VI-8. A SIMPLE METHOD FOR PRECISE PHASE SHIFT MEASUREMENT

C. F. Augustine

Weinschel Engineering Company, Inc., Gaithersburg, Maryland

This paper discusses a simple method of measuring the phase shift of circuit components with very high accuracy. The method is substantially independent of loss in the circuit component. This is accomplished by using a systematic technique that eliminates errors due to the usual measuring system imperfections. The method uses a hybrid junction, a dual channel null detector circuit, and a high quality phase shift standard whose design is presented in some detail. Phase shift measurement accuracies of 1 degree have been reliably obtained on components with loss up to 40 db.

All practical microwave phase measuring systems use distinct reference and measurement channels that meet in some form of phase comparator. Phase comparators yield output signals proportional to level unbalances as well as phase differences between the channels. These outputs must then be interpreted in terms of phase shift only without sacrificing resolution or accuracy. This interpretation places severe demands on the measuring system when components are inserted in the measurement channel having large losses or gains. Several modulation schemes (References 1, 2, and 3) have been developed to cope with this problem. Their use, however, adds to the complexity of the measuring system and increases the problem of predicting accuracy. The method that will be described uses a dual channel phase comparator. This phase comparator has the basic advantages of simplicity and high resolution even though the component under test has large loss or gain. Very high accuracies can be obtained by following a definite measurement procedure. This procedure will be explained. Factors influencing resolution and accuracy will be cited and values given for typical situations. The construction details of a phase shift standard, a key element in the system, will be described.

A block diagram of a measuring system employing a dual channel phase comparator is shown in Figure 1. Signal from the microwave source is amplitude modulated at a 1 kc rate and divided equally between the reference and measurement channels. A precision phase standard is part of the reference channel. The two channels terminate in two isolated ports of a coaxial hybrid junction. Bolometers are used to detect signal levels at the remaining two isolated ports. The 1000 cps envelope recovered by the bolometers is amplified in two separate audio channels. A synchronous differential null detector subtracts the outputs of the two audio channels and provides a final output voltage proportional to this difference. This output, if plotted as a function of phase difference between the reference and measurement channels, is ideally a sinusoid having zero crossovers whenever the phase difference between the reference and unknown channels is precisely $n\pi$ radians. The zero crossovers are used as reference conditions for the phase measurement. In practice, the ideal condition is normally not obtained. An actual output characteristic compared with the ideal case is shown in Figure 2. The period of the actual output characteristic is 360 degrees but the phase shift between successive crossovers is not 180 degrees. This inequality in spacing is caused by unequal power division in the hybrid junction, differences in bolometer inefficiencies, and differences in amplifier gains between the two audio channels. Furthermore, the position of the null in the actual case is altered by changes in amplitude balance only between the RF reference and measurement channels. It is, therefore, necessary to use an additional technique to precisely establish the relation between a reference null and phase differences. This technique will be explained with the aid of the equations in Figure 3.

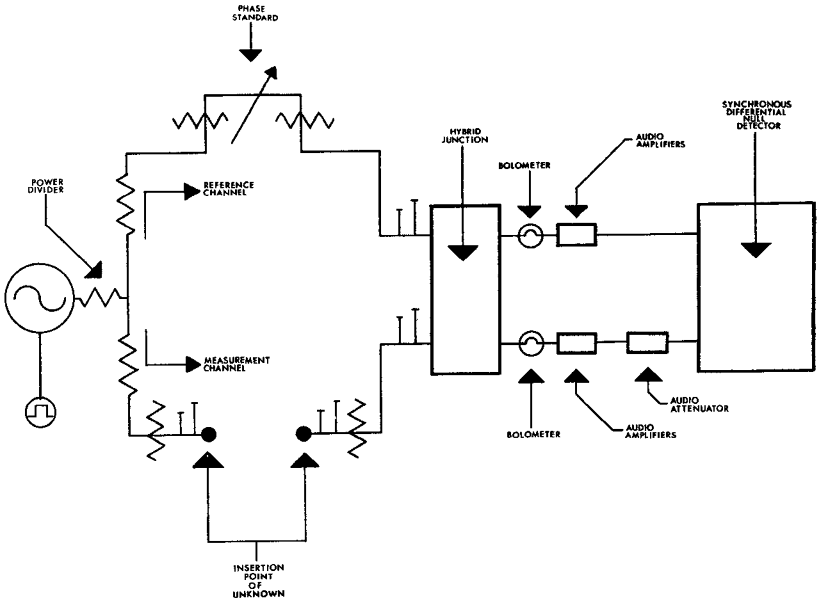


Figure 1. Basic Block Diagram

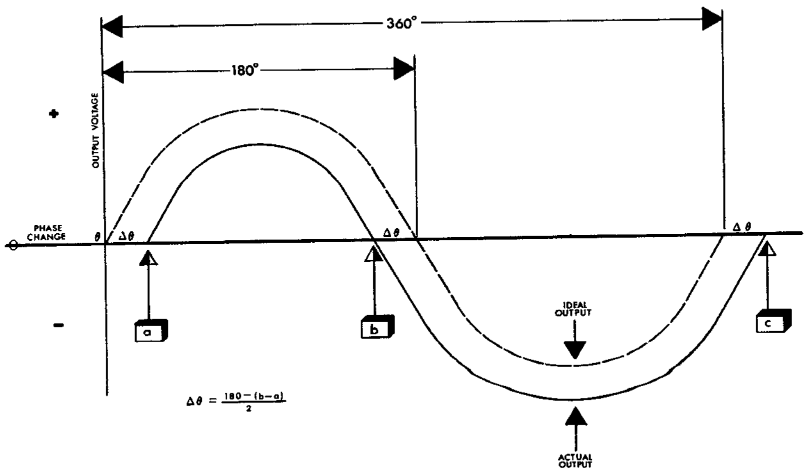
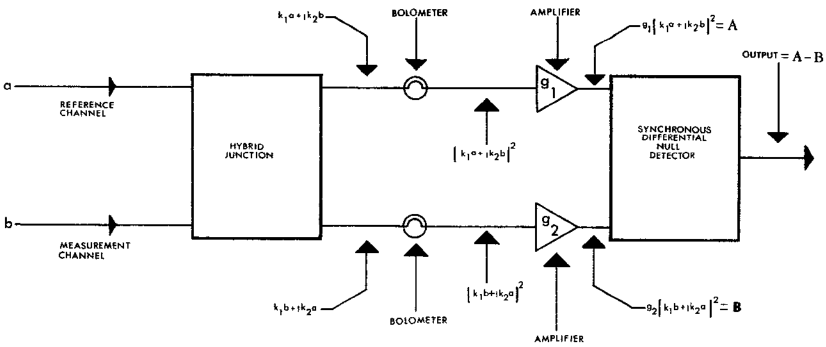


Figure 2. Zero Crossover Relationship



$$A - B = k_1(g_1|a|^2 - g_2|b|^2) + k_2(g_1|b|^2 - g_2|a|^2) + (g_1+g_2)k_1k_2|a||b|\sin\theta \qquad 1$$

IMPOSE CONDITIONS, $\sin\theta = 0$, $A - B = 0$

$$\frac{g_1}{g_2} = \frac{k_1|b|^2 + k_2|a|^2}{k_1|a|^2 + k_2|b|^2} \qquad 2$$

Figure 3. Dual Channel Phase Comparator, Amplitude, Zero Crossover Relationship

The complex inputs to the hybrid junction in Figure 3 are denoted by a and b. Signals appearing at the bolometers can be expressed as $k_1a + jk_2b$ and $k_1b + jk_2a$ where the constants k_1 and k_2 describe the junction coupling characteristics. After square law detection and amplification, the difference between the two audio channels is given by Equation 1 in Figure 3. Equation 1 shows that the desired condition A-B = 0 at the crossovers when $\theta = n\pi$ is obtained provided $g_1 = g_2$ and $k_1 = k_2$ regardless of the magnitudes of a or b. However, if either of these two provisions is not obtained, θ need not be zero at the crossover. By imposing the constraints on Equation 1 that A-B = 0 when $\theta = n\pi$, the relation between gain and coupling given by Equation 2 in Figure 2 shows that there is a ratio of audio amplifier gains that will yield $\theta = n\pi$ for any combination of values of k_1, k_2, or a, b. Furthermore, since $\sin\theta \neq \sin(\theta + \pi)$ unless $\theta = n\pi$, the unique reference condition, $\theta = n\pi$ can be established by adjusting the gain of either audio amplifier such that the phase shift is precisely 180 degrees between successive crossovers, both before and after the insertion of the unknown. Any shift in crossover after these adjustments are made is due to actual phase change rather than loss or gain of the unknown.

When measuring through devices having large loss, measurement errors can be introduced due to decreased resolution and the more pronounced effect of crosstalk through the hybrid junction. The audio signal unbalance for a 1 degree phase shift about a crossover as a function of RF unbalance between the reference and measurement arms is shown in Figure 4. Using output powers normally available from laboratory signal generators, the resolution limit of audio unbalance is about 0.01 db. Figure 4 shows that the increase in error due to lack of resolution is not pronounced for RF unbalances up to 20 db. Since this unbalance can occur both before and after the insertion, phase measurements can be made on components having losses up to about 40 db.

The construction details of a line stretcher type of phase shifter designed for this system are shown in Figure 5. The slab line construction eliminates the need for sliding contacts on both inner and outer conductors, as is the case in coaxial line stretchers. The sliding trombone center conductor section is fabricated using very thin-walled tubing. A firm spring-action sliding contact is obtained by plating hard gold on the inside tip of the thin-walled tubes. The trombone section is supported between the ground planes in the region of minimum field strength by using tapered dielectric supports

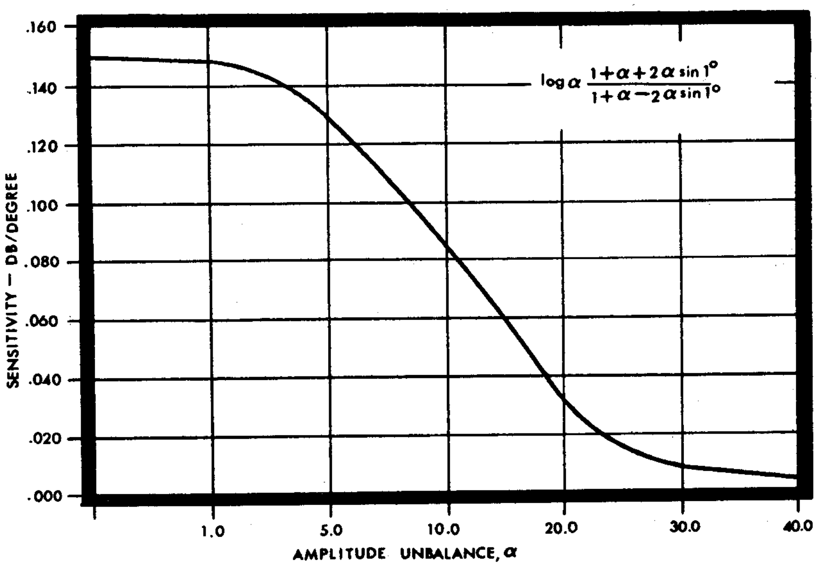


Figure 4. Balance Sensitivity in DB/Degree Near Crossover versus Amplitude Unbalance

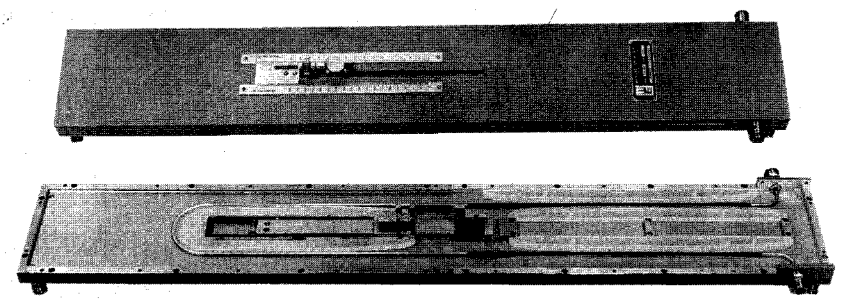


Figure 5. The Phase Shift Standard

that produce no significant discontinuities. Phase errors that might occur due to impedance interaction effects between the connectors are significantly reduced by inserting long, well-matched 3 db attenuators between the connectors and the trombone section. Maximum possible errors due to impedance interaction effects are typically 0.15 degree from 1 to 12 gc. Overall accuracy can be predicted by adding this error to that resulting from limited mechanical resolution. The resolution that can be obtained with precision scales and verniers is about 1/20 mm of line stretch. The overall accuracy of the standard is, therefore, about 0.21 degree at 1 gc, 0.45 degree at 5 gc, and 0.75 degree at 10 gc.

Measurement errors result from inaccuracies in the phase standard, impedance interaction effects at the insertion points of the unknown, leakage through the hybrid junction, and resolution limits. Maximum possible errors for typical measuring situations are tabulated in Figure 6 Some discussion regarding the causes and methods of minimizing errors as well as experimental data will be given.

VARIABLES															
FREQUENCY, GC	1	5	10	1	5	10	1	5	10	1	5	10	1	5	10
TERMINAL IMPEDANCE, VSWR	1.02	1.05	1.05	1.02	1.05	1.05	1.02	1.05	1.05	1.02	1.05	1.05	1.1	1.1	1.1
HYBRID JUNCTION ISOLATION, db	30	30	30	25	25	25	25	25	25	25	25	25	25	25	25
IMPEDANCE FACING HYBRID JUNCTION, VSWR	1.02	1.05	1.05	1.02	1.05	1.05	1.02	1.05	1.05	1.02	1.05	1.05	1.1	1.1	1.1
AMPLITUDE UNBALANCE, db	0	0	0	0	0	0	10	10	10	20	20	20	0	0	0
IMPEDANCE OF UNKNOWN, VSWR	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25

MAXIMUM PHASE ERROR, DEGREES																
HYBRID JUNCTION LEAKAGE	04	09	09	08	.17	.17	18	.27	27	.54	81	81	10	.10	10	PERIODIC ERROR
INTERACTION EFFECTS @ BRIDGE TERMINALS	12	30	30	12	30	30	12	.30	30	12	30	30	60	60	.60	PERIODIC ERROR
PHASE STANDARD ERRORS DUE TO IMPEDANCE INTERACTION	15	.15	15	15	.15	15	15	15	15	.15	.15	15	15	15	15	PERIODIC ERROR
PHASE STANDARD ERROR DUE TO READOUT ERROR	.06	.30	60	.06	30	60	06	.30	60	06	.30	.60	.06	.30	.60	RANDOM ERROR
	.37	.84	1 14	41	.92	1.22	.51	102	1.32	.87	156	1.86	91	1 15	1.45	MAX. POSSIBLE ERROR

Figure 6. Summary of Maximum Possible Errors

REFERENCES

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