LB-915

A P-N-P TRIODE ALLOY JUNCTION TRANSISTOR FOR RADIO-FREQUENCY AMPLIFICATION

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Approved

Stuart Wm. Seeley

Introduction

The p-n-p alloy junction transistor described in LB-868, *Germanium p-n-p Junction Transistors,* is for low-frequency use only, although a few selected units did operate in the broadcast band. The present bulletin describes a new medium-frequency (0.3 to 3 Mc) p-n-p transistor. In comparison with the better selected units of the *LB-868* design, which gave power gains of the order of only 10 db at 455 kc, a new unit (neutralized to eliminate feedback) will give as high as 39 db gain at this frequency, 12 db gain at 10 Mc, and has an oscillation limit of 40 Mc. A noise factor at 1 Mc of as low as 3 db is achieved.

One of the chief limiting factors in the high-frequency performance of the alloy transistor is a resistance-capacitance low-pass filter effect in its input. This is produced by the germanium resistance (between the external base connection and the active junction region) and the emitter-to-base capacitance. The latter is extraordinarily high because of the relatively slow diffusion of charge carriers into the base region, which must be charged up and discharged with minority carriers. To reduce both resistance and capacitance in the new design, a thick wafer of low-resistance germanium is used, and the active junctions are placed on a very thin section produced by drilling a well into the wafer. The distance between junctions is reduced so that the emitter-base diffusion capacitance is cut by a factor of about 20 over the low-frequency design of *LB-868*. The series resistance component is reduced by a factor of 3 to 5.

Another frequency-limiting factor in the alloy junction transistor is the charge carrier transit-time dispersion. This is minimized in the new medium-frequency design by attention to accurate parallelism of the junctions and by the small spacing between them, which is only 0.0005 inch. A third frequency-limiting factor is sometimes imposed by other capacitances, such as that of collector-to-base, and collector-to-emitter. These are reduced in the present design by reducing the active area of the emitter and collector junctions, while taking special precautions to maintain centering.

The present design of transistor uses similar processing methods to those described in *LB-868*. Because of the more critical dimensions and the higher performance, greater care and precision is required for good results.

General Discussion

In normal broadcast receiver design, an amplifier giving good gain in the frequency region of ½ to 3 Mc/s is desirable. In order to fulfill this need, keep power consumption to a minimum, and retain the simplicity and versatility of the triode alloy-junction transistor, a development was undertaken to extend the frequency range of this type of transistor.

To follow the course of the present development, it is desirable to discuss first the important factors which limit the frequency response of the triode transistor such as the TA-153 transistor described in *LB-868*. The important factors stem from a combination of two effects; one inherent to transistor operation and the other extrinsic to transistor action but arising from the constructional details. In the operation of this type of transistor it is well known that minority charge carriers, after injection by the emitter, flow to the collector by a process of diffusion through the base region and receive little or no aid from electric fields. Such diffusion currents flow under the influence of a density gradient (i.e., different carrier charge densities in different regions of the base layer). Thus, when a signal is applied to the transistor, the number of carriers in the base region must be varied up and down in accordance with the signal in order to produce the resulting diffusion current flow to the collector to reproduce the signal in the output circuit. This change in the charge of the base region induced by the applied signal acts as an emitter-to-base capacitance. Furthermore, because this charge flow in and out of the base region is a diffusion flow, an extraordinarily high capacitance results, (of the order of 0.01 μf in the TA-153 transistor).

This capacitance is much greater than that associated with the transition region of the emitter junctions above. The "diffusion" capacitance is given approximately by

$$C_{b'e} = \frac{q}{kT}\,\frac{W^2 I_E}{2D}$$

where $C_{b'e}$ is the input capacitance element of the common emitter representation of Fig. 1, W is the effective thickness of the base region, I_E is the d-c emitter current, D is the diffusion constant for minority carriers in the base region, q is the electronic charge, k is Boltzmann's constant and T is the absolute temperature. When I_E is expressed in milliamperes, and W is in mils, this formula gives the capacitance in farads as

$$C_{b'e} = \begin{cases} 2.8 \times 10^{-9} W^2 I_E & \text{(for p-n-p units)} \\ 1.34 \times 10^{-9} W^2 I_E & \text{(for n-p-n units)} \end{cases}$$

Since this capacitance is proportional to the square of the thickness of the base region, it is important to minimize this distance in transistors designed for high frequency applications. Note that this capacitance is proportional to the d-c current and does not involve the junction area. It is evident that a measurement of $C_{b'e}$ will provide a measure of the effective thickness of the base region.

Now, in the construction of the alloyed junction transistor, the external base connection to the germanium wafer is made at some distance from the active junction region. The resistance of the germanium between the base connection and the active junction region constitutes a series base lead resistance ($r_{bb'}$ of Fig. 1) through which the input signal must pass, with consequent attenuation before it can be applied to the intrinsic transistor. Furthermore, the charging current for the emitter-to-base capacitance discussed above

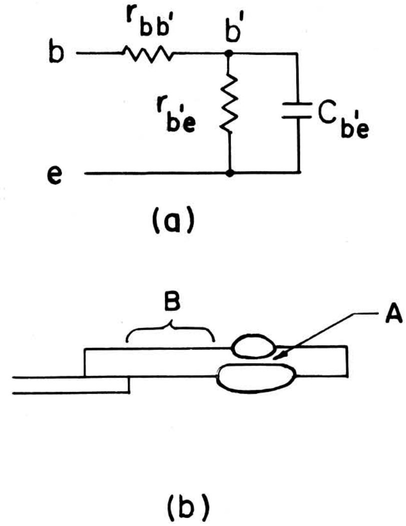

Fig. 1 - (a) Equivalent input circuit of the transistor and (b) transistor cross-section showing the physical location of the parts of $R_{bb'}$ on a TA-153 audio transistor.

must also flow through this resistance. This combination of series resistance and emitter-to-base capacitance constitutes a low pass filter which is one of the most important limiting factors of transistors such as those described in *LB-868*.

The presence of this base lead resistance, in addition to diminishing the input signal available to the actual transistor junctions, is also a feedback element and its presence in the transistor leads to a reduction in the overall output resistance and an increase in the overall output capacitance of the transistor.

In addition to the input circuit effects discussed above, there are also further consequences resulting from the fact that charge carriers flow from the emitter to collector by a diffusion process. Diffusion flow is essentially a random process with the individual carrier making many collisions and changing direction of motion many times during its travel across the base region. Directivity to this random motion is supplied by the concentration gradient discussed above. Thus, the transit time for the individual carriers must vary widely giving rise to a dispersive effect in the transfer function (i.e., transconductance). This transit time dispersive effect in the transfer of carriers to the output circuit also limits the frequency response of transistors but, for transistors such as the TA-153, its effect is not as large as the input circuit effects discussed above.

The above transit-time dispersion effects in the transfer function have been discussed as resulting only from diffusion phenomena. There may also be an additional effect of similar nature (i.e., transit time dispersion) due to different path lengths caused by non-planar geometries and end effects. This difference in path length may be minimized by small emitter-to-collector spacings, planar junctions and accurate centering.

The picture given above of the consequences of diffusion flow in the base region has tended to separate the effects on the input circuit from those concerned with the transfer generator. This leads quite naturally to the π equivalent-circuit representation used in this bulletin (Fig. 7). It may be well to point out that, in other representations, such as an equivalent T circuit, the transfer generator (alpha) involves both the transfer transit-time dispersion effects and base-charge variation effects. This is as it should be, for alpha is the current gain amplification factor, and must account for changes of current between the input and output. Indeed, the collector-to-emitter current gain cut-off frequency is related to $C_{b'e}$ by

$$f_{c\alpha} = \frac{q}{2\pi kT} I_E / C_{b'e}$$

and a measurement of $C_{b'e}$ at low frequencies may be substituted for a measurement of $f_{c\alpha}$ at considerably higher frequencies.

Another frequency-limiting factor, which may become significant as transistors are designed to minimize the above effects, is the presence of other capacitances, such as that of collector-to-base and collector-to-emitter. The collector-to-base capacitance may be reduced by reducing the area of the collector junction. There is also a contribution to this capacitance due to transit-time variation effects caused by a variation of the effective base thickness with the instantaneous collector voltage.

The above considerations will be applied in this bulletin to the development of a p-n-p medium-frequency transistor. Similar considerations would also apply to n-p-n transistors.

Factors Governing Design

As will now be understood from the preceding discussion, in the design of high-frequency transistors it is important that, in addition to satisfying the requirements for good transistor action at audio frequencies, particular attention must be given to the following parameters.

1. Thickness of base layer.
2. Series base lead resistance.
3. Capacitance.

As pointed out in the general discussion the value of $C_{b'e}$ (or $f_{c\alpha}$) is degraded in proportion to the square of the distance between the emitter and collector junctions. This distance should be as small as can conveniently be obtained and a reasonable value of spacing to aim for is 0.0005 inch.

In the alloy type transistor, an emitter-to-collector spacing of 0.0005 inch can be obtained in two ways, (a) by using a thick base wafer and a large impurity alloy penetration, or (b) by using a thin germanium base wafer with small impurity alloy penetration. With method (a), however, the junctions are hemispherical rather than parallel planes and consequently the possible hole path lengths may vary considerably. In method (b) the junctions are more nearly flat and parallel; this method was therefore chosen. With thin base wafers it is necessary that the impurity alloy depth of penetration be small. Accurate control is then necessary to prevent emitter-to-collector shorts.

The factors governing the penetration of indium by solution into the germanium base material were discussed in *LB-868*. A shallow penetration as desired here can be secured by (1) a short firing time, i.e., shorter than that required for an equilibrium solution of the alloying action, (2) using a small volume of indium, (3) using a disc of indium-germanium alloy. The method described in this bulletin is a combination of all three but depends principally on the latter two.

In order to secure plane parallel junctions, heating at a high temperature is desirable to secure rapid wetting over the entire region of the junction. Various combinations of alloy disc composition and temperature are possible and several have been tried. However, as the atomic per cent of germanium in the indium-germanium alloy is raised above 10 per cent, it is more difficult to secure a homogeneous alloy, and the mechanical properties of the alloy become poorer. The alloy which has been found most advantageous at the present time contains 5 atomic per cent germanium in indium and this is the alloy used in all experiments described herein.

As discussed previously it is important that $r_{bb'}$, the resistance of the germanium connecting the active junctions and the base tab be as small as possible. This resistance is shown in the input equivalent circuit of Fig. 1a. The values of this equivalent circuit can be measured by means of specially designed bridges.[1]

The series resistance, $r_{bb'}$, consists of two regions, as shown in Fig. 1b: region "A" directly between the junctions and region "B" between the junctions and the base connection. Obviously, the resistance of both these regions is reduced by using as low a resistivity base material as possible. In the "B" region, no limitation on resistivity exists. However, on the "A" region, two good junctions must be formed.

Shockley[2] has shown that, in order to have a good hole emitter, the conductivity of the emitter section must be much higher than that of the base region. Experimentally, it is found that, as the resistivity of the base region is decreased, good junctions are more difficult to make. Here, then, an engineering compromise must be made between a desire for low base resistance and good junctions, as evidenced by high alpha and high back-resistance values. The resistance of the "A" region, which is

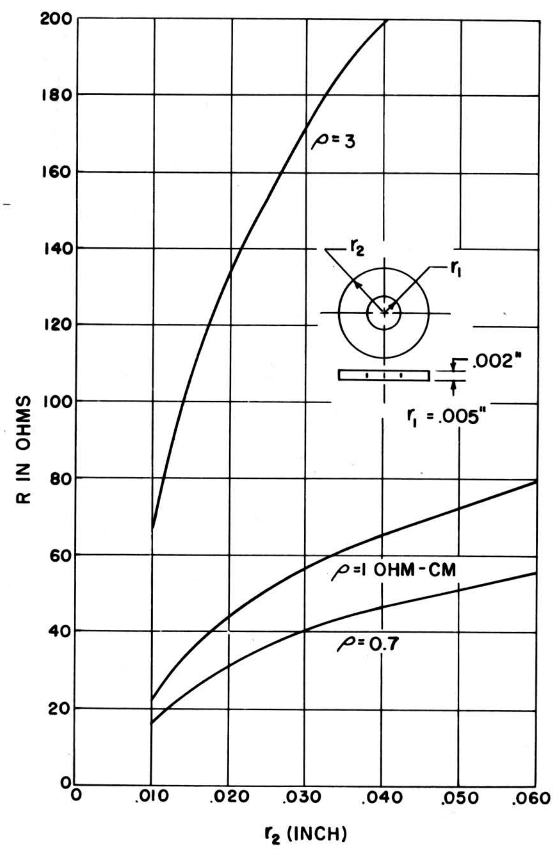

Fig. 2 - Resistance between concentric cylinders of germanium.

[1] LB-900, *Equipments for Measurement of Junction Transistor Small-Signal Parameters for a Wide Range of Frequencies.*

[2] W. Shockley, "The Theory of P-N Junctions in Semi-Conductors and P-N Junction Transistors". *Bell Sys. Tech. Jour.*, Vol. 28, pp. 435-489, 1949.

directly between the junctions, is also reduced by the carriers injected by the emitter, i.e., conductivity modulation. Considering the present state of the art and the necessary engineering compromises a resistivity of 0.6 to 0.8 ohm-cm was chosen after some exploratory tests.

Region "B" may be examined to see how this resistance can be reduced. In order to obtain an idea of the magnitude of resistance involved in the region "B" for a thin flat-wafer base, consider the simplified geometry shown in Fig. 2. The resistance in ohms between concentric cylinders is given by:

$$R = \frac{\rho}{2\pi L} \ln \frac{r_2}{r_1} \text{ ohms}$$

ρ = resistivity of germanium in ohm-cm.

r_1, r_2 = radius of the inner and outer cylindrical surfaces

L = wafer thickness in cm.

If r_1 is kept constant at 0.005 inch (the size of the emitter junction), and r_2 is varied upward from 0.010 inch, the curves of Fig. 2 are obtained.

If such a flat-wafer construction were used for the high-frequency transistor, and ρ = 3 ohm-cm, it is seen from Fig. 2 that a series resistance of 200 ohms would be introduced to a ring contact 0.040 inch from the center of the emitter. The curves also show that the contribution of the first few thousandths of an inch around the junctions is important. From these curves the disadvantages of high resistivity germanium and of the flat-wafer construction are apparent.

Several methods of reducing the resistance of the region "B" are possible. As a guide, methods other than those finally used are discussed first. One way to reduce the resistance of portion "B" is to solder a ring, a few thousands of an inch larger than the junctions, to the germanium that surrounds the junctions. Great care must then be taken to keep the indium alloy and solder from shorting and to obtain proper etching after assembly. Another possible procedure is to form junctions, protect the junctions with a suitable lacquer, and then plate a metal on the exposed base wafer. It is necessary to make a plated contact which is ohmic, i.e., does not inject an appreciable number of holes. Such ohmic contact can be made by sand blasting the base and then plating. A word of caution on these methods is in order. As has been shown in another bulletin[3], surface recombination is a critical factor in obtaining low-frequency transistor action. An ohmic contact or plated region of considerable area too near the emitter junction could lead to such a high recombination rate as to make the transistor unsatisfactory. A compromise is necessary which leaves sufficient low-recombination surface around the junctions, and yet not so much as to leave the base resistance high.

After exploration of the above methods, a design was chosen in which only germanium surrounds the junctions. The structure is shown Fig. 3 which is drawn approximately to scale. Here it is seen that, as soon as the immediate vicinity of the junctions is left, the thickness of the wafer increases and thus decreases the series base lead resistance; since only germanium surrounds the junctions, low surface recombination can be attained at the same time. The technique of making this construction is described later.

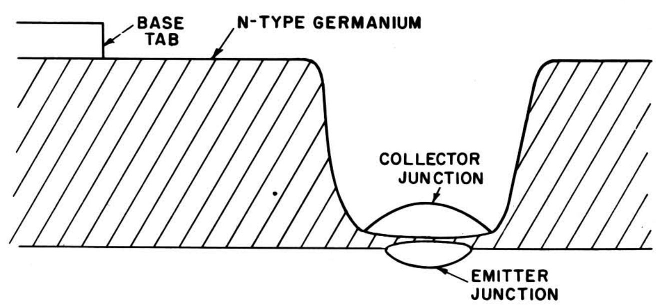

Fig. 3 - Cross-section view of junction geometry.

The collector-to-base capacitance should be no larger than necessary. The junctions of the alloy type transistor are usually of the abrupt or Shottky type. Formulas for this case are developed by Shockley[2] and, when expressed in convenient units, lead to the following equation for the capacitance of an abrupt junction.

$$C = 0.071\, d^2 \frac{1}{\sqrt{\rho_b V_c}} \mu\mu f$$

[3] LB-916, *The Variation of Current Gain with Junction Shape and Surface Recombination in Alloy Transistors,*

where:

d = diameter of the junction in mils.

V_c = collector voltage.

ρ_b = resistivity of the base material in ohm-cm.

Thus the diameter of the collector has the greatest influence and should be made small. This should preferably be done without decreasing α_{ce}, collector-to-emitter current amplification factor. In order to keep α_{ce} high, the area of the emitter must be kept to two-thirds or less than that of the collector[3].

As the area of the emitter is reduced, the ratio of emitter circumference to area increases and surface recombination becomes more important. Consequently etching must be carefully done. Also, as the area of the emitter and collector become small, alignment of emitter and collector is more difficult. As an engineering compromise, the emitter was made 0.010 inch in diameter and the collector 0.015 inch in diameter. (Methods of assembly are discussed later). This reduction of area should result in a reduction of collector-to-base capacitance of about 9 times over that of the TA-153. However, the resistivity of the base layer has been reduced by a factor of 4 which increases the capacitance. A net decrease of capacitance by a factor of about 3 was achieved.

Method of Fabrication

The general method of making alloy transistors has been described previously in *LB-868* and here only the critical and necessarily different techniques will be described. The germanium chosen is n-type, of 0.6 - 0.8 ohm-cm resistivity, grown as a single crystal in the 111 direction. The alloy discs are 5 atomic per cent germanium in indium, 0.005 inch thick, 0.010 inch and 0.015 inch diameter, for emitter and collector, respectively. The base wafer in the high-frequency transistor is 0.025 inch thick and has a 0.020 inch diameter well, 0.023 inch deep, which reduces the thickness at the point where the junctions are applied to 0.002 inch.

Several methods of drilling this well in germanium are possible and again the methods which were *not* used in the final technique are mentioned first. By masking portions of a wafer with lacquer, or pressure jigs of plastic, and immersing in acid, wells can be etched in the wafer. In another method a metal plate with the appropriate hole is placed over a wafer of germanium and a well carved out by abrasive material carried by compressed air or a liquid under pressure. All these methods were successful but, for laboratory purposes, were superseded by the method described below.

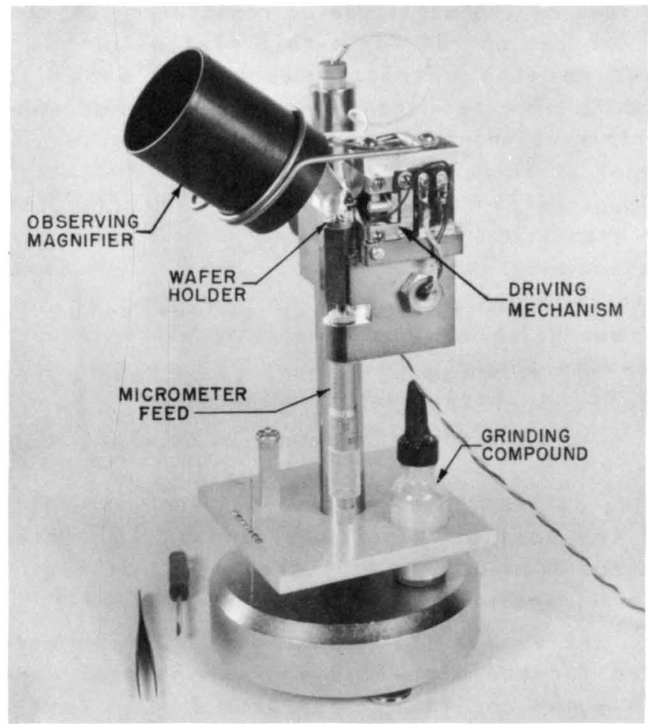

Fig. 4 - Well drilling apparatus.

In the final method used in the laboratory, a brass tool loaded with a grinding compound is moved in a vertical motion so that the germanium is chipped or ground away. The action is similar to, but slightly more refined, than the air hammer which is used to break up concrete. A picture of the device used to fabricate all the base wafers of germanium used in this report is shown in Fig. 4. The schematic drawing of Fig. 5 shows the mechanical action. The coil shown in the figure is driven by an oscillator at about 1000 cps, and this motion is transmitted to the screw, the point of which is 0.020 inch in diameter. The actual motion of the tool point is only about 0.001 inch. The wafers are clamped or waxed on the top of the wafer support post, which, in turn, is held in place magnetically. A drop of glyerine, containing Linde 305 grinding compound[4], is applied to the germanium wafer. The germanium wafer is pushed against the vibrating tool by the micrometer feed to get the desired depth of penetration. Drilling is continued until a thickness of about 0.006 inch of germanium remains at the bottom of the well. A time of about four minutes is required to drill one well. The drilling operation greatly disturbs the crystal surface, like sand blasting, and increases surface recombination. After drilling, the disturbed surface is removed by etching the entire crystal as described in

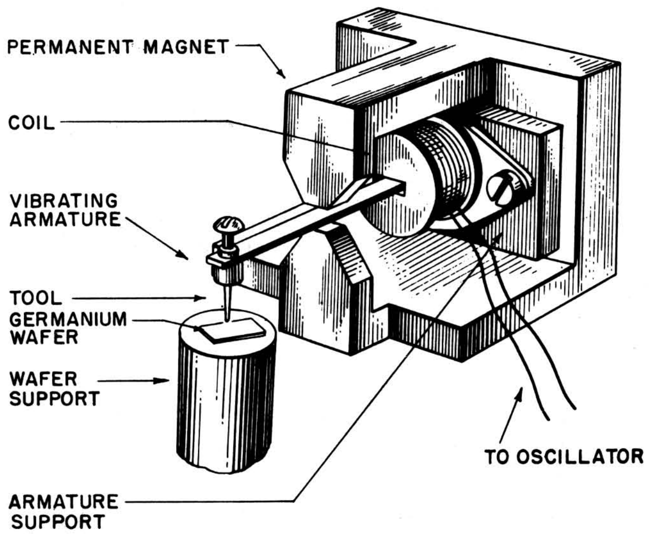

Fig. 5 - Schematic drawing of well drilling apparatus.

LB-868 until the thickness at the bottom of the well is 0.002 inch.

Since the above-described method is essentially a fine scale chipping, mechanical crystal imperfections of the germanium should not run perpendicular to the thin section of the crystal. Crystals grown in the 111 direction and cut perpendicular to this direction have given the best results. Use of this crystallographic arrangement has also given more consistent junction formation and separation than the use of 100 direction crystals.

Since the area of the collector junction is smaller by about a factor of 9 than that of the TA-153, considerably more care must be used in assembly in order that the junctions be aligned opposite to each other. The method of doing this is evident from the sketch in Fig. 6 which shows the technique of locating the 0.010 inch diameter emitter dot so that it is aligned opposite to the well in the germanium. After loading, the assembly jig is fired in dry hydrogen for 2 minutes at 600 degrees C. After cooling, this unit is turned over with the emitter indium-alloy dot in the hole of the jig. A collector alloy disc of 0.015 inch diameter is placed in the well. The base tab is placed against the wafer and the entire assembly heated for 5 to 10 minutes at 610 degrees C.

[4]Linde Air Products Co., New York, N. Y.

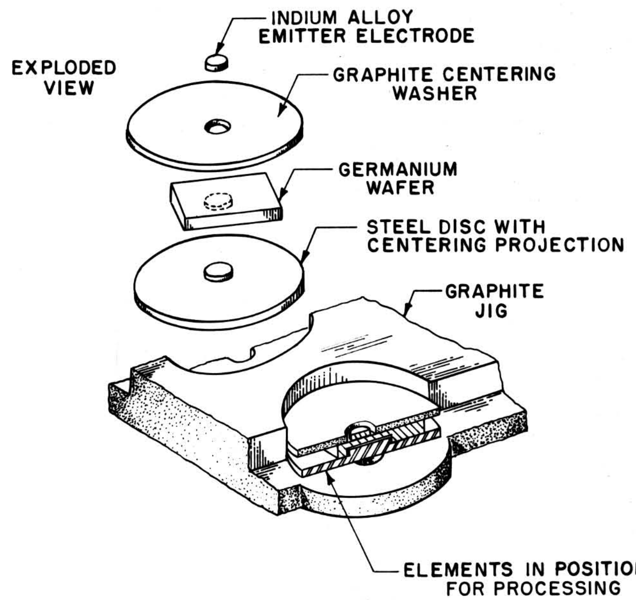

Fig. 6 - Jig for applying indium emitter electrode.

Connections to these junctions are made as described in *LB-868* except that, because of the smaller junctions, smaller wires with less tension are used. Soft annealed nickel wires of 0.004 inch diameter work well.

Electrical Measurements

The electrical engineer likes to reduce an electron device to an equivalent circuit composed of elements with which he is familiar so that he can apply standard circuit theory. Many types of equivalent circuit are possible and not all engineers prefer the same types. The simplest circuit, with the fewest parameters that are all independent of frequency, is best but not always obtainable. Most of the published literature on transistors is in terms of the T-equivalent circuit or loop-derived parameters. Many engineers that are familiar with vacuum tube terminology prefer the π-equivalent or nodal-derived parameters. One set of parameters can of course be derived from the other set if the set is complete.[5]

In Fig. 7 a single-generator π-equivalent circuit is shown for the common-emitter connection. The circuit parameters have been tested and found to be independent of frequency as long as the frequency is not too high.

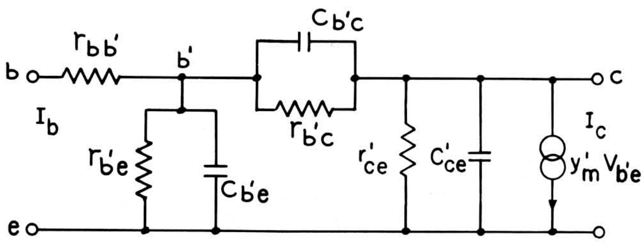

Fig. 7 - Single-generator base-input π-equivalent circuit.

Although not yet completely investigated, the circuit is believed sufficiently close as long as $\frac{\omega W^2}{4D_p} < 0.2$ where ω = angular frequency, W is the spacing between junctions and D_p = diffusion constant for holes. For the transistors of this bulletin, the circuit is believed to be a reasonable approximation up to a frequency of the order of 3 Mc. The elements shown in this circuit were measured in bridges previously described[1]. The values measured on six transistors are given in Table I. The value of the spacing between junctions, W, is calculated from $C_{b'e}$ by applying diffusion theory as previously described. The values of the circuit constants in the output were not determined because their effect is negligible in comparison with the other parameters and the measurement is difficult. In Table I, transistors A to E are typical. Transistor F is included to show the effect of an appreciably larger value of W, even though the construction is otherwise the same.

For comparative purposes, a range of values for TA-153 audio p-n-p transistors described in *LB-868* is included. The value of W for the TA-153 transistor was not as accurately controlled since the transistor was intended for audio use.

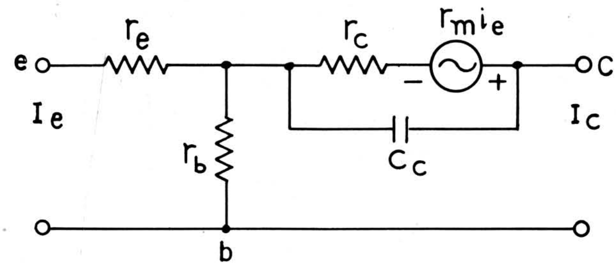

Fig. 8 - Low frequency emitter-input T-equivalent circuit.

In Table II the low-frequency parameters of the common-base T-equivalent circuit of Fig. 8 are shown, again in comparison with

Table I

π-equivalent Circuit Parameters Measured at E_c = -6V, I_c = 1 ma

Transistor	A	B	C	D	E	F (Note 2)	Approx. TA-153 range
$r_{bb'}$ ohms	50	115	60	70	77	100	200-500
$r_{b'e}$ ohms	1250	1500	600	1400	430	500	600-2000
$C_{b'e}$ μμf	300	700	900	600	800	2100	10,000-25,000
$r_{b'c}$ megohms	1.2	0.10	0.14	0.86	0.13	1.9	4
$C_{b'c}$ μμf	10.4	7.7	16.7	9.5	17	11	35
W mils (Note I)	0.33	0.55	0.56	0.46	0.52	0.88	1-3

Note I - Calculated from $C_{b'e}$ as previously described.

Note 2 - This transistor is included to show the deviation to be expected from a higher-than-normal value of W.

[5] LB-889, *Application of Linear Active Four-Terminal Network Theory to Transistors.*

Table II

T-equivalent Circuit Parameters

E_C = -6V; I_E = 1 ma

Transistor	A	B	C	D	E	F	Approx. TA-153 range
r_e ohms	4	18	20.6	14.6	19.4	16	5-20
r_b ohms	1000	300	140	270	130	250	400-2000
r_c megohms	0.4	0.06	0.16	0.40	0.16	0.45	0.5-3.0
α_{ce}	0.977	0.982	0.976	0.955	0.952	0.963	0.95-0.99
α_{cb}	41	51	40	21	19	25	20-100
I_{co} μa	20	10	10	14	18	8	2-20

those of the TA-153. The parameters r_c and α_{ce} are slightly poorer in the high-frequency transistor because they were compromised to get better high-frequency performance. These low-frequency parameters, of course, give no clues to high-frequency performance but are included in the data for those who wish to make comparisons.

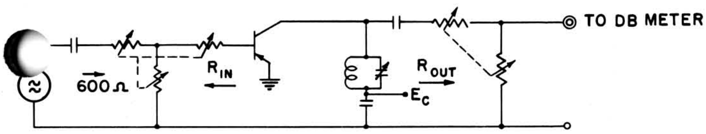

Fig. 9 - Simplified diagram of circuit used for gain measurement versus frequency.

An important characteristic of a high-frequency transistor is, of course, the single-frequency power gain as a function of frequency. Fig. 9 shows a simplified schematic circuit of the test set used to measure power gain. This circuit is similar to the low-frequency dynamic test set previously described[8] except that it is designed to go up to a frequency of 10 Mc per second. Input matching is made only with the resistive component while the output is conjugate matched by adjusting the capacitance and output impedance. The feedback is not neutralized. In Fig. 10 is plotted the gain of a transistor with common emitter and common base connections.

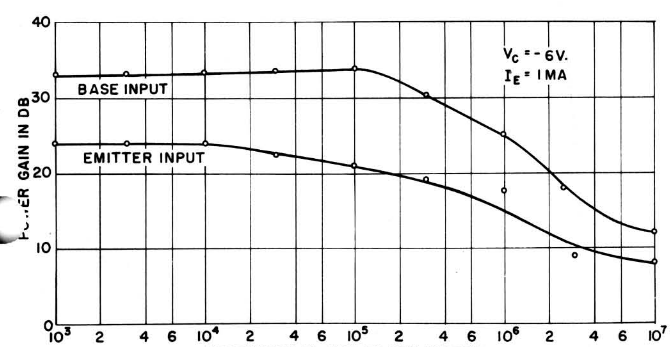

Fig. 10 - Single-frequency power gain measured in the circuit of Fig. 9.

[8]LB-871, *Dynamic Test Set for Transistors*.

In Table III the gain of the six transistors is shown for the various conditions described in the footnotes of the table. It will be noted that the larger-W transistor (F) shows poorest performance at 1 and 10 Mc. Table III also gives the noise factor. There is a considerable variation of 1-kc noise factor[7] among various units at the present time but the 1-Mc noise factor does not vary as much. In Fig. 11 the noise factor of one unit is plotted as a function of frequency up to 1 Mc/s.

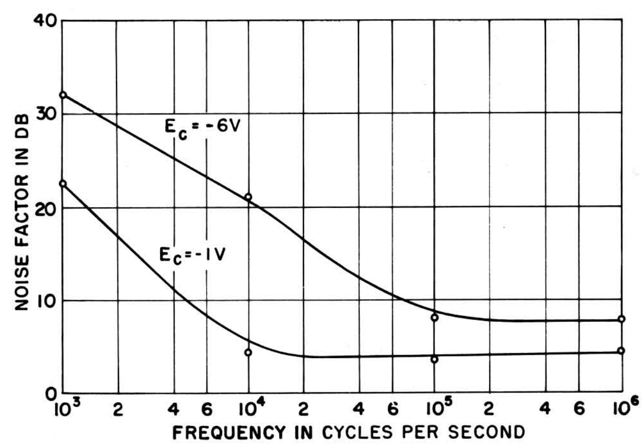

Fig. 11 - Noise factor versus frequency; common emitter connection.

[7]LB-876, *Noise Factor Measurements of Transistors*.

Table III

Gain and Noise Factor Values

Transistor	A	B	C	D	E	F	Approx. TA-153 range
4 kc gain db (Note 1)	35	37	39	34	34	38	35-48
455 kc gain db (Note 2)	35	32	39	35	34	34	<0-10
1 Mc gain db (Note 3)	24	23	25	24	23	22	<0-7
10 Mc gain db (Note 3)	13	10	11	9	8	5	-
1 kc noise factor db (Note 4)	14	23	33	24	16	20	15-25
1 Mc noise factor db (Note 5)	4	5	8	7	5	6	-

All values of gain measured at E_C = -6V, I_E = 1 ma

Note 1 - R_{in} = 500 ohms, R_{out} = 30,000 ohms.

Note 2 - Input and output conjugate matched and feedback neutralized.

Note 3 - Input resistive matched and output conjugate matched in circuit of Fig. 9.

Note 4 - E_C = -1V, I_E = 1 ma, R_{in} = 560 ohms.

Note 5 - E_C = -1V, I_E = 1 ma, R_{in} = 100 ohms.

Experiments with a simple oscillator circuit show that the high-frequency transistors described will oscillate at frequencies of 30 to 40 Mc per second.

Conclusions

A p-n-p triode transistor was achieved capable of as much as 39 db gain at 455 kc/s when used in a neutralized, conjugate-matched circuit. Without neutralizing, 12 db at 10 Mc could be obtained. The noise factor at 1 Mc/s was 3 to 7 db.

A spacing between junctions of 0.0005 inch and a low base-lead resistance was obtained by using a low-resistivity base section with the collector junction located at the bottom of a well in the germanium. An indium-germanium alloy was used to obtain more planar junctions which are about 1/3 the size used in the TA-153.

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