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TRANSISTOR PERFORMANCE IN INTENSE MAGNETIC FIELDS

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16. Abstract

The forward current transfer ratio ($h_{FE} = (\Delta I_{collector}/\Delta I_{base})$) of a germanium junction transistor, operating in the common emitter mode, is reduced by the application of a magnetic field. This reduction is greatest when the magnetic field vector is perpendicular to the direction of minority carrier motion through the base region. The base thickness is also an important variable. Transistors with smaller base (planar diffused) regions are less affected by magnetic fields.

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SUMMARY

The forward current transfer ratio ($h_{FE} = (\Delta I_{collector}/\Delta I_{base})$) of a germanium junction transistor, operating in the common emitter mode, is reduced by the application of a magnetic field. This reduction is greatest when the magnetic field vector is perpendicular to the direction of minority carrier motion through the base region. The base thickness is also an important variable. Transistors with smaller base (planar diffused) regions are less effected by magnetic fields.

INTRODUCTION

Where instruments using transistors are to be operated in a strong magnetic field, there is a need to know what changes the field may produce in the performance of the transistors. Our experimental purpose was to determine how the operational characteristics at 300 K of various types of transistors are effected by both the magnetic field strength and the orientation.

Suhl and Shockley (ref. 1) have shown that minority carriers, holes in N type semiconductors, migrate to one side of a sample as a result of the Lorentz force. Karakushan and Stafeev (ref. 2) proposed a magnetic field-effect-diode in which magnetoresistance is the control mechanism. They have predicted and confirmed experimentally that when the diffusion length is much less than the diode thickness the diffusion length decreases as the magnetic field is increased. The decrease in the diffusion length results in a cooresponding decrease in the forward current. The diffusion length is the mean net distance a particle diffuses during its life time. Garfinkel and Engeler (ref. 3) have observed a majority-carrier effect upon p-n junctions in which the Hall potential alters the biasing

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of the junction. Parshad and Mehta (ref. 4) have observed that with fixed bias voltage the forward and reverse currents of a germanium diode both decrease in a magnetic field, but that a silicon diode was not affected. They were unable to explain their results on the basis of either magnetoresistance or the deflection of minority carriers by magnetic fields.

Research has also been done on the effect of a magnetic field on transistors. The effect of a magnetic field on the diffusion of carriers across the base region in junction transistors has been analyzed by Dobrovolskii (ref. 5). Misra and Srivastava (ref. 6) have derived a linear relation between the magnetic field and the diffusion constant (the coefficient of the gradient of the concentration in the expression for the current density, ref. 7). The diffusion constant is proportional to the square of the diffusion length. Misra and Srivastava have also performed experiments on an alloy junction Ge transistor. Their results show the predicted linear decrease in the diffusion constant with increasing magnetic field.

APPARATUS AND MEASUREMENT PROCEDURE

A rotatable transistor socket was mounted on a magnet probe as shown in figure 1. The probe was sufficiently massive to preclude significant temperature gradients. The mount allowed $\pm 180^{\circ}$ rotation about an axis normal to the plane of the transistor socket. The axis is also perpendicular to the field of the magnet. It was possible to place the transistor in any position relative to the field (figs. 1(b) and (c)) by bending the transistor leads. The transistor collector characteristics were obtained in four angular positions 90° apart on each of three mutually orthogonal axes; this gave a total of 12 positions.

The transistors were all operated in the common-emitter mode. And the collector current against collector voltage curves for a series of base currents were plotted by a transistor curve tracer, which obtains collector characteristics by the following sequence of operations. The lowest preselected value of base current is applied to the transistor. The collector voltage is ramped up to a preset limit and then ramped back to zero. When the collector voltage reaches zero the base current is increased by a preselected amount and the collector voltage is ramped up and down again. The cycle is repeated at 120 hertz, for a preset number of base currents and then the base current is set back to zero and the whole process begins over again. The signals applied to the transistor are shown graphically in figure 2. The family of collector current-collector voltage curves generated by the series of base currents is displayed on the oscilloscope of the transistor curve tracer. Permanent records (fig. 3) were obtained with an oscilloscope camera. Because the transistor was separated from the curve tracer by 16-meter leads, parasitic oscillations occurred which distorted the characteristic curves. This required a low-pass filter at the transistor socket and shielding between the base and collector leads, as shown in figure 2. The filter prohibited the passage of signals above 100 kilohertz.

A water-cooled magnet with a 10.2-centimeter-diameter bore was used in the tests. Continuously adjustable fields up to 7.5 tesla were available by means of the excitation of a 200 kiloampere homopolar generator. It took about 5 seconds to increase the magnetic field from 0 to 7.0 tesla. Care was taken in the measurement procedure to avoid the effects of eddy current heating. Position adjustments of the transistor could be made without taking the probe out of the magnetic field.

The transistors tested were chosen to be representative of several types. For example, both pnp and npn transistors made from both germanium and silicon were tested. Alloy junction and planar diffused types were tested. The basic kinds of transistors and methods of fabrication are described in reference 8. The transistors tested are listed in table I.

Following the test, the same transistor (or one of the same type number and manufacturer) was opened to determine the orientation of the transistor base plane relative to the transistor case and leads. From this it was possible to determine the direction of the magnetic field in the active regions of the semiconductor chip for each set of characteristic curves. For any transistor the active region of the base can be taken as the volume between parallel planes formed by the emitter-base and collector-base junctions. The direction of minority carrier diffusion in the base is perpendicular to these junction planes, therefore the direction of the drift velocity $\overline{v}_d$ of minority carriers in the base can be taken as the reference vector for comparison with applied magnetic field vector $\overline{H}$.

RESULTS

In figure 3 the characteristics curves are presented for each of the transistors listed in table I. One set of curves is shown with H = 0 tesla, and another set is shown with

TABLE I. - TRANSISTOR PARAMETERS

Transistor	Material	Type of construction	Cutoff frequency, MHz	Forward current transfer ratio, h_{FE}, T		$h_{FE}(7)/h_{FE}(0)$
				0	7	
2N328A	Silicon (pnp)	Alloy	---	19	16	0.83
2N525	Germanium (pnp)	Alloy	1	59	18.5	.31
2N918	Silicon (npn)	Planar diffused	600	46.5	43	.96
2N1302	Germanium (npn)	Alloy	3	34.5	6	.17
2N4400	Silicon (npn)	Planar diffused	200	68	63	.94
2N4402	Silicon (pnp)	Planar diffused	150	91	86	94
TIXM01	Germanium (pnp)	Planar diffused	---	41	27.5	.67

$H = 7.0$ tesla. In all cases v_d is perpendicular to H. Table I also contains the forward current transfer ratio for both $H = 0$ tesla and $H = 7.0$ tesla and their ratio.

The results can be summarized as follows:

(1) Degradation of h_{FE} is greater in germanium transistors than silicon transistors.

(2) The alloy junction type of transistor exhibited more degradation than the planar diffused type.

(3) Maximum degradation always occurred when the magnetic field was perpendicular to the direction of minority carrier motion across the base region. The TIXM01 was very insensitive to the angle between H and v_d.

(4) In the planar diffused transistors tested, there were positions relative to the magnetic field in which noise fluctuation in the collector current appeared, as shown in figures 3(c), (d), (e), and (f). This noise was not maximum when the magnetic field vector and the minority carrier motion vector were perpendicular or colinear, but rather was maximum at approximately 45°. This noise fluctuation was not observed in alloy junction transistors in any position.

A series of characteristic curves were taken at 1.0-tesla intervals with the 2N525 germanium pnp transistor with v_d perpendicular to H. From these curves the value of h_{FE} at $V_{CE} = 8$ volts and $I_B = 1.8$ milliamperes were read and plotted in figure 4. On an h_{FE} against H graph these points fit the function.

$$h_{FE} = 55.5 \exp\left(-\frac{H}{6.75}\right)$$

DISCUSSION OF RESULTS

Because of the lack of specific information about manufacturing techniques and transistor materials it is impossible to pinpoint the cause of the degradation in h_{FE}. However, several of the results can be discussed with respect to the earlier experimental work mentioned in the INTRODUCTION. The degradation effect may be a result of several contributing factors such as magnetoresistance, a magnetic field dependent diffusion length (ref. 2) and a Hall voltage biasing of the transistor junctions (ref. 3).

If the magnetoresistance of transistor materials is treated as a field-dependent series resistance in the collector, base, and emitter, then the voltage applied across any two elements is divided between voltage across the junctions and voltage drop across the series resistance. As the magnetic field increases the fraction of the constant applied voltage biasing the junction decreases. For example, if the collector voltage is held constant, then the ratio of the voltage across the series resistor to the junction voltage increases. The collector current would decrease with magnetic field resulting in an apparent decrease in h_{FE}. Furthermore, if the magnetoresistance effect is larger in Ge than Si, it would explain the greater degradation in Ge transistors. The observed sensitivity to orientation would result if the transverse magnetoresistance of common transistor materials is larger than the longitudinal magnetoresistance. It is also conceivable that the differences between alloy junction and planar diffused transistors are due to differences in geometry.

The degradation in h_{FE} is consistent with decreases in the diffusion constant observed by Misra and Srivastava (ref. 6). The minority carrier current density in the base of a transistor is directly proportional to the diffusion constant (ref. 7). Therefore, a decrease in the diffusion constant should cause a decrease in the forward current transfer ratio. The experiments and analysis of Karakushan and Stafeev (ref. 2) showed that the diffusion length should only be sensitive to magnetic field when the diode length is much larger than the diffusion length. This might correspond to our observation that the larger alloy junction transistors suffer more degradation than the thinner planar diffused transistors.

The third possible contributing effect is the Hall voltage junction biasing suggested by Garfinkel and Engeler (ref. 3). This effect would be greater at the emitter-base junction of a transistor because the bias potential at this junction is smaller than at the collector-base junction. In the alloy junction transistors the Hall voltage in the base region would probably be shorted out by the metal disk that generally is used to hold the semiconductor chip.

No heuristic argument is available to explain the noise fluctuation observed in the collector current of planar diffused transistors. The set of twelve characteristic curves did not reveal a simple direction dependence with either magnetic field or current.

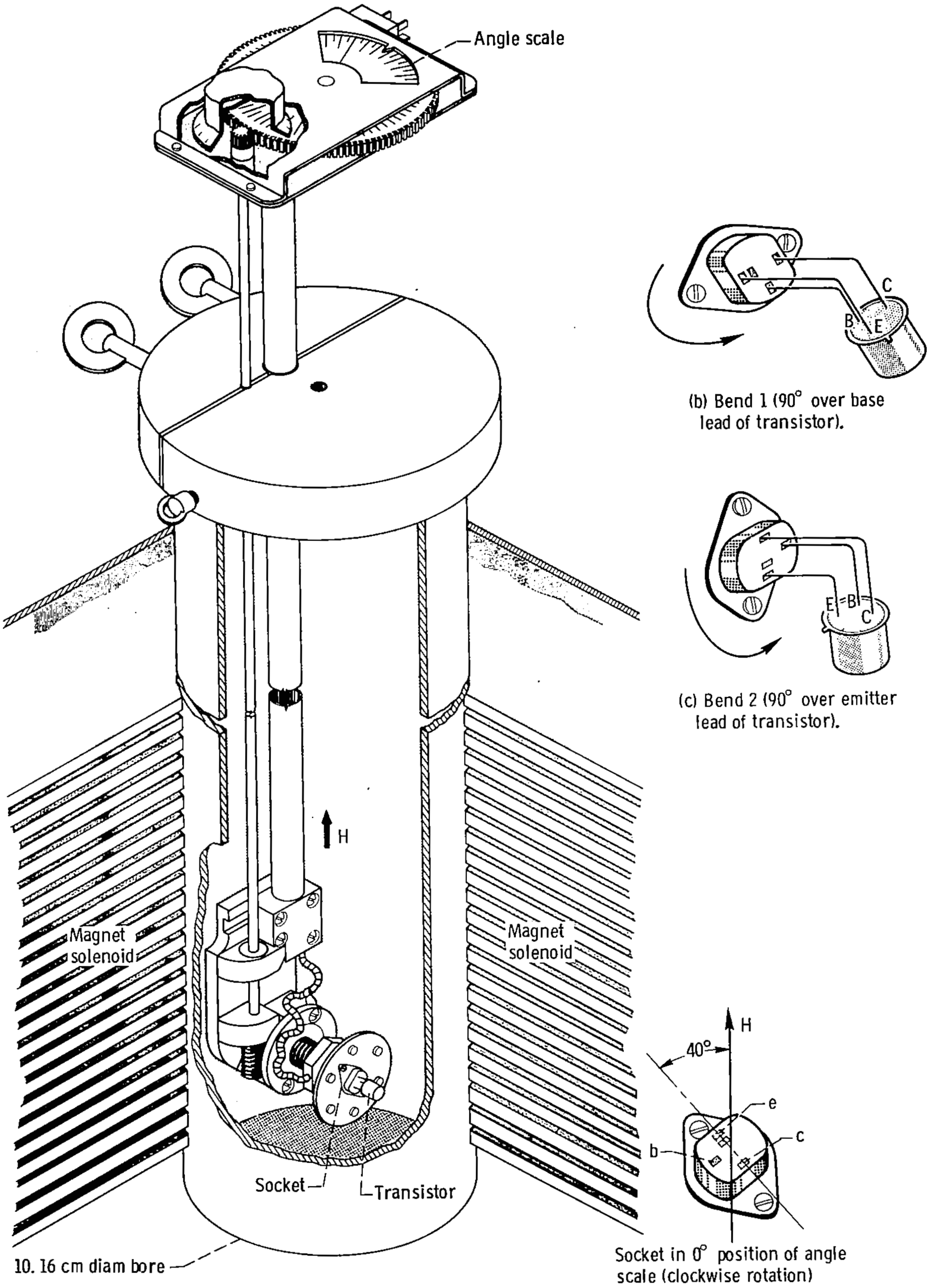
CONCLUSIONS

In the common emitter mode of operation, transistors exhibited several characteristics in magnetic fields which may be useful. Silicon transistors experience less gain degradation in strong magnetic fields than germanium transistors. Transistors of the alloy junction type of construction experience more degradation than planar diffused types. Therefore, if the noise in the planar diffused transistors is not a problem, then silicon planar diffused transistors are the best choice to use in magnetic fields. If the noise is a problem then the silicon alloy junction transistor is the best choice. Our results also suggest that it is alway better to orient the transistor so that carrier flow in the base region is parallel to the magnetic field.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 30, 1969,
129-02-05-14-22.

REFERENCES

1. Suhl, H.; and Shockley, W.: Concentration of Holes and Electrons by Magnetic Fields. Phys. Rev., vol. 76, no. 1, July 1, 1949, p. 180.
2. Karakushan, É. I.; and Stafeev, V. I.: Large Area Magnetodiodes. Soviet Phys.-Solid State, vol. 3, no. 7, Jan. 1962, pp. 1476-1482.
3. Garfinkel, M.; and Engeler, W. E.: Magnetic Field Effect on the Current Distribution in p-n Junctions. J. Appl. Phys., vol. 36, no. 6, June 1965, pp. 1877-1882.
4. Parshad, R.; and Mehta, S. C.: Effect of Magnetic Field on the V-I Characteristics of Solid State Diodes. Indian J. Pure Appl. Phys., vol. 5, no. 1, 1967, pp. 23-25.
5. Dobrovolskii, V. N.: Effect of a Magnetic Field on the Propagation of Collateral Current Carriers. Ukr. Fiz. Zh., vol. 5, 1960, pp. 333-344.
6. Misra, Maheshwar; and Srivastava, G. P.: Diffusion of Minority Carriers in the Base of an Alloy Junction Transistor in the Presence of a Magnetic Field. J. Appl. Phys., vol. 39, no. 4, Mar. 1968, pp. 2127-2131.
7. Condon, E. U.; and Odishaw, Hugh, eds.: Handbook of Physics. McGraw-Hill Book Co., Inc., 1958, pp. 8-52.
8. Kiver, Milton S.: Transistors. Third ed., McGraw-Hill Book Co., Inc., 1962.



(b) Bend 1 (90° over base lead of transistor).

(c) Bend 2 (90° over emitter lead of transistor).

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(a) Schematic diagram of transistor mount.

Figure 1. - Rotatable transistor mount in magnet.

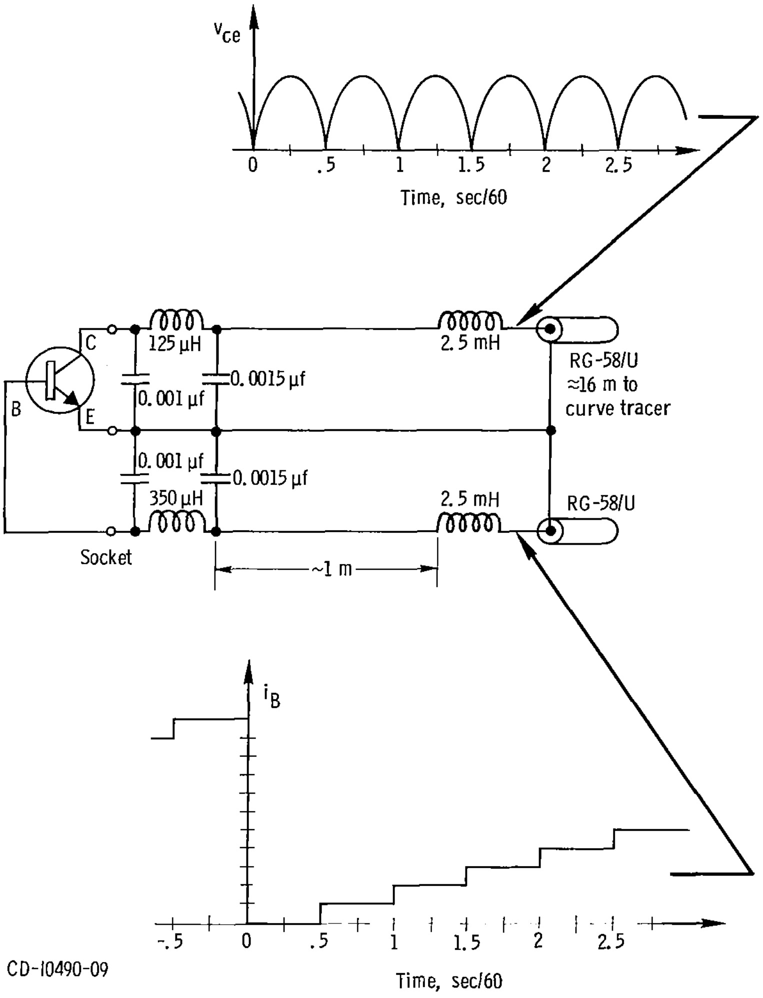

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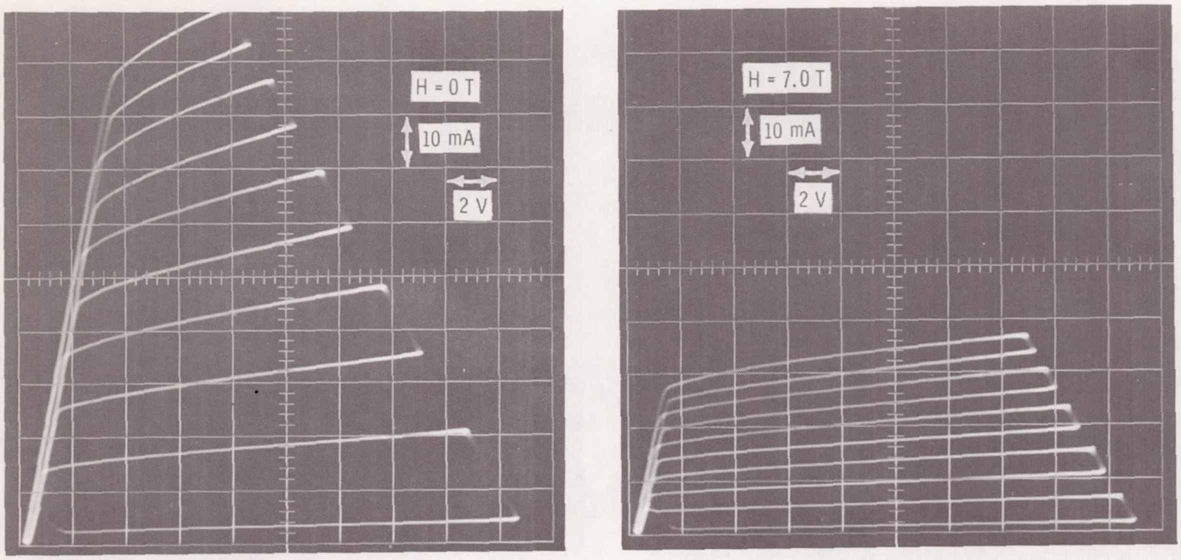
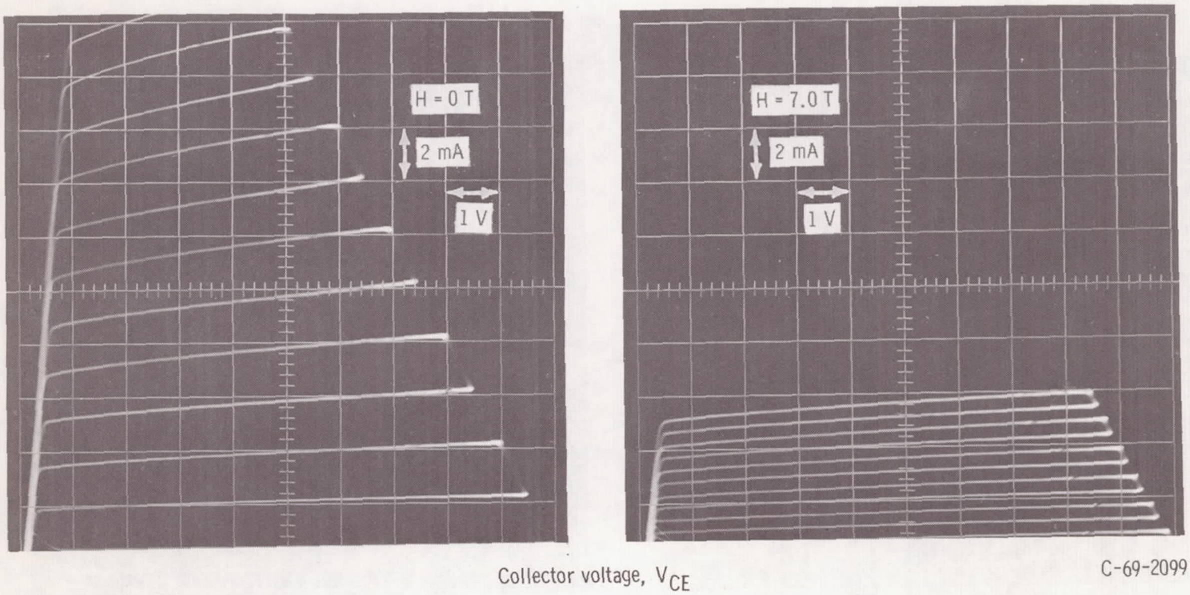
Figure 2. - Transistor connection to curve tracer and high frequency filter.

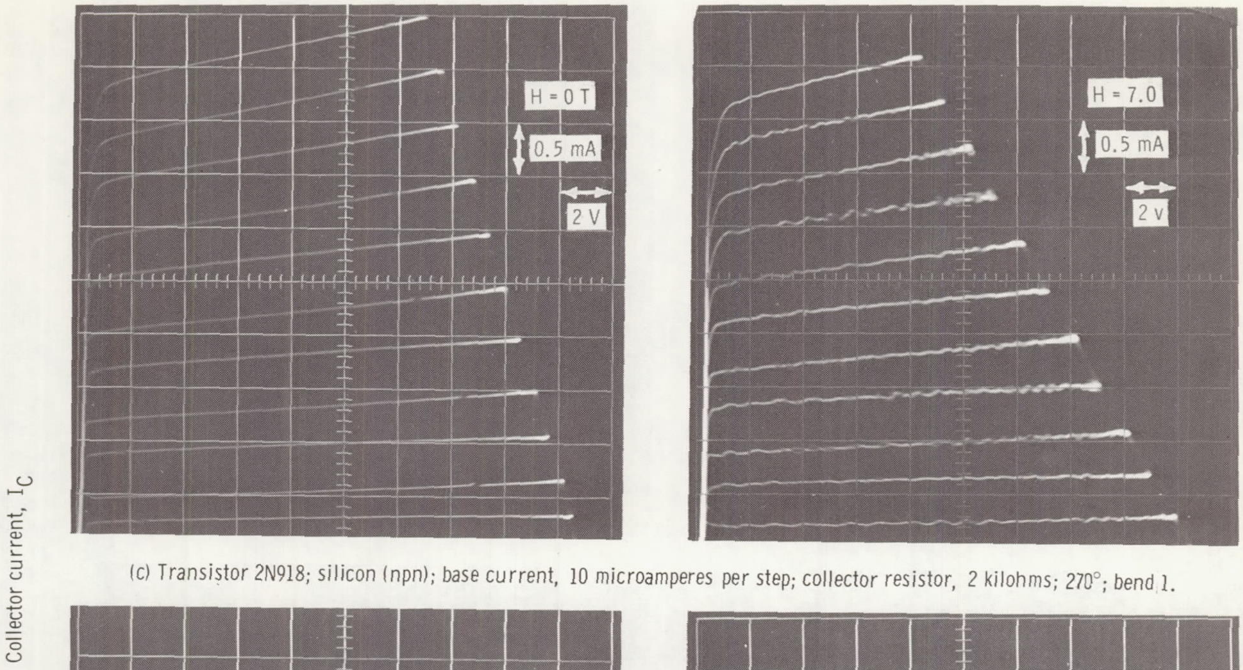


(a) Transistor 2N525; germanium (pnp); base current, 200 microamperes per step; collector resistor, 100 ohms; 0°; bend 1.

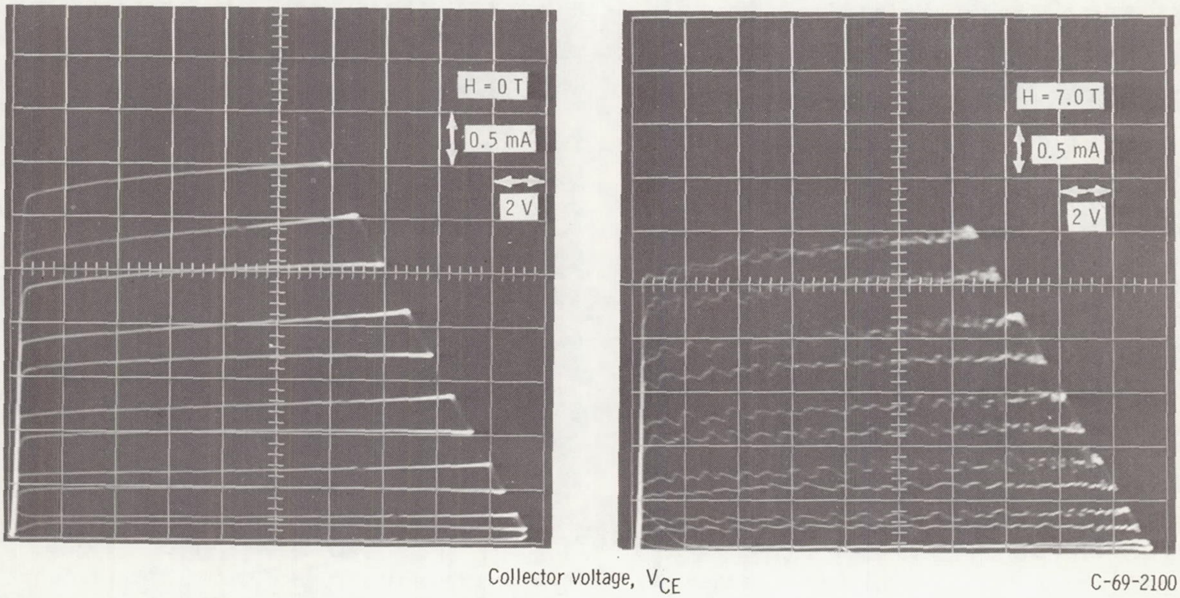


(b) Transistor 2N1302; germanium (npn); base current, 50 microamperes per step; collector resistor, 200 ohms; 90°; bend 2.

Figure 3. - Characteristic collector curves for five transistors, taken with zero field and with 7 tesla in the direction of maximum degradation.

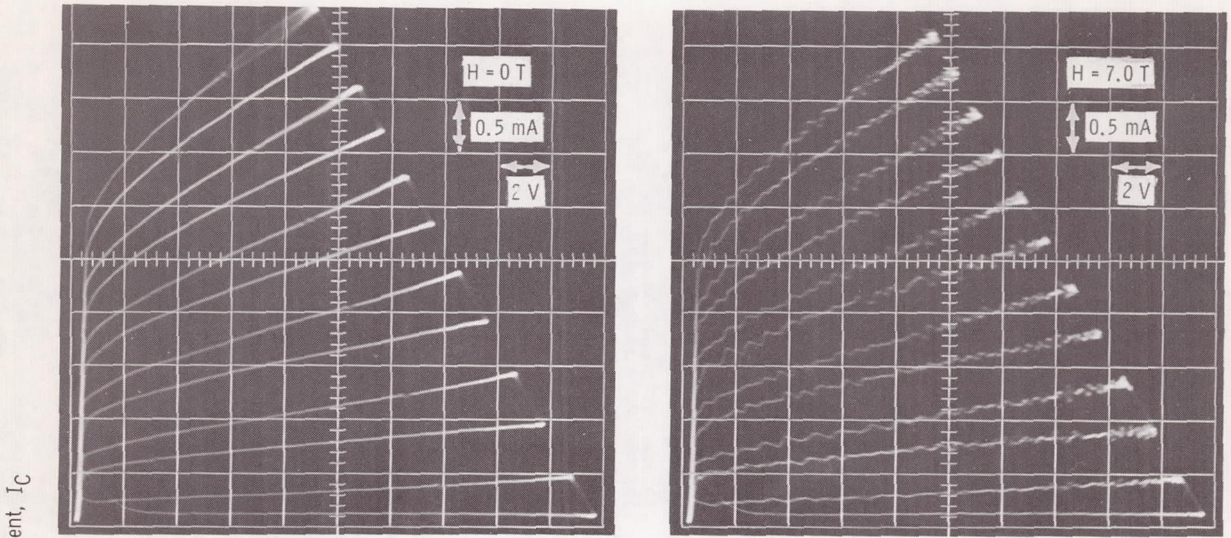


(c) Transistor 2N918; silicon (npn); base current, 10 microamperes per step; collector resistor, 2 kilohms; 270°; bend 1.

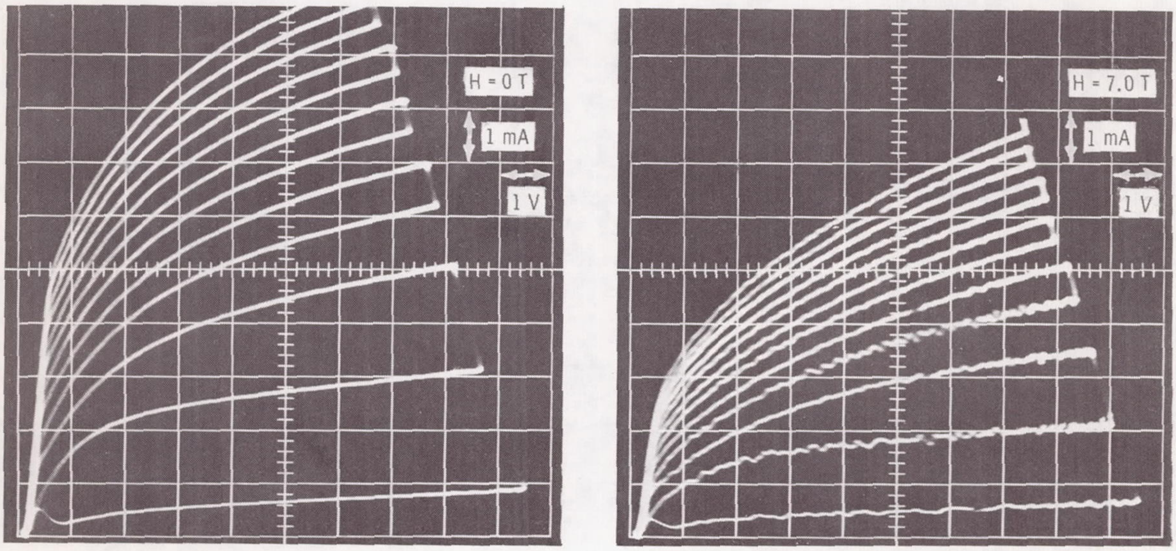


(d) Transisitor 2N4400; silcon (npn); base current, 5 microamperes per step; collector resistor, 2 kilohms; 90°; no bend.

Figure 3. - Continued.



(e) Transistor 2N4402; silicon (pnp); base current, 5 microamperes per step; collector resistor, 2 kilohms; 90°; bend 1.



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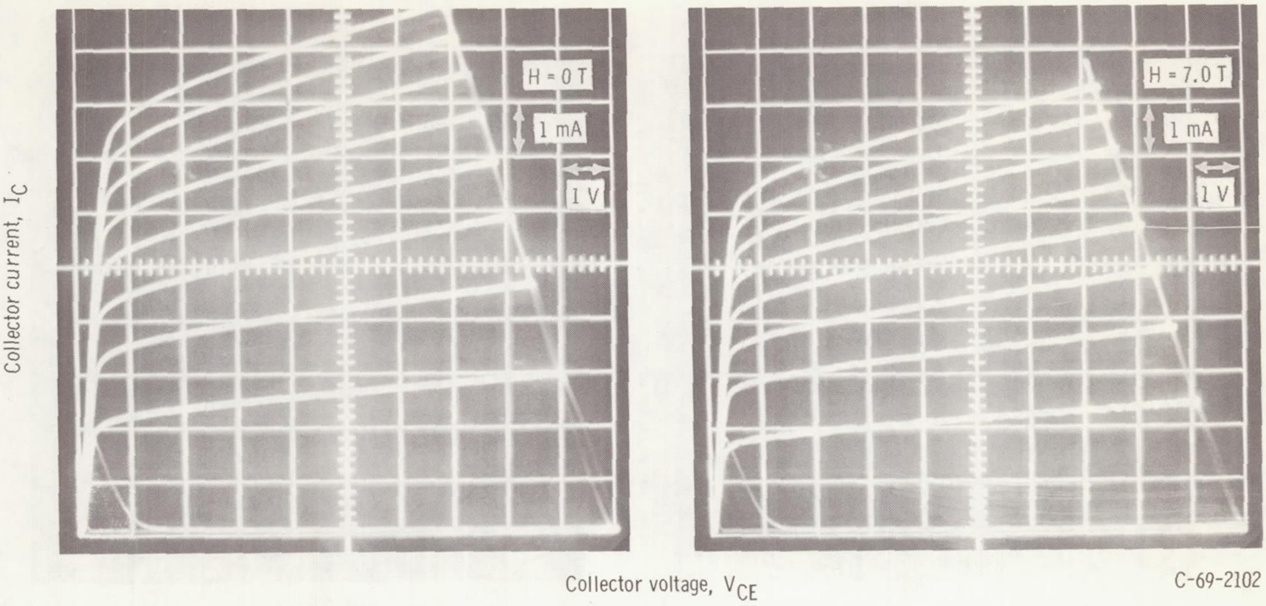
(f) Transistor TIXM01; germanium (pnp); base current, 20 microamperes per step; collector resistor, 200 ohms; no bend.

Figure 3. - Continued.



(g) Transistor 2N328A; silicon (pnp); base current, 50 microamperes per step; collector resistor, 200 ohms.

Figure 3. - Concluded.

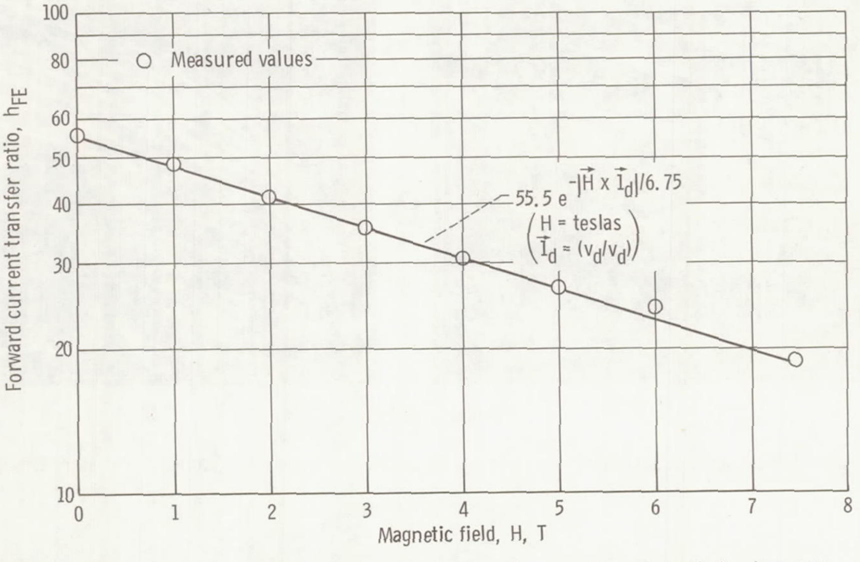


Figure 4. - Dependence of common-emitter forward current transfer ratio (h_{FE}) on magnetic field (H).

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