NORTHERN ALBERTA INSTITUTE OF TECHNOLOGY

EDMONTON ALBERTA

ELECTRONICS DEPARTMENT

An example of heat sinking might be connecting the diode thermally to the chassis or to some type of radiating element. Low power diodes, switching diodes, etc., do not normally use an external heat sink, and the typical thermal resistance might be on the order of 250° centigrade per watt. Rectifier diodes and diodes designed to handle more power might be mounted in an encapsulation that has a heavy stud which can be protruded through the chassis and bolted down tight. This allows the chassis to aid in radiating the heat generated at the junction to the surrounding air. It is possible using external heat sinking to reduce the total thermal resistance down to a few degrees centigrade per watt.

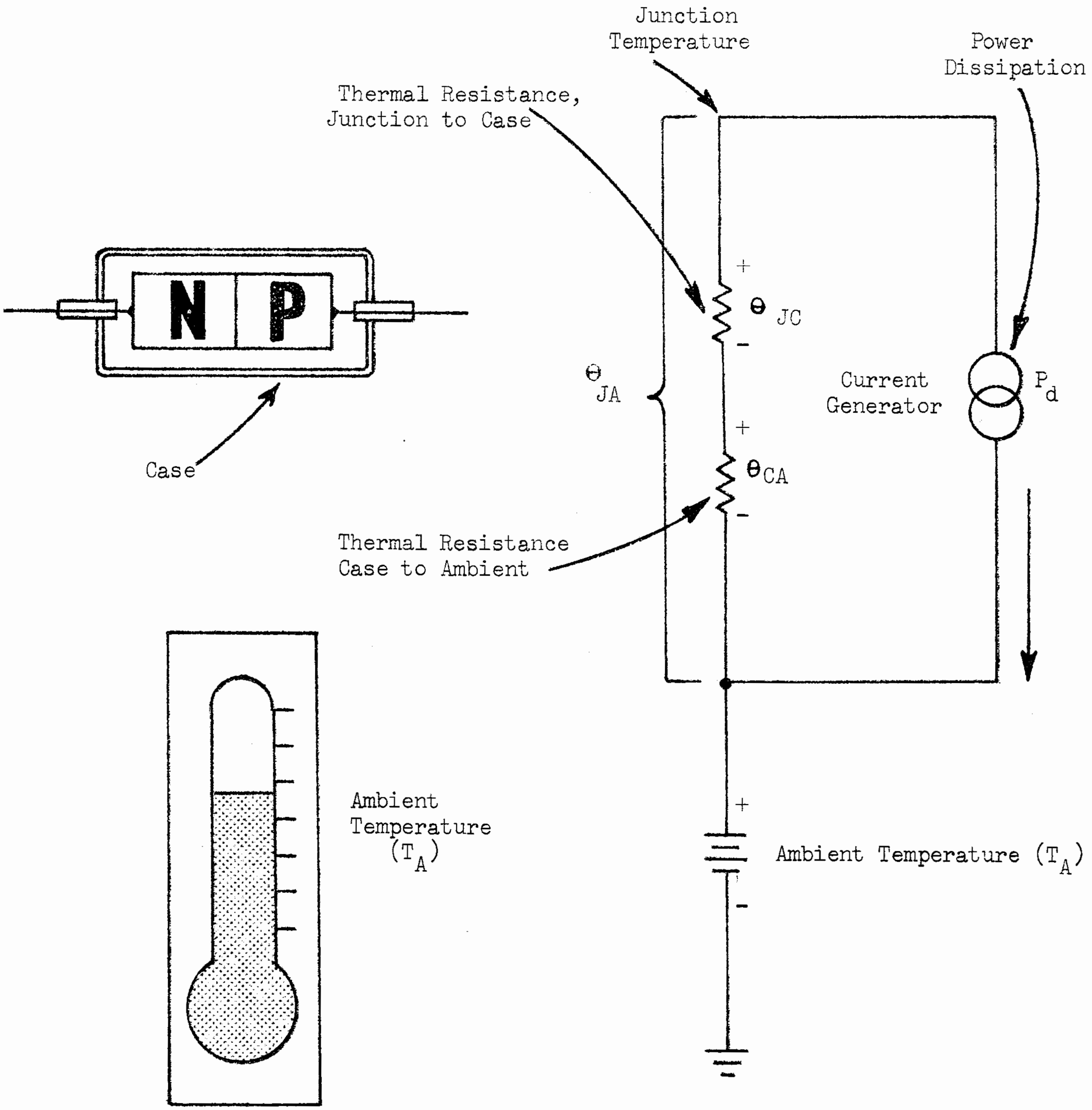
Figure 1 shows the analogical association of electrical and thermal characteristics of a PN junction. A model is shown of the diode in its case in Figure 1, and no external heat sinking is being used. The predominate thermal resistances involved are the thermal resistance between the junction and the case and the thermal resistance between the case and the surrounding air; in other words, the opposition offered in the transfer of heat from the junction to the case or encapsulation and the opposition offered to heat transfer from the case to the surrounding air. The sum of the two predominate thermal resistances will give the total thermal resistance from junction to ambient. Note that thermal resistance is related analogically to electrical resistance, while ambient temperature is related analogically to electrical voltage, and power dissipation is related analogically to electrical current. Once these associations have been made, Ohm's Law may be used in solving for junction termperature, or maximum power dissipation, etc.

Since the voltage rises across the thermal resistances are aiding in polarity to the ambient temperature, the junction temperature, measured from the point shown in Figure 1 will be some voltage greater than the ambient temperature. Since power dissipation is related to an electrical current, the product of this current and the thermal resistances gives the voltage drops across the thermal resistances in the analogy. Therefore, the product of power dissipation and thermal resistance will give the voltage (or temperature rise) at the junction. This, added to the ambient temperature, will give the junction temperature. Expressing this as a formula gives:

$$T_J = \theta_{JC} P_d = \theta_{CA} P_d + T_A$$

where T_J is the junction temperature, P_d is power dissipation, θ_{JC} is the thermal resistance junction to case, θ_{CA} is the thermal resistance case to ambient, and T_A is the ambient temperature. It is well to remember that these formulas are possible as a result of relating the thermal characteristics to electrical characteristics and using Ohm's Law. The formula for the maximum power dissipation for a given ambient temperature and thermal resistance is simply the allowable change in junction temperature divided by the thermal resistance, or in formula form:

$$P_{max} = \frac{\Delta T_J \text{ allowable}}{\theta_{JC} \mp \theta_{CA}} = \frac{T_{Jmax} - T_A}{\theta_{JA}}$$



Junction Power Dissipation = Current
Opposition to Heat Transfer = Resistance
Ambient Temperature = Voltage
Junction Temperature = Voltage

Analogical Association of Electrical
and Thermal Characteristics

Figure 1

As an example, consider a PN junction diode that has a maximum operating junction temperature of 100° centigrade and the ambient temperature is 50° centigrade. In this case, the total allowable change in junction temperature due to dissipating power is the difference in these two temperatures, or 50° centigrade. If the thermal resistance is 250° centigrade per watt, the maximum power dissipation is o.2 watts, or 200 milliwatts. Notice that we did nothing more than divide the change in ° centigrade per watt that would occur at the junction into the allowable change in junction temperature, and this gave us the maximum power dissipation of the junction.

Let's take another example, only this time let's determine how many ° centigrade above the ambient temperature the junction is existing. A diode has a total thermal resistance of 25° centigrade per watt and is dissipating two watts of power. What is the junction temperature if the ambient temperature is 25° centigrade? In this case, the rise in junction temperature is simply the product of the thermal resistance and the power dissipation at the junction. Two watts of power times 25° centigrade per watt indicates that the junction will be 50° centigrade above the surrounding air. Since we have stated that the surrounding air is at 25° centigrade, we would expect the measure 75° centigrade at the junction. Looking at the same problem, if we had the ability to make temperature measurements at the junction and of the surrounding air, we can certainly determine the thermal resistance of the device. Considering the previous problem where the surrounding air temperature was 25° centigrade and the junction temperature was 75° centigrade we can see that the product of junction current and voltage would give the amount of power we were dissipating; in this case, two watts. Dividing two watts into the rise in junction temperature above ambient would give us the number of degrees centigrade per watt, or the thermal resistance of the junction; in this case 25° centigrade per watt. The association of the thermal characteristics has simply given us a convenient set of tools to work with in dealing with thermal characteristics. We are able to use the basic theorems that apply to electrical characteristics and calculate the thermal characteristics of the semiconductor junction.

When an external heat sink is used to reduce the total thermal resistance junction to ambient, the rather large thermal resistance case to ambient is shunted by a much smaller thermal resistance. Thermal resistance case to heat sink and heat sink to ambient will shunt thermal resistance case to ambient and will have a much smaller value.

Figure 2 shows the thermal to electrical analogy when an external heat sink is used. In this case, a diode with a stud that allows it to be connected thermally to the chassis or some external heat sink with a large radiating surface is used. If it is necessary to isolate the semiconductor junction electrically from the heat sink, a separate electrical insulator must be used between the diode and the external heat sink. When this is the case, the electrical insulator must have a low thermal resistance, or we can say it must have good thermal conducting characteristics. Note in Figure 2 that the thermal resistance case to heat sink and heat sink to ambient has replaced thermal resistance case to ambient. Ambient temperature is still related analogically to a voltage, and thermal resistance is related analogically to electrical resistance. The junction temperature is related analogically to a voltage, and power dissipation to a current. Therefore, the analogy remains the same as previously discussed, and the product of the power dissipation and the thermal resistance will give the rise in junction temperature above ambient temperature.

Note in Figure 2 that even if the thermal resistance of the heat sink and the connection of the diode to the heat sink were zero, the power dissipation is limited by the thermal resistance junction to case. Junction temperature will always be greater than ambient temperature by the product of power dissipation and the inherent thermal resistance. Thermal resistance junction to case is determined by the semiconductor device in its encapsulation. Thermal resistance heat sink to ambient is determined by the radiating surface of the heat sink, and thermal resistance case to heat sink is set by the thermal connection between the device and the heat sink. If no electrical insulator is needed, the case of the diode can be connected directly to the heat sink. The chart at the bottom of Figure 2 indicates some typical thermal resistances case to heat sink for direct connection and for several types of insulating washers. When no insulating washer is needed and the case is connected directly to the heat sink, the typical thermal resistance is in the order of 0.2^{o} centigrade per watt. Note in the chart at the bottom of Figure 2 that when silicon lubrican is added, the thermal resistance is reduced to 0.1^{o} centigrade per watt. Silicon lubricant is made available by several manufacturers and, when applied to the insulating washer or between the semiconductor device and its heat sink, reduces the thermal resistance. Reducing the thermal resistance case to heat sink, of course, reduces total thermal resistance and allows a higher power dissipation for a given ambient temperature. The silicon lubricant has good heat conducting properties and fills in the gaps between the semiconductor device and the heat sink or insulating washer. Much the same effects can be obtained by using an abrasive and highly polishing the surfaces that are going to come together. The silicon lubricant minimizes the need for polishing the surface of the semiconductor case and the heat sink for good heat transfer.

When an insulating washer is required, silicon lubricant will still reduce the inherent thermal resistance case to heat sink. Figure 2 lists three typical insulating washers that are used with semiconductor devices. Note that the thermal resistances will be substantially reduced by the application of silicon lubricants.

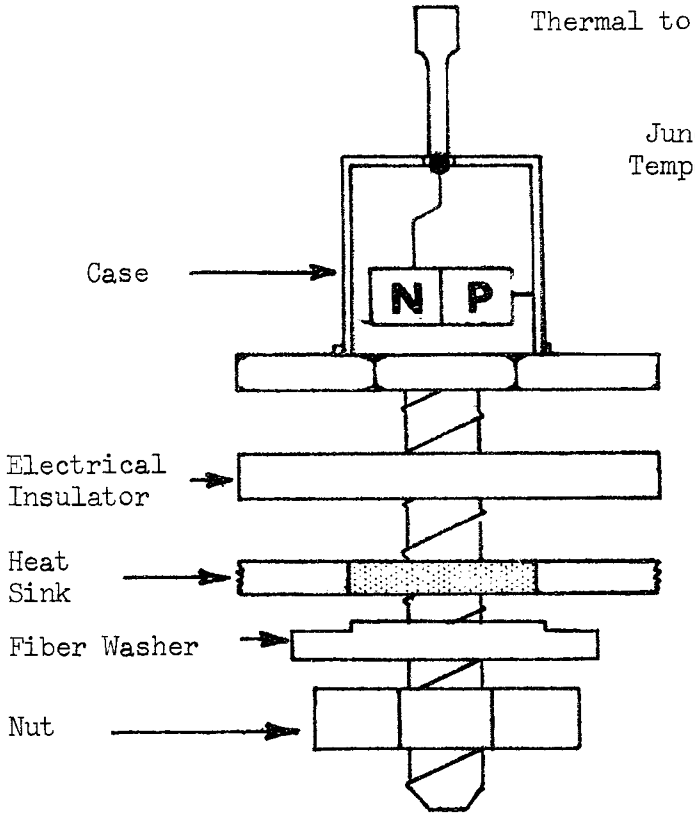
It should be brought out at this time that it takes a period of time for the junction temperature to change when power dissipation changes. In other words, if we were to suddenly increase the power dissipation, it would take a period of time for the junction temperature to change to its new value. In order to gain a set of tools to deal with the period of time involved in the change in junction temperature, a time constant of thermal resistance and thermal resistance and thermal capacitance is assumed. Figure 3 shows the thermal capacitance in shunt with the thermal resistance of the device. To simplify the thermal to electrical analogy, only one thermal capacitancy si shown in shunt with all three of the thermal resistances in Figure 3. It should be remembered that there are individual time constants made up of thermal resistance junction to case and it's associated thermal capacitance, thermal resistance case to heat sink and it's associated thermal capacitance. To keep the model as simple as we can and still have tools to work with, we have assumed one thermal time constant of total thermal resistance in shunt with thermal capacity.

Thermal capacity is given in dimensions of watt-seconds per degree centigrade. The product of thermal resistance in degrees centigrade per watt and thermal capacity in watt-seconds per degrees centigrade will give a resultant time. The time, as a result of taking the product of thermal capacitance and thermal resistance will be one thermal time constant. Assuming that, at time zero, there is no dissipation and suddenly the diode is caused to conduct resulting in a power dissipation, it will take approximately five thermal time constants for the change in junction temperature to occur. In other words, when we start dissipating power, it will take about five thermal time constants for the junction temperature to get to its final value above the surrounding air temperature. We can also say that, if the junction temperature is at some level above ambient temperature and the power dissipation is removed or reduced, it will take approximately five thermal time constants for the junction temperature to reach ambient once again.

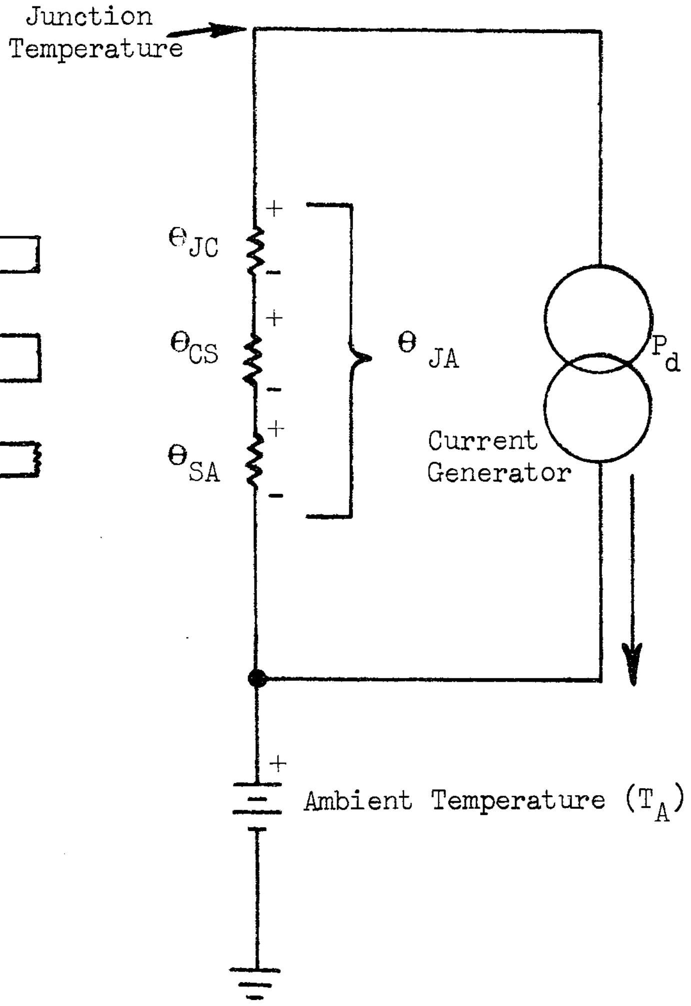
Let's stop and take stock for a moment. First of all, the thermal characteristics are related analogically to electrical characteristics to give a set of tools to work with when dealing with thermal characteristics. Once the tools have been gained, the basic electrical theorem can be used to solve problems dealing with thermal characteristics. First of all, thermal resistance and power dissipation, being related analogically to current and resistance, allows junction temperature to be calculated as a voltage at some potential difference above ambient temperature. This also allows the calculation of the maximum power dissipation for a given thermal resistance and ambient temperature. Transposing the formulas involved allows the calculation of any one quantity when the other two are known. When external heat sinking is used, the total thermal resistance is reduced. Thermal resistance case to ambient is replaced by a lower thermal resistance made up of a thermal resistance case to heat sink and heat sink to ambient. Silicon lubricant added between the diode and the heat sink, or to the insulating washer when it is required, reduces the total thermal resistance. If it is necessary to deal with the time involved in the temperature change at the junction, another component is added and termed thermal capacitance. Thermal capacitance is given in watt-seconds per degree centigrade. The product of thermal capacitance and the thermal resistance gives a time constant that will allow us to deal with the time involved in the change of junction temperature when power dissipation changes. It might be difficult at this time to see the need for thermal capacitance; however, we will deal with thermal capacitance when we deal with pulse power effects.

CALCULATING A REQUIRED HEAT SINK

Tables 1, 2, and 3 plot the thermal resistances in typical metals for a variety of areas and thicknesses. Using these charts, the size of the heat sink required to give us a specified thermal resistance when dealing with a semiconductor device can be determined. As an example, consider table 10. Suppose the required thermal resistance is 4° centigrade per watt or less. Looking at the horizontal plot in table 10, find 4° centigrade per watt. Next find where the line indicating 4° centigrade per watt intersects one of the curves. Notice that it will intersect the $\frac{1}{4}$" thickness aluminum plate and the 1/8" thickness aluminum plate. Taking the point of intersection with the $\frac{1}{4}$" aluminum plate and moving to the left, the graph indicates that it will take over 70 square inches of dissipating area in order to give a thermal resistance of 4°centigrade per watt. Dealing with 1/8" plate in table 10 and finding the point of intersection with the 4° centigrade per watt curve it would require around 180 square inches of dissipating area in order to give a thermal resistance of 4° centigrade per watt. When thinking of heat sinking a diode or some other semiconductor device, one might first determine the type of insulating washer that is going to be used (if it is required), and the table at the bottom of Figure 2 gives the typical



Thermal to Electrical Analogy



NOTE: When a heat sink is used, θ_{CS} and θ_{SA} replace θ_{CA}, The sum of θ_{CS} and θ_{SA} is always much lower than θ_{CA}

Junction Power Dissipation = Current
Opposition to Heat Transfer = Resistance
Ambient Temperature = Voltage
Junction Temperature = Voltage

Insulating Washer	Typical Thermal Resistance (θ_{CS}) in °C/W	
	Dry	W/Silicon Lubricant
None	0.2	0.1
Teflon	1.45	0.8
Mica	0.8	0.4
Anodized Aluminum	0.4	0.35

Figure 2

THERMAL TO ELECTRICAL ANALOGY

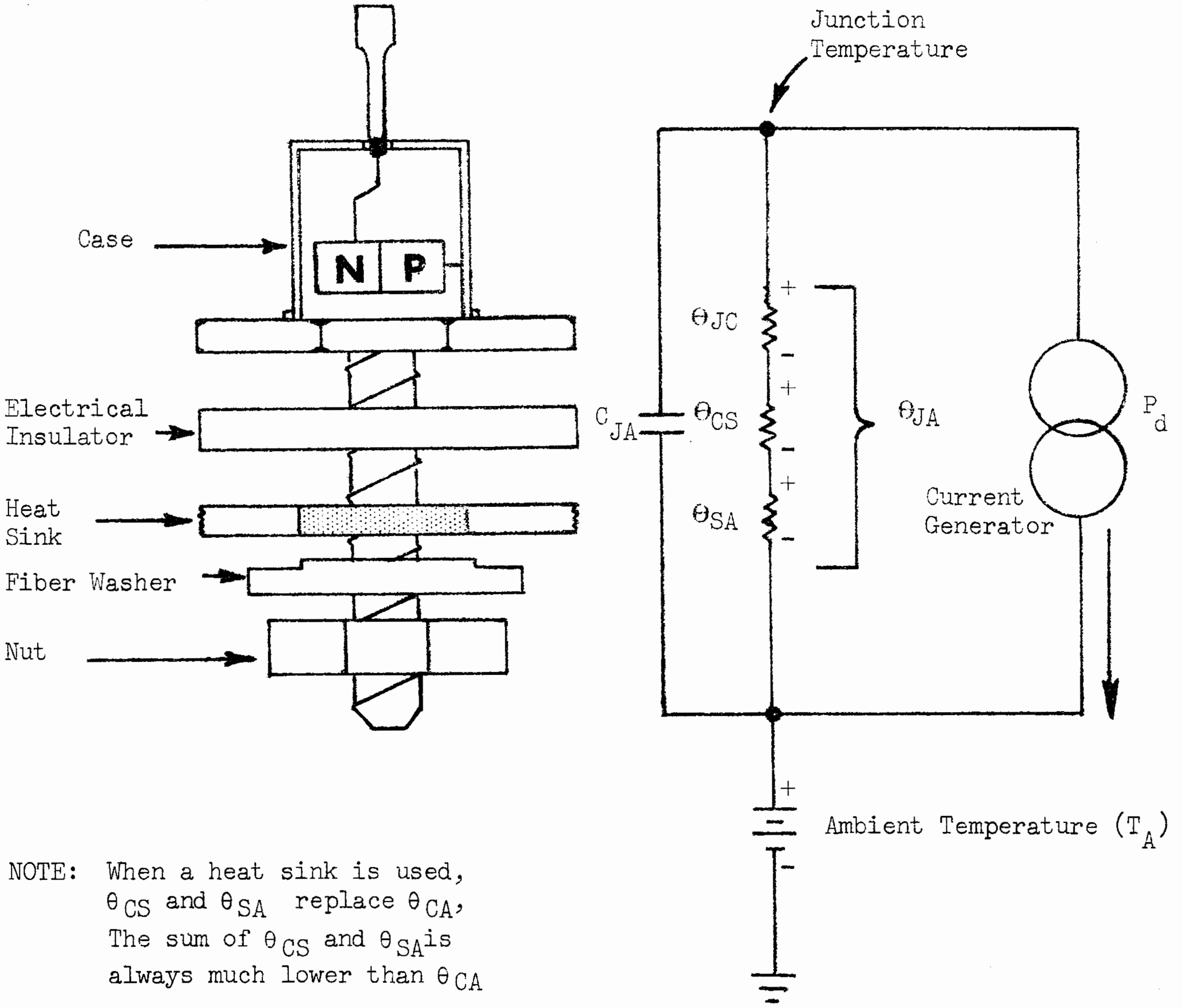


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Figure 3

thermal resistance case to heat sink. The manufacturer normally lists the thermal resistance or thermal conductance (which is simply the reciprocal of thermal resistance) for the semiconductor device. Knowing the amount of power the device is going to dissipate, and what ambient temperature is expected, the maximum allowable thermal resistance of the heat sink could be calculated. Tables 1, 2, or 3 could be used to determine how much dissipating area would be required to hold the thermal specifications.

In order to calculate the required thermal resistance of the heat sink, we might take the formula:

$$P_{Dmax} = \frac{T_{Jmax} - T_A}{\theta_{JA}}$$

and transpose it to solve for thermal resistance:

$$\theta_{JA} = \frac{T_{Jmax} - T_A}{P_{Dmax}}$$

Total thermal resistance is equal to the sum of the individual thermal resistances

$$\theta_{JA} = \theta_{JC} + \theta_{SA}$$

and, therefore, the thermal resistance of the heat sink is equal to:

$$\theta_{SA} = \theta_{JA} - \theta_{CS}$$

In terms of temperature and power dissipation, the thermal resistance of the heat sink is equal to:

$$\theta_{SA} = \frac{T_{Jmax} - T_A}{P_{Dmax}} - \theta_{JC} - \theta_{CS}$$

In other words, if the allowable change in junction temperature is divided by the maximum power that it is expected to dissipate, total thermal resistance is obtained. Subtracting the known values of thermal resistance from the total allows the calculation of the maximum allowable thermal resistance of the heat sink. Tables such as shown in table 1, 2, and 3 might then be used to determine the total dissipating area required to give the desired thermal resistance.

Size limitations might require that the heat sink be of some configuration that will give the required radiating area and yet hold it to a small size. Some manufacturers have come forth with heat sinks with radiating fins. This allows the radiating area to be larger while keeping the size small. Some chassis on whick the devices are mounted are vented or finned to increase the radiation surface.

It has not been stated as yet, however, the considerations that we are presently covering apply to all semiconductor junction devices to include all types of diode devices and transistors. Although we are more acutely aware of the thermal considerations and limitations with higher power devices, it is well to

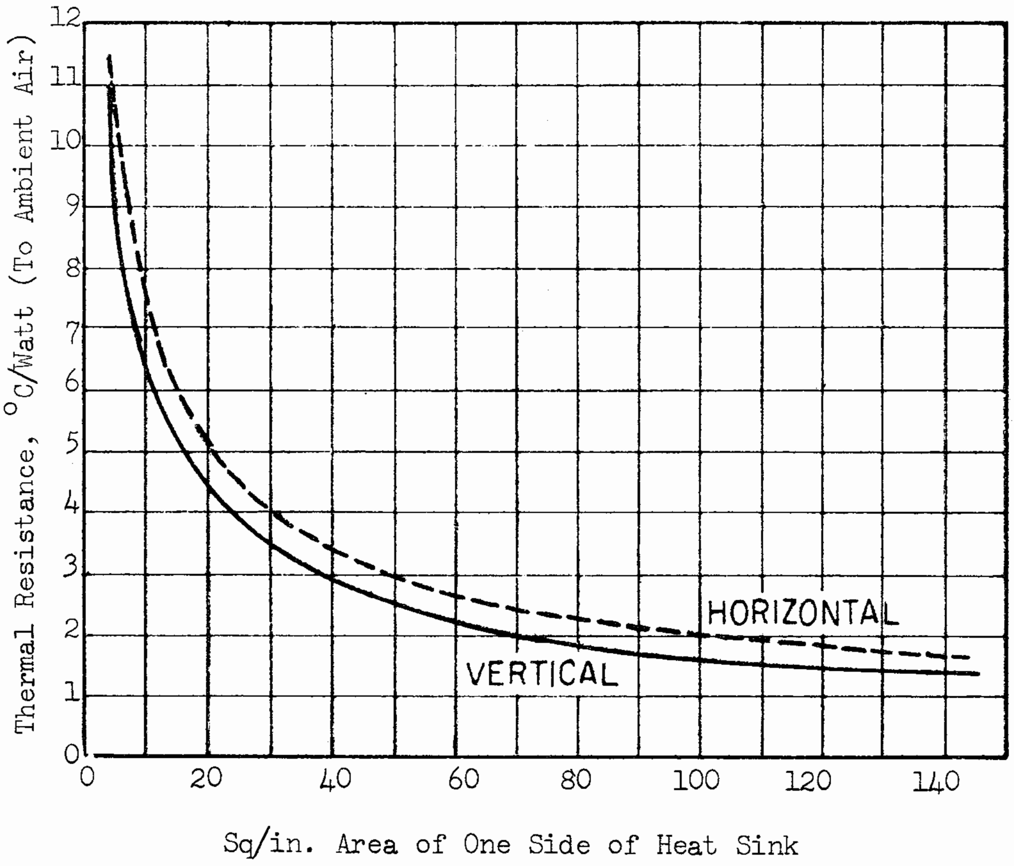


Table 1. The variation in heat-transfer characteristics of/1/8-in.-thick aluminum as its area and method of mounting are varied.

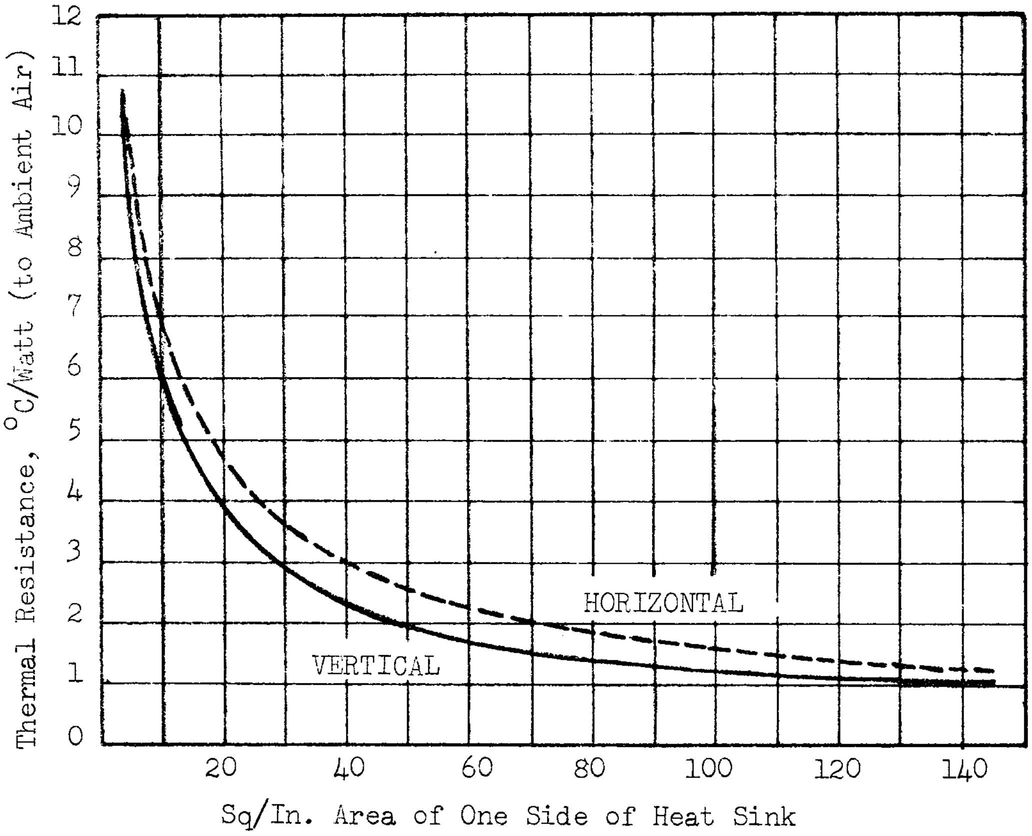


Table 2. The variation in heat-radiating efficiency of 1/8-in.-thick copper as its area and method of mounting are varied.

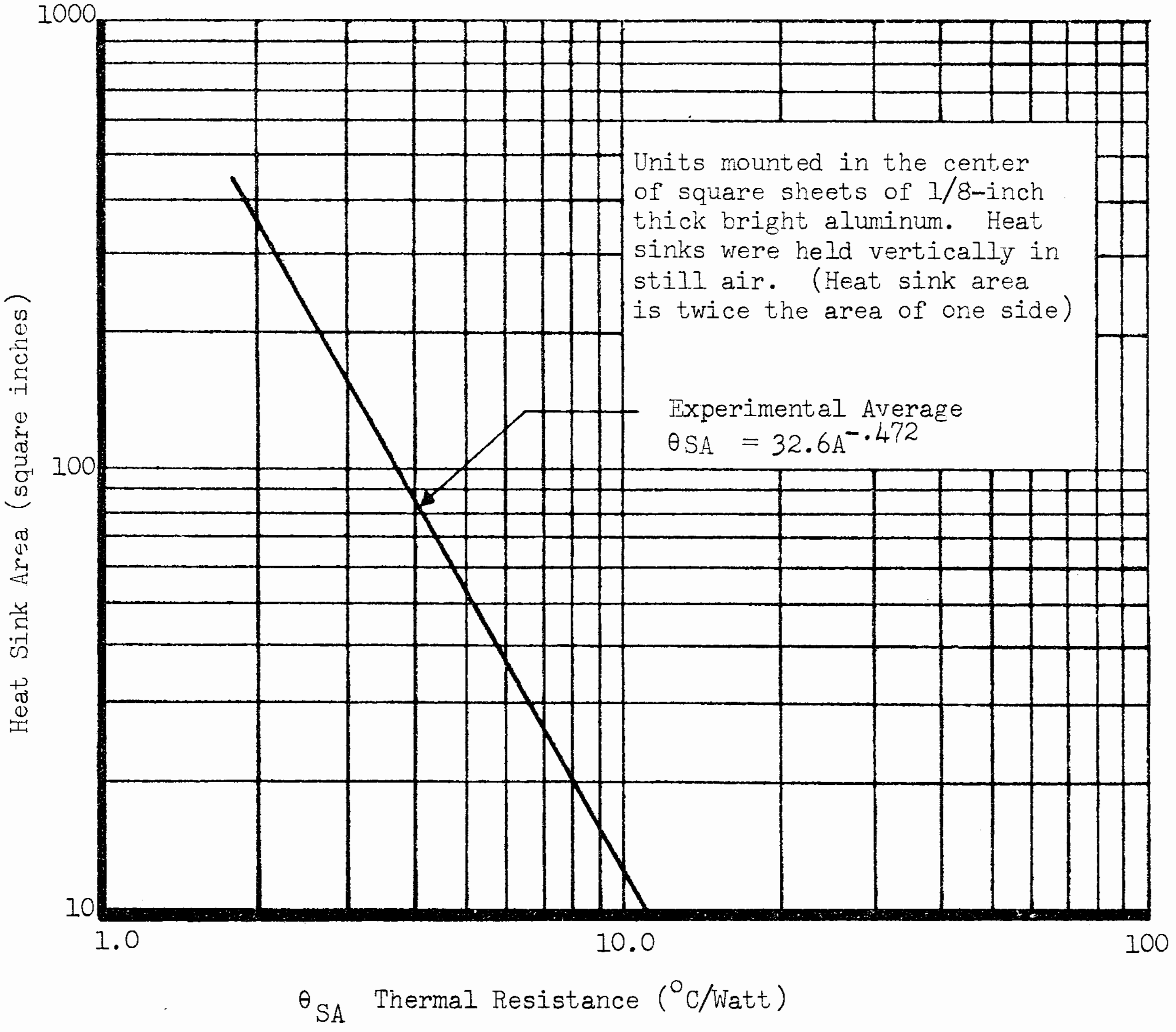


Table 3. - HEAT SINK AREA VERSUS THERMAL RESISTANCE

TABLE 3

remember that these considerations apply to low power devices as well. Any semiconductor device will have its maximum power dissipation limited by the surrounding air temperature, the total thermal resistance and the maximum operation temperature of the junction. Changes in temperature at the junction as a result of power dissipation as well as changes in the surrounding air temperature will change the currents and voltages associated with the device. In diode devices, the predomonant effects are changes in the leakage or saturation current of the diode with reverse voltage applied, changes in the voltage across the diode with forward voltage applied, and changes in the voltage across the diode when the diode is in a reverse breakdown condition.

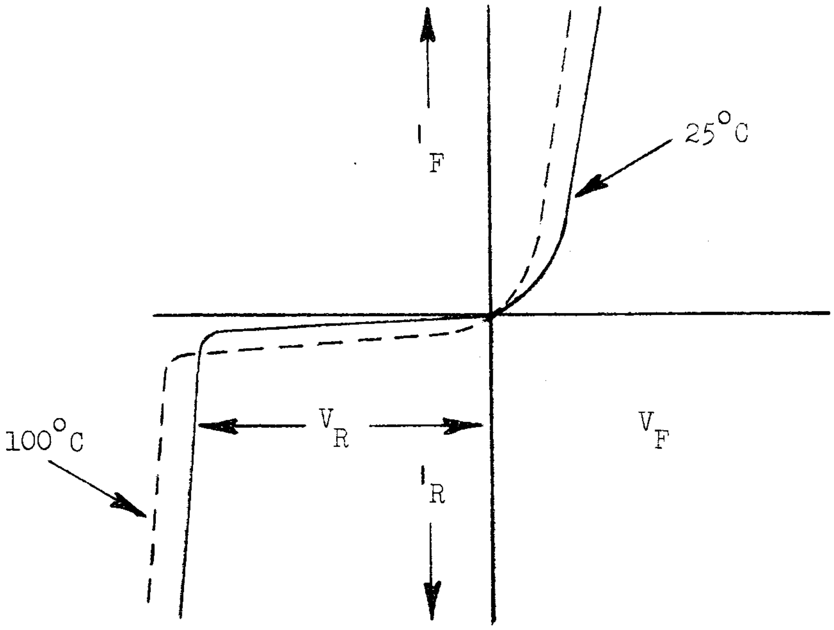


Figure 4.

Figure 4 is a voltage versus current curve for a semiconductor diode with forward and reverse voltage applied. The solid curve indicates the characteristics at 25° centigrade, and the dotted curve indicates the characteristics at 100° centigrade. You will note that with forward voltage applied, the forward d-c resistance and the forward d-c voltage decreases with an increase in temperature. With reverse voltage applied, the d-c resistance of the diode decreases with an increase in temperature and the reverse or saturation current increases. The voltage across the device in its reverse breakdown condition, however, increases with an increas in temperature. This, of course, is assuming that the diode is in an avalanche breakdown condition and, therefore, we show the breakdown occuring above 6 volts. A temperature can be reached at which the device starts losing its characteristics and a decrease in the reverse d-c voltage across the diode can be observed. Within the normal operating temperatures of the vice, we can say that the forward d-c resistance and voltage varies inversely as temperature varies; therefore, the forward voltage and resistance characteristics of a semiconductor diode have a negative temperature coefficient of voltage. The reverse d-c resistance of a semiconductor device not in a reverse breakdown mode can be said to vary inversely as the temperature varies. The reverse d-c resistance decreases as the temperature increases. This is a result of the formation of more hole electron pairs with an increase in temperature, increasing number of current carriers available and decreasing the resistance of the device. When the semiconductor device is in an avalanche breakdown mode at greater than 6 volts of reverse voltage, the d-c voltage across the device will increase with an increase in temperature. If the device is diped heavily enough to have it operating in the tunnel breakdown mode, an increase in temperature will cause the voltage across the reverse biased diode to decrease. Showing the breakdown voltage to be above 6 volts, we can then refer to the voltage of the device in breakdown as having a positive temperature coefficient of voltage. It should be kept in mind that the temperature change as indicated here can originate externally or internally of the diode. Internal temperature changes as a result of power dissipation and external temperature changes as a result of a change in the surrounding air temperature.

POWER DISSIPATION

The maximum power dissipation capabilities of the transistors are limited by the same factors as those discussed for the basic diode. The maximum temperature at which the junction can operate without harm, the surrounding air temperature, and the total thermal resistance from junction to surrounding air will limit the power dissipation.

Like the basic diode, the transport of carriers in the transistor will result in carriers changing energy bands and giving off energy in the form of heat and light. The primary concern at the transistor junction is the energy given off in the form of heat. The more power dissipated at the junction, the more heat is given off.

The heat generated at the junction raises the junction temperature above that of the surrounding air (or the case of the transistor). The junction can reach an operating temperature at which it is harmed if too much power is dissipated. Like the basic diode, some of the generated heat can be moved away from the junction and more power dissipated for the same ambient temperature and transistor if external heat sinking is used.

The collector junction normally dissipates the greater amount of power of the two junction. In other words, the product of the collector current and voltage is generally greater than the product of the emitter current and voltage (referring to the junctions). The transistor is normally mounted in a case and this offers opposition to transfer of heat from the junction to surrounding air. The thermal resistance from the junction to the case will be set by thermal connection to the encapsulation in which the transistor is placed. If the radiation from the case to the surrounding air is relied on to move the heat away from the junction, the power dissipation capabilities of the transistor can be rather limited. Connec case of the transistor thermally to the chassis or some external heat sink can move a greater amount of heat away from the transistor's case and allow more power dissipation for the same ambient temperature.

The difference between the ambient or surrounding air temperature and the maximum allowable operating temperature of the junction, gives the allowable rise in junction temperature as a result of dissipating power at the junction. The opposition offered in the path of the heat transfer from the junction to the surrounding air is termed thermal resistance. The higher the thermal resistance, the less heat will be transfered (other considerations being equal).

Figure 5 shows the thermal to electrical analogy as applied to the transistor. This analogy is very similar to the analogy as used with the basic diode and the formulas are also very similar. In the majority of cases, the thermal resistance of interest is between the collector junction and the case, and between the case and the surrounding air as illustrated in Figure 5. The collector junction has the higher power dissipation than the emitter junction typically. Once the thermal to electrical analogy is formulated, such as shown in Figure 5, Ohm's Law, Kirchoff's Law, and the basic theorems may be applied to solve the thermal considerations of the transistor as was done for the basic diode earlier in this volume.

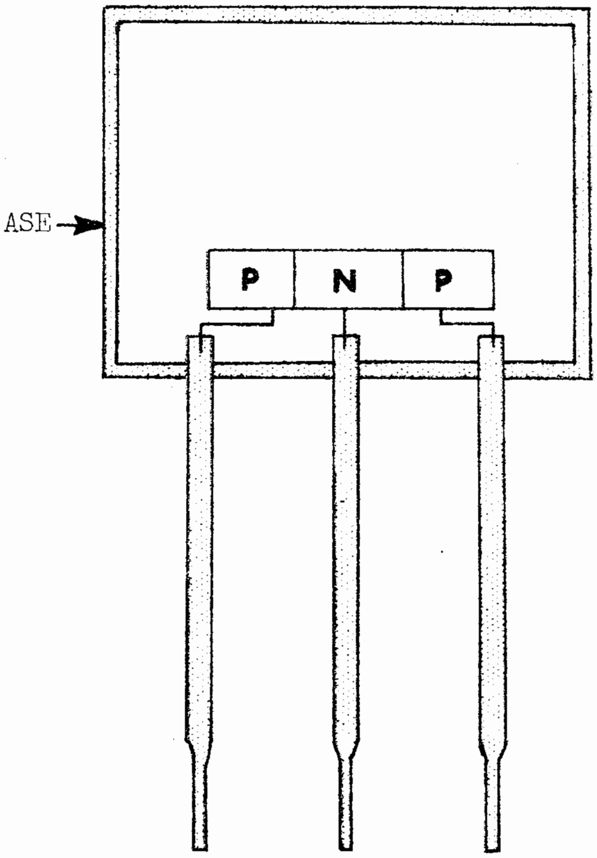
In the analogy, the product of thermal resistance total and the power dissipation gives the rise in junction temperature (voltage in the analogy) and this rise in temperature added to the ambient temperature (which is also analogically compared to a voltage) gives the junction temperature. In other words, the sum of the junction temperature rise as a result of dissipating power and the ambient temperature gives the actual operating temperature of the junction. Thermal resistance is expressed in degrees centigrade per watt.

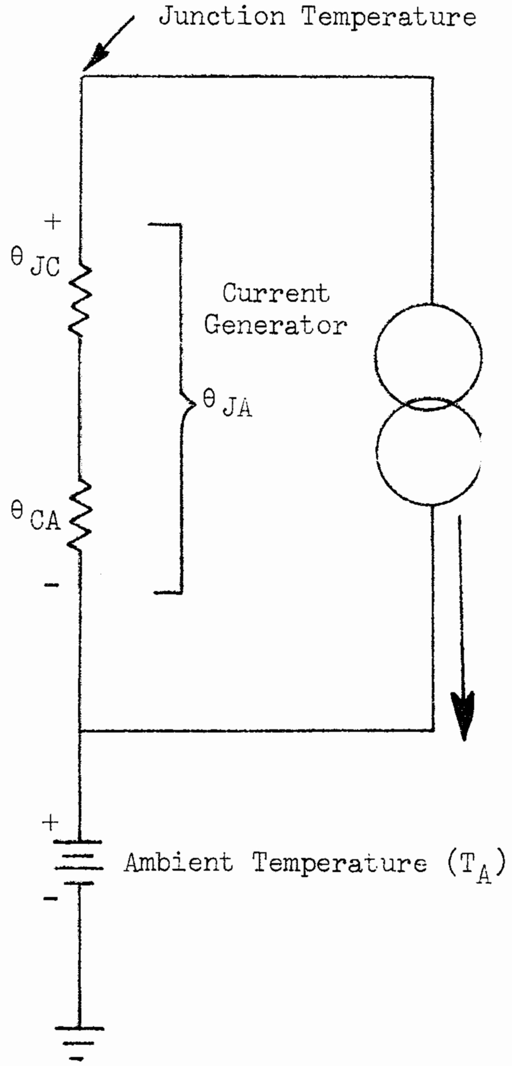
Connecting the transistor thermally to an external heat sink (such as the chassis) can be termed heat sinking the transistor. Heat sinking reduces the total thermal resistance by reducing the thermal resistance from the case to the surrounding air. Figure 6 shows the thermal to electrical analogy when an external heat sink is used to reduce the total thermal resistance.

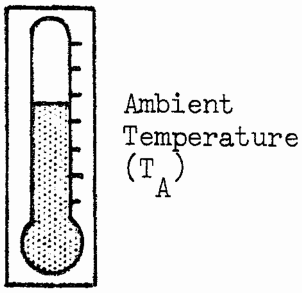
When an external heat sink is used, two thermal resistances, θ_{CS} and θ_{SA}, re-place the thermal resistance, θ_{CA}. In other words, the thermal resistance, case to ambient or surrounding air, is replaced by two other thermal resistances. The sum of the thermal resistances, θ_{CS} and θ_{SA}, will always be much lower than θ_{CA}, the thermal resistance from case to ambient. (These considerations are the same as was discussed with the basic diode. They are simply being applied to the transistor.)

The collector junction is of prime interest when we are dealing with the thermal resistance from the collector junction to the case, from the case to the heat sink, and from the heat sink to the surrounding air. Higher power handling transistors generally have the collector connected directly to the case to aid in the heat transfer. In most cases, this requires the case to be insulated electrically from the heat sink. The electrical insulator used must have good heat conductivity and still electrically insulate the transistor from the chassis. In some instances, the transistor manufacturer connects the emitter thermally to the case, and the transistor is referr as a reverse polarity device.

To make a good thermal contact with the transistor, the insulating washer must have no ridges or gaps between the insulating washer and the transistor, and between the insulating washer and the heat sink. The gaps and so forth can be minimized by highly polishing the insulating washer, the transistor, and heat sink so that a good contact is made. If the polishing that must be done to make a good thermal contact is prohibitive, silicon lubricant can be added to the insulating washer to fill in the gaps. Silicon lubricant will establish a good thermal contact between the transistor and the insulating washer and the insulating washer to fill in the gaps. Silicon lubricant will establish a good ther-



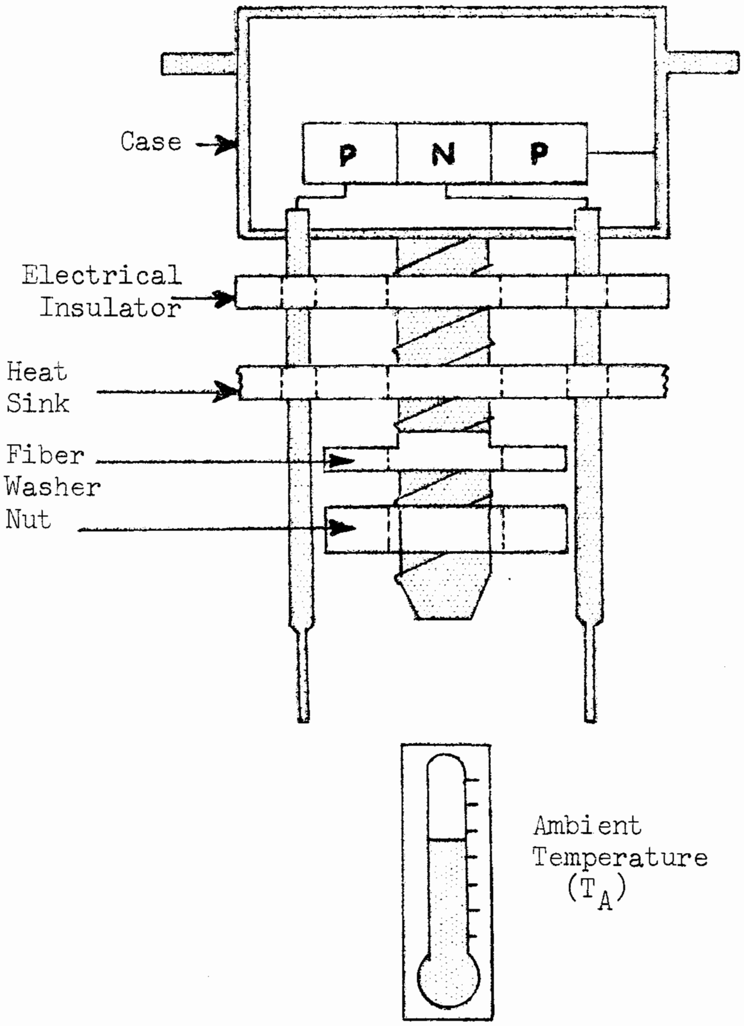


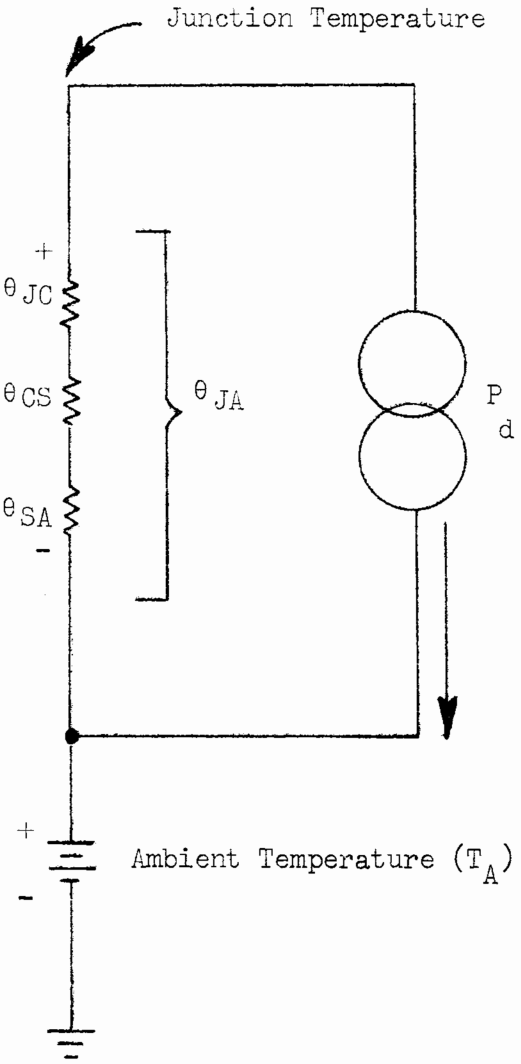


THERMAL		ELECTRICAL EQUIVALENT
Ambient Temperature	=	Voltage
Thermal Resistance	=	Resistance
Power Dissipation	=	Current
Junction Temperature	=	Voltage

Figure 5

THERMAL TO ELECTRICAL ANALOGY





NOTE: When a heat sink is used, θ_{CS} and θ_{SA} replace θ_{CA}. The sum of θ_{CS} and θ_{SA} is always much lower than θ_{CA}.

Junction Power Dissipation = Current
Opposition to Heat Transfer = Resistance
Ambient Temperature = Voltage
Junction Temperature = Voltage

Insulating Washer	Typical Thermal Resistance, (θ_{CS}) in °C/W	
	Dry	W/Silicon Lubricant
None	0.2	0.1
Teflon	1.45	.8
Mica	0.8	0.4
Anodized Aluminum	0.4	0.35

THERMAL TO ELECTRICAL ANALOGY WHEN USING A SEPARATE HEAT SINK

Figure 6

mal contact between the transistor and the insulating washer and the insulating washer and the heat sink without polishing. If no heat sink is used, silicon lubricant can still be used form a good thermal contact between the transistor's case and the heat sink. The chart at the bottom of Figure 6 shows the typical thermal resistances with and sithout silicon lubricant for several types of insulating washers.

Let's apply the thermal to electrical analogy as shown in Figure 6 to a typical power transistor:

Given:

$\theta_{SA} = 3.2^\circ C/watt$
$\theta_{JC} = 1.2^\circ C/watt$
$\theta_{CS} = 0.6^\circ C/watt$

Maximum junction operating temperature (T_{Jmax}) = $150^\circ C$

Ambient temperature (T_A) = $50^\circ C$

The sum of the individual thermal resistances as listed gives the total thermal resistance. In the case that we have just listed, $\theta_{JC} + \theta_{CS} + \theta_{JA} = 5^\circ C/watt$. The total thermal resistance for the transistor we are discussing is $5^\circ C/watt$. We have stated that the expected ambient temperature is $50^\circ C$ and the maximum allowable junction temperature is $150^\circ C$. From this we can calculate the allowable rise in junction temperature as a result of power dissipation by subtracting the ambient temperature from the maximum operating temperature of the junction. In the case stated, we can allow a temperature rise at the junction of $100^\circ C$ as a result of dissipating power:

$$(\Delta T_{Jallowable} = T_{Jmax} - T_A = 150^\circ C - 50^\circ = 100^\circ C)$$

We can also state that the product of power dissipation and the total thermal resistance must not exceed the maximum allowable rise in junction temperature. We can arrange this to solve for the maximum power dissipation that the transistor can tolerate. We can state in formula form that:

$$P_{Dmax}\, \theta_{JA} = T_{Jmax} - T_A$$

where P_{Dmax} equals the maximum power dissipation of the transistor, θ_{JA} is the total thermal resistance, T_{Jmax} is the maximum operating temperature of the junction, and T_A is the ambient temperature. Rearranging this formula, we can say that:

$$P_{Dmax} = \frac{T_{Jmax} - T_A}{\theta_{JA}}$$

Substituting the values for the transistor that we have previously stated, we find that:

$$P_{Dmax} = \frac{150^\circ C - 50^\circ C}{5^\circ C/watt}$$

To find the maximum allowable power dissipation for a given ambient temperature, divide the thermal resistance into the allowable change in junction temperature, which in this case is $\frac{100^\circ C}{5^\circ C/watt}$ which gives us a maximum allowable power dissipation of 20 watts.

Let's try this again with the following characteristics given:

$\theta_{JC} = 2.1^{o}C/watt$, $\theta_{CS} = 0.8^{o}C/watt$, $\theta_{SA} = 5.1^{o}C/watt$, $T_A = 70^{o}C$, $T_{Jmax} = 150^{o}C$

Let's solve the maximum power dissipation (P_{Dmax}) of the transistor with these conditions. With an ambient temperature expected of 70°C and a maximum allowable junction temperature of 150°C, we have an allowable temperature rise at the junction as a result of dissipating power of 80°C. The total thermal resistance is the sum of all the thermal resistances or, in this case, 8°C. An allowable change in junction temperature of 80°C divided by 8°C/watt gives a maximum power dissipation of 10 watts. Showing that in formula form:

$$P_{Dmax} = \frac{T_{Jmax} - T_A}{\theta_{JA}} = \frac{150^{o}C - 70^{o}C}{8^{o}C/watt} = 10 \text{ watts}$$

DIODE THERMAL CONSIDERATIONS AS RELATED TO POWER DISSIPATION:

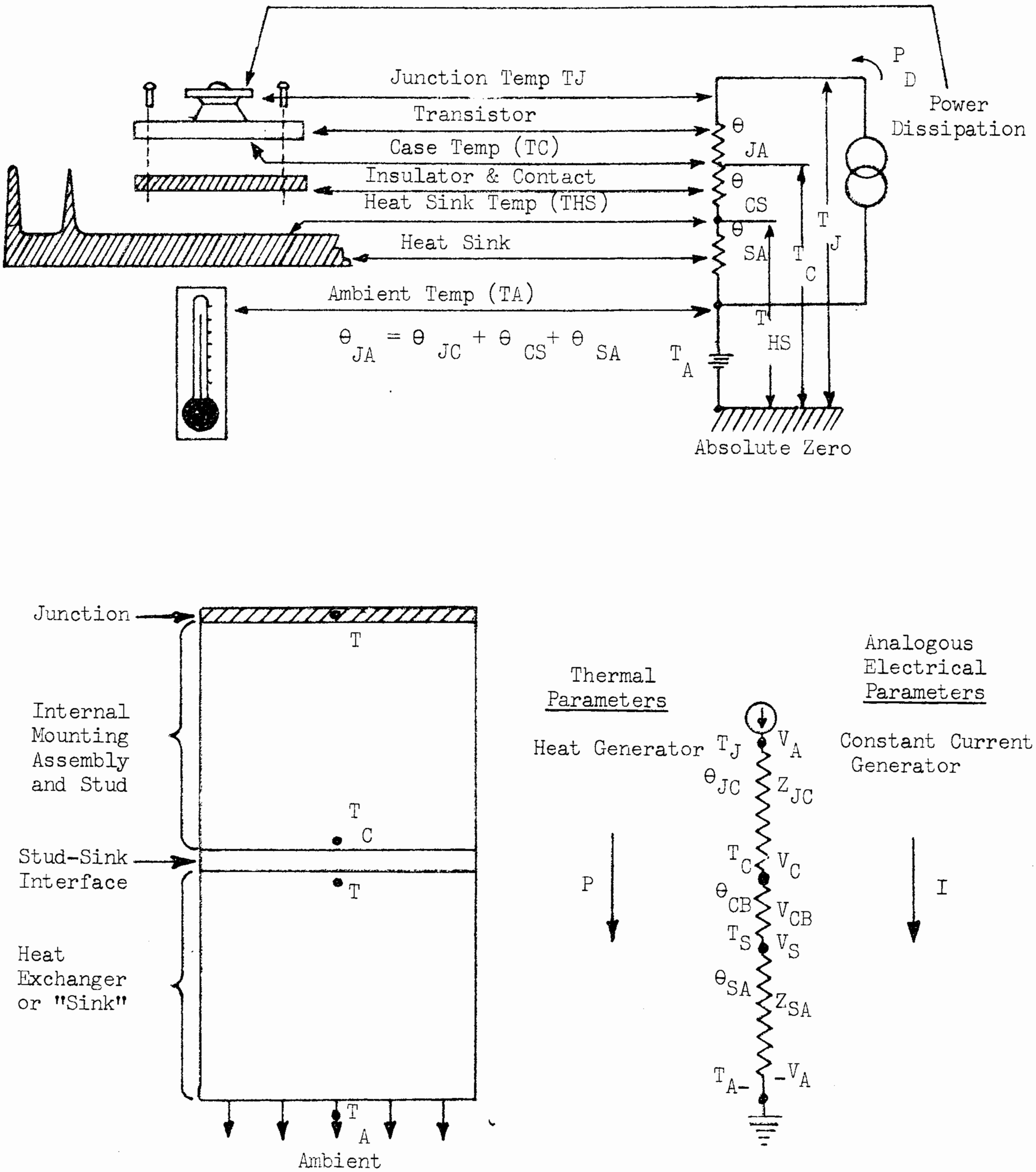
It has already been stated that the current, voltage, and resistance of a semi-conductor PN junction is related exponentially to the temperature. A temperature rise at the junction will cause a change in the current, voltage, and resistance of the semiconductor junction. The change in temperature at the junction can be caused externally or internally of the diode. A change in the ambient or surrounding air temperature will change the temperature of the junction for a given power dissipation, and a change in power dissipation at the junction will change the junction temperature for a given ambient temperature. A conducting junction will generate heat since the carriers changing bands must give up their energy in the form of heat and light. Any heat generated at the junction will raise the junction temperature about that of the surrounding air. At a given temperature, a PN junction will no longer serve as a rectifying device. Since the current is related exponentially to the temperature, a temperature limit will be reached where a further change in temperature will cause the diode to be essentially a short circuit and damage to the circuit or the diode can result. With germanium PN junctions, this is typically a 100° centigrade, while with silicon PN junctions, this is typically 150° centigrade. Depending on the intrinsic material and the type of doping and the construction of the device, this may vary above and below the typical values given. The diode is normally enclosed in some type of encapsulation or case, and there is opposition to the transfer of heat to the surrounding air. The opposition offered in series with the path of heat transfer from the junction to the surrounding air is related analogically to electrical resistance and is termed thermal resistance. Thermal resistance is the opposition to the transfer of heat from the junction to the surrounding air and its dimensions are given in degrees centigrade per watt of power dissipation at the junction. In other words, if a junction is dissipating one watt of power, the product of this one watt and the thermal resistance will give the rise in junction temperature above that of its surroundings. A diode has a maximum temperature that the junction can reach without damage or losing its characteristics. The diode has a thermal resistance;that is determined by the thermal path from the junction to the surrounding air. The power dissipation capabilities of a diode will be limited by these factors. It should be remembered that the junction temperature of a conducting diode is always riding on the surrounding air temperature and also have a part in determining how much power the diode can dissipate.

In order to determine the temperature of a conducting junction, it will be necessary to know the surrounding temperature, how much power the junction is dissipating and the thermal resistance in the path of heat transfer from the junction to the surrounding air. The junction temperature will be the sum of the temperature rise at the junction due to dissipating power and the surrounding air temperature. Since the product of power dissipation and thermal resistance gives the rise in junction temperature due to dissipating power, the lower the thermal resistance the greater the power dissipation capabilities for a given ambient temperature. It should be noted, however, that even if thermal resistance was zero ohms, the power dissipation would be limited by the ambient temperature, so there is a practical limit to the increase in power dissipation that can be accomplished by reducing the thermal resistance.

To determine the maximum power that may be dissipated for a given ambient temperature when the thermal resistance of the diode from the junction to the surrounding air is known, the following formula can be used:

$$P_{max} = \frac{T_{Jmax} - T_A}{\theta_{JA}}$$

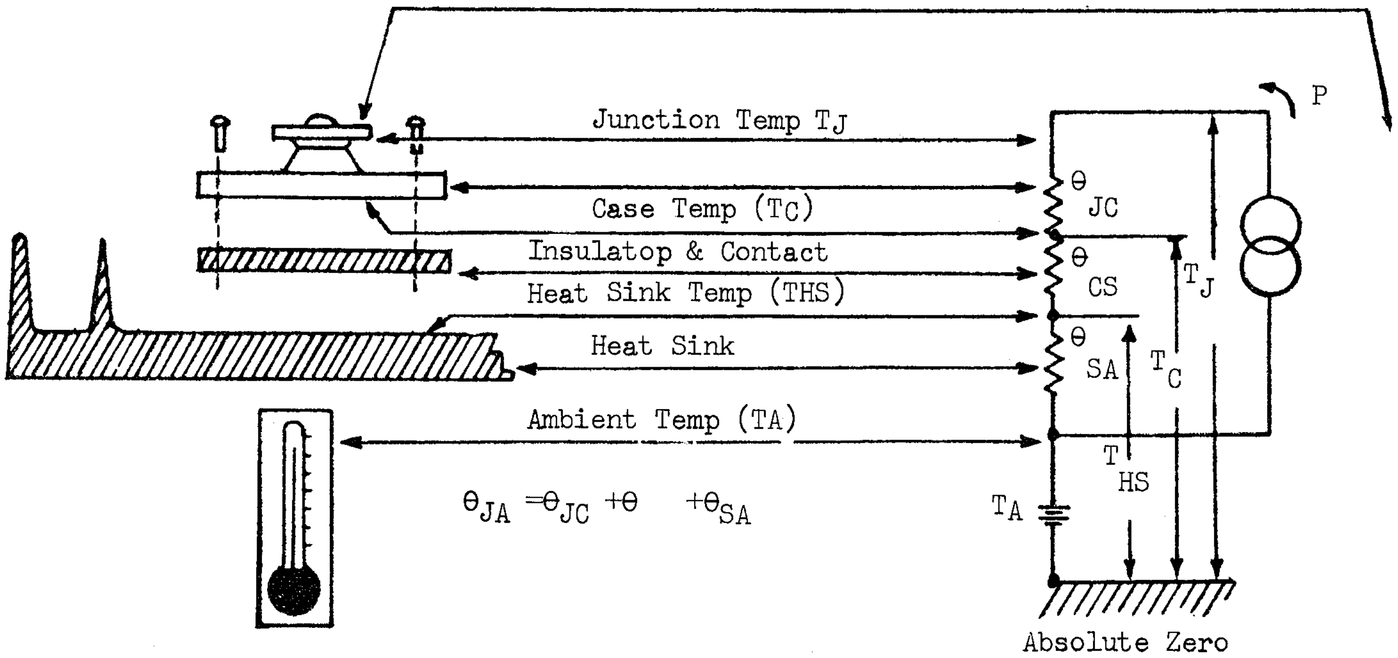
P_{max} indicates the maximum allowable power dissipation, T_{Jmax} indicates the maximum junction temperature of the device under operating conditions, T_A indicates the ambient temperature, and θ_{JA} is the symbol given thermal resistance of a diode, an external heat sink can be added to aid in transferring the heat to the surrounding air.



Thermal Circuit for a Semiconductor Power Device with Electrical Analog

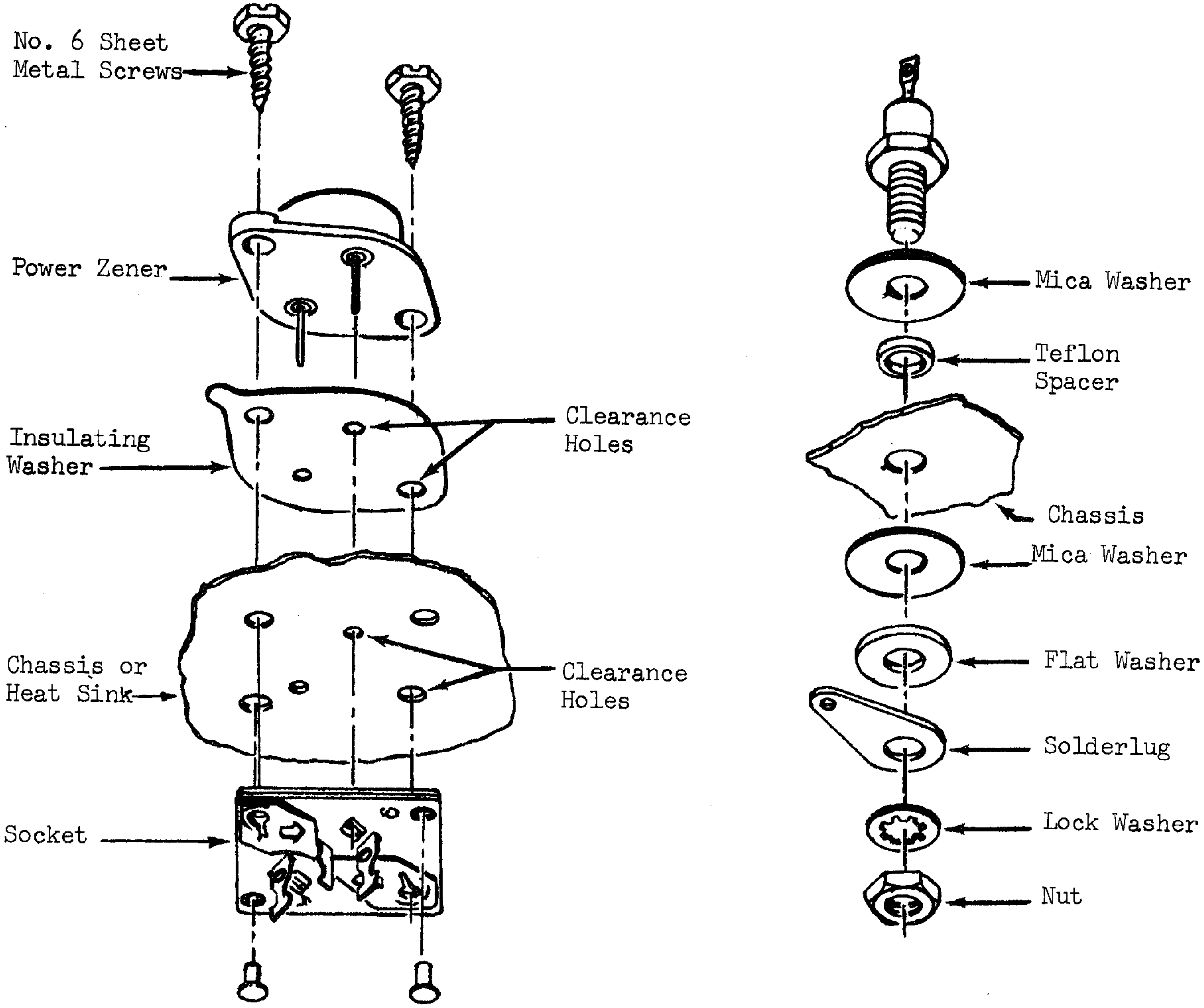
Figure 7

THERMAL	SYMBOL	UNIT	ELECTRICAL
Power Dissipation	P	Watts	Constant Currunt Generation
Temperature Rise	AT	^{o}C	Voltage Rise
Thermal Resistance	O	$^{o}C/W$	Resistance
Thermal Capacitance (Specific Heat)	C	$W\text{-}sec/^{o}C$	Capacitance



Thermal-to Electrical Analogy

Figure 8



Installation of Mounting Kits

Figure 9