# Measurement of Time-Quadrature Components of Microwave Signals*

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*Summary*—**A phase-sensitive coherent detector used for microwave laboratory measurements is described. The receiver measures the real ($|E|$ cos $\alpha$) and imaginary ($|E|$ sin $\alpha$) components of a signal $E$ with equipment which is less elaborate than that required for measuring the amplitude $|E|$ and phase $\alpha$. Furthermore, many calculations are more convenient if $E$ is presented in rectangular rather than polar form.**

**Measurements made with the receiver on known fields in waveguides are included to demonstrate its accuracy. The receiver has a sensitivity of $-125$ dbw at 9,375 mc.**

## INTRODUCTION

LET $E$ DENOTE some microwave signal which is being received, and let $|E|$ and $\alpha$ denote its amplitude and phase, respectively. $E$ may be a function of time or a function of the position of a probe exploring the fields near a transmitting antenna, etc. For convenience in making calculations[1] it is often desirable to record the time-quadrature components $|E|$ cos $\alpha$ and $|E|$ sin $\alpha$. These are also called the real ($\Re[E]$) and imaginary ($\Im[E]$) components, respectively, of $E$. Indeed, it is found that it is possible to make direct measurements of $\Re[E]$ and $\Im[E]$ with equipment which is less elaborate than that required for direct measurements of $|E|$ and $\alpha$.

## THEORY

Fig. 1 illustrates the equipment used for measuring $\Re[E]$ and $\Im[E]$. The detector is commonly referred to as a coherent or synchronous[2] detector for reasons which will become obvious. Receivers of this type have been proposed and analyzed in the past[3] but have involved certain difficulties which have been overcome only recently with the development of nonreciprocal ferrite components and new modulation techniques.

The receiver is used at a frequency of 9,375 mc. Two type 821 Sperry barretters are used as the detecting elements. An unmodulated signal $A$ of constant phase and amplitude is applied to the barretters directly from the klystron. In addition a test signal $E$, amplitude modulated at some low frequency (1,000 cps), is applied. The barretters are connected to the collinear arms of a hybrid junction, and signals $A$ and $E$ arrive through the two orthogonal arms. Tuning is provided in one collinear arm to achieve maximum isolation between signals $A$ and $E$. Because of the properties of the hybrid junction, the total signals arriving at barretters 1 and 2 are, respectively,

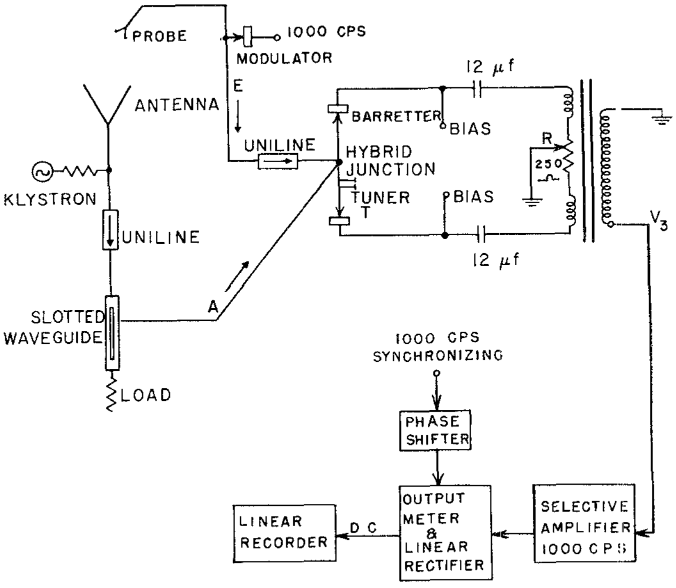

Fig. 1—Equipment for measuring the real and imaginary components of a microwave signal.

$$E_1 = A + E, \tag{1a}$$

and

$$E_2 = A - E. \tag{1b}$$

If we arbitrarily call the phase angle of signal $A$ zero, then

$$E_1 = A + |E| \cos\alpha + j|E| \sin\alpha \tag{2a}$$

$$E_2 = A - |E| \cos\alpha - j|E| \sin\alpha. \tag{2b}$$

The output voltages $V_1$ and $V_2$ of barretters 1 and 2 are proportional to $|E_1|^2$ and $|E_2|^2$, respectively. That is,

$$V_1 = (A + |E| \cos\alpha)^2 + (|E| \sin\alpha)^2 \tag{3a}$$

$$V_2 = (A - |E| \cos\alpha)^2 + (|E| \sin\alpha)^2. \tag{3b}$$

An audio transformer takes the difference between $V_1$ and $V_2$, yielding

$$V_3 = 4|A|\,|E| \cos\alpha. \tag{4}$$

Since $A$ is held constant, $V_3$ is proportional to $R[E]$.

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[1] J. H. Richmond, "Simplified calculation of antenna patterns, with application to radome problems," submitted for publication in *Trans. IRE*, PGMTT.

[2] M. E. Brodwin, C. M. Johnson, and W. M. Waters, "Low level synchronous mixing," 1953 IRE CONVENTION RECORD, Part 10, "Microwaves," pp. 52–57.

[3] R. L. Cosgriff, "A Study of Detectors and Amplifiers Used in Antenna Instrumentation," Tech. Rep. 487-5, December 28, 1953, Antenna Lab., Ohio State Univ. Res. Found.; prepared under Contract AF 18(600)-160, Air Res. and Dev. Command, Wright Air Dev. Center, Wright-Patterson AF Base, Ohio.

Now, a similar detector could be added alongside the one shown in Fig. 1 and adjusted to provide an output signal $4\,|A|\;|E|\,\sin\alpha$ proportional to $\mathfrak{I}[E]$. This could readily be accomplished by applying signals $A$ and $E$ as before but with a phase shift of 90 degrees applied to $A$. At present, however, this additional complexity of equipment is avoided at the cost of a certain increase in operating time. This is done by running each experiment twice in rapid time sequence, recording $\mathfrak{R}[E]$ on the first run, shifting signal $A$ through 90 degrees in phase with the slotted waveguide shown in Fig. 1, and recording $\mathfrak{I}[E]$ on the second run.

Incidentally, the coherent detector of Fig. 1 can readily be adapted for automatic phase plotting.[4]

## Equipment Components and Adjustment

The Uniline is a nonreciprocal ferrite device which allows transmission in the forward direction with little loss but provides a large attenuation for energy traveling in the reverse direction. The purpose of the Unilines shown in Fig. 1 is to help isolate the klystron from variations in load impedance and to provide extra isolation between signal $A$ and the modulator.

The modulator in use consists of a 1N23 crystal in a tunable detector mount. A low-frequency (1,000 cps) modulating signal of about three volts is applied to the crystal, and the resulting variations in crystal impedance produce amplitude modulation on the radio-frequency wave traveling down the waveguide. As compared with square-wave modulation of the klystron, crystal modulation involves a loss of 3 or 4 db of sensitivity because of incomplete modulation and other factors. However, it is essential that the reference signal be unmodulated; hence, klystron modulation would not be suitable. If the reference signal were modulated, the measurement of small test signals would be interfered with by a residual output signal present in the receiver due to imperfect audio nulling. A simple audio nulling circuit (merely potentiometer $R$) is satisfactory if the reference signal is unmodulated, since then the only undesired signal component produced by the barretters due to the reference signal is a dc signal and hence is rejected by the selective amplifier.

The selective amplifier was built at the Antenna Laboratory.[5] It has a pass band of 4 cps centered at 1,000 cps.

The linear rectifier to be used depends on factors such as the dynamic range required. A chopper rectifier, synchronized with a properly phased signal from the modulator, should be satisfactory. A type 1N34 germanium diode is in use at present. The diode is operated at a signal level large enough to obtain linear response.

Two nulling operations are involved in adjusting the receiver. Signal $A$ is disconnected from the hybrid junction, and a test signal $E$ of about 1 mw is applied. A detector is connected to the hybrid junction at the terminal where signal $A$ was removed. Tuner $T$ is now adjusted for a null indication at the detector. A second nulling operation is now performed by adjusting potentiometer $R$ for a minimum indication on the output meter.

## Performance

As a test of accuracy, the real- and imaginary-components plotter was used to measure known fields in a waveguide. The antenna shown in Fig. 1 was replaced with a slotted waveguide. A probe moving along the waveguide axis extracted a test signal $E$. Measurements were taken with the slotted waveguide terminated with a matched load and then with a metal reflector. The results are shown in Figs. 2 and 3 (opposite). In both cases, theory indicates that $\mathfrak{R}[E]$ should be a sinusoidal function of distance $x$ along the waveguide axis. As is evident in the figures, excellent agreement was obtained between the theoretical and measured functions. Any slight disagreement is as likely to be caused by an imperfect slotted waveguide or termination as by any inherent defect in the detector. These measurements were repeated with equally good results at signal levels up to 1 mw with a reference power of 1 mw.

The sensitivity of the receiver with a reference signal of 10 mw was measured as $-125$ dbw at 9,375 mc. That is, a test signal power of $-125$ dbw was required to raise the receiver output by 3 db over the output level observed in the absence of any test signal. This could no doubt be improved, if desired, by using a more efficient modulator, improving the impedance match between the barretters and the selective amplifier, adjusting the barretter bias current to the optimum value, etc. A bias current of 5 ma was used for each barretter.

TABLE I

Average Receiver Noise Output as a Function of Barretter Bias Current and Reference Power Level in Absence of Test Signal

| Bias current (ma) | Reference power (mw) | Noise output (volts) |
|---|---|---|
| 0 | 0 | 0.33 |
| 5 | 0 | 1.00 |
| 5 | 10 | 1.18 |

The measurements in Table I above show that the output noise of the receiver increases somewhat as the barretter bias current is increased, but is quite insensitive to the reference signal level.

Eq. (4) indicates that the output signal should be proportional to the reference level $A$ for a given test

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[4] J. Bacon, "An Automatic $x$-Band Phase Plotter," Proc. Nec. Conf., Chicago, Ill.; October, 1954.

[5] Described in J. Bacon, "Selective Bolometer Amplifier," Tech. Rep. 301-24, September 15, 1950, Antenna Lab., Ohio State Univ. Res. Found.; prepared under Contract W 33-038 sc 16520, Air Res. and Dev. Command, Wright Air Dev. Center, Wright-Patterson AF Base, Ohio.

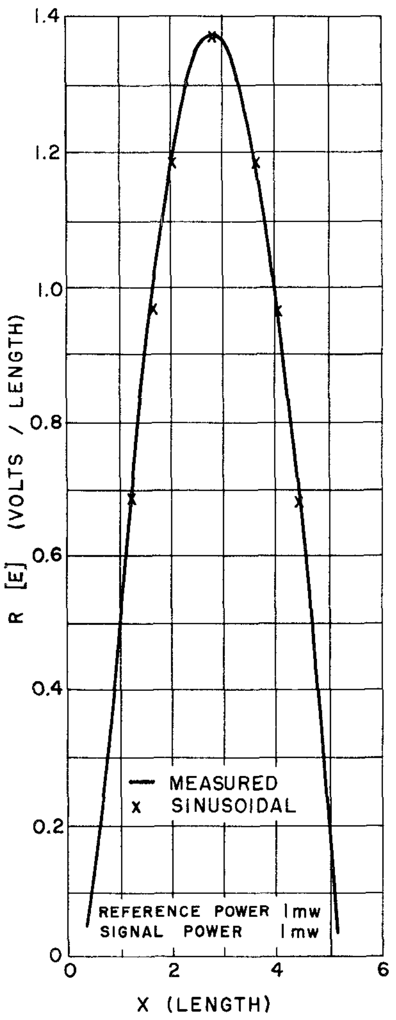

Fig. 2—Real component of electric field intensity in matched waveguide.

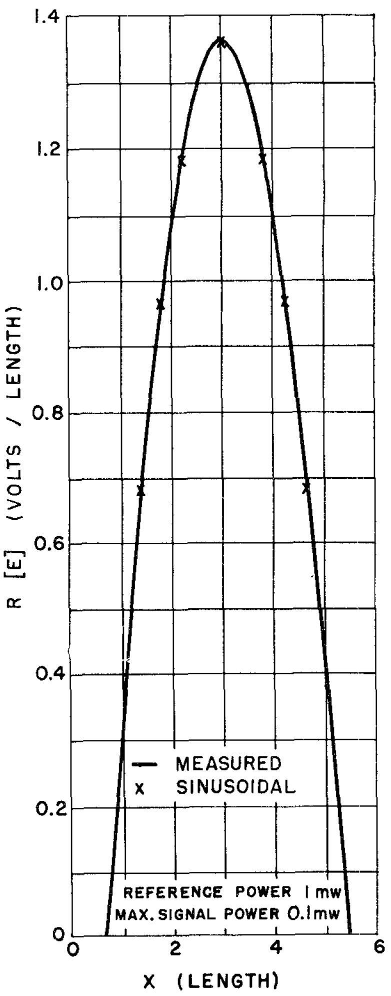

Fig. 3—Real component of electric field intensity in shorted waveguide.

signal $E$ and a given phase angle $\alpha$. This was found to be accurate for reference levels greater than the test signal level. At smaller reference levels, the output approached a small constant value.

It was found that crystals performed as well as barretters in the coherent detector. The waveguide field measurements shown in Figs. 2 and 3 were repeated using 1N23 crystals with equally good results. The sensitivity of the coherent detector using crystals was found to be −123 dbw at 9,375 mc. This measurement was made with the reference signal adjusted to the optimum level, which was found to be −36 dbw.

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