THERMAL CHARACTERISTICS OF MODERN FEEDFORWARD CATV AMPLIFIERS

Lamar West
Scientific-Atlanta, Inc.

INTRODUCTION

CATV system performance has become extremely important in recent times. Previous amplifier technologies have proven inadequate to meet the new performance demands required for competitive system operation. Feedforward technology has matured so that it can now meet these performance demands while offering reliable system operation.

Previous attempts at feedforward have been unable to operate at a sufficient level of reliability to make them practical. One of the most devastating factors limiting reliability was thermal variations. This application note deals with this problem and presents the manner in which modern single hybrid approaches have eliminated it.

SECTION I: STATION THERMAL CHARACTERISTICS

The reliability of the active components within a trunk station is directly related to the average component operating temperature. The introduction of feedforward has resulted in a significant increase in the power dissipation of a trunk station. Consequently, thermal design of the station has become a significant factor in station performance and reliability.

The following is a brief presentation of the thermal analysis of a particular trunk station (Scientific-Atlanta) loaded with feedforward electronics. The presentation deals with a fully loaded station under extremely severe operating conditions and therefore is intended as a worst case analysis. Most station configurations will result in significantly lower power dissipations and operating temperatures due to less electronics and lower ambient temperatures. Moreover, the conclusions drawn may not be applicable to other manufacturer's equipment.

The calculations presented are for a housing aerially mounted in a 50°C (122°F) environment with the sun shining directly on the finned strand side external housing surface. The solar radiation absorption encountered in this configuration is approximately equivalent to assuming an ambient temperature environment of +60°C (+140°F) with no solar loading.

There are four major sources of power dissipation in the fully loaded feedforward trunk station:

1.	Power Supply Module	16.3 Watts
2.	Feedforward Trunk Module	21.6 Watts
3.	Feedforward Bridger Module	20.4 Watts
4.	Reverse Module	5.3 Watts

The station is designed so that all of these modules mount directly to the finned external walls of the station. Note that this manufacturer's station has unusually large external surface area.

A fully loaded feedforward trunk station was instrumented with eleven thermocouples so that internal temperatures could be measured. A twelfth thermocouple was used to measure the ambient temperature. Measurements were taken at +21°C (+70°F). A summary of the thermocouple locations and measured temperatures follows:

Trunk Amplifier (450MHz FF)

1. Module Air (in area of FF block) 122°f (50°C)
2. FF Block Sink (side of block near top) 126°F (52.2°C)
3. Bottom of Module Heat Spreader (under FF block) 121°F (49.4°C)
4. Housing Beneath Trunk Module 113°F (45°C)

Bridging Amplifier

5. Module Air (in area of FF block) 120°F (48.8°C)
6. Bottom of Module Heat Spreader (under FF block) 120°F (48.8°C)

Automatic Control Module

7. Module Air 130°F (54.4°C)

Status Monitoring Transponder

8. Module Air 131°F (55°C)

Transformer

9. Core 136°F (57.8°C)

Power Supply Module

10. Module Air (around voltage regulator) 128°F (53.3°C)
11. Housing Beneath Module 101°F (38.3°C)

The feedforward gain block is mounted to a module heat spreader which is in turn mounted to the outside station housing wall. The data presented above can be used to calculate thermal resistances of these interfaces. The module heat spreader is required to accommodate the modular design of the Scientific-Atlanta trunk station.

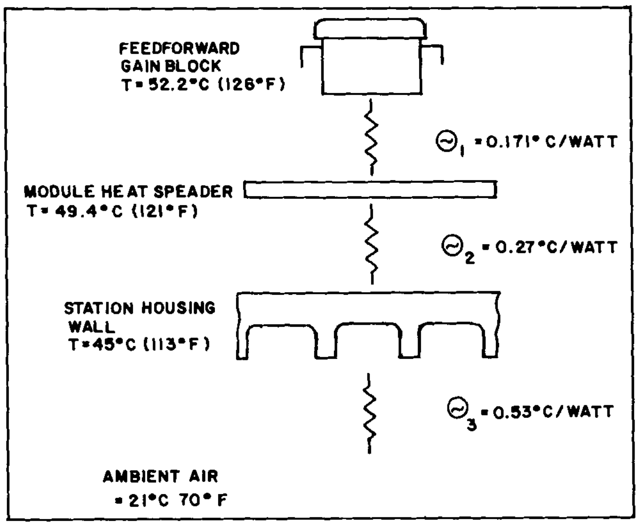

FIGURE 1

There are three forms of heat transfer within the trunk station and from the station housing to its environment - conduction, convection and radiation. Conduction and convection are essentially linear with respect to the temperature gradient (delta T) between the station and ambient. Radiation transfer is proportional to delta T raised to the fourth power (radiation becomes more efficient at higher values of absolute temperature). It has been shown that conduction is the major source of heat transfer in a trunk station. Consequently, it can be assumed as a worst case analysis that there is a constant temperature rise internal to the station with respect to outside ambient.

The measured data indicates a feedforward hybrid heat sink temperature of 52.2°C (126°F) with an outside ambient temperature of 21°C (70°F). If we assume a constant temperature delta between the inside of the station and outside ambient of 31.2°C (56°F) and we assume that the maximum ambient temperature is +60°C (+140°F) then the maximum feedforward heat sink temperature will be 91.2°C (196°F). Note: this number includes thermal input from solar radiation.

SECTION II: THERMAL CHARACTERISTICS OF THE FEEDFORWARD GAIN BLOCK

A major source of problems with previous attempts at developing a broadband feedforward amplifier for CATV applications has been the construction techniques utilized. Feedforward gain blocks consisted of two conventional dual push-pull hybrid amplifiers, two lumped element or distributed element delay lines, four discrete directional couplers and miscellaneous elements for fine-tuning response. This approach suffered from performance degradation as a result of several parameters, among which are: thermal variations, mechanical shock and time.

The single hybrid approach has the advantage of superior performance with respect to the above parameters. Hybridization has inherent to it the advantage of improved reliability over a discrete approach due to the elimination of many mechanical and electrical interfaces. The components used in such an approach are of significantly lower mass and are mounted in a manner that results in greater immunity to mechanical shock. Most importantly the package has been designed with special attention paid to thermal characteristics resulting in an actual reduction of worst case transistor die operating temperatures over a discrete two-hybrid approach.

The single hybrid feedforward package has significantly larger heat sinking surface area than the combined surface area of two conventional push-pull hybrids. The heat sinking area of a conventional hybrid approach is given by twice the heat sink area of a push-pull hybrid or (see Fig. 3):

$$\text{Area}_{hs} = 2 \times 0.320\text{in} \times 1.775\text{in} = 1.136\text{in}^2$$

The heat sink area of the single hybrid feedforward block is given by (see Fig. 2):

$$\text{Area}_{hs} = 2.068\text{in} \times 1.18\text{in} = 2.440\text{in}^2$$

or more than twice the heat sinking area.

Experimental data has been taken to confirm the superior thermal characteristics of the hybrid feedforward gain block. The details of this measurement follow:

1. Thermal Scan Fixture for the Feedforward Package

The package is mounted on a base plate in the same kind of arrangement as it is being used in the field. (Figure 4) A hole is made through the base plate and the package to monitor the infrared emitted by the transistor dice. The whole fixture is mounted on a temperature regulated base. Thermocouples, situated in the package near the base and on the base plate are used to monitor the package temperature.

2. Principle of Measurement

An infrared microscope with a 15X objective (giving a spot size of approximately 2 mils) is focused on the hottest point of each die.

A reading of the radiation emitted by the die is recorded. The power is then shut off and the whole package is brought to a temperature that gives the same reading. This temperature is the die temperature measured by the I.R. microscope.

3. Transistor Temperature in the Feedforward Amplifier

The power dissipation of the output stage transistors of the amplifier gain blocks are shown in Figure 5.

The temperature of the four transistors, Q1 through Q4, of the error amplifier have been recorded for 2 different case temperatures.

The maximum die temperature is +142°c when the feedforward case temperature is +100°c.

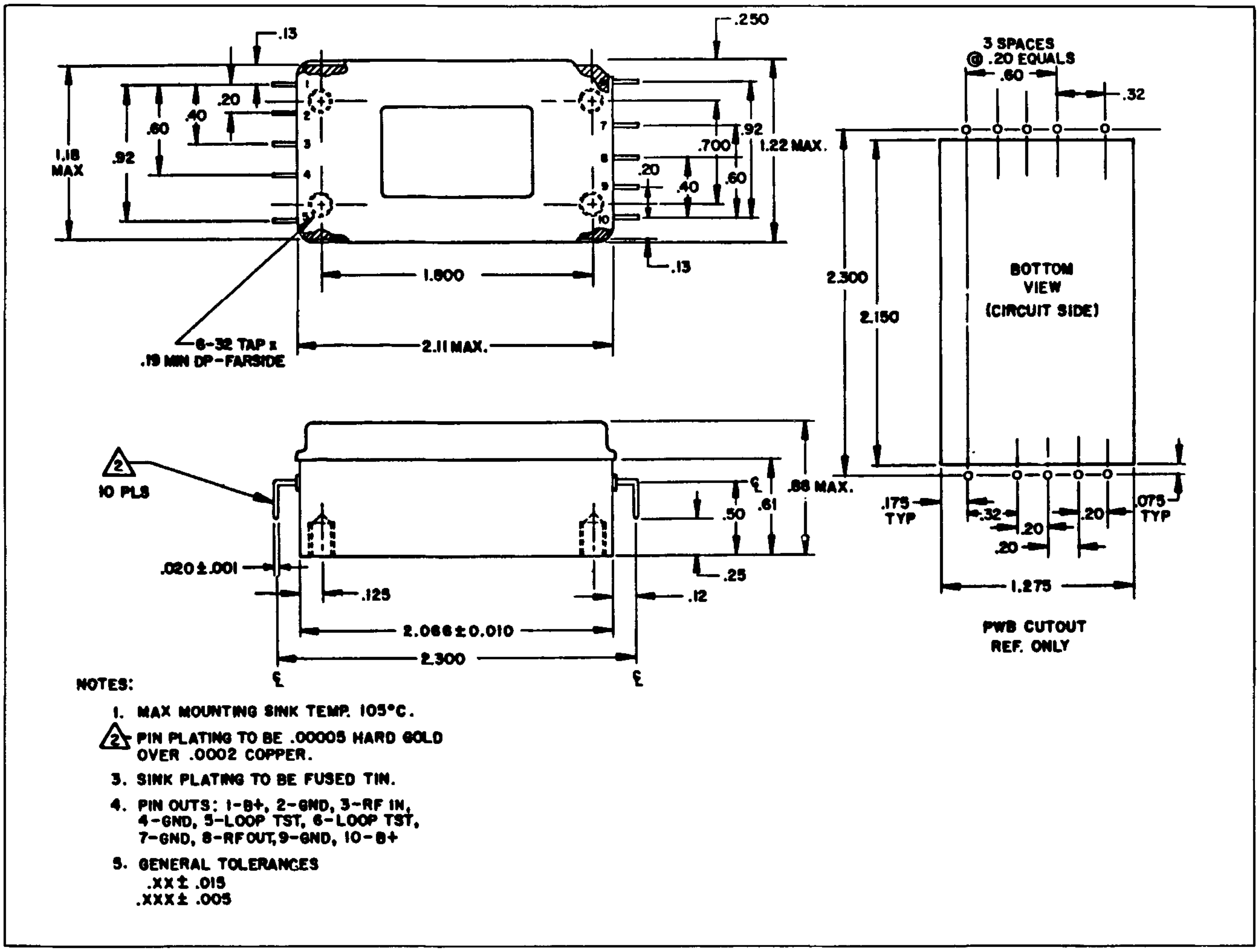

FIGURE 2

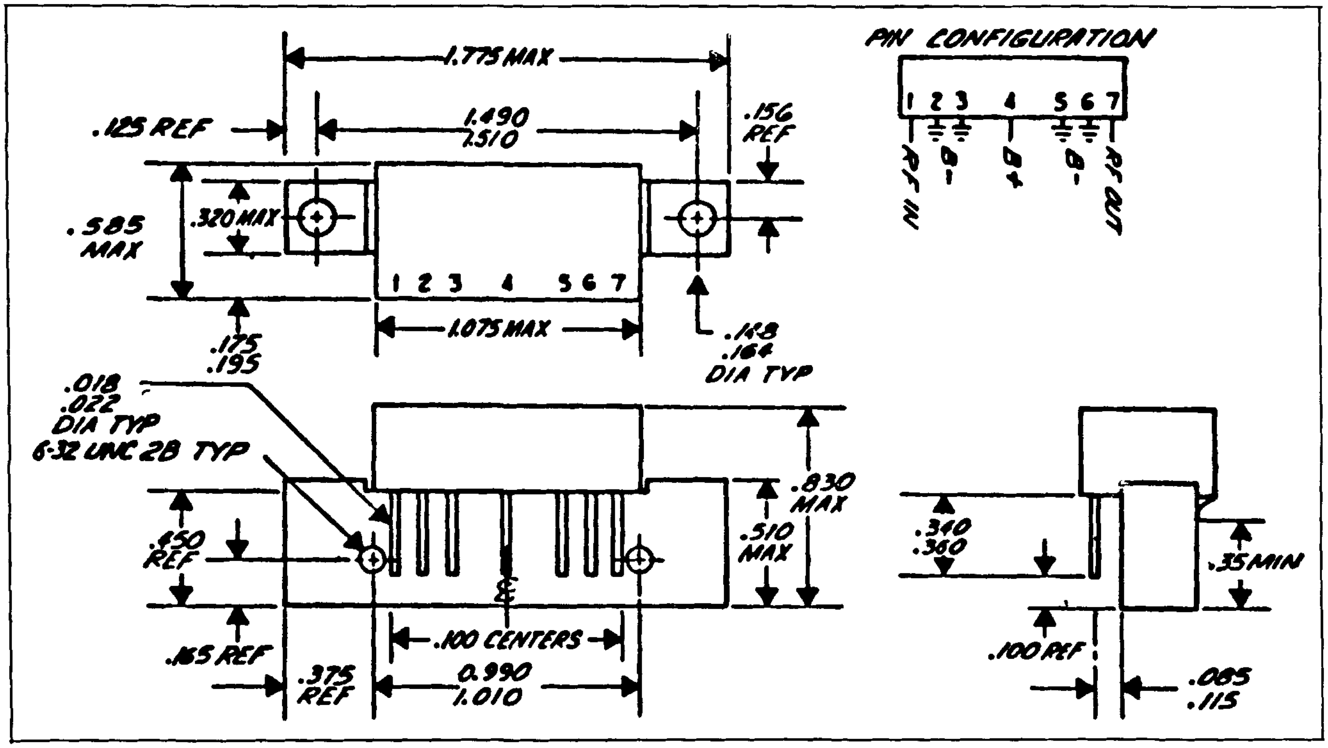

FIGURE 3

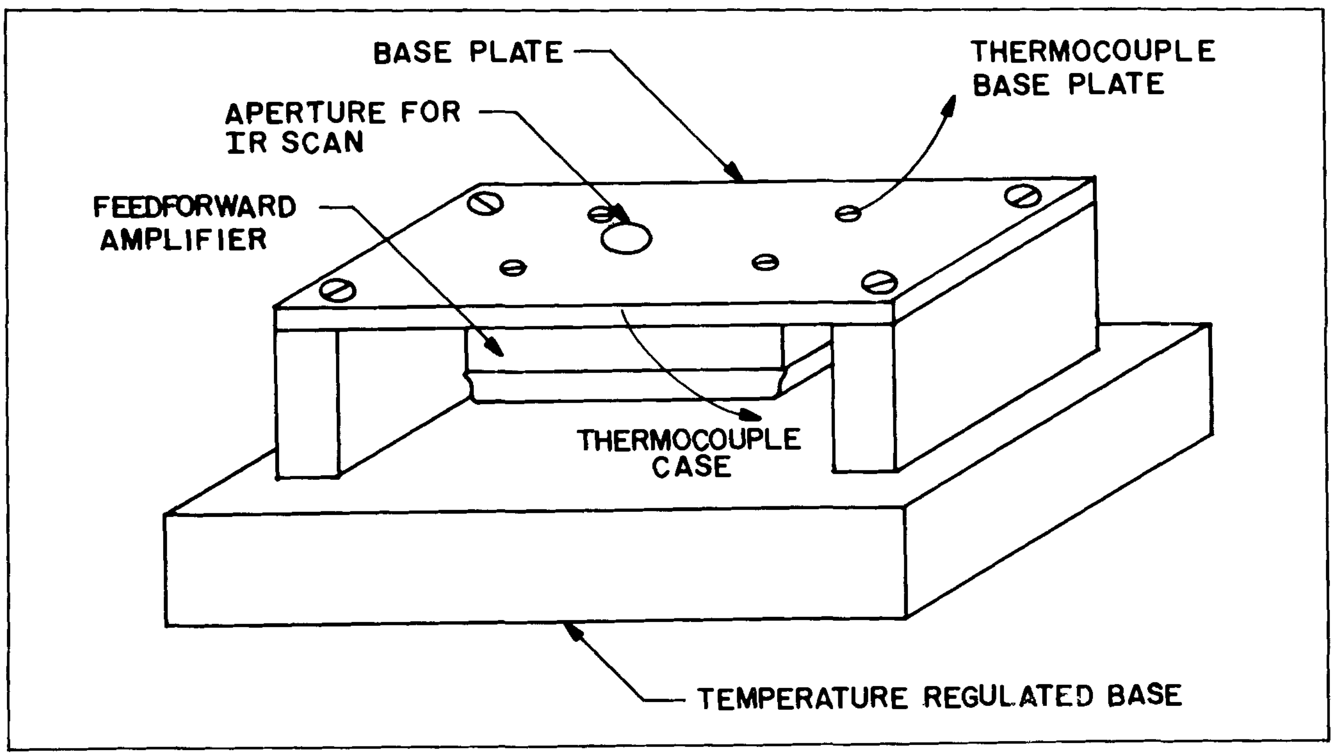

FIGURE 4 THERMAL SCAN FIXTURE FOR THE FEEDFORWARD PACKAGE

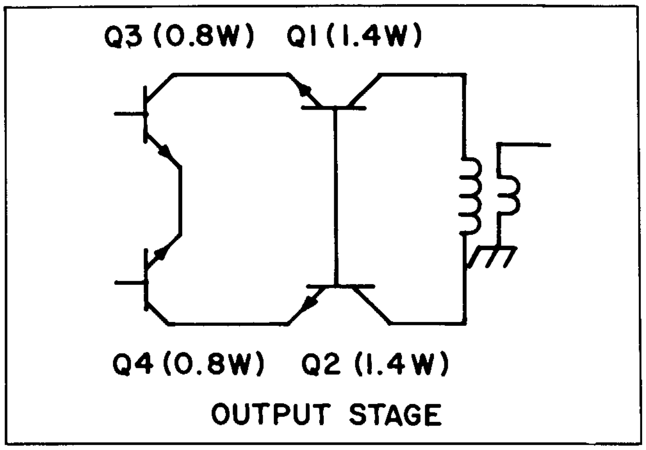

FIGURE 5
POWER DISSIPATION OF THE OUTPUT STAGE TRANSISTORS

	+65°C CASE		+100°C CASE	
	TEMPERATURE	θjc	TEMPERATURE	θjc
Q1	+100°C	25°C/W	+140°C	29°C/W
Q2	+105°C	29°C/W	+142°C	30°C/W
Q3	+ 89°C	30°C/W	+124°C	30°C/W
Q4	+ 89°C	30°C/W	+128°C	35°C/W

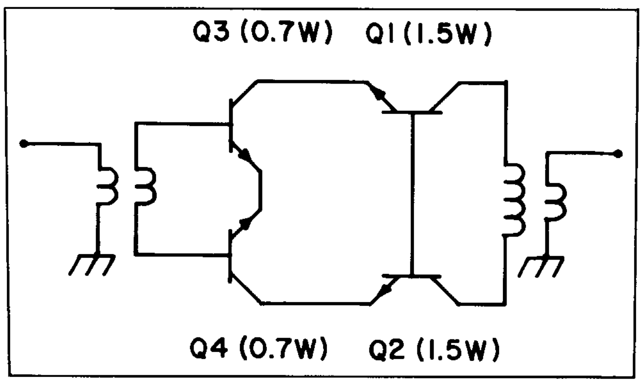

FIGURE 6
POWER DISSIPATION IN STANDARD CATV AMPLIFIERS

	+65°C CASE		+100°C CASE	
	TEMPERATURE	θjc	TEMPERATURE	θjc
Q1	+115°C	33°C/W	+151°C	34°C/W
Q2	+120°C	36°C/W	+159°C	39°C/W
Q3	+ 89°C	34°C/W	+125°C	36°C/W
Q4	+ 85°C	28°C/W	+120°C	28°C/W

4. Comparisons with Standard CATV Modules

The standard biasing for CATV amplifiers is shown in Figure 6.

Measurements were made on an 18dB gain block using the same transistors as in the feedforward amplifier. The results were:

1) Thermal resistances are on the average 4°C lower in the feedforward package than in the standard CATV package.

2) The hottest die temperature in the feedforward amplifier is 14°C lower than in a standard CATV amplifier for the same case temperature.

3) It has been shown by over two years of reliability data that a junction temperature of +150°C will result in a mtbf in excess of 142 years. The worst case junction temperature seen by the hybrid feedforward gain block mounted in a Scientific-Atlanta trunk station is significantly less than +142°C. The resulting reliability far exceeds the requirements of a CATV amplifier.

SECTION III: FEEDFORWARD PERFORMANCE AS A FUNCTION OF OPERATING TEMPERATURE.

Feedforward distortion performance is the result of extremely fine adjustment of the amplitude and phase characteristics of the two feedforward R.F. signal loops. De-tuning of these signal loops will result in a serious degradation of distortion cancellation.

Previous attempts at feedforward have been seriously impaired by the effects of temperature on the feedforward cancellation. The two hybrid push-pull amplifiers maintained their own independent thermal operating characteristics. The delay lines suffered as a result of mechanical variations from thermal expansion and contraction. Consequently, distortion cancellation suffered serious reduction as the amplifier's operating temperature changed.

The single hybrid approach to feedforward has virtually eliminated these problems. The two push-pull R.F. amplifiers are of a special design that includes thermal compensation to stabilize amplitude and phase response. Moreover, both amplifiers are mounted to the same heat sink to ensure temperature tracking. Delay lines are fabricated on a single ceramic substrate and mounted to a single heat sink for temperature tracking.

RF amplifiers and delay lines are measured in an automatic network analyzer station and matched by computer sorting. This eliminates the need for numerous manual tuning adjustments that suffer as a result of temperature variations. Hybridization also results in the elimination of interconnections and a reduction of size in components, both of which suffer as a result of thermal variations.

The hybrid feedforward amplifiers are tuned at an elevated temperature close to be the center of the operating range. This minimizes distortion degradation at both temperature extremes.

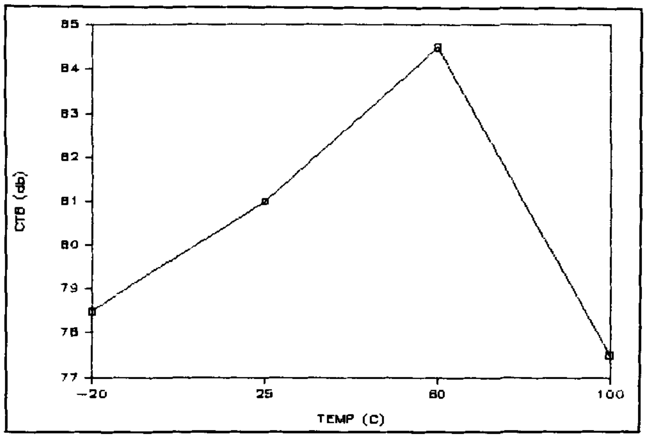

FIGURE 7

Figure 7 is a graph depicting the Composite Triple beat performance vs. heat sink temperature of a typical hybrid feedforward gain block. The measurement was made at 445.25MHz with full 450MHz channel loading at an output level of +48dBmV with +3dB of linear tilt. The graph demonstrates how tuning at an elevated temperature tends to equalize the distortion performance degradation at the temperature extremes.

CONCLUSION

The feedforward concept has been around for many years. However, only in the past year have advances in hybrid amplifier technology made a reliable broadband feedforward CATV amplifier possible.

A feedforward station design must include consideration of thermal factors as these factors impact both distortion performance and reliability. One must consider how much heat is generated and how effectively this heat is removed from the station. As the analysis indicates, when these factors are carefully considered the feedforward station becomes a practical reality.

ACKNOWLEDGEMENTS

I would like to thank Mr. Jack Powell and his saff at TRW RF Devices Division for their help in obtaining data regarding the transistor dice operating temperatures within the hybrid RF amplifier.

REFERENCES

1. Ozisik, M. Necati: Basic Heat Transfer, McGraw-Hill Book Company, Inc. New York, New York, 1977.

2. Scott, Allan W.: Cooling of Electronic Equipment, John Wiley and Sons, New York, New York, 1974.

3. Millman, Jacob and Cristos Halkias: Integrated Electronics: Analog and Digital Circuits and Systems, McGraw Hill, New York, New York, 1972.