III-2. A Technique for Measuring Phase Modulation or Rapid Phase Changes of a Microwave Signal

W. P. Ernst

Plasma Physics Laboratory, Princeton University, Princeton, N.J.

There have been many schemes devised to detect phase shift at microwave frequencies. Most of them are capable of high accuracy when measuring a steady state phase change. The problem becomes a little more complex when one desires to monitor phase when it is varying with time, where the time intervals may be in the order of a few microseconds. The double probe method[1] has been adapted to measure phase modulation, but falls short in two instances: a) the range of phase change is limited, i.e., up to 90°; b) the technique is difficult to adapt to measurements at millimeter wavelengths. The "zebra-stripe" Wharton[2,3] microwave interferometer is capable of handling wide dynamic phase shifts, but here again we find a disadvantage in that a large number of fringe shifts, caused by very large phase changes, make it cumbersome to resolve the phase *vs* time contour. Another scheme by Osborne[4] presents the phase *vs* time as a polar plot, where timing pulses appear as dots on the display. Multiradian phase shifts are again difficult to resolve.

The system to be described is modeled after one described by Heald,[5] but differs in that the carrier frequency is fixed and a method of calibration has been incorporated.

Simplified Theory. For a phase modulated signal, the instantaneous value of the modulated carrier voltage may be written

$$E_t = Em \sin (\Omega t + \Delta\theta \sin \omega t) = Em \sin \beta \tag{1}$$

where the term $\Delta\theta \sin \omega t$ is the phase modulating term (here assumed sinusoidal for simplicity). If the carrier voltage is plotted as a rotating vector, β includes the phase variation about a constant radian velocity. The change of β with time is the instantaneous angular velocity $\Omega_t = 2\pi F_t$, and $\Omega_t/2\pi$ is the apparent instantaneous frequency, F_t, due to the phase modulation and the fixed frequency F. Thus,

$$F_t = \frac{1}{2\pi}\frac{d\beta}{dt} = \frac{\Omega}{2\pi} + \frac{\omega\Delta\theta}{2\pi} \cos \omega t = F + f\Delta\theta \cos \omega t.$$

The term $f\Delta\theta \cos \omega t$ is the change of instantaneous frequency due to phase modulation. It is to be noted that the change in frequency is not only proportional to $\Delta\theta$ but also to f, which is the frequency of the phase modulating process. Hence, when the phase modulated signal is passed through a frequency discriminator circuit, the faster the phase is changing with time, the larger the ΔF, and the greater the voltage out of the discriminator detector network. If we follow the discriminator output with an integrating circuit, where $E_o \sim 1/f$, there will result an output voltage which is proportional to the amount of phase change only—and not to the rate of phase change.

Circuit Description. Figure 1 is a block diagram of the system which was built to measure the phase modulation of a 70 Gc/s signal (the particular application will be mentioned subsequently). The carrier signal, *fc*, is split into two paths by the directional coupler. One coupler output goes to a single sideband generator where the carrier frequency is shifted to *fc* + 30 Mc. The shifted carrier is passed through the phase modulating medium and then on to a balanced mixer. The local oscillator input to the mixer is the original carrier *fc* from the other directional coupler output. The difference frequency, 30 Mc, is amplified in a conventional preamplifier and then applied to a limiter-discriminator circuit, which has a center frequency of 30 Mc and has a linear "S" curve over ±3 megacycles. The discriminator detector output is then followed by an integrating network whose RC time constant is consistent with the maximum rates of phase shift to be measured. The integrator output is applied to the Y-axis of a viewing oscilloscope which is triggered by a timing pulse.

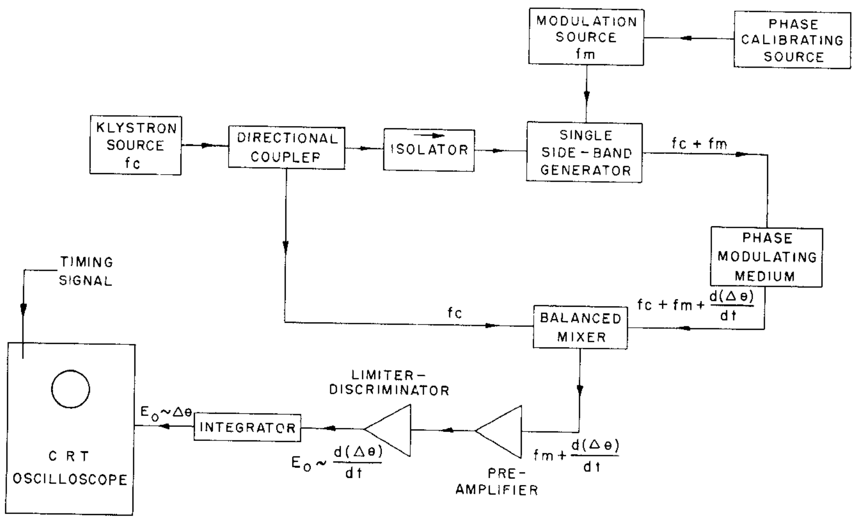

Fig. 1. Block diagram of a system for measuring microwave phase modulation.

To calibrate the system, two methods may be used: a) a ferrite phase modulator may be placed in the test leg and then a known amount of phase modulation imposed on the upper sideband *fc* + 30 Mc for calibrating the integrator output; or, b) the 30 Mc signal into the single sideband generator may be phase modulated in a known way. The latter method has been used in this system. Figure 2 shows some oscilloscope pictures of the calibrating signal and integrator output wave forms for different rates of phase change.

Application. The particular application for this system has been in the measurement of electron density in a hot plasma. It is well known that when plasma (ionized gas) is placed in the path of a microwave probing signal whose frequency is greater than the plasma frequency, the phase of the probing signal will be changed due to the varying index of refraction of the plasma medium. The amount of change is proportional to the electron

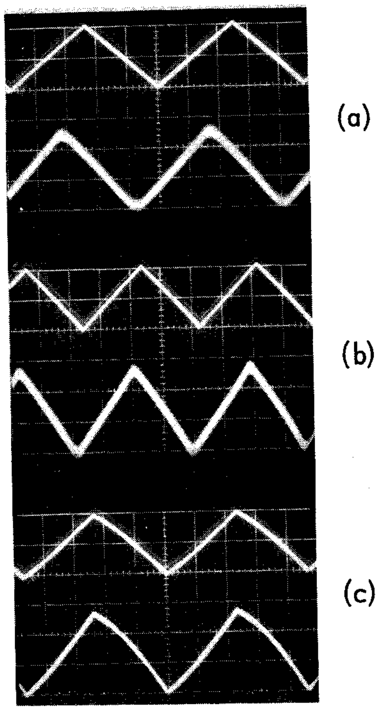

Fig. 2. Oscilloscope display showing the input waveform (top trace) to 30 Mc phase modulator to produce 2π radians of phase shift; and the system integrator output (bottom trace) for different phase modulating frequencies.

(a) $f =$ 100 Kc Scope Sweep 2 μsec/cm
(b) $f =$ 50 Kc " " 5 "
(c) $f =$ 10 Kc " " 20 "

density of the plasma. In a pulse-type plasma device, the electron density may vary very rapidly with time—thus causing a rapid change of phase with time of the microwave signal. The system as described has been used to monitor the "fine-grain" variations of electron density in a plasma generating device.

REFERENCES

1. P. Lacy, "A Versatile Phase Measurement Method for Transmission Line Networks," *IRE Trans. on Microwave Theory and Techniques*, Vol. MTT-9, pp. 568–569 (November, 1961).
2. C. B. Wharton, "Microwave Diagnostics for Controlled Fusion Research," UCRL Report No. 4836, 1957.
3. W. P. Ernst, "An Electron Density Measuring System for Hot Plasma Research," *Microwave J.*, Vol. 4, No. 2, pp. 49–54 (February, 1961).
4. F. J. Osborne, "Microwave Plasma Diagnostics by Phase and Amplitude Measurements," R. C. A. Report No. 9-801-15, Montreal, Canada.
5. M. A. Heald, "Proposal for a New Type of Phase Measuring System Having an Output Voltage Proportional to Phaseshift," Princeton University PPL Microwave Memo No. 4, 1959.

JASIK LABORATORIES, INC.
100 Shames Drive Westbury, L.I., New York

Research, Development and Production: Antennas,
Antenna Systems and Associated Components