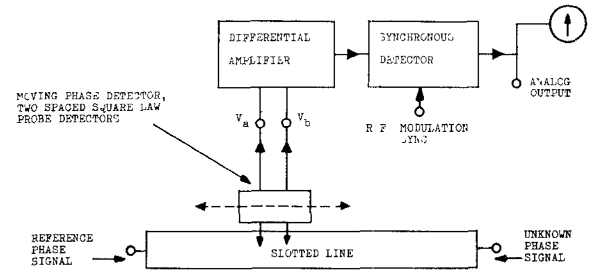

Fig. 1—Direct-reading microwave phase meter (using double square-law probe phase detector on slotted line).

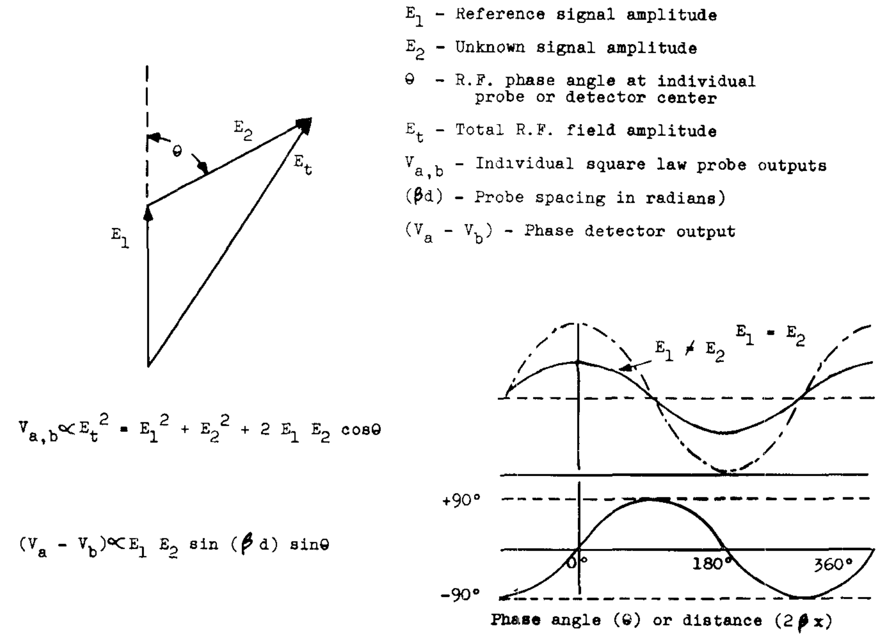

Fig. 2—Individual probe and phase detector output relations.

angle ($2\beta x$) and this angle is added to the meter indication.

The spacing of the two probes determines only the sensitivity of the phase detector. For broad frequency use, the spacing can be a quarter wavelength at the center frequency.

Phase measurement accuracy in transmission systems is frequently limited by reflections. The moving-probe type of phase detector provides inherently low reflection measurement apparatus. Equality of reference and unknown signal amplitudes is not required for operation; however, it is desirable in order that errors due to reflections of the strong signal in the weak signal channel may be kept to a minimum value.

This phase meter method has been used from 300 Mc through X band with 10:1 frequency range for a fixed spacing of the two probes.

For power levels of 1 to 10 mw for the reference and unknown signals, a sensitivity of 0.1° has been obtained with 1-kc modulation.

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A VHF High-Power *Y*-Circulator*

A number of articles [1] on the theory, design and application of three-port circulators may be found in the literature. Specific devices of this kind are commercially available for low signal power levels. In this letter a high-power version of a three-port or *Y*-circulator is presented. The characteristics measured at high power are compared with measurements performed at low power.

A strip-line structure was chosen for the junction configuration. To obtain a required $\pm 2\frac{1}{2}$ per cent bandwidth at the center frequency of 220 Mc, with a constant applied magnetic field, the junction geometry of the center conductor was chosen in the form of a clover leaf. A MnMg aluminate ferrite (such as Trans-Tech 414)[1] with a low saturation magnetization was selected to obtain the desired performance at these low frequencies. The rather unfavorable temperature characteristics of this material, however, necessitated forced cooling. The ferrite disks above and below the strip-line junction are placed in a pillbox enclosure. The space between the edge of the circulator ferrite disks and the inner wall of the circular enclosure is filled with a coolant of low loss, high dielectric strength fluid such as Freon 113 (Trichloro-trifluoroethane).[2]

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[1] TT414 is a product of Trans-Tech., Inc., Gaithersburg, Md.

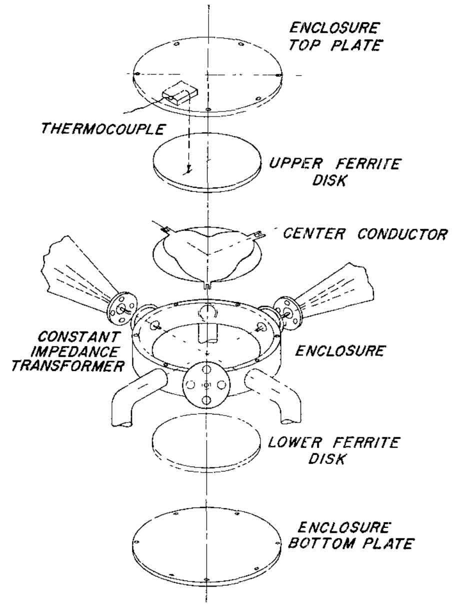

Fig. 1—Exploded view of the *Y*-circulator element.

In the high power environment, care has to be taken to avoid discontinuities in dielectrics to prevent electrical breakdown. On the design being presented, electrical breakdown was observed with dc above 15 kv. The attenuation introduced by the dielectric loss of the coolant is insignificant in the 200-Mc region.

The circulator element was designed with the following geometric parameters. A ferrite disk of 5-in diameter is used. The enclosure diameter was chosen to be 7 in. Fluid inlets and outlets are distributed around the periphery of the circular enclosure and located in the three electrically-neutral regions (60° off each port). A thermocouple consisting of a Chromel-Alumel wire pair is attached to the top ferrite disk so as not to interfere with the circulating coolant. Two holes are situated at the top and bottom ground plate to facilitate the escape of air during the filling process. Fig. 1 shows an exploded view of the circulator element.

To enable the investigation of the circulator over an appreciable bandwidth a broadband transformer design was selected for the three ports. For a limited frequency band of operation, a compensated transformer of reduced length is desirable to reduce the overall size and weight of the circulator.

A coolant such as Freon 113 was selected primarily for electrical reasons. The ferrite disk temperature has to be kept at approximately 24°C at a maximum of 2 kw average transmitted RF power. The dissipated power is then of the order of 200 w. The cooling volume of the circulator is in the order of 120

[2] Freon 113 is a product of the Du Pont Co., Wilmington, Del.

cm³. This volume is replaced two to three times per second. A by-pass valve has been included to control the flow rate of the liquid through the circulator. The cooling system operates in a closed loop.

Measurements

Electrical characteristics of the device were obtained at both low and high signal power levels. The low power measurements provided a reference for the performance evaluation of the component when subjected to high transmitted power. During the developmental work an interesting phenomenon was observed. Isolations in the order of 50 db or more could be obtained in discrete ferrite temperature regions. The insertion loss however remained unaffected by large changes of ferrite temperature. This temperature effect can easily be observed on TT414 ferrite as the temperature for optimum circulator performance lies in the room temperature region. These observations suggest that materials with high Curie temperature could be used in low-frequency circulators providing the device is operated at a temperature other than room ambient. Experiments performed at room temperature on VHF circulators containing high M_s (magnetization saturation) materials were unsuccessful. Similar measurements under various temperature conditions were performed with the circulator presented here. The obtained isolation and loss at low power levels for varying ferrite temperatures is illustrated together with the characteristics obtained at high power levels (Fig. 4). The magnetic field has been adjusted at each temperature point for maximum isolation. A ferrite temperature for optimum circulator performance was established in the vicinity of 24°C.

Fig. 2 illustrates the isolation and loss characteristics of the circulator for variable magnetic fields at different ferrite temperatures. The isolation characteristic for a constant applied magnetic field is also included for a ferrite temperature of 24°C. Fig. 3 shows the applied magnetic field for maximum isolation as a function of ferrite temperature. The ferrite disk temperature was controlled by means of the circulating fluid surrounding the ferrite disks. The measurements were performed after the device reached thermal equilibrium.

The VSWR of the circulator was measured at low power levels in the frequency region of 215 to 225 Mc and was in the order of 1.08:1 maximum.

High Power Measurements

The circulator was used as a duplexer substitute in a radar front end. A matched dummy load simulated the antenna. The isolation between the transmitter and the receiver terminals was measured as a function of the ferrite temperature, or indirectly as a function of the transmitted power. The results obtained are compared with the isolation-ferrite temperature measurements at low power levels. In most cases the high power measurements were made at thermal equilibrium of the ferrite disks. Some instantaneous temperature-isolation checks were made to verify the measured slope of the isolation-temperature function obtained at high transmitted power.

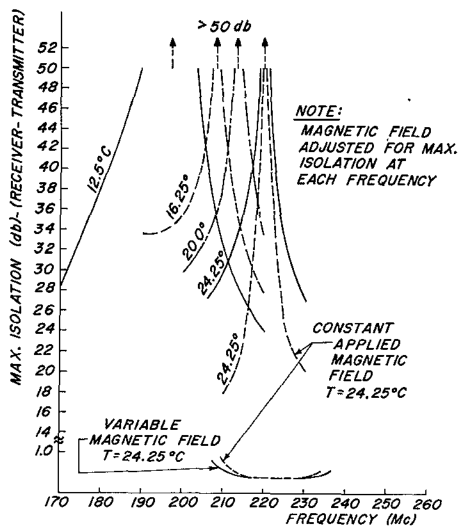

Fig. 2—Maximum isolation vs frequency for varying ferrite temperature.

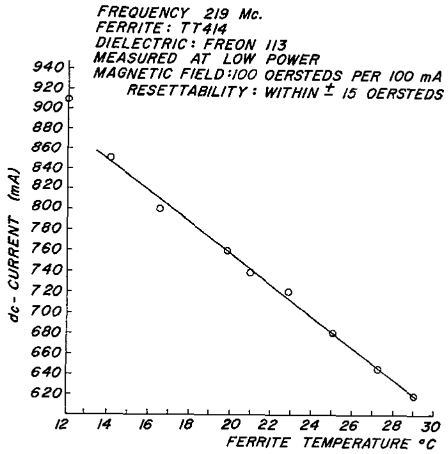

Fig. 3—Applied magnetic field for maximum isolation as a function of temperatures varying from 12°C to 29°C.

The measured ferrite temperature does not reflect the true temperature existing in the active region of the ferrite disks, as the heat distribution can be assumed to be nonuniform. The refrigerated coolant circulating through the circulator element causes additional thermal disturbances. The relation between the measured and the true ferrite temperature is given in Fig. 4. This relation was obtained by comparison of the low and high power characteristics. The existing temperature gradient can be evaluated from these measurements.

Fig. 4 also shows the isolation obtained as a function of the measured ferrite temperature at low and high magnitudes of transmitted power.

The low and high power measurements can be compared to evaluate the high power performance of the device. The temperature difference between points of equal isolation obtained at low and high power furnished a means of comparison. The width between points of equal isolation differs in the order of 0.2°C, which can be considered well within the accuracy of the measurement.

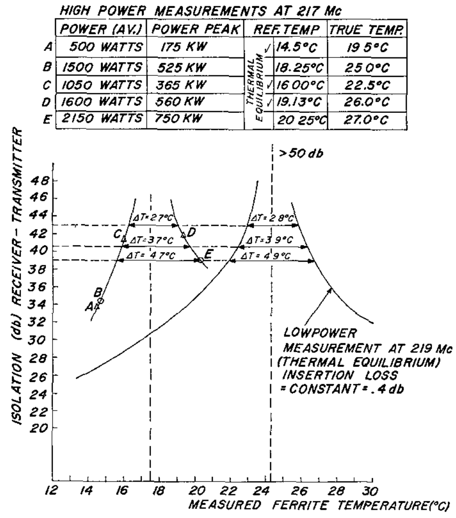

Fig. 4—Comparison of the isolation-temperature characteristics obtained at low and high transmitted power levels.

The comparison shows that the relative isolation-temperature characteristics do not differ appreciably; therefore the performance of the device can be considered independent of the magnitude of the transmitted power for the range of power levels used in these experiments.

Peak power of 1 Mw was applied over a short period of time. No electrical breakdown or deterioration of the circulator characteristics was observed.

Conclusion

An insertion loss of 0.3 to 0.5 db and an isolation of 50 db or more can be obtained at the center frequency for which the circulator was designed. The necessary magnetic field is not excessive at low frequencies, the dc control power being of the order of 10 to 20 w. No significant changes in electrical characteristics were observed when the device was subjected to transmitted RF power in excess of 2 kw with a peak power in the order of 1 Mw.

In conclusion a summary of performance data obtained with the above high-power Y-circulator structure is presented.

TABLE I

Frequency (Mc)	Variable magnetic field		Constant field		VSWR
	Isolation (db)	Loss (db)	Isolation (db)	Loss (db)	
225	32	0.4	24	0 45	1.08
219	>50	0.4	>50	0.40	
215	36	0.4	24	0.55	

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