

# **TRANSISTOR**

Theory and Application

elephone umber
yState
yState
•

© 1958 by International Business Machines Corporation 590 Madison Avenue, New York 22, N. Y. Printed in U.S.A. Form 223-6783-1

### Contents

INTRODUCTION	VOLTAGE MODE TRANSISTOR CIRCUITS
TRANSISTOR THEORY	DC-COUPLED NPN INVERTER
	DC-COUPLED PNP INVERTER
SEMI-CONDUCTOR PHYSICS	NPN EMITTER FOLLOWER
Germanium Processing 6	PNP EMITTER FOLLOWER
Atomic Structure 6	NEON INDICATOR
Covalent Bonding	Trigger
N-Type Germanium	
P-Type Germanium	CURRENT-SWITCHING CIRCUIT
Minority Carrier Current	N BLOCK
NP JUNCTION DIODE 8	P ВLОСК
Formation of the Rectifying Barrier	CONVERTER, TUBE LEVEL TO CURRENT-SWITCHING LEVEL 30
Reverse-Biased Diode	CONVERTER, CURRENT-SWITCHING P LEVEL TO TUBE LEVEL 30
Normal Reverse Current	Driver Relay or Driver Indicator
Avalanche Breakdown	Trigger
Zener Breakdown	
Forward-Biased Diode	COMPLEMENTARY TRANSISTOR RESISTOR
JUNCTION TRANSISTOR	LOGIC (CTRL) CIRCUITS
NPN JUNCTION TRANSISTOR	Types of Blocks
Alloyed-Junction Construction	Translating Blocks
Static Condition	Non-Translating Blocks
Reverse-Biased Conditions	Emitter Followers
Breakdown	CIRCUIT DESCRIPTIONS
Punch-Through	PNP Translating Circuit
Forward-Biased Transistor	NPN Translating Circuit
PNP JUNCTION TRANSISTORS	NPN Non-Translating Circuit
NPN TRANSISTOR CIRCUITS	PNP Non-Translating Circuit
Grounded-Base Circuit	Emitter Followers
Characteristic Curves	LOGIC PRESENTATION
Alpha	DOT Functions
	S-Line Rule
Grounded-Emitter Circuit	R-Line Rule
Alpha Prime	DOT Function Use
Grounded-Collector Circuit	LOADS
PNP Transistor Circuits	Converting Loads
Grounded-Base Circuit	Current Switching to CTRL
Grounded-Emitter Circuit	CTRL to Current Switching
Load Lines	
TRANSIENT EFFECTS	APPENDIX
Turn-on Delay	1. Table of Elements
Turn-on Transition	2. IBM Transistor Specifications and Types 44
Turn-off Delay	Transistor Parameters
Turn-off Transition	IBM Transistor Types
FREQUENCY CUT-OFF	3. VOLTAGE LEVELS AND SYMBOLS

## Transistor Theory and Application

SINCE 1948, the electronics industry has had a new device available that exhibits great promise as a replacement for the electron tube. This device is as small as the eraser on a lead pencil, requires no heater or filament, has a life expectancy of at least four times that of an electron tube (20,000 hours of operation), and is resistant to damage from shock or vibration. This device is called a transistor.

While it seemed that the transistor would immediately revolutionize the electronics industry, production problems have been numerous and difficult to overcome, so that it has been only since about 1956 that industrial electronics has seriously turned to this modern-age wonder. The future applications are still possibly beyond our imagination.

The transistor is a member of the same family as the copper oxide or selenium rectifier and the germanium diode, which have been in common usage for a number of years and are, therefore, no longer strangers to us. It will be noted that these devices are all electronically active solids. This being the case, it naturally follows that machines or units using transistors, diodes, selenium rectifiers, and other associated devices are said to employ "solid state circuitry."

Although the operation of the transistor outwardly resembles that of the vacuum tube, actual details of the internal happenings are quite different. To gain an acceptable understanding of transistor operation, it will be necessary to investigate the electron theory in more detail than was the case in studying vacuum tubes. For this reason, much of the first section discusses atomic structure and behavior. While it may be true that transistorized units can be serviced without knowing the

theory behind their operation, a much more complete understanding of the service techniques will be gained by having some theoretical background.

Transistors are divided into several basic types, each having its own peculiarities and advantages. The alloy junction type will be dealt with here. The alloy junction transistor is used in business machines because its characteristics include rugged construction, low noise level, good stability, low operating voltages, good powerhandling ability and efficiency, and a reasonably good frequency response. Each type can be further described as being either NPN or PNP transistors, one being a complement of the other. The NPN action is similar to that of a vacuum tube in that a plus signal input causes conduction, whereas the PNP is caused to conduct by a negative signal. While the two complementary transistor types somewhat complicate the study of transistors, they are extremely valuable in that they add flexibility to business machine design.

Transistors control current flow on an entirely new principle. In the vacuum tube, output current is controlled with a small input signal by means of varying an electrostatic field at the grid. In the transistor, output current is controlled by varying the number of current carriers (free electrons in a normal conductor) available for conduction. The number of current carriers available is controlled by means of a varying input current. This is the reason a transistor is often referred to as a current-controlled or current-amplifying device, while a vacuum tube is basically a voltage amplifier.

This manual has four general sections: Transistor Theory Noltage Mode Transistor Circuits, Current Switching Circuits, and Complementary Transistor Resistor Logic (CTRL) Circuits.

### **Transistor Theory**

#### SEMI-CONDUCTOR PHYSICS

#### Germanium Processing

The basic material in the transistor is germanium. Processing of this element begins with germanium dioxide powder obtained from the soot of zinc smelting furnaces. A silver-grey ingot of germanium is obtained by heating the powder to about 650° C in an atmosphere of hydrogen. For further purification, the ingot is slowly moved along through several RF heating coils separated by enough distance to allow the ingot to solidify between the coils. Impurities prefer the molten to the solid state; therefore, they can be "drawn off" to one end as the ingot is moved. This is called a "zone refining" process because one area or zone of the material is purified as it is melted when passing one of the RF coils. With several coils, the ingot is actually purified in one pass to the same degree that would require several passes if only a single coil were used. The degree of purity can be measured by its electrical resistivity, which increases as impurities are removed. The resistance of a cubic centimeter of this purified, or intrinsic, germanium is about 60 ohms. This resistance drops to about four ohms with the addition of only one part impurity to one hundred million parts germanium.

#### Atomic Structure

An atom may be thought of as a central mass composed of one or more protons, each having a positive charge, surrounded by an equal number of negative charges or electrons rotating about it. Most of the mass is concentrated in the nucleus, but the outer electrons play a large part in determining the chemical and physical properties of the element.

The electrons rotate about the nucleus in orbits that are not necessarily circular or in the same plane, but there is a certain average discrete orbit in which any electron tends to stay and these orbits bunch into groups or bands. For simplicity, these orbits are normally pictured as being regular and circular. More energy must be applied to remove electrons from the inner bands, because they are more tightly held by the nucleus. Each band can contain a certain normal maximum number of electrons, and a band that contains this number is called a filled band. It is much more difficult to remove

an electron from a filled band than from an unfilled band. The energy gaps between bands are "forbidden" regions where no electrons are normally found.

Further investigation of atomic structure from the standpoint of electrical conduction would indicate that good conductors have few electrons in their outer bands. Examples would be gold, silver, and copper with one electron each. The difference in conducting abilities of these three elements is due, in part, to the distance of this single outer electron from the nucleus.

On the other hand, further study of atomic structure indicates that as an element becomes more complex and the outer band builds up to eight electrons, any additional electrons must go in the next band regardless of whether or not the band containing eight is filled. The inert gases (neon, argon, and krypton) exhibit this stable condition of eight electrons in the outer ring which is known as the "octet" theory. It will be important in further study of transistors because the eight electrons are tightly bound. Tightly bound electrons exhibit the characteristics of an electrical insulator.

From the above, it would appear that an element having its outer ring or band about half-filled would fall somewhere between the conductor and insulator classification, and would be called a semiconductor. Such is the case with the germanium atom, which has four electrons in its outer band.

In the germanium atom (Figure 1), the inner orbit electrons arrange themselves into bands of two, eight,

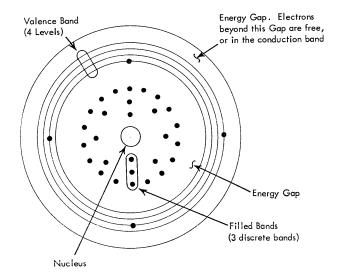


Figure 1. Diagram of Germanium Atom

and 18 electrons. These bands are filled. The four outer electrons, called valence electrons, are in an unfilled band. Since the inner, filled bands will be unaffected electrically, we need concern ourselves only with the outer or valence band which has four electrons.

#### Covalent Bonding

Valence electrons rotate in orbits that are far removed from the nucleus; in fact, valence orbits of one atom cross the valence orbits of its neighbor. During the course of its travel, an electron is acted upon by its nucleus and the nuclei of its neighboring atoms, so that in germanium one atom has its own four electrons in the valence band and in addition feels the effects of an electron from each of its four neighbors. The result of this combination is similar to the insulator action described in the octet theory, because there are now eight electrons in a relationship called "covalent bonding."

The balance of energy existing between adjacent valence electrons determines the geometric arrangement of the atoms. This arrangement of atoms is called a "lattice." The covalent bonding of the four valence electrons of germanium develops a diamond-shaped lattice represented in the single-plane drawing, Figure 2. It requires about fifteen times as much energy to remove a covalent bonded electron as is required to remove one in a valence ring without covalent bonding.

#### N-Type Germanium

Since pure germanium is a relatively poor conductor, controlled amounts of impurities are added to allow more current flow. This is known as "doping." Antimony is a typical impurity used for this purpose. It has filled rings of two, eight, 18, 18 and an outer valence ring of five. The significant point is that antimony has

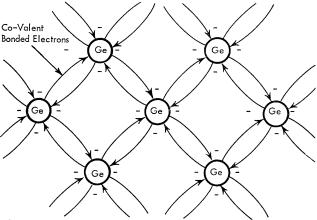


Figure 2. Diamond-Shaped Germanium Crystal Lattice

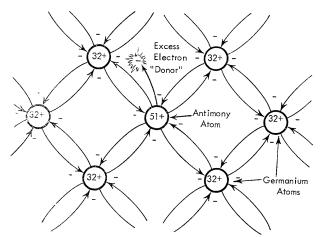


Figure 3. N Type Germanium Crystal

one more electron than germanium in its valence band. This excess electron, because it is not in a covalent bond, is relatively easy to remove (Figure 3); therefore, conduction in the doped material can take place relatively easily by means of these "donor" electrons, because the excess electrons can be easily "donated" to the conduction band. N-type germanium is so named because the majority carriers are electrons and, therefore, negative.

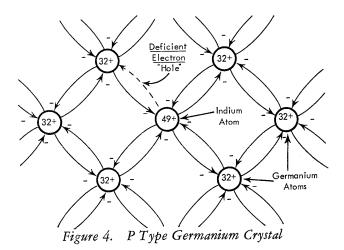
At normal room temperature the donor electrons, as well as a few from the covalent bonded group, are thermally agitated out of the valence band. These are now free carriers. In this temperature range, therefore, a supply of electrons is available for conduction.

Note that the electrons were liberated by the addition of energy supplied by temperature, or heat, in the above case. Also, when an electron was thermally agitated out of the valence band, the atom was left with a positive charge. This positive charge is said to be "bound" because the nucleus of the impurity atom is locked in place in the crystal.

A small voltage applied across a sample of N-type germanium causes a reasonably large amount of conduction. This current is a function of the number of donor electrons available in the material and is called "extrinsic conductivity." Increased current must come as a result of "intrinsic conductivity" that results when electrons break their covalence bonds. Obviously, because transistors are operated at room temperature, most of the conduction in N-type material is extrinsic.

#### P-Type Germanium

Indium can be used as dope to produce P-type material. Indium has only three electrons in the outer ring. Therefore, after doping the germanium with indium, the indium atom has the equivalent of seven electrons



in its valence ring—three of its own and the effects of four from the adjacent germanium atoms (Figure 4). This leaves a gap or "hole" which would need to be filled to complete the octet. This vacant energy level is called an acceptor level because it is quite ready to accept an electron from any source. Should an electron come along and fill this hole, however, the atom then has a negative charge that is not free to move because the atom is locked in place in the crystal and the extra electron is held in the lattice structure by covalent bonding. This is known as a bound negative charge.

At normal operating temperatures, there is enough thermal activity to keep these acceptor levels filled, leaving a number of vacancies in the valence band of germanium atoms equal to the number of acceptor impurity atoms present in the crystal. Thus, there is a constant supply of holes in the P-type material ready to serve as current carriers.

If a sample of this material is subjected to an electrical potential, the holes tend to migrate toward the negative terminal. Actually, electrons move from the valence band of one atom to the valence band of the next, without requiring the additional energy to jump up into the conduction band. But this is called "hole flow." If the voltage and temperature were low and the sample contained only P-type impurities, this type of conduction would be the only type to occur, and it would be limited by the number of acceptor levels, or holes, contained in the sample.

#### Minority Carrier Current

In N-type material, thermal activity dislodges some electrons that are in covalent bond, just as in intrinsic or pure germanium. The electron leaves behind a hole that tends to move in a direction opposite to that of the majority carrier electrons if an electric field is present.

This resultant electron and hole are called a "couple." At normal operating temperatures, this current by movement of holes is less likely to occur than free, majority carrier, electron current. Therefore, holes are referred to as minority carriers in N-type germanium. A hole is likely to meet a free electron, before traveling very far, and be eliminated. This is called recombination and takes place quickly after the minority carriers come into being. Minority carriers, therefore, have a finite average lifetime.

In P-type material, as well, a couple can be produced because of heat. The electron becomes a minority carrier, leaving behind a majority carrier hole. The free electron moves toward the positive terminal, acting as a minority current carrier until it meets a hole and recombines.

Minority carriers are always present to some extent at normal temperatures. Minority carrier current, from increased couples, increases rapidly with temperature and makes transistors quite temperature-sensitive.

#### NP JUNCTION DIODE

IF N- AND P-TYPE germanium are fused together, the junction exhibits rectifying action. An understanding of the action of this device is most essential to the understanding of transistor action.

#### Formation of the Rectifying Barrier

Assume, to begin with, that all holes are on the right side of the junction while all the free electrons are on the left. Also, neglect for now the effect of any holes or free electrons that may be produced as thermally generated couples.

The N region contains a number of donor atoms which may be assumed to be distributed uniformly throughout the volume. At normal temperatures, most of these have lost their fifth electron, and, therefore, have a bound positive charge (circled plus signs in Figure 5). The free electrons are moving at random but also are uniformly distributed (minus signs in Figure 5). This means that each unit of volume con-

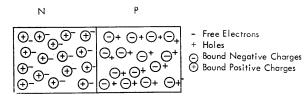


Figure 5. Initial Status Existing in N and P Materials

tains equal numbers of bound positive charges and free negative charges, and there is no resultant electric field within the volume as yet.

In the P region, similar conditions exist. Most of the acceptor atoms have received electrons from adjoining germanium atoms, because of thermal excitation, and are bound negatively-charged atoms as a result. Holes that originated as a result of these acceptor atoms diffuse at random in germanium atoms through the volume. At this point, with the assumption that no free electrons or holes have crossed the junction, there is no potential difference within either region or across the junction (Figure 5).

Because there is no external potential difference across the NP junction device, a free electron near the junction is just as likely to cross the boundary into the P region as to move more deeply into the N region. Similarly, a hole is likely to cross from the P region over to the N region (Figure 6).

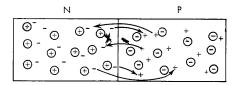


Figure 6. Random Crossing of Junction by Electrons from N Material and Holes from P Material

Most of the electrons that diffuse across the junction into the P region will recombine with a hole while still close to the junction. Each of these electrons has left behind in the N region an unbalanced, bound, positively charged atom, represented by the circled plus signs in Figure 7. When the electron reaches the P region and recombines with a hole, the result is that it has eliminated a plus charge in the germanium atom, leaving a bound negative charge somewhere nearby in the impurity atom, and making this region slightly more negative. These bound negative charges are represented by the circled minus signs. Holes have also crossed the junction, leaving behind further bound negative charges and recombining with free electrons on the N side. Thus, the

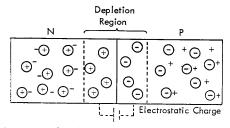


Figure 7. Result of Migration of Electrons and Holes

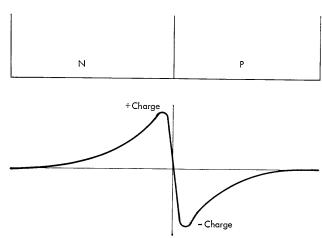


Figure 8. Electrostatic Charge or Potential Hills of an N-P Junction

N side has fewer free electrons to balance the bound positive charges near the junction. The result is a building up of an electrostatic charge, called a potential hill, on each side of the junction as shown in Figure 8. This charge opposes the movement of electrons from the N region into the P, and of holes from the P into the N region; thus, the higher the hills or charge, the fewer the holes or free electrons that are able to cross. Eventually, the hills become high enough to reduce the movement of carriers across the junction to a rate just sufficient to balance the movement in the opposite direction of carriers produced by thermally generated couples. The height of the potential hill is, of course, dependent upon the impurity concentration in the two regions. Note that the potential at each end of the device is the same; the potential hill region where the material is depleted of free current carriers may be only a few atoms thick. This region forming the barrier is called the depletion region. This forming of the junction of the N and P materials, the diffusion, the setting up of the electrostatic potential hill, and the subsequent stable condition happen during the cooling after the alloying or fusion of the N and P materials; they remain substantially the same until a voltage potential is applied across the materials.

#### Reverse-Biased Diode

If a source of voltage is connected, as shown in Figure 9, with the positive terminal to the N region and the negative to the P, the diode is said to be reverse-biased. The battery voltage in this case tends to aid the potential barrier at the junction. The positive terminal attracts free electrons of the N region and the negative terminal attracts free holes of the P region. This causes

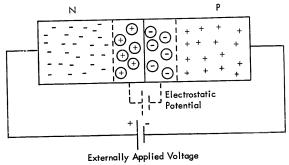


Figure 9. Reverse-Biased N-P Diode

both types of free carriers to move away from the barrier, leaving behind more bound charges that are not balanced. The height of the barrier is thus increased.

The battery attempts to deliver electrons to the P region and to remove an equal number from the N so as to produce current flow. Neglecting for now intrinsic conduction, that is, conduction caused by thermally generated couples, extrinsic conduction would have to be a result of the movement of free electrons in the N region from the barrier to the positive terminal and, at the same time, a movement of holes from the barrier to the negative terminal. Obviously, this is impossible because there is no inexhaustible supply of free carriers at the junction to maintain this flow. In fact, when the battery was first connected, this process started and immediately enlarged the depletion region near the junction. Comparative reverse-biased circuits showing the NP junction, diode, and tube are shown in Figure 10.

#### Normal Reverse Current

Reverse current in a diode exists, but is undesirable. On the other hand, this reverse current is necessary for a transistor to operate.

Free carriers can be created near the junction simply by supplying enough energy to produce a couple; unfortunately, this happens continually at normal temperatures. If a couple occurs in the P region, the free electron, a minority carrier, moves at random and may reach the junction during its lifetime. If so, it is attracted across the barrier both by the bound positive charges

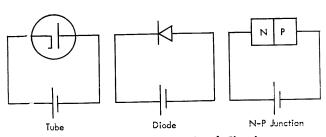


Figure 10. Reverse-Biased Circuits

and by the bias. The N region now contains one more electron than it needs for equilibrium, and the P region one extra hole. Therefore, the N region delivers an electron to the positive terminal and the P region delivers a hole to the negative terminal where it recombines with an electron from the wire. A similar process occurs if the couple occurs in the N region. The minority carrier hole may reach the barrier, where it is attracted across it and becomes a majority carrier proceeding toward the negative terminal.

Reverse current is intrinsic conduction, that is, the result of the generation of minority carriers. These are produced by breaking valence bonds as the result of heat. Of the minority carriers that are produced, some reach and cross the junction. The remaining minority carriers come in contact with majority carriers and recombine. The fraction of those produced that reach the junction depends somewhat on the bias, but to a larger extent on the minority carrier lifetime, which is a function of the density of majority carriers or amount of doping. The number produced per second depends on the temperature of the junction. Unfortunately, this increases quite rapidly. A typical figure would be a multiplication of current by ten for each rise of 30 degrees centigrade.

If the reverse bias voltage is increased gradually, the resulting back current increases rapidly for the first fraction of a volt, until nearly all the available minority carriers are under the influence of the bias. A further increase in voltage produces only a slight increase in reverse current up to a point, then a rapid increase limited only by the external circuit. This is shown in Figure 11.

This last rapid increase in reverse current is the result when additional minority carriers are produced from two possible sources. They both represent a breakdown of the reverse resistance of the diode. The two

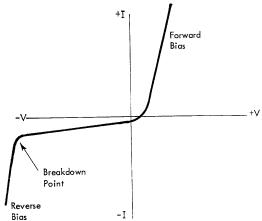


Figure 11. Diode Characteristic Curve

possible sources of current are discussed in the two following sections.

#### Avalanche Breakdown

Electrons gain energy as they move under the influence of an electric field. As reverse bias is increased, minority carriers in the P region cross the junction and acquire sufficient energy to bombard and dislodge valence ring electrons from germanium atoms in the N region. This increases the number of electrons available in the N region that can be supplied to the positive bias return. When sufficient bias voltage is supplied to start this process of generating couples, reverse current increases rapidly, in much the same way that a rolling stone starts an avalanche.

#### Zener Breakdown

This type of breakdown is named after the man who first proposed an explanation of the process. The force that an electric field exerts on an electron is proportional to the strength of the field; this is measured in volts per centimeter. The voltage appearing across a junction is small but is concentrated in such a short distance that fields having a magnitude of 100,000 volts per centimeter, or more, may exist there. When this field becomes sufficiently strong, valence-bonded electrons are pulled from their orbits and provide a source of carriers.

In each breakdown case, the amount of reverse current is limited by the resistance of the external circuit and not by the diode. Breakdown currents do not damage the diode unless the power dissipation is increased to a point where temperature rise causes physical damage to the junction. Power dissipation is equal to the product of the voltage across the diode after breakdown and the current flowing through it. A typical value of power limitation is 50 milliwatts, but this may be increased to several watts depending upon case construction, size of the junction, or the use of a heat sink.

#### Forward-Biased Diode

When a bias voltage is connected with the positive terminal to the P region, and the negative terminal to the N region (Figure 12), the diode is forward-biased. The applied potential repels the majority carriers of each region toward the junction. Some N material electrons recombine with the bound positive charges at the N side of the barrier, and some P material holes recombine with the bound negative charges at the P side

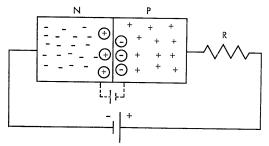


Figure 12. Forward-Biased N-P Diode

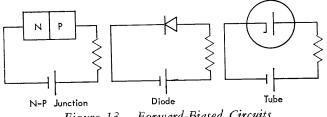
of the barrier; this reduces the potential hill at the junction by cancelling part of the electrostatic charge. Also, there is a diffusion through the barrier to become minority carriers on the opposite side.

For example, some majority carrier electrons may combine with bound positive charges but the greater percentage diffuse through to the P material to become minority carriers. Again, some of these electrons may combine with the majority carrier holes but the greater percentage are swept through the P material under the influence of the positive potential.

The high velocity of the minority carrier electrons dislodge other valence electrons in the P material so that more carriers are added to the conduction process. The charge of the minority carrier electrons also develops an electric field that further assists the transfer of thermally generated majority carriers toward the junction. This process is cumulative and results in a flow of carriers that greatly exceeds the amount which would normally be governed by the resistivity of the germanium.

As stated above, the potential hill is lowered when the forward bias voltage is applied. It is actually not reversed at the barrier, regardless of the voltage applied; however, the voltage dropped at the barrier is reduced nearly to zero. While some voltage is dropped at the barrier and a small amount is dropped in the P and N regions, because of the inherent resistivity of the material, most of the voltage dropped is across a limiting resistor in the external circuit. Only enough voltage can be maintained across the junction to cancel the lowered potential hill.

A high-current transfer is possible when there is a minimum of recombination of minority carriers. In the example of the NP diode, a high electron flow will result when there is a low concentration of holes in the P material; this is called electron injection or minority carrier injection. A predominance of hole flow would result if the N material contained fewer impurities than the P material.



Forward-Biased Circuits Figure 13.

Semi-conductor diodes develop a drop of only a few tenths of a volt, and consequently exhibit a low impedance when conducting in the forward direction; therefore, these devices should be protected with a current-limiting resistor when passing current in this direction. A comparison is made between a forward biased semi-conductor, a crystal and a vacuum tube diode in Figure 13.

#### JUNCTION TRANSISTOR

THE STUDY of semi-conductor diodes has provided the foundation on which transistor action can be analyzed. The diode characteristic curve shows that reverse current is essentially constant over a fairly wide range of reverse bias voltages. Remember, this reverse current is minority carrier current. By devising a means of controlling the number of minority carriers available, this current could be varied accordingly. By providing varying numbers of minority carriers, a family of curves similar to vacuum tube characteristic curves would result. In Figure 14 a mythical electron source is assumed to be able to inject minority carriers into the P region of a reverse-biased PN device close to the junction. When electrons are not being supplied, only the normal reverse diode current flows. Adding electrons to the P region from the external source provides extra minority carriers. Some of these carriers combine with the excess holes in the P region but the remainder come under the influence of the bias supply and are drawn across the PN junction. The increase in current noted at meter  $A_2$ is less than the increase of injected carriers indicated by

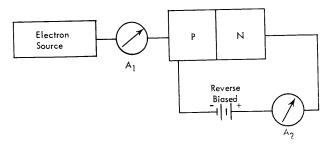


Figure 14. Theoretical Electron Injection

meter  $A_1$ ; this is the result of the recombination and canceling in the P material.

#### NPN JUNCTION TRANSISTOR

RECALL that a forward-biased semi-conductor diode supplies electrons from an N region to a P region. If an N material is fused to the P side of an existing PN diode and connected with a forward bias, the effect is an electron source feeding into the P material. The threeelement structure is a junction transistor (Figure 15). The original P material is called the base, the added N material electron source is called the emitter, and the original N section is called the collector. The emitter is always indicated by the arrowhead in a schematic. This arrow indicates the direction of conventional current flow through the transistor.

The amount of current passed by the forward-biased diode is the sum of two components: electrons traveling from N to P and holes traveling from P to N. The ratio of these components is determined by the numbers of available electrons and holes at the junction. This, in turn, is controlled by the ratio of donors in the N region to acceptors in the P region. These impurity concentrations can be expressed in terms of resistivity; alloys with large numbers of free carriers have low resistivities. From basic Ohm's law, it can be concluded that the total current across the junction is a function of the voltage across the junction and the resistivity of the junction. The net current is partially influenced by the concentration of majority carriers in each region. To obtain a minimum of recombination of electrons and holes in the base, the P-type base is doped with a lower concentration of impurities than the emitter. This unequal concentration is represented by a typical ratio of emitter to base resistivities of one to one hundred.

Minority carrier lifetime is affected by the recombination rate and the length of material the minority carrier must travel before recombination occurs. The measurement of this phenomenon is called "diffusion length," which is defined as the length of material at

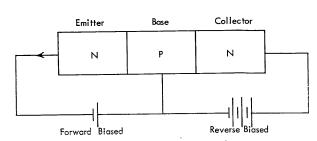


Figure 15. NPN Junction Transistor

which the number of injected carriers is reduced by 63% of its original value. A curve of free carriers vs. length of material (Figure 16) shows an exponential recombination rate that is similar to the discharge curve of a capacitor. In order to have a large percentage of the injected carriers cross the junction into the external circuit, the thickness of the base region must be considerably less than the diffusion length of the minority carriers. Percentages above 99 can be realized when the base thickness is only three to six ten-thousandths of an inch.

#### Alloyed-Junction Construction

The construction of a typical NPN alloyed or fused junction transistor is shown in Figure 17. A P-type germanium block about .002 inch thick and .060 inch square is used for the base material. A lead-antimony dot .010 inch in diameter is used for the emitter. A slightly larger lead-antimony dot, .015 inch square, is used for the collector. Each of these dots is alloyed to

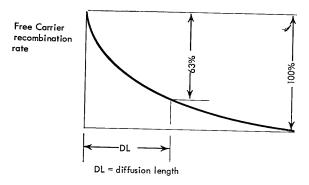


Figure 16. Recombination Curve

the base by controlled heating; the resulting crystal has an N-type impurity layer at each of the two junctions. The depth of penetration of the N-type layers into the base is dependent upon the time and temperature of the alloying process. This penetration determines the final thickness of the base which will be about .0006". This dimension is extremely critical and one of the problems complicating the manufacture of uniform transistors.

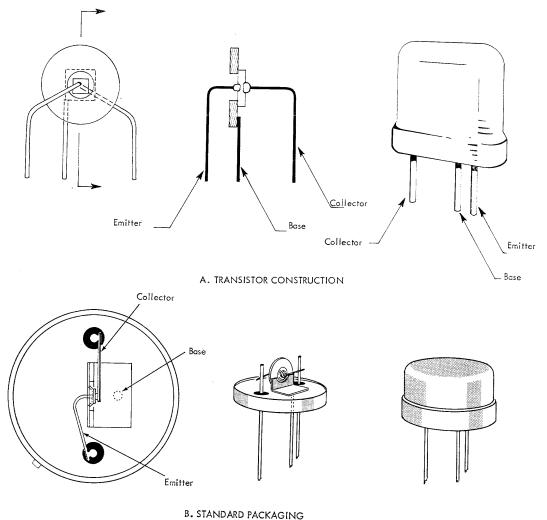


Figure 17. Transistor Construction

A gold plated ring is bonded to the base material; wire leads are then fused to the gold ring and to the emitter and collector dots. The assembly is mounted on a glass base and the entire unit is hermetically sealed in a small metal container.

The transistor package shown in Figure 17(A) is the type originally used by IBM. In this type, the leads are in line, with the emitter and base closer together and the collector wider spaced. The center lead is the base.

In order to conform to an industry standard, the packaging has been changed to that shown in Figure 17(B). In this case, looking at the bottom of the unit and starting at the tab, the leads are emitter, base, and collector, reading in a clockwise direction. Instead of being in line, the base lead is offset and an equal distance from the emitter and collector leads.

#### Static Condition

Majority carriers in each region cross the two junctions exactly as they did in a diode, building up a potential hill. This potential hill opposes the movement of majority carriers, electrons, from either the collector or emitter into the base.

As a result, at the completion of the transistor alloying process, there are developed potentials as indicated by the battery symbols in Figure 18. This is the condition that exists until external voltages are applied to the several transistor connections.

#### **Reverse-Biased Conditions**

Transistors are operated in any of the standard modes used in vacuum tube circuits. They can be used as RF or AF amplifiers and are ideally suited for system logic design because they approximate a switch. When the unit is cut off, its output impedance is a megohm or more; this drops to less than 50 ohms when the unit is in full conduction. The transistor is basically a current device and is controlled by changing input current signals. Practical applications, such as machine systems, use voltage changes to indicate various conditions within the system. These voltages are converted to current changes at the input to the transistor and changed back to voltage changes at the output. An output current is a linear

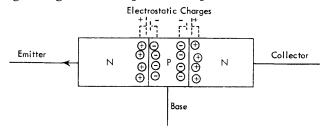


Figure 18. NPN Transistor Electrostatic Charges

reproduction of an input current rather than voltage change.

Where transistors are used as a switch, the intermediate current ranges are not significant because the transistor is operated at cut-off or in saturation. Under this condition, and as an introduction to transistor action, consider the input merely as a bias voltage between the base and the emitter.

The NPN circuit of Figure 19 is shown with a switch controlling the base-to-emitter bias voltage. When the base is negative with respect to the emitter, the transistor is cut off. The potential hill is increased and majority carriers cannot cross the barrier. The same action occurs at the collector junction because it is always reverse-biased. The previous discussion on collector bias indicates that only minority carrier current is able to cross the collector junction. This is the normal back-current present when the transistor is cut off and is appropriately called  $I_{co}$  (cut-off current).  $I_{co}$  increases rapidly with increases in temperature; it is measured with the emitter circuit open.

#### Breakdown

Transistors exhibit the effect of both Zener and avalanche breakdown owing to excessive reverse voltages, just as diodes do. Regardless of the current passed by the emitter circuit, increased collector voltages result in increased electric fields and, therefore, in larger reverse currents. The process is additive and large currents result with small increases in collector voltage after the critical (breakdown) voltage has been reached. A typical value of breakdown is 20 to 40 volts. Practical applications should not exceed ten volts between the collector and base for reliable circuit operations.

#### Punch-Through

The value of reverse voltage on the collector-base junction can be increased only until another critical point, called punch-through, has been reached. As the voltage across the base-collector junction is increased, the depletion region is widened. This depletion region widens more rapidly across the base than the collector

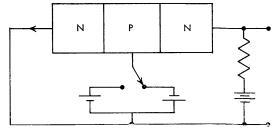


Figure 19. NPN Transistor Circuit

because the base material has fewer impurity atoms. Consequently, a point is reached at which the depletion region extends completely across the base. A further increase in voltage effectively adds electrons to the P material in the base, and decreases its resistance. The emitter, base, and collector each contain an excess of electrons after this critical voltage is reached and the entire transistor acts as a low-resistance device. This shows up as an increase in emitter potential because any increased collector voltage no longer develops a voltage drop across the transistor. The point at which this action starts is called the punch-through voltage, and occurs at about 15 volts.

#### Forward-Biased Transistor

Reversing the switch in Figure 19 forward biases the NPN transistor, putting it into conduction. Now the emitter-base potential hill is lowered by a voltage that provides an attractive force to the majority carriers in the emitter. It is convenient to remember that transistors are driven into conduction with a voltage polarity equal to the type of base material; e.g., NPN units turn on with a positive voltage and PNP units turn on with a negative voltage. Forward-biasing the emitter-base junction causes emitter carriers to travel into the base to become minority carriers. The base-collector junction is reverse-biased for majority carriers but forward-biased for minority carriers. Therefore, the emitter carriers that enter and diffuse across the base are drawn into the collector circuit. In the transfer from the emitter to the base, some of the carriers may combine with the majority carriers of the base. But, because base thickness is small and the impurity concentration of the base is low, the net result is that a high percentage of emitter carriers cross the base and enter the collector region. The total collector current is the normal  $I_{co}$  plus the amount of emitter current that does not recombine in the base to form base current.

#### PNP JUNCTION TRANSISTORS

By STARTING with a base material of N-type germanium, and adding P-type to either side, a PNP transistor is developed. Actually, this is done by fusing indium dots to the N-type germanium base. In this PNP transistor, the theory is the same as it was for the NPN. The difference between the two is that the majority carriers are now holes instead of electrons. A battery effect is built up as shown in Figure 20. As stated before, this PNP transistor is a complement of the

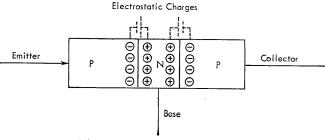


Figure 20. PNP Transistor

NPN already described. This means that while an NPN transistor is put into conduction by a plus voltage at the base, with reference to the emitter, as in a tube, the PNP requires a negative voltage at the base. This provides for more direct circuitry than can be achieved in some cases with tubes.

A PNP transistor is shown in Figure 21 with a reverse bias, or cut-off, condition. Transferring the switch would put this unit into conduction. In this schematic, the arrowhead is reversed from that shown in the NPN because the current flow (conventional) is in the opposite direction.

As previously stated, the arrows in both cases indicate conventional current flow. A clearer approach might be made if emitter majority carriers are considered, regardless of the type of transistor involved. The NPN units have electron flow from the emitter through the base to the collector. In PNP transistors, the path may be considered the same except that *holes* are the majority carriers from the emitter.

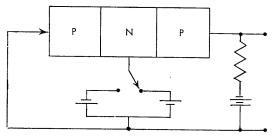


Figure 21. PNP Transistor Circuit

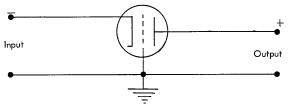
#### NPN TRANSISTOR CIRCUITS

DIRECT analogies can be made between NPN transistors and vacuum tube circuits; therefore, the following illustrations will refer to the NPN variety only.

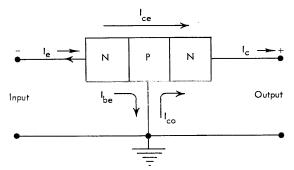
#### Grounded-Base Circuit

A transistor application similar to a grounded-gridamplifier tube circuit is the grounded-base circuit. A typical circuit is shown in Figure 22, along with its corresponding tube circuit. The transistor emitter could be compared to the tube cathode, the base to the grid, and the collector to the plate.

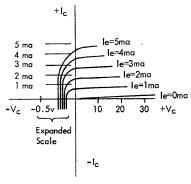
The arrows on the diagram indicate the direction of electron flow at the terminals of the transistor. Collector current consists only of  $I_{co}$  before an input current is supplied. This is indicated on the collector voltampere  $(V_cI_c)$  characteristic curve as  $I_c=0$ . Increasing the emitter current to 1 ma increases the collector current to 1 ma, plus the normal  $I_{co}$ , minus the emitter current that recombines in the base  $(I_{be})$ . Further increases in emitter current result in corresponding increases in collector current. However, the change in output current is always less than the input change because of base recombinations. A typical grounded-base junction transistor actually delivers less current at its output than is received at its input; however, a power



GROUNDED GRID TUBE CIRCUIT



NPN GROUNDED BASE CIRCUIT



GROUNDED BASE NPN  $V_c I_c$  CHARACTERISTICS

Figure 22

gain is developed because of the difference in impedance levels between the input and output circuits. The emitter base is a forward-biased diode with an impedance near 50 ohms. The output is a reverse-biased diode with an impedance of about a megohm.

#### Characteristic Curves

The V<sub>c</sub>I<sub>c</sub> characteristic curves best describe the transistor action of the grounded-base circuit. Collector currents are measured at various collector voltages with the emitter current held constant. A family of curves develops when several values of emitter current are plotted. Each value of input current develops an essentially constant value of collector current throughout the range of the collector reverse-bias voltage. The curves show that a slightly forward-biased collector junction is needed to reduce the collector current to zero. This is necessary because many of the emitter carriers attain a sufficient velocity to cross the collector junction, regardless of the magnitude of the aiding field. As the collector reverse-bias is reduced to zero, some forward-biased current flows in the collector that subtracts from the normal emitter current reaching the collector. The small forward bias retards emitter carriers and starts a flow of forward collector-to-base carriers. When the forward and reverse currents cancel, the collector current drops sharply to zero. This circuit is used for impedance matching, voltage amplification, and power gain.

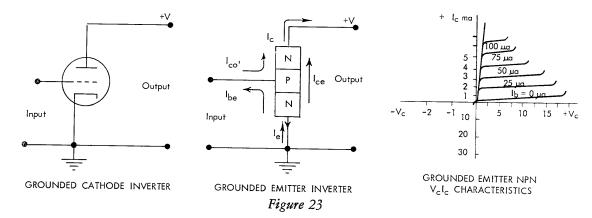
#### Alpha

Current gain is represented by the Greek symbol alpha ( $\alpha$ ) and is defined as the ratio of change in collector current to the change in emitter current when the collector voltage is held constant. Because some recombination occurs in the base, collector current changes are less than emitter current changes and the ratio is always less than one for junction transistors. Typical values of  $\alpha$  are from .95 to .99.  $\alpha = \frac{\Delta I_{ce}}{\Delta I_{c}}/V_{c}$ 

#### Grounded-Emitter Circuit

A second analogy between tube and transistor circuits might be the grounded-cathode-inverter tube circuit vs. the grounded-emitter transistor circuit.

Base input circuits are affected by the low impedance of the emitter-base diode as well as the high impedance of the collector-base diode. This presents a higher impedance to the driving source than the previously discussed grounded base circuit. Input signals are applied to forward-bias the emitter-base diode and a large number of carriers cross the junction. The description of a



forward-biased diode noted that only a small influence was necessary to initiate a scattering process and a cumulative flow of carriers. Small current signals of majority carriers into the base induce a large flow of emitter carriers to cross the junction. Again, emitter carriers diffuse across the base, come under the influence of the collector potential, and are drawn across the collector junction.

Figure 23 shows comparable grounded-emitter and grounded-cathode inverter circuits. Also shown are the various electron paths involved in the input and output of the grounded-emitter circuit. The  $V_cI_c$  curves show that when base current is zero, only  $I_{co}$ ' flows as collector current.  $I_{co}$ ' is an amplified cut-off current equal to  $I_{co} \div 1$  minus  $\alpha$ . When 25  $\mu a$  is injected into the base, about 2 ma flows in the collector circuit. This connection provides an appreciable current gain between the input and output circuits.

#### Alpha Prime

The symbol  $\alpha'$  is used to designate the current gain between the collector and base. It is defined as the ratio of the change in collector current to the change in base current with a constant collector voltage. This is an important transistor characteristic, or parameter, and is dependent upon the construction of the transistor as well as the circuit in which it is used. Typical values are from 20 to 150. (Alpha prime is referred to as "beta" by some authors.)  $\alpha' = \frac{\triangle I_{ce}}{\triangle I_{be}}/V_c$ 

#### Grounded-Collector Circuit

The NPN grounded collector emitter follower transistor circuit, in the third analogy, can be compared to the grounded plate cathode follower tube circuit (Figure 23A). As in the grounded emitter circuit, the base input presents a high impedance to the driving source. The output voltage differs from the input signal voltage by the amount of the emitter-to-base voltage drop (about

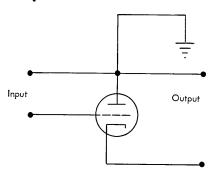
0.2 volts in a typical application). Current amplification is the highest of the three circuits discussed.

This circuit, with its high input and low output impedances, is generally used for impedance matching and line driving.

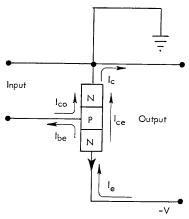
Characteristic curves are not usually shown for this circuit.

#### PNP TRANSISTOR CIRCUITS

CONNECTIONS for PNP transistors involve only the reversal of collector and bias potentials from equivalent

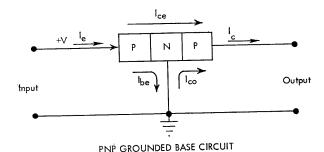


GROUNDED PLATE CATHODE FOLLOWER



GROUNDED COLLECTOR EMITTER FOLLOWER

Figure 23A



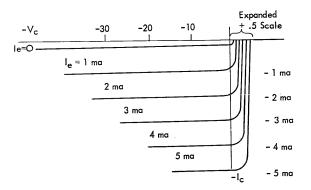


Figure 24. Grounded-Base PNP Circuit, V.I. Characteristics

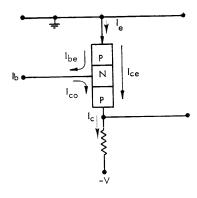
NPN circuits. This reversal means that a negative potential applied to the base, relative to the emitter, of the PNP transistor causes it to conduct. This being the case, a PNP transistor circuit is *not* analogous to a tube circuit because this would be equivalent to saying a tube could be caused to conduct in a reverse direction (electrons flowing from plate to cathode) by applying a negative signal to the grid.

#### Grounded-Base Circuit

A PNP grounded-base circuit is shown in Figure 24. The direction of the arrows indicating current flow in this diagram is similar to that in the NPN diagram, but in the present case indicates hole flow. Since the collector voltage is now negative, the  $V_{c}I_{c}$  curves are developed in the third graphical quadrant. The theory for NPN grounded base is duplicated in this circuit except that the majority carriers from the emitter are holes. Alpha remains less than one.

#### Grounded-Emitter Circuit

Again, NPN theory can be adapted to the PNP variety and analyzed as hole carriers travelling through the unit in the directions indicated in Figure 25.



PNP GROUNDED EMITTER CIRCUIT

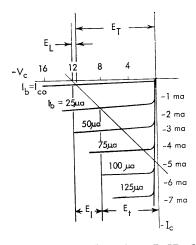


Figure 25. Grounded Emitter PNP Circuit,  $V_oI_c$  Characteristics

#### Load Lines

The  $V_cI_c$  characteristic is similar to the previously discussed version except that a typical load line has been added to this diagram. Terminating points are established on the voltage axis at the open circuit voltage across the transistor and on the current axis at the short circuit current through the transistor. A cut-off transistor has only Ico flowing; this intersects the load line and the drop across the transistor is measured horizontally from the zero reference point  $(E_T)$  while only a small voltage  $(E_L)$  is dropped across the load. Almost the entire terminal voltage appears across the transistor because only a small current is flowing; this indicates that the unit has a high impedance when cut off. An input signal of 25 µa develops a collector current near 1.5 ma; the voltage across the transistor drops to 8 volts  $(E_t)$ ; 4 volts  $(E_t)$  appears across the load resistor. Increasing the input signal to 100 µa develops 5 ma of collector current. This is the saturation current for the transistor and is limited by the power dissipation ability of the unit. The voltage across the transistor drops to

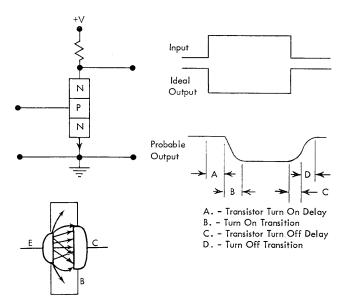


Figure 26. Transistor Transient Effects

a low value; this is usually less than 0.3 volt. The high current and low voltage drop indicate that the transistor has a low impedance when in saturation.

#### TRANSIENT EFFECTS

ANALYSIS of the grounded emitter connection of Figure 26 shows that the circuit is functioning as an inverter. Normally, the transistor is cut off and output is near the positive collector return voltage. A positive input signal drives the unit into conduction; only a small voltage drop develops across the transistor and the output approaches the emitter return voltage. Ideally, a positive square-wave input should produce a negative square-wave output. The ideal square wave is not achieved because of two transistor parameters that affect the output signal; one is transit time and the other is minority carrier storage in the base. An NPN unit is discussed; however, the same theory applies to PNP transistors.

#### Turn-on Delay

A finite difference in time results when an electron is passed by various types of materials. The N-type semiconductors contain an excess number of electrons; adding an electron to one side of this material immediately causes an electron to leave the opposite side so that equilibrium can be maintained. It is not necessary that the added electron travel the full width of the ma-

terial before an electron leaves the opposite side. One electron is just as effective a carrier as another; therefore, the net transfer can be considered to have a very small transit time.

Adding electrons to P-type semiconductors produces a slightly different effect. This material contains few, if any, free electrons. When an electron is added to one side, a finite interval of time exists before it arrives at the opposite side. In NPN transistors, a delay results because electrons must cross the P-type base region. Electrons leaving the emitter arrive at the collector some interval of time later as represented by A in Figure 26. This is called the "turn-on delay time."

#### Turn-on Transition

Unfortunately, electrons do not all leave the emitter with the same velocity; consequently, they arrive at the collector at different times. In addition to this, the electrons may take any of several random paths between the emitter and collector. The combined effect is that the fastest and most direct electrons arrive at the collector first, the slower electrons arrive a short time later and, finally, the slowest electrons that took the most indirect path arrive at the collector last. The net result is a gradual build-up of carriers reaching the collector, and a rather steady arrival rate when the transistor is in full conduction. This effect may show up as a sloping leading edge of the output signal and is defined as the "turn-on transition time" (B in Figure 26).

#### Turn-off Delay

When a negative input signal reverse-biases the emitter-base diode, electrons in transit across the base region continue to flow to the collector circuit. Some of the electrons may combine with holes for short periods of time during the transfer across the P material; this is a "minority carrier storage" effect. Both of these actions affect the interval of time between the last electrons leaving the emitter and the last electrons arriving at the collector. This is represented as time C and is called the "turn-off delay time" (C in Figure 26).

#### Turn-off Transition

The differences in velocities and path length also affect the arrival time of the last electrons to reach the collector. A gradual tapering off of collector carriers results when the transistor is cut off. This is the "turn-off transition time" (*D* in Figure 26).

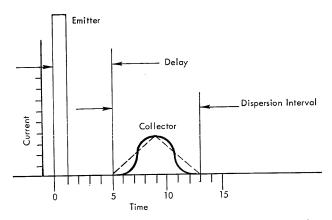


Figure 27. Collector Arrival Rate of Emitter Carriers

#### FREQUENCY CUT-OFF

THE RANDOM speeds and paths of electrons leaving the emitter develop a spread in arrival times at the collector. This spread in arrival time is called the "dispersion interval." An emitter pulse having a width of one unit of time may be delayed five units of time and then spread itself over eight units of time at the collector. The total number of carriers may be the same but the number of time intervals is quite different. The curve of collector arrival time is approximated by two straight dashed lines in Figure 27.

Emitter signals having a pulse time that is long compared to the time of the dispersion interval display no unwanted effects in the carrier travel through the transistor. This is shown in Figure 28, where the total collector current is made up of components of several dispersion intervals. Throughout the sine wave cycle, components add to each other and the current output is equal to alpha times the emitter input signal.

When emitter signals are short compared to the time of the dispersion interval, collector current does not follow the emitter current. The width of the dispersion interval causes some of the maximum amplitude current components to flow during the time of minimum emitter currents. In the same way, minimum amplitude currents flow during the time of emitter max-

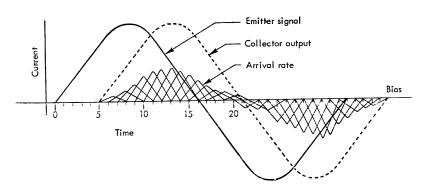


Figure 28. Composite Arrival Rate of Emitter Carriers

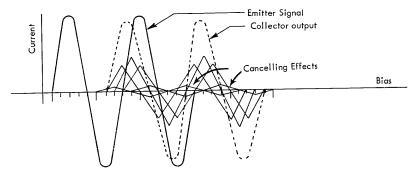


Figure 29. High-Frequency Cancelling Effects of Collector Current Components

imum amplitude. Total collector current is the net sum of all components; therefore, if some components cancel others, the net result is a reduction in collector gain (Figure 29). A measure of this property is the frequency cut-off point ( $f_{co}$ ). It is also called the alpha cut-off point and is defined as the frequency at which alpha reduces to 70.7 percent of its low frequency current gain. An arbitrary low frequency reference point that is becoming standard is ten percent of the frequency at alpha cut-off. Current gain is measured at this frequency and

remains rather constant as frequency is increased up to some upper limit. Alpha decreases rapidly beyond this point until the transistor no longer functions efficiently. A typical point at which the current gain reduces to 70.7 percent  $(3\ db)$  is five megacycles (Figure 30) in alloy junction transistors.

Alpha cut-off can be increased by reducing the width of the base region, but this also reduces the punchthrough voltage; therefore, a compromise is made between the two parameters.

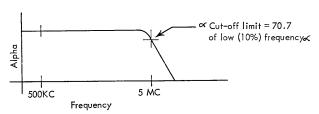


Figure 30. Frequency Cut-off

### **Voltage Mode Transistor Circuits**

THE IBM 608 Calculator has transistor circuits that operate on a signal of five volts. The signal lines are at a level of either zero or minus five volts. Since this is a larger swing than in some transistor circuits, it is called a voltage mode.

The voltage mode system uses saturating types of transistors generally, where they act as switches and are either in full conduction or cut off. Inverters and triggers are examples of this type of operation.

Emitter followers, which are similar in operation to cathode follower tube circuits, are also widely used in voltage mode operation. While emitter followers are not cut off or saturated, they still use the same input and output signal voltages as the inverters and triggers.

Typical NPN and PNP circuits illustrating common usage are illustrated, along with a description of their operation.

#### DC-COUPLED NPN INVERTER

FIGURE 31 is a basic NPN inverter circuit that produces current and voltage gain with signal polarity inversion.

The transistor is fundamentally a current device. System logic is developed and referred to as voltage signal. This circuit is designed to convert the voltage pulses to current pulses at the input and current pulses

to voltage pulses at the output. The input voltage signal is converted to a current source by inserting a high resistance  $(R_1)$  in series with the transistor. The load resistance  $(R_3)$  converts a current output to a voltage output.

An inverter circuit could be designed with an input consisting only of  $R_1$ ; however, its operation is not reliable. Back current  $(I_{co})$  from collector to base increases rapidly with temperature and age and develops a drop across  $R_1$  that could switch the inverter from cut-off into conduction.

From measurements, it has been determined that a cut-off condition can be insured if the base-to-emitter junction is reverse-biased by minus 0.2 volt. The addition of  $R_2$  develops a voltage divider that establishes the base at minus 0.2 volt. The transistor is cut off and a current path is established for  $I_{co}$ , from ground through  $R_3$  and  $R_2$  to minus 15 volts. The value of  $R_2$  is determined by the maximum amount of  $I_{co}$ . This back current is directly affected by, and increases with, temperature; therefore, the function of  $R_2$  is basically that of temperature compensation. The voltage drop developed across  $R_3$  because of  $I_{co}$  is small; the output signal is near ground potential. An input signal from minus 5 to 0 volts forward-biases the emitter-base junction and drives the transistor into conduction.

 $C_1$  is a pulse shaper used to improve the fall time of the output signal. As frequency increases beyond given

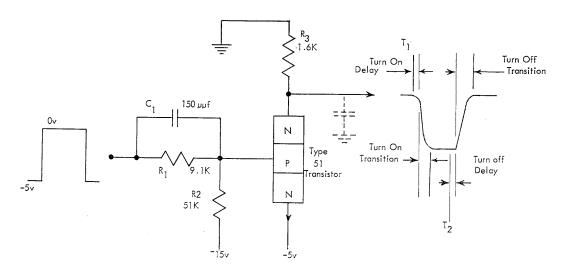


Figure 31. NPN Inverter

limits, alpha decreases in a transistor. A square wave is made up of many frequencies; the highest frequencies provide the steep leading edge. When the gain is low at the high frequencies, only the lower-order frequencies will be amplified and the leading edge of the output loses the steepness of the input signal. C1 provides an effective short circuit to the leading edge of the input pulse; this supplies an instantaneous change in base current that is very large compared to the base current that is supplied through  $R_1$  after  $C_1$  has been fully charged. A large, instantaneous base current causes a large output and compensates for the decreased gain of the transistor at the higher frequencies. The value of this capacitor is selected so that the output approaches the inverted shape of the input signal. If the value is too large, the output tends to peak up and overshoot the final negative limit.

Ideally, the output voltage should immediately shift to minus 5 volts; however, a small turn-on delay time results because of the carrier transit time in the transistor. The conducting transistor presents a very low impedance and only a small voltage drop is developed across it. Usually, a drop of 0.1 to 0.3 volt can be expected between emitter and collector. A capacitive load or the distributed line capacity of the output circuit charges from 0 to the new level of minus 5 volts through the low impedance of the conducting transistor. The wave front is essentially an inversion of the input signal.

An input signal shift from 0 to minus 5 volts again reverse-biases the transistor to cut it off. Because excess carriers may be in random storage throughout the base material and some of the carriers are in transit at the time of the turn-off signal, a slight delay results before the carriers stop flowing in the collector circuit. This represents a small turn-off delay time. A capacitive load or the distributed line capacity of the output circuit must now discharge to 0 volts through the relatively high impedance of the load resistor. An increased RC time constant results, and the turn-off transition time is usually longer than the turn-on transition time. The range of turn-off time may be from 0.1  $\mu$ sec for a pure resistive load to 1  $\mu$ sec for a 350  $\mu$ pf capacitive load.

NPN inverters are generally used where a sharp negative-going leading edge is required.

#### DC-COUPLED PNP INVERTER

THE INVERTER in Figure 32 is a basic PNP inverter circuit and is a direct complement of the NPN unit. In Figure 32:

- C<sub>1</sub> Pulse shaper; improves the rise time of the output signal.
- R<sub>1</sub> Determines the base current that is to be supplied by the preceding state.
- R<sub>2</sub> Limits the base voltage to the desired bias value when the input signal goes to the lower limit of the positive input. It also serves as a temperature-compensating resistor and provides a current path for I<sub>co</sub>.
- $R_3$  Limits the current passed by the transistor.

A normal level of 0 volts reverse-biases the transistor so that only  $I_{co}$  flows in the load circuit; the output line

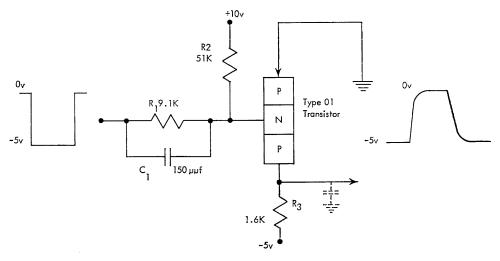


Figure 32. PNP Inverter

is near minus 5 volts. A negative signal alters the input network to forward-bias the emitter-base junction; base current is supplied and the transistor is driven into conduction. Capacitive loading discharges through the transistor to raise the output line quickly to near ground potential.

An input signal-shift in the positive direction again cuts off the transistor; the output line approaches the lower minus 5 volt level. A sloping trailing edge may result because capacitive loading must charge through the RC time constant made up of the capacity and the load resistor  $R_3$ .

#### NPN EMITTER FOLLOWER

FIGURE 33 shows a current driver used for interstage power amplification. The driver has a current gain nearly equal to alpha prime and a voltage gain slightly less than one. In this figure:

R<sub>1</sub> Collector resistor; controls collector current to reduce overshoot and ringing in the input signal.

R<sub>2</sub> Emitter and load resistor

 $R_3$ — $C_1$  Oscillation suppression circuit.

Collector and emitter voltages are always as shown and the base voltage is determined by the value of the input signal. When the input is at the lower level of —5 volts, the base is positive with respect to the emitter and about 3.2 ma flows in the emitter circuit. This is between the cut-off and saturation limits of collector current; therefore, a small voltage drop appears between the base and emitter leads. The output line establishes itself between the —5 volt input signal and the —15 volt emitter return. The output voltage should not be more negative than —5.3 volts when the input signal is —5 volts.

A positive input signal raises the base voltage to 0 volts and emitter current increases to about 5 ma. This increases the voltage drop across the load resistor and causes the output to approach ground potential.

The collector is returned to a voltage more positive than the input signal; therefore, the base-collector diode does not become forward-biased and  $T_1$  never goes into saturation. This minimizes the effects of minority carrier storage in the base, and a fast fall time results at the trailing edge of the output signal. Emitter current flows at either input level; the transistor is never cut off, nor is it driven into saturation.

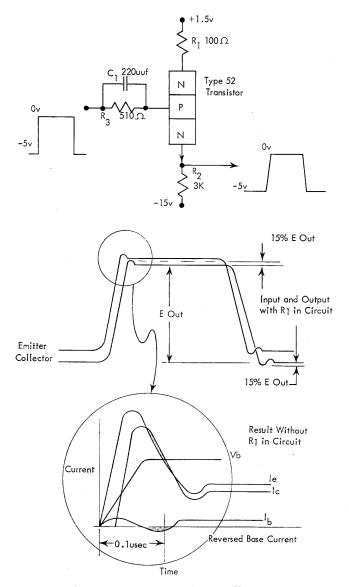


Figure 33. NPN Emitter Follower

Transient overshoot effects are developed when the input signal is quickly changed from one level to another. The NPN emitter followers develop an overshoot on the leading edge when the transistor goes into heavier conduction; a similar overshoot occurs on the trailing edge when the current is reduced.

Turn-on overshoot is a function of the delays in transit from the emitter to the collector. Transit delays develop a phase shift between the input and output signals. A sudden increase in input voltage results in a surge of emitter and collector current. The phase shift between input and output current tends to keep collector current flowing at the trailing edge of the emitter surge current. This gives the effect of larger collector current than the emitter current that is being

supplied. An unbalanced condition occurs where the difference between collector and emitter currents is supplied by a reversed-base current. The reversed-base current develops a voltage drop across the base resistance that effectively raises the base voltage. The increased base voltage is reflected as a peak or overshoot in the emitter output voltage. The 100-ohm collector resistor prevents  $I_c$  from becoming larger than  $I_c$  on the trailing edge of the surge current and, thereby, eliminates the reversal of base current and minimizes the overshoot transient in the output circuit.

Turn-off overshoot is a function of the turn-on time of the emitter-base diode. Lowering the input signal to minus 5 volts reduces conduction through the transistor and the output is effectively clamped to the input level through the forward bias of the emitter-base diode. When the clamping action of the diode is slow, or if an appreciable difference of potential is required to cause clamping action to take place, the output line overrides the level of the input signal. As clamping action goes into effect, the lower level of the output signal becomes more stable. Any overshoot above 15% of the output signal should be recognized as a possible source of extraneous pulses.

The NPN emitter followers are used for current amplification of positive-going signals, because capacitive loads or distributed line capacity can be quickly discharged to the upper level through the low impedance of the heavily conducting transistor.

#### PNP EMITTER FOLLOWER

THE CURRENT driver shown in Figure 34 is a direct complement of the NPN unit. In this figure:

 $R_1$  Overshoot control resistor.

 $R_2$  Emitter load resistor.

 $R_3$ — $C_1$  Oscillation suppression circuit.

The PNP circuits are connected with a negative voltage on the collector. To maintain a uniform type of drawing, all positive voltages are shown at the top of circuit diagrams. This results in PNP emitter connections at the top of the diagram. A normal 0-volt input causes about 3.2 ma to pass through the transistor. Conduction increases to about 5 ma when the input signal drops to minus 5 volts. The action of this circuit is similar to that of the NPN unit except that the output is slightly more positive than the input signal. The voltage drop across the emitter-base diode causes this shift in level. Transient effects in PNP emitter followers

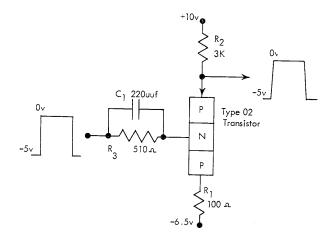


Figure 34. PNP Emitter Follower

are similar to those described for the NPN circuit. Overshoot on the leading edge develops when current is reduced in the transistor. This is a function of the turn-on time of the emitter-base diode. Trailing edge overshoot is a turn-on transient that is a function of the transit delays between the emitter and collector.

The PNP emitter followers are used for current amplification of negative-going signals, because distributed line capacity can charge to the lower level through the low impedance of the heavily conducting transistor.

#### **NEON INDICATOR**

THE CIRCUIT for neon indicators (Figure 35) is used to control the relatively high voltage required to ignite a neon by the small voltage signals available in a transistor unit. The transistor provides a low-impedance

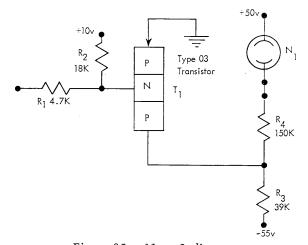


Figure 35. Neon Indicator

shunt when the neon is not to be lit. This circuit is usually driven by transistor logic where loading or input levels are not too critical. In Figure 35:

 $R_1$  Determines the base current that is supplied by the driving circuit.

 $R_2$  Raises the base voltage to the desired bias value so that cut-off is insured when the input goes to the lower limit of its positive swing (minus 1.0 volt).

 $R_1$  and  $R_2$  Also make up a voltage divider that maintains the proper bias on the transistor within the allowable variations of  $I_{co}$ .

 $R_3$  Is the load resistor for  $T_1$  and limits the current through  $T_1$  when it is in conduction.

 $R_4$  and  $R_3$  Limit the current through  $N_1$  when the neon is conducting.

N1 NE75 neon. This neon should ignite at 90 volts or less and should extinguish at 55 volts or less. The neon conducts between .1 and .4 ma and develops a drop of 60 to 70 volts across it when in conduction.

#### TRIGGER

THE VOLTAGE MODE trigger (Figure 36) as used in the 608 Calculator always consists of two PNP inverters, cross-coupled between the output of one transistor and the input of the other. Because of this coupling action, the trigger has two stable states; it is either on or off. In all cases, a trigger is considered to be on and indicate a logical ONE when the output from the right side is

at a positive level, or zero volts. Note that if a comparison is attempted between the transistor trigger and a tube trigger, the output corresponds; that is, when the trigger is on, the right output will be up. Conversely, when the trigger is off, the left output is up. However, note also that in a tube trigger the left half is conducting when the trigger is on. Since the 608 trigger uses the PNP transistor, the opposite is true; that is, to have an up-level at the right output, the right transistor must be conducting.

The circuit illustrated in Figure 36 is a DC control, clamped trigger. It can be flipped by a negative input to the non-conducting base. In this circuit:

 $R_1$  and  $R_{10}$  Limit the base current.

 $R_2$  and  $R_9$  Are speed-up resistors. They prevent the transistors from becoming biased too far beyond cut-off.

 $R_3$  and  $R_8$  Collector load resistors.

 $R_4$  and  $R_7$  Cross-couple the output of one transistor to the input of the other.

 $R_5$  and  $R_6$  Off-bias resistors; also act as temperature compensators by providing a conduction path for  $I_{co}$ .

 $C_1$  and  $C_2$  Speed up capacitors; quickly switch the base input when a change in voltage appears at the opposite collector.

 $D_1$  and  $D_2$  IBM type AA diodes; prevent the output from going below —5 volts when the transistor is cut off.

Assuming that the trigger is off, and  $T_1$  is conducting, as an initial condition, the top of  $R_3$  will be about zero volts and  $T_2$  will be held cut off. With  $T_2$  cut off, the right output will be at the —5 clamped voltage.

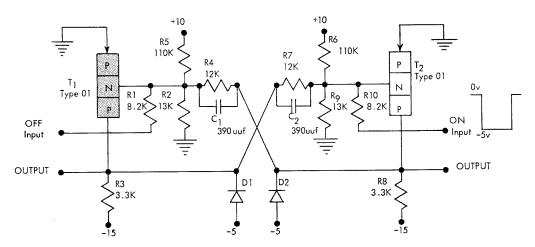


Figure 36. DC Input Trigger

A negative pulse is now applied at the ON input. The increase in current flow through the voltage divider,  $R_6$  and  $R_{10}$ , drops the voltage at the base of  $T_2$ , putting it into full conduction.

The point above  $R_8$  rises toward zero volts. This positive shift is fed directly to the base of  $T_1$  through  $C_1$  and  $R_4$ , and cuts  $T_1$  off.

As  $T_1$  is cut off, the point above  $R_3$  drops to the —5

clamped voltage. This drop in voltage is fed through cross-coupling  $C_2$  and  $R_7$  to the base of  $T_2$ , causing  $T_2$  to continue conducting. The trigger has thus been turned on and will remain in this status.

The trigger could now be turned off again if a negative pulse were applied to the OFF input. The action would be the same as described above, except that the corresponding components on the opposite side would be used in the description.

### **Current-Switching Circuits**

THE VOLTAGE MODE of operation is too slow for computers operating at increased speeds. This is because of several factors:

- 1. Capacitance Transistor input capacitance and other capacitance, and the impedance through which this capacitance must be charged.
- 2. Alpha cut-off frequency.
- Storage time in saturating transistors and associated diodes.

To permit for this increased operating speed, current switching logic is being developed. Since this system is in its infancy, constant changes and improvements are being made, so that this section is preliminary in nature and will be revised as additional developments are released.

Current switching logic is a system that performs logical functions by switching well defined currents, on the order of 6.6 ma, from one part of a circuit to another. Increased speeds are attained by using transistors in circuits designed to avoid operation at or near transistor saturation. To further reduce delay time through voltage build-ups, small voltage swings are employed, just enough to insure transistor conduction or cut-off under worst-case conditions.

To improve alpha cut-off frequency, new transistors are being developed with this parameter increased to about 70 megacycles. These "drift" transistors, as they are called, will not be specifically discussed at this time. However, circuits covered will be representative.

Collector diodes are always reverse biased by approximately six volts to avoid saturation and the inherent delay due to carrier storage. For this reason, the output voltage differs from the input by six volts in most of the circuits discussed. This, therefore, establishes two reference levels about which the signal voltages swing. These levels have been established as 0 and —6 volts.

Voltage swings about ground are referred to as N lines, and usually drive N-base transistors. These lines are usually generated by the coupling network (loading) of P-base transistor circuits.

Voltage swings about the minus six-volt reference are referred to as P lines and usually drive P-base tran-

sistors. They usually are generated by the coupling network of N-type transistor circuits.

Circuits are designed to produce nominal voltage swings of approximately 0.8 volt about either reference level, above and below, or a total of 1.6 volt from an UP level to a DOWN level. This would give an approximate voltage of +0.8 volt for the UP N line, and —0.8 volt for a DOWN N line. The P lines would be at —5.2 or —6.8 volts. These voltages are used in our discussion; however, they are approximate and vary slightly with different circuits.

Note that the input and output lines of any given block are often translated as far as reference levels are concerned. In other words, the input lines for an N block are at the zero reference, and the output lines at the —6 reference. Conversely, the input lines to the P block are at a —6 volt reference, so the output lines are at the zero level. This translation is being used throughout most of the circuits discussed. However, translation is not used in all circuits. A block could have an N line as both the input and output, or a P line in both cases. When using translating blocks, logic flow is developed by alternating N and P blocks.

When using positive logic, a basic N block is always an AND circuit. A basic P block is always an OR circuit. Conversely, when using negative logic, the N block is always an OR circuit and the P block an AND circuit.

In order to take care of the input and output circuits of computers or other devices which have extremely high internal speeds, circuits must be designed which will have either inputs or outputs compatible with current switching reference levels and signal voltages on one end, with the other end compatible in reference level and voltage swing to the input or output device.

A typical application would be the use of a tube-type card reader as an input device. This machine has a signal swing from +10 to -30 volts, which must be translated to current switching circuit levels.

Another case would be the use of a tube-type printer as an output unit from a high-speed device. In this case, the current switching signals must be translated to tube circuit levels.

Both the above circuits would be called converters. The difference between them would be indicated by the logic block input and output line symbols, as well as the component card number.

The operation of relays or lights is accomplished by the use of a driver relay (DR) or driver indicator (DI). The circuit is the same for these two applications. The two different names are used to standardize logic block terminology.

Representative circuits are illustrated and described for each of the above conditions. It should be pointed out that these are typical operating circuits, and consequently may or may not be the specific configuration used in a machine. It should also be noted that there are many types of triggers and trigger inputs. Only one is shown and described.

There are two output lines from each N or P block. The lower output is always the "in-phase" and the top output is the "out-of-phase." An N and a P block are shown in Figure 37. The in-phase line carries the input wave shape through the block, as the name implies. The out-of-phase output is an inverted signal; therefore, both the input signal and an inverted signal are available from each of these blocks, and may be used in circuit logic without added circuit delay.

#### N BLOCK

A BASIC N block consists of two N-base transistors connected as shown in Figure 38, considering only transistors  $T_1$  and  $T_2$ . This block, as stated earlier, is always a positive AND circuit or negative OR circuit.

As a starting point in the discussion of its operation, consider  $T_1$  only in the circuit. Since the emitter is connected to +6 volts through a 1K resistor and the base is grounded, the transistor is forward biased, and conducting. Under this condition, the emitter of the transistor will be at perhaps +0.2 volt. The lower, or in-phase, output will be at about -5.2 volts (+P line).

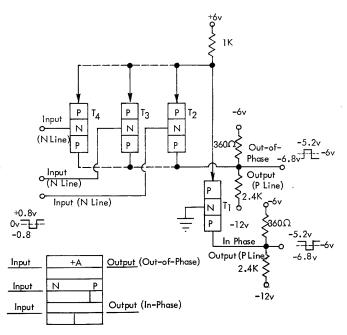


Figure 38. Basic N-Block Circuit

Now, if  $T_2$  is added to the circuit and a plus signal is applied to the input, the in-phase output remains as before. However, note that there is now an inverted, or out-of-phase, output at the collector of  $T_2$ . This output will be at the —P level or —6.8 volts.

Applying a minus signal to  $T_2$  reverses the conditions. The emitter of both  $T_1$  and  $T_2$  are connected to the same point and it was established to be about +0.2 volt when  $T_1$  was conducting. When -0.8 volt is applied to the input of  $T_2$ , this transistor is now forward-biased and conducts. The emitter voltage falls slightly below ground. Since  $T_1$  has a grounded base, it is now reverse biased and cut off. Conduction through  $T_2$  raises the out-of-phase output to -5.2 volts (+P line). At the same time, since  $T_1$  is now cut off, the in-phase output is dropped by the voltage divider to a -6.8 volts (-P line).

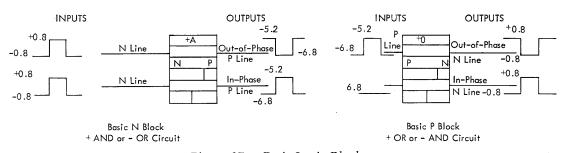


Figure 37. Basic Logic Blocks

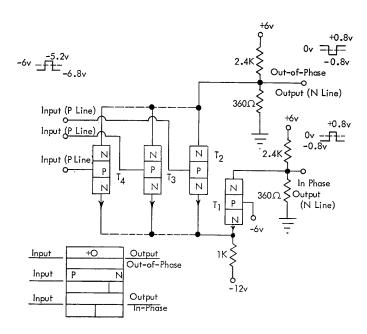
If  $T_3$ ,  $T_4$ , or more transistors are added, they act in parallel with  $T_2$ . All of the inputs must be up to have the in-phase output up. This condition indicates that the circuit is a positive AND circuit. On the other hand, if any one of the inputs is dropped, the in-phase output also drops. This characteristic indicates a negative OR circuit.

#### P BLOCK

The basic P block consists of two P-base transistors in the circuit shown in Figure 39, using only  $T_1$  and  $T_2$ . Disregarding  $T_2$  as a starting point for discussion, the emitter of  $T_1$  is connected to -12 volts through a 1K resistor. The base is at -6.0 volts, so  $T_1$  is forward-biased and conducting. Conduction in this case is through the voltage divider of the in-phase output, dropping the output to -0.8 volt (-N line). The emitter voltage is about -6.2 volts.

By adding  $T_2$  to the circuit and assuming a negative signal input (—6.8 volts), the above condition is maintained because  $T_2$  is reverse-biased and cut off. An out-of-phase output is available now as a result of  $T_2$  and its output voltage divider. This output is established at +0.8 volt (+N line) by the voltage divider.

Raising the input to -5.2 volts (+P line) puts  $T_2$  into conduction and cuts  $T_1$  off because the -5.2 volts at the base forward-biases  $T_2$  and causes increased con-



BASIC P BLOCK CIRCUIT

Figure 39. Basic P-Block Circuit

duction through the 1K resistor, raising the emitter voltage of both transistors to about -5.4 volts. Since  $T_1$  is now cut off and  $T_2$  is conducting, the outputs are reversed. The in-phase output is +0.8 volt (+N line), and the out-of-phase output is -0.8 volt (-N line).

From the above discussion, it is apparent that a plus input gives a plus in-phase output. If only  $T_1$  and  $T_2$  are in the circuit, a —P signal would give a —N in-phase output.

If  $T_3$ ,  $T_4$ , or more transistors were added as shown, any input going positive would give a plus in-phase output. Therefore, this is a positive OR circuit. On the other hand, if all inputs are minus, the in-phase output is minus, making this also a negative AND circuit.

#### CONVERTER, TUBE LEVEL TO CURRENT-SWITCHING LEVEL

This converter is used to convert tube levels (+10, -30 volts) to current switching transistor levels.

Starting with an initial condition of -30 volts at the input to Figure 40, the diode is cut off. The base of  $T_1$  is about -7.0 volts because of the 10K, 33 K voltage divider.  $T_2$  is conducting, and the P output is at -5.2 volts. The N output is at -0.8 volt.

Raising the input to +10 volts causes the diode to conduct, raising the base of  $T_1$  to -5.0 volts. This forward bias causes  $T_1$  to conduct, dropping the collector voltage to -5 volts, which is coupled to  $T_2$  through the 6.8K resistor, causing the voltage at the base of  $T_2$  to drop. Reverse-biasing  $T_2$  cuts it off and the voltage dividers in the outputs establish the N line at +0.8 volt, and the P line at -6.8 volts. Note that the N output is in phase, and the P output is out of phase.

# CONVERTER, CURRENT-SWITCHING P LEVEL TO TUBE LEVEL

THE CONVERTER (Figure 41) is a circuit used to translate P-line current switching transistor levels to inphase tube levels (+10, -30 volts). A -6.8 volts (-P line) will cut off  $T_1$ . This puts the base of  $T_2$  at about +7.0 volts, cutting it off also. The emitter of  $T_3$  under this condition will be at -12 volts, and the base at about -7 volts, so that all three transistors will be cut off and the output will be at about -30 volts.

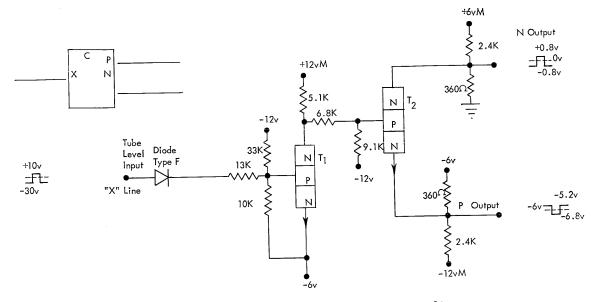


Figure 40. Converter, Tube Level to Current Switching

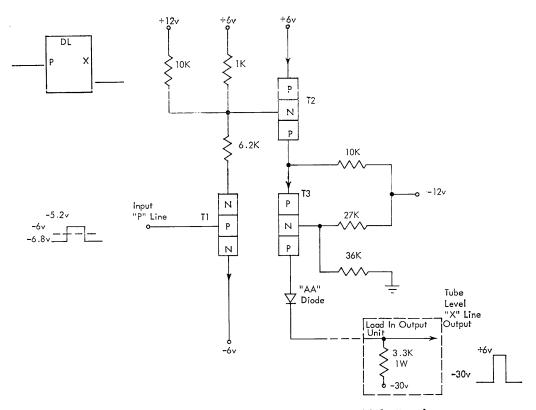


Figure 41. Converter, Current Switching to Tube Level

Raising the input to —5.2 volts (+P line) will put  $T_1$  into conduction, bringing the base of  $T_2$  to about +5 volts, causing it to conduct.  $T_3$  conducts because it now has +5 volts at the emitter and is forward-biased. This conduction puts the plate of the diode into a forward bias, causing it to conduct through the 3.3K resistor, and raising the output voltage to 6 volts. The input to this circuit may be either the in-phase or out-of-phase output from the driving N block.

#### DRIVER RELAY OR DRIVER INDICATOR

THE DRIVER RELAY (DR) or driver indicator (DI) circuit (Figure 42) is used to pick up a relay or light a light. This is actually done by providing a ground connection for either of these devices if a power transistor is put into conduction.

Starting with a -6.8 volt input (-P line),  $T_1$  is cut off. The input to the base of  $T_2$ , the power transistor, is about +6 volts, and  $T_2$  is cut off. This is equivalent to saying that the relay or light has an open circuit.

Raising the input to -5.2 volts (+P line), forward-biases  $T_1$ , causing it to conduct. The base of  $T_2$  goes toward -5 volts through the voltage divider ac-

tion, putting the power transistor into conduction. The resulting current flow picks the relay or lights the light.

The diode, IN92, short-circuits the inductive voltage spike when the field collapses around the relay coil as the power transistor is again cut off.

#### **TRIGGER**

A TRIGGER used in current-switching circuits is illustrated in block form in Figure 43. It consists of a basic +O block and a basic +A block with the in-phase outputs cross-coupled. Only one input is shown to each of the blocks, but this can be increased by adding transistors as in the basic blocks. The name of the trigger is determined by the function it performs; in other words, a plus trigger is one which performs the function described by its name when it has been turned on by a plus input to the P block. On the other hand, a minus trigger is flipped by a negative pulse to the N block, causing the result called for by the trigger name. In either case the trigger is said to be on when performing its named function.

A further definition is that a plus trigger is on when both the N and P in-phase outputs are up and the outof-phase outputs are down. Conversely, a minus trigger

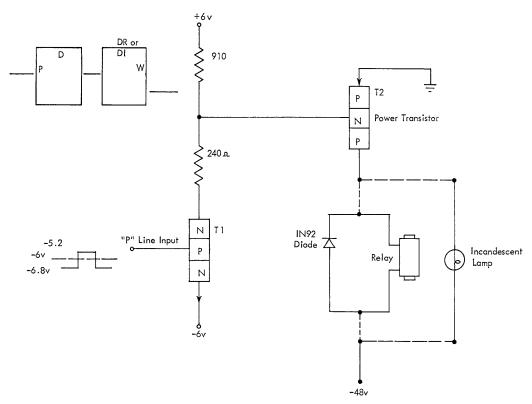


Figure 42. Driver Relay or Driver Indicator

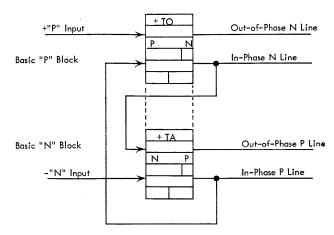


Figure 43. Plus-Set Trigger

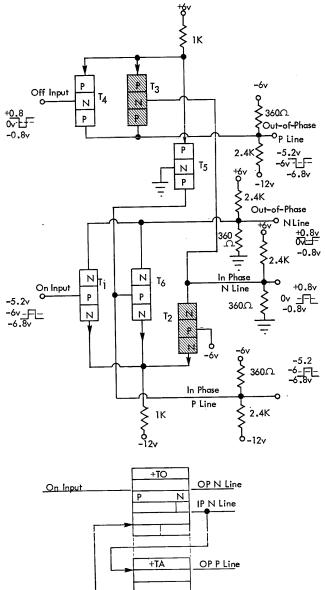
is on when the out-of-phase outputs are up, and the in-phase outputs are down.

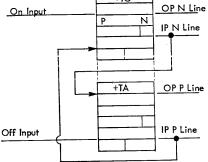
To flip a trigger from one stable state to the other, all inputs must be at their inactive levels; that is, all P lines must be down and all N lines must be up at the time the input signal is received.

Figure 44 is a circuit diagram of a trigger. Assume it is a plus trigger, and that it is in an OFF status. As an initial set of conditions, T2 and T3 will be conducting,  $T_1$ ,  $T_4$ ,  $T_5$ , and  $T_6$  will be cut off. The out-of-phase N and P lines will be up, and the in-phase lines will be down.

If a plus input is now applied to  $T_1$ , causing it to conduct,  $T_2$  is cut off as described in the basic P-block description. The in-phase N output rises. This rise in voltage cuts off  $T_3$  and allows the out-of-phase P output to fall.  $T_5$  conducts, raising the in-phase P output. This is cross-coupled to the base of  $T_6$  putting it into conduction and holding the trigger in the flipped or ON status. Note now that with the trigger on, the in-phase N and P outputs are up.

To turn the trigger back off again, it is necessary to apply a negative pulse to  $T_4$ , putting it into conduction.  $T_5$ is cut off.  $T_6$  is cut off as a result of cross coupling from





DC Input Trigger Figure 44.

 $T_5$ , and  $T_2$  goes into conduction again. The drop in voltage at the output of  $T_2$  is coupled back to hold  $T_3$ in conduction and hold the trigger in the OFF status.

## Complementary Transistor Resistor Logic (CTRL) Circuits

IN THE FIRST transistorized machines to be marketed, circuits were designed from the standpoint of vacuum tube logic. This was the case with the IBM 608, as an example, which illustrates the use of high-specification type 01, 02, 51, and 52 transistors, as well as the conventional components found in the same type of tube circuits, such as capacitors, many different resistors, and diodes.

As the need for additional speed arose in transistor operation, current switching was developed. However, current switching required more transistors, and the cost of such circuits rose accordingly.

Neither of the above systems is the answer to the relatively low-speed, high-production machines used for input-output devices on the larger computers, and other special units and devices. For this reason, still another system is being developed to fill this need. This system is called Complementary Transistor Resistor Logic (CTRL).

Basically the CTRL system consists of blocks employing five resistors and one transistor. The transistors used are the relaxed-specification types 33, 83, 25, and 75, and, therefore, represent a smaller cost. The resistors used are those with five percent tolerance. The basic block provides three inputs, forming an AND or OR circuit input to the transistor, and a single output from the transistor collector, which may be used to drive several other blocks.

Some of the advantages of the CTRL system are:

- 1. It gives excellent performance at minimum cost.
- 2. Good flexibility is provided.
- 3. Two levels of logic are provided in some blocks, without the usual two-block delay.
- 4. The NPN translating circuits and PNP non-translating circuits can be driven from current-switching P lines.
- 5. A resistor network enables translating and nontranslating circuits to drive current-switching circuits.

#### TYPES OF BLOCKS

#### Translating Blocks

The six basic CTRL blocks may be divided into three general groups. In one of these groups, the transistor, NPN or PNP, is biased on and conducts only when all inputs are at zero volts. Dropping one or more inputs to minus 12 volts in the NPN block causes the transistor to be cut off. Raising one or more inputs to +12 volts for the PNP block has the same effect. This block is called the *translating* NPN or *translating* PNP block.

Since the transistor conducts with all inputs at zero volts, the amount of conduction is controlled by the bias resistor and remains constant. Because minority carrier storage is a result of saturation, and saturation a result of the amount of conduction, these can be controlled in this type of block, and the turn-off time is relatively good and constant.

#### Non-Translating Blocks

The second group is made up of the non-translating blocks. In these blocks the transistor is normally biased off when all inputs are at zero volts. When a PNP input drops to minus 12 volts, or an NPN input rises to +12 volts, the transistor is put into conduction. Shifting a second input from the zero-volt level causes additional conduction, and shifting a third input causes still more. The result is varying degrees of conduction depending on the number of inputs, with the accompanying varying degrees of saturation. In this group, the minority carrier storage becomes more of a problem and the turn-off time is slightly longer. Note, however, that the variation in the same type of transistor within tolerance causes more change in turn-on and turn-off times than exists between the translating and non-translating blocks.

The signal voltages required for the translating and non-translating blocks are as follows:

Circuit Title		Inputs		Ou	Logic Block	
	Number	Voltage	Line	Voltage	Line	Symbol
Translating PNP	alļ	0v	-R.	0v,	+S	-A, +0, C
	one or more	+12v	+R	-12v	<b>-</b> S_	
Translating NPN	all	0v	+S	0v	R	+A, -0, C
-	one or more	-12v	<b>-</b> S	+12v	+R	
Non-Translating	all	0v	+S	-12v	-S	+A, -0, I
PNP	one or more	-12v	<b>-</b> S	0v	+S	
Non-Translating	all	0v	-R	+12v	+R	-A, +0, 1
NPN	one or more	+12v	+R	0,	-R	1
PNP Emitter	_	0v	+S	0v	+S	DE
Follower		-12v	<b>-</b> S	-12v	-S	
NPN Emitter		0v	-R	0v	-R	DE
Follower		+12v	+R	+12v	+R	

A = AND O = OR C = Converter

DE= Driver, Emitter Follower

Figure 45. Basic CTRL Information

R line: Up-level is from +5.6 to +12 volts.

Down-level is from 0.0 to +0.2 volts.

The R line voltages will be referred to as zero and

+12 volts.

S line: Up-level is from —0.2 to 0.0 volts.

Down-level is from —5.6 to —12 volts.

The S line voltages will be referred to as 0 and —12 volts.

#### **Emitter Followers**

In addition to the four blocks mentioned, there are also both NPN and PNP emitter followers, which permit branching and additional logic.

The signal voltages for emitter followers are:

R line: Minimum up-level, +6.6 volts. Minimum down-level, +0.2 volts.

S line: Minimum up-level —0.2 volts. Minimum down-level —6.6 volts.

These lines will also be referred to as 0 and  $\pm 12$  volts.

Figure 45 is a table of the six basic CTRL circuits, and the conditions of the inputs to arrive at the various outputs. Note that all outputs, except emitter followers, are inverted, or out of phase with the controlling input or inputs. Also, as the name indicates, the translating circuits in addition to inverting also translate from an R input to an S output, or from an S input to an R output.

#### CIRCUIT DESCRIPTIONS

#### PNP Translating Circuit

The PNP translating circuit (Figure 46), with all inputs at a zero-volt level, forward biases the transistor,  $T_1$ ,

causing it to conduct. The output is then about zero volts. Raising one or more of the input lines to +12 volts will cut off the transistor and allow the output to approach the -12 level.

 $R_1$  is a limiting resistor which maintains a forward bias with the inputs at zero volts and forms a part of the voltage divider to drop the voltage at the base of  $T_1$ when an input rises, causing the transistor to be cut off. The —12M voltage supply can be varied for marginal checking.

 $R_2$  is the collector load resistor.

 $R_3$ ,  $R_4$  and  $R_5$  are input voltage divider resistors.

This circuit performs the logical function of a complemented minus AND circuit, complemented + OR, or inverter translator.

The input is an R line, and the output an S line; therefore, this is a translating block.

Turn-off time is in the range of 0.25 to 2.25 µsec.

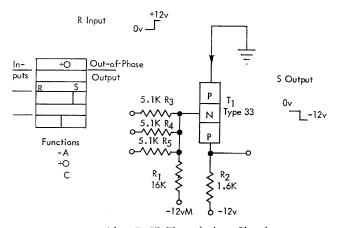


Figure 46. PNP Translating Circuit

#### **NPN Translating Circuit**

The NPN translating circuit (Figure 47), with a starting condition of zero volts on all inputs, forward biases the transistor,  $T_1$ , causing it to conduct and providing an approximately zero volt output. Dropping any one or more of the input lines to -12 volts will cause  $T_1$  to be cut off and allow the output voltage to rise toward +12 volts.

The component functions and operating time are the same for this circuit as for the PNP translating circuit.

Since the input is an S line and the output an R line, this circuit also translates the signal level.

This circuit is used as a complemented plus AND, complemented minus OR, or inverter translator.

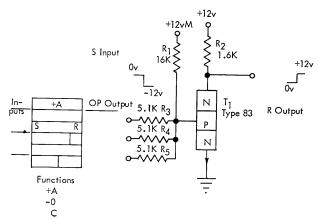


Figure 47. NPN Translating Circuit

#### NPN Non-Translating Circuit

Assuming an initial condition of all inputs at the zero volt level, in Figure 48, the NPN non-translating circuit transistor,  $T_1$ , is cut off. The output under this circumstance approaches the plus 12-volt level.

Raising one or more of the inputs to +12 volts brings the base of  $T_1$  up, causing it to conduct, and dropping the output to 0 volts. Raising a second input to +12 volts will cause increased conduction through  $R_1$  and a higher voltage at the base of  $T_1$ , putting the transistor further into saturation. Raising the third input again increases transistor conduction and the degree of saturation. For this reason the turn-off time of this circuit is greater than that of the two previous circuits. Turn-off time is from 1.0 to 2.8  $\mu$ sec.

With this circuit, both the input and output are R lines.

This circuit can be used as a complemented —AND, complemented +OR or inverter.

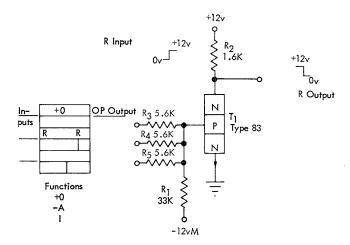


Figure 48. NPN Non-Translating Circuit

#### PNP Non-Translating Circuit

The PNP non-translating circuit (Figure 49) performs the functional purpose of a complemented plus AND, complemented —OR, or inverter.

With all inputs at a zero volt level,  $T_1$  is cut off and the output is about -12 volts. If one or more of the inputs drops to the -12 volt level,  $T_1$  conducts, raising the output voltage toward ground. Each additional input causes additional saturation and extended turn-off time, as explained for the NPN inverter.

Both the input and output of this block are S lines. The block output is inverted from the input.

Turn-off time is comparable to that of the NPN non-translating circuit.

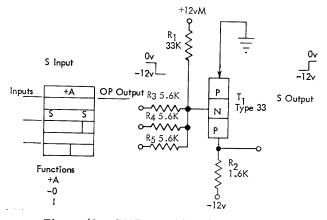
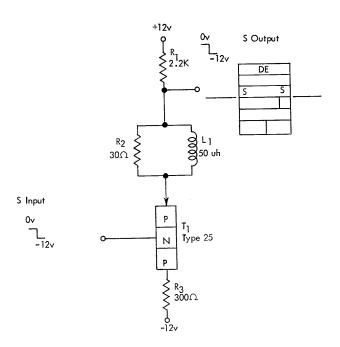


Figure 49. PNP Non-Translating Circuit

36

#### **Emitter Followers**

Emitter followers are used at the output of translating and non-translating blocks. They provide for branching circuits and additional logic. More than one emitter follower of the same type may use the same emitter load resistor.



PNP EMITTER FOLLOWER

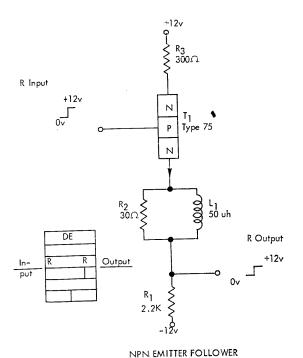


Figure 50, Emitter Followers

The PNP emitter follower illustrated in Figure 50 may be used at the output of the PNP translating circuit or the PNP non-translating circuit. The output will be in phase with the input, and differ in voltage the amount of the emitter-base diode drop, which will be from 0.2 to 0.4 volt. Five inverter or CTRL blocks may be driven by each emitter follower. An emitter follower may *not* drive another emitter follower.

 $R_1$  is the load resistor.

 $R_2$  and  $L_1$  are stabilizing components.

 $R_3$  is a power dissipating resistor used to prevent excess reverse bias between collector and base when the input is at zero level.

The NPN emitter follower may be used at the output of the NPN translating circuit or the NPN non-translating circuit. For a description of the circuit, see the PNP emitter follower.

Figure 51 illustrates some of the circuits which can serve as inputs to the various blocks, as well as the circuits which can be driven from these blocks.

#### LOGIC PRESENTATION

CONSIDERABLE effort is being directed toward making all types of circuits compatible from a logic block or systems page standpoint. For this reason, CTRL logic blocks will be the same as were shown for current switching circuits except for the labeling of the input and output lines. By using this method of logic presentation it is possible to follow logic through systems pages with a minimum of effort, regardless of the type of circuit being used. It is only necessary to refer to the line symbol, and its voltage value, if checking out the machine itself. As long as logic standardization is followed, it is no problem to go from CTRL to current switching or back to CTRL on the same page.

Current switching lines were labeled N and P. The CTRL lines will be R and S, as explained previously. It will also be noted that all CTRL blocks except emitter followers will have only an out-of-phase output. Since the single output of either the translating or non-translating block is always inverted, or out of phase, from the controlling input or inputs, it is impossible to have an in-phase output.

Referring to Figure 52, note that the translating PNP logic block serves the function of a complemented minus AND circuit since all three inputs must be —R lines to have a | S line output. This is also equivalent to call-

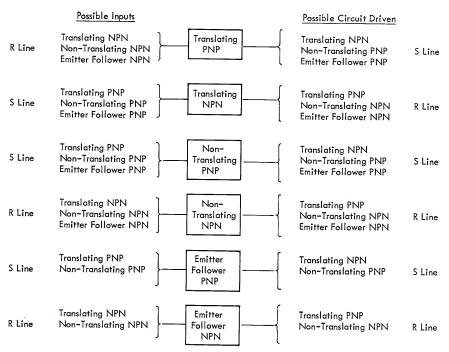


Figure 51. Possible Inputs and Outputs

ing it a complemented +OR circuit because if any one or more of the inputs are +R lines the output will be a -S line.

If only one input were used, this block would serve as a converter, where an R line input would be translated to an out of phase S line output.

The translating NPN logic block serves as a complemented + AND circuit where all + S line inputs will cause a -R line output. This circuit, then, could also be called a complemented minus or circuit, because if one or more input S lines goes negative it will give a + R line output.

With this block also, a single S line input would give an out-of-phase R line output and act as a converter.

The non-translating PNP block serves the function of a complemented +AND circuit, where, again, all inputs must be +S lines to get a —S line output. This could be called a complemented —OR circuit also, since any one or more inputs of —S would give a +S output. By using a single input only, this circuit becomes an inverter.

The non-translating NPN circuit provides the logical function of a complemented + OR because any +R line input gives a —R output. All —R line inputs provide a complemented —AND function. A single input would cause this circuit to act as an inverter.

#### **DOT Functions**

Under certain conditions, R or S outputs of a similar level from logical blocks can be tied together, sharing a common collector load. This provides the second level of logic in some circuits within one block of delay. The first level is provided by the resistor AND or OR input to the transistor.

#### S-Line Rule

The S line outputs from two or more logical blocks tied together result in a +OR or a —AND. A +S condition on either line will make the output of the DOT +S. Only a —S on both lines will make the output of the DOT —S. See Figure 53.

#### R-Line Rule

Two R-line outputs from two or more logical blocks tied together result in a +AND or a -OR. (A -R on either line will make the output of the DOT -R; a +R on both, and both alone, will make the output of the DOT +R.) See Figure 54.

#### **DOT Function Use**

The use of the DOT function with different blocks falls into three general categories:

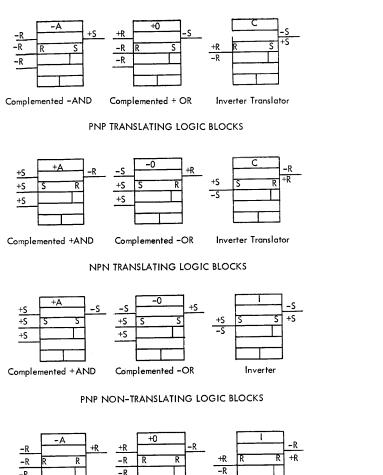


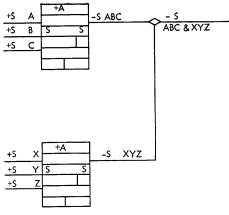
Figure 52. CTRL Logic Blocks

Complemented +OR

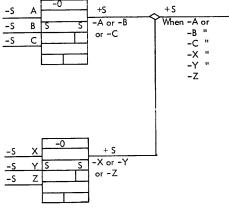
NPN NON-TRANSLATING LOGIC BLOCKS

Complemented -AND

- 1. Providing Greater than Three Input AND and OR Circuits. Since up to six collectors can be tied in parallel, 18-way AND and OR circuits can be made using blocks and the DOT function as in Figures 53 and 54. However, when showing this in systems diagrams, only the block with the collector load resistor will contain the A or the O. The other blocks will be considered as extenders, and the actual DOT of the outputs will not be shown. The E block is identical to the regular logical block, except that it has no collector load. The actual system representation will be as in Figure 55.
- 2. Creating AND-to-OR and OR-to-AND Functions. If the output of two OR circuits are to be AND'ed (OR to AND) or the output of two AND circuits OR'ed (AND to OR), this can in cases be done with a DOT function (Fig-



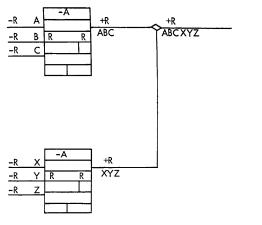
DOT - A FUNCTION



DOT + O FUNCTION

Figure 53. DOT Function, S Lines

- ure 56). In systems diagrams this should be shown as in Figure 57. In this representation, the O after the —A indicates the function produced by tying the outputs together. The sign of the DOT will not be shown, but will always be understood to be opposite the sign of the first symbol; i.e., in Figure 57 a +O.
- 3. Using DOT Function on Outputs of Non-homogeneous Blocks (Not both AND or OR), or Emitter Followers. The remaining combinations of the DOT functions that are available are shown in Figure 58 and will be represented as shown in Figure 59. However, in the case of emitter follower DOT functions, a sign will be used with the DO or DA to indicate a plus or minus function; i.e., +DA, —DO, and so on, as in Figure 59.



DOT + A FUNCTION

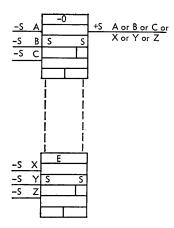


Figure 55. Systems Representation of DOT Function

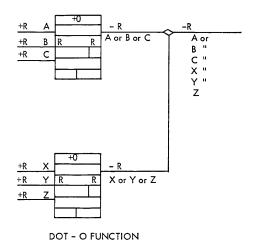


Figure 54. DOT Function, R Lines

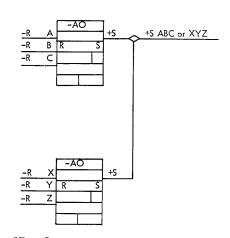


Figure 57. Systems Representation of AND to OR

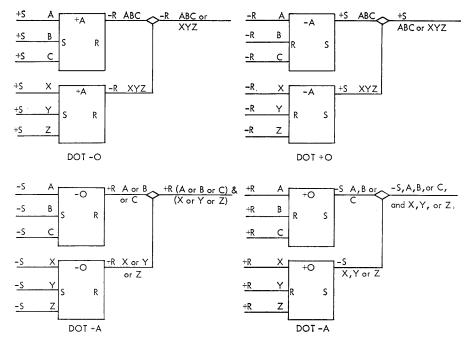


Figure 56. AND to OR, OR to AND Functions

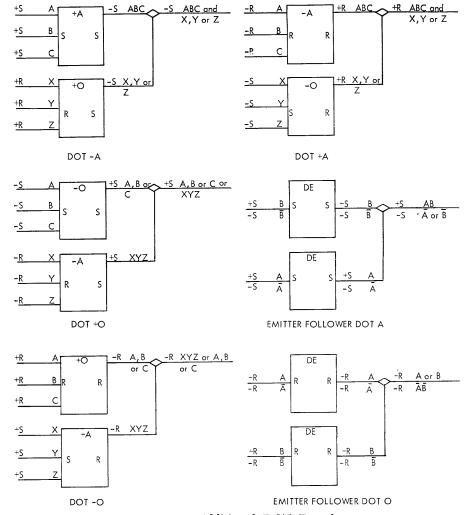


Figure 58. Additional DOT Functions

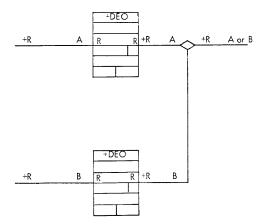


Figure 59. Systems Representation of Additional DOT Function

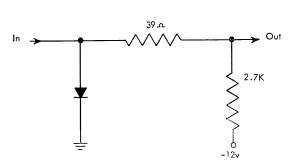


Figure 60. N-Block Current Switching to CTRL S Line

#### **LOADS**

#### Converting Loads

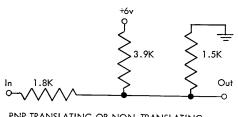
Several circuits are provided as special converting loads for converting from current switching to CTRL and from CTRL to current switching. These loads will take the place of the collector load (from N-block current switching to the CTRL S line, Figure 60) or connect directly to the standard output in the other cases shown (Figure 61).

#### Current Switching to CTRL

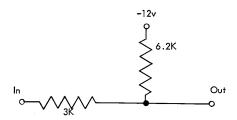
For this conversion, the load used appears as shown in Figure 60. This circuit can take only the output of current switching N block (P line) and will convert the level to a +8 or -8 level (0 volts or -12 volts) for CTRL circuits. With the current-switching transistor conducting 6 ma, the output will be clamped at 0 volts. With the transistor cut off, the output approaches -12 volts.

#### CTRL to Current Switching

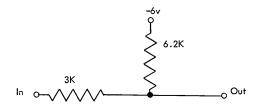
For converting from CTRL to current switching, a purely resistive load will be used, which will be able to take an R or S line from CTRL and convert it to the corresponding line in current switching. See Figure 61.



PNP TRANSLATING OR NON-TRANSLATING CTRL TO N BLOCK CURRENT SWITCHING



PNP TRANSLATING OR NON-TRANSLATING CTRL TO P BLOCK CURRENT SWITCHING



NPN TRANSLATING OR NON-TRANSLATING
CTRL TO N BLOCK CURRENT SWITCHING
Figure 61 Conserting Loads

Figure 61. Converting Loads, CTRL to Current Switching

## Appendix 1. Table of Elements

			(2)	(8)	(18)	(32)	(50)				(2)	(8)	(18)	(32)	(50)	(72) (	(98)
			K	L		N	0				K	L	M	Ν	0	Р	Q.
1	Hydrogen	Н	1				×	52	Tellurium	Te	2	8	18	18	6	42	
2	Helium	He	2					53	lodine	1	0	н	ù	11	7		
3	Lithium	Li ·	11	1				54	Xenon	Хe	n	11	11	11	8		
4	Beryllium	Be	11	2				55	Cesium	Cs	n	11	11	п	8	1	
5	Boron	В	t)	3				56	Barium	Ва	t1	n	11	11	8	2	
6	Carbon	С	11	4				57	Lanthanum	La	11	п	13	11	9	11	
7	Nitrogen	Ν	u	5				58	Cerium	Ce	n	u	0	20	.8	11	
8	Oxygen	0	11	6				59	Praseodymium	Pr	11	0	11	21	8	11	
9	Fluorine	F	11	7				60	Neodymium	Nd	11	0	n	22	8	11	
10	Neon	Ne	u	8				61	Promethium	Pm		11	u	23	8	n	
11	Sodium	Na	11	11	1			62	Samarium	Sm	11	11	u	24	8	11	
12	Magnesium	Mg	u	н	2			63	Europium	Eυ	ш	u	11	25	8	11	
13	Aluminum	Al	11	п	3			64	•	Gd	и	11	11	25	9	u	
14	Silicon	Si	11	11	4			65	Terbium	Tb	11	11	11	26	9	n	
15	Phosphorus	P	11	п	5			66	Dysprosium	Dy	п	н	п	28	8	11	
16	Sulfur	Ś	u	11	6			67	Holmium	Ho	n	н	u	29	8	u	
17	Cholorine	CI	u	п	7			68	Erbium	Er	11		11	30	8	11	
18	Argon	A	11	n	8			69	Thulium	Tm	н	n	n	31	8	11	
19	Potassium	ĸ	11	11	8	1		70	Ytterbium	Yb	11	n	11	32	8	11	
20	Calcium	Ca	н	н	8	2		71	Lutetium	Lu	11	11	u	32	9	u	
21	Scandium	Sc	n	п	9	2		72	Hafnium	Hf	n	n	u	11	10	**	
22	Titanium	Ti	11	11	10	2		73	Tantalum	Τα	n	11	11	n	11	n	
		V	11	11	11	2		74	Tungsten	W	11	n	11	u	12	tı	
	Vanadium	V Cr	11	11	13	1		75	Rhenium	Re	n	ti	n	n	13	11	
24	Chromium	Mn	n	В	13	2		76	Osmium	Os	11	11	n	11	14	11	
25	Manganese		п	n	14	2		77	Iridium	lr	11	11	11	п	15	п	
26	Iron	Fe Co	11	n	15	2		78	Platinum	Pt	п	п	п	u	17	1	
27	Cobalt							70 79	Gold	Au		11	11	11	18	(I)	all
28	Nickel	Ni	11	n	16	2			Contract of the last of the la	Hg	11	11	11	11	11	-12	
29	Copper	Cu	11		18	1			Mercury Thallium	TI	n	n	11	u	- 11	3	
30	Zinc	Zn		n	n	2		81		Pb	п	11		11	0	4	
31	Gallium	Ga			11	3			Lead	Pb Bi	u			u	11	5	
32		Ge		11		4		83	Bismuth	Po	11	11		0		6	
	Arsenic	As		11	"	5		84	Polonium		11	11	u	0		7	
	Selenium	Se	11	"	tı	6		85	Astatine	At	11		11	0	11	8	
35	Bromine	Br				7		86	Radon	Rn	11	u	u	0	13	8	1
	Krypton	Kr	11	n	11	8		87	Francium	Fr Ra		11	11	11	u	8	2
37		RЬ	11	11	ur ur	8	1	88	Radium	Ac	ш	11	11	- 11	11	9	11
38		Sr				8	2	89	Actinium		п	11	п	11	0	10	11
39		Υ		n	"	9	2	90	Thorium	Th	11	11	п	11	20	9	п
40	Zirconium	Zr	11	"	"	10	2	91	Protactinium	Pa	11			ш	21	9	13
41	Niobium	Νb	11	n	п	12	1	92	Uranium	U	11	11	0	11	23	8	11
42	Molybdenum	Мо	11	11	u	13	1	93	Neptunium	Np	11	11	11	11		8	u
43	Technetium	Тс	11	11	11	13	2	94	Plutonium	Pu	11	11	11	11	24		11
44	Ruthenium	Rυ	11	0	11	15	1	95		Am	11	"	" "		25	8	n
45	Rhodium	Rh	ii.	11	11	16	1	96	Curiùm	Cm	11	11	11	n	25	9	
46	Palladium	Pd	II.	11	III	18		97	Berkelium	Bk					25	10	11
47	Silver	Ag	ii.	11	11	18		_ 98	Californium	Cf	11	"	11	"	27	9	"
48		Cd	11	11	11	18	2	99	Einsteinium	Ε	п	и	11	n 	28	9	11
49		In	11	ŧ	n	18	3	100	Fermium	Fm	п	11	11		29	"	
50			II.	п	11	18	4	101	Mendelevium	Md	11	H,	11	п	30	11	11
	lin	Sn				, 0	•		111011001011								
51	Tin Antimony	Sh Sb	11	11	u	18	5	102		No	11	11	11	11	31	11	п

## Appendix 2. IBM Transistor Specifications and Types

VARIATIONS in materials, geometry, and construction result in transistors with widely varying parameters. Transistors are assigned type numbers depending on the specified parameters which must fall within given limits. A two-digit numerical series starting with 01 is assigned to all PNP transistors; a similar two-digit series starting with 51 is used for NPN varieties.

#### TRANSISTOR PARAMETERS

Collector Cut-Off Current,  $I_{cbo}$ . The emitter is open circuited and a reverse voltage is applied to the collector-base junction. Maximum collector current is specified in microamperes.

Collector Cut-off Current with Reverse-Biased Emitter,  $I_{cbo}$ \*. With the base common, and the emitter and collector junctions both reverse-biased, the reverse collector current cannot exceed a specified limit. This reverse-biased transistor current should be no more than  $I_{cbo}$ .

Emitter Cut-Off Current, I<sub>ebo</sub>. The collector is opencircuited and a reverse voltage is applied to the emitterbase junction. Maximum emitter current is specified in microamperes.

Collector Breakdown Voltage, BV<sub>cbo</sub>. Collector breakdown voltage is determined by passing a controlled amount of reverse current through the collector-base junction and measuring the collector voltage drop. The emitter is open-circuited for this test.

Emitter Breakdown Voltage, BV<sub>ebo</sub>. Emitter breakdown voltage is determined by passing a controlled amount of reverse current through the emitter-base

junction and measuring the emitter voltage drop. The collector is open-circuited for this test.

Punch-through Voltage,  $V_{pt}$ . A specified reverse collector-to-base voltage is applied and the emitter-to-base voltage should fall within an established upper limit.

Current Ratio, Common Emitter,  $\alpha_{fe}$ . Collector current is measured at specified values of base current and collector voltage to establish a minimum current ratio for the transistor.

Collector-to-Emitter Saturation Voltage,  $V_{ce}$ . Sufficient collector voltage and base current are supplied to drive the transistor into saturation. At this point, the impedance of the transistor becomes very low and is measured as a low-voltage drop across the emitter-collector terminals. A maximum voltage, in the order of tenths of a volt, is specified for this parameter.

Base-to-Emitter Saturation Voltage,  $V_{be}$ . This measurement is made under the same conditions as the  $V_{ce}$  test.

Common Emitter Turn-on Time,  $T_{on}$ . Turn-on time is measured as the interval of time between the 10% point of an input pulse and the point at which the output pulse reaches a specified voltage level. A particular circuit and condition are used to determine this turn-on parameter.

Alpha Cut-Off Frequency. Alpha cut-off frequency is the frequency at which the magnitude of the small signal common base current ratio  $(\alpha_{fe})$ , has fallen to .707 of its low-frequency value.

K Factor. The ratio of the temperature rise at the junction to the power dissipated by the transistor is called the K factor. Low K-factor units dissipate more

	·			I <sub>C</sub> Ma 55	×. PC	I <sub>EBC</sub> Max 55°			CBO in.	B∨ <sub>E</sub> Mi 55°		U_	1	FE*	n)	fion s)	ion s)	×		U		ion
Туре	Part #	Usage	Machine	na	@ V <sub>C</sub> Volts	ηα	@ V <sub>E</sub>	Volts	@ IC ma	Voʻlts	@ le ma	VpT @ 25°	I <sub>E</sub> (ma)	Min	Max	V <sub>CE</sub> (Saturation Volts)	V <sub>BE</sub> (Saturation Volts)	<sup>†</sup> ON (us) Max	K Factor	Pwr Dis (MW @ 55º	f αζ <sup>°</sup> (ΜC)	VEB (Saturation Volts)
		PNP Transistors																				
01	345741	Voltage Mode Trigger	608	32	5	32	5	20	.07	20	.070		5.0	50	300	.2	.3	0.2	.4	35	5	
02	345742	Voltage Mode E.F.	608	32	5	32	5	20	.07	20	.070		5.0	50	300		.25	0.5	.4	35	5	
		Voltage Mode Neon Driver	608	70	45	60	45	60	. 10	60	.100					0.5	0.3		.4	35		
04	345744	Voltage Mode Line Driver	608	32	5	32	5	20	.07	20	.070	15				.222	.348	0.2	4	35	5	
	0.457.45	C . A 1+C	608 738	00	_	32	_	20	07	20	.070	1.5	5.0	50	300				.4	35	5	
		Sense Amplifier		32	5 50	32 1ma	5 20	20 75	2.5		2.5	60	5.0	30	300	.555		75	.003		.5	
		Relay Driver, 48v	608	1ma 32	5	32	5	20	.07	20	.070			_		.2	.3	.1-1.0	.2	55	5	
13	344892	100KC Current Switching Ckts	100	32	_3	32	Э	20	.07	20	.0/0	13		<del> </del>	1	.2	.3	.1-1.0	- • 4	- 33	J	
1,,	0.45740	N D: 45	6 08 729	75	40	32	5	45	.10	20	.100	45	İ	1		.3 .	.3		.4	35		
		Neon Driver, 45v Drift-Current Switching	129	42	5	_32		20	.40	2.8		20	1		33	1.0	.3		.2	35	70	.2232
13	326/9/	Drift-Current Switching		42	2			20	.40	2.0	.04	20	8		40.0	1.0			• 4	33	/ 0	.2202
16	526880	Drift-Current Switching		42	5			20	.40	1.8	.04	20	1	i	33	1.0			.2	35	70	.2232
ļ		Jan 1											8		40							
					25°c				25°c		25°c											. 1
17	526882	Drift-Development Use Only		7	5			20	.05	1.5			1.0		50				.2		70_	.235
20	526795	25v Line Driver	729	32	5	32	-5	30	.07	20	.07	25				.2	.3	1.2	.2	55	4	
21		Read-Write Driver	729	32	5	32	5	30	.07	20	.07	25	<u>i</u>			.4	.4	.6	.35	55	5	
22		Power Transistor	729	2.5m		2ma		70	12 -	30	12	60	i			1.0	1.0	75		5 50W		
23		Relay Driver, 48v	729	1 ma	50	lma		75	2.5	50	2.5	60				.75		75	.003		.5	
24	362090	Relay Driver, 20v	608	lma	20	1 ma	20	45_	2.5	30	2.5	40				.6	.75	50	.003	Spec	5	
		NPN Transistors																				
51	345747	5v Trigger	608	32	5	32	5	20	.07	20	.07	15		50	300	.2	.3	0.2	.4	35	5	
52		Voltage Mode E.F.	608	32	5	32	5	20	.07	20	.07	15	5	50	300		.25	0.5	.4	35	5	
54		Voltage Mode Line Driver	608	32	5	32	5	20	.07	20	.07	15				. 1922	.2738	0.2	.4	35	5	
57	345750		608	32	5	32	5	20	.07	20	.07	15	1			.3	.65	0.5	4	35		
63		100KC Current Switching		32	5	32	5	20	.07	20	.07	15		<u> </u>	ļ	.2	.3	.1-1.0	.2	55	5	
65	526798	Drift-Current Switching		42	5			20	.4	2.8	.04	20	1 8		33 40	1.0			.2	35	70	.2232
			1										1		33							
		Drift-Current Switching	ļ	42	5			20	.4	1.8	.04	20	8	<u></u>	40	1.0			.2	35	70	.2232
67	526883	Drift-Development Use Only	<u> </u>	7	5			20	.05	1.5	.003		11	<u> </u>	50						70	.235

heat than do units with higher K factors; therefore, they have smaller effects on  $I_{cbo}$ . Typical IBM transistors have a K factor range between .2 and .8.

#### IBM TRANSISTOR TYPES

Type 01/51 PNP-NPN. These are saturating types of transistors specified for the IBM 608 voltage-mode circuits and used in trigger, inverter, and level-setter circuits. These transistors have a minority carrier storage  $(V_{st})$  test, which none of the others must meet. This parameter, plus the minimum  $\alpha'$  of 50, makes these transistors difficult and expensive to produce.

Type 02/52 PNP-NPN. These are similar to the 01/51 devices except for somewhat relaxed specifications;  $V_{st}$  is not specified here. These transistors are used in emitter-follower circuits where they are never driven into saturation. Types 01/51 may be used in circuits calling for 02/52 units; however, 02/52 transistors may not be used in circuits calling for 01/51 units.

Type 03 PNP 60-Volt Neon Driver. The predominant characteristic of this transistor is its high punchthrough voltage (60 volts). It is used to drive neon indicators.

Type 04/54 PNP-NPN. Specifications for these transistors are the same as for the 01/51, except that the collector current is measured at the higher values of 10 and 50 ma. These types are used in line driver and power inverter voltage mode circuits.

Type 06 PNP. Specifications for this transistor are the same as for the type 01, but an additional performance test is made to simulate its application as a sense amplifier to detect and amplify small magnetic core impulses.

Types 12/23/24 PNP. The 12 and 23 are power devices designed to drive 48-volt relays. The problems of stability and cost of the types 12 and 23 units, along with a low-voltage approach to relays, brought about the type 24 transistor. It is used for driving the IBM 608 20-volt relays.

Types 13/63 PNP - NPN. These transistors are used in alloy-junction current switching circuits.

Type 14 PNP. This is the 45-volt neon driver transistor used in the standard indicator circuit.

Type 15/65 PNP-NPN. These are drift-type transistors used in high speed current switching, non-saturating circuits.  $BV_{ebo}$  is equal to, or greater than, 2.5 volts for these units.

Type 16/66 PNP-NPN. These are drift-type transistors used in high-speed current switching, non-saturating circuits.  $BV_{ebo}$  is equal to, or greater than, 1.5 volts for these units.

Type 20 PNP. These are similar to type 13 with  $BV_{cbo}$  equal to, or greater than 25 volts.

Type 21 PNP. This device is used in the magnetic head driver in the IBM 729 Tape Unit. This unit has a

fast turn-on specification at collector currents equal to 60 ma.

Type 22 PNP. This is a power transistor. It is used in the IBM 729 Tape Unit.

Type 25/33 PNP 75/83 NPN. These are the general purpose transistors which will be used in most alloy junction applications. Type 33 can be used in place of type 25, and type 83 can be used in place of type 75 in most applications. However, types 25 and 75 cannot be substituted for types 33 and 83.

Circuit refinements and cost reduction cause constant changing of both the transistor types and individual parameters under the various types. For this reason, the material presented is correct insofar as possible at a certain level. Changes after that level, of course, will be covered later.

Туре	Part #	Usage	I <sub>ce</sub> MA 55°		I <sub>be</sub> MA 55'	X	BVcbo	Vpt	V <sub>ce</sub>	$V_{be}$	t <sub>on</sub>	К	fac
		PNP Transistors											
25	318322	Alloy Current Sw & Ctrl	35	16	30	.2	16	16	.2	.3	.1-1.5	.2	4
					35	6							
_ 33	318324	Alloy Current Sw & Ctrl	30	25	26	.2	25	25	.23	.348	.1-1.0	.2	4
					30	10							
		NPN Transistors											
75	318323	Alloy Current Sw & Ctrl	45	16	36	.2	16	16	.2	.335	.1-1.2	.2	4
<u>_</u> _					45	6							
83	318325	Alloy Current Sw & Ctrl	36	20	32	.2	20	20	.23	.345	.18	.2	5
					36	10							

## Appendix 3. Voltage Levels and Symbols

FIGURE 62 is a table indicating the symbols used for the various line voltages used in this manual.

Circuit	Ref	Plus	Minus	Line
	Voltage	Voltage	Voltage	Symbol
Current Switching Current Switching CTRL CTRL Relay Tube	0 -6	+0.8 -5.2 +12.0 0.0 0.0 +10.0	-0.8 -6.8 0.0 -12.0 -48.0 -30.0	± N ± P ± R ± S ± W X

Figure 62. Reference Voltages and Signal Levels