# AMPLIFIERS FOR FUTURE NETWORKS

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## Abstract

CATV distribution systems for the decade of the 90s will have new requirements placed on them to satisfy market demands for new services and higher reliability. These requirements will affect the architectures and layouts of distribution systems, and the type and performance of the RF amplifiers used in the RF portion of the distribution system.

Fiber's great bandwidth combined with shorter RF cascades opens up the possibility of using more bandwidth to provide more services to the consumer or different services to new consumers. This paper examines amplifier technologies that can be used to satisfy the requirements of new distribution systems. It also looks at migration paths for current systems so that they can satisfy future bandwidth requirements.

The performance of current amplifiers and the implications of their performance on the performance of extended bandwidth amplifiers is examined. Performance improvement opportunities within the RF amplifier will be identified. The resulting optimized amplifier performance will be analyzed.

## I. INTRODUCTION

Future Networks for the delivery of Cable Television signals will almost certainly evolve from the fiber optic based architectures being implemented now. Gone will be the long cascades of amplifiers extending from the headend to the last subscriber. Most of the amplifiers will be replaced by fiber optics. Networks built now utilizing fiber optics to replace trunk amplifiers may use fiber even more extensively as they evolve into networks of the future.

Networks of the future will carry more information. The form that this additional information will take is not yet clear, nor is the final configuration of the RF distribution system; but almost certainly, amplifiers will still have a critical role.

The amplifiers that remain in these future networks must be able to operate effectively in these new architectures with greater channel loadings than systems are currently carrying. The changes in technology that will allow future networks to be practical will be available in the next five years.

## II. FUTURE SYSTEM REQUIREMENTS

Many of the networks of the future will be based on the combined fiber and RF architectures, some of which are being built now. These combined fiber and RF architectures are often call Fiber to the Feeder (FTF). Both FTF systems and the future networks have the following common goals:

1. They must be cost effective so that they justify their capital investment.

2. They must deliver reliable service

3. They must deliver high quality pictures

In addition to the above, FTF systems can have an unique goal:

4. They must have a path to the future. The fiber and RF design and equipment of the FTF plant must lend itself to being reconfigured to meet the future network requirements without the need for a complete rebuild.

Future networks also have an unique goal:

5. They must deliver more information than systems currently carry.

The form this additional information will take will vary, but almost certainly it will require the provision of additional bandwidth in the distribution system. Bandwidths of up to 1 GHz have been proposed.

The exact mechanism of a 550 MHz FTF system upgrade to 1 GHz is not discussed in this paper, but because an upgrade appears to be the most cost effective means of ensuring a cost effective transition between 550 MHz and 1 GHz, some aspects of this paper are based on an upgrade scenario.

## III. FUTURE AMPLIFIER REQUIREMENTS

The amplifiers used in future systems are essential for the achievement of these systems goals. The amplifiers used in these future networks must satisfy the following requirements:

1. They must have the highest output capability for the lowest cost to ensure cost effective systems.

2. They must operate reliably in these two areas:
   a. ability to operate without failure (MTBF)
   b. ability provide consistent performance (especially distortion) over a wide range of environmental and system conditions

3. They must amplify signals up to 1 GHz

4. They must perform at performance levels higher than those of current 550 MHz RF amplifiers

The future performance requirements of amplifiers are going to be influenced by:

1. Costs of fiber links

2. The performance of fiber links.

3. The maximum number of subscribers that can be served from one fiber receiver.

4. Cost of 1 GHz amplifiers

5.   The type of signals to be carried.

The cost of 550 MHz fiber links may well decrease over the next five years but this decrease could well be offset by the increased cost of the fiber equipment required to carry the additional signals up to 1 GHz. Also performance improvements in 550 MHz fiber links over the next five years may be offset by the performance degradation caused by the increased channel loading. These two factors affect the depth of penetration into the network of fiber optics, and therefore the number of amplifiers in cascade.

The type of services being offered in future networks will also determine the number of amplifiers in cascade after the fiber receiver. To provide videostore like services, the number of potential subscribers fed from one fiber receiver may have to be limited. FTF systems today may feed up to 2,000 or more potential subscribers from 3 or 4 amplifier cascades. Future signal delivery requirements may limit this number to 500 subscribers and thus reduce the RF amplifier cascade.

Amplifier cost will go up as the bandwidth goes from 550 MHz to 1 GHz. Required features such as Automatic Level Control (ALC) along with other extended manufacturing bandwidth requirements will make 1GHz amplifiers cost more than 550 MHz amplifiers.

Two different signal type scenarios are being discussed for use in future networks:

1.   Full loading of 50 MHz to 1 GHz with 6 MHz spaced NTSC channels (approx 151 channels).

2.   Loading 50 MHz to 550 MHz with 77 6 MHz spaced NTSC channels and loading of 550 MHz to 1.0 GHz with digital or FM signals.

The net effect of all these factors on amplifiers is that RF amplifier cascades must be reduced. A one GHz RF amplifier will have to perform with better output capability than its 550 MHz counterparts so that the overall system cost and performance targets can be met.

To quantify this performance improvement an analysis of Composite Triple Beat (CTB) performance requirements follows:

## Amplifier Requirements for Full 1 GHz Channel Loading

The 151 channel loading requirement represents an increase in the average amplified power level over that of a 77 channel loading. The effect of this increase on Composite Triple Beat (CTB) can be theoretically calculated using the following formula:

$$Loading\ CTB_{increase} = 20 \times \log\left(\frac{\#\ of\ 1\ GHz\ channels}{\#\ of\ 550\ MHz\ channels}\right) \quad (1)$$

Assuming a 77 channel 550 MHz loading and a 151 channel 1 GHz loading, the increase in CTB becomes:

$$Loading\ CTB_{increase} = 20 \times \log\left(\frac{151}{77}\right) \quad (2)$$
$$= 5.8\ dB$$

This equation assumes amplifier behavior is predictable. The reality may be worse than

this calculation shows. A beat pile up calculation shows a four fold increase in the number of beats in a 1 GHz system over the number in a 550 MHz system indicating a 12 dB increase in CTB. The maximum number of beats occurs in the area where hybrid amplifier's transistors will be most linear, so the actual measured change in CTB from 77 to 151 channels will be from 5.8 dB to 12 dB.

Higher amplifier output levels will be required at 1 GHz to overcome the higher losses that will occur in an upgrade from a 550 MHz system.

In an upgrade from a 550 MHz FTF system to a 1 GHz system, a 7.5 dB cable spacing between amplifiers at 550 MHz has been assumed. At 1 GHz this cable spacing would be 10.4 dB (for .500" PIII cable). The increase in amplifier output level to compensate for this would be:

$$Cable\ Output\ Level_{increase} = 10.4 - 7.5$$
$$= 2.9\ dB \quad (3)$$

In addition an increase in flat loss of 2.6 dB has been assumed which would have to be overcome by an increase in amplifier output level. To fully compensate for the increased losses in an upgrade situation, an amplifier would have to operate at a higher output level. This output level would be equal to the sum of increase cable loss (3) plus the 2.6 dB increase in flat loss:

$$Output\ Level_{increase} = 2.9 + 2.6 \quad (4)$$
$$= 5.5\ dB$$

The CTB increase because of this increase in output level would be:

$$Output\ Level\ CTB_{increase} = 2 \times 5.5 \quad (5)$$
$$= 11.0\ dB$$

The amplifiers of a future network might have to compensate for the fiber link. If AM fiber is used, the increased channel loading at 1GHz will cause an increase in CTB. If the optical system itself does not degrade significantly with 151 channel loading, the RF portion will. AM light to RF receivers contain RF amplification. Assuming the optical system does not degrade significantly when the loading changes from 77 to 151 channels, the RF section will degrade as shown below:

$$Fiber\ CTB_{increase} = 20\,x\log(\frac{151}{77}) \quad (6)$$
$$= 5.8\ dB$$

To compensate for these increases in distortions with 151 channels (from 77 channels) some system operating conditions would be changed. The RF amplifier cascade would be reduced, most likely by a factor of two. The improvement in CTB for a halving of the amplifier cascade (assuming amplifiers of equal performance) is:

$$Cascade\ CTB_{decrease} = 20\,x\log(\frac{1}{2}) \quad (7)$$
$$= -6.0\ dB$$

FTF systems operate at 550 MHz with 9 dB of amplifier output tilt typically. Systems built for 1 GHz will operate with increased amplifier output tilt (this is possible because the RF amplifiers are not the CNR limitation) as much as 12.0 dB has been proposed. The improvement in CTB because of the 3 dB increase in amplifier output tilt would be:

$$Tilt\ CTB_{decrease} = \frac{\Delta\ tilt}{-2}$$
$$= \frac{3}{-2}$$
$$= -1.5\ dB \qquad (8)$$

The total amplifier CTB change is the sum of the effects of the channel loading increase (2), the output level increase (5), the fiber link performance degradation (6), the reduction in RF amplifier cascade (7), and the increase in amplifier output tilt (8):

$$Loading\ CTB_{increase} = 5.8\ dB$$
$$Output\ Level\ CTB_{increase} = 11.0\ dB$$
$$AM\ Link\ CTB_{increase} = 5.8\ dB$$
$$Cascade\ CTB_{decrease} = -6.0\ dB \qquad (9)$$
$$Tilt\ CTB_{decrease} = -1.5\ dB$$

$$\overline{Total\ CTB_{increase} = 15.1\ dB}$$

To put this number in perspective, a 1 GHz amplifier would have to have 6 dB better CTB performance for a 77 channel loading than a current hybrid.

## Amplifier Requirements for 77 Channel loading with Digital and/or FM Signals

While it may seem that loading the 550 MHz to 1 GHz spectrum with a combination of Digital and FM carriers would minimize the additional performance requirements of the RF amplifiers, the opposite is true.

Firstly, the 77 NTSC channels in the 50 to 550 MHz band will generate significant distortion products in the 550 MHz to 1 GHz band. The Digital and FM signals will be fundamentally more immune to these distortions than NTSC signals. However, the Digital and FM signals will operate at lower levels than the NTSC channels and so some improvement in amplifier distortion performance above 550 MHz will be necessary to ensure adequate signal quality.

Secondly the Digital and FM signals while operating at lower levels than the NTSC signals will add to the total amplifier output power and will produce additional distortion products. Whether these distortions appear as discrete carriers or as a general increase in the system noise floor will depend on nature, number and type of these signals (and will also depend upon picture content). Regardless of whether these distortions are discrete or widespread, the RF amplifiers will have to operate at higher levels of distortion performance than current 550 MHz amplifiers.

To understand how amplifiers of the future will be able to meet the performance criteria of future networks, it is important to understand what limits the performance of current 550 MHz amplifiers.

## IV. CURRENT AMPLIFIER PERFORMANCE

Current 550 MHz RF amplifiers are not well optimized, they represent older technology that has been stretched from 300 or 450 MHz. Hybrid suppliers traditionally receive the blame for the performance limitations of our amplifiers. Some of this blame is well placed. Amplifier are presently being produced with power doubler hybrids with 77 channel CTB performance of 63 to 67 dB (at 44 dBmV flat output). As much as 5 dB of CTB is lost in the hybrid due to splitting and combining inefficiencies. The cost of RF amplifier hybrid production is directly related to the performance requirements and the hybrid supplier's yield of

that product. Only 50% of transistors produced by a hybrid manufacturer can be used in hybrids to meet present performance requirements. New generation transistors for use in RF hybrids are designed more to improve hybrid supplier's yields than to advance the technology by increasing bandwidth or improving hybrid distortion performance.

However, not all of the blame for current amplifier performance lies with the hybrid suppliers. Amplifier manufacturers count on hybrid suppliers to improve the hybrids before we improve our amplifiers. For instance the input hybrid of an amplifier typically has a 5.5 dB noise figure. The amplifier that these hybrids are used in are specified with a noise figure of 9 dB. The 3.5 dB of carrier to noise performance is lost due to the input test points, diplex filter, output stage contributions, circuit inefficiencies within the station (see Figure 1.) and specification headroom taken by the amplifier manufacturer to ensure production yields.

Interstage losses (Interstage Gain Control and Pin Diode Attenuator) can be as much as 8 dB at 550 MHz. A reduction of these losses by 2 dB can reduce the gain requirement of the input hybrid resulting in better amplifier distortion performance.

Output losses directly affect the distortion (CTB, CSO etc.) performance of the amplifier. These distortions are primarily produced by the output hybrid U2 (see Figure 1.). An output hybrid has to overcome the output losses to deliver signals to the output ports, every dB of extra hybrid output level required to compensate for output losses represents another 2 dB degradation of the amplifier's CTB performance.

The losses of a typical 550 MHz amplifier used in FTF systems (with two outputs) are shown in Table 1. The insertion losses of the same devices at 1 GHz are also listed. Amplifier performance at bandwidths greater than 550 MHz will suffer from the same production limitations as does 550 MHz equipment.

## V. AMPLIFIERS FOR FUTURE NETWORKS

If a 1 GHz amplifier were to be built using the 1 GHz losses shown in Table 1., internal losses would increase by:

$$Internal\ Loss_{increase} = \sum 1\ GHZ_{losses} - \sum 550\ MHz_{losses} \quad (10)$$
$$= 20.5 - 17.5 = 3.0\ dB$$

In addition the amplifier would have to overcome the additional losses of the system at 1 GHz (4). This would mean a total increase in gain of the amplifier's hybrids of:

$$Hybrid\ Gain_{increase} = Internal\ Loss_{increase} + System\ Loss_{increase}$$
$$= 3.0 + 5.5\ dB = 8.5\ dB \quad (11)$$

Therefore 18 and 22 dB gain hybrids used today for 550 MHz operation would have to be replaced with 22.5 dB and 26 dB gain hybrids respectively for 1 GHz operation.

The output loss increase alone of such an amplifier would be 1.5 dB which means that the output hybrid of the 1 GHz amplifier must have 3 dB better CTB performance than its 550 MHz counterpart. Combined with the required 5.5 dB higher output level required to overcome higher system losses (4), the total CTB improvement of the
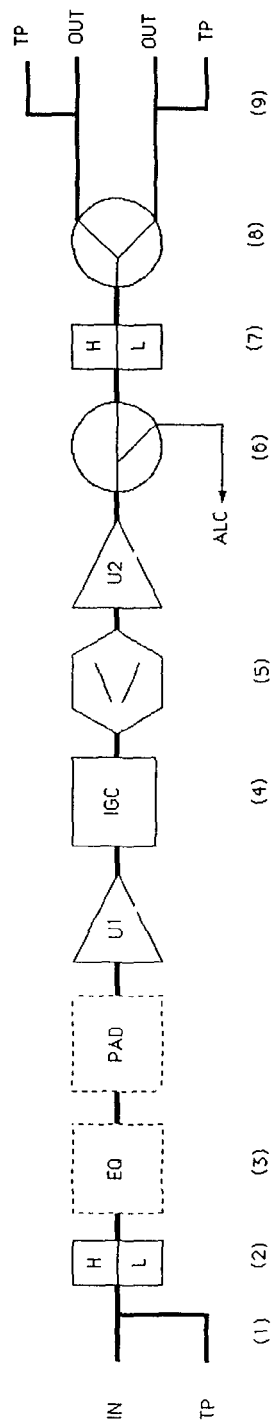
Figure 1. Amplifier Block Diagram

## Table 1. Typical 550 MHz Amplifier Circuit Losses

| Block Diagram Ref # | Component Description | dB Loss @ 550 MHz | dB Loss @ 1 GHz |
|---|---|---|---|
| (1) | Input Test Point | 0.75 | 1.0 |
| (2) | Diplex Filter | 0.5 | 0.75 |
| (3) | Equalizer | 1.0 | 1.0 |
| (4) | Interstage Gain Compensator | 1.0 | 1.0 |
| (5) | Pin Diode Attenuator | 7.0 | 8.0 |
| (6) | ALC Pick Off | 1.5 | 2.0 |
| (7) | Diplex Filter | 0.5 | 0.75 |
| (8) | Two way splitter | 4.5 | 5.0 |
| (9) | Output Test Point | 0.75 | 1.0 |
| | TOTAL INSERTION LOSS | 17.50 | 20.50 |

## Table 2. Optimized Amplifier Circuit Losses

| Block Diagram Ref # | Component Description | dB Loss @ 550 MHz | dB Loss @ 1 GHz |
|---|---|---|---|
| (1) | Input Test Point (eliminated) | 0.0 | 0.0 |
| (2) | Diplex Filter | 0.2 | 0.2 |
| (3) | Equalizer | 1.0 | 1.0 |
| (4) | Interstage Gain Compensator | 1.0 | 1.0 |
| (5) | Pin Diode Attenuator | 4.5 | 5.5 |
| (6) | ALC Pick Off | 0.6 | 0.8 |
| (7) | Diplex Filter | 0.2 | 0.2 |
| (8) | Two way splitter | 3.5 | 3.75 |
| (9) | Output Test Point | 0.75 | 1.0 |
| | TOTAL INSERTION LOSS | 11.75 | 13.45 |

Reference Numbers refer to Figure 1.

output hybrid would have to be:

$$Output\ Hybrid\ CTB\ \Delta = 3 + 11 \quad (12)$$
$$= 14\ dB$$

If 1 GHz amplifiers were built with the insertion losses listed in Table 1., the hybrids required would be very expensive and draw large amounts of power and could not be developed based on the next generation of RF transistors. The lack of optimization of current 550 MHz amplifiers, the performance required for extended bandwidth amplifiers can only be achieved by selecting and optimizing the active and passive devices used to construct them.

## Optimized Amplifiers for Future Networks

The most significant area of optimization is the output losses between the output hybrid U2 (see Figure 1.) and the output ports of the amplifier housing. Every dB of reduction is nearly 2 dB of CTB performance improvement. A 2.5 dB reduction in these losses improves the amplifier's CTB performance by 5 dB. A reduction of 2.5 dB in interstage losses has the same distortion effect as replacing U1 (see Figure 1.) with a power doubler hybrid. In addition to improving distortion effects of the station pre-amp, interstage optimization reduces the power consumed by the station by as much as 7 Watts. Further optimization reduces gain requirements of the hybrids which results in further distortion improvements and increased gain stability versus temperature.

Table 2. represents optimized losses for the amplifier shown in Figure 1. The insertion losses are optimized for 1 GHz, and show the effect on 550 MHz losses. The input test point has been eliminated to help achieve this optimization.

Optimization is the process of maximizing the performance of each circuit in the amplifier. As can be seen tenths of dBs can add up significantly, 7.05 dB of loss can be removed from the amplifier shown in Figure 1. Achieving the circuit optimization described in this paper has been done by computer modeling of circuits in such a manner that the computer model functions exactly as the circuit functions when tested by normal sweep equipment. Computer circuit optimization is verified by bench performance test.

The selection of optimized active and passive components for a 1 GHz amplifier will result in increased cost and/or a loss of traditional features. A $0.75 transformer used in a splitter with a 5.5 dB loss at 1 GHz could be replaced by a $1.50 transformer and give an insertion loss of 4.0 dB at 1 GHz.

Applying the same techniques to the amplifiers active amplification stages would improve CTB, CSO and noise performance of the amplifier and also the RF portion of the fiber link.

## VI. CONCLUSION

1. Future networks will need RF amplifiers with increased bandwidth and distortion performance capabilities regardless of the type of additional channel loading.

2. 1 GHz amplifiers built using techniques in use today will require active devices that are many years (perhaps a decade) away from being available.

3. Active and passive component optimization with an RF amplifier will allow practical 1 GHz amplifier designs to realized within a few years.