PROCEEDINGS

OF THE

RADIO CLUB OF AMERICA

Volume 26 1949 No. 2

GERMANIUM CRYSTAL DIODE AND TRIODE DEVELOPMENTS

A summary of a talk given to the Radio Club of America on January 15, 1949 by *Dr.Stuart T. Martin,and **Harold Heins

During the war much research was done on crystals for radar detectors since they were found to be superior to vacuum tubes as a microwave mixer. One of the materials, germanium, researched by S. Benzer under the direction of Dr. L. Horowitz of Purdue University, was found to be unsatisfactory as a microwave mixer, but, when suitably treated, to have the remarkable property of maintaining high reverse resistance at voltages ranging from 50 to 150 volts.

The combined properties of high forward conductance and high reverse resistance made germanium of interest as a general purpose diode material for lower frequency applications. After the war, a high voltage type 1N34 was introduced commercially by Sylvania Electric.

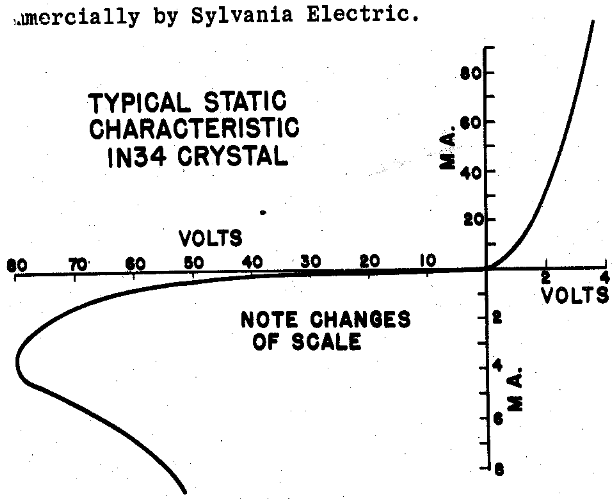


Fig. 1

Typical static characteristics of the 1N34 germanium diode are shown in Figure 1. At sufficiently high reverse voltage the dynamic resistance becomes zero and then negative. This characteristic suggests the possibility of making simple negative resistance oscillators by operating the diode in these regions.

Figure 2 shows a semi-log plot of resistance versus voltage for several germanium diode types and reveals that between zero and a current limited by allowable diode dissipation, the forward and reverse static resistances vary over wide limits. Forward resistance drops rapidly as forward voltage is increased and reaches a value of about 100 ohms at one volt.

Back resistance increases rapidly with reverse voltage to a peak between -3 and -100 volts depending on diode type. If reverse voltage is increased beyond the peak, back resistance decreases. Maximum resistance is produced in the 1N34 at about -3 volts; in the 1N38 at about -10 volts; and in the 1N39 between -75 and -100 volts. Generally speaking, the higher the peak back voltage rating, the higher the reverse voltage at which peak resistance occurs.

The shape of the diode curve shown in Figure 2 indicates that static and dynamic resistances are very low above approximately 0.2 volts and that the current-voltage curve is essentially linear down to small values. This curve passes through the point 0 where contact potential and initial velocity effects are absent.

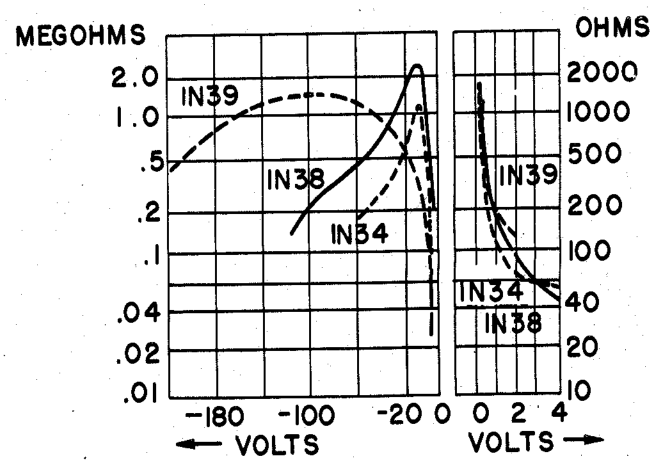


Fig. 2

Comparison with vacuum tube diodes shows that the germanium diode is superior with respect to increased conductance and reduced interelectrode capacitances, the latter due to small, effective, point contact area. The superior characteristics

* Chief Engineer,
** Engineer,
Electronics Division, Sylvania Electric Products, Inc.

of the germanium diode provide greatest benefit in video detection where bandwidth requirements limit load resistance to relatively low values.

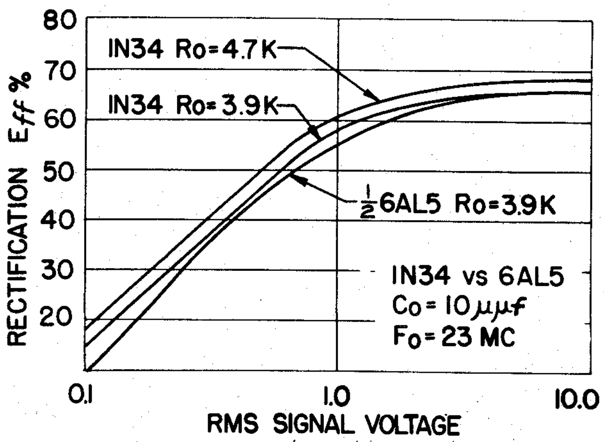


Fig. 3

Figure 3 shows measured rectification efficiencies with typical values of load resistance. The 1N34 curve of RO = 4700 ohms, C = 10 uuf indicates results obtainable in a typical 4.5 mc video detector for television receivers. Data on the 6AL5 detector, having the same video bandwidth and a load resistor at 3900 ohms is shown for comparison. The much more linear characteristic of the 1N34 in television applications may result in better white and near white values in the received video image.

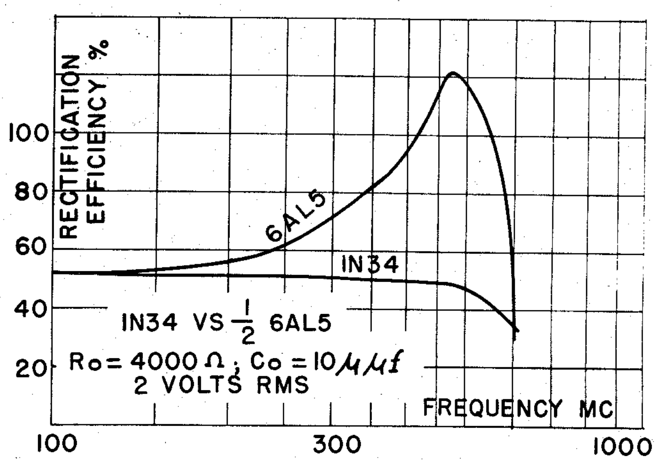


Fig. 4

Figure 4 shows a further comparison between the 1N34 and the 6AL5 on relative frequency response in the 100 to 600 mc region in the same video detector circuit. The 6AL5 shows a definite resonance peak around 450 mc and a sharp drop thereafter while the 1N34 response is flat up to 500 mc.

In common with all semi-conductors, reverse to front resistance of the germanium diode deteriorates with increasing temperature. This is shown in Figure 5 where variations of forward and reverse currents with temperature are plotted on a semi-log scale. Greatest increase in current or decrease in

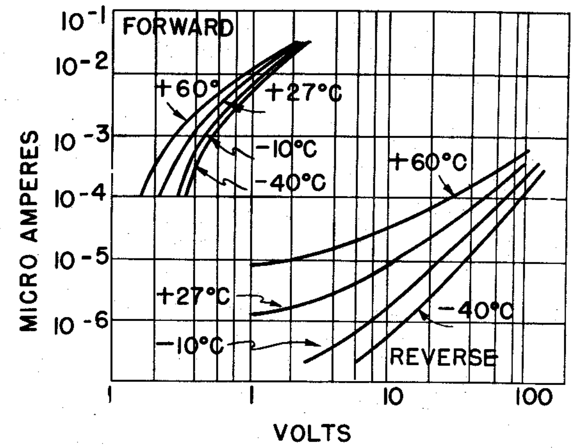


Fig. 5

resistance occurs at low voltages and, as voltage is increased, current changes become considerably smaller.

Figure 6 (on page 5) shows three 1N34 germanium diodes in a conventional d-c restorer-sync separator arrangement for television receivers. Use of the germanium diodes shown in the d-c restorer CR1 improves operation by providing a more secure clamp at the blanking level due to higher diode conductance. This reduces the tendency toward shift in black level toward white when video content is dark, In this service germanium diode life tests at 100 volts on a 15% duty cycle have shown no deterioration or failure after 3600 hours.

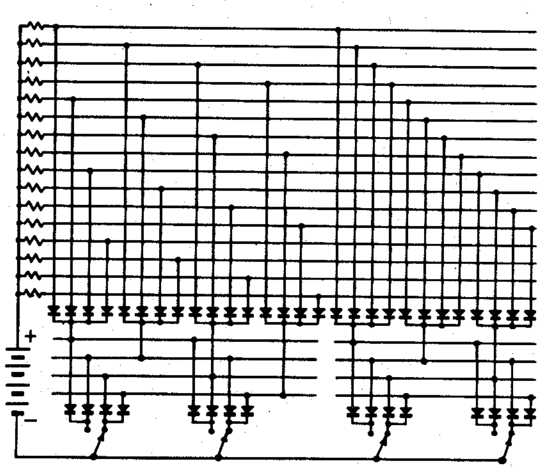


Fig. 7

Figure 7 shows a typical application of a multiposition switching diode network in the computer field. Each of sixteen possible combinations of the input switch settings selects one particular output channel. This type of matrix has been expanded to sixty-four channels with a switching rate from channel to channel corresponding to 1 mc.

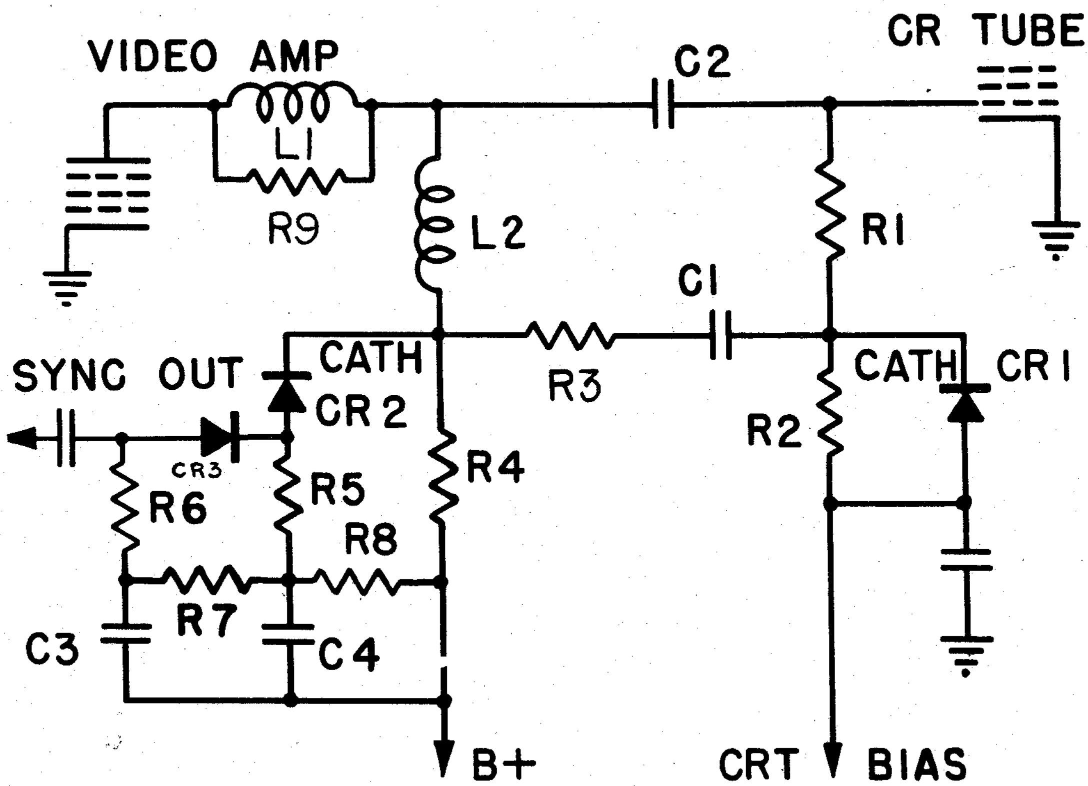


Fig. 6

GERMANIUM DIODE DC RESTORER AND SYNC SEPARATOR

Typical Values

R1	Grid Resistor - 100K
R2	Restorer load resistor - 1 Meg.
R3	Isolating resistor - 10 K
R4	Video load resistor - 3.3 K
R5	Sync load resistor - 5.6 K
R6	Sync load resistor - 6.8 K
R7	Sync bias resistor - 220 K
R8	Sync bias resistor - 100 K
R9	Damping resistor - 22 K
L1	Peaking inductor - 200 uh
L2	Peaking inductor - 95 uh
C1	Coupling capacitor - .05 uf
C2	Coupling capacitor - .05 uf
C3	Sync bias capacitor - .01 uf to 1 uf. See note.
C4	Sync bias capacitor - .01 uf to 1 uf. See note.
CR1	Sylvania 1N38 germanium diode - restorer diode.
CR2, CR3	Sylvania 1N34 germanium diodes - separator diodes.

Video amplifier tube 6V6GT.

Note: larger values of C3 and C4 increases sync amplitude but may introduce low frequency jitter or picture bounce. These capacitors should be as large as possible consistent with stability.

With 40 volt peak composite video signal at plate of last video amplifier, sync amplitude 5.2 volts at input of sync amplifier. Video leakage less than 1% at 10 volt input level, and essentially zero at higher levels. Sync pulse rise time and pulse shape unaffected by separator action.

TYPE	IN54	IN55	IN56	IN57	IN58	IN59	IN60
I_F 1V	5.0	3.0	15.0	3.6	5.0	3.0	5.0
I_R - 10V	.01	—	—	—	—	—	—
I_R - 20V	—	—	—	—	—	—	0.4
I_R - 30V	—	—	0.3	—	—	—	—
I_R - 75V	—	—	—	0.3	—	—	—
I_R - 100V	—	0.3	—	—	0.8	—	—
I_R - 150V	—	0.8	—	—	—	—	—
I_R - 250V	—	—	—	—	—	0.8	—
I_{PEAK}	50	150	40	100	115	275	60

Fig. 8

Figure 8 shows the characteristics of some of the newer types of standardized germanium diodes which have resulted from demand for a wide variety of applications. Many other types are being developed for special applications requiring a wide range of rated voltage and back resistance.

*Germanium Triodes

The germanium triode consists merely of a germanium diode with an additional catwhisker or contact on the germanium block. With the application of suitable applied potentials a change of value in one contact will modify current flow in the other contact, resulting in power amplification.

Actually the crystal amplifier is an exceedingly complex device involving many mechanical, chemical, physical and electrical problems. Theoretical explanation of the phenomenon underlying action of the device is in the province of the competent mathematical physicist who is well versed in present theories of the physics of the solid-state.

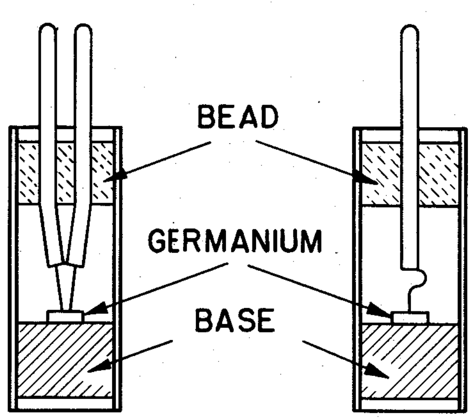


Fig. 9

Construction of a model crystal amplifier is shown in Figure 9. The two whisker contacts with a separation of one or two mils, are fitted with springs to provide contact pressure and mechanical stability. "Interaction" or power amplification is a function of the whisker contact separation.

*Transistors

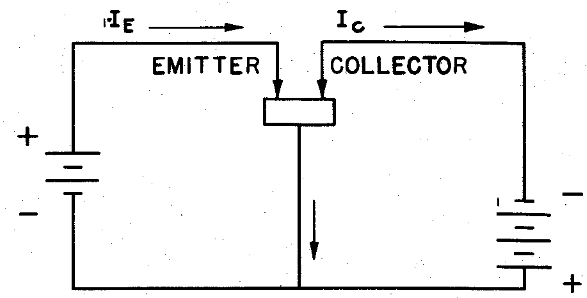


Fig. 10

Figure 10 shows the crystal amplifier as a circuit element. The input electrode, called the "emitter" is made a few tenths of a volt positive with respect to the germanium while the output or "collector" electrode is made from 10 to 50 volts negative. Currents drawn by the emitter range from a fraction to several ma. and flows in a manner normal for a positive anode in a diode.

Collector currents range from 1 to 4 ma. and flow in the opposite direction to emitter currents. They are a function of the collector voltage with various emitter potentials as a parameter. Characteristic curves are obtained which roughly resemble those of a conventional triode with a positive grid.

The outstanding characteristic of the germanium triode is that it functions only with a positive input potential, and, in contrast to vacuum tube triodes, draws power from the signal source. Input impedance is in the order of several hundred ohms while output impedance ranges from 10,000 to 30,000 ohms. Also in contrast to the thermionic triode, the germanium triode functions with a positive input and a negative output electrode.

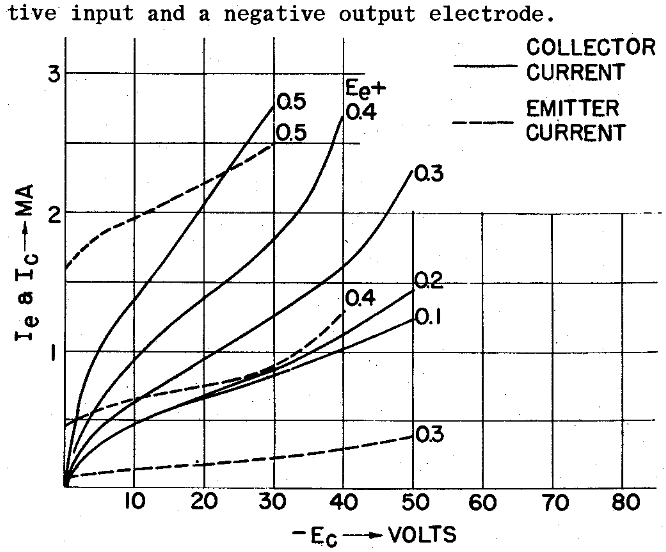


Fig. 11

Characteristics of a typical crystal triode are shown in Figure 11. Collector current I_c and

and emitter current I_e are plotted against collector voltage $-E_c$ with emitter potential $-E_e$ as an independent parameter. Emitter current curves are shown dotted. At an operating point of $E_c = -30$ volts and $E_e = -0.5$v., the computed transconductance is approximately 7000 micromhos and the amplification factor approximately 75.

It must not be assumed that the characteristics are symmetrical with respect to the input and output electrodes. In general they are far from symmetrical due to the differences in electrical treatments usually required to optimize power gain.

In contrast with vacuum tube triodes there is no phase change in the input voltage with respect to the input signal. A positive going signal input produces a positive going output voltage which is important in connection with self biasing arrangements. For instance a resistance in the branch of the circuit common to both emitter and collector produces regeneration.

Crystal amplifiers, generally speaking, cannot be completely cut off with respect to output current. Plate current can be cut off in a vacuum tube triode when sufficient bias is used but in crystals collector current bottoms sharply on the normal inverse diode characteristic. Occasionally a crystal unit may be found which operates best close to zero input bias. This indicates control with slightly negative emitter potentials, but even then collector current bottoms sharply and overdrive causes clipping.

$-E_C$ V	E_E V	I_C MA	I_E MA	E_S V	L_S MA	R_L KΩ	E_L V	— G_V	— G_I	G_P DB	P_O MW
35	.50	4.0	.8	.03	.12	11	1.4	47	1.17	17.5	1.8
28	.48	3.6	.8	.15	.65	15	8.0	53	.89	16.8	43
27	.51	4.2	1.5	.30	1.35	12	11.9	39.5	.81	15.1	11.8

G_V = VOLTAGE GAIN

G_I = CURRENT GAIN

G_P = POWER GAIN

Fig. 12

Typical dynamic operating data taken on the unit described above are summarized in the table in Figure 12, showing current gain in the order of .8 to 1.2. High power gains are still feasible even though current gains are low.

Power output of transistors or germanium triodes has been stated by the Bell Telephone Laboratories to be 25 mw, but our experience indicates that this value is not compatible with power gains of the order of 15 db or more. By optimizing the load, bias and driving power it is possible to realize 25 mw but gain will be down. The table in Figure 13 summarizes the data on one of the highest gain amplifiers obtained by Sylvania to date.

$-E_C$ V	E_E V	I_C MA	I_E MA	E_S V	I_S MA	E_L V	— G_V	— G_I	G_P DB	P_O MW
29	1.6	3.3	1.6	.01	.19	4.5	450	1.47	28.4	1.18
31.5	1.5	3.2	1.5	.02	.36	7.8	390	1.39	27.4	3.55
33	1.5	3.3	1.5	.05	.75	14.7	295	1.26	25.7	12.8
45	1.0	2.7	1.0	.10	.95	18.0	180	1.15	23.2	19.0

$R_L = 17$ KΩ

Fig. 13

The germanium used in diodes and triodes is one of a class of materials known as semi-conductors. These materials all have lattice imperfections required for efficient rectification. In copper oxide rectifiers lattice imperfections arise from a stoichiometric defficiency of copper in the lattice produced by appropriate heat treatment. Not so well known is the fact that the oxide-cathode is also a semi-conductor with lattice imperfections due to an excess of barium atoms in the crystal structure.

In germanium diodes lattice imperfections are artificially introduced into the lattice by adding a slight trace of a suitable donor with appropriate valence. In the triode an additional surface treatment is given to enhance surface layer properties. Both diodes and triodes receive an electroforming treatment which is probably related to the electroforming of copper oxide rectifiers and oxide cathodes.

Treatment of germanium diodes is adjusted to produce the highest possible inverse resistance and peak back voltage, consistant with low forward resistance. In the triode it is usually necessary to adjust the electrical treatment, or pulsing, to reduce inverse impedance to reasonable values for optimum power gain.

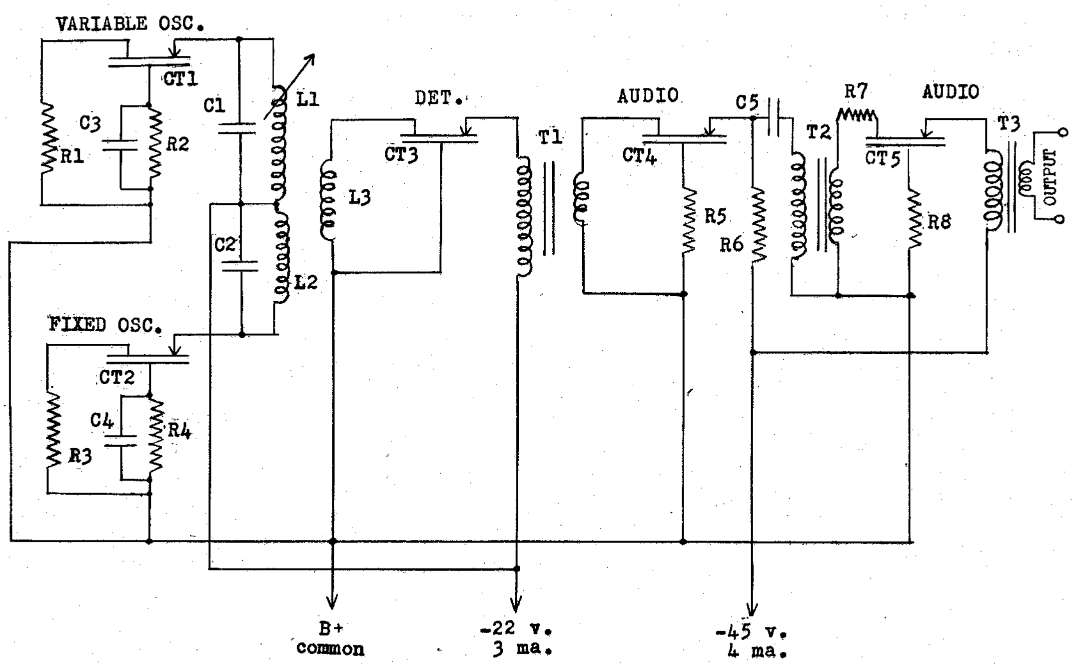
Although we have seen a tendency of some crystals to progressively deteriorate, our experience with diodes and triodes leads us to believe that increased life, stability and uniformity will result from further research and development. The triode is somewhat noisier than vacuum tube triodes but it should prove useful for many applications since noise level is sufficiently low to permit two or more stages of amplification in the audio region.

Limit of frequency is a greater consideration since an amplifier will exhibit a declining gain in the vicinity of 3 mcs. This may be due to mobility of the positive holes and the relatively large two mil spacing of electrodes. Limitations on frequency, noise and power output appear to be fundamental.

EDITOR'S NOTE:

After the presentation of his Germanium Crystal paper, Dr. Martin demonstrated a Transistor Beat-Frequency Oscillator. The oscillator, connected to a loud speaker, attracted considerable interest, therefore, the following data is being reproduced with Dr. Martin's permission.

TRANSISTOR BEAT-FREQUENCY OSCILLATOR



Typical Values

R1 oscillator grid resistor - 22K
R2 oscillator bias resistor - 3.9K
R3 oscillator grid resistor - 22K
R4 oscillator bias resistor - 3.9K
R6 audio load resistor - 15K
R7 stabilizing resistor - 120 ohms
C1 tuning capacitor - 510 uuf
C2 tuning capacitor - 510 uuf
C3 osc bias bypass - .01 uf
C4 osc bias bypass - .01 uf
C5 audio coupling capacitor - .01 uf
T1 15000 ohm to 500 ohm audio transformer
T2 15000 ohm to 500 ohm audio transformer.
T3 15000 ohm to voice coil transformer.
CT1 through CT5 Sylvania GT372 transistors.

R5 and R8-audio bias resistors. See note below.

NOTE: audio bias resistors must be adjusted to the particular transistor in use and transistors in general are not replaceable without adjustment of operating conditions. Bias to be adjusted for maximum gain consistent with stability and values will range between 47 ohms and 270 ohms for average units.

The power output obtained will range between 2.0 and 5.0 milliwatts across a reflected load of 15,000 ohms. Audio frequency range will be from 300 cps to 30,000 cps approximately with waveform distortion of approximately 10% at 1000 cps. The RF oscillators operate in the vicinity of 250 kilocycles and deliver from 3 to 5 volts RMS. No attempt has been made to minimize locking in of the oscillators at low frequency separations, and this effect limits the low frequency end of the range to that specified.