POINT-CONTACT
and
JUNCTION TRANSISTORS

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Transistors are superior to vacuum tubes in many respects, but also have certain limitations which must be considered in designing new equipment.

Fig. 1. Schematic representation of (A) the point-contact transistor and (B) the junction transistor.

What is a Transistor?
Transistor is the name given to a crystal-type amplifying element made of a semiconductor such as silicon or germanium. It is interesting to note that the name was derived from the fact that this device had been called a "transistor" by early workers in the field who were really searching for new ways of making nonlinear resistors. At present, a transistor is equivalent to a triode. Its physical embodiment can be extremely small, since its ability to amplify does not depend upon its size. It is very rugged.

The ability of a transistor to amplify depends upon the unusual property of semi-conductors to support two kinds of conduction simultaneously: one, the travel through the material of excess electrons, and two, the travel through the material of "holes," which are really the lack of electrons and therefore constitute an equal positive charge. In a semiconductor, electrons travel much more slowly than they do in a conductor and "holes" travel even more slowly than the electrons.

Transistors are constructed in two distinctly different types. One is called the point-contact type; the other is called the junction type. Their construction results in different performance characteristics which will become apparent as this story unfolds.

What Can It Do?
In most circuits, the transistor will do the same job as a vacuum tube while consuming 1/1000 as much power. Take, for example, a radio or television set. In all stages up to the second detector, the signal level is less than a milliwatt and in most of them less than a micro-watt. Yet an average of a watt or more heater power and a watt of plate and screen power are burned up in order to obtain the desired amplification.

Transistors can give 20 to 30 db of gain, depending upon the type, while consuming less than two milliwatts of power. The junction type of transistor is about ten times more efficient than the point-contact type for small-signal amplification.

As the transistor has no filament or heater, there are no problems of filament burn-out. Transistor life has been predicted in several ways, all of these predictions pointing toward a figure of 70,000 to 90,000 hours, or approximately ten years. Since a transistor does not stop working suddenly, there being nothing to burn out, the life figure above has been based on the time at which its gain will drop 3 db. For most applications, this is not necessarily the end of its useful life.

Table 1 gives a tabulation of the properties of both the point-contact and junction type compared with vacuum tubes. As will be seen from this tabulation, transistors can do a better job than tubes within the limits of power and temperature up to 30 mc.

Photo Transistor
The boundary in a junction type transistor is extremely photosensitive and therefore can be made into an attractive phototube. The first photoverts of this type were simply diodes.

One important characteristic of a transistor photovert is its spectral sensitivity which is most strong in the red and infrared regions. A second important characteristic is its efficiency. A PN junction unit (diode) had a sensitivity of 30 ma/lumen, and 10 to 15
Why the Excitement?

Transistors are causing a great deal of excitement at this time because:

1. Projection of practical quantities of the point-contact type into the near future.
2. Large advances in circuit design have been made in the past year.
3. The bringing of the junction transistor out of the laboratory and the readiness of it for production opera even newer and broader fields of application.
4. Stability of design has been established.
5. Dependability of units has been assured by uniform production.
6. Deimenisibility has been established.
7. Uniformity can now be designed to a certain set of parameters.
8. There is a need to shift the industry to the impact of this device so that circuit design work can be now be done to take advantage of transistors.
9. Manufacturers believe that most rapid progress can be made under pressure of circuit design to stabilize types.
10. Five manufacturers are already "in the business." These are Westinghouse Electric, General Electric, Raytheon, Sylvania and RCA.

How Does It Work?

The operation of the transistor can be best explained by reference to the characteristics of the semiconductors.

Certain elements in the fourth column of the Periodic Table exhibit properties whereby they seem like insulators in one condition and conductors in another under other conditions they seem like conductors. These elements have been called semiconductors.

In the molecular structure of a material like diamond, all valence bonds are satisfied, so the material behaves like an insulator. If the crystal is heated, the thermal excitation can cause a valence electron to be knocked out of its usual place, leaving this electron (negative charge) to free itself in the crystal. The place from which the electron came is called a "hole," and this area exhibits a local positive charge. Under this condition, the diamond behaves somewhat like a conductor. Eventually, the electron and the hole may recombine. At all times, however, the entire crystal is electrically neutral.

Certain other elements in the fourth column of the Periodic Table, like silicon and germanium, require less energy to knock electrons out of the valence bond position; in fact, at normal temperatures, electrons and holes are being liberated and recombined continually. These are called intrinsic semiconductors.

If an electric field is applied to an intrinsic semi-conductor, the electrons move toward the positive terminal and the holes move toward the negative terminal. Holes can be treated exactly like electrons except that their charge is of opposite sign.

It was learned early that the presence of certain impurities in a semi-conductor greatly changed its conductivity. These impurities were identified and the following two effects catalogued:

If an impurity in the fifth column of the Periodic Table is present, atoms of this impurity replace atoms of the semi-conductor in the crystal structure. These columns are given the name of impurity atoms are now called donors or acceptors.

If an impurity in the third column of the Periodic Table is present, the impurity atoms similarly replace those of the original material in the crystal.

These columns have three valence electrons and, consequently, one valence bond is left unfulfilled. The holes thus formed are also free to move in the crystal and the material is now called a P-type semi-conductor.

These impurity atoms are generally referred to as acceptors.

It is interesting to note that only a few donors or acceptors are required to produce substantial changes in the resistance of a semiconductor.

Two other properties of semiconductors are important:

1. Holes can be introduced into an N-type semiconductor and electrons can be introduced in a P-type semi-conductor by passing current into it.

2. Electrons travel much more slowly in a semi-conductor than they do in a conductor, and holes travel even more slowly than electrons.

Now, examine the operation of a PN junction rectifier (Fig. 2). This may be made up of a single crystal of germanium, for example, the two parts of which contain different impurities. One part is N-type and the other part is P-type. If a potential is applied to the two ends of this rectifier so that the positive terminal is connected to the P material and the negative terminal to the N material, the electrons and holes move toward each other and recombine. The voltage source keeps this going. The apparent resistance is very low, and a high current flows.

If we reverse the polarity of the applied potential, the effect is just opposite. The holes and electrons arc pulled away from the junction and away from each other, and the unit tends to become an insulation. Very little cur-

Table 1: A tabulation of the various characteristics of the point-contact and junction transistors compared with the characteristics of conventional vacuum tubes.

<table>
<thead>
<tr>
<th>Point-Contact</th>
<th>Junction</th>
<th>Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>25 to 50 db</td>
<td>25 to 50 db</td>
</tr>
<tr>
<td>Efficiency (Class A)</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>Life</td>
<td>70,000 hrs.</td>
<td>90,000 hrs.</td>
</tr>
<tr>
<td>Vibration</td>
<td>100 g</td>
<td>100 g</td>
</tr>
<tr>
<td>Shock</td>
<td>20,000 g</td>
<td>20,000 g</td>
</tr>
<tr>
<td>Uniformity</td>
<td>± 3 db</td>
<td>± 3 db</td>
</tr>
<tr>
<td>Minimum powers</td>
<td>10,000 watts</td>
<td>10,000 watts</td>
</tr>
<tr>
<td>Temperature</td>
<td>70°C</td>
<td>70°C</td>
</tr>
<tr>
<td>Frequency</td>
<td>30 to 70 mc</td>
<td>3 to 5 mc</td>
</tr>
<tr>
<td>Gain x bandwidth</td>
<td>1000 mc</td>
<td>1200 mc</td>
</tr>
<tr>
<td>Noise figure</td>
<td>45 db</td>
<td>15 db</td>
</tr>
<tr>
<td>Power</td>
<td>100 mw</td>
<td>1 watt</td>
</tr>
</tbody>
</table>
A transistor, therefore, possesses two mechanisms whereby power gain can be obtained when it is used as an amplifier. One of these is due to the fact that the output impedance is considerably higher than the input impedance; the other is due to the current gain possible in point-contact types and the newer hook-collector types of units.

**Transistor Characteristics**

The transistor is definitely a three-terminal device. Unlike the vacuum tube, the fact that the transfer characteristics are bilateral cannot be forgotten, even for equivalent circuits. Changes in output conditions can be the input characteristic as changes in input conditions affect the output characteristic.

The transistor is definitely a voltage amplifier. By varying an input voltage, a much larger variation in an output voltage is obtained. Too, transistors like best to see constant current power supplies whereas tubes work best with constant supply potentials.

As mentioned previously, the emitter circuit of a transistor is a diode biased in its forward or conducting direction. The bias supply for this element should be of a constant current nature to prevent self-destruction. The alternating current equivalent circuit of a transistor for most applications is represented as a three-terminal network with two series resistances, \( r_1 \) and \( r_2 \), and one shunt resistor, \( r_s \), as shown in Fig. 5. These parameters are resistive at normal audio frequencies. The transfer representation of the transistor generator would be a current supply having the value \( I_s \), shunted across \( r_2 \).

The input impedance of a transistor is determined by the sum of \( r_1 \) and \( r_2 \) and has practical values from 200 to 600 ohms. The output impedance is equivalent to \( r_2 \) plus \( r_s \). This may be from 20,000 ohms to over a megohm.

Like a vacuum tube the transistor has an upper frequency limit caused by the capacitive between the elements. Because of the close spacing, these capacities are somewhat greater than in vacuum tubes. Capacity effect on the emitter is not serious because of its inherently low impedance, but the capacity effect upon the collector is somewhat more important, especially in junction types. The principal frequency limitation of a transistor, however, is due to another cause, namely, the slow transit speed of the electrons and holes in the semiconductor material. These two effects define an upper frequency limit for junction type units at 3 to 5 mc., while point-contact units have been used up to 70 mc.
Temperature provides another serious limitation to the environment of a transistor. At elevated temperatures, the noise generated within the unit becomes important in magnitude, and the thermal agitation causes a large change in the collector impedance, thereby affecting the amplification.

Much has been said about noise in transistors, which is evidence that research has only begun on the fundamental causes of this noise. This noise, like other random noise, decreases as frequency increases. A point-contact type unit shows a noise factor of 49 to 59 db while junction type units have a much better noise figure, 10 to 15 db, which compares favorably with tubes.

**Power Circuits**

Like the vacuum tube, the transistor lends itself readily to all types of circuits including amplifiers, oscillators and switching circuits. In many cases, the transistor shows improved flexibility since there is no common filament supply to consider. Low input impedance minimizes shielding problems.

The commonly used grounded base connection is equivalent to a grounded grid vacuum tube circuit. In this connection, the principal problem is stability. Base resistance is common to both input and output circuits. Since there is no phase reversal in the transistor element, the common base resistance constitutes a regenerative feed-back path—most important in units with an output greater than unity.

The value of $r_b$ has been controlled in all units currently being manufactured to provide inherent stability when no external resistance is added to the base circuit.

In the grounded base connection, between matched impedances, up to 20 to 30 db gain per stage is easily achieved. Because the impedance transformation through a transistor-amplifier is a step-up, it is always necessary to use an interstage stepdown transformer to realize full power gain.

At a large sacrifice to gain, it is possible to cascade grounded base transistor stages directly. In this sort of an amplifier, 6 to 8 db gain per stage is possible.

Another popular circuit is the grounded emitter circuit, equivalent to a conventional grounded cathode tube circuit. Input and output impedances are both on the same order of magnitude—from 4000 to 10,000 ohms. Output impedance is negligible if $r_e$ is greater than one and must be stabilized.

This circuit has a transfer phase shift of 180°. Practical amplifiers can be built with 20 to 30 db gain per stage. Cascaded stages without interstage transformers show an improvement over the grounded base connection.

The transistor may also be used in a grounded collector circuit. This circuit, which has a high input impedance and a low output impedance, is equivalent to a cathode follower tube amplifier.

Both input and output impedances may be negative in this connection, but the circuit can be stabilized with external resistors. It is interesting to note that this circuit has a phase reversal going through it in one direction while it has no phase shift going through it in the opposite direction. It is possible to make an amplifier of this type with 15 db of gain in both directions.

To produce low noise input, higher power output and more gain per stage without interstage transformers, combinations of grounded base followed by grounded collector stages and grounded emitter followed by grounded collector stages may be used.

For oscillators, several circuits have shown good performance. A parallel resonant circuit in the base is a very popular circuit. Coupled series-resonant circuits in the emitter and collector leads produce a TE-TC oscillator. A few conventional circuits that have
### Table 2. Data sheet showing characteristics of several point-contact and junction transistors.

<table>
<thead>
<tr>
<th>Manufacturer's number</th>
<th>Transistor type</th>
<th>Contact</th>
<th>Contact</th>
<th>Contact</th>
<th>Contact</th>
<th>Contact</th>
<th>Contact</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BG</td>
<td>WTL</td>
<td>WTL</td>
<td>WTL</td>
<td>WTL</td>
<td>RCA</td>
<td></td>
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<tr>
<td></td>
<td>Diameter</td>
<td>.255</td>
<td>.16</td>
<td>.239</td>
<td>.128</td>
<td>.259</td>
<td>.239</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Height</td>
<td>.778</td>
<td>.58</td>
<td>.750</td>
<td>.562</td>
<td>.750</td>
<td>.750</td>
<td></td>
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<tr>
<td></td>
<td>Mounting</td>
<td>87/49</td>
<td>5 pin sub.</td>
<td>8672</td>
<td>8672</td>
<td>8672</td>
<td>8672</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collector, ma.</td>
<td>4</td>
<td>2</td>
<td>15</td>
<td>40</td>
<td>10</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collector voltage</td>
<td>40</td>
<td>100</td>
<td>50</td>
<td>80</td>
<td>50</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collector dissipation (watt)</td>
<td>100</td>
<td>25</td>
<td>120</td>
<td>80</td>
<td>200</td>
<td>200</td>
<td></td>
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<tr>
<td></td>
<td>Emitter current (ma.)</td>
<td>10</td>
<td>1</td>
<td>15</td>
<td>40</td>
<td>15</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cutoff frequency (mc.)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Input (emitter)</td>
<td>250</td>
<td>50</td>
<td>800</td>
<td>195</td>
<td>190</td>
<td>25</td>
<td></td>
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<tr>
<td></td>
<td>resistance, r.</td>
<td>15K</td>
<td>20K</td>
<td>15K</td>
<td>20K</td>
<td>15K</td>
<td>20K</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feedback (base)</td>
<td>75</td>
<td>200</td>
<td>600</td>
<td>115</td>
<td>75</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Current amplification</td>
<td>2.5</td>
<td>2.1</td>
<td>2.5</td>
<td>.98</td>
<td>2</td>
<td>.98</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output (collector)</td>
<td>250</td>
<td>400</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Operation (Grounded Base)</td>
<td>2.5</td>
<td>2.1</td>
<td>2.5</td>
<td>.98</td>
<td>2</td>
<td>.98</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collector current (ma.)</td>
<td>0.5</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collector voltage</td>
<td>10</td>
<td>22</td>
<td>5</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collector current</td>
<td>1.5</td>
<td>1.5</td>
<td>4</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average power gain (db)</td>
<td>18</td>
<td>.19</td>
<td>18</td>
<td>20/12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average power output (watt)</td>
<td>3</td>
<td>20</td>
<td>4.8 /50</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Noise figure (db)</td>
<td>45</td>
<td>45</td>
<td>48</td>
<td>54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Input termination</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Output termination</td>
<td>25K</td>
<td>25K</td>
<td>25K</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Approximate.

A. At 60 degrees C ambient.

B. Specifications, net data.

C. Lower right values are strong signal conditions.

D. Upper left values are weak signal conditions.

E. Grounded base connection.
RAYTHEON GERMANIUM JUNCTION TRANSISTORS

Since publication of this article in Radio and Television News, Raytheon Manufacturing Company has announced availability of two Junction Transistors -- types CK721 and CK722.

The CK722 is immediately available in quantity; the CK721 is available in limited quantities until April 1963.

TYPE CK721

MECHANICAL DATA
CASE: Plastic and Glass
BASE: None (0.010" tinned flexible leads** Length: 1.5" min. Spacing: 0.08" center-to-center)

TERMINAL CONNECTIONS: (Red dot is adjacent to lead 1)
Lead 1: Collector
Lead 2: Base
Lead 3: Emitter

ELECTRICAL DATA
RATINGS - ABSOLUTE MAXIMUM VALUES:
- Collector Voltage: -20 volts
- Collector Current: -5 ma.
- Collector Disconnection (at 30ºC): 35 mv.
- Emitter Current: 5 ma.
- Ambient Temperature: 50 ºC

AVERAGE GAIN CHARACTERISTICS - GROUNDED Emitter: (at 30ºC)
- Collector Voltage: -1.5 volts
- Collector Current: -0.5 ma.
- Base Current: -6 µa.
- Current Amplification Factor: 40
- Power Gain*: 38 db
- Noise Factor # (1000 cycles): 22 db

AVERAGE OUTPUT CHARACTERISTICS - GROUNDED (Emitter): (at 30ºC)
- Collector Voltage: -3 volts
- Collector Current: -2 ma.
- Gain Current: -30 µa.
- Load Resistance: 1050 ohms
- Distortion: 8 percent
- Power Output, E: -2.6 ma.

* Source: 1000 ohms; load: 20,000 ohms.
# A = 1.0 volts (±0.5 volts) to the collector.
+ With a driving power of 5 microamperes from a source of 1000 ohms.
** Socket types: Clinch
Res. 14106 & 14109
or equivalent
MECHANICAL DATA

USE: Plastic and Glass

BASE: None (0.010" tinned flexible leads)**Length: 1.5" min.

Sealing: 0.08" center-to-center

TERMINAL CONNECTIONS: (Red dot is adjacent to lead 1)

Lead 1 Collector
Lead 2 Base
Lead 3 Emitter

WEIGHT: 0.025 ounces

MOUNTING POSITION: Any

ELECTRICAL DATA

RATINGS - AMOUNT MAXIMUM VALUES:

Collector Voltage -20 volts
Collector Current -5 ma.
Collector Dissipation (at 30°C) 30 mw.
Emitter Current 5 ma.
 Ambient Temperature 50°C

AVERAGE GAIN CHARACTERISTICS - GROUNDED EMITTER: (at 30°C)

Collector Voltage -1.5 volts
Collector Current -0.5 ma.
Base Current -20 ma.
Current Amplification Factor 12
Power Gain* 30 db
Noise Factor η (1000 cycles) 22 db

" Source: 1000 ohms; Load:

* Source: 1000 ohms; Load: 20,000 ohms

# As -1.5 volts (-0.5 ma.) to the collector.

** Socket types: Clech Nos. 12458 & 24256 or equivalent.

TYPICAL COLLECTOR CHARACTERISTICS (CK722)