DESIGN CONSIDERATIONS FOR MECHANICAL PACKAGING OF A CATV TRUNK STATION

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ABSTRACT

There are many aspects to be considered during the design of the mechanical package of a CATV trunk station. The various alternatives to be considered, and the basis for decisions made during housing design will be presented to help establish comparative guidelines, and to provide a base of information to aid comparison of the various designs on the market.

Attention will be given to housing configuration, selection of materials and parts fabrication processes, compatability of materials and other topics that are considered during the design process. Special attention will be given to analyzing the thermal performance of an amplifier and showing how good thermal performance can be created by housing configuration during design. Component operating temperatures have a primary effect on unit reliability. Additional options that increase total station heat dissipation, the introduction of higher gain block hybrids and the growing popularity of pedestal mounting, make unit thermal performance more and more important.

The general requirements to be considered during the design of a trunk station housing consist of housing size and form factor, product reliability and maintainability, product service life, unit strength and weight, and unit producibility.

This paper will outline the specific requirements of the general considerations listed above and then will show how each of these requirements can be satisfied. To design an integrated, functional producible final housing assembly, consideration must be given to proper housing internal geometry and module placement, proper material selection and parts manufacturing processes, and proper unit thermal performance.

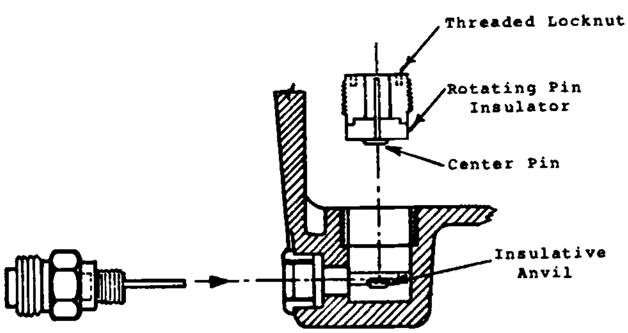
Housing Geometry and Module Placement

Housing geometry and configuration has a primary effect on unit maintainability, reliability, external form factor and producibility.

Module placement is determined by the required interfaces with the external cables, equalization of heat distribution within the housing and module to module interconnections. Trunk and bridger module placement into the housing strand side is dictated by external cable inputs, and the high heat dissipation of the amplication hybrids requires that these modules be mounted directly to an external housing wall to ensure reliable operation. The power supply and reverse amplifier are the remaining high dissipation modules so that their optimum placement is in the opposite housing half. This will provide a uniform heat dissipation input into each housing half to maximize the use of the external housing surfaces for cooling. These modules should also be mounted to an external housing wall to provide adequate cooling for high dissipation components. Power supply placement should be to the hinge side of a standard housing to minimize the torque required to restrain the moving housing half during housing opening. Placement of the Dual Pilot and Status Monitoring/Bridger Switching modules is less critical since module power dissipation is low (dissipation of each module is less than one-half of the bridger hybrid alone). Placement of these modules is therefor governed by module interconnections to provide a simple, producible interconnection system.

Module to external cable center conductor interconnection plays an important role in overall unit performance. The center conductor to module interconnection scheme must meet several requirements. First, the cable seizure mechanism must clamp the center conductors of the external cables while minimizing center conductor deformation and damage. A seizure that minimizes center conductor deformation will reduce center conductor stress concentrations and will make the center conductor less likely to break during the cyclic loading produced during unequal expansion and contraction of the cable outer and inner conductors (copper center conductor and aluminum outer conductor). Next, the seizure should provide a direct interconnection to the modules that is as close to 75 ohms in impedance as possible to minimize system impedance mismatch. Lastly, the seizure itself should be capable of withstanding the center conductor loads.

A cable seizure mechanism as shown in Figure 1 will satisfy all of these requirements. This seizure minimizes center conductor deformation and damage since the rotating pin insulator becomes stationary after contacting the center conductor allowing only compressive forces to be input. This is superior to a seizure that relies on a screw to contact the center conductor since a screw would input both compressive and twisting forces in a drilling action. The cable seizure shown creates an "F" connector when installed into the housing. The modules plug directly into this connector minimizing impedance mismatch.



Cable Seizure Mechanism

Figure 1

Modules should be easily removable from the housing to allow quick replacement of a failed module. Module covers should be easily removable to facilitate module trouble-shooting and to allow the quick interchanging of pads, equalizers, trim networks and feedermakers when these items are mounted within the module.

External housing size and shape should allow pedestal mounting within a TV104 enclosure or smaller and the vertical dimension of a strand mounted unit should allow it to fit within a 12 inch strand to phone line spacing. The external housing should be gasketed to provide both an EMI and water tight enclosure for the electronics. It is preferable to incorporate separate EMI and water gaskets with the water gasket outboard of the metal EMI gasket. Dual purpose gaskets offer reduced performance since they are a compromise of the two functions. In a dual purpose gasket, the presence of the rubber for water sealing increases the electrical contact resistance between the housing and the conductive particles or fibers within the gasket and the presence of the particles or fibers decrease the compressability and resilience of the rubber gasket compromising its sealing ability.

Cable connectors should mate with stainless steel inserts installed into the housing so that if anything is stripped during connector installation, it will be the relatively inexpensive connector and not the housing. Connector port spacing should be a minimum of 1.60 inches to allow the installation of the 1 3/8 inch Hex. bodied connectors used for some one inch cable.

Material Selection

Material selection is the predominant factor that determines unit strength, weight and service life. Proper material selection will also enhance product producibility and reliability.

The properties required of the external housing are good corrosion resistance, pressure tightness and strength, low weight, and good electrical and thermal conductivities. Die cast aluminum meets these requirements and offers the additional advantages of being relatively low in price with the capability of producing complex shapes so that cooling fins, screw bosses and other features may be cast in. The inherent corrosion resistance of aluminum to both marine and industrial environments is good as can be seen from the comparison of metals shown in Table 1. With good casting design, aluminum die castings can typically be cast to be pressure tight to 10 psig. This is adequate for a trunk housing since only a 5 psi pressure decrease would occur inside the housing with an instantaneous internal air temperature change from 160° to $-50^{\circ}F$. Of the aluminum die casting alloys, Alloys 13 and 360 provide the best combination of properties with Alloy 360 offering slight advantages over Alloy 13. A comparative table of cast aluminum alloys is presented as Table 2.

Table 1

Average Atmospheric Corrosion Rates of Various Metals for 10- and 20- Year Exposure Times*

mils (in.x10^{-3})/Yr.

	Atmosphere					
	N.Y. City (industrial)		La Jolla,CA (marine)		St.College,PA (rural)	
	Years					
	10	20	10	20	10	20
Aluminum	0.032	0.029	0.028	0.025	0.001	0.003
Copper	0.047	0.054	0.052	0.050	0.023	0.017
Lead	0.017	0.015	0.016	0.021	0.019	0.013
Tin	0.047	0.052	0.091	0.112	0.018	-
Nickel	0.128	0.144	0.004	0.006	0.006	0.009
65% Ni, 32% Cu, 2% Fe, 1% Mn (Monel)	0.053	0.062	0.007	0.006	0.005	0.007
Zinc (99.9%)	0.202	0.226	0.063	0.069	0.034	0.014
Zinc (99.0%)	0.193	0.218	0.069	0.068	0.012	0.013
0.2% C Steel (0.02 P, 0.05 S, 0.05 Cu, 0.02 Ni, 0.02 Cr)	0.48					
Low-alloy Steel (0.1 C, 0.2 P, 0.04 S, 0.03 Ni, 1.1 Cr, 0.4 Cu	0.09					

*Reference 5

Table 2

COMPARATIVE TABLE for COMMON ALUMINUM DIE CAST ALLOYS

	Alloy*			
	380	13	360	384
Corrosion Resistance	4	2	2	3.5
Pressure Tightness	2	2	1	2
Castability**	2	1	1	1
Iridite Protection	5	3	3	4
Thermal Conductivity	0.24	0.29	0.27	0.23
Surface Appearance	3	2	1	N/A
Machinability	3	4	3	3
Electrical Resistivity	6.90	5.56	6.16	7.50
Density	0.098	0.096	0.095	0.098

Excellent = 1 Poor = 5

*Data from references 2, 3 and 4

**Castability is considered to be a combination of fluidity and resistance to hot cracking.

The properties required of the module housings are similar to those of the external housing except that pressure tightness is not a factor. Again, aluminum alloys are the natural choice, but since pressure tightness is not a requirement, a module made from formed sheet and plate can utilize the increased thermal conductivities (approximately double) of the wrought alloys to decrease the temperature rises within the module.

The materials for clamps, hinges and other external hardware should provide adequate strength and corrosion resistance to perform their functions during the service life of the amplifier and should be galvanically compatible with the cast housing. A chart showing the galvanic compatability of metals is shown as Figure 2. Since there are many factors involved in the overall compatability of metals other than the metals themselves, the chart should be used only as a guideline. One important factor is the area ratio of the anodic and cathodic materials. When combined, an anodic metal will sacrifice itself to protect the cathodic metal, so that very large areas of anodic metals in contact with a small area of cathodic material is not as bad as a joint with the area ratios reversed. Aluminum and stainless steel are not galvanically compatible, for example, but an aluminum housing joined by stainless steel bolts would be acceptable where a stainless steel housing joined with aluminum bolts would not. Due to the complexity of the galvanic process and the number of metals in contact in a typical trunk housing, accelerated corrosion testing for any new product should be performed with new product performance compared to the performance of a satisfactory previous product.

Thermal Design and Performance

The reliability of the amplification hybrids and other electrical components within a trunk station is directly related to the average component operating temperatures. With the growing list of trunk options available, increasing numbers of reverse systems, the introduction of high gain block hybrids and the growing popularity of pedestal mounting thermal performance grows in importance.

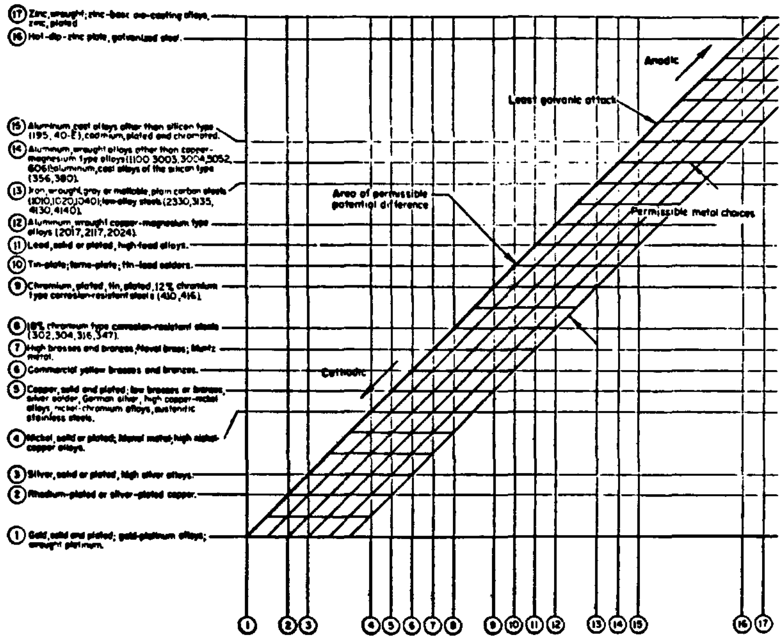
A thermal analysis of the finned Scientific-Atlanta trunk housing with outside dimensions of 9 1/2"x8 3/8"x19" is presented. To give meaning to the calculated temperatures, a curve of hybrid failure rate multipliers versus mounting surface temperature is shown as Figure 3. The analysis is segmented with the temperature rise associated with each discrete thermal resistance, as shown in Figure 4, presented separately.

The calculations presented are for a housing aerially mounted in 50°C (122°F) environment with the sun shining directly on the finned strand side external housing surface. The calculations show a hybrid mounting sink temperature of 76.34°C.

If the same calculations were performed for a housing painted white for added corrosion protection, an addition benefit of the white paint would be shown.

Figure 2

Galvanic Compatability of Metals



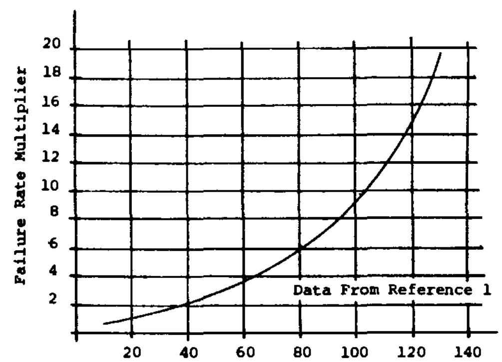
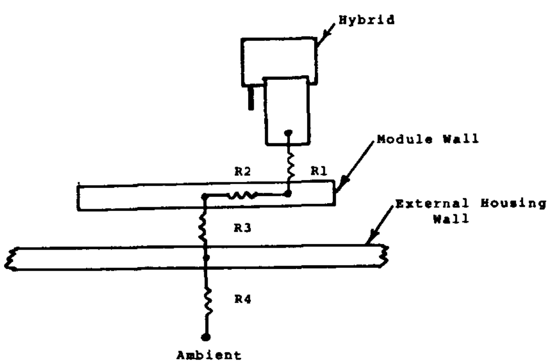


Figure 3



Thermal Resistances From A Hybrid To The Outside Environment

Figure 4

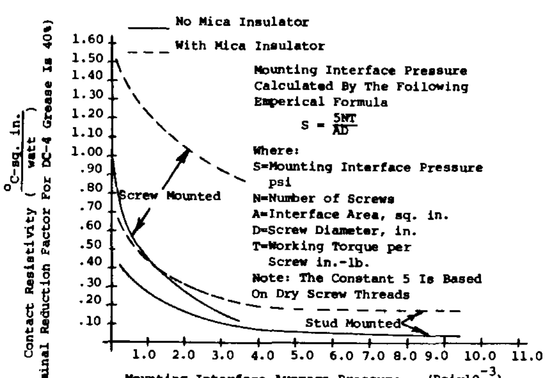


Figure 5

The temperature rise from the housing to the ambient would be reduced significantly due to the reduced solar absorptivity and increased radiative emissivity of the white paint. For a white housing, the reduced temperature rise from the housing to the ambient can be shown to lower the hybrid temperature by 8.5°C.

Pedestal mounting will cause housing temperatures to rise by placing a thermal barrier between the housing and ambient. Pedestal mounting in a TV104 will cause amplifier internal temperatures to rise approximately 20.3°C for an unpainted housing and 11.3°C for a painted housing.

The calculated temperatures presented and the operating temperature differences between the trunk amplifiers on the market take on more meaning when compared to the maximum recommended hybrid mounting temperatures and the hybrid failure rate curve shown in Figure 3. Typical maximum recommended hybrid mounting temperatures are 90°C or 100°C depending on device type; and hybrid failure rates can increase by a factor of 67% with only a 20°C increase in hybrid operating temperature (80°C to 100°C).

The amplifier analyzed has the trunk and bridger modules mounted to the finned wall of the strand-side housing half and the reverse and power supply modules mounted to the other finned outside wall. The Dual Pilot and Status Monitoring/ Bridger Switching modules are mounted to a hinged plate in the center of the housing. The total station dissipation is 52.74 watts with the following power breakdown:

400 MHz Trunk Module -	11.76 watts (two hybrids at 5 watts each)
400 MHz Bridger Module -	8.20 watts (one hybrid at 8.2 watts)
Sub-Split Reverse Module -	7.68 watts
Power Supply -	18.00 watts
Dual Pilot Module -	3.60 watts
Status Monitoring/Bridger Switching Module -	3.50 watts

The power dissipation within the station is well distributed with 23.81 watts input to the strand side housing half and 28.93 watts input to the other housing half. As may be noted from the power breakdown, the hybrids are the predominate dissipation sources within the modules with the high gain bridger hybrid dissipating 8.2 watts. The analysis will calculate the mounting temperature for this device.

The discrete thermal resistance steps from the hybrid to the outside surroundings for an aerially mounted trunk consist of the resistance from the hybrid body to the module bottom, the resistance within the module bottom as the heat spreads, the resistance from the module bottom to the external housing wall, and the resistance from the external housing to the surrounding environment. These thermal resistances are shown in Figure 4 as R_1, R_2, R_3, and R_4 respectively.

Even though the analysis presented is of a particular amplifier design and configuration, the same resistance steps occur in all trunk stations with the resistance values varying with housing design and configuration. Therefore, after calculation of each discrete resistance and temperature rise, the critical parameters determining the resistance will be listed to aid qualitative comparison of units.

R_1 (Hybrid To Module Wall Resistance)

There is a thermal resistance associated with the contact interface of any joint through which heat must pass. The resistance and temperature gradient are given by:

$R = rc/A$ and

$\Delta T = R \times q$ where:

R = Thermal resistance (°C/watt)

rc = Contact resistivity $\left(\frac{°\text{C-sq. in.}}{\text{watt}}\right)$

A = Contact area (sq. in.)

ΔT = Temperature rise across resistance (°C)

q = Heat traveling across resistance (watts)

Joint interface pressure and contact resistivity may be determined from Figure 5 for a hybrid mounted to a sink with two No. 4 screws torqued to 5.5 in.-lbs. with thermal grease applied to the interface.

$$S = 5(2)(5.5)/1.75(.3)(.112) = 935.4 \text{ psi}$$

$$rc = .50(.40) = .20\ °\text{C-sq.in.}/\text{watt}$$

$$R = .2/1.75(.30) = .38\ °\text{C}/\text{watt}$$

$$\Delta T = .38(8.2) = 3.1°\text{C}$$

As can be seen from the calculations, the important parameters are contact pressure, contact area and the presence of the thermal grease.

R_2 (Spread Resistance Within The Module Wall)

Once the heat flows from the hybrid to the module wall, it will spread prior to transfer to the external housing. There is a thermal resistance associated with the spread which results in a hot spot underneath the hybrid. The resistance is given by:

$R = {}^{L}/_{kA_c}$ where

L = Length of heat path = 1.00 in.

k = Thermal conductivity (6061 Alum. Alloy) = $5.1 \frac{\text{watt}}{^{\circ}\text{C in.}}$

A_c = Crossectional area of heat path = 2.55(.19) sq. in.

$R = {}^{1.00}/_{5.1(2.55)(.19)} = .40^{\circ}\text{C/watt}$

$\Delta T = R(q) = .40(8.2) = 3.3^{\circ}\text{C}$

In this case, the critical parameters are the heat path length and crossectional area and the module material. For a cast module, the thermal conductivity would be approximately halved doubling the temperature rise. The long narrow heat path from the hybrid to the contact area between the module and the external housing found in some amplifier designs would cause temperature gradients to increase significantly.

R_3 (Module Wall to External Housing Resistance)

To get from the module to the external housing, the heat must again cross a contact resistance, but this time without the aid of the thermal grease. Joint interface pressure and contact resistivity may again be determined from Figure 5 for a 2.55 in. by 2.00 in. area clamped by a No. 8 screw torqued to 8.0 in.-lbs.

$S = {}^{5(1)(8.0)}/_{2.55\ (2.00)(.164)} =$ 47.82 psi

$rc = 1.00\ {}^{^{\circ}\text{C-sq. in.}}/_{\text{watt}}$

$R = {}^{1.00}/_{2.55\ (2.00)} = .20^{\circ}\text{C/watt}$

$\Delta T = R(q) = .20(8.2) = 1.64^{\circ}\text{C}$

The important parameters are contact pressure and contact area. The joint resistance and temperatures rise are directly proportional to contact area and are a strong function of clamping pressure. Clamping pressure is determined by the size and number of screws mounting the module into the housing.

R_4 (Resistance From Housing to Environment)

So far, only the dissipation of the bridger module hybrid (8.2 watts) has been used to calculate the temperature rises associated with the heat path resistances. Now, to find the temperature rise from the external housing to the ambient, the total heat input to the housing half must be used. Solar load must be added to the internal dissipation of 23.81 watts to determine the total heat input to the housing half. Heat input due to sunshine is:

$q = \alpha\ A_p\ S$ where

q = Heat input (watts)

α = Solar Absorptivity (.35 - Bare Alum., .15 - White Paint)

S = Solar constant (.73 ${}^{\text{Watts}}/_{\text{sq. in.}}$)

A_p = Projected area illuminated by sun (sq. in.)

For a condition where the sun shines directly on an unpainted finned housing bottom

$A_p = 17.27\ (6.96)$ sq. in. and

$q = .35(6.95)(17.27)(.73) = 30.7$ watts

So, the total heat input into painted and unpainted housing halves would be 36.91 and 54.50 watts respectively.

During calculations of the heat path from the hybrid to the housing, only conduction heat transfer has been considered. Calculation of the heat paths from the housing to the ambient will consider conduction to spread the heat from the sink area to the other housing areas and then will consider parallel heat paths to the ambient of convection to the air and radiation to the surroundings. The external housing will be considered to consist of two discrete temperature zones. Zone one will be the housing area that directly contacts the modules and will be a housing hot spot. Zone two will consist of the remaining housing half except the input and output housing ends that will be ignored since they are remote from the sink area. Therefore, R_4 will consist of the series resistors of R_s and R_{z2} in parallel with resistor R_{z1}, where the resistance designators are defined as follows:

R_s - Resistance associated with the heat spreading from Zone 1 to Zone 2.

R_{z1} - Resistance associated with the convection and radiation paths from Zone 1 to the surroundings.

R_{z2} - Resistance associated with the convection and radiation paths from Zone 2 to the surroundings.

The total resistance R_4 can be calculated by combining the series and parallel resistances in the following way:

$$R_4 = 1/\left[\frac{1}{R_{z1}} + \frac{1}{R_s + R_{z2}}\right]$$

Calculations to determine R_s, R_{z1} and R_{z2} will now be presented.

R_s (Spread Resistance)

This resistance may be calculated by determining the conduction shape factor of the surface shown in Figure 6 that represents an external housing half with the side walls folded down. The cross-hatched area represents the sink area or Zone 1. The other areas are the unit side walls and the remaining areas of the housing bottom or Zone 2.

The conduction shape factor is defined by the equation

$R = {}^1/kC$ where

R = Thermal resistance ($^\circ$C/watt)

k = Thermal conductivity (360 Alum. Alloy) = 2.9 $^{\text{watt}}/^\circ$C-in.

C = Conduction Shape Factor (in.)

Methods for determining the conduction shape factor for surfaces similar to the one shown are defined in Section 3-4 of Reference 1. The shape factor for the housing geometry shown is 1.84 in. Therefore,

$R_s = {}^1/2.9(1.84) = .19^\circ$C/watt

R_{z1} (Resistance From Zone 1 to Ambient)

The thermal resistance associated with convection to the ambient air and radiation to the surroundings from a finned surface to its environment is:

$R = {}^1/(hcA\eta_f + hr\,A\eta)$ where

R = Thermal Resistance ($^\circ$C/watt)

hc = Convection coefficient ($^{\text{watts}}/^\circ$C-sq. in.)

A = Surface Area (sq. in.)

η_f = Fin efficiency for convection

hr = Radiation coefficient ($^{\text{watts}}/^\circ$C-sq. in.)

η = Fin efficiency for radiation

A value of hc equal to .007 $^{\text{watts}}/^\circ$C-sq. in. is given in Reference 6 for a smooth surface in a 2.0 mph breeze. The value for hr is given by the equation

$hr = \varepsilon\sigma\,(T_1^{\,2}+T_2^{\,2})(T_1+T_2)$ that can be approximated for small temperature differences by:

$hr = 4\varepsilon\sigma\,T_2^{\,3}$ where

ε = Surface emissivity (.15 - Bare Alum., .90-White Paint)

σ = Stefan-Boltzmann constant = $3.66\text{x}10^{-11}$ ($^{\text{watt}}/$sq.-in.$^\circ$K^4)

T_1 = Radiating surface temperature ($^\circ$K)

T_2 = Surroundings temperature ($^\circ$K)

The surface area of Zone 1 consists of the 6.95x7.25 inch finned housing area to which the module sinks are mounted. There are four fins that are .72 inches high and eight fins that are .97 inches high. Therefore,

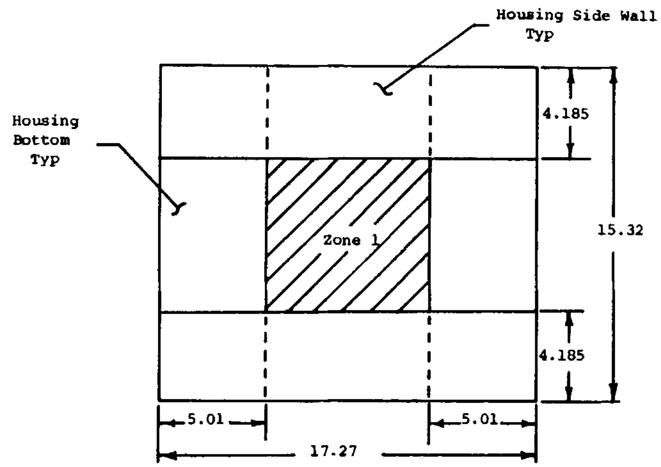
$$A = 6.95(7.25)-12(6.95)(.16) + 4(2)(.72)\left(\frac{1}{\cos 2^\circ}\right)(6.95) = +8(2)(.97)\left(\frac{1}{\cos 2^\circ}\right)(6.95) = 185.03 \text{ sq. in.}$$

Since all fins do not transfer heat with the same effectiveness, a convective fin efficiency must be defined. Convective fin efficiencies versus fin parameters are shown in Figure 7. Fins on trunk housings are typically quite efficient since a housing with extremely long and thin fins would be difficult to die cast. The fin efficiency for the housing being analyzed is

$\eta_f = .998$

The radiative efficiency of the finned area may be determined from Figure 8 and is

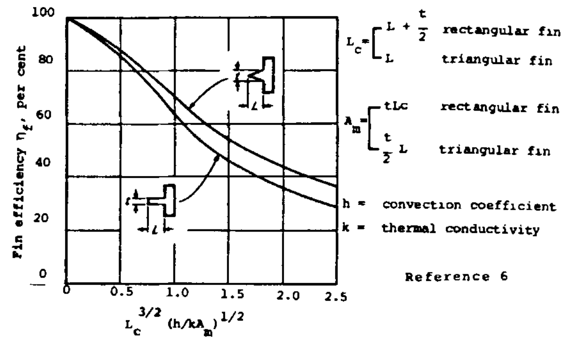
$\eta = .475$



External Housing Surface

Figure 6

Figure 7



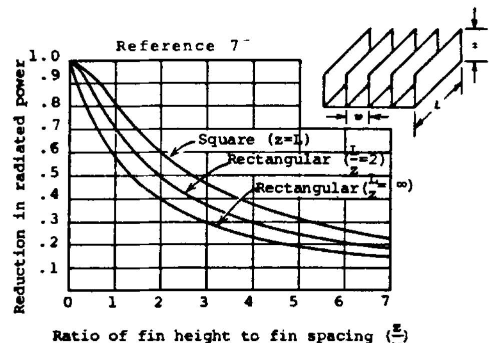


Figure 8

The analysis will be performed for a unit operating in a 50°C (122°F) environment so that

$$hr = .15(3.66\text{x}10^{-11})(4)(323)^3 = 7.40\text{x}10^{-4}\ \text{watts}/^\circ\text{C-sq.in.}$$

$$R_{z1} = {}^1/\left[(.007)(185.03)(.998) + (7.4\text{x}10^{-4})(185.03)(.475)\right]$$

$$R_{z1} = .74^\circ\text{C/watt}$$

R_{z2} (Resistance From Zone 2 to Ambient)

The thermal resistance associated with convection to the air and radiation to the surroundings from the Zone 2 area can be determined in the same way as it was for the Zone 1 area except that not all of Zone 2 is finned. The calculations are shown below

$$A\eta_f = .998\ 6.95(5.59) + 8(2)(.97)\left(\frac{1}{\cos 2^\circ}\right)(6.95) - 8(.16)(6.95) + 2(17.27)(4.185) + 6.95(4.43) = 312.94\ \text{sq. in.}$$

$$A\eta = .475\ (6.95)(5.59) + 8(2)(.97)\left(\frac{1}{\cos 2^\circ}\right)(6.95) - 8(.16)(6.95) + 2(17.27)(4.185) + 6.95(4.43) = 240.43\ \text{sq. in.}$$

$$R_{z2} = {}^1/\left[(.007)(312.94) + (7.4\text{x}10^{-4})(240.43)\right] = .42^\circ\text{C/watt}$$

Substituting into the equation to combine the series and parallel resistances

$$R_4 = {}^1/\left[\frac{1}{.74} + \frac{1}{.19+.42}\right] = .33^\circ\text{C/watt}$$

$$\Delta T = R(q) = .33(54.5) = 18.3\ ^\circ\text{C}$$

The important parameters determining the resistance and temperature rise from the housing to the ambient are the external housing area, and the length and crossectional area of the path used to spread the heat through the housing.

The hybrid sink temperature is the sum of the temperature rises plus the ambient temperature so that the hybrid sink temperature

$$T_{hybrid} = 50+18.3+1.64+3.3+3.1 = 76.34^\circ\text{C}$$

During comparison of trunk amplifier housings, the presence of some of the desired design features can be determined after a quick inspection. Unfortunately, many features that play important roles in unit service life and reliability are not easily determined. A total evaluation of expected unit performance cannot be obtained without consideration of the less obvious aspects like unit thermal design and material selections and combinations.

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