# XI. TRANSISTOR CIRCUITS

Prof. H. J. Zimmermann
Prof. R. B. Adler
Prof. S. J. Mason
M. F. Friedman
J. Gross
C. R. Hurtig

## A. DIRECT-COUPLED AMPLIFIERS

The dynamic range of a direct-coupled transistor amplifier is limited by the temperature dependence of the saturation current $I_{co}$. Previous reports described a balancing circuit that allows a reduction of the effective saturation current at the output by a factor of approximately 10:1, compared to a nonbalanced circuit. We have devised a bridge circuit that permits a reduction of the temperature-sensitive current by a factor of 50:1, compared to a nonbalanced circuit. A diagram of the balanced bridge circuit is shown in Fig. XI-1. The transistor on the left is employed as an amplifier in a grounded-emitter connection. The transistor on the right is employed as a balancing unit and is also a grounded-emitter connection. The two transistors form two arms of the bridge; the resistors $R_4$, paralleled by $R_3$, form the remaining two arms. The output resistance $R_0$ is usually the input impedance of the succeeding stage of the amplifier. The bridge is balanced in the following manner. With the transistors removed, the current in the output resistance is zeroed by adjustment of $R_3$. The dc voltages developed across the two resistors, $R_1$, are then made equal. Transistors chosen to have nearly identical values of saturation current at room temperature are then connected and the current in the output is zeroed by the adjustment of $R_b$. If we use transistors having values of saturation current of approximately 3 μa at room temperature, the temperature-dependent current flowing in the output is kept less than 5 μa over the temperature range of 0° C to 55° C. This amounts to an average reduction of approximately 50:1 for the units tested. The minimum detectable signal current is approximately 0.5 μa at the input; the minimum detectable signal power is approximately $2 \times 10^{-9}$ watt.

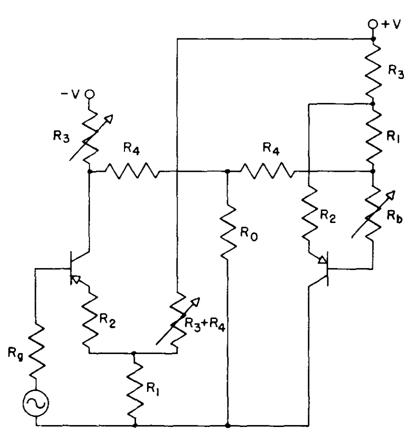


Fig. XI-1

Zero centered output, balanced bridge circuit.

Although the power gain of the bridge depends upon the ratio of load-to-generator resistances, power gains up to 20 db are readily obtainable. The average frequency response of this type of bridge, with CK721 transistors, is 50 kc/sec.

When transistors with saturation currents of 0.1 μa become available, it should be possible to reduce the minimum detectable signal power to approximately $10^{-11}$ watt. Upon the availability of silicon transistors with reverse currents comparable to those obtained with silicon-alloy junction diodes, the minimum detectable signal power of a single nonbalanced stage may be as low as $10^{-13}$ watt over the temperature range of 0°C to 55°C.

C. R. Hurtig

## B. TRANSISTOR SAWTOOTH GENERATOR

A sawtooth generator was developed which has as its basic components a junction transistor for the current source and a point-contact transistor used as a switch (see Fig. XI-2). The sawtooth voltage is obtained across a capacitor that is charged by the current source and discharged through the switch. The sweep frequency may be varied over a wide range by changing the size of this capacitor. The circuit may be allowed to free-run or may be triggered by externally generated pulses. The circuit was examined in the free-running state.

Sweep speeds from 30 cps to 300 kc/sec were obtained. The low frequency was limited only by the size of capacitor available; the upper frequency limit was determined principally by the collector junction capacitance and stray capacitances. The negative resistance input characteristic of the point-contact transistor controls the switching operation. Since the amplitude of the sawtooth voltage and the fall time are dependent upon negative resistance characteristics, the peak and valley points of the switch were stabilized so that different transistors of the same type can be used. Thirteen such transistors tested in the circuit, at a frequency of 20 kc/sec, resulted in a deviation of ± 5.25 percent from the average output of 19 volts. An average ratio of sweep duration to fall time of 10.4:1 was obtained at this frequency. On the basis of tests made with a single transistor it was found that as the frequency was lowered to 30 cps this ratio remained substantially constant. As the frequency was increased the ratio decreased, until at 300 kc/sec it was approximately 5:1. It is possible to adjust this ratio, subject to the limitations discussed below.

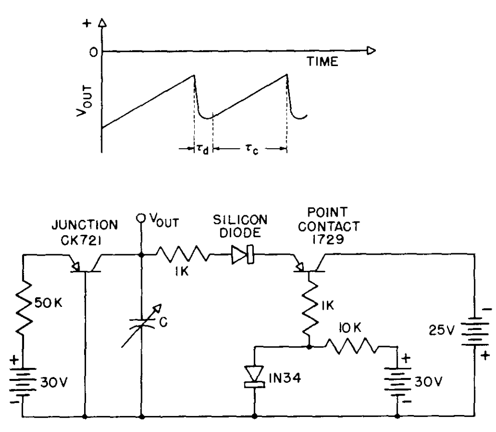


Fig. XI-2
Transistor sawtooth generator.

It can be shown that the ratio of the sweep duration to the fall time is given approximately by the expression

$$\frac{T_c}{T_d} \approx \frac{V}{2.2\ IR}$$

where $T_c$ is the sweep duration, $T_d$ is the fall time, V is the sawtooth voltage amplitude, I is the charging current, and R is the input resistance of the switch in its closed state. This ratio may be made as small as desired by increasing the input resistance of the switch when it is in the closed state. Increasing the charging current will also decrease the ratio, but current and power ratings of the junction limit the magnitude of current available. The upper value of this ratio depends upon three factors:

(a) the minimum charging current that is practicable. Since sweep linearity is also dependent upon the size of the charging current, a compromise must be made in reaching an optimum value for the current; (b) the minimum switch resistance that is possible. The current and power ratings of the point-contact transistor switch establish this minimum value; (c) the frequency response of the point-contact transistor.

Sweep nonlinearity, defined as the percentage by which the minimum slope falls below the maximum, depends upon how closely we approach the ideal current source during the charging of the capacitor. At an impedance level of 1 megohm, the nonlinearity for a sawtooth amplitude of 20 volts is theoretically equal to 1.3 percent for a charging current of 1.5 ma.

M. F. Friedman