ON NOISE FIGURES IN TRANSISTOR AUDIO AMPLIFIERS

by

E Bhagiratharao

Defence Electronics Research Laboratory, Hyderabad

ABSTRACT

The noise figures of two general purpose transistors of Philips and Hitachi (Japanese) make have been determined under identical experimental conditions with a view to see whether they differ in their noise properties. The variation of noise figure of Philips as well as Hitachi transistors with (*i*) frequency (*ii*) collector voltage (*iii*) collector current (*iv*) emitter current and (*v*) input impedance have been investigated. It was concluded that Philips and Hitachi transistors do not differ much in their noise properties, when operated under identical conditions. For both the transistors the noise figure increases with collector voltage, collector current and emitter current. Increasing input impedance of either of the transistors increases the noise figure when the input impedance exceeds two thousand ohms. For both transistors the noise figure decreases with frequency, then remains constant over a small frequency band and finally increases slowly with frequency.

Introduction

Noise may be defined as an unwanted signal that may be present in a communication system. The usefulness of any communication system working under certain conditions depends upon the noise generated inside the system itself. The present investigation aims at the study of such noise in the transistor amplifier under various operating conditions.

Theoretical

The transistor noise is predominantly made up of shot noise and flicker noise. In addition extraneous components of noise have been observed which are attributed to poor emitter and collector-lead connections and internal microscopic breaks and strains. The shot noise which exhibits a flat noise spectrum upto fairly high frequencies, is due to the corpuscular character of the current flow in the transistor and thus represents a basic limiation. The causes of flicker noise are not fully understood[1], even though its characteristics have been studied by several investigators. [2,3,4] .

The noise performance of a device is commonly rated by comparing the noise power output from the actual device with that from its noise free equivalent. One such measure of the performance of any device is its noise figure. The noise figure at a specified input frequency is defined as the total noise power at the output over the noise power at the output due to the thermal noise of the source. *If* I_n stands for the input equivalent saturated diode current, the noise may be represented[1] by a noise generator "i_n" such that

$$\overline{i_n^2} = 2\,e\,I_n\,\triangle f \quad \ldots \quad (1)$$

The thermal noise power of the source may be represented [1] by a current generator 'i_T' parallel to the source such that

$$\overline{i_T^2} = 4\,k\,T\,g_s\,\triangle f \quad \ldots \quad (2)$$

where g_s stands for the source conductance. Hence noise figure 'F' is given by the equation.

$$F = \frac{2e\;I_n\;\triangle f}{4\,k\,T\,g_s\,\triangle f} = \frac{e\,I_n}{2\,k\,T\,g_s}$$

replacing $\frac{1}{g_s}$ by 'R_g' and substituting the numerical values of e and k

$$F=20\ I_n\ R_g \text{ for } T=290°k \quad \ldots \quad (4)$$

or in db $10 \log_{10} 20I\ R_g$ . . . . (5)

Investigations carried out

The following four investigations have been carried out using Phillips Transistor OC71 and Japanese Transistor 2N15.

(*a*) Variation of noise figure with frequency for OC71 (Phillips) and 2N15 (Hitachi) with input impedance (R_g) maintained at (*i*) 5000 ohms and (*ii*) 500 ohms

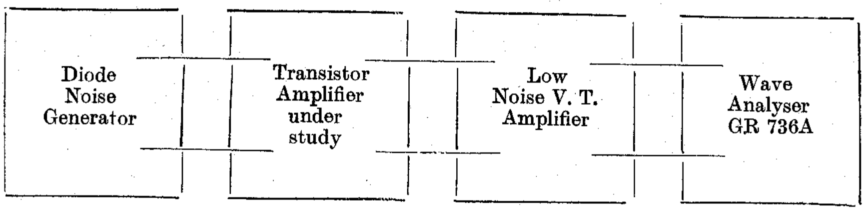
(*b*) Variation of noise figure with collector voltage (V_c), the collector current (I_c) and input impedance (R_g) being kept constant; and with collector current (I_c), the collector voltage (V_c) and input impedance (R_g) being kept constant.

(*c*) Variation of noise figure with emitter current (I_e) collector voltage (V_c) being kept constant.

(*d*) Variation of noise figure with input impedance (R_g) the collector voltage (V_c) and collector current I_e being kept constant.

Method of Determining the Noise Figures

To determine the noise figures of transistor amplifiers, a technique similar to that employed for vacuum tube amplifiers has been used. The block schematic diagram of the method employed is shown in Figure I.



(*a*) *Equipment*

The diode noise generator employs CV172 for white noise generation. The diode plate current can be varied from 0 to 5 M.A. by changing the diode filament voltage. The current can be read by a milliammeter in the diode plate circuit. The output impedance of the noise generator can be varied from 120 Ω (which is the meter resistance) to 10,000 Ω.

The transistor amplifier under investigation is completely shielded. The grounded-base configuration is used in the present investigation. In the amplifier under study facilities are provided to alter the emitter voltage and collector voltage as well as resistances in emitter and collector circuits.

The low noise vacuum tube amplifier used in the investigation is a four stage negative feed-back amplifier. The amplifier gain can be varied from about 25 db to 40 db. When the gain is maximum the noise figure of the amplifier is 1·2 db. Below 30 db the noise figure of amplifier is less than 0·5 db. *For most of the measurements* the *amplifier gain was maintained below 30 db so that the amplifier could be taken to be free from noise.*

The *wave analyser* may be regarded as a variable frequency filter network. General Radio Wave Analyser 736A is used in these investigations. This has a band-width of four cycles. The centre frequency can be varied from 0 cycles to 16 Kc/Sec. When the necessary calibration procedure is carried out the voltmeter of the wave analyser indicates absolute voltages. In the most sensitive range of the wave analyser, an input of 300 μV gives full scale deflection.

(*b*) *Procedure*

The procedure to determine the noise figure is as follows. With noise generator switched off, the reading of the wave analyser is noted. Then the noise generator is switched on and the output of the noise generator is increased till the wave analyser reading gets doubled. This implies that the contribution of the noise current, available at the input of the transistor amplifier towards the total output power is equal to the magnitude of noise power generated by the amplifying device itself. From the noise diode current I_n, required to give this amount of power, the noise figure is calculated by using formulae 4 and 5.

Experimental

Every precaution was taken to see that the measurements made were accurate and repeatable. Constant voltage transformer was used between mains supply and the wave analyser, Noise generator and amplifier. The noise generator, vacuum tube amplifier and the transistor amplifier were shielded properly. But, as reported by earlier investigators[5,6,7] the meter of the wave analyser showed low frequency fluctuations. This was minimised by increasing the time constant of the D.C. amplifier of wave analyser and by connecting 4500 μF. Condenser across the wave analyser meter, a correction of 2·5 db being added to all readings. The gain of the vacuum tube amplifier is found to decrease rapidly below 100 c/sec. For these two reasons the accuracy of measurements is not greater than 10% at frequencies below 100 c/sec and 5% at frequencies above 100 c/sec. The meter of the wave analyser took quite some time to come back to the initial reading after experiencing any low frequency fluctuation. This is due to the high capacity connected across the meter. Hence before a particular value of noise current is accepted as reliable, the determination of noise current (required to double the wave analyser output) is done number of times successively, until the noise current reading comes out to be the same.

As mentioned in Section II, the noise figure of the transistor amplifier is determined under various conditions. In Graph I is shown the variation of Noise figure of OC71 and 2N15 with frequency, when R_g is equal to 5000 ohms. In Graph II are presented the variation of noise figure of OC71, and 2N15, with frequency when the input impedance R_g is equal to 500 ohms. In Graph III the variation of noise figure of OC71 and 2N15 with collector voltage is presented. Similarly in Graph IV the variation of noise figure with collector current for the above two transistors is presented. All the measurements presented in Graphs III and IV are made at 500 cy/sec with R_g 500 Ω. In Graph V measurements similar to those in Graph III (i.e., variation of noise figure with collector voltage) but for a frequency of 1000 cy/sec. are presented. In Graph VI the variation of noise figure with emitter current is presented. Finally in Graph VII is shown the variation of noise figure of OC71 and 2N15 with input impedance R_g.

Discussion of the Results

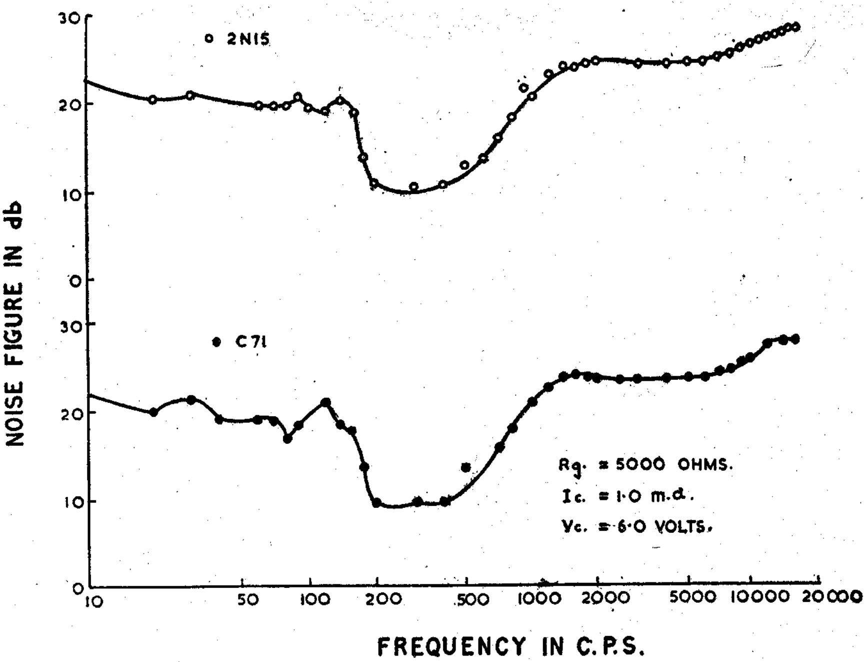
From Graph I, it will be seen that the noise figure comes out to be high for both the transistors whatever be the frequency. As the collector voltage and current are low, the high value of noise figure is due to the high input impedance. The 'scatter' of points shown in the Graph does not permit a smooth curve to be drawn through all of them. However it may be seen that from 200 cy/sec to 400 cy/sec noise figure is low and that between 1 kc and 16 kc noise figure shows a consistant rise. The variation of noise figure exhibited by both the transistors is similar. Observations presented in Graph II are taken with a view to compare the performance of OC71 and its equivalent 2N15 under identical low noise conditions. It is very interesting to observe that the variation exhibited by the two transistors is strikingly similar. The differences between the two curves may not be more than that which will be exhibited by two OC71 or two 2N15. It is interesting to see that between 50 and 200 cycles noise figure decreases with frequency. The noise figure again shows an increase until a frequency of 600 cps is reached. Above 600 cycles the noise figure does not show significant change with frequency. It may be seen that there is general agreement between Graphs I and II in that the noise figure is high at low frequency, passes through a minimum value at some hundreds of cycles. Graph I shows slight increase in noise figure with frequency in the case of both transistors above 1 KC. But data presented in Graph II is limited to 1 KC only. All the measurements presented in Graphs III, IV, V and VI are taken with low value of input impedance. From these four graphs it may be mentioned that there is no significant difference in the noise behaviour of OC71 and 2N15. All the four graphs lead to another conclusion that the noise figure of the two transistors increases with collector voltage and collector current and also with emitter current. Similar conclusion was reported by earlier investigators.[5,6,7] Comparing Graphs III and V it will be seen that for the same operating conditions noise figure determined at 1 KC (Graph V) is higher than noise figure obtained at 500 cy/sec. This conclusion was arrived at from Graphs I and II in which the variation of noise figure with frequency has been studied. In the Graph VII the effect of input impedance (R_g) on noise figure of amplifier is presented. If any more proof is required that the noise performances of OC71 and 2N15 are not different this graph provides it. Except for slightly higher noise figures obtained for 2N15 at input impedance values greater than 2,000Ω the noise figures obtained for both the transistors for R_g values between 120 Ω and 2000 Ω come out to be the same within experimental errors. For both transistors the noise figure shows an increase with higher values of input impedance. This is in agreement with Graph I. Similar conclusion was arrived by earlier investigators.[5,6,7]

Conclusions

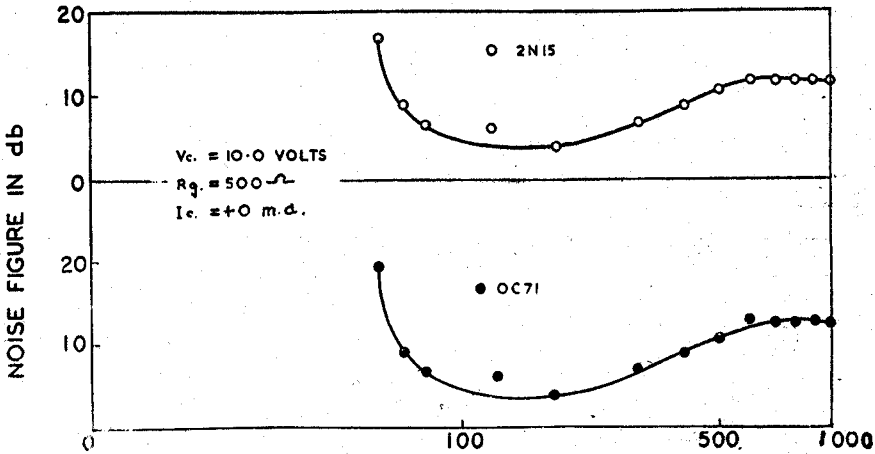
The following conclusions have been arrived at as a result of the investigations carried out:—

(1) The variation of noise figure with frequency for Phillips transistor is more or less the same as that for Japanese (Hitachi) transistor in the amplifier (Graph II).

(2) Starting from very low frequencies, the noise figure of the transistor amplifier at first decreases with frequency, then remains constant at the minimum value *over a small frequency band* and finally increases slowly with frequency.



Graph I



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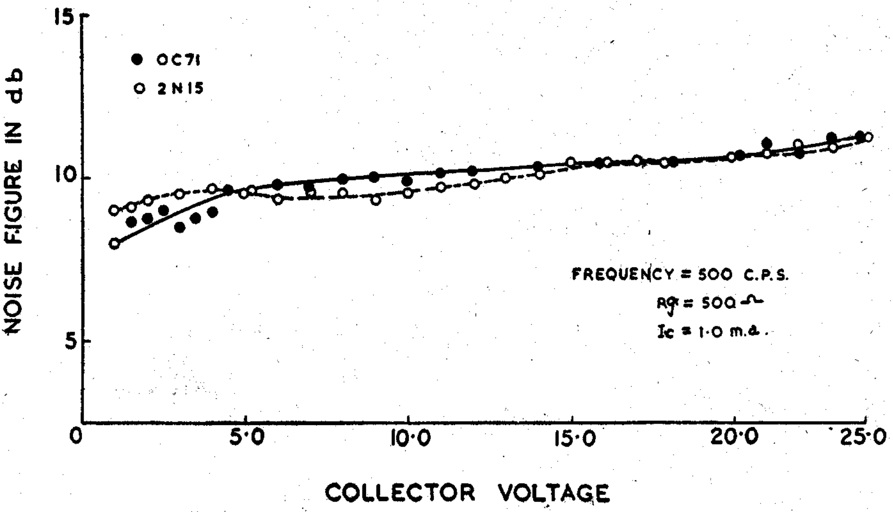
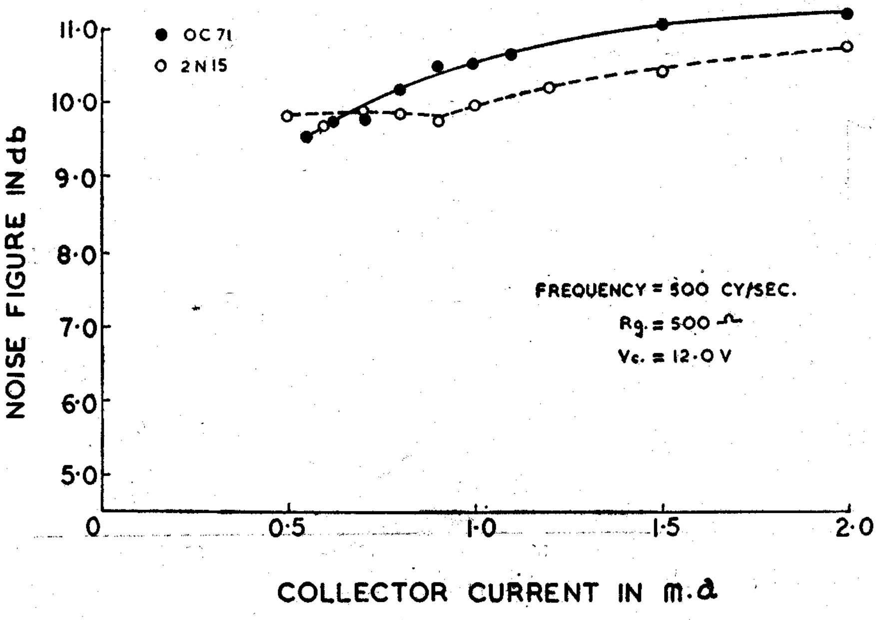
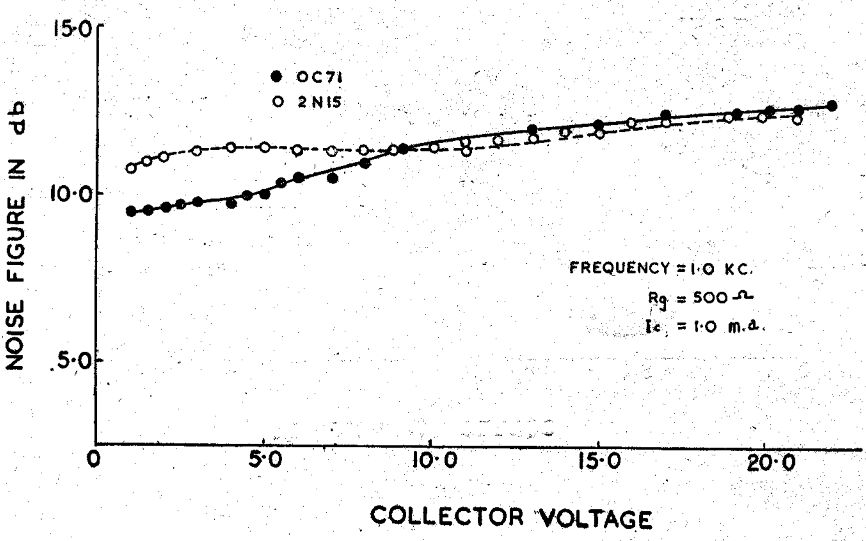
Graph II



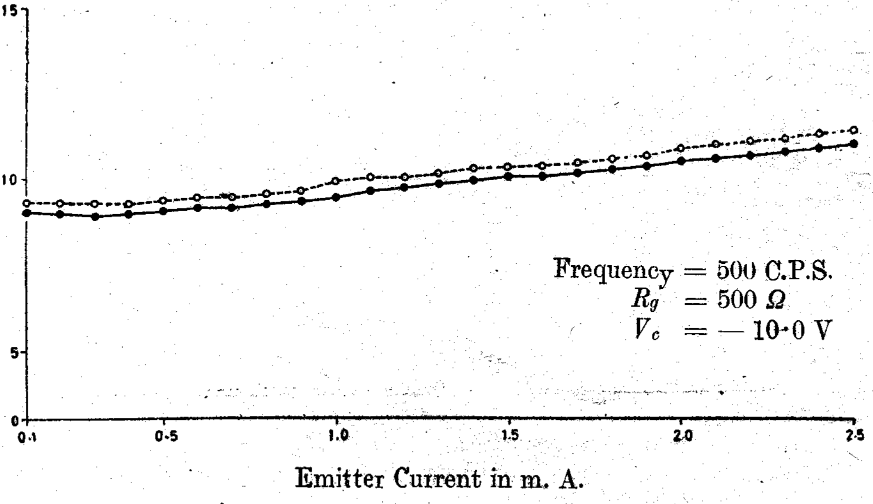
GRAPH III



GRAPH IV



GRAPH V

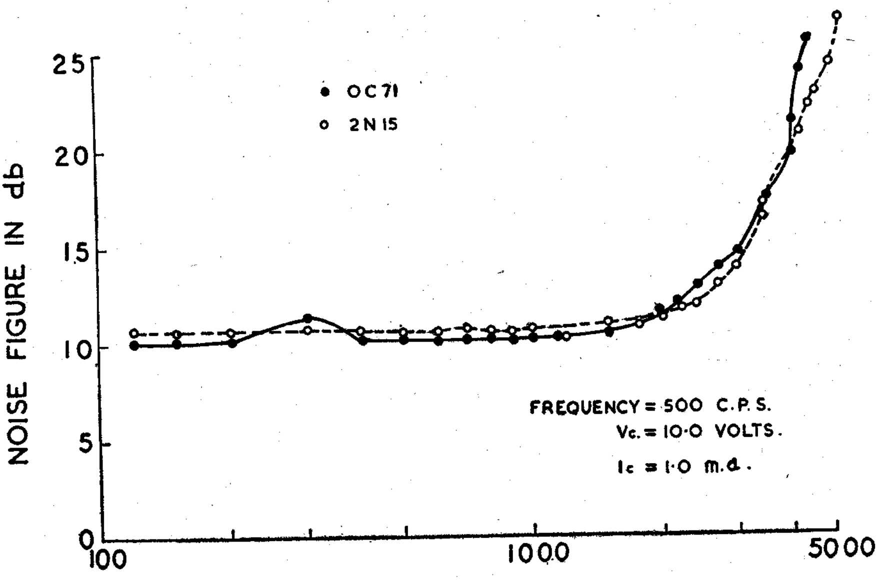


GRAPH VI

(3) The noise figure of a transistor amplifier increases with increase of collector voltage and of collector current at both 500 and 1000 c.p.s.

(4) The noise figure of a transistor amplifier increases with increase in emitter current at 500 c.p.s.

(5) The noise figure of a transistor amplifier more or less remains constant with increase in input impedance upto 2000 ohms and then increases rapidly with increase in input impedance.



GRAPH VII

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References

(1) Van der Zeil, A., *Proc. I.R.E.*, **46**, 1019, 1958.
(2) Kingston, R. H., J. *Appl. Phys.*, **27**, 101, 1956.
(3) Kingston, R. H. & Mc. Whorter, A. L., *Phys. Rev.*, **103**, 534, 1956.
(4) Kingston, R. H., et. al., "*Surface Physics.*", Univ. of Penn.
(5) Bargallinni, P. M., *et. al.*, *Proc. I.R.E.*, **43**, 217, 1955.
(6) Keon ian & Schaffner, J. S., *Proc. I.R.E.*, **40**, 1456, 1952.
(7) Montgomery, H. C., *Proc. I.R.E.*, **40**, 1461, 1952.