SOME CONSIDERATIONS FOR APPLYING SEVERAL FEEDFORWARD GAIN
BLOCK MODELS TO CATV DISTRIBUTION AMPLIFIERS

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Abstract

Many systems are being designed with amplifiers containing Feedforward technology because of its improved dynamic range over conventional push-pull hybrids. All Feedforward amplifying stages achieve this improved distortion performance by cancelling the distortion created in the stage's main amplifier. During the process of designing a Feedforward amplifying stage for use in trunk amplifiers, four circuits were modeled that would fulfill the basic requirements of a Feedforward amplifier stage. These four circuit models are presented with the operational advantages and disadvantages of each. In addition, the performance characteristics of several trunk stations using the most advantageous Feedforward circuit models are compared to each other and to conventional push-pull type trunk stations. The performance characteristics of several line extenders using the most advantageous Feedforward circuit models are also presented.

1. Introduction

Since the advent of Feedforward technology, its operational benefits and usefulness have not been well defined. We believe some insight into Feedforward theory would be helpful. Our purpose is to answer three basic questions. These are:

1. What is the optimum Feedforward gain block configuration?
2. What is the optimum Trunk Station configuration using Feedforward gain blocks or standard push-pull hybrids in conjunction with a Feedforward gain block?
3. Is the optimum trunk Feedforward gain block also the optimum for line extender amplifiers?

2. Designing an Optimum Feedforward Gain Block

The first consideration was to evaluate several Feedforward gain block configurations. We weighed the following characteristics: Gain, Noise Figure, Distortion Performance, Maximum Reach, and Power Consumption. Figure 1 illusrates the signal path of a Feedforward stage from input to output. Each characteristic of the Feedforward amplifying stage will be discussed separately to demonstrate how performance is determined.

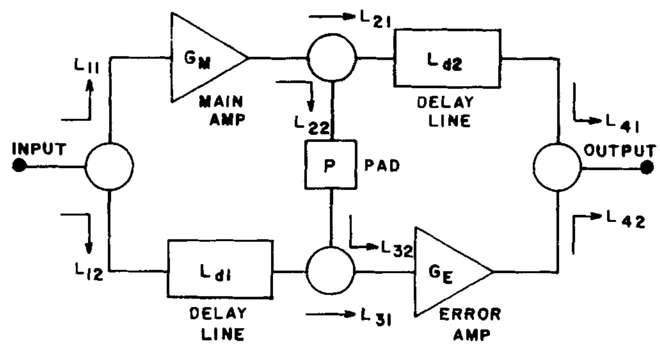


FIGURE 1
FUNCTIONAL BLOCK DIAGRAM OF A FEEDFORWARD GAIN BLOCK

2.1 Gain

The first design rule is that gain of a Feedforward Amplifying Stage equals the gain in the signal path minus incurred losses.

$$G_{FF} = G_M - L_{11} - L_{21} - L_{d2} - L_{41} \quad (1)$$

Where: G_{FF} = gain of the Feedforward Stage,
G_M = gain of the main amplifier,
L_{11}, L_{21}, L_{41} = coupler losses, and
L_{d2} = second delay line loss

The second rule is that gain of the signal path input to output in the stage equals gain of the error path. This assumes $L_{21} = L_{31}$. That is:

$$G_M - L_{11} - L_{21} - L_{d2} - L_{41} = G_E - L_{12} - L_{d1} - L_{31} - L_{42} \quad (2)$$

Where: G_E = error amplifier gain,
L_{12}, L_{31}, L_{42}, = coupler

losses, and
L_{d1} = First delay line loss

Equipped with Equations 1 and 2, the circuit designer can model several Feedforward gain stages using standard hybrids for G_M and G_E. The four circuit models in Figure 2 represent the only possible configurations left to the designer, since Equation 2 limits the circuit losses.

2.2 Noise Figure

Noise Figure of Feedforward gain stage is determined by the noise performance of the error amplifier leg. Since the noise produced by the main amplifier is canceled by the first loop, the Noise Figure of a Feedforward stage can be calculated in the following manner.

$$NF_{FF} = NF_{GE} + L_{31} + L_{D1} + L_{12} \quad (3)$$

Where: NF_{FF} = Noise Figure of the Feedforward stage, and
NF_{GE} = Noise Figure of the error amplfier

2.3 Distortion Performance

Assuming that the limiting performance parameter is composite triple beat, distortion performance of the Feedforward stage is determined by the distortion produced by amplifier G_M and the distortion improvement factor K_D. Distortion improvement factor is a measure of the increase in output capability of the Feedforward stage as compared to the output capability of G_M. The amount of distortion cancelation achieved by the error amplifier loop is directly proportional to the amplitude and phase balance within loop. It has been determined that 24 to 25 dB of cancelation can be realized if the amplitude balance is within .25 dB peak-to-valley and the phase error is held within 2 degrees.[1] K_D is the distortion cancelation accomplished in the loop minus the circuit losses incurred between G_A and the Feedforward stage output. The distortion improvement factor, therefore, is:

$$K_D = \frac{24 - 2(L_{21} + L_{d2} + L_{41})}{2} \quad (4)$$

Where: K_D = the distortion improvement factor, dB

2.4 Maximum Reach

Maximum reach is the longest cascade in dB that the gain blocks can be cascaded given a specific noise and distortion performance.

The hybrids used in the Feedforward circuits have a noise figure of 6 dB and a 56 dB carrier-to-composite beat performance at +46 dBmV flat output, loaded to 450 MHz with 60 channels. Maximum reach is a system with a desired 43 dB carrier-to-noise ratio and 59 dB carrier-to-composite triple beat ratio. Maximum reach can be calculated from the following equations.

$$R_{max} = N \times G_{FF} \quad (5)$$

$$N = 10^X \quad (6)$$

$$X = \frac{Vspec - Vopt}{10} - \frac{59 - CCTBspec}{20} \quad (7)$$

$$Vopt = Vspec + \frac{43 - CNRspec}{2} - \frac{59 - CTBspec}{4} \quad (8)$$

Where: R_{max} = maximum reach in dB,
N = number of gain blocks in cascade
Vspec = specified gain block output level,
CCTBspec = Specified gain block carrier-to-composite triple beat ratio, and
CNRspec = specified gain block carrier-to-noise ratio

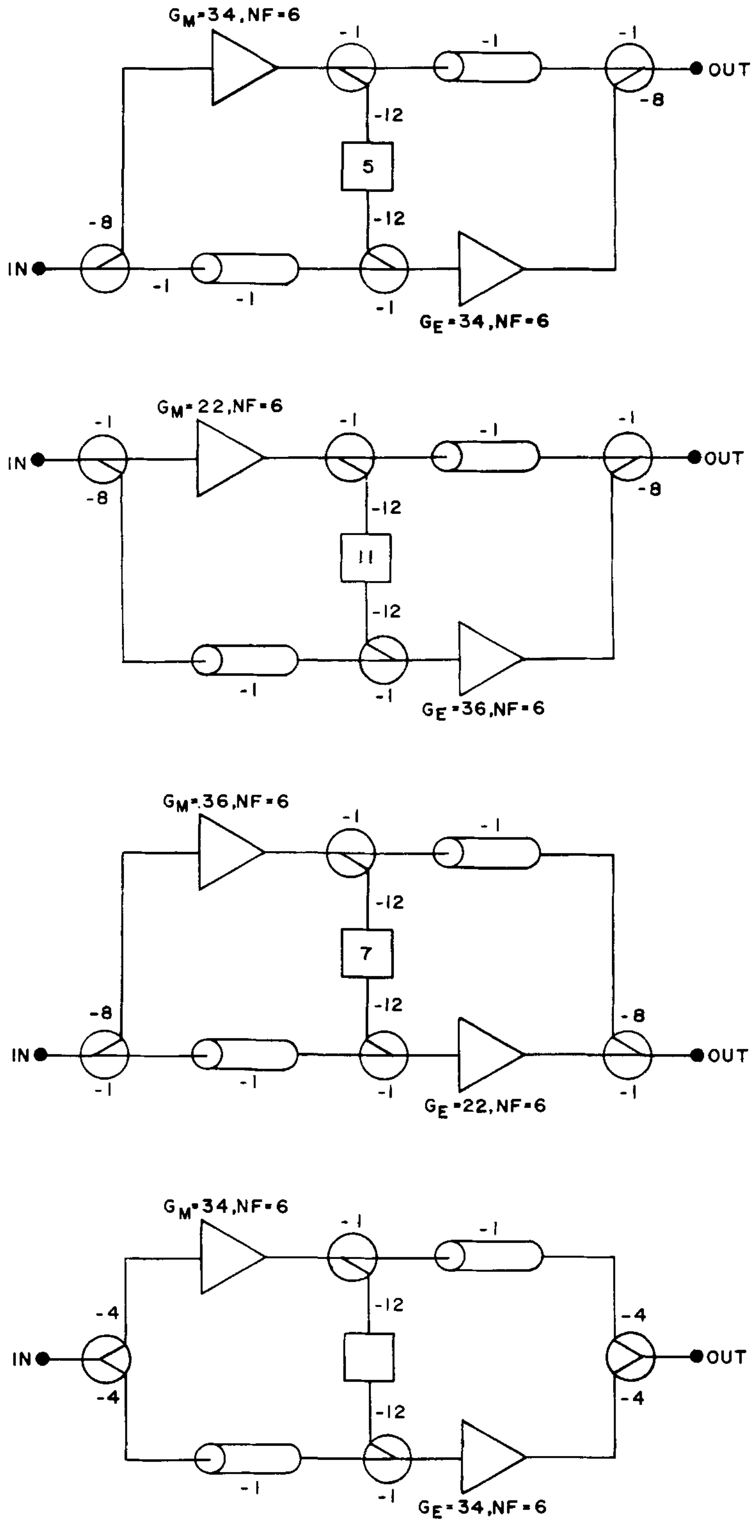
2.5 Feedforward Circuit Models

To evaluate gain block performance (Figure 2), we assume the same noise and distortion assigned to G_M and G_E gain blocks. The blocks use standard values of G_M and G_E. Then gain, K_D, N_F, power consumption, and reach are calculated using Equations 1, 3, 4, 5, 6, 7, and 8. Table 1 gives comparisons.

	FF1	FF2	FF3	FF4
Gain, dB	23	18	18	24
NF, dB	9	16	9	12
K_D, dB	9	9	2	6
R_{max}, dB	1725	846	1134	792
Power, W	16.3	13.4	13.4	16.3

TABLE 1
Comparison of Performance of Several Feedforward Gain Blocks

FF1 is, therefore, the optimum gain block; it simultaneously produces minimum noise and maximum distortion cancelation. FF1 also provides maximum cascade when analyzed for trunkline use. FF2 is also attractive, even though its noise is high. The performance of each gain block is given in Table 1.



FF1

G=23dB

NF=9dB

K_D=9dB

R_{max}=1725

P=16.3W

FF2

G=18dB

NF=16dB

K_D=9dB

R_{max}=846

P=13.4W

FF3

G=18dB

NF=9dB

K_D=2dB

R_{max}=1134

P=13.4W

FF4

G=24dB

NF=12dB

K_D=6

R_{max}=792

P=16.3W

FIGURE 2

SEVERAL FEEDFORWARD GAIN BLOCKS

3. Configuring a Trunk Station.

Figure 3 illustrates a generic trunk station with two amplifying stages, G1 and G2, and losses from housing, slope, gain, PIN Diode attenuator, and an automatic level control/bridger amplifier sampling circuit.

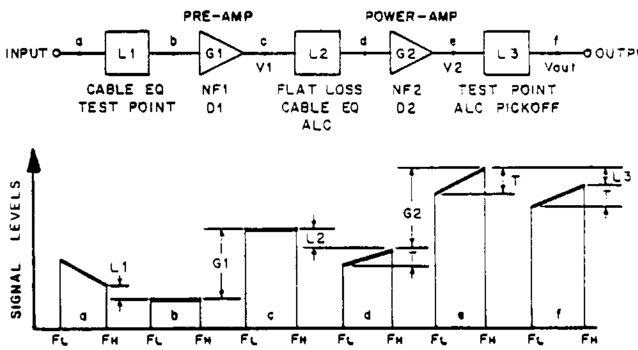


FIGURE 3
TRUNK STATION CONFIGURATION

Since FF1 and FF2 have advantages previously noted, we will model those gain stages into the trunk station in Figure 3. The distortion specifications in Table 2 were calculated by applying the distortion improvement factor, K_D, to the following equation.

$$D_{FF} = D_{GM} - 2K_D \qquad (9)$$

Where: D_{FF} = distortion of the Feedforward gain block at 46 dBmV out, 60 channels flat, and
D_{GM} = distortion of G_M at 46 dBmV out, 60 channels flat

Gain Block	Gain, dB	CCTB* dB	NF, dB	Power, Watts
FF1	23	74	9.0	16.3
FF2	18	74	16.0	13.4
GB12	12	58	8.0	4.8
GB18	18	58	6.0	5.8
GB22	22	56	6.0	5.3

*46 dBmV out, flat, 60 channels, 450 MHz

TABLE 2
Comparison of Performance of Several Gain Blocks to be Used in Trunk Design

Table 2 lists distortion performances of FF1 and FF2 as well as several standard push-pull hybrids specified at +46 dBmV out, 60 channels flat. With information from Figure 3 and Table 2, we modeled several trunk amplifiers and evaluated their performance. Trunk model evaluation was based on specifications of trunk spacing, optimum output signal level, carrier-to-composite triple beat ratio, carrier-to-noise ratio, noise figure, maximum cascade in dB maximum number of amplifiers in cascade, and power consumption. These specifications were drawn as outlined below.

3.1 Trunk Spacing

Trunk spacing is the maximum cable distance in dB at the highest operating frequency at which the station can be placed. Measured at 70°F, spacing includes all circuit losses and the reserve gain required for automatic level control.

$$GT = G1 + G2 - L1 - L2 - L3 \qquad (10)$$

Where: GT = trunk spacing,
G1 = gain of G1,
G2 = gain of G2,
L1 = 2.5 dB,
L2 = 10.0 dB, and
L3 = 1.5 dB

or,

$$GT = G1 + G2 - 14 \qquad (11)$$

3.2 Optimum Output Signal Level

Optimum output signal level is the station output level that permits maximum cascading of amplifiers while still meeting system performance requirements for both carrier-to-noise and carrier-to-composite triple beat. The trunk stations (Table 3) were optimized for a system with a carrier-to-composite triple beat ratio of 59 dB and carrier-to-noise ratio of 43 dB. To calculate the optimum output voltage for a trunk station, use Equation 8.

Where: Vspec = specified trunk station output level,
CNRspec = specified trunk carrier-to-noise ratio, and
CCTBspec = specified trunk carrier-to-composite triple beat ratio

3.3 Distortion Calculations

The station carrier-to-composite triple beat ratio, carrier-to-noise ratio, and noise figure are all determined by inserting Table 2 gain blocks into Figure 3 and calculating, on either a voltage or power basis, their distortion effect on station performance.

3.4 Maximum Trunk Reach

Maximum reach is defined as the maximum length in dB that trunk stations can be cascaded and still meet the trunk system requirements of 59 dB carrier-to-composite triple beat ratio and 43 dB carrier-to-noise ratio. To calculate maximum cascade, substitute trunk station performance for the Feedforward gain block performance in Equations 5, 6, 7, and 8.

Where: N = number of trunk stations in cascade

From Table 3, we conclude:

1. For the 31-32 dB Spaced Units. With a push-pull hybrid pre-amplifier and (FF1) output amplifier, trunk number 2 performs better than the 32 dB spaced trunk with two Feedforward stages. Power consumption in trunk station 2 is 11 watts less than trunk station 1.

2. For the 27 dB Spaced Units. The reach and power consumption of Model 4 is superior to that of 3. Model 4 requires 7.6 watts less.

No	Trunk Spacing dB	G1	G2	Maximum * Reach dB	Maximum* Cascade	Hybrid Power Watts	Vopt dBmV	Carrier-to-CTB dB	Carrier-to-Noise dB	Noise Figure dB
1	32	FF1	FF1	608	19	32.6	41.0	84.7	55.5	12.5
2	31	GB22	FF1	682	22	21.6	37.5	86.0	56.5	9.0
3	27	FF1	FF2	783	29	29.7	38.1	88.3	57.5	12.5
4	27	GB18	FF1	918	34	22.1	36.1	89.8	58.4	9.7
5	21	GB12	FF1	1050	50	21.1	34.5	93.0	59.9	12.6
6	22	GB18	GB18	704	21	12.5	29.4	89.3	58.1	8.3

*Using 43 dB CNR, 59 dB Composite Triple Beat Ratio

TABLE 3
Trunk Station Model Specifications

3.5 Power Consumption

The power consumption listed in Table 3 represents only the DC power consumed by G1 and G2.

3.6 Trunk Comparison

Table 3 summarizes performance of the trunk station models generated by installing Table 2 gain blocks into Table 3. All models are loaded to 450 MHz with 60 channels operating with a 7 dB output tilt.

Table 3 lists 21-22, 27, and 31-32 dB as three trunk spacing categories. Performance calculations assume that G1 operated at a distortion level 5 dB higher than normally encountered. We could, therefore, buffer the final trunk station performance calculation, since the input hybrid contributes to station distortion performance.

3. For the 21-22 dB Spaced Units. The dynamic range improvement of the FF1 gain block in Model 5 is reflected in the significantly improved reach.

From the Feedforward gain block modeling and performance data of the six trunk station models, C-COR proceeded to develop trunk station Models 2, 4, and 5. These stations are configured with an FF1 output gain block and a push-pull hybrid preamplifier of either 12, 18, or 22 dB to achieve spacings of 21, 27 and 31 dB.

4. Line Extenders

The line extender presents a different problem than the trunk because a gain of 34 dB is required. That gain spans the gap between +16 dBmV--the typical input level of the line extender--and the output capability limit of +50 dBmV of a Feedforward line extender. The 16 dBmV input level is mandated by the minimum signal level required on the feeder line; the 50 dBmV signal level is dictated by the non-linearity of Feedforward gain blocks operated above +46 dBmV out. Figure 4 illustrates a Feedforward line extender, and Table 4 lists performances of two models. One uses an FF1 output gain block; the other uses an FF2. For evaluation, both extenders were loaded to 450 MHz with 60 channels operating with a 7 dB output tilt. Extender distortion characteristics were calculated using the same methods for calculating trunk amplifier performance.

5. Conclusions

Answers to questions about Feedforward and its application to CATV distribution equipment follow.

1. The optimum Feedforward gain block configuration is FF1 (Figure 3).

2. The optimum Feedforward trunk station contains a standard push-pull hybrid as a pre-amplifier and an FF1 gain block as an output amplifier.

3. The optimum Feedforward gain block in line extenders is the same FF1 required for trunk application.

Model Number	Spacing dB	G1	G2	Output Level dBmV	Input Level dBmV	Carrier-to-CTB	Carrier-to-Noise	Noise Figure	Power
1	33	GB18	FF1	50	17	69.0	66.8	9.2	22.1
2	32	GB22	FF2	50	18	66.8	67.3	9.7	18.7

TABLE 4
Line Extender Model Specifications

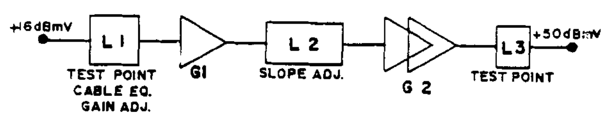


FIGURE 4
FEEDFORWARD LINE EXTENDER CONFIGURATION

From Table 4, we can conclude that Model 1 performed best, even though extender Models 1 and 2 both failed to produce the desired 34 dB extender spacing. G1 limited the distortion performance of Model 2 because of the low-gain characteristics of FF2. Although its power consumption is high, Model 1 or some similar design is the most desirable Feedforward line extender.

References

[1]Meyer, Eschenbach and Edgerley, "A Wideband Feedforward Amplifier" IEEE Journal of Solid State Circuits, December 1974.

[2]Preschutti, Joseph P., "Feedforward Gain Block Performance Criteria" Engineering Report #695, C-COR Electronics, Inc., 1981

[3]Haney, Alan P., "Feedforward Trunk Gain Block Configuration" Engineering Report #704, C-COR Electronics, Inc., 1982.