ON THE USE OF FEEDFORWARD TECHNIQUES

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ABSTRACT

Feedforward techniques as applied to system operation are discussed. Cost benefit data is given, with particular emphasis toward rebuild and bandwidth extension situations.

INTRODUCTION

The cable television industry has progressively required more linearization and bandwidth from its amplifiers. The concomitant channel loading describes some onerous requirements for distortion handling capability for both new build and system expansion applications.

The industry has crossed similar thresholds several times since its infancy, the most recent being just over a decade ago when the circuit architecture went from single ended to push-pull. We are at another such cross point where it is unlikely that dramatic transistor improvements will be achieved in the short term leaving that other circuit arrangements must be utilized that give the required improvements for today's loading.

Feedforward technology as applied to our present day CATV amplifiers will do that today. The purpose of this paper is to examine some case studies that will show how the application of this technology is relevant to the problems that a system operator faces today.

PREVIOUS FEEDFORWARD WORK

The development of a wideband CATV amplifier more linear than could be obtained with push-pull methods alone was described in 1976 by Prochazka and others.[1, 2] Early hypothetical work on the application of such an amplifier to the CATV operating economics was done by Henscheid and Birney in 1977.[3] Some of the first applications of hardware were recorded by Evans and Rhone[4] in 1979. The work by Henscheid and Birney has particular relevance to these case studies and correlates reasonably well.

CASE STUDY DESCRIPTION

The purpose of the studies was to examine the economics of feedforward linearization as applied to some given practical situations. It was also desired to examine the use of feedforward techniques to relieve dependence on coherent carrier techniques in dealing with composite triple beat distortion in extended bandwidth systems. Particular desire to maintain system transparency for services other than NTSC television[5] (such as high definition television) motivated the preference toward feedforward as opposed to coherent carrier techniques. In all cases except where specifically noted the use of HRC/IRC is not assumed or required. Its use would be optional, to achieve greater maintenance headroom.

The case studies presented represent sample designs done to aid decision making in daily practice. They were not necessarily chosen to be nationally or universally representative. The size of the sample ran from 10 to 40 miles, and included representative topography, exclusive of special or unusual areas. Cases 2 and 3 involve work done on the same area. Case 1 is a separate older study and is included to help identify historical trends.

While much data exists from these cases, only cost per mile data and certain relevant indicators are given; burdensome detail has been omitted. Readers are encouraged to structure similar cases around their existing circumstances for their own decision support.

CASE STUDIES

Case 1 involves construction of a 400 MHz system in a southwestern state considered in the summer of 1981 just as 400 MHz usage became popular. Amplifier linearity at that point was such that comparison from an all standard to an all feedforward case yielded a cost difference of about 12% for the total feedforward case. It is important to note here that IRC was mandatory in this case to meet composite triple beat (CTB) specifications. The amplifier specifications at that point were such that 400 MHz equipment could not be operated with the required distortion and noise parameters without unusually short cascades or unusually low distribution levels so as to be impractical.

This particular model was done over terrain which allowed the use of very long feeder lines without restrictions imposed by geography or mandatory trunk routing. The reduced actives count is tabulated and as a result of that reduced count the total power consumption was just about equal for the two cases. Other operating considerations were that the desired (transparent) specifications were met and exceeded without dependency on HRC/IRC techniques in the "B" case. A 450 MHz, 62 channel design today closely parallels these results.

Case 2 involved consideration of a new build in the late 1982 time frame with improved amplifier specifications to deal with, and the purpose of the case was to study the costs of one choice over another. Cases "A through D" are tabulated to show the relative cost impact for the active equipment for those four applications of feedforward technology. It is interesting to note here that in one case feedforward line extender application had a slight reducing effect on the costs for the total actives. It is necessary to point out that the model included optimization of the available technology to this particular system resulting in the choice of different gains of trunk station which reflects in the actives per mile count.

As in Case 1 the reduction in actives count made power draw virtually equal for the feedforward cases as for the standard case. Other operational considerations involve additional distortion headroom in the feedforward cases which could not be obtained without the use of coherent carrier techniques in the standard consideration. The reduction of actives count is also a significant operating consideration, though no attempt is made to quantify it.

This particular city is a typical eastern seaboard city with more than normal restrictions in routing and feeder line lengths and it is fair to say that all of the benefits of the longer feeder line that resulted from the use of feedforward could not be used in this layout, skewing this comparison slightly in favor of the conventional technology. It is more likely that a different topography would have yielded different results, probably more towards equal or lower costs in all feedforward comparisons to standard technology.

Case 3 involved a hypothetical bandwidth extension problem and is the heart of this discussion. There are all over the nation cable television systems operating with only a few years remaining on the present franchise, but a critical need for more bandwidth. This leads to a decision involving channel expansion techniques and their cost, which when added to the subscriber terminal costs, can exceed what may be possible to recover in the remaining franchise life. It is the purpose of this case discussion to point out that, subject to a few special considerations, it is possible to remain within the zone of good engineering practice and allocate the appropriate use of feedforward technology toward the problems that the average system operator will see in the next few years and that the application of this technology can achieve for the operator certain types of incremental bandwidth extension for proportional incremental costs. It should not be assumed that our discussion is to state a case whose technical and mechanical integrity is equal to new construction because always the desired long-term standpoint would be to reconstruct with new components, if it can be afforded. We will, however, see some acceptable compromise in this third case.

A few trends are worth examination as we consider this hypothetical case. First, almost all traditional systems, whatever their original cascade, have grown outward as the community has expanded and have approached cascade lengths of, say, 30 amplifiers. Any bandwidth extension or loading extension should consider a cascade of that depth. Second, the cost of active equipment has continued to slowly decline as a percentage of the total cost of plant construction leaving that any work that can be done with active changeouts yields the most efficient techniques for bandwidth and loading extension. Third, coaxial cables that have been manufactured within the last decade (particularly the gas injected types) are more predictable than their predecessors and, subject to an occasional malfunction of the manufacturing process, the performance of coaxial cable can be predicted and accurately projected for 50 to 100 MHz or more beyond its original frequency of use.

Empirical testing must be applied whenever this technique is considered this because certain channels may be rendered unusable because of periodic discontinuities in the cable affecting transmission in the extended bandwidth areas. The underlying assumption here is, of course, that the cable currently in existence is mechanically sound and not seriously flawed due to kinks, cracks, holes and all of the other ills of cable system operation. A separate discussion on the validity of the cable assumption is treated in Appendix 1.

Take, then, for assumption, a typical early 1970's system with an original upper bandwidth of 260 MHz, but a channel loading specification of 21 channels with a cascade of 20 trunks, 1 bridger and 2 line extenders. An operator with such a system who chose to expand the channel capacity might consider the following approach. We will assume, as previously stated, that the original cascade involving 20 trunk amplifiers has now gone to 30 and that the desired (best case) performance might be 400 MHz, 52 channels. Accordingly, as shown in 3(b), by using the existing trunk locations and feedforward technology available today in all the amplifiers by direct changeout, one might achieve that desired loading and bandwidth for an amplifier cost of about $3000.00 per mile, which correlates closely to the active costs in a new 400 MHz build. This assumes, of course, the existing cable is reused. The location of the line extenders is not necessarily considered to be the same as before. The required performance cannot be achieved with standard amplifiers.

Case 3(c) was drawn to demonstrate where the greater value of feedforward application really is, and as we would expect that value is in the higher level distribution plant amplifiers. Case 3(c) assumes the availability of a trunk amplifier with the necessary gain performance, but without assuming feedforward performance of that trunk amplifier and the summary shows that the required system performance can be met with only feedforward technology applied to the bridgers and line extenders. This yields about a 20% reduction in the total actives price, compared to 3(b).

The effect of this is substantial; it means that existing cable television systems can be fully modernized without disregard of good engineering practice. It means that cable television systems can be upgraded for costs that are more in line with what operators can realistically afford and facilitate rapid expansion in all of their plants and it means that the system architecture need not be radically changed to introduce multiple hubs, microwave, FM, multiple cable, or other transportation methodologies. There are, however, some considerations that must be taken into account such as the accumulation of inbound noise (and ingress) in a plant that was intended to be retrofitted for interactive operation, but there are adequate techniques to deal with those problems.

The opportunity for this type of incremental bandwidth extension and the opportunity to maximize the cost benefit from it rests with a larger than presently available family of equipment to be manufactured giving housing compatibility, especially in the distribution amplifiers. It is very likely that as a practical matter, an operator wouldn't push toward the full loading that has been shown in cases "B and C" from operation where only 21 channels had been possible before, but even a channel doubling for the costs that are suggested is quite a cost effective upgrade.

CONCLUSIONS

The purpose of this paper has been to show the following:

1. New designs with typical cascade depths at 450 MHz require the use of feedforward technology in order to be totally transparent.
2. Except with unusual system topography, the use of feedforward techniques is quite cost effective.
3. Operators faced with decisions on upgrading channel capacity but without the necessary time to recover investment on total rebuilds can particularly use feedforward technology to expand existing cable television systems to the requisite channel loading.
4. The techniques are most cost effective in distribution amplifiers.

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APPENDIX I

The cost effectivity of feedforward technology is discussed in the text. Minimizing the cost of bandwidth extension involves reuse of the existing cable and that issue is discussed separately here for purposes of clarification and support, since Case 3 assumed the use of existing cable.

As stated before the long-term consideration always favors reconstruction with new components, though when faced with the need for bandwidth extension without guarantee of adequate time to recover the investment, the shorter term consideration moves toward the use of existing cable without sacrificing sound technical principles.

Any mention of cable reuse usually spawns a veritable flood of concerns from the cable engineering community, and appropriately so, since it suggests the move towards uncertainty and technical risks. A survey of the relevant literature suggests that no theoretical limits await us for the types of extension this paper discusses so that our concerns are motivated by our experience and knowledge of the practical realities of cable manufacture and installation. Primarily, they deal with the uncertainty of structural return loss integrity of the cable at the extended frequencies.

Earlier experience with discontinuities in feeder lines was not always good,[6] as anyone that dealt with pressure taps can attest. Some early work (1968) by Lubars and Olszewski[7] characterizes the physical tolerances necessary for production of cables as bandwidth extensions to 300 MHz were achieved. Reasonable extrapolation from that work and comparison to then known manufacturing techniques shows an acceptable degree of risk for the extension techniques discussed in this paper. An internal publication of one of the cable manufacturers[8], again dealing with earlier bandwidth extension problems, treats the subject quite thoroughly. Defined are manufacturing perturbations that deal with dimensional variations of the inner conductor or outer conductor, variations in the dielectric between the two conductors, and off-centeredness of the inner conductor relative to the outer conducter. The effect of each on structural return loss is treated, and again, extrapolation of that data to today's case can lead one to responsibly believe that the risk is well worth taking as presented in the context of the paper. Private conversations[9] with leading cable manufacturing engineers confirm these assumptions. There are cases where certain empirical tests have been conducted on cables of the first generation gas injected era (and earlier) with results consistent with those assumed in this paper.

It is fundamental and mandatory to assume that any operator considering the bandwidth extension techniques using existing cables would do the necessary empirical testing involving amplitude sweep performance and perhaps time domain reflectometry performance so as to convince himself that the particular run of cable extant throughout his system is free of the manufacturing defects that could have yielded product suitable for use at the original frequency but no higher. These tests need not be burdensome; the standard time domain reflectometer has adequate sensitivity to diagnose discontinuities that might effect frequencies out to 400 MHz. Certainly, but not conclusively, amplitude sweep perturbations greater than those desired by the operator are indicative of structural return loss failures, though all three tests might be done to reduce the uncertainty. Once the cable is adequately characterized for the intended performance, an informed decision can be made about its usefulness and the desire to replace it.

It is important to point out that at the frequencies in question, in addition to the manufacturing process, construction irregularities can also play an important role, since a lashing machine could have easily introduced flaws at every revolution that begin to be visible in the 400 MHz vicinity. The characterization process will discover the unusable frequencies and allow responsible, informed decisions, that have major influence on project costs.

CASE STUDY SUMMARIES

		COSTS PER MILE, ACTIVES		ACTIVES PER MILE		
	DESCRIPTION	(Relative)	[Actual]	(Trunk)	[L. E.]	REMARKS
CASE 1						
Early 400 MHz New build, Southwestern states. 06/81	(a) All standard 20+1+2 cascade	(1.0)		(1.28)	[3.53]	(1,2)
	(b) All feedforward	(1.12)		(0.67)	[2.13]	
CASE 2						
Northeastern states New build 400 MHz 11/82	(a) All standard	(1.0)		(1.3)	[2.5]	(3,4,7)
	(b) Standard trunk feedforward line extenders	(0.98)		(1.1)	[1.9]	
	(c) Standard line extenders feed-forward trunk	(1.11)		(0.8)	[2.6]	(5)
	(d) All feedforward	(1.29)		(1.1)	[1.6]	(6,7)
CASE 3						
Expansion Model	(a) 260 MHz, 21 channel, 20+1+2 cascade	NA		(0.4)	[2.2]	(8)
	(b) 400 MHz, 52 channel loading, 30+1+2 cascade, all feed-forward	(1.0)	[3311]	(0.4)	[2.7]	(9,10, 11,12)
	(c) Assumed availability of 30 db gain, 400 MHz standard trunk module	(0.80)	[2651]	(0.4)	[2.7]	(13,14, 15)

REMARKS TO CASE STUDY SUMMARIES

(1) 53 db CTB, 43 db C/N
(2) IRC Mandatory to meet CTB specifications.
(3) 54 db CTB, 45 db C/N, all cases.
(4) 20+1+2 cascade, all cases.
(5) 30 db trunk spacing.
(6) 22 db trunk spacing.
(7) Feeder/trunk (standard) = 3.22/1
Feeder/trunk (feedforward) = 4.11/1
(8) Typical early 1970's system.
(9) Physical locations constant on trunk, variable on line extenders.
(10) Existing cable used.
(11) List price used.
(12) 30 db trunk spacing, 34 db gain line extender.
(13) Assumed cost of 10% above standard gain, and optimistic distortion performance that could, depending on hybrid and cascade performance, require paralleling techniques, but not feedforward techniques.
(14) 53 db CTB, 43 db C/N, all cases.
(15) Feeder/trunk = 6.6/1

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