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Digitized Phasemeter

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A device for measuring the phase of periodic signals in the audio or low ultrasonic frequency range is described. The error in the measurement is independent of signal amplitude within limits, and for signals usually met in practice is less than 0.1°. The device is easy to operate. The only adjustment required is the setting of the sensitivity of an electronic counter. Results of phase measurements are read on the counter. A way in which the measurement can be made independent of even order harmonics in the test signal is also discussed.

The purpose of the device being described is to measure phase of periodic electrical signals in the audio or low ultrasonic frequency range. The error in the measurement is independent of the amplitude of the signal within limits. For signals usually met in practice, the error is less than 0.1°.

The methods of phase detection generally employed are of two kinds: null detection [1] [1] and zero crossover detection [2]. In the first method, the difference in phase between the test signal and a standard is reduced to zero by the use of a calibrated phase shifter. This method has the disadvantage of requiring careful adjustment of the nulling circuits.

In the method of zero crossover detection, two signals are clipped and compared in a mixing circuit. The pulse width of the resultant rectangular wave is a linear measure of the phase difference between the original signals. This method is used frequently because of its relative simplicity; fewer adjustments are required. The accuracy depends upon the ability to clip inputs of various amplitudes close to their zero crossings. Such close clipping produces rectangular waves approximately in phase with their related input signals.

The device described here is an improvement over other phasemeters using zero crossover detection because of the use of stable circuits which accurately clip input signals at their zero crossings. The transistor circuitry is simple and requires no bias or other circuitry adjustments. The accuracy of the clipping action is preserved through the mixing and metering operations. Phase measurements are read on an electronic counter. Any counter capable of handling 1 MHz repetition rate pulses may be used. Over a 20 Hz to 20 kHz frequency range, a phase error of less than 0.1° is obtained for input signals of 0.1 to 20 V. Signals of a considerably wider frequency range and lower amplitude may be employed with some loss in accuracy.

The best null detection instruments presently have greater ultimate accuracy but require frequent complex adjustments or have restricted ranges of phase.

A block diagram of the overall phasemeter is shown in figure 1. There are two identical input channels. The input signals must be periodic with uniformly spaced zero crossings. The number of zero crossings per period must be the same for both input signals. The input channels each shape an input signal into a rectangular wave. The rectangular waves are combined in a mixer, and the resultant is applied to a gate. A series of 1 MHz pulses fed to a counter is interrupted when the gate is closed. The average number of pulses counted during a gating cycle is proportional to the phase difference between the input signals. The gated series of pulses usually includes a fraction of a pulse appearing at the beginning and end of each sequence. This fraction is determined by the width of the gating signal. The count of the fractional pulse is averaged over many gating periods so that the phase is sufficiently resolved at the 1 MHz rate. Adequate resolution is obtained even when the number of pulses to be counted is small, as occurs during a gating period of short duration.

When the phase detector and counter are used together for the first time, the counter sensitivity control should be adjusted so that the fractional pulse is averaged properly. This control may be adjusted in the following way: A signal of high frequency ω_1 is fed into one input of the phase detector and a signal of lower frequency ω_2 is fed into the other input. A gating signal results which causes the gate to transmit one quarter of the 1 MHz pulses to the counter. During each cycle of gating the signal from the mixer consists of a half cycle rectangular pulse derived from the lower frequency input added to a series of shorter half cycle rectangular pulses derived from the high frequency input. The number of pulses in the series depends upon the arbitrarily chosen ratio of ω_1 to ω_2. Unless ω_1 and ω_2 are integrally related, the time interval between the pulse recurring at the low frequency rate and the high frequency series of pulses varies in a continuous and periodic way. On the average, the gate is closed during half a gating cycle due to the lower frequency pulse and half of the remaining half of the gating cycle due to the high frequency pulses. With those inputs the sensitivity control is adjusted to give a 0.25 MHz reading on the counter. It is desirable to use input signals at the high end of the frequency range when making this

[1] Figures in brackets indicate the literature references at the end of this paper.

adjustment because the effect of fractional megahertz pulses is greatest when the gate is open for short times. Thus, an adequate adjustment with high frequency input signals will be correct for lower frequencies. In the method of adjustment described the presence of some noise in the input signal is unimportant since the count is averaged over many gating cycles.

The circuit used to convert an input wave to an accurately inphase rectangular wave is shown in figure 2. The basic elements consist of amplifier Q_3 of large gain, and feedback diodes CR_3 and CR_4. These work in the following way: An input signal applied to the base of Q_3 is greatly amplified until the collector output voltage breaks down the forward resistance of either diode CR_3 or CR_4. Above this breakdown voltage, any increase in the collector voltage is fed back to the base input of Q_3. The large negative feedback sharply reduces the gain of the amplifier. The action of Q_3 and Q_4, which results in a clipped wave, is symmetrical for positive and negative input signals. Since the gain of Q_3 is large, the breakdown occurs abruptly soon after the input voltage departs from zero. Consequently, the diode

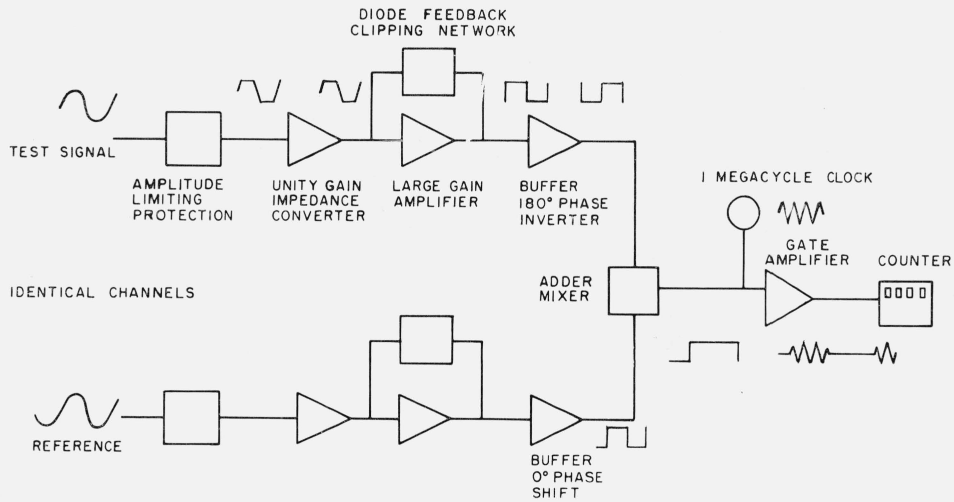

FIGURE 1. *Block diagram of phasemeter.*

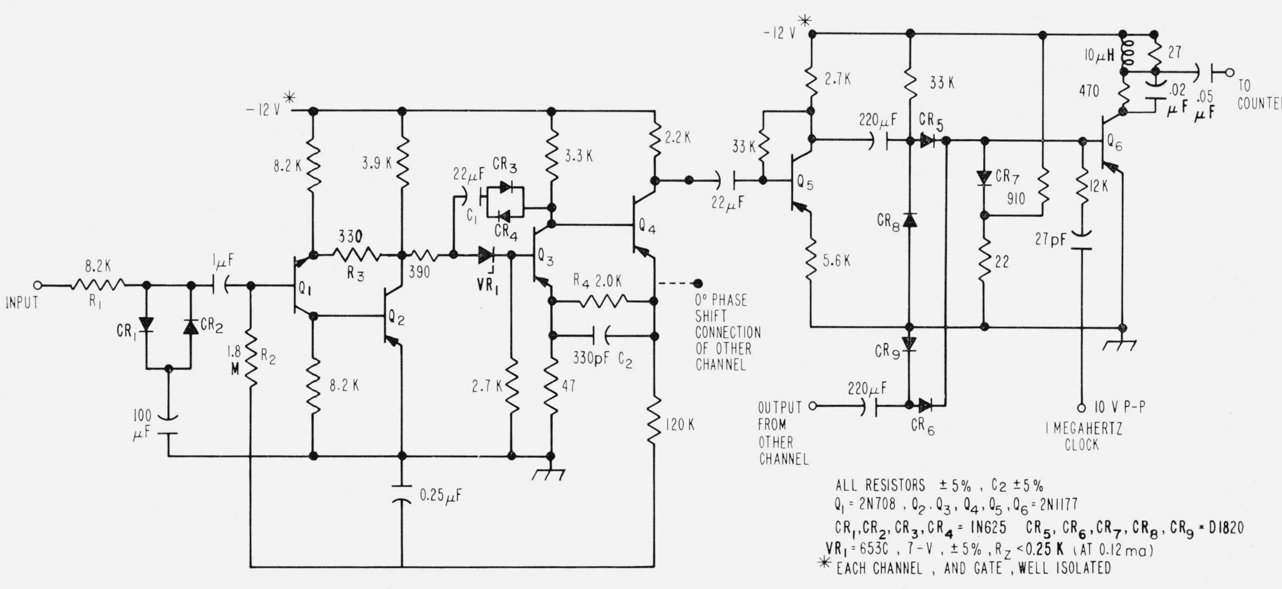

FIGURE 2. *Schematic pf phasemeter (one shaper channel shown).*

characteristics may differ somewhat without delaying the clipping action. The large negative feedback during breakdown prevents Q_3 from saturating or cutting off, avoiding transistor storage and delay problems. (The use of nonlinear devices as feedback elements in an operational amplifier is illustrated by Greenwood, I.A., et al. [3].)

The rest of the circuitry performs as follows: A portion of the signal from the output of Q_3 is returned to the input of Q_3, through Q_4, resistor R_4 and capacitor C_2. The feedback is positive and controlled so that the gain of Q_3 is large yet stable. C_2 opposes the "Miller effect" capacitance shunting the input of Q_3. The resulting speedup in the vertical rise of the clipped wave at high frequencies sharpens the gating action. A reduction of high frequency phase shift also occurs. The low source resistance coupling Q_2 to Q_3 minimizes this phase shift. The negative feedback through R_3, which lowers the source of resistance of Q_2, also raises the input resistance of Q_1 to several megohms shunted by R_2. The input capacitance of the unity gain amplifier Q_1–Q_2 is less than 10 pF.

The phase shift introduced by each channel is negligible in the midfrequency range, but increases at the extreme of the range for which the metering circuit is designed. This error may amount to a fraction of a degree at 20 Hz and at 20 kHz. However, as both channels are nominally identical in components, the relative phase error between the channels is much smaller.

The positive portions of the rectangular waves obtained from each channel are combined at the diode mixer CR_7. Diodes CR_5 and CR_6 are slightly forward biased so that small positive signals are readily transmitted to the mixer. The negative portions of the clipped wave from either channel are not transmitted. This prevents a negative signal from interfering by cancellation with the gating action of a positive signal. Thus, slowly rising high frequency pulses cause gating at their start with little delay. The positive rectangular pulses developed across CR_7 drive gating amplifier Q_6 to cutoff. The gated series of 1 MHz pulses is subsequently taken from the collector junction of Q_6 when the gate is open.

Each channel is protected from overload by diodes CR_1 and CR_2. Series resistor R_1 limits the amount of current through these diodes and tends to isolate the input signal source. R_1 is sufficiently small so that the attenuation and phase shift associated with it are unimportant. When diodes CR_1 and CR_2 break down, they may have a loading effect on the source. Greater isolation of the source from this loading effect may be desired. This would be desirable, for instance, when making simultaneous phase and voltage measurements of the source. A cathode follower or Darlington amplifier inserted ahead of R_1 provides sufficient isolation.

Phase measurements become independent of even order harmonics if minor changes are made in the circuitry of figure 2. Diodes CR_3 and CR_4 may be connected directly rather than through C_1 to the collector output of Q_3. This makes the pulse width of the clipped wave a function of the d-c voltage at the collector. R_2 is adjusted so that the diodes break down symmetrically. Without compensation, even harmonics may cause unsymmetrical clipping. Figure 3 indicates a composite input wave with unequally spaced zero crossings resulting from the presence of an even order harmonic. The corresponding clipped wave has unequal positive and negative portions. The d-c error component caused by this inequality is returned to the input of Q_1 through R_2 as negative feedback. This gives rise to a corrective voltage drop developed across CR_3 and CR_4. This voltage drop shifts the triggering level so that the clipping is symmetrical. Consequently, the phase shift due to the even order harmonic is corrected.

If odd harmonics are present, no correction occurs. In this case (fig. 4) the zero crossings of the composite wave are shifted uniformly in the same direction, so that the positive and negative portions of the wave are equal. As a result, there is no d-c component to restore the phase.

Occasional readjustment of R_2 is required with C_1 removed, because of the tendency of the diode voltage to drift. This tendency can be controlled, if the d-c error component resulting from drift is amplified before returning as feedback to Q_1.

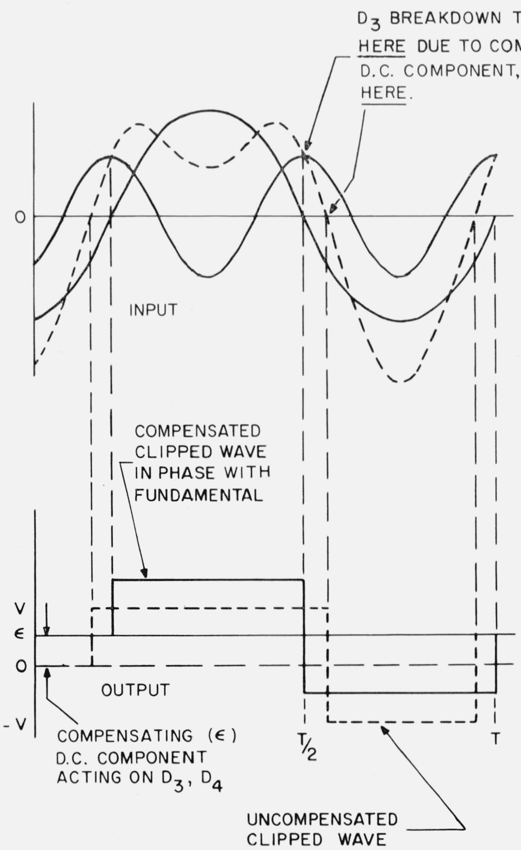

Figure 3. *Zero phase of clipped wave with compensation of phase shift due to 2d harmonic.*

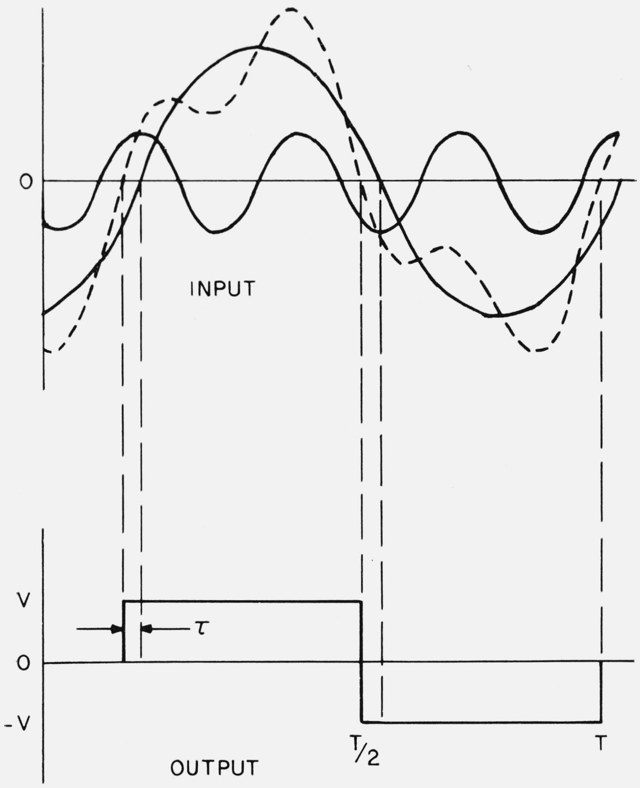

FIGURE 4. *Phase shift (τ) of clipped wave due to 3d harmonic.*

Although good accuracy is obtained with noncritical general purpose components, improvement can be made by the use of faster-acting diodes and transistors. Their faster rise times should produce sharper gating with less delay.

References

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[2] Y. P. Yu, Coincident slicer measures phase directly, Electronics, P. 99 (Sept. 12, 1958).

[3] I. A. Greenwood et al., Electronic Instruments Radiation Laboratory series **21,** ch. 5 (McGraw-Hill Book Co., Inc., New York, N.Y., 1948).

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