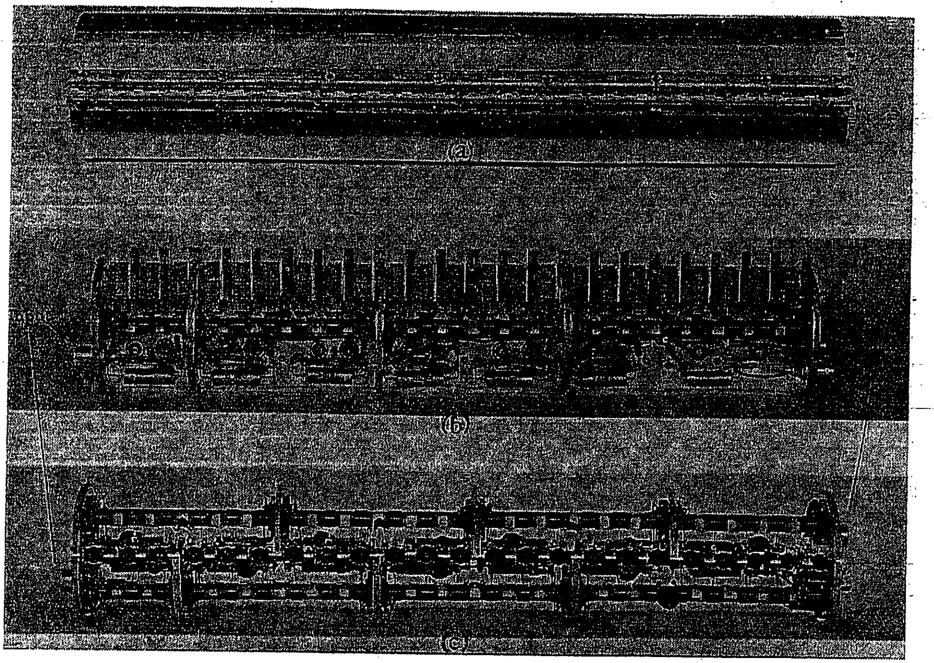

Fig. 4—80-db distributed amplifier. (a) amplifier enclosed in cylindrical jacket. (b) side view, jacket removed. (c) Top view, jacket removed.

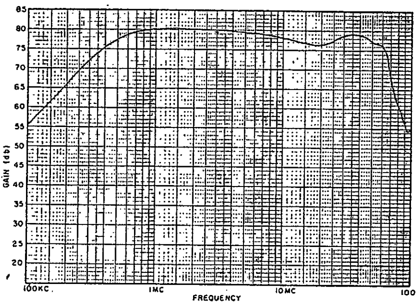

Fig. 5—Distributed amplifier frequency response.

ment is twenty-three 5840's, there being 5 tubes in the seventh (output) stage to obtain a greater output voltage swing than is available from the 3 tube stages. Fig. 5 shows the amplifier gain in db as a function of frequency for a total $B+$ current of 230 ma. The upper 3-db cutoff is at 55 mc.

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Self-Bias Cutoff Effect in Power Transistors*

In a recent article[1] the author pointed out that the majority carrier current flowing through the base region of a transistor towards the base connection causes an ohmic voltage drop which is in such a direction as to reduce the forward bias on parts of the emitter distant from the base lead. In power transistors this effect is serious and substantially all the emitter current is carried by a small area of the emitter near to the base contact. In that article an expression was derived for this effect at moderate current densities, which, when the emitter efficiency term is included, can be written, for a *p-n-p* transistor,

$$i(x) \approx j(0)\left[1 + x\sqrt{\frac{1}{2W\sigma_b}\left(\frac{\sigma_b W}{\sigma_e L_e} + \frac{1}{2}\frac{W^2}{L_b^2}\right)\frac{q}{kT}j(0)}\right]^{-2}, \tag{1}$$

where $j(x)$ is the emitter current density at a distance x from the base connection (see Fig. 1), W is the base width, σ_e the conductivity, L_e the diffusion length of minority carriers in the emitter region, and σ_b the conductivity of the base region.

It has been pointed out to me by Mr. N. Golden of Transistor Products and Dr. R. N. Hall of the General Electric Company that the case of most practical interest occurs at injection levels much higher than those discussed. A more general solution for the high level case is presented below.

Webster[2] has derived an expression for α as a function of emitter current. If we omit surface terms and consider the semi-infinite transistor in Fig. 1, then for the *p-n-p* case,

$$1-\bar{\alpha}(x) \approx \left[\frac{\sigma_b W}{\sigma_e L_e} + \frac{1}{2}\frac{W^2}{L_b^2}\right]\left[1 + \frac{z}{2}\right], \tag{2}$$

where

$$z = \frac{W\mu_e}{D_p\sigma_b}j(x), \quad \bar{\alpha} = \frac{1}{j}\int_0^j \alpha\, dj. \tag{3}$$

If $\bar{\sigma}_b(x)$ is the average base conductivity "seen" by the base current at x, then

$$\bar{\sigma}_b(x) = h\sigma_b\left(1 + \frac{z}{2}\right), \tag{4}$$

where h is a weighting factor, approximately equal to $\frac{1}{2}$ for high currents.

If $i_b(x)$ is the base current at x, then

$$\frac{di_b}{dx} = -(1 - \bar{\alpha})j(x), \tag{5}$$

and if $V(x)$ is the forward bias voltage of the emitter relative to the base at x,

$$i_b(x) = -W\bar{\sigma}_b\frac{dV}{dx} - \frac{kT}{q}\frac{d\bar{\sigma}_b}{dx}W, \tag{6}$$

where the second term on the right takes account of the flow of electrons through the base by diffusion.

These two equations are now treated by the method of reference 1, but taking into account the dependence of $\bar{\sigma}_b$ on x given by (4). We also assume that we can write

$$j(x) = j_0 e^{qV/kT}, \tag{7}$$

where j_0 is a constant. The equations can now be solved, but the result is a complicated implicit expression for $j(x)$. To obtain an explicit expression we assume

$$z = \frac{W\mu_e}{D_p\sigma_b}j(x) \gg 1 \tag{8}$$

for all x less than the value in which we are interested. This restricts our discussion to values of $j(x)$ greater than about 20 amperes per square centimeter in typical cases. Essentially, (8) implies that the conductivity of the base region is due principally to the electrons accompanying the injected holes, rather than to the original base material conductivity.

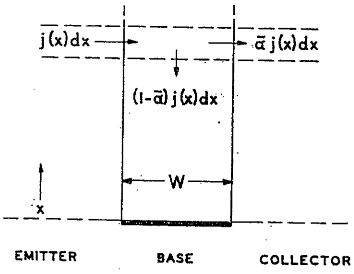

Fig. 1

With this restriction we find

$$j(x) \approx j(0)\left[1 + x\sqrt{\frac{1}{6W\sigma_b}\left(\frac{\sigma_b W}{\sigma_e L_e} + \frac{1}{2}\frac{W^2}{L_b^2}\right)\frac{q}{kT}j(0)}\right]^{-2}, \tag{9}$$

which then gives the fall-off of emitter current density with distance from the base connection (or the edge of the emitter in more complicated geometries). Eq. (9) differs from low level case only by factor $\sqrt{1/3}$ in coefficient x. Of this factor $1/\sqrt{2}$ is due to inclusion of diffusion term[3]; $\sqrt{2/3}$ to modulation of the base conductivity.

I should like to express my thanks to Dr. Hall and Mr. Golden for their interest and for many helpful suggestions.

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[1] N. H. Fletcher, "Some aspects of the design of power transistors," Proc. IRE, vol. 43, pp. 551–559; May, 1955.

[2] W. M. Webster, "On the variation of junction transistor current amplification factor with emitter current," Proc. IRE, vol. 42, pp. 914–920; June, 1954

[3] R. N. Hall has treated the effects of diffusion and independently arrived at this same result. (Private communication.)