APPENDIX XIII

MEASUREMENT OF NOISE FACTOR

1. Definition of Noise Factor.

The noise factor F of an amplifier is defined numerically by the expression:

$$F = \frac{S_1/n_1}{S_2/n_2}$$

where S_1/n_1 is the available signal-to-noise power ratio at the amplifier input and S_2/n_2 is the available signal-to-noise power ratio at the amplifier output when the temperature of the source is standard i.e. 290°K.

The "term available" power implies the maximum power which can be obtained from a source.

The noise factor may also be expressed in decibel notation as:

$$F = 10 \log_{10} \frac{S_1/n_1}{S_2/n_2}$$

In present usage, noise factor, and noise figure are synonymous.

Noise Temperature T_F in degrees Kelvin and Noise Factor F are related by the expression:

$$T_F = (F - 1)\ 290$$

2. General

Unless otherwise specified, noise measurements are to be made by the dispersed signal source method. The source is usually a temperature limited diode. This noise source is satisfactory up to the frequency at which transit time and lead inductance effects become significant; with present diodes this is in the region of some hundreds of Mc/s. For higher frequencies, noise discharge tubes may be used. The specification will state the type of source to be used.

A general outline of the test equipment is shown in block diagram form in fig. 1.

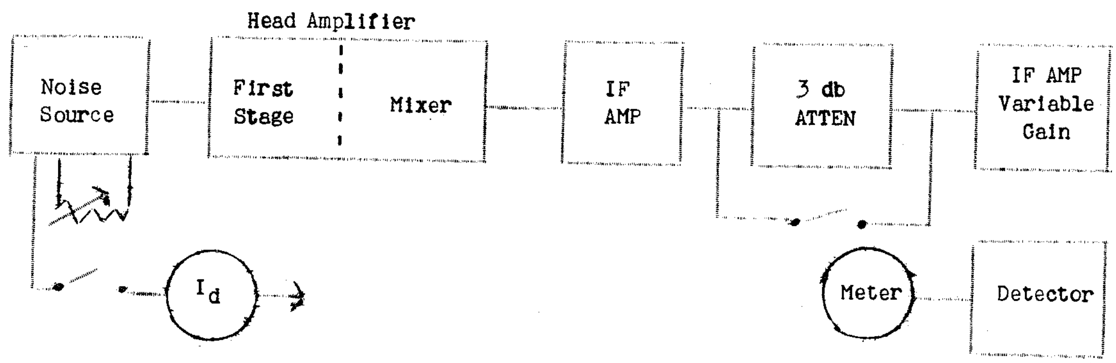

Fig. 1.

The valve to be measured for noise factor comprises the first stage of a receiving system which will be specified.

The overall noise factor of the system is given by:

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \text{-----} \frac{F_r - 1}{G_1 . G_2 . \text{------} G_{(r-1)}}$$

Where F_r = the numerical value of the noise factor of the r^{th} stage when fed from a source impedance equal to the output impedance of the $(r - 1)^{th}$ stage

$G_{(r-1)}$ = the numerical value of the available power gain of the $(r - 1)^{th}$ stage.

Usually the gain of the first stage is made sufficiently high so that the noise arising from succeeding stages will be negligible. In addition the bandwidth of the first stage must be wider than that of all the following stages.

For certain systems, where this condition cannot be obtained it is usual to measure the overall noise factor of the system. In these cases, if it is desired to measure the noise factor of the valve itself, it is necessary to measure the gain G_1 of the first stage and the noise factor F_2 of the second stage and make corrections in accordance with the above equation.

The specification will state:

(a) the input coupling conditions and whether these conditions shall be adjusted for optimum power match or for optimum noise factor

(b) the frequency of measurement

(c) the bandwidth of the system

(d) the gain of the first stage when this is required to be specified.

3. Methods of Measurement.

The noise factor may be measured, when specified, by one of the methods described in the following paragraphs.

The measurement is made by comparing the noise output of the first stage of a receiving system with an equal amount of noise produced by the noise source i.e. the input to the receiver from the noise source is adjusted until it exactly doubles the noise output of the first stage. This is achieved by the use of an amplifier, detector and output indicating meter.

Either the law of the detector must be known so that an accurate doubling of noise input power can be obtained or, alternatively, some device must be used to eliminate the effect of this law.

In the methods described below, this has been done by the use of a calibrated attenuator, in method A and by the use of two similar noise sources and an output meter shunt in method B.

If a saturated noise diode is used as the noise source and the diode anode current is measured, the noise factor F of the system is calculated from the formula:

$$F = \frac{e}{2\ KT} I_d R$$

where e = electron charge (1.60×10^{-19} coulomb)

k = Boltzmann's constant (1.38×10^{-23} joule per degree)

T = temperature of the source resistor in ^{O}K

I_d = anode current of the noise diode in amperes

R = value of the source resistor in ohms.

For a source resistor temperature of $290^{O}K$, this formula reduces to:

(1) numerically, $F = 20\ I_d R$

(2) in db notation, $F = 10 \log_{10} (20\ I_d R)$

3.1 Method A

This method is shown in fig. 1. It uses a passive power halving attenuator as early in the system as is practicable where the signal level is small enough to avoid any errors due to circuit nonlinearities. Such an attenuator can be calibrated by standard methods external to the circuit. The attenuator must not affect the frequency response of the system and must be correctly matched into the amplifier.

The output indicating meter is required to indicate a standard reference reading at some arbitrary power level.

With the noise diode switched off, the output meter is set to the standard reference reading by adjustment of the gain of its auxiliary amplifier. The diode is then switched on and the attenuator is switched into circuit. The diode anode current is adjusted by control of the diode filament supply until the output meter is again set to the same mark. The noise factor is then calculated from the above formula.

3.2 Method B

This method is shown in fig. 2 and uses a calibrating unit and an output meter shunt. The calibrating unit consists of two saturated diodes, each with its own amplifying system with outputs connected to a common output. The noise outputs of the diodes must be considerably greater than the noise outputs of the amplifiers so that the latter have no effect on the calibration.

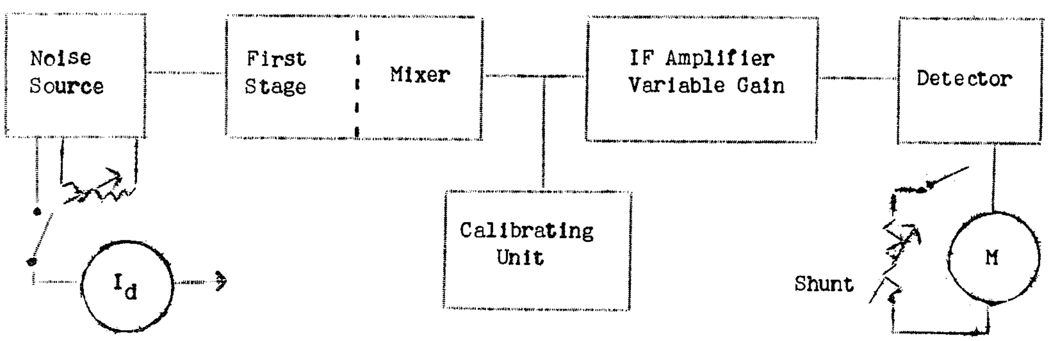

Fig. 2

With a typical valve in the test position, the gain of the receiver system is adjusted to give a suitable reading on the output meter. This reading becomes the standard reference reading.

3.2.1 Receiver calibration

The receiver is calibrated by feeding the calibrator unit into the IF amplifier with one of the calibrating noise sources operating and the gain of its associated amplifier is adjusted until the reading on the output meter is equal to the standard reference reading obtained with the valve under test. With the second calibrating noise source switched into circuit in place of the first, its associated amplifier is also adjusted to give the same standard reference reading. This results in the equalisation of the two calibration noise sources.

Both noise sources are then switched on together doubling the noise input to the receiver. The shunt across the output meter is adjusted until the deflection is exactly equal to the standard reference reading.

The receiver and shunt are now calibrated.

3.2.2 Valve test

The Calibrator unit is removed and the valve to be tested is connected into circuit and the meter shunt removed. The gain of the IF amplifier is adjusted to give the standard reference reading on the output meter. With the noise source switched on and the meter shunt connected in circuit, the noise source is adjusted to give the standard reference reading on the output meter. The anode current of the noise diode is measured and the noise factor of the amplifier calculated.

3.3 Precautions for Methods A and B

1. It is essential to stabilise both the noise diode anode voltage and filament voltage supplies against mains voltage fluctuations, and to take adequate precautions to eliminate, by suitable filtering, any radio frequency signals which may be present on the outputs from these supplies.

2. It is usually advisable to provide a well screened enclosure or room, for the measuring equipment and the operator, and to provide adequate radio frequency filtering for the mains power supply, where they enter the screened enclosure or room.

3. For absolute measurement it is essential to maintain the temperature of Noise Source Resistance at 290°K or to make correction for any difference from this temperature. Arrangements should be made to maintain the test amplifier at a constant temperature which should be recorded.

4. The noise generator must be designed to have an output impedance equal to that of the source used with the circuit under test.

The value of source resistance must be accurately known. This source resistance consists of a resistor shunted by a tuned circuit, the effect of which may not always be negligible. Therefore, it is necessary for absolute measurements, to be able to ascertain the dynamic impedance represented by this tuned circuit and thus calculate the resultant value of source resistance which will be the true value for noise factor measurements.

Frequent checks of the value of the source resistor should be made to eliminate errors due to its value altering with time due to resistor ageing, etc.

It is essential to provide the best possible coupling between the noise source resistor and the input terminals of the test amplifier to obtain minimum noise factor. This coupling is not necessarily the same as that for the best impedance match.

The actual noise factor of the tube or valve will be somewhat lower than the measured value due to various losses, such as those occurring in the matching transformer, etc.

5. It is essential to measure the noise diode anode current with the best possible accuracy and to make frequent checks of the accuracy against some standard.

3.4 Method C

The use of gas discharge noise sources at frequencies above several hundred megacycles - to be included.