Low Base Resistance Integrated Circuit Transistor

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Abstract—**The design of a transistor with a very low base resistance is presented. This transistor, manufactured in a standard IC-process, has been designed especially for the input stage of amplifiers for very low impedance transducers, such as moving coil phonocartridges (MCC) and thermocouples. The base spreading and aluminum interconnection resistances have been minimized by careful geometrical design within the constraints of the process. The total equivalent noise voltage of this transistor corresponds to the thermal noise of a resistor of 1.4Ω.**

I. Introduction

Very low impedance transducers usually require transformers for noise matching. The use of transformers, however, down to the low end of the audio frequency band (MCC) or at even lower frequencies (thermocouples), is troublesome because of their hum sensitivity and linear and nonlinear distortion. To avoid transformers, special purpose amplifiers are required with input devices, with equivalent noise voltage sources having extremely low spectral energy densities [1]. This correspondence deals with the geometrical design of such a device. Since our goal is to realize fully monolithic transducer amplifiers, restrictions in the design of this transistor are imposed by the specific properties of our standard IC-process (Table I and Fig. 1).

Furthermore, the transistor size is limited by the maximum chip dimensions and the area consumed by additional circuitry. These considerations finally lead to maximum allowable transistor dimensions of $\simeq 625 \times 330\ \mu m$.

II. Noise Model of the Transistor

The noise of the bipolar transistor can be represented by a current source parallel to and a voltage source in series with the transistor input terminals (Fig. 2).

The voltage source has a density spectrum of

$$S_u = 4kT\left(r_b + R_{bA1} + \frac{r_e}{2} + R_{eA1}\right),$$

in which r_b is the sum of R_{bi} and R_{be}, the intrinsic and extrinsic base resistances, respectively (Fig. 1), and R_{bA1} and R_{eA1} represent the base and emitter interconnection and contact resistances.

III. Minimization of the Equivalent Noise Voltage

In this section the contributions of the different components to the total noise voltage will be discussed successively, and next a minimization procedure is given.

A. Intrinsic Base Resistance R_{bi}

According to Hauser [2]

$$R_{bi} = \frac{\rho L_1}{12Wh},$$

in which ρ represents the base resistivity underneath the emitter, W is the basewidth, L_1 the emitter width, and h the emitter length, as defined in Fig. 1.

TABLE I

	Resistivity	Width (μm)
Epilayer	0.7 Ω · cm	10
Base Diffusion	200 Ω/□	2.5
Emitter Diffusion	6 Ω/□	1.9

B. Extrinsic Base Resistance R_{be}

This contribution can be calculated from

$$R_{be} \simeq \frac{9 \cdot 10^2 L_2}{hd},$$

in which L_2 is the base contact-to-emitter spacing and the factor $9 \cdot 10^2$ is the average resistivity. This value can be derived from the Irving curves [3] if the collector background concentration and the surface concentration are known. Although the current density lines between emitter edge and base contact are not in parallel, the formula holds to a good approximation. Thus far it seems profitable to choose the emitter length h as long as possible, but a long and thin transistor inherently exhibits a high interconnection resistance. An interdigitated structure greatly reduces this resistance (Fig. 3).

C. Interconnection Resistances R_{bA1} and R_{eA1}

For an interdigitated structure with n emitter and $n + 1$ base fingers

$$R_{bA1} + R_{eA1} = \frac{2hR_{sq}}{3nb_1} + \frac{1}{2}\frac{b_{\max}R_{sq}}{3h_1}.$$

The quantities b_1, $h_{\max}$, $b_{\max}$, and h, have been defined in Fig. 3, and R_{sq} is the sheet resistivity of the interconnection strips (20 mΩ/□).

The first term of the right-hand side is the contribution of the aluminum base and emitter strips which are in parallel (vertical strips in Fig. 4), while the second term represents the resistance of the connecting strips (horizontal strips in Fig. 4). The resistance of one emitter finger together with two half-base fingers is $(2hR_{sq})/b_1$. For n parallel emitter and base fingers the resistance is $(2hR_{s1})/nb_1$.

It can be shown that both vertical and horizontal aluminum strips must be counted for one-third of their ohmic resistance, because the current density in the strips is a linear function of the distance from the injection point.

D. Minimization Procedure

We can now write for the total base resistance

$$r_b + R_{bA1} + R_{eA1} = \frac{\rho L_1}{12nWh} + \frac{9 \cdot 10^2 L_2}{ndh} + \frac{2hR_{sq}}{3nb_1} + \frac{b_{\max}R_{sq}}{6h_1},$$

in which

$$b_{\max} = n\{2b_1 + 10\} = 625\ \mu m$$

and

$$h_{\max} = 2h_1 + h + 20 = 330\ \mu m.$$

Manuscript received July 25, 1979; revised October 18, 1979.

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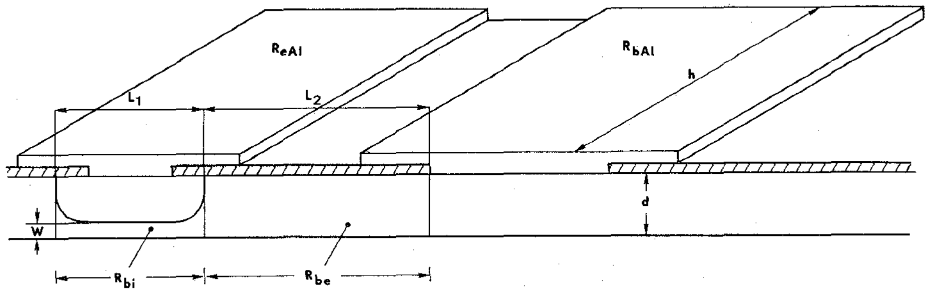

Fig. 1. Dimensions of active part of transistor: $d = 2.5\ \mu m$, $W = 0.6\ \mu m$, and $\rho/W = 6.5\ k\Omega$. Minimum dimensions in our process are: $L_1 = 7.8\ \mu m$ and $L_2 = 9\ \mu m$.

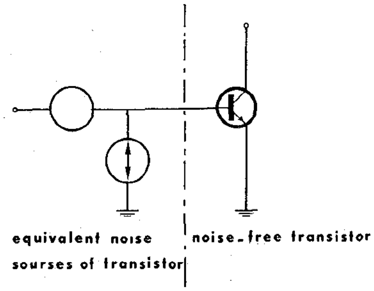

Fig. 2. Representation of the noise of a bipolar transistor.

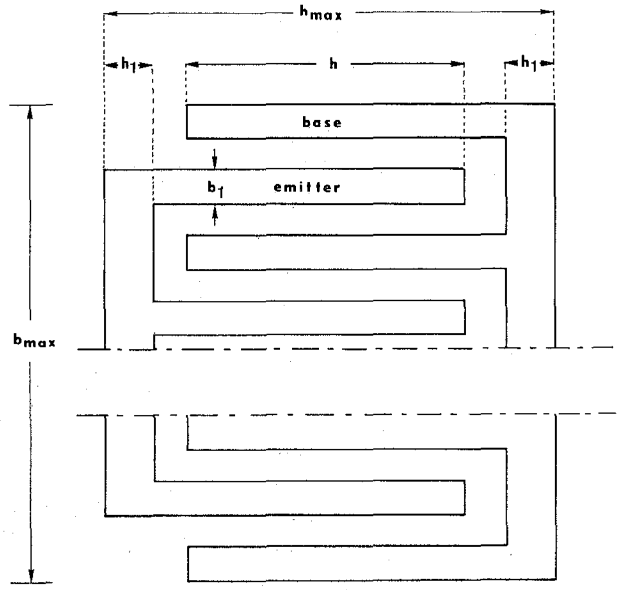

Fig. 3. Aluminum interconnection pattern for an interdigitated transistor structure with n emitter fingers.

Inserting the minimum values of L_1 and L_2, ρ/W, and R_{sq}, it is possible to eliminate n and h, so that the base resistance is a function of b_1 and h_1 only. It appears in our case, that this function has a minimum for $b_1 \simeq 1\ \mu m$. This is yet beyond our technological possibilities. With our minimum clearances it follows $n = 19$. In this case, the function exhibits a rather flat minimum around $h_1 \simeq 15\ \mu m$, and the theoretical value of $r_b + R_{bAl} + R_{eAl}$ amounts to 1.55 Ω.

Of course it is attractive to further reduce the horizontal strip resistance by covering the inactive parts of the transistor with aluminum (Fig. 4).

IV. Experimental Results

Noise measurements on transistors designed according to the described method indicate total equivalent noise voltages corresponding to 1.4 Ω. Measurements of f_T and h_{fe} show an increase of both parameters with emitter current in the range of 1–100 mA.

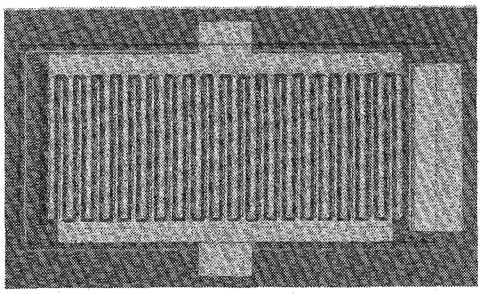

Fig. 4. Photomicrograph of low base resistance transistor. Dimensions are: 330 × 625 (μm^2).

At $I_E = 100$ mA and $V_{cb} = 8$ V, $f_t = 220$ MHz and $h_{fe} = 110$. These results are in good agreement with measured values of transistors with standard dimensions in our process, provided that an appropriate scaling factor is introduced.

The transistor was applied in the input stage of a breadboarded preamplifier for a MCC, resulting in a substantial improvement of signal-to-noise ratio [1].

Acknowledgment

The authors would like to thank the staff of the IC-workshop, in particular F. de Jong for the preparation of the transistors.

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Switching Speeds of MOS Inverters

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***Abstract*—Delay equations are developed to describe the transient response of MOS inverters.**

Manuscript received August 4, 1977; revised October 22, 1979.

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0018-9200/80/0400-0246$00.75 © 1980 IEEE