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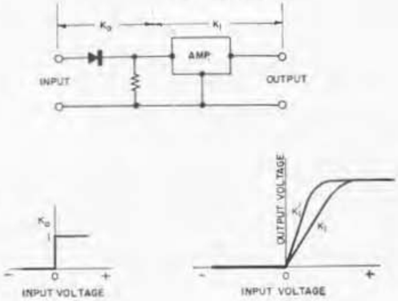
A NEW CIRCUIT FOR AMPLITUDE COMPARISON

Also IN THIS ISSUE

One of the fundamental operations to be performed with electronic circuits is that of amplitude comparison. *Amplitude comparison* is the determination of equality between two voltages, rather than the selection of a waveform that is above or below a given amplitude, as in *amplitude selection*. The amplitude comparator does not result in the faithful reproduction of a portion of a waveform, but rather, produces an output pulse at the moment of equality of two voltages.

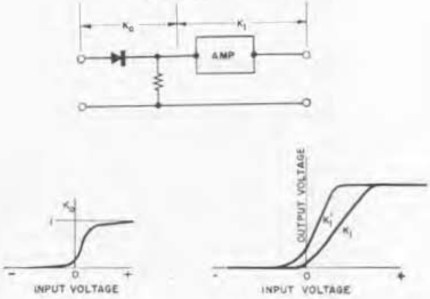
The operation of any amplitude comparator depends upon the characteristics of some non-linear device. First, let us consider an amplitude comparator using an ideal diode, as shown in Figure 1. The diode is simply a switch. When the input voltage is negative, the output is zero; when the input voltage is positive, the output is K times the input until the amplifier reaches saturation. A change in the amplifier gain can change only the slope of the input-output relation. The discontinuity of slope is determined completely by the ideal diode. If the output is differentiated, a voltage step will be obtained at the moment the input crosses zero volts. Only the magnitude of the step will depend on the amplifier gain and the rate

Figure 1.



IDEAL DIODE

Figure 2.



PRACTICAL DIODE

of change of the input voltage.

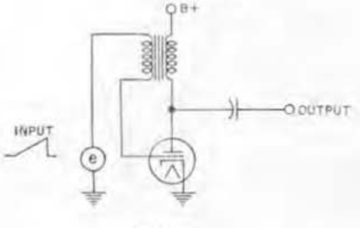
Figure 2 shows what happens when a more practical diode is used. There is no discontinuity of slope. The amplifier gain changes not only the slope of the input-output characteristic, but also the point at which the curve appears to depart from zero. If this output is differentiated, a pulse will be obtained. Both the magnitude and position of the output pulse, however, depend upon amplifier gain. Thus, the accuracy of an amplitude comparator based on a practical diode depends not only upon the stability of the diode characteristic, but also upon the ability of the circuitry to determine some point on the non-linear characteristic.

There are two basic classes of amplitude comparators. First, are those that use linear amplification and pulse shaping. This group is subject to the difficulties shown in Figure 2. They are all "slope sensitive," that is, the time at which the output waveform reaches a given voltage level depends upon the frequency or slope of the input voltage. The amount of gain in the amplitude comparator determines the minimum frequency at which operation is possible. Obviously, these circuits are useless as d-c comparators.

The second group consists of those that use a regenerative amplifier around a non-linear device. In this group, the output pulse is initiated when the input voltage reaches some predetermined d-c level. The pulse rise time is determined by the bandwidth of the regenerative amplifier. In many of these circuits, the regenerative amplifier and non-linear device are combined into one triode. The familiar blocking oscillator shown in Figure 3 is a typical example. The transformer in the plate circuit provides the positive feedback path. If the input is sufficiently negative, the tube is cut off. As the input voltage rises, a point is reached where the tube starts to conduct, and at this point a regenerative action starts, providing a sharp negative pulse at the plate with a slope independent of the input waveform. The amplitude comparison depends not only on the stability of the triode characteristics but also on the applied plate and heater voltages, since these seriously affect the cut-off voltage.

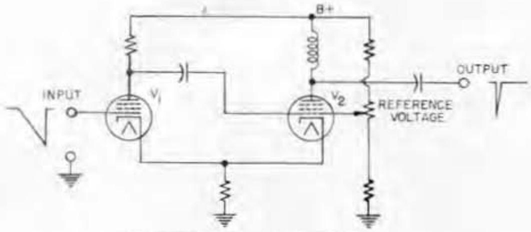
Another example shown in Figure 4 is a monostable multivibrator, often called the "long-tailed pair." V_2 is normally off, and V_1 is on, acting as a cathode follower since the cathode resistor is large. As the input voltage and, therefore, the cathode of V_2 go negative, a point is reached, determined by the reference voltage on the grid of V_2, where V_2 starts to conduct. This completes a positive feedback path from the plate of V_1 back to the cathode of V_1, and a regenerative action starts, producing a sharp negative pulse across the

Figure 3.

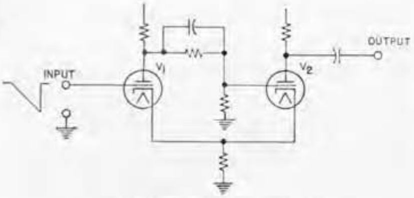


BASIC
BLOCKING OSCILLATOR

Figure 4.



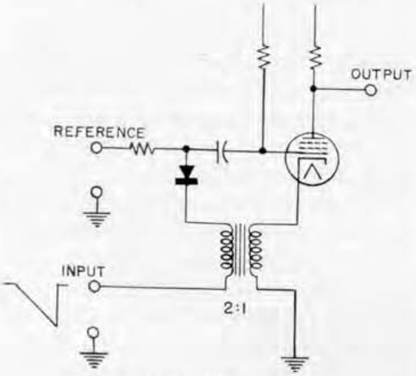
MONOSTABLE MULTIVIBRATOR



SCHMITT TRIGGER CIRCUIT

Figure 5.

inductor in the plate of V_2. The accuracy of this circuit also depends upon the stability of the tube characteristics and upon the applied voltages, although drift from heater voltage changes tends to cancel to some degree.



MULTIAR

Figure 6.

Figure 5 shows the familiar Schmitt trigger circuit. V_1 is normally on and its low plate potential holds V_2 off. A decreasing input voltage waveform will eventually permit V_2 to conduct. Positive feedback through the common cathode resistor starts a regenerative action, which cuts off V_1 and gives a negative output at the plate of V_2. As in the previous circuits, the point of amplitude comparison depends upon both the triode characteristics and the applied voltage.

One other circuit which is useful, because it is reasonably independent of the amplifier tube characteristics and the applied plate voltage, is the Multiar shown in Figure 6. Accuracy of amplitude comparison depends primarily upon the diode characteristics. Normally, the pentode is conducting. The positive feedback path through the transformer is broken by the diode, which is nonconducting. When the input voltage decreases to the point where the diode conducts, a regenerative action starts, rapidly cutting off the pentode.

Optimum sensitivity for this type of circuit can be derived and demonstrates the fundamental limitation. In the functional circuit of Figure 7, the open loop gain is

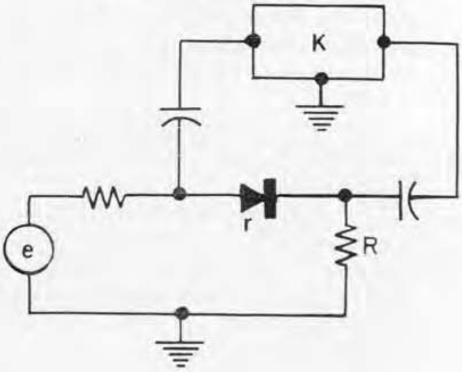
$$G = \mathrm{K}\frac{R}{R+r}.$$

The change in loop gain caused by a change in the diode resistance is

$$\frac{dG}{dr} = -\frac{R\mathrm{K}}{(R+r)^2}$$

The value of R for maximum sensitivity, can be found by differentiating this expression with respect to R and setting the result equal to zero.

Figure 7. Functional schematic of the regenerative feedback type of circuit.



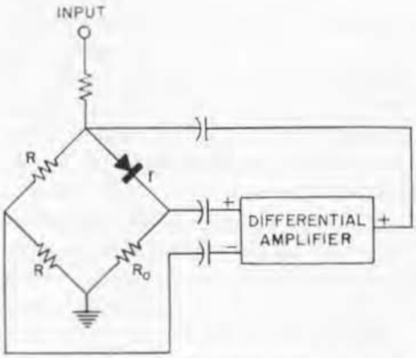


Figure 8. Functional diagram of new circuit, in which sensitivity increases directly with amplifier gain.

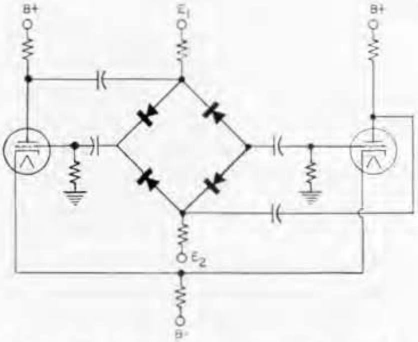


Figure 9. An amplitude comparator, based on the circuit of Figure 8.

$$\frac{d\left(\frac{dG}{dr}\right)}{dR} = -K\,\frac{(R+r)^2 - 2R\,(R+r)}{(R+r)^4}$$

$$= 0$$

Solving this equation, we get

$$R = r$$

For maximum sensitivity, therefore, the diode should be operated at its most non-linear point, and the series resistor should be chosen to equal the resistance of the diode at this point. The amplifier gain required for optimum sensitivity is K = 2.

In this type of circuit, the diode is used to change the amount of positive feedback. When the loop gain reaches plus one, the circuit will oscillate. Increased sensitivity can not be obtained by increasing the amplifier gain beyond K = 2.

Figure 8 shows a new circuit in which the sensitivity increases directly with amplifier gain.

The significant difference between this circuit and previous circuits is the use of two feedback paths: a positive feedback path including the diode and the resistor R_o; and a negative feedback path including the two resistors R. The polarity of the net feedback depends upon the diode resistance. When the diode resistance is greater than R_o, the net feedback is negative. When the diode resistance is less than R_o, the net feedback is positive. As the input voltage varies from negative to positive, the diode impedance changes, thus changing the sign of the feedback from negative to positive. As in other regenerative circuits, oscillation occurs when the loop gain reaches plus one. However, in this circuit, a loop gain of plus one can be reached by progressively smaller changes of diode resistance as more and more gain is used in the amplifier.

This circuit makes it possible to determine a point on the characteristics of the non-linear device with as much precision as desired. However, no circuit can improve the inherent stability of the non-linear device.

An amplitude comparator [1] based on this idea is shown in Figure 9. The use of four diodes in the bridge gives another factor of four in the sensitivity and provides some cancellation of drift in diode characteristics with tempera-

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[1] U. S. Patent No. 2,715,718.

ture. To insure that the amplitude comparator will operate at a particular voltage level, independent of the slope of the input voltage, requires that the four capacitors that couple the diode bridge to the differential amplifier be sufficiently small so that a negligible amount of the input signal be coupled to the amplifier stage. For proper operation, the input voltage serves only to change the effective resistance of the diodes and, therefore, the polarity of the feedback. Noise in the amplifier stage should then trigger the regenerative action.

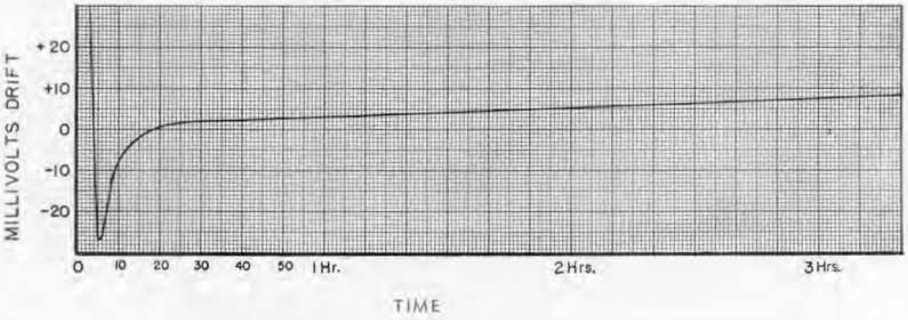
If a d-c voltage greater than that required to start the regenerative action is applied to the diode bridge, an output pulse will be generated. After this pulse, it is necessary for the plate and grid coupling capacitors to recharge. As soon as recharge occurs, another pulse will be generated. Thus, the output consists of a train of pulses spaced by the recovery time. If the input voltage consists of a sawtooth sweep, the recovery time can be made sufficiently long so that the circuit will be reset by the trailing edge of the sweep, and a single output pulse can be obtained.

Another effect of the diodes and the coupling capacitors is a hysteresis effect. If the time constants are not chosen carefully, it will be found that once the circuit starts to oscillate, it requires a relatively large change of applied voltage to stop the oscillation. One of the simplest methods to avoid this effect is to use small inductors to couple the signal voltage to the diode bridge.

By using sufficient amplifier gain, the effects of plate and heater voltage changes can be made as small as desired. With a single double triode such as the 12AT7, the gain is sufficient to reduce these effects to a few millivolts. The sensitivity of this circuit is about one-tenth of a millivolt. This sensitivity is so much greater than the stability of the diodes being used that any further increase in sensitivity, which could easily be obtained by adding another stage, would be useless.

In order to measure the sensitivity and also to determine how much stability could be obtained, a comparator was built with four germanium diodes. To reduce the effect of temperature on the diode characteristics, they were placed in a small octal-socket-size crystal oven. This oven held the diode temperature constant within one degree. Figure 10 shows the drift from a cold start for a three-hour period. The shape of the curve for the first few minutes as the oven warms up is irrelevant. Drift with the cycling of the oven is less than one millivolt. The slow drift is about 2.5 millivolts per hour and ends as the diodes stabilize their characteristics, as shown in Figure 11. Figure 12 shows the effects of line voltage. Both plate

Figure 10. Three-hour record of drift of the new circuit from a cold start.



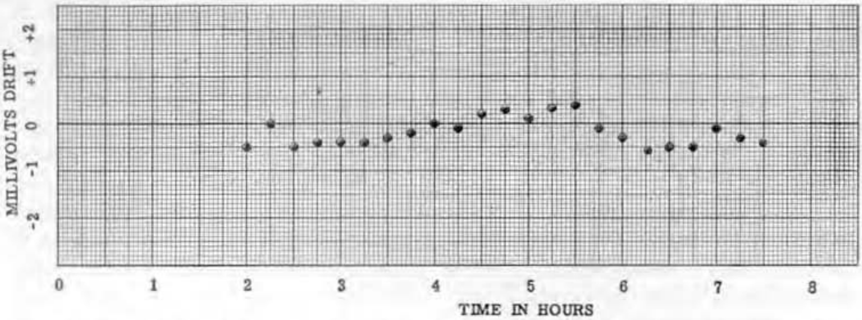


Figure 11. Drift record after diodes and other circuit elements reach temperature equilibrium.

and heater supplies were varied simultaneously.

Since the sensitivity of this comparator is so much greater than the stability of the diodes used in the bridge, it seems desirable to find some other non-linear device which is more stable with temperature than the germanium diodes. As long as the non-linear device is stable, more sensitivity can be obtained by adding additional amplifier gain. Much work remains to be done in this direction.

In addition to its many applications in electronic equipment, this circuit has interesting possibilities in industrial measurement and control systems. Wherever it is possible to generate a variable impedance with temperature, pressure, position, or other quantity, it is possible to use this comparator circuit directly, without first generating a voltage proportional to the quantity to be measured. The circuit does not require voltage information but can generate an output pulse directly from an impedance change. For such applications, the diode bridge would be replaced by a combination of linear resistors and elements with a resistance change proportional to the quantity to be detected. Thus any of these quantities could be controlled by a relatively simple circuit with high sensitivity.

— M. C. Holtje

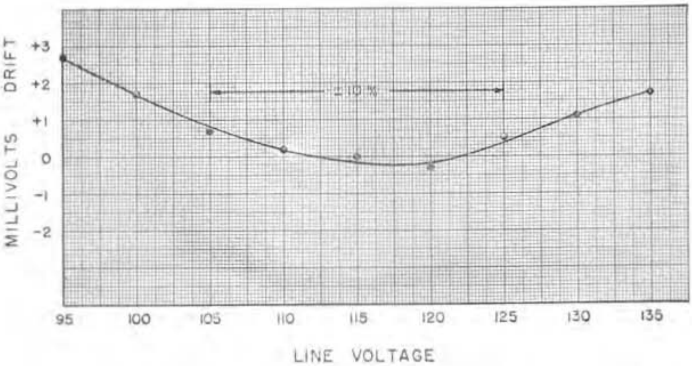


Figure 12. Effect of line voltage variations.

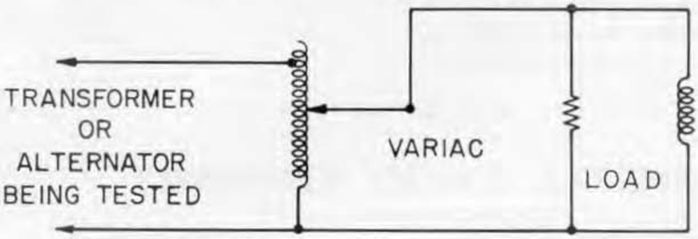
THE VARIAC® AS A MEANS OF PROVIDING CONSTANT-POWER-FACTOR, VARIABLE-CURRENT LOAD

In educational-laboratory testing of alternators and transformers it is frequently desirable to provide a constant-power-factor, variable-current load. Adjustment of both resistive and reactive elements to achieve ten or twelve points for a curve is both tedious and time consuming. With the circuit of Figure 1, the desired load magnitude can be obtained quickly and easily.

At a 1:1 ratio adjustment of the Variac Autotransformer the reactive and resistive components are made to take approximately full load current at the desired power-factor. For other currents the Variac is adjusted to other ratios. The load then appears to the source as $(N_1/N_2)^2\,(R + jX)$, where N_1 and N_2 are the turns in the primary and secondary circuits, respectively, and $R + jX$ are the equivalent series components of the load. While the parallel inductance and resistance of the Variac must be taken into account at high transformation ratios, the simple expression is adequate for most uses.

The single-phase illustration is easily extended to three-phase circuits by use of a three-phase Variac® assembly.

Note: We are indebted to Professor J. Bruce Wiley, of the University of Oklahoma, for this interesting application of the Variac. — EDITOR



Load magnitude is varied by adjusting Variac, while power factor remains fixed.

MISCELLANY

Among the friends from overseas whom we have welcomed to our plant and laboratories at Cambridge during the past several months are:

Professor Abrahao Izecksohn, of Escola Nacional de Engenharia, Rio de Janeiro; and Dr. Guilherme Ribeiro, Civil Engineer, Sao Paulo, Brazil.

C. S. Rangan, Scientific Officer, National Physical Laboratory, New Delhi; and V. K. B. Unni, Senior Technical Assistant, India Meteorological Department, New Delhi, India.

Enzo Finardi, Sales Manager, Ing. Giovanni Canegallo, Technical Director, and Dorando Massimello, Director, Societa Elettrotecnica Chimica Italiana, Milan, Italy.

Dr. Masashi Naito, Electro Technical Laboratory, Tokyo; Keiichi Takama, Director and Assistant Chief, Meisei Denki K. K., Tokyo; and Yoshiji Toyoshima, Furukawa Electric Company, Ltd., Yokohama, Japan.

André Levy Soussan, Realisations Electroniques Du Maroc, Casablanca, Morocco.

Dr. M. Gevers, Research Project Engineer, Philips Research Laboratories, Eindhoven, Netherlands.

Dr. John R. Whittaker, Principal, Technical College, Dundee, Scotland.

Karl-Ake Jarbelius, General Swedish Electric Company, Ludvika, Sweden.

SOME BULLET!

Before the munitions makers start bidding for the right to our new atomic rifle, we hasten to explain that, in the photograph on page 8 of our October issue, the bullet was travelling about 2,700 feet per second, not 10,000. The 10,000 figure is the flashing speed of the stroboscope, as stated in the first paragraph of the caption. Our ballistics expert denies all responsibility for the second paragraph, claiming that the error is obviously an editorial one.

After an exhaustive investigation the editor has decided to apologize and to claim he was out of town when it happened.

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