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LB-876

NOISE FACTOR MEASUREMENTS OF TRANSISTORS

RADIO CORPORATION OF AMERICA

RCA LABORATORIES DIVISION

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Approved

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Introduction

This bulletin describes a technique and equipment which have been found useful in measuring the noise factor of transistors. Measurements may be made at 1 kc, 10 kc and 100 kc. The equipment may be used with either point-contact or junction type transistors. Because relatively high noise factors must sometimes be measured the signal-generator method is used.

The theory of noise factor measurement has been discussed in detail in LB-775, *Noise Factor and its Measurement*, but a brief summary of the considerations involved is included here.

Definition of Noise Factor

The noise of a device usually is compared with the theoretical noise of the input impedance to which it is connected. This theoretical noise of the input impedance for a frequency bandwidth Δf may be represented by a voltage generator of zero internal impedance and of mean squared voltage,

$$\overline{e^2} = 4kTR\Delta f$$
$$= 1.6 \times 10^{-20} R\Delta f \ (T = 290°K), \quad (1)$$

in series with the resistor. R in Eq. (1) corresponds to the input resistance of the network, k is Boltzmann's constant (1.38×10^{-23} joules per degree), T is the temperature in degrees Kelvin and Δf is the bandwidth over which the noise is measured.

The noise across the output load of an amplifying transistor is chiefly the noise produced in the transistor and the amplified noise of the input impedance to which it is connected. It is convenient, therefore, to express the total noise as some factor times the noise contribution due to the input impedance, i.e., some factor times the noise output an ideal transistor with no internal noise would have. This factor, with a few standardizing qualifications discussed below, is the noise factor of the actual transistor.

The standard temperature is 290 degrees Kelvin (62.6°F) for which room temperature is a good approximation.

The bandwidth Δf is the noise bandwidth of the amplifier of the measuring equipment. It is established by plotting a power response curve and constructing a rectangle of the same area and with the height of a reference frequency, f_o, being the same for both curves as shown in Fig. 1.

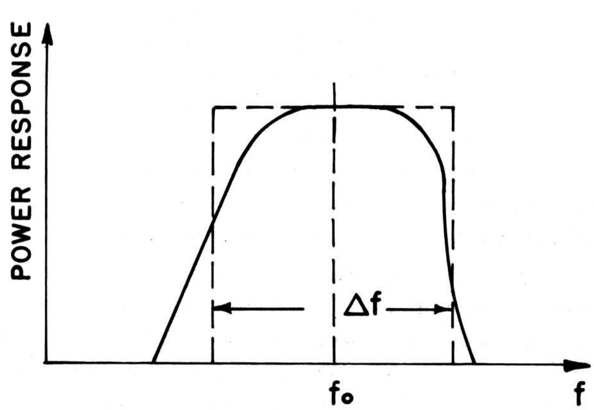

Fig. 1 - Bandpass characteristic of the amplifier (solid line) and noise bandwidth Δf of equal area (dotted line).

Analytically the definition of the noise factor is

$$F = \frac{N}{N_R} = \frac{N_R + N_T}{N_R} = 1 + \frac{N_T}{N_R} \qquad (2)$$

where N_T is the contribution to the total noise output N due to the transistor and N_R is the noise due to the input resistor R.

The two noise contributions combined can be thought to have their origin in a signal source of

$$\bar{e}^2 = 4kT\Delta fRF$$

in series with the input resistor R as shown in Fig. 2.

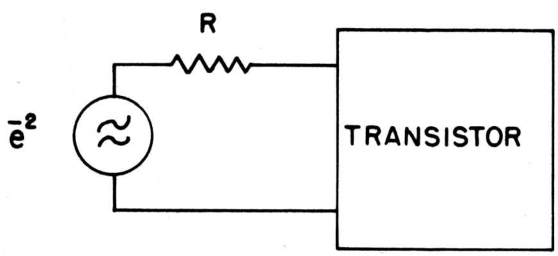

Fig. 2 - Representation of noise generator at the input of the transistor.

Noise Factor Measurements with a Signal Generator

The basic diagram for the measurement of the noise factor of a transistor by means of a signal generator is shown in Fig. 3. This signal generator with a source impedance whose value approaches zero is connected in series with the resistance R with which the transistor is to be tested. The output of the transistor is connected to an amplifier whose band-pass characteristic is known. The output of the amplifier is connected to the meter which must be capable of indicating noise power and a combination of signal and noise powers.

Let the amplifier output noise power be N_1 with the signal generator turned off. The signal generator (c-w) is turned on to produce a power output, N_2, which is a combination of noise and signal powers. The signal-to-noise power ratio at the band-pass amplifier output is then

$$\frac{S}{N} = \frac{N_2 - N_1}{N_1} \qquad (4)$$

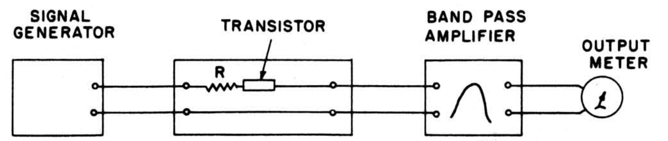

Fig. 3 - Basic block diagram for noise factor measurements.

If e_o is the signal generator voltage the noise factor F may then be calculated

$$F = \frac{e_o^2}{(S/N)\, 4kTR\Delta f} = 0.62 \times 10^{20} \frac{e_o^2}{(S/N)\, R\Delta f} \quad (T = 290^\circ K) \qquad (5)$$

if the noise bandwidth Δf is known.

Noise Factor Measuring Setup

To measure noise under various conditions for various types of transistors and at several frequencies, the equipment was designed to serve a wide variety of purposes.

The block diagram of Fig. 4 shows the basic arrangement. Point-contact as well as p-n-p and n-p-n junction transistors can be measured. The polarities of the bias supplies and meters are reversed by one switch. The built-in meters are connected to read emitter

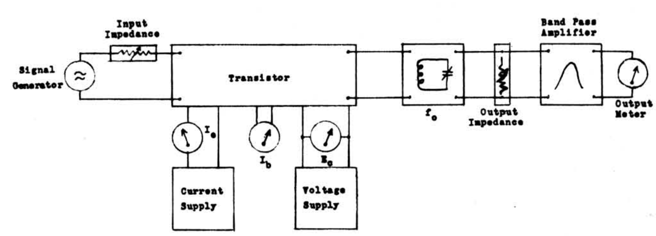

Fig. 4 - Block-diagram showing the connections and adjustments of the transistor.

and base currents. The necessary resistors (low-noise type, e.g., Nobleloy type X-1, Continental Carbon Inc.) for adjusting input and output impedances over wide ranges are built into the equipment. The circuit is arranged to keep the emitter d-c current and th

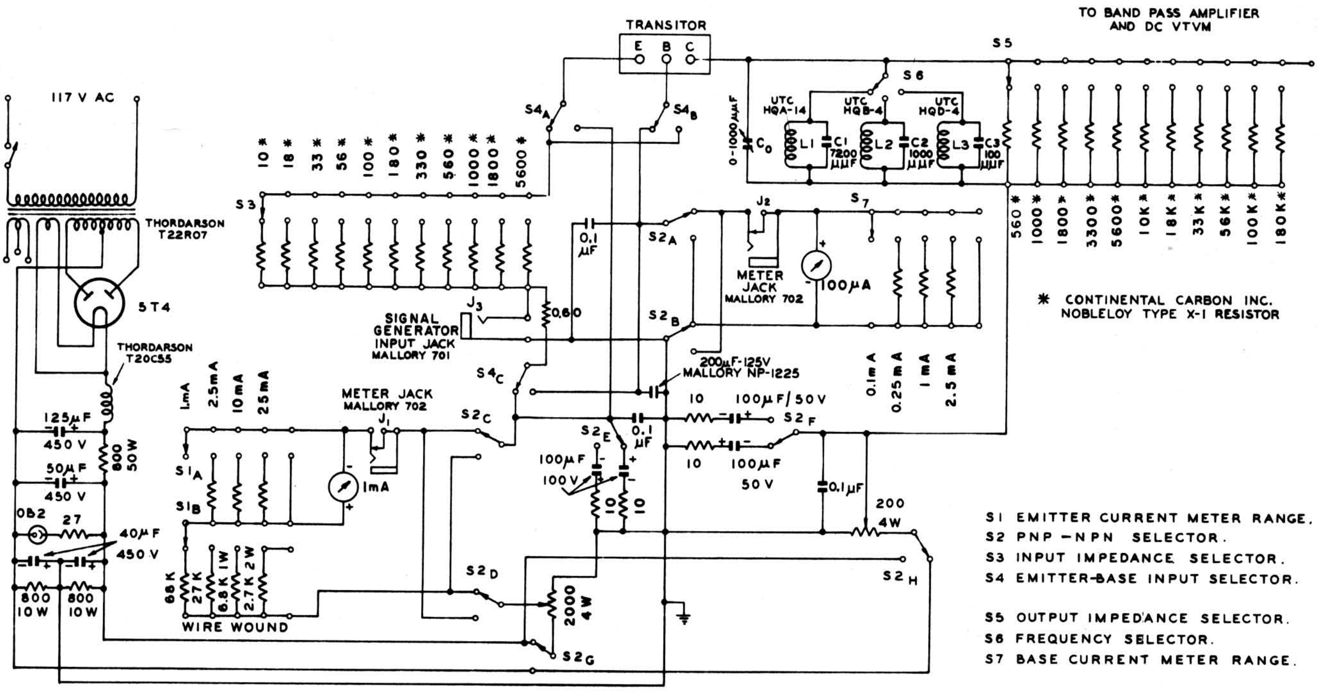

Fig. 5 - Schematic of noise factor measuring setup.

collector d-c voltage constant. To enable the latter, in the collector output a tuned circuit of very high impedance (several times the highest required output impedance) is used for each measuring frequency. A variable condenser is provided to retune the circuit, allowing for transistor capacitance. The transistors can be measured with emitter- or base-input. The complete schematic diagram is shown in Fig. 5.

The schematic diagram of the bandpass amplifier is shown in Fig. 6. The input stage is a pentode of fairly low noise and low-noise resistors are used in the circuits. It is followed by another amplifier and bandpass circuits for 1 kc, 10 kc and 100 kc. The bandpass filters consist of two coupled tuned circuits. Toroids are used for minimum pickup and the coupling is achieved by a capacitor. The bandwidth is designed to be approximately 10 per cent of the center frequency for the three test frequencies of 1, 10 and 100 kc. The output is a cathode follower to which the output meter is connected. As this is a permanent setup a thermo milliammeter is used as an output meter. It is protected to some extent because the output tube itself limits excessive amplitudes without causing false readings under normal conditions. The power output is controlled by a volume control and a range selector switch.

Operation of the Noise Meter

In order to protect the output meter from burnout the volume control of the amplifier should be turned all the way down before any controls are adjusted around the transistor.

After having set the input selector and adjusted the input and output impedances, the desired operating point is fixed by the transistor emitter d-c current and collector d-c voltage; the base current can be measured as a reference. The tuned circuit in the collector is assumed to be set to the frequency of the desired bandpass of the amplifier and is broad enough not to affect the selectivity of noise bandwidth. The signal generator is still turned off.

After all these preliminary settings the volume control of the amplifier may be opened slowly until the output meter OM reads a convenient value near the center of the scale.

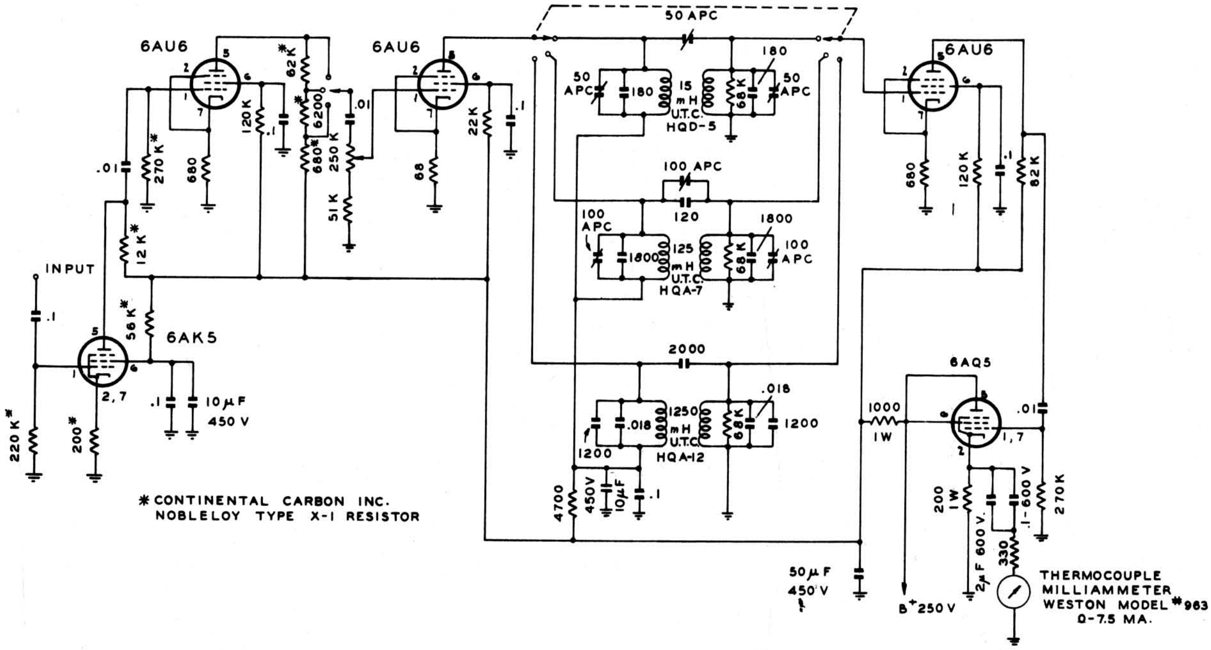

Fig. 6 - Bandpass amplifier with output meter.

Then the signal generator, tuned to the reference frequency of the desired band, is turned up slowly (μvolts!) until the output meter OM reads twice the power of the first setting (or $\sqrt{2}$ = 1.4 times the current, respectively). The signal generator with an output impedance of 600 ohms the voltage across which is known, is connected to the 0.6-ohm input in series with a 600-ohm resistor and a blocking condenser of 4μf. This produces a 1000-to-1 voltage division or 60-db attenuation which has to be taken into consideration when reading the generator output voltmeter. Doubling the power is a matter of convenience, the power could be increased by any other amount. The signal generator voltage then is read and from this reading the noise factor can be computed according to Eq. (5).

In the case described here the signal-to-noise ratio in the output was made equal to one. Therefore Eq. (5) becomes

$$F = \frac{e_{oc}^2}{4kTR\Delta f} \qquad (6)$$

where e_{oc}^2 is the signal generator voltage which is required to produce an output power equal to the output power due to the combined noise of the transistor and its input resistance.

If we introduce the values for k and T Eq. (6) reads

$$F = 0.62 \times 10^{20} \frac{e_{oc}^2}{R\Delta f} \qquad (7)$$

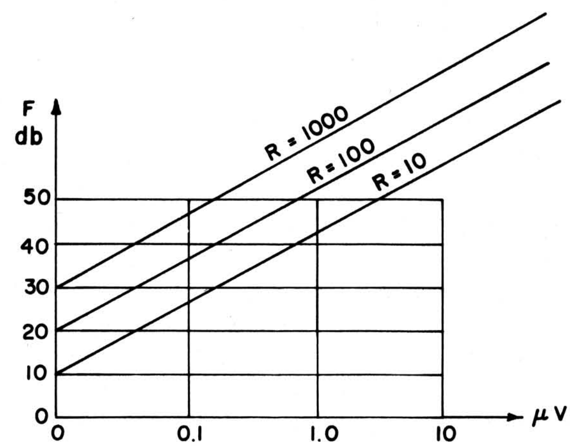

Fig. 7 - Chart which gives noise factor as a function signal generator voltage for different input resistances.

For fast and convenient readings of noise factors a chart (Fig. 7) can be made which takes the noise bandwidth into account and reads noise factor as a function of signal-generator voltage with the input resistance as the parameter. As the noise bandwidth is not the same for different center frequencies (different bandpass filters) a different chart has to be used for each frequency.

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