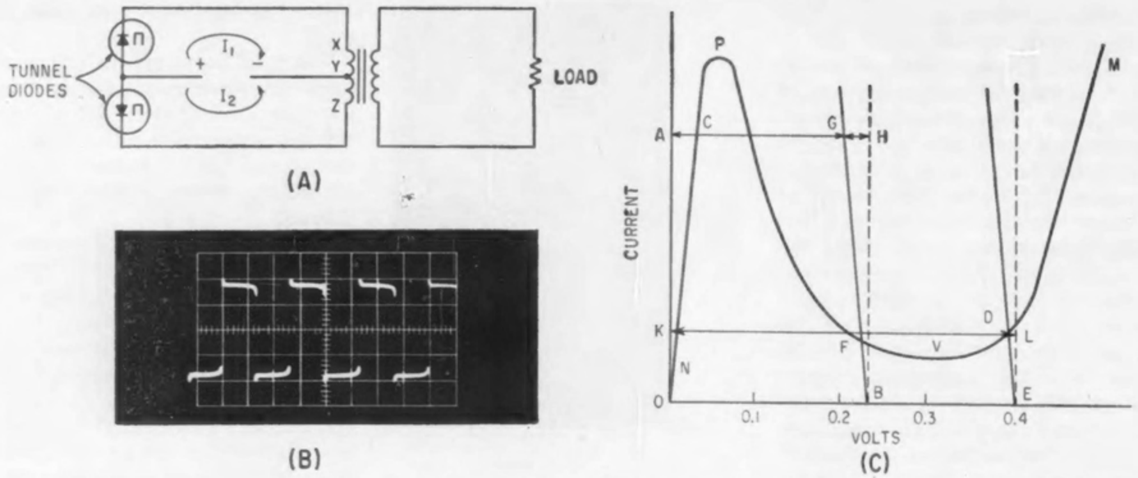

FIG. 1—Operation of square wave generator (A) to obtain typical output wave (B) is understood by analyzing the circuit's operating characteristic curve (C)

Generating Square Waves

Two tunnel diodes, a transformer and a power source produce high-quality square-wave output for low-frequency applications

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A TUNNEL DIODE oscillator circuit, developed at the U. S. Naval Research Laboratory, was primarily intended to convert power sources of less than a volt, to higher, more practical voltage levels. However, the operating characteristic of this oscillator, and the high quality a-c square-wave output obtained, make this circuit useful as a low-frequency square-wave signal generator.

A typical circuit consists of two tunnel diodes and a square-loop magnetic core transformer, Fig. 1A. Typical output wave shape is shown in Fig. 1B. Operation of the circuit depends upon the tunnel diode characteristic, exemplified by the curve plotted for a germanium diode, Fig. 1C.

Several circuits have been constructed using tunnel diodes with peak current ratings from 1 ma to 10 amperes, and designed for various frequencies. The circuits are advantageous where thermoelectric generators are power sources. Such generators are low-voltage high-current sources and, as such, are ideally suited as power supplies.

To understand how the circuit in Fig. 1A operates, assume that the input terminal voltage is *OB* (Fig. 1C), and the slope of the load line is such that this line intersects the tunnel diode characteristic curve at point *F*, somewhere within the negative resistance region, that is, between the peak and valley points.

When the input voltage is applied to the terminals in Fig. 1A, currents I_1 and I_2 will flow in the directions shown. If both loops including the diode characteristics were identical, the currents would be identical at all times and the circuit would not oscillate.

However, in a circuit this condition is impossible, since the loop impedances and diode characteristics will be slightly different. So assume that I_1 is larger than I_2 and quickly reaches its operating or dynamical equilibrium point, *C*, in Fig. 1C. When operating at this point, *AC* represents the voltage across the diode, *CG* represents the voltage induced in the primary winding by the changing flux in the core and represents the induced component of the load voltage referred to the primary circuit, and *GH* represents the ir drop of the primary circuit. The sum of these three voltages equals input voltage *OB*.

The changing flux in the core induces a voltage in the lower half of the primary winding also equal to *CG*. However, polarity adds to the input voltage in determining the voltage impressed across the lower tunnel diode. Thus, if *BE* is made equal to *CG* and the load line *DE* is drawn parallel to *BG*, the operating point for the lower loop

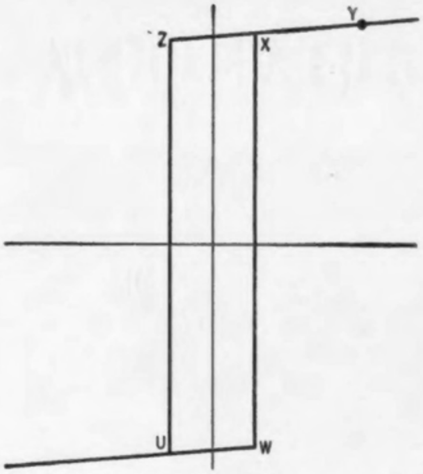
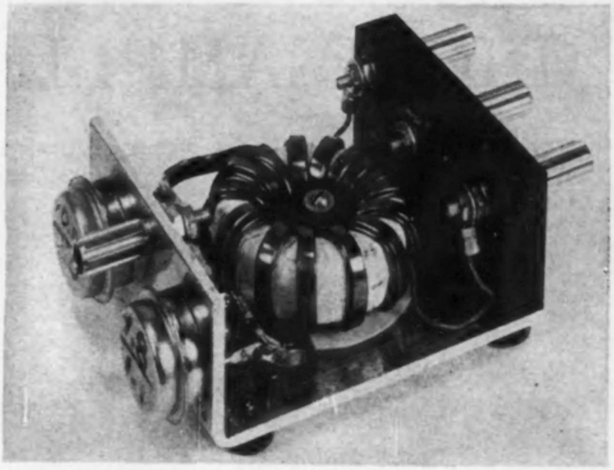


FIG. 2—Idealized hysteresis loop for the magnetic core



Square-wave generator using tunnel diodes having a peak current rating of approximately 10 amperes

With Tunnel Diodes and Cores

is established at point *D*. Thus, in the lower loop, *KO* is the current, *KD* represents the voltage across the diode and *DL* represents the ir drop in the primary loop. The sum of *KD* and *DL* equals the sum of the input voltage *OB* and the induced voltage *BE*.

Thus the parameters of the circuit constrain operation so that while the core flux changes from *W* to *X* in Fig. 2, the induced voltage *CG* remains constant. Both the magnetizing current and the load current remain constant.

When the core saturates (point *X* of Fig. 2), suddenly the induced voltages *CG* and *BE* decrease rapidly. The only way this can happen with the operating points remaining on the diode characteristic curve is for the difference between I_1 and I_2 to increase rapidly. This can only be accomplished by I_1 increasing and I_2 decreasing. Thus *C* moves toward *P*, and *D* moves toward *V*. Also the operating point for the transformer core moves from *X* to *Y*.

When the peak and valley points are reached, $(I_1 - I_2)$ no longer increases because of the tunnel diode characteristics, and an unstable condition occurs. Rapid transient conditions cause the operating point for the upper loop to shift from *P* to *M*, and the lower loop to shift from *V* to *N*. Operation at these points requires that the induced voltage in the windings be reversed, which is accomplished by a rapid decrease in $(I_1 - I_2)$. Thus I_1 must decrease and I_2 must increase very rapidly, causing the operating point of the upper loop to move from *M* to *D* and the lower loop to move from *N* to *C*. During this time the transformer core operating point moves from *Y* to *Z* in Fig. 2. When point *Z* is reached, the flux decreases from *Z* to *U* establishing a stable condition similar to the period while traversing the distance *WX* with the exception that the induced voltages in the windings are now reversed. This condition with the operating point for the lower loop at *C* and the upper loop at *D* will continue until the core saturates in the negative direction. At this time the circuit quickly switches to the initial conditions and completes one cycle of operation, which will now be repeated. Since the switching transient takes place rapidly, the load voltage is an a-c square wave.

Frequency output of the circuit depends upon the size and material of the core, the number of turns on the primary windings, and the input voltage. These are related by

$$E = N \frac{2BA}{t} 10^{-8}$$

where *E* is the voltage across the coil in volts; *N* is the number of turns on each half of the primary windings; *B* is the maximum flux density of the given core material in gausses; *A* is the cross-sectional area of the core in square centimeters; and *t* is the time duration of one half cycle in seconds.

Power output of the circuit depends upon the peak currents of the tunnel diodes, since the input voltage is limited to approximately 0.25 volt (for germanium). At present, tunnel diodes can be made in the ampere range, but no theoretical peak current limit exists. Apparently the peak current is a function of cross-sectional area only.

Improved fabrication techniques should produce the large-area uniform junctions for higher peak currents.

The impedance of the primary circuit, including the input generator, must be low for the circuit to oscillate in the mode explained. However, considerable latitude is permitted in the secondary circuit, because of the normally high voltage step-up of transformer.