RCA
ELECTRON TUBES
Application Note
AN-181

Transistor Dissipation Ratings for Pulse and Switching Service

The permissible dissipation of a transistor is determined by the maximum permissible temperature of its collector junction (usually given in published data as "Maximum Storage Temperature"). Published maximum-dissipation ratings for RCA transistors are for class A or class B operation with signals having sinusoidal waveforms. These ratings do not apply for pulse or switching service.

When a transistor is used in pulse or switching service its instantaneous dissipation may greatly exceed its class A or class B dissipation rating, depending upon the pulse width and pulse-repetition rate employed. The resulting rise in collector-junction temperature depends upon the thermal time constant and thermal resistance of the transistor, and may easily be great enough to destroy the transistor unless the peak dissipation is limited to a safe value. Because it is impractical to give maximum-peak dissipation values for all possible combinations of pulse width and duty cycle in the published data for a transistor, the value for a specific pulse or switching application must be determined by the circuit designer.

Determination of Permissible Dissipation

To help circuit designers determine these peak-dissipation values, this Note gives the maximum permissible collector-junction temperatures, typical thermal time constants, and maximum thermal resistances of 39 RCA transistor types specially designed for or frequently used in pulse and switching service.

These thermal parameters are given in Table I. Also given are two graphs which can be used to determine the permissible peak dissipation for any of the types listed in terms of pulse width, duty cycle, and either ambient temperature or case temperature.

Each graph consists of two sets of curves. One is a family of "Normalized Curves" giving the ratio of the permissible rise in junction temperature to the product of peak dissipation and thermal resistance $[\Delta T_j(\max)/P(\max)R_T]$, as a function of thermal time constant (τ_1), pulse width (t_o), and duty cycle (d). The other is a "Multiplication/Division Chart" giving $P(\max)R_T$ and $\Delta T_j(\max)$ as functions of either ambient temperature or case temperature. In Graph No.1, R_T is the thermal resistance between the collector junction and free air, and $P(\max)R_T$ and $\Delta T_j(\max)$ are given in terms of ambient temperature. This graph is most useful

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for computer and other low-power applications. In Graph No. 2, R_T is the thermal resistance between the collector junction and the transistor case, and P(max)R_T and ΔT_j(max) are given in terms of case temperature. This graph is most useful for higher-power switching applications.

Temperature Considerations

Separate graphs are provided for computer and industrial service because maximum-junction-temperature ratings for industrial-type transistors are usually higher than those for other types, and because the different methods of cooling employed in computer and industrial equipment make it necessary to use different thermal constants to determine permissible peak dissipation. Transistors used in computer equipment are generally cooled by radiation and convection, whereas those used in industrial switching equipment are generally provided with heat sinks and cooled by conduction as well as by radiation and convection. When a transistor is used in computer service, therefore, its significant thermal resistance is that between the collector junction and the surrounding air, and the significant temperature is the ambient temperature. When a transistor is used in industrial switching service, its significant thermal resistance is that between the collector junction and the transistor case, and the significant temperature is the temperature of the case.

The mathematical derivations of the "Normalized Curves" are given in the Appendix.

Use of Graphs

To determine permissible-peak-power dissipation for a specific transistor type in a pulse or switching application first determine the thermal time constant τ_1, and the appropriate thermal resistance R_T of the transistor from Table I. Insert the value of τ_1 in the ratio t_o/τ_1 for the "Normalized Curves", and the value of R_T in the P(max)R_T coordinates of the multiplication/division chart. Determine the value of $\Delta T_j(\max)/P(\max)R_T$ from the intersection of the appropriate duty-cycle curve with the coordinate for t_o/τ_1.

Then read right along the coordinate for $\Delta T_j(\max)/P(\max)R_T$ to the corresponding diagonal on the multiplication/division chart. Determine the value of P(max)R_T from the intersection of this diagonal with the coordinate for ambient temperature or case temperature, whichever is applicable. Solve for P(max).

Example:

Determine P(max) for transistor type RCA-2N404 in a computer application using a pulse width of 10 microseconds and a duty cycle of 0.01, for an ambient temperature of 25 degrees C.

Solution:

t_o = 10 microseconds = 10^{-5} second

From data shown in Table I for the 2N404

R_T = 500 degrees C per watt

τ_1 = 10 milliseconds, or 10^{-2} second

Therefore:

$$\frac{t_o}{\tau_1} = \frac{10^{-5}}{10^{-2}} = 10^{-3}$$

On the "Normalized Curves" of Graph No. 1, the value of $\Delta T_j(max)/P(max)R_T$ for $t_o/\tau_1 = 10^{-3}$ and $d = 0.01$ is 0.085. The diagonal for 0.085 on the multiplication/division chart of Graph No. 1 would be slightly more than halfway between the diagonals for 0.08 and 0.09, and would intersect the coordinate for T_a = 25 degrees C at $P(max)R_T = 710$.

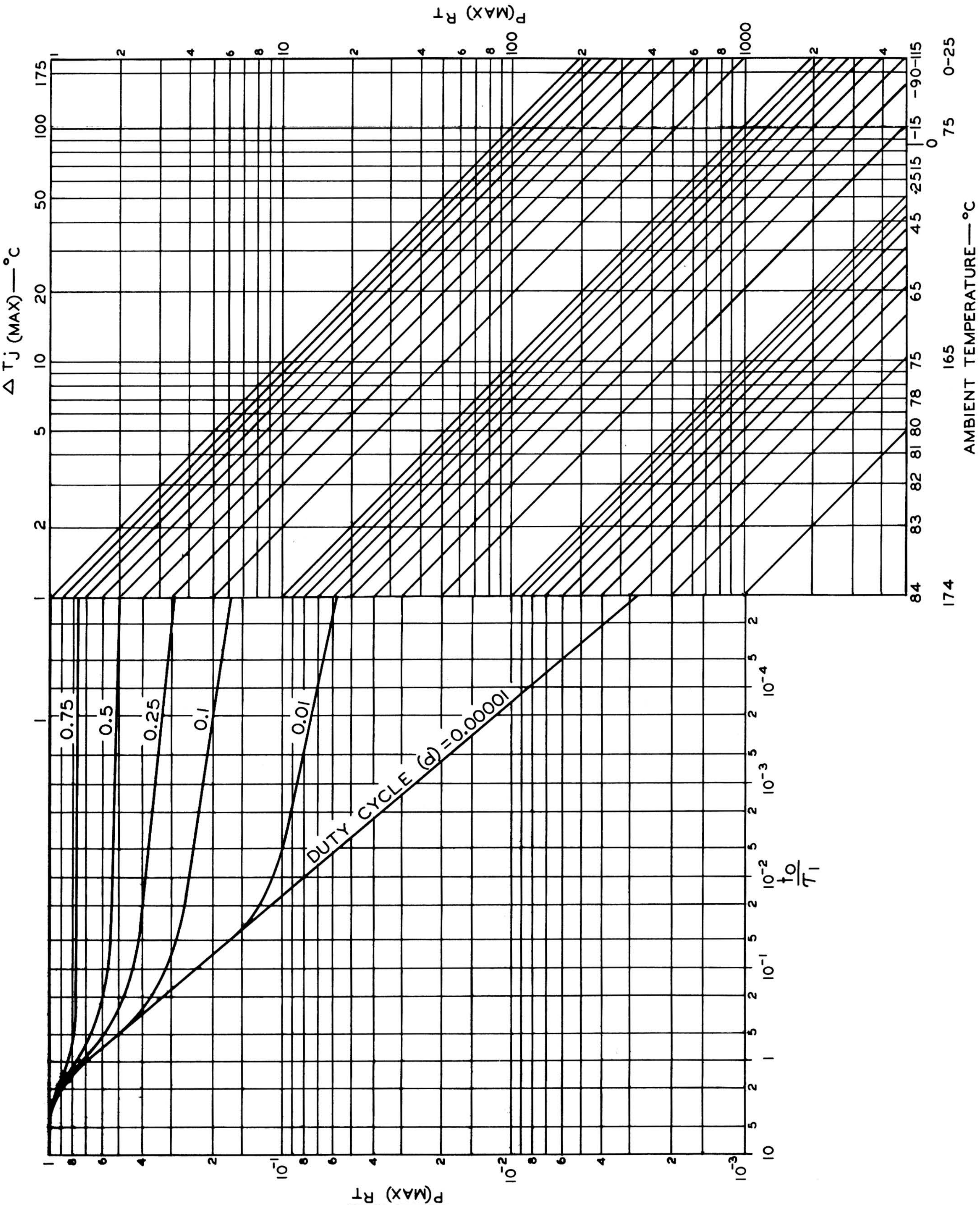
Therefore

$$P(max) = \frac{710}{R_T} = \frac{710}{500}$$

$$= 1.42 \text{ watts, or } 1420 \text{ milliwatts}$$

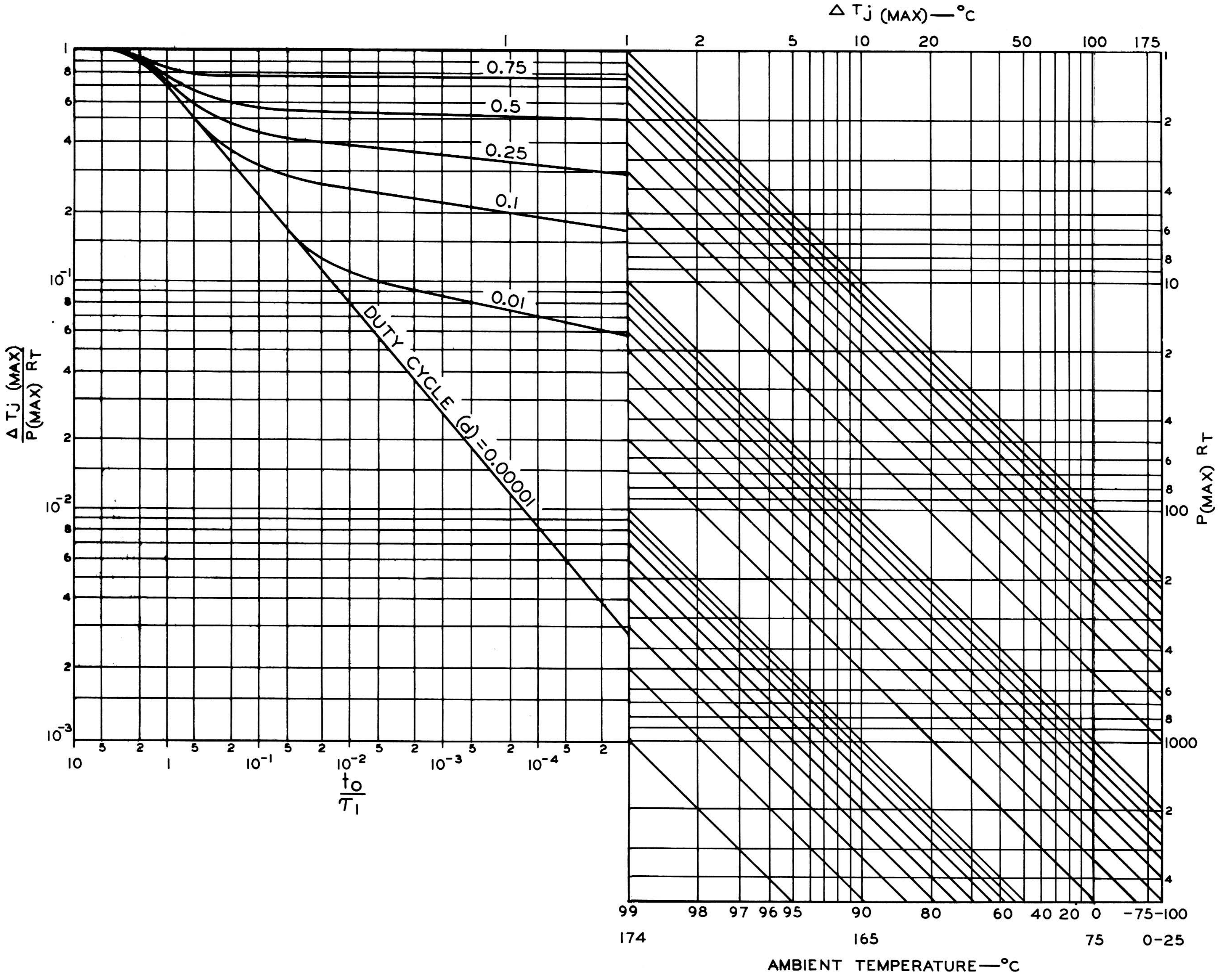
TABLE I

RCA TRANSISTOR TYPE	MAXIMUM PERMISSIBLE COLLECTOR-JUNCTION TEMPERATURE T_j(max) DEGREES C	TYPICAL THERMAL TIME CONSTANT τ_1 MILLISECONDS	MAXIMUM THERMAL RESISTANCE R_T DEGREES C/WATT	
			COLLECTOR JUNCTION TO AIR (USE WITH GRAPH No. 1)	COLLECTOR JUNCTION TO CASE (USE WITH GRAPH No. 2)
2N109	85	12	400	
2N139	85	10	750	
2N140	85	10	750	
2N217	85	12	400	
2N218	85	10	750	
2N219	85	10	750	
2N247	85	12	750	
2N269	85	10	500	
2N270	85	12	240	
2N274	85	12	750	
2N356	85	15	600	
2N357	85	15	600	
2N358	85	15	600	
2N384	85	10	600	
2N398	85	12	750	
2N404	85	10	500	
2N456	100	8	-	1.4
2N457	100	8	-	1.4
2N561	100	8	-	1.5
2N578	85	15	500	
2N579	85	15	500	
2N580	85	15	500	
2N581	85	12	500	
2N582	85	12	500	
2N583	85	12	500	
2N584	85	12	500	
2N585	85	12	500	
2N586	85	12	240	
2N643	85	10	500	
2N644	85	10	500	
2N645	85	10	500	
2N1014	100	8	-	1.5
2N1067	175	8	100	30
2N1068	175	8	100	15
2N1069	175	10	-	3
2N1070	175	10	-	3
2N1090	85	12	500	-
2N1091	85	12	500	-
2N1092	175	8	225	5



Δ Tj (MAX)—°C
1
2
5
10
20
50
100
175
P(MAX) RT
10
100
1000
AMBIENT TEMPERATURE—°C
0-25
-90-115
-15
0
75
-25
15
45
65
75
165
78
80
81
82
83
84
174
Δ Tj (MAX) / P(MAX) RT
10^-1
10^-2
10^-3
to / T1
10^-4
10^-3
10^-2
10^-1
0.75
0.5
0.25
0.1
0.01
DUTY CYCLE (d) = 0.00001

Graph No. 1


Δ Tj (MAX)—°C
1
2
5
10
20
50
100
175
0.75
0.5
0.25
0.1
0.01
DUTY CYCLE (d) = 0.00001
$\frac{\Delta T_j \text{ (MAX)}}{P_{\text{(MAX)}} R_T}$
1
8
6
4
2
10^{-1}
8
6
4
2
10^{-2}
8
6
4
2
10^{-3}
10
5
2
1
5
2
10^{-1}
5
2
10^{-2}
5
2
10^{-3}
5
2
10^{-4}
5
2
$\frac{t_0}{T_1}$
$P_{\text{(MAX)}} R_T$
1
2
4
6
8
10
2
4
6
8
100
2
4
6
8
1000
2
4
99
98
97
96
95
90
80
60
40
20
0
-75-100
174
165
75
0-25
AMBIENT TEMPERATURE—°C

Graph No. 2

APPENDIX

When a power pulse is applied to a transistor the resulting change in the temperature of the collector junction is determined by the pulse amplitude and width, and by the thermal time constant and thermal resistance of the transistor. The junction temperature is a maximum at the termination of the pulse and reaches its minimum value during the interval after the pulse has been removed. The junction temperature at any instant during the applied pulse is given by

$$T_{j1}(t) = PR_T\left(1-\frac{8}{\pi^2}\sum_{n=1,3,5\ldots}^{\infty}\frac{1}{n^2}\epsilon^{-\frac{t}{\frac{1}{n^2}\tau_1}}\right)+T_a$$

where (t) is the time after application of the pulse in seconds

P is the amplitude of the power step in watts

R_T is the thermal resistance of the transistor in degrees C per watt

τ_1 is the thermal time constant of the transistor in seconds

T_a is the ambient temperature in degrees C.

The temperature to which the junction cools after the pulse has been removed is given by

$$T_{j2}(t) = \left(\Delta T_j(\max)\frac{8}{\pi^2}\sum_{n=1,3,5\ldots}^{\infty}\frac{1}{n^2}\epsilon^{-\frac{t}{\frac{1}{n^2}\tau_1}}\right)+T_a$$

where (t) is the time after removal of the pulse in seconds

$\Delta T_j(\max)$ is the difference between the maximum temperature reached by the junction during the pulse and the ambient temperature $[T_{j1}(t) - T_a]$

With repeated pulses the maximum temperature of the collector junction approaches the limit

$$T_j = PR_T\left(\frac{1-a}{1-ab}\right)+T_a$$

$$\text{where } a = \left(\frac{8}{\pi^2}\sum_{n=1,3,5\ldots}^{\infty}\frac{1}{n^2}\epsilon^{-\frac{t_o}{\frac{1}{n^2}\tau_1}}\right)$$

$$b = \left(\frac{8}{\pi^2}\sum_{n=1,3,5\ldots}^{\infty}\frac{1}{n^2}\epsilon^{-\frac{t_o}{\frac{1}{n^2}\tau_1}\left(\frac{1-d}{d}\right)}\right)$$

t_o is the pulse width in seconds

d is the duty cycle $\left(\frac{t_o}{\text{pulse repetition period}}\right)$

The maximum rise in junction temperature in normalized form is

$$\frac{\Delta T_j(\max)}{P(\max)R_T} = \frac{1-a}{1-ab}$$

$$= \frac{\left(1 - \frac{8}{\pi^2}\sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2}\epsilon^{-\frac{t_o}{\frac{1}{n^2}\tau_1}}\right)}{1 - \left(\frac{8}{\pi^2}\sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2}\epsilon^{-\frac{t_o}{\frac{1}{n^2}\tau_1}}\right)\left(\frac{8}{\pi^2}\sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2}\epsilon^{-\frac{t_o}{\frac{1}{n^2}\tau_1}\left(\frac{1-d}{d}\right)}\right)}$$

where τ_1 and R_T are, respectively, the thermal time constant of the transistor and the thermal resistance between the collector junction and the transistor case.

The "Normalized Curves" in Graph No.1 and Graph No.2 are plots of $\Delta T_j(\max)/P(\max)R_T$ as a function of t_o/τ_1, with duty cycle as a parameter. The "Multiplication/Division" portions of these Graphs are provided to facilitate determination of P(max). In Graph No.1, the use of the thermal resistance between the collector junction and free air instead of separate values of R_T for the transistor and the case provides a safety factor and simplifies determination of P(max) for applications where heat sinks are not involved.