ELECTRON TUBES

RCA Application Note

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Receiver Sensitivity and Gain Measurements at High Frequencies

Methods of measuring the sensitivity and gain of rf amplifiers and converters of receiving systems operating in the FM broadcast band or in the television bands are described in this Note. When conventional voltage-input methods used in the standard AM broadcast band are applied at high frequencies, difficulties result because the input voltage required to produce a given output is dependent on the point of input to the circuit being measured. The methods described in this Note, however, are based on the power input to a circuit rather than on the voltage input and are advantageous because the power input required to produce a given output is independent of the point of input.

General Considerations

When a circuit such as that of Fig. 1 is part of a receiver, sensitivity measurements are conventionally made by connecting a standard signal generator supplying a modulated signal to terminals (1-1) through a specified "dummy antenna" network, and then adjusting the signal to produce a specified standard output from the receiver. In a low-frequency receiver, it is common practice to obtain additional data by connecting the signal generator successively to points (4-4), (3-3), and (2-2) through a low-impedance blocking capacitor. The frequency and voltage of the signal generator are adjusted for each test point to give the standard receiver output.

The voltage input at the intermediate frequency required at terminals (4-4) to give the standard output may be described as the voltage sensitivity of the receiver at the first if grid. Similarly, the inputs at the signal frequency required at points (3-3) and (2-2) may be described as the voltage sensitivities at the converter grid and at the rf grid, respectively. The ratio of the required input at (4-4) to the required input at (3-3) is the conversion voltage gain from converter grid to if grid provided that the receiver is nearly free of feedback effects. The ratio of the required input at (2-2) to the required input through the dummy antenna to (1-1) is frequently referred to as the antenna circuit gain, but it must be understood that the dummy antenna is considered as part of the antenna circuit for this definition.

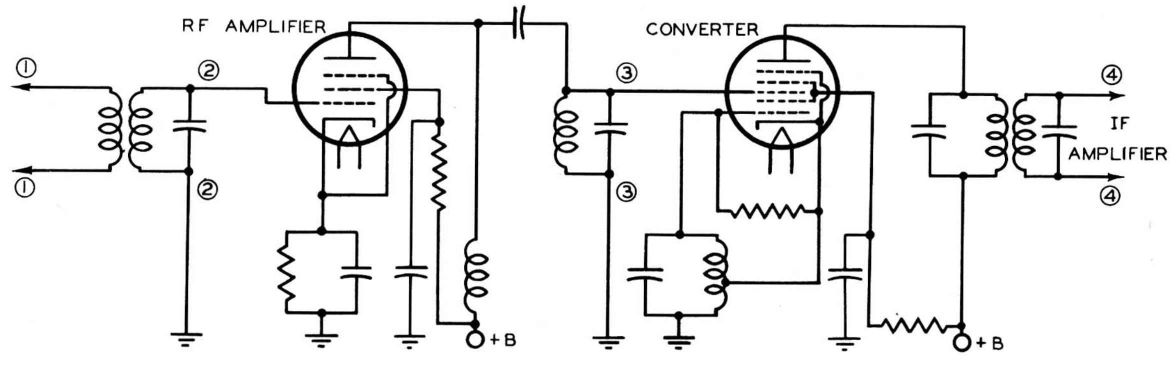

Fig. 1 - Typical RF Amplifier and Converter Circuit.

High-Frequency Considerations

At high frequencies, the attempt to make these measurements with the foregoing method leads to erroneous and misleading results. The major difficulty is caused by the substantial reactances of even short pieces of wire at high frequencies. A signal generator is calibrated in terms of the open-circuit voltage across its terminals, but it is physically impossible to bring these terminals exactly to the points at which voltage-sensitivity measurements are desired, even when the terminals are at the end of a flexible cable.

It is possible, however, to introduce a measured amount of power into a circuit of a receiver without encountering similar difficulties. A method of introducing a measured amount of power is illustrated in Fig. 2. In this figure, a resistor R and an adjustable capacitor C are connected between the signal generator and the receiver tuned circuit. Maximum power will be transferred to the tuned circuit when capacitors C and C_1 are adjusted so that the impedance of the circuit between point (a) and ground is resistive and equal to r which is the sum of the added resistance R and the internal resistance of the generator. The method applies to either circuit of Fig. 2. Although the required capacitor adjustments will be different, the amount of power which can be transferred with a given signal-generator terminal voltage is the same for either circuit. When the adjustments for maximum output have been completed, the available power, P, is equal to the power transferred to the receiver circuit and is given by the equation

$$P = e^2/4r$$

where e is the open-circuit voltage at the generator terminals,

and r is the sum of the added resistance R and the internal resistance of the generator.

In practice, the resistor R is connected to the high-potential terminal of the signal generator, and the adjustable capacitor C is connected between the resistor and a point near the high-potential end of the receiver circuit under consideration. A value for resistor R of approximately 300 ohms has been found suitable for frequencies near 100 megacycles. At other frequencies, however, different resistor values may be more suitable. Two pieces of hook-up wire twisted together may be used for the adjustable capacitor C. The circuit is tuned to resonance with the signal frequency by use of whatever tuning means are provided and the receiver output is noted. Various adjustments of the series capacitance are tried, with readjustment of the receiver circuit to resonance in each instance, until the adjustment giving maximum receiver output is found. The signal-generator voltage is then adjusted to the value giving standard power output from the receiver and this voltage is recorded. The power sensitivity can then be computed from the signal generator voltage and the resistance, r.

Example

Measurements made on an FM receiver are given as an example of the application of this method. The receiver circuit used is not identical to

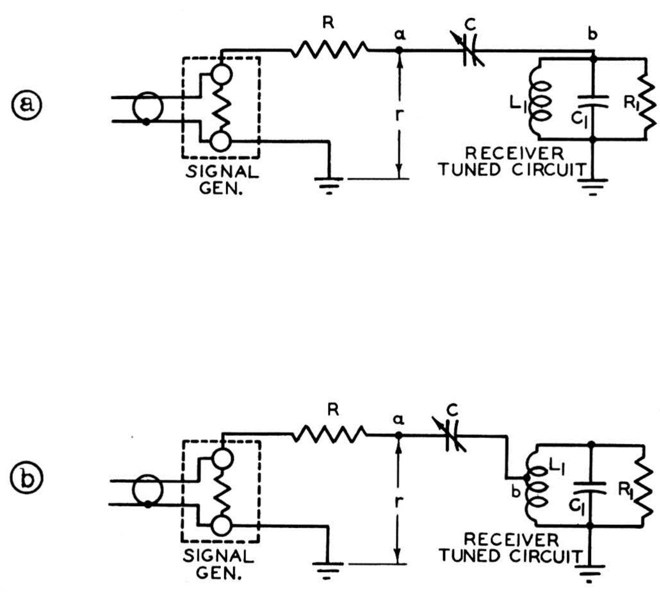

Fig. 2 - Connection of Signal Generator to Resonant Circuit for Maximum Power Transfer.

that shown in Fig. 1, but it corresponds closely enough to permit use of Fig. 1 in the explanation of the data. The signal frequency used was 98 megacycles frequency modulated with 400 cycles. The receiver output was 50 milliwatts. The tubes used were type 12BE6 as a converter and type 6BJ6 as an rf amplifier. The resistor was 260 ohms and the output resistance of the signal generator was 26.5 ohms, giving a total resistance of 286.5 ohms. Since the antenna circuit of the receiver is designed for 300 ohms, this resistor can also be used for the dummy antenna. Connections corresponding to points (2-2) and (3-3) of Fig. 1 were made through a twisted-wire capacitor and connections to (1-1) were made through the resistor only. The measurements are tabulated below.

Point of Input	Signal Generator Output volts	Available Power P watts
(3-3)	125×10^{-6}	13.7×10^{-12}
(2-2)	23×10^{-6}	0.46×10^{-12}
(1-1)	23×10^{-6}	0.46×10^{-12}

Power Ratio, (3-3) to (2-2)	29.6
Power Ratio, (2-2) to (1-1)	1.0

The power ratio (3-3) to (2-2) is the effective power gain of the rf amplifier stage. This ratio represents the real advantage in sensitivity obtained by adding the rf stage to the receiver, and, therefore, conveys more significance to the designer than a measurement of grid-to-grid voltage gain.

The power ratio (2-2) to (1-1) indicates the degree of coupling and the efficiency of the antenna transformer. The observed value of unity indicates that a close impedance match was obtained and that the additional losses obtained when the antenna winding is used are negligible within the limits of accuracy of the measurements.

Advantages

When measurements are made at the input circuit of the converter tube (point (3-3), Fig. 1), an important advantage is obtained by this method because the signal is introduced with only a slight disturbance of the circuit by the measuring equipment. The impedance of the input circuit to the signal frequency is reduced to half its normal value, but the impedance of the circuit to the oscillator frequency changes very little. At high frequencies, the amount of oscillator-frequency voltage induced in the signal-grid circuit is frequently an important factor in determining the performance of the converter tube. Consequently, a method of measurement which does not affect the induced voltage gives a better indication of tube performance than a method in which the signal grid is effectively short-circuited to ground.

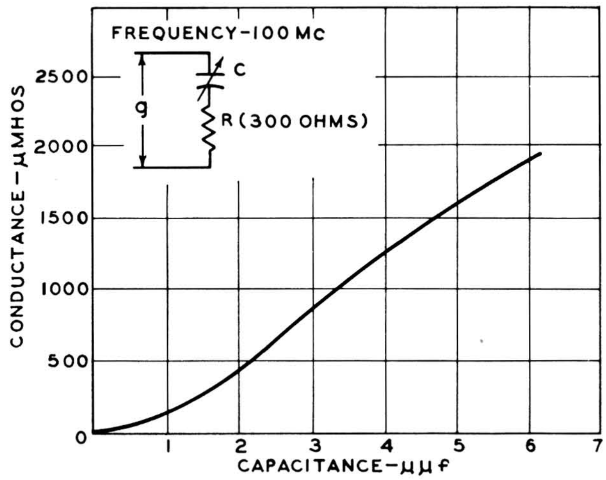

Fig. 3 - Variation of Conductance with Capacitance of Series RC Circuit.

The power-measurement method described can also give data concerning the resonant impedance of the circuits to which connections are made. When a resistance match is obtained at point a, (Fig. 2a or 2b), the resistance components from points b to ground for the generator and the circuit are also equal. For the generator, the admittance is

$$Y = \frac{1}{r + \frac{1}{j\omega C}}$$

$$= \frac{j\omega C(1 - rj\omega C)}{1 + r^2\omega^2 C^2}$$

$$= \frac{r\omega^2 C^2}{1 + r^2\omega^2 C^2} + \frac{j\omega C}{1 + r^2\omega^2 C^2}$$

The conductive component $\frac{r\omega^2 C^2}{1 + r^2\omega^2 C^2}$ can be evaluated when the capacitance is known, and is equal to the conductance of the circuit measured between the points to which connections are made. The curve of Fig. 3 shows the variation of conductance with capacitance for a resistance of 300 ohms at a frequency of 100 megacycles. It is frequently sufficient in practice to note that an increase in the required capacitance for matching represents an increase in conductance. When a tube or other component is changed, the effect of the change on the circuit impedance can be quickly evaluated by this method.

The capacitance and effective series resistance of a capacitor formed of two pieces of Belden #8861 rf hook-up wire at a frequency of 100

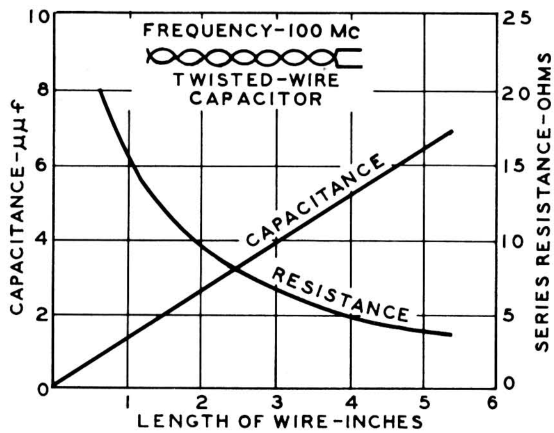

Fig. 4 - Capacitance and Effective Series Resistance of Twisted-Wire (Belden #8861) Capacitor.

megacycles is given in Fig. 4. Measurements were made on a high-frequency Q meter. The series resistance can usually be disregarded, but it may be measured and taken into account when greater accuracy in power or impedance measurements are desired.