Wide-Band Microwave Transmission Measuring System*

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Summary—**A relatively broad-band balanced microwave measurement system has been built using a traveling-wave tube amplifier which permits automatic phase and amplitude transmission measurements to be made simultaneously as a function of frequency over the frequency range 8.7 kmc–9.6 kmc. A phase accuracy of ±1 degree can be achieved for a change of attenuation in the unknown of 24 db. Loss measurements can be made with an accuracy of ±2 per cent. The bridge is built largely of commercially available components and can be easily duplicated. The basic technique is compatible with additional broad-banding efforts as improved components become available, and it will eventually be applicable to all microwave frequencies.**

INTRODUCTION

A RELATIVELY broad-band microwave measuring system has been developed which permits rapid search over a wide frequency range at X band to meet the growing requirements for impedance, admittance, and transmission measurement in the microwave range. Simultaneous automatic recording of both phase and amplitude response of a general two-port waveguide component as a function of some parameter (such as time, magnetic field, frequency, temperature, etc.) is featured. Of particular note is the accuracy and easy facility with which transmission data as a function of frequency can be obtained. The system is built largely of commercially available components for circuit simplification over previous work[1,2] and also for easy duplication.

DESCRIPTION OF EQUIPMENT

General

A block diagram of the symmetric automatic microwave transmission measuring system is shown in Fig. 1. The system, as used for phase measurements, is built around a traveling-wave tube used in a "frequency offset" application.[1–3] The source of microwave energy is an X-band traveling-wave tube whose helix is modulated with a 20-kc sawtooth waveform. This sawtooth serves to phase modulate the f_0 signal at a 20-kc rate, causing the output frequency of the traveling-wave tube to be displaced to f_0+20 kc. Other frequencies, f_0, f_0-20 kc, and other sidebands are all at least 20 db below the desired output signal. A ferrite frequency offset generator has been similarly utilized by Dropkin.[4] This signal, f_0+20 kc, is fed into two symmetric arms of the measurement system through a Wheeler Hybrid T.[5] (The Wheeler "T" is a quality matched hybrid junction with the necessary electrical and mechanical symmetry to provide a high degree of symmetry and interarm isolation over a 12 per cent frequency band, 8.5–9.6 kmc.) One arm of the measurement system is termed the "reference arm" while the other is the "unknown arm," *i.e.*, the one which contains the unknown in a measurement. Each arm is terminated in a matched load. It is important in broad-band phase measurements that these arms be of the same electrical length. All signals used for measurement are decoupled from the main arms through broad-band waveguide directional couplers. The unknown arm contains both a precision calibrated phase shifter, having small attenuation variation, and a precision attenuator having small phase shift. The phase shifter has only 0.4-db attenuation variation for a 360 degree phase shift range. The attenuator has less than 1 degree phase shift for all values of attenuation up to 40 db. These accuracies hold over an 8.5 to 12.4-kmc frequency range.

Phase Measurement

For phase measurement, each arm of the measurement system has a symmetrically located crystal mixer. The local oscillator signal, f_0, from the klystron is fed symmetrically to each mixer through a Wheeler Hybrid T.[5] Provisions are made for signal level adjustment. Each crystal mixer is a hybrid T balanced mixer. For low signal work, this type of mixer contributes appreciably to the suppression of local oscillator noise. A Hughes H-plane folded hybrid T[6,7] is used, fitted with the Microwave Development Laboratories crystal holders, which will take the 2N23D series two-tip 415 crystals, thus permitting choice of mounting polarity. This type of folded hybrid T was chosen because of its high interarm isolation over the frequency range of 8.5 to 9.6 kmc as well as for its mechanical convenience in the

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* Manuscript received by the PGMTT, April 21, 1958; revised manuscript received, June 20, 1958. The work for this paper was supported by the United States Air Force.

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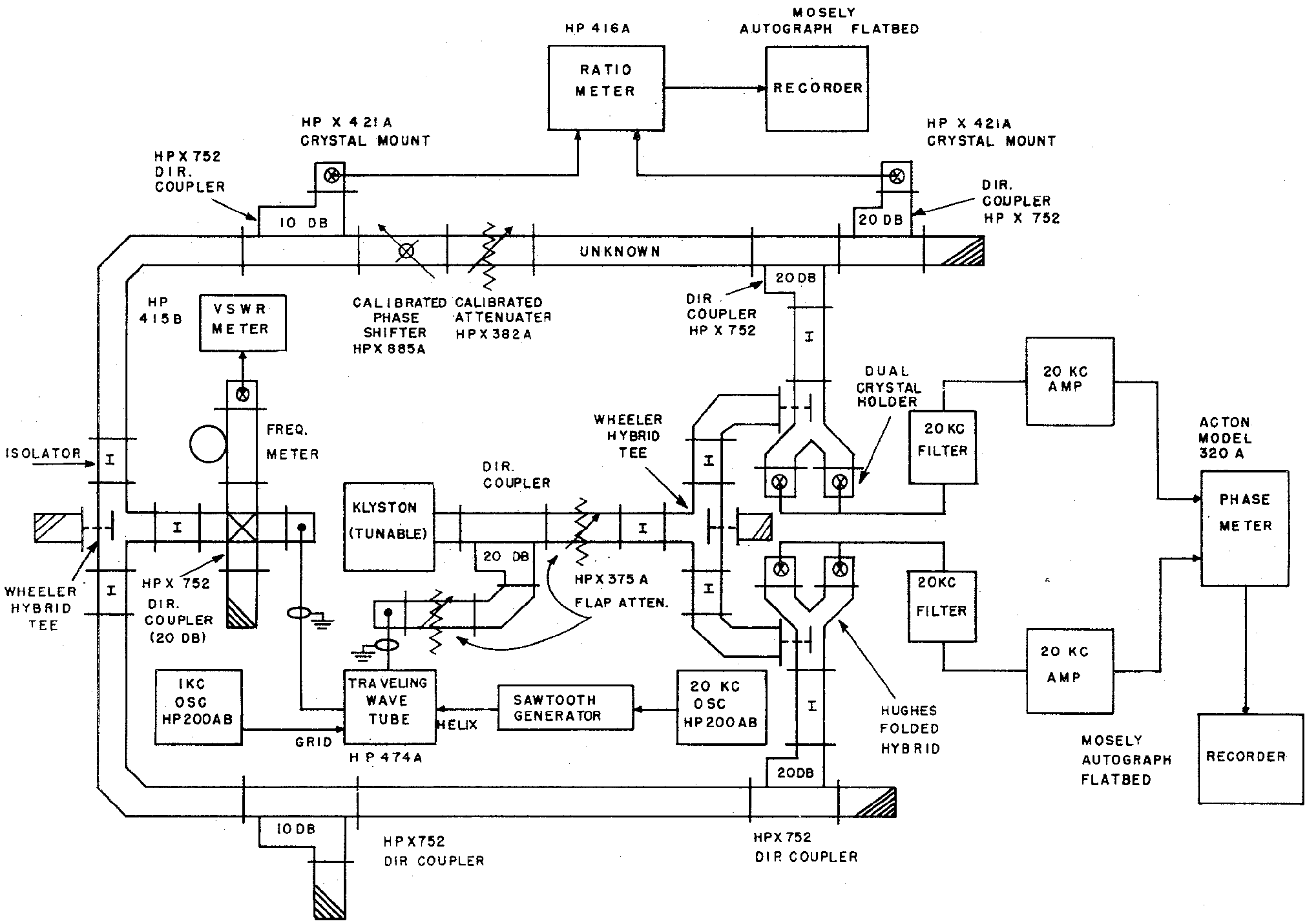

Fig. 1—Symmetric microwave transmission measuring system.

fitting of the crystal holders. The rapid degradation of isolation outside of the 8.5–9.6-kmc frequency range is one of the component properties which limits the frequency range over which the desired precision can be obtained. The available components were adequate for the application requirements to be satisfied by the present equipment. In principle, the single sideband source and the symmetrical arrangement are broad-band techniques. The useful bandwidth depends upon the precision specified and the mechanical symmetry which can be obtained.

In the mixers, then, two 20-kc intermediate frequency signals are generated which are compared in the phase meter for a phase measurement. First, however, each of these two signals is passed through a high-Q 20-kc passive filter to insure a nondistorted waveform which can be used for accurate phase comparison. This is necessary because a "notch" in the IF sinusoidal waveform is caused by the "flyback" of the TWT's helix modulating sawtooth voltage. Wide-band RC coupled amplifiers bring the levels of the two 20-kc signals up to that required by the phase meter. The dc output of the phase meter drives the y axis of the Mosely X-Y-Autograph Recorder, thus giving a continuous record of phase variations as a function of the particular independent variable being used.

Attenuation Measurement

Attenuation (or gain) transmission measurements are easily made by sampling the magnitude of the RF field before and after the unknown by use of the directional couplers. A 1-kc oscillator drives the grid of the traveling-wave tube to amplitude modulate the input signal to the bridge, f_0+20 kc. The crystal detector before the unknown provides the 1-kc input to the "incident" channel of a ratio meter while the detector after the unknown feeds the "reflected" channel. The ratio meter automatically measures the change of attenuation of the unknown substantially independent of changes of the input signal level. The recorder output of the ratio meter drives an x-y recorder for continuous recording of the amplitude response of the unknown as a function of the varied parameter. The directional couplers can be rearranged for reflectometer measurements.

OPERATIONAL CHARACTERISTICS

Fixed-Frequency Measurements

The curves in Fig. 2 and Fig. 3 illustrate the results obtained from the system in a typical fixed-frequency measurement. These curves, simultaneously recorded, show the phase and attenuation responses of a small rod of ferrite material in round waveguide as a function of a

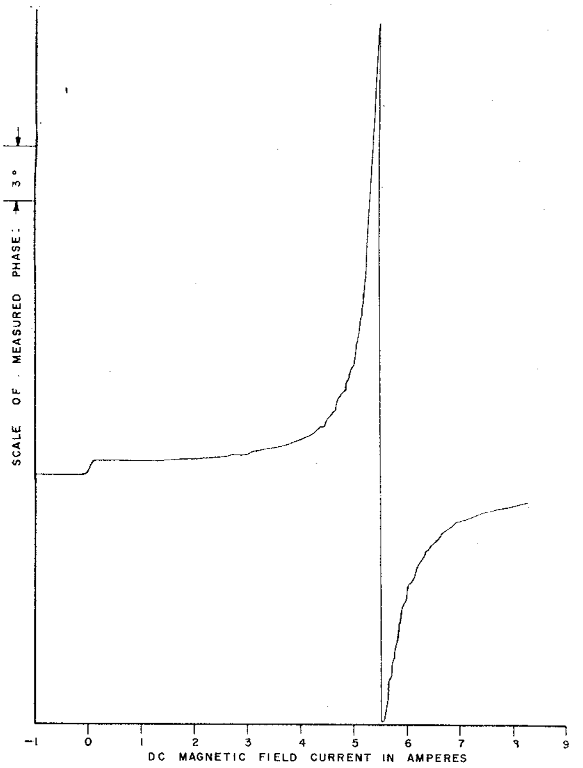

Fig. 2—Phase shift of a ferrite rod in circular waveguide as a function of dc magnetic field for condition of RF circular polarization.

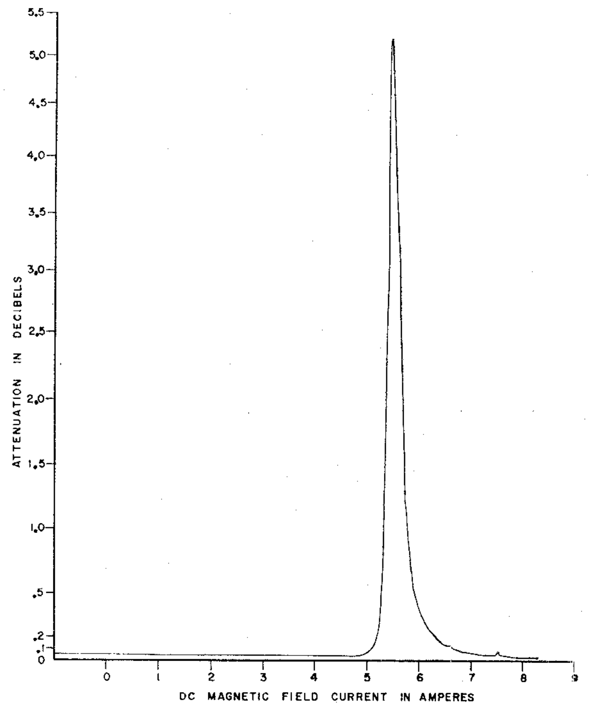

Fig. 3—Attenuation of ferrite rod in circular waveguide as a function of dc magnetic field for condition of RF circular polarization.

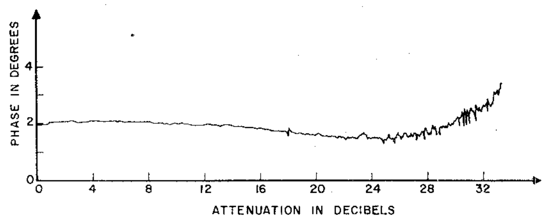

Fig. 4—Measured phase vs dial setting for a Hewlett-Packard X382A precision attenuator placed in unknown arm of measurement system.

longitudinal magnetic field through the rod in one direction. In this case, the microwave signal incident on the sample was circularly polarized. That is, the waveguide "unknown" which was inserted into the arm of the bridge was a piece of round waveguide in a solenoid, preceded and followed by quarter-wave plate sections of round waveguide, each with its rectangular-to-round waveguide transition section. In Fig. 3, the scale of attenuation is shown as calibrated with the sample holder inserted in the "unknown" arm without the ferrite rod. Thus, the displacement of the attenuation curve from zero db represents the minimum insertion loss due to the ferrite rod. In the case of the phase measurement, only the scale is indicated since relative phase shift alone is of significance in a given measurement.

At a fixed frequency, attenuation measurements can be made to within an accuracy of ± 2 per cent of the calibrating attenuator dial reading in decibels. This is the accuracy of the Hewlett-Packard X382A precision calibrated attenuator, which is used to calibrate the system prior to a measurement. The sensitivity may be increased to 0.1 db per inch at any setting of the precision calibrated attenuator. Even at 40-db attenuation, system noise is of the order of 0.02 db. At less than 20-db attenuation, system noise corresponds to less than 0.01 db.

Phase measurements at a fixed frequency can be made with an accuracy of ± 2 degrees. This is essentially the accuracy of the Hewlett-Packard X885A precision calibrated phase shifter (which is 2 degrees from 8.2–10 kmc, and 3 degrees from 10–12.4 kmc). This waveguide phase shifter is used to calibrate the recorders prior to a measurement. In this case, any phase error due to the Acton 320AB Phase Meter, which has a quoted relative accuracy of better than 2 per cent of the differential phase reading, would be avoided. Fig. 4 shows a system phase measurement as a function of the dial setting of a Hewlett-Packard X382A attenuator placed in the "unknown" arm. This shows a maximum variation of 0.5 degree for a 24-db change in level, which is well within the 1 degree accuracy of the attenuator. Although the system sensitivity here limits the dynamic attenuation range to 24 db, this 24-db range can be shifted by resetting the gain of the 20-kc amplifiers.

Measurements as a Function of Frequency

The electrical symmetry of this balanced microwave transmission measuring system permits accurate phase measurements as a function of frequency. In Fig. 5, the residual phase response of the system alone is shown when the precision attenuator and phase shifter have been replaced with open waveguide after a calibration

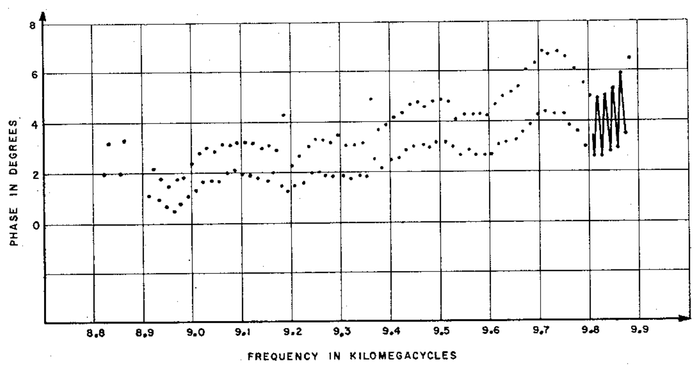

Fig. 5—Residual phase response of symmetric measuring system without calibration phase shifter and attenuator and without padding isolators for mixers.

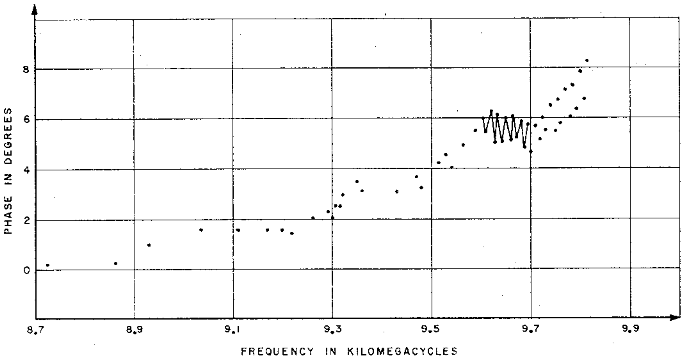

Fig. 6—Residual phase response of symmetric measuring system without calibrating phase shifter and attenuator with padding isolators for mixers.

of the recorders has been made. The calibrating components were removed to improve symmetry in waveguide portions of the system. In Fig. 5, the short period phase variation can be correlated with the reflections from the crystal mixers as a function of frequency. The longer period phase variation (as contrasted with gradual slope) is due to some other discontinuity. Assuming an isolator with a "reverse" reflection coefficient of $\Gamma_I=1.3$, a reflection coefficient from a discontinuity in open guide would need to be only $\Gamma_d=1.14$ to give a one degree measured phase error in the system. The gradual slope seen can probably be attributed to an actual small path length differential in the two arms of the system.

When a padding isolator was placed just at the signal input to each of the crystal mixers, the phase vs frequency response shown in Fig. 6 resulted. The undesirable mismatch characteristics (especially those due to the crystals) were reduced, but the path length differential was accentuated (probably due to difference in the isolators). A small phase perturbation device could be used to eliminate the slope of the response shown in Fig. 6, and thus achieve a phase vs frequency response within ±1 degree for frequency variations from 8.7 to 9.8 kmc. The results shown demonstrate a system phase error of ±2.5 degrees for frequency variations from 8.7–9.6 kmc, with about half this error for half the frequency range.

Higher accuracy is possible when a phase vs frequency measurement is made on an unknown, if the residual phase shift of the system itself is determined and subtracted from the results. In practice, when less precise results are needed, even the calibrating phase and attenuation components can be left in the unknown arm of the system at the expense of symmetry. In such cases, a correction process (subtraction) would be applied to improve the final data.

CONCLUSIONS

This balanced relatively broad-band microwave transmission measuring system can be used to simultaneously and automatically record the phase and amplitude response of a two-port waveguide device as a function of some chosen parameter, such as magnetic field or frequency. With the present components, automatic phase measurements can be made as a function of frequency from 8.7–9.6 kmc with an accuracy of ±2 degrees for a change of attenuation in the unknown of from 0–24 db. A method of reducing this error to ±1 degree has been indicated. Simultaneously, automatic loss measurements can be made with an accuracy of ±2 per cent. Measurements made at a fixed frequency are quickly accomplished and improved accuracy is achievable.

As a piece of test equipment, this balanced system has a great deal to offer in today's need for accurate and rapid transmission measurements over substantial frequency band. The present work has been confined to the 8.7–9.6-kmc frequency range.

It has been demonstrated that the system has certain accuracies of phase and amplitude in variance in the frequency range of 8.7–9.6 kmc. Fundamentally, this highly symmetrical system has capabilities far in excess of this range. With improvement in bandwidth of waveguide components, such as the hybrid *T* and isolators, this can be realized. In the meantime, different frequency ranges within the *X* band can be covered by proper choice of waveguide components. The basic system can easily be applied in other frequency bands.

The system in its present form can be driven by electronically swept microwave sources. Of course, the frequency sweep rates permitted will depend upon both the bandwidth of the receiving components of the system and upon the type of transmission function under examination. Higher speed data accumulation can be engineered into measurement systems of this type as requirements become more stringent.

This system, and modifications of it, are proving to be very useful in antenna phase plotting.

ACKNOWLEDGMENT

The authors wish to acknowledge the competent technical assistance of Tabor P. Baker.