FIELD EXPERIENCE WITH FEEDFORWARD AMPLIFIERS

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ABSTRACT

The demand for an amplifier that gives a high level of distortion immunity while providing large amounts of amplification has driven the CATV industry over the last three to four years. The introduction of feedforward technology presented a viable solution to this problem. During its infancy, feedforward presented a manufacturing challenge to the CATV suppliers who sought to participate. The development and introduction of the integral feedforward package approximately three years ago however, offered the industry an excellent opportunity to maximize cascade lengths for optimum performance while maintaining superior distortion results.

This paper will look into the areas of reliability on the integral feedforward package from the standpoint of heat transfer, and mean time between failures (MTBF). This paper will also investigate the conditions under which feedforward amplifiers are being used. Areas in this section include the economics of feedforward and how field personnel know that feedforward is offering the distortion improvements they need for their systems to function properly.

INTRODUCTION

Since the idea of feedforward was first conceived nearly twenty years ago, many indepth articles have been published on the mechanisms that make this technology so important in the CATV industry. This paper will not delve deeply into these mechanisms but provide more of an overview into where feedforward is today.

The first application of feedforward presented itself approximately four years ago when two discrete hybrid amplifiers were matched with two delay line circuits and associated tuning circuitry to form a feedforward stage. This unit presented difficulties not only for the equipment manufacturer in both gain and phase matching, but for the cable operator as well.

No longer was the cable operator allowed to luxury of field replacement of hybrid modules. If one section of a feedforward stage failed, the unit had to be returned to the factory for re-alignment.

The introduction of the integral feedforward package around three and a half years ago, however offered many advantages over the discrete approach several of which are:

- Lower die temperature than standard CATV die
- Better temperature tracking of the 4 individual sections of the feedforward stage (i.e. 2 gain blocks, 2 delay lines)
- Better and more controlled loop cancelation
- No fine tuning by the cable operator
- Better and more predictable flatness
- Better and more predictable distortion improvements
- Smaller size

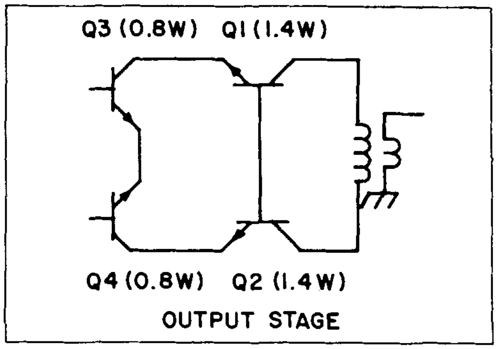
These features and others are what attracted equipment manufacturers to this concept, which revitalized feedforward. In turn, this allowed the cable operators the flexibility to realize the extra distortion headroom many of today's systems demand. However, many questions arose during the introduction of the integral feedforward package and in the feedforward concept in general. These questions consist of such concerns as the thermal properties of both the feedforward package and trunk station; how can feedforward be maximized to obtain the optimum performance versus price and finally; how are feedforward amplifiers checked for proper operation? It is these areas where we will now focus our attention.

FEEDFORWARD GAIN BLOCK AND TRUNK STATION THERMAL CHARACTERISTICS

The integral feedforward package offers a large thermal advantage over the discrete feedforward concept. The entire concept of feedforward operation is based on two RF loop cancelations. These loops consist of both amplitude and phase characteristics and any misalignment may result in reduced distortion cancellation. In the case of discrete feedforward the four individual components (2 gain blocks and 2 delay lines) could all exhibit different thermal expansion over temperature which could cause this misalignment.

The integral feedforward package however, offers thermal compensation to protect the amplitude and phase alignment. Common heat sinking of both amplifiers and delay lines are added insurance that provides the stability needed for proper cancellation.

With the mounting of all the components of a integral feedforward package to a common heatsink, the question of power dissipation of the transistor dice is brought to bear. Figure 1 shows a simplified schematic of the output stage of one of the amplifier gain blocks of a feedforward amplifier.



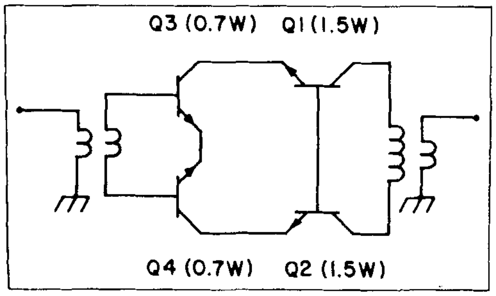
+65° C Case Temperature	OjC
Q1 +100° C	25° C/W
Q2 +105° C	29° C/W
Q3 + 89° C	30° C/W
Q4 + 89° C	30° C/W

+100° C Case Temperature	OjC
Q1 +140° C	29° C/W
Q2 +142° C	30° C/W
Q3 +124° C	30° C/W
Q4 +128° C	35° C/W

FIGURE 1

POWER DISSIPATION OF THE OUTPUT STAGE TRANSISTORS

As can be seen from the following chart, two different case temperatures were recorded for transistors Q1-Q4. When the maximum case temperature reaches +100° when the die temperature reaches +142°C. In comparison, data was taken on an 18dB push/pull hybrid utilizing the same transistors as the feedforward unit. Figure 2 shows this simplified schematic.



+65° C Case Temperature	OjC
Q1 +115° C	33° C/W
Q2 +120° C	36° C/W
Q3 + 89° C	34° C/W
Q4 + 85° C	28° C/W

+100° C Case Temperature	OjC
Q1 +151° C	34° C/W
Q2 +159° C	39° C/W
Q3 +125° C	36° C/W
Q4 +120° C	28° C/W

FIGURE 2

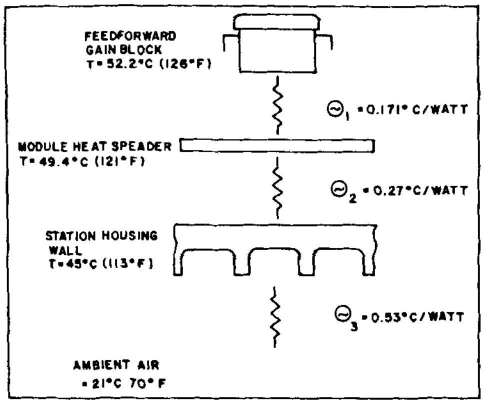
POWER DISSIPATION IN STANDARD CATV AMPLIFIERS

This data shows that on an average the thermal resistance of feedforward is 4° C/W lower in feedforward than in a push/pull package and that with similar case temperatures, feedforward shows a lower die temperature of 14°C over push/pull.

The next consideration that must be given is provide a path to convey the heat produced by the feedforward package to the external air. As with any active components the reliability is based on the average component operating temperature. Since feedforward results in a larger power dissipation than push/pull circuits, equipment manufacturers had to pay special attention to trunk station thermal design.

In the case of a Scientific Atlanta trunk station, the feedforward block is mounted to a heatsink located on the amplifier module. This in turn is mounted to the finned outside station housing wall. Figure 3 shows this mounting configuration

FIGURE 3



With an outside ambient temperature of 21° C (70° F) the feedforward heatsink temperature will be 52.2° C (126° F). If the assumption is made that a constant temperature difference of 31.2° C (56° F) holds between the outside ambient air and the inside of the station then the maximum feedforward heat sink temperature will be 91.2° C (196° F) when the outside ambient temperature reaches 60° C (140° F).

Reliability data accumulated over a three year period shows that with a junction temperature of 150° C the mean time between failures (MTBF) results in a lifetime in excess of 142 years. Since the worst case junction temperature seen in a Scientific-Atlanta trunk housing is far less than 150° C excellent reliability can be expected.

FEEDFORWARD PERFORMANCE VS. PRICE

The introduction of the feedforward technology has opened up a new arena for hardware comparisons where distortion parameters are concerned. The most common distortion limitations are Composite Triple Beat (CTB) and System Noise. The feedforward concept offers improvements in the area of Composite Triple Beat, but shows a slight degradation in noise. A trade-off in distortion parameters can be utilized by the cable operator in two ways: first in a supertrunk application where levels can be run higher to make the noise not a limiting factor and second in a combination of feedforward and push/pull amplifiers which provides a good alternative to Parallel Hybrid Amplifiers at lower costs.

In the case of supertrunk applications the operator can choose three different gain combinations of feedforward trunks allowing for higher operating levels which in turn results in a lower number of actives needed. The following example shows a system price versus end of line performance comparison with three different gain feedforward trunks (22,26 and 30dB) in conjunction with three different cable sizes (0.750,0.875 and 1.000"). The desired end of line performance is 45dB C/N and 57dB CTB.

TABLE 1

Typical Trunk Amplifier Specifications
450 MHz, 62 Channel Loading

Trunk Amplifier	Gain(dB)	CTB(dB)	NF(dB)
22dB PP Trk.	22	81	9.1
28dB PP Trk.	28	82	9.3
22dB FF Trk.	22	99	12.0
26dB FF Trk.	26	99	10.0
30dB FF Trk.	30	99	9.0

Note: Specifications Include All Loses.
All Numbers Are Referenced To 33dBmV.
All Distortion Numbers Within This Paper Are Derived From Table 1.

TABLE 2

22 dB Gain Feedforward (450MHz)
0.750"
Cable Total = 110,880 ft.
Cable Cost = $40,000
FF Trunk Total = 55 (22dB)
FF Trunk Cost = $54,000

0.875"
Cable Total = 110,880 ft.
Cable Cost = $53,000
FF Trunk Total = 50 (22dB)
FF Trunk Cost = $48,000

1.000"
Cable Total = 110,880 ft.
Cable Cost = $77,000

FF Trunk Total = 46 (22dB)
FF Trunk Cost = $43,000

System Cost With 22dB Spacing
0.750" = $ 94,000
0.875" = $101,000
1.000" = $120,000

TABLE 3

26dB Gain Feedforward (450MHz)
0.750"
Cable Total = 110,880 ft.
Cable Cost = $40,000
FF Trunk Total 48 (26dB)
FF Trunk Cost $48,000

0.875"
Cable Total = 110,880 ft.
Cable Cost = $53,000
FF Trunk Total = 42 (26dB)
FF Trunk Cost = $42,000

1.000"
Cable Total = 110,880 ft.
Cable Cost = $77,000
FF Trunk Total = 38 (26dB)
FF Trunk Cost = $38,000

System Cost With 26dB Spacing
0.750" = $ 88,000
0.875" = $ 95,000
1.000" = $115,000

TABLE 4

30dB Gain Feedforward (450MHz)
0.750"
Cable Total = 110,880 ft.
Cable Cost = $40,000
FF Trunk Total 42 (30dB)
FF Trunk Cost = $45,000
0.875"
Cable Total = 110,880 ft.
Cable Cost = $53,000
FF Trunk Total = 36 (30dB)
FF Trunk Cost = $38,000
1.000"
Cable Total = 110,880 ft.
Cable Cost = $77,000
FF Trunk Total = 33 (30dB)
FF Trunk Cost = $35,000

System Cost With 30dB Spacing
0.750" = $ 85,000
0,875" = $ 91,000
1.000" = $112,000

Now that the financial models are in place, Table 5 provides a comparison of the price of feedforward versus end of line performance.

TABLE 5

	C/N(dB)	CTB(dB)	Cost
22dB Spacing			
0.750"	44.7	55.9	$ 94,000
0.875"	45.2	57.0	$101,000
1.000"	45.7	57.6	$120,000
26dB Spacing			
0.750"	44.4	55.4	$ 88,000
0.875"	45.0	56.4	$ 95,000
1,000"	45.4	57.4	$115,000
30dB Spacing			
0.750"	43.0	54.5	$ 85,000
0.875"	43.7	55.9	$ 91,000
1.000"	44.0	56.9	$112,000

As can be seen from the data in order to meet the desired 45dB C/N and 57dB CTB while maintaining the lowest cost possible, the selection of the 22dB gain trunk in combination with the 0.875" cable would be the most appropriate.

Feedforward also provides the cable operator the ability to mix and match this technology with push/pull technology to achieve a attractive economic model while still providing quality end of line performance. This next example shows how a forty percent feedforward and sixty percent push/pull cascade provides a end of line performance of 43dB C/N and 61dB CTB for the total system.

TABLE 6

Feedforward Specifications
C/N = 60.2dB
CTB = 91.0dB
Output = 37dBmV

TABLE 7

Push/Pull Specifications
C/N = 54.9dB
CTB = 85.9dB
Output = 31dBmV

TABLE 8

Cascade Analysis
1. Feedforward Segment (8 Amplifiers)
$CTB(Csc) = (-91.0) + 20 \log(8)$
$= -72.9$
$C/N(Csc) = (-60.2) + 10 \log(8)$
$= -51.2$
2. Push/Pull Segment (13 Amplifiers)
$CTB(Csc) = (-88.0) + 20 \log(13)$
$= -65.7$
$C/N(Csc) = (-54.9) + 10 \log(13)$
$= -43.8$
3. FF(8) And PP(13) Combined
$CTB(Csc) = 20 \log(10^{-72.9/20} +$

$$10^{-65.7/20})$$
$$= 62.5\text{dB}$$
$$C/N(Csc) = 10 \log(10^{-51.2/10} + 10^{-43.8/10})$$
$$= 43.1\text{dB}$$

Table 9 next shows the price of this forty percent feedforward and sixty percent push/pull combination.

TABLE 9

40 Percent FF And 60 Percent PP
1. Price of FF Amplifier = $ 500/ea.
   Total Price Of FF = $4,000
2. Price Of PP Amplifier = $ 250/ea.
   Total Price Of PP = $3,250
3. Total Price Of 21 Amplifier Cascade = $7,250

As can be seen from the proceeding data, the mixture of feedforward and push/pull technologies offers the operator quite an arsenal to optimize his cable plant for the best performance versus cost.

FEEDFORWARD TRADE-OFFS

As with any new technology that in introduced trade-offs must sometime occur in order to realize the maximum benefits of that technology. In the case of feedforward the trade-offs are represented in the forms of flatness and in the ability to check the distortion improvement that is offered.

Where flatness is concerned the combination of two gain blocks within the same circuit, each having its own flatness, creates a unit that cannot match the flatness of the push/pull units that preceded it. When this is introduced into a trunk amplifier module a degraded module flatness specification is realized. When a cascade of these units are combined with the other irregularities of a cable plant (i.e. cable,connectors,passives etc.) the operator is hard pressed to meet the N/10 +1 (N = number of amplifiers in cascade) flatness specification that is generally used in the industry for acceptable flatness. To combat this problem, system trimming is often needed in increased numbers over a push/pull amplifier cascade.

The ability to check distortion improvements provided by feedforward can sometimes be cumbersome. Many operators feel that this level of testing is not necessary and in most cases they are right. Others however, like to keep tabs on the operation of both gain blocks within the package to truly know if the distortion improvement they paid extra money for is really there.

In the case of Scientific-Atlanta feedforward amplifiers an external test set can be utilized to check both the error and main amplifiers of the package. This is accomplished by sampling the RF signal from the output test point while providing a 4KHz square wave modulation to the feedforward power supply. If the unit is functioning properly, a pass indicator is illuminated on the test set and a fail indication if not. The test set also allows the operator to turn off and on the +24VDC supply to the individual error and main amplifiers within the package in order to see this modulation effect. With this device on similar tests, there can be no question or not of the feedforward amplifiers operation.

CONCLUSION

While not new, feedforward still confuses many people. Since its early implementation of discrete circuitry, feedforward has made great strides. The integral feedforward package offers excellent performance in terms of:

- Thermal stability and heat transfer
- Reliability
- Ease of operation
- Distortion immunity
- Economics

There are drawbacks to feedforward however, these include:

- Reduced flatness
- Larger power consumption

Overall, feedforward offers the cable operator a nice solution to today's problems faced in terms of economy versus distortion improvements. Weather in supertrunk applications or in a mix and match scheme with push/pull, feedforward has proven that it is a technology here to stay in the CATV industry.

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