IX. TRANSISTOR CIRCUITS[*]

Prof. H. J. Zimmermann Prof. S. J. Mason C. R. Hurtig
Prof. R. B. Adler A. H. Lipsky

A. VOLTAGE-TUNED TRANSISTOR-AMPLIFIER

Tests were conducted on the previously reported voltage-tuned transistor-amplifier to evaluate its dynamic characteristics. Sinusoidal control signals in the frequency range of 0.015 cps to 0.8 cps were used.

These tests disclosed:

a. The value of the resonant frequency of the amplifier under dynamic operation differs from its static value.

b. The shift in resonant frequency from the static value is in the sweep direction.

c. The magnitude of the shift increases as the sweeping speed increases.

d. The magnitude of the shift decreases as the resonant frequency increases.

e. Under dynamic operation, the amplifier gain and, consequently, its Q differ from their static values; positive-going control voltages cause an increase in both quantities, negative-going ones cause a decrease.

f. If the circuit is forced into oscillations when operating at low values of control voltage, these oscillations may be self-sustaining.

The predominant cause of resonant-frequency shift with fast sweeps is a general phenomenon found whenever resonant circuits are swept rapidly; briefly, when the frequency passes rapidly through resonance, not enough time for the establishment of steady-state equilibrium conditions is allowed. Figure IX-1 is a sketch of the envelope response of the tuned amplifier to a positive-going sinusoidal control signal, and is characteristic of this phenomenon.

Hok (1) and Marique (2) discuss the response of a resonant circuit to linearly varying frequencies. Each paper presents a family of dimensionless curves which
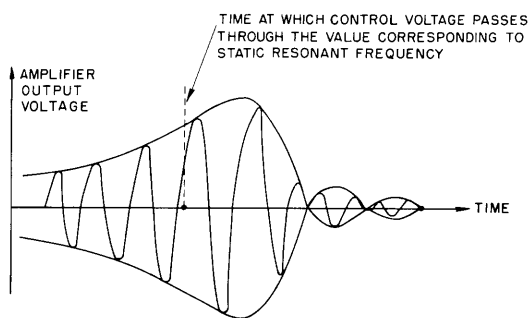

Fig. IX-1. Envelope response of the tuned amplifier to the positive-going portion of a 0.8-cps sinusoidal control signal.
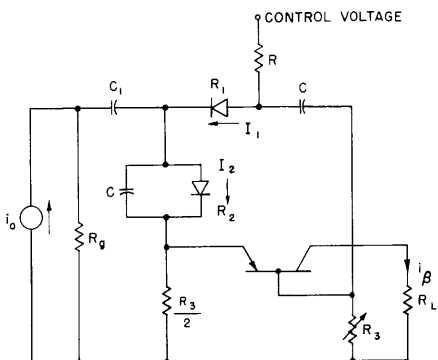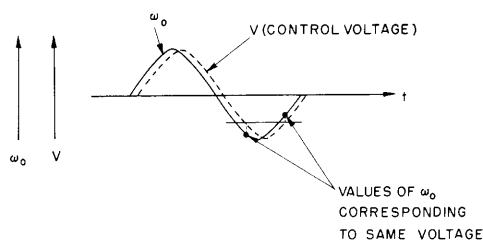
Fig. IX-2. Simplified diagram of Wien bridge.

Fig. IX-3. Effects of phase shift on resonant-frequency shift.

make it possible, if the bandwidth and rate of change of frequency are known, to calculate the expected shift in resonant frequency. These curves indicate that this phenomenon becomes negligible for sweeping speeds that are numerically smaller than the bandwidth squared; the sweeping speed is expressed in cycles/sec^2 and the bandwidth is in cps. This criterion will be used in differentiating between slow and fast sweeps.

Experiments with fast sweeps show good agreement between the measured frequency shift and the calculated shift based on Hok's curves, with a suitable approximation for sinusoidal sweeps.

At slow speeds, at which Hok's curves predict negligible resonant-frequency shift, the measured shifts are of the order of tenths of a bandwidth. This is caused by capacitors C and C_1 in the circuit diagram of the Wien bridge shown in Fig. IX-2. The resonant frequency (ω_o) of this bridge is

$$\omega_o = \frac{1}{C(R_1 \cdot R_2)^{1/2}}$$

The resistances R_1 and R_2 are given by

$$R_1 = \frac{K}{I_1} \qquad\qquad R_2 = \frac{K}{I_2}$$

where I_1 and I_2 are the bias currents through the diodes; K is a constant approximately equal to 26 mv. I_1 and I_2 are equal for static control voltages, and are approximately equal for low-frequency control voltages. Under static conditions, ω_o equals I_1/CK. With the resistor of large value, R, in the current path, ω_o is proportional to the control voltage. However, when I_1 and I_2 differ in phase from the control voltage, this
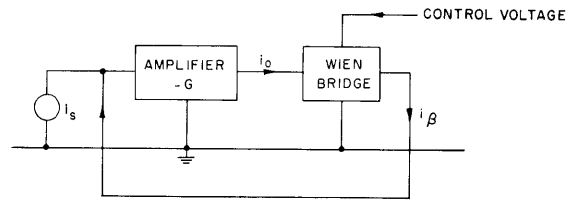
Fig. IX-4. Block diagram of voltage-tuned amplifier.

proportionality is modified by a phase angle, several tenths of a degree, which will cause resonant-frequency shifts of the order of tenths of a bandwidth. Figure IX-3 shows how this phase shift will cause a shift in center frequency when plotted against control voltage.

A block diagram of the tuned amplifier is shown in Fig. IX-4. The current gain of the amplifier at the resonant frequency is

$$\left(\frac{i_o}{i_s}\right)_{\omega = \omega_o} = \frac{G}{1 + G\left(\dfrac{I_2 - I_1}{2I_1 + I_2}\right)}$$

where G is the current gain of the amplifier with the Wien bridge removed, and I_1 and I_2 are the diode currents, as shown in Fig. IX-2.

Experiment has shown that the effect of C_1 on the control currents is the chief cause of gain variations with tuning. If a positive-going step in control voltages is applied, C_1 will draw a charging current, which will make $I_1 > I_2$. This will cause the amplifier gain to become larger. A negative-going step has the opposite effect.

In most cases, this sensitivity to rates of change of control voltage will limit the control voltage to waveforms without positive steps. For example: A saw-tooth control voltage that sweeps with positive slope and returns with a negative step will be acceptable. A saw-tooth voltage of appreciable amplitude that sweeps with a negative slope and returns with a positive step will cause the amplifier to oscillate.

A. H. Lipsky

References

1. G. Hok, J. Appl. Phys. 19, 242-250 (1948).
2. J. Marique, Proc. IRE 40, 945-950 (1952).