A Method of Measuring Phase at Microwave Frequencies

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A method of measuring microwave phase differences is described in which it is unnecessary to compensate for amplitude inequalities between the signals whose phases are being compared. The apparatus described is also suited for the measurement of the magnitude of a transfer impedance as well as the phase.

WITH the increasing interest in wide-band amplifiers and circuits for microwave communication systems the measurement of the transfer phases of such components has become a necessary procedure. A commonly used technique for measuring phase at microwave frequencies is to sample the signal at the input and output of the device to be measured and to obtain a null balance between the two signals by varying the phase of one signal by a known amount. If the two samples are not of nearly equal amplitudes, it is necessary to attenuate the larger one with an attenuator of known phase shift. The latter operation presents difficulties.

A method of phase measurement has been developed which overcomes these difficulties by permitting measurements to be made with samples of unequal amplitudes. The method uses the homodyne detection principle and operates in the following manner: The output energy of a signal oscillator is divided into two portions. One portion is applied to a balanced modulator where it is modulated by an audio-frequency signal. The suppressed-carrier, double-sideband signal from the modulator is applied to the device to be measured. As before, means are available for sampling the signal at both the input and output of the device. The other portion of the oscillator power is fed through a calibrated phase shifter and is applied to a crystal detector in the manner of a local oscillator in a double-detection receiver. The signal samples are then alternately applied to the crystal detector where they are demodulated by the action of the homodyne carrier. In each case the phase shifter is adjusted so that the audio signal is a minimum in the detector output. This occurs when the phase of the homodyne carrier is in quadrature with the signal sidebands. The difference in phase between the two adjustments of the phase shifter is equal to the phase difference between the two samples.

Figure 1 shows the apparatus used for measuring phase in this manner. Radio frequency power from a suitable oscillator is applied to the H-plane branch of an hybrid junction[1] where it divides and emerges in equal portions

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[1] W. A. Tyrrell, "Hybrid Circuits for Microwaves," *Proc. I. R. E.*, Vol. 35, No. 11, pp. 1294–1306; November 1947.

from the two lateral branches. The portion applied to the calibrated variable phase shifter at the top of the figure becomes the homodyne carrier. The remaining portion is applied to a balanced crystal modulator[2] through a second variable phase shifter which need not be calibrated. The latter was introduced in order that the phase of any modulated power reflected due to an imperfect balance in the modulator could be shifted so that it would be in quadrature with the homodyne carrier and would, therefore, not produce an audible signal in the detector.

The portion of the power which enters the modulator is modulated by a signal derived from an audio-frequency oscillator. The suppressed-carrier, double-sideband signal which leaves the modulator is applied, after a certain amount of attenuation, to the input of the device to be measured. Probes are provided at the input and output of the latter for sampling the signal. Provision is made for connecting either probe to a crystal detector of the type used for detecting an amplitude-modulated signal.

The homodyne carrier emerging from the calibrated phase shifter is attenuated to a level of about one milliwatt and is applied to the crystal detector. The output of the detector is connected to an audio-frequency amplifier terminated by a pair of headphones or an output meter. An attenuator may be placed between the amplifier and the detector as an aid in measuring the magnitude of a transfer impedance.

The procedure for adjusting the apparatus and measuring phase is as follows:

With both sampling probes disconnected from the detector the variable phase shifter between the oscillator and modulator is adjusted until the output of the detector is zero. This balances out the effect of any signal reflected by the modulator. The input probe is then connected to the detector and the calibrated phase shifter is adjusted until the signal disappears in the audio output. When this occurs the homodyne carrier is in quadrature with the signal sidebands, and the resultant signal applied to the detector is equivalent to a phase-modulated wave having a low modulation index, and consequently is not demodulated by a detector of the type used here.

The input probe is then disconnected from the detector and the output probe connected. The phase shifter is again adjusted for a null in the audio output. The difference in phase between the two adjustments of the phase shifter is equal to the phase shift between the input and output of the device. If the probes are not located exactly at the input and output terminals of the unknown it may be necessary to make a correction in the meas-

[2] C. F. Edwards, "Microwave Converters," *Proc. I. R. E.*, Vol. 35, No. 11, pp. 1181–1191; November 1947.

ured phase by allowing for the known phase shift in the line between the probes and the actual terminals of the unknown.

So much for the general method. Certain precautions are necessary in order to avoid errors in measurement. In practice the carrier is not completely suppressed in the output of the balanced modulator. It may be at a
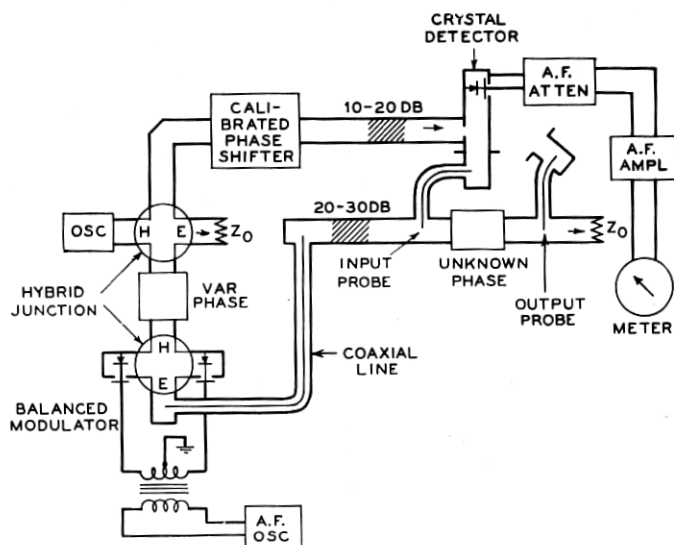
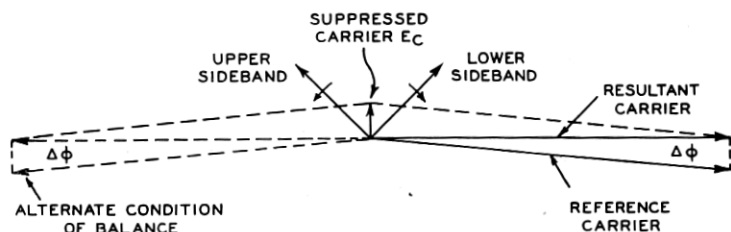Fig. 1—Schematic circuit for microwave phase measurement.

Fig. 2—Vector diagram of balanced condition with the resultant carrier in quadrature with the signal sideband.

level of the order of 10 to 20 decibels below the sidebands. Since the residual carrier will be added to the homodyne carrier in the detector, and since the null adjustment will be reached when the *resultant* carrier is in quadrature with the sidebands, it is desirable that the residual carrier be low in level compared with the homodyne carrier. The error in phase $\Delta\phi$ introduced by the residual carrier is shown in the vector diagram of Fig. 2. A difference in level of about 40 decibels between the homodyne and residual carriers will give an error of not more than half a degree in phase. The

homodyne method of detection has all the conversion efficiency of the usual double-detection arrangements and, in addition, has the advantage in this particular application of having a very low noise level due to the relatively narrow band required for the audio signals.   The 40-decibel level difference mentioned above is accordingly not a serious handicap.

Other precautions must be observed.   The homodyne carrier can be brought in quadrature with the signal for two different phases 180° apart. This is illustrated in Fig. 2.   In many applications, where only the variation
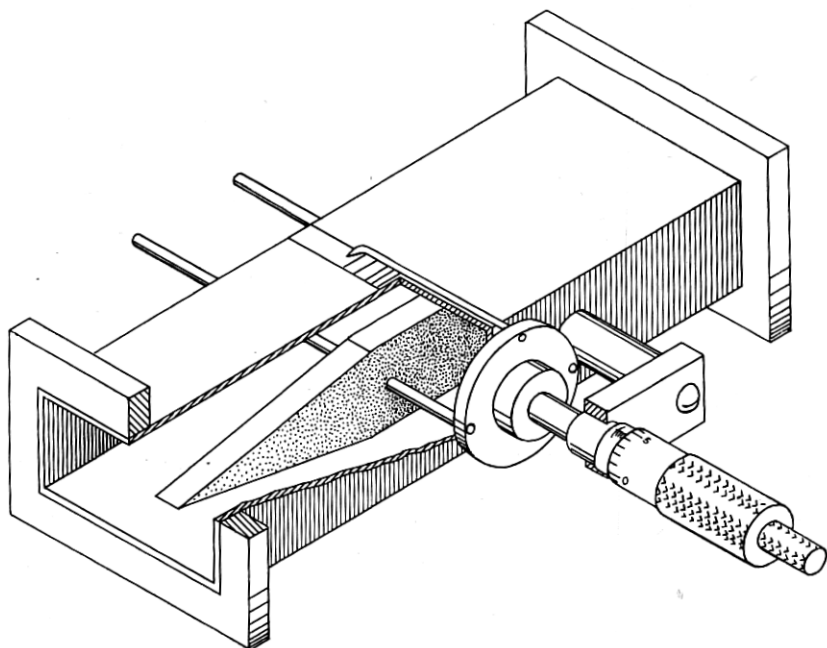

Fig. 3—Variable phase shifter using a polystyrene vane.

in phase difference is of importance, this uncertainty of 180° can be ignored. The correct setting of the homodyne carrier phase can, however, be determined very easily.   Assume that the input probe is connected to the receiver and that the phase has been adjusted for a balance.   Then disconnect the audio frequency drive from one of the crystals in the balanced modulator. The residual carrier will now no longer be suppressed and the error angle $\Delta\phi$ of Fig. 2 will become larger.   Whether the homodyne carrier is lagging or leading the signal carrier can be determined by observing whether more or less phase shift, respectively, must be introduced to restore balance.   A similar test performed with the output probe will indicate whether or not it is necessary to add 180° to the measured phase difference.   If either probe

test indicates a lead, whereas the other probe indicates a lag, then the addition of 180° is indicated.

In microwave circuits it frequently happens that the transfer phase varies quite rapidly with the frequency, particularly if some part of the circuit is at or near resonance.   In measuring the phase characteristics of a circuit of this type over a band of frequencies it is necessary, therefore, to take the points of measurement close enough together to avoid phase errors corresponding to multiples of 360°.

When a balance has been established so that the signal is minimized in the detector output, one may observe the presence of the second harmonic of the audio tone.   This harmonic is a distortion term generated in the detector. If it is objectionable, it can be eliminated either by a low-pass filter in the audio output, or by using a balanced detector.

In measuring transfer impedances it is desirable to know the ratio of the magnitudes of an output voltage and an input voltage as well as the phase difference.   The equipment described here can be used for measuring amplitudes by adjusting the phase shifter for a maximum signal in the audio output.   Maximum signal levels can then be compared with the aid of an audio-frequency attenuator and output meter connected as shown in Fig. 1.

The apparatus was assembled with standard 4000-megacycle waveguide components.   A satisfactory phase shifter was made of an ordinary vane-type variable attenuator by replacing the resistance strip with a vane of quarter-inch thick polystyrene six inches in length.   This phase shifter gave a total shift of about 100°.   Constructional details of this phase shifter are shown in Fig. 3.   Other phase shifters could have been used with equally satisfactory results.   It is desirable, however, that the phase shifter be impedance matched to the line in which it is located in order that reaction back on the oscillator shall be a minimum.   In the shifter of Fig. 3 the ends of the polystyrene vane have been tapered two inches at each end to accomplish this result.

The phase shifter can be readily calibrated by using a standing wave detector fitted with a sliding probe as a standard of phase.   The standing wave detector is terminated on one end and connected to the modulated signal source on the other.   The signal picked up by the sliding probe is applied to the crystal detector.   Knowing the guide wavelength in the standing wave detector, known phase shifts can be introduced by sliding the probe along the guide.   By adjusting the phase shifter in the homodyne carrier path for balance, calibration points can be established.

The measuring procedure described above has been tested experimentally at 4000 megacycles with very satisfactory results.   With ordinary care it was possible to measure phase differences with an accuracy of better than half a degree.