp.781-784, 1965.
18. G.T.Roome, H.A.Hair, "Thin Ferrite Devices for Microwave Integrated Circuits," IEEE Trans.MTT-16, pp.411-419, 1968.
19. L.R.Whicker, "Recent Advances in Digital Latching Ferrite Devices," 1966 IEEE Internatl.Conv.Record, part 5, pp.49-57.
20. I.Bardash, J.J.Maune, "A Waveguide Reciprocal Latching Ferrite Phase Shifter," 1968 IEEE G-MTT Symposium Digest, pp.274-281.
21. C.R.Boyd,Jr., "A Dual-Mode Latching Reciprocal Ferrite Phase Shifter," IEEE Trans.MTT-18, pp.1119-1124, 1970.
22. R.C.Roberts, "An X-Band Reciprocal Latching Faraday Rotation Phase Shifter," 1970 IEEE G-MTT Symposium Digest, pp.341-345.
23. C.R.Boyd,Jr., L.R.Whicker, R.W.Jansen, "Study of Insertion Phase Variation in a Class of Ferrite Phasers," IEEE Trans.MTT-18,pp.1084-1089,1970.

References--cont'd.
24. R.W.Babbit,R.A.Stern,"Non-Reciprocal Ferrite Phase Shifters for Millimeter Applications,"1978 IEEE Internatl.Microwave Symposium Digest, pp.94-96.

TABLE 1: CHARACTERISTICS OF TYPICAL JUNCTION CIRCULATORS

CIRCULATOR TYPE	CENTER FREQUENCY (GHz)	BANDWIDTH	ISOLATION	INSERTION LOSS	POWER CAPACITY
Waveguide	12.4-18 18-26.5	--	20 dB 17 dB	.3 dB .5 dB	20 W avg., 1 kW peak 15 W avg., 500 W peak
Strip Trans-mission Line	4-8 12.4-18	--	20 dB 18 dB	.4 dB .5 dB	35 W 25 W avg., 250 W peak
Switching	2.9 35	8.9% 5%	26 dB 15 dB	.35 dB .5 dB	15 kW peak
Lumped Constant	1.2 .4-5	30%	20 dB 20 dB	.6 dB .4 dB	--
Waveguide	75-110	2%	20 dB	1.0 dB	--

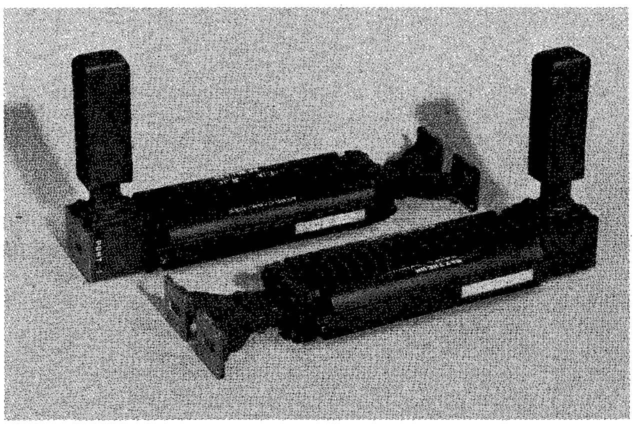

Figure 1. Matched Ku-Band Circulators.

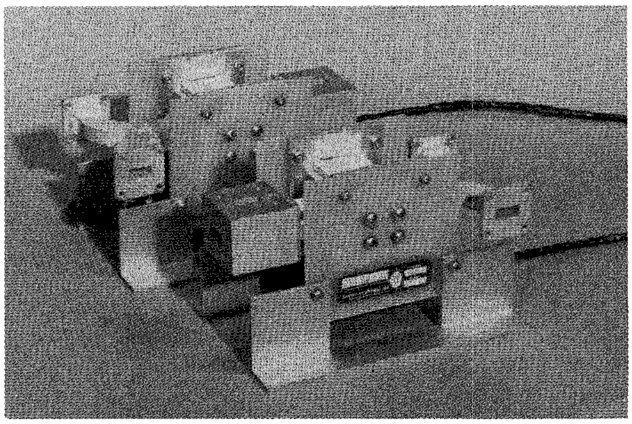

Figure 2. Matched Ku-Band Switches.

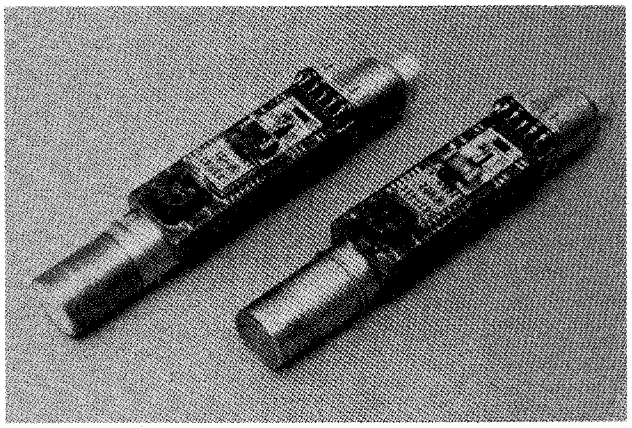

Figure 3. EAR System Phase Shifters.