AN ECONOMIC ASSESSMENT OF AM FIBER OPTIC APPLICATIONS

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ABSTRACT

Recent technological advancements in fiber optic hardware have moved this technology to the forefront of attention for utilization in Cable TV distribution plants. FM fiber optics is well on the way to replacing AML (microwave) sites and/or RF distribution supertrunks. AM fiber optics is under consideration for replacement or supplementing the standard RF distribution trunks. The application of fiber optic technology is viewed as being consistent with future bandwidth expansion requirements of high definition television and increased system reliability.

The purpose of this paper is to review only the economic aspects of fiber optic applications. Based on present AM fiber link performance versus typical RF CATV equipment, three practical distribution system scenarios are examined. In each scenario an economic assessment of an AM fiber node approach is assessed by comparison to a typical RF distribution plant.

The scenarios presented in this document were selected from a lengthy list of actual system upgrade/rebuild analyses which Jerrold's System Design and Proposals Department has performed over the last 18 months. These specific examples were chosen as being representative of the type of system expansions being considered most prevalent.

It is not the intent of this paper to conclude whether AM fiber or typical RF distribution plant is an appropriate economic decision. Rather, it is intended to highlight those areas where each has its advantages and to stress the importance of giving appropriate consideration to the application of a hybrid architecture for CATV systems.

2-1/2 MILES ADDITIONAL TRUNK REACH FOR $20K

The major benefit of an AM fiber optic link, in a CATV distribution network, is the trunk reach advantage AM fiber optics technology has over standard RF amplifier/coaxial cable technology. The issue, however, is whether the benefit is worth the extra cost.

In a straight 550 MHz trunk run analogy, a current generation AM fiber link of approximately 7.3 miles provides a carrier-to-noise performance of 52 dB and a composite-triple-beat performance of 65 dB. Utilizing eight 26 dB gain, 550 MHz feedforward amplifiers and one-inch cable, the same performance specifications are possible at a maximum distance of 4.8 miles. The AM fiber link (equipment and cable) would cost approximately $60-65K compared to $40-45K for the feedforward supertrunk (equipment and cable). In both cases, the cost per mile equates to approximately $8.6K; however the economics of the $20K for 2-1/2 miles of additional trunk reach will vary from system to system.

Equipment Specifications

In order to minimize the variety of equipment used in the following scenarios, all systems will be 550 MHz (77 Channels) new builds, rebuilds or upgrades. Table Number 1 provides the critical operating specifications for the RF and fiber optic active devices utilized throughout the paper. It is also important to emphasize that all economic assessments are made with the assumption of 40 channels/fiber transmitter - receiver links.

TABLE NUMBER 1
EQUIPMENT SPECIFICATIONS

I. STANDARD RF ACTIVE DEVICES

AMPLIFIER DESCRIPTION	GAIN (dB)	NOISE FIGURE (dB)	OUTPUT LEVEL (dBmV)	CTB @ OUTPUT (dB)
550 MHz, 26 dB Feedforward Trunk	26	12	38	85
550 MHz, 30 dB Feedforward Trunk	30	11	41	79
550 MHz, Quadrapower™ Bridger	25	17	48	65
550 MHz, Power Doubling Line Extender	30	13	45	68

II. AM FIBER LINE

Transmitter Input Level (dBmV)	30
Receiver RF Output Level (dBmV)	32
Loss Budget (dB)	6
Channels/Link	40
Carrier-to-Noise (dB)	52
Composite-Triple-Beat (dB)	65

SCENARIO I - 450-550 MHz UPGRADE

System Information

The existing distribution system is carrying 60 Channels (450 MHz) with several trunk runs having 27 amplifier cascades. The active equipment in the system utilizes conventional technology Trunk cable is 3/4 inch foam dielectric and has been tested successfully beyond 600 MHz.

The goal of the upgrade is to expand channel capacity to 77 Channels (550 MHz). If possible, it would be most desirable to save existing trunk locations and, therefore, trunk/feeder tie points. In addition, franchise documents specify the system (at the tap) must meet the following specifications:

Carrier-to-Noise	47 dB
Composite-Triple-Beat	53 dB

Standard RF Upgrade

The equipment selected for the standard upgrade was 26 dB gain, feedforward trunks with Quadrapower™ bridgers and power doubling line extenders. The trunk stations provided for maintaining the existing locations and cable. The desired system performance specifications, however, could not be accomplished with reasonable bridger and line extender levels. Even with bridger and line extender output levels at 43 dBmV and 40 dBmV respectively, the 27 amplifier cascade produced inadequate specifications (C/N: 46.3 dB and CTB: 51.0 dB).

AM Fiber Upgrade

Using an AM fiber link with a 6 dB loss budget (approximately 12 Km) allowed for a maximum cascade of 9 trunk amplifiers. Originating from the headend, the fiber link would terminate at the eighteenth amplifier. At that point, the RF output would be split, amplifiers 10 through 18 reversed and both nine amp cascades (18-10 and 19-27) fed by the AM fiber link.

Using the same RF equipment selected for the standard RF upgrade, the desired system performance specifications are achievable. In addition, reasonable feeder levels (bridger: 47 dBmV, line extender: 44 dBmV) can be maintained.

Scenario I Economics

The massive amount of feeder system changes required for the standard RF upgrade make a detailed economic comparison unnecessary. Based on preliminary calculations, the standard RF upgrade would cost approximately $300-$350/Mi. more (RF distribution equipment costs only) than the AM fiber upgrade. Based on the system mileage of 600 miles, the RF approach would require approximately $195K additional expenditures for RF distribution equipment. The $120K for the three AM fiber nodes would represent a $75K savings for equipment alone. Realistically, the only economic approach would be the AM fiber link. In addition, it represents the only approach to satisfy the system performance requirements.

SCENARIO I - 450 MHz TO 550 MHz UPGRADE

A. EXISTING SYSTEM

- o Channel Loading: 60 Channel, 450 MHz.
- o Longest Cascade: 27 Amps.
- o Equipment Type: Conventional Trunk, Bridger and Line Extenders.
- o Trunk Cable: 3/4 Inch.

B. DESIRED SYSTEM

- o Channel Loading: 77 Channel, 550 MH
- o System Specification Targets: CTB: 53 dB; C/N: 47 dB.
- o Other: Maintain Trunk Amplifier Locations and Cable.

C. CONVENTIONAL RF UPGRADE

- o Equipment Type: Feedforward Trunk, Quadrapower^{TM} Bridgers and Power Doubling Line Extenders.
- o Cascade and Level Analysis:

Amplifier	Cascade	Input Level	Output Level
Trunk	27	14 dBmV	40 dBmV
Bridger	1	--	43 dBmV
Line Extenders (2)	2	10 dBmV	40 dBmV

- o System Distortion Analysis:
  - Composite-Triple-Beat: 46.3 dB
  - Carrier-to-Noise: 51.0 dB

D. AM FIBER UPGRADE

- o Equipment Type: 12 Km AM Fiber Optic Link, Feedforward Trunk, Quadrapower^{TM} Bridger and Power Doubling Line Extenders.
- o RF Cascade and Level Analysis:

Amplifier	Cascade	Input Level	Output Level
Trunk	9	12 dBmV	38 dBmV
Bridger	1	--	47 dBmV
Line Extenders (2)	2	14 dBmV	44 dBmV

- o System Distortion Performance:

	Fiber	RF	System
Composite-Triple-Beat:	65 dB	55.7 dB	53.1 dB
Carrier-to-Noise:	52 dB	48.9 dB	47.1 dB

SCENARIO II - TOTAL 550 MHz REBUILD

System Information

Primarily due to the condition of the existing plant, the system operator had decided to do a complete system rebuild to obtain a 550 MHz, 77 Channel distribution plant. The entire project, with the exception of a few long cascade runs, meets desired specifications with 7/8 inch cable and 26 dB gain feedforward trunks, Quadrapower^{TM} bridgers and power doubling line extenders.

It is desired to reduce the longer cascades to a maximum of 25 amplifiers deep, in order to obtain system specifications of 46 dB carrier-to-noise and 51 dB composite-triple-beat. Reducing the cascade lengths is also advisable for ongoing maintenance purposes.

Alternative Analysis

Three options were selected for consideration in reducing the cascade lengths. The first option was to reduce cable losses by installing 1-1/4 inch trunk cable. This would allow the required distance to be covered with 24 amplifiers. The other two options involved the use of an AM fiber optic link with a 4 dB loss budget covering approximately 7.7 Km. One of the optics options would use 7/8 inch trunk cable, while the other would incorporate 1-1/4 inch cable. These two fiber options reduced the cascades to 20 amps and 14 amps respectively.

Since the majority of the system was in compliance with the desired system specifications, it was decided that the feeder levels would not be altered to make any of the options under

SCENARIO II - 550 MHz TOTAL REBUILD

- SYSTEM INFORMATION
  - Initial design, utilizing feedforward trunk and 7/8 inch cable required several 31 amp cascades. It was desired to reduce all cascades to 25 amplifiers or less.

- ALTERNATIVE ANALYSIS
  - Option 1 - Use the same RF amplifiers, but upgrade cable to 1.125 inch cable.
  - Option 2 - Use the same RF amplifiers and cable, but add a 7.7 Km AM fiber link (4 dB loss budget, C/N: 53 dB, CTB: 65 dB).
  - Option 3 - Use the same RF amplifiers, but upgrade cable to 1.125 inch cable and add 7.7 Km AM fiber link.

		Initial Design	Option 1	Option 2	Option 3
RF Amplifier Cascade		31	24	20	14
Cable:	Quantaity (1000 Ft.)	118.6	118.6	118.6	118.6
	Cost ($K)	$ 56.9	$ 97.2	$ 56.9	$ 97.2
Amps:	Quantity	61	46	61	46
	Cost ($K)	$ 81.8	$ 61.7	$ 81.8	$ 61.7
P.S.:	Quantity	31	23	31	23
	Cost ($K)	$ 37.2	$ 27.6	$ 37.2	$ 27.6
Conn:	Quantity	220	174	220	174
	Cost ($K)	$ 2.2	$ 3.8	$ 2.2	$ 3.8
AM Fiber Link:					
(2) Transmitter	($K)	--	--	$ 30.0	$ 30.0
(2) Receivers	($K)	--	--	$ 10.0	$ 10.0
7.7 Km F.O. Cable	($K)	--	--	$ 13.9	$ 13.9
	TOTAL COST	$178.1	$190.3	$231.9	$244.2
System Performance:					
Carrier-to-Noise (dB)		45.5	46.4	46.1	47.1
Composite-Triple (dB)		49.7	51.2	50.3	51.6

consideration meet the performance parameters. Based on this criteria, option 3 was eliminated (CTB: 50.3).

Scenario II - Economics

Option 1 met the desired criteria (cascade length and system performance) at a cost increase of only $12,200 compared with the existing design. Option 3 also met the criteria; however, the cost increase is estimated at $66,100. Option 1 was selected by the operator. Since option 3 offered approximately the same performance as option 1, the $53,900 incremental cost increase was not economically justifiable. Attempting to justify the extra expenditures, based on the cost savings realized through cascade reductions (Option 1: 24 amps, Option 3: 14 amps) would have been unsuccessful, since the majority of the remaining cascades in the system were between 19 and 24 amplifiers deep.

SCENARIO III - 300 MHz TO 550 MHz UPGRADE/REBUILD

System Information

The existing 355 mile, 300 MHz system is operating with conventional active devices in cascades less than or equal to 20 amps. The feeder line levels are 44 dBmV for bridgers, 43.5 dBmV for line extenders and 8 dBmV at the tap. Trunk and feeder cable (3/4 inch and 1/2 inch) has been tested to 600 MHz and is reusable.

The system, by franchise agreement, is now required to expand channel capacity to a minimum of 70 Channels. The option of constructing a "B" cable system of 300 MHz to obtain the additional 35 Channels was discussed, but eliminated from consideration due to the ongoing maintenance problems it would cause. It was decided to upgrade, if possible, to 550 MHz. Cable would be saved as much as possible; however, system specifications of C/N: 47 dB, CTB: 52 dB and 13 dBmV tap levels would dictate how much of the existing plant could be saved.

Due to design limitations, all taps and system passives would have to be replaced as well as all active devices. In addition, based on preliminary calculations and the vast amount of feeder line construction activity already required, it was decided to upgrade the feeder cable to 5/8 inch cable.

AM Fiber Optic Upgrade

By utilizing an AM fiber link, backbone trunk architecture to reduce RF amplifier cascades to 4, trunk locations could be maintained, in addition to 75% of the existing trunk cable (25% had to be replaced with 1.0 inch cable to reduce losses). 30 dB gain feedforward trunk/Quadrapower™ bridger mainstations were required for trunk spacing and maximum bridger levels (49 dBmV). The additional loss of 550 MHz vs. 300 MHz, in addition to a tap level increase of 5 dBmV, required that most areas needed line extenders to be cascaded three deep.

Following the analysis that proved the compliance of the above hybrid fiber optic/RF distribution plant to system specifications (C/N: 47.7 dB, CTB: 52.1 dB and 13 dB tap levels) a review was conducted to reduce the number of fiber nodes required. A cascade analysis revealed that the end of line performance of a nine trunk amplifier cascade was approximately equal to the AM link, followed by a four amp cascade. Therefore, the AM backboning was modified so that cascades emanating from the headend would be nine amps deep. All other cascades would be limited to four amplifiers, one bridger and three line extenders. Using this approach, the number of fiber nodes was reduced from 14 to 10.

SCENARIO III - 300 MHz TO 550 MHz UPGRADE/REBUILD

A. EXISTING SYSTEM
- o 300 MHz.
- o Longest Cascade: 20 Amps.
- o Equipment Type: Conventional Trunk, Bridger and Line Extenders.
- o Cable Type: 3/4 inch trunk, 1/2 inch feeder.
- o Levels: Bridger - 44 dBmV.
  Line Extenders: (2) - 43.5 dBmV.
- o Tap Port Level: 8 dBmV at 300 MHz.
- o 355 miles of plant.

B. DESIRED SYSTEM
- o 550 MHz, 77 Channels.
- o Reuse Trunk Locations and Cable (where possible).
- o Desired System Specifications: CTB = 52 dB, C/N = 47 dB
- o Tap Port Level (minimum): 13 dBmV at 550 MHz.

C. UPGRADE/REBUILD INDEPENDENT
- o All Connectors will be replaced.
- o Cable is reusable if design losses are acceptable.
- o All Taps and System Passives will be replaced.

D. UPGRADE ANALYSIS
- o Equipment Type: AM fiber optic links, 30 dB gain, feedforward trunk, Quadrapower™ bridger and power doubling line extenders.
- o System Changes:
  - 25% of the trunk cable would require change-out to 1.0 inch cable.
  - 100% of the feeder cable would require change-out to 5/8 inch cable.
  - Line Extenders would be required to cascade 3 deep in some cases.
  - Trunk amp cascade limited to 9 deep from headend and 4 off any fiber node.

SCENARIO III

D. UPGRADE ANALYSIS (CONT'D.)

- System Performance: F.O. link + 4 trunks + 1 bridger + 3 line extenders or 9 trunks + 1 bridger and 3 line extenders.
  C/N = 47.7 dB.
  CTB = 52.1 dB.
- Tap Port Levels: 13 dBmV at 550 MHz.
- Operating Levels:

Amplifier	Cascade	Input Level (dBmV)	Output Level (dBmV)
30 dB Feedforward Trunk	4	9.0	39.0
Quadrapower™ Bridger	1	25.0	49.0
Line Extenders	3	13.0	43.0

- 73 Km of F.O. cable and 10 AM fiber nodes required.

E. TOTAL REBUILD ANALYSIS

- Equipment Type: 26 dB gain, feedforward trunk, Quadrapower™ bridgers and power doubling line extenders.
- System Changes: All trunk and feeder replaced with 3/4 inch and 5/8 inch cable respectively.
- System Performance: 20 trunks + 1 bridger + 2 line extenders.
  C/N = 47.0.
  CTB = 52.6.
- Tap Port Levels: 13 dBMv.
- Operating Levels:

Amplifiers	Cascade	Input Level (dBmV)	Output Level (dBmV)
26 dB Feedforward Trunk	20	14	40
Quadrapower™ Bridger	1	25	45
Power Doubling Line Extender	2	3	42

Standard RF Total Rebuild

A total rebuild approach was analyzed, using 3/4 inch trunk and 5/8 inch feeder cable. 26 dB gain feedforward trunk amps with Quadrapower™ bridgers and power doubling bridgers were required. With bridger, line extender and tap levels of 45 dBmV, 42 dBmV and 13 dBmV respectively, system performance of 47.0 dB carrier-to-noise and 52.6 dB composite-triple-beat were demonstrated.

Scenario III - Economics

More trunk amps are required in the rebuild than the upgrade because each has 4 dB less gain, but also because more trunk is required in the rebuild. At the equipment line, the total rebuild would seem to offer a $250K advantage. This advantage is offset by the cable, strand, hardware and installation labor to replace the entire trunk network, compared to less extensive requirements for the upgrade. Taps passives and feeder cable prices and installation were not part of the analysis, since they would be required in both the rebuild and upgrade.

The economic analysis indicates no clear advantage to either approach. At present, the operator is reviewing the option from an ongoing maintenance viewpoint. The rebuild approach offers a completely new plant but a number of 20 amp cascades. The upgrade offers cascades of 4 to 9 amps (maximum) but, many areas with three cascaded line extenders.

SCENARIO III - COST COMPARISON

	AM FIBER UPGRADE Quantity	AM FIBER UPGRADE Total $	TOTAL REBUILD Quantity	TOTAL REBUILD Total $
A. EQUIPMENT COSTS				
1. Standard RF Equipment				
o Amplifiers	163	$ 233,900	255	$ 357,000
o Line Extenders	1705	530,250	1666	518,126
o System Passives	1737	66,000	1890	71,800
o Power Supplies	102	122,400	133	159,600
2. Fiber Optic				
o AM Transmitter	20	$ 300,000		--
o AM Receiver	10	100,000		--
SUBTOTAL EQUIPMENT		$1,352,550		$1,106,526
B. CABLE, HARDWARE, STRAND AND INSTALLATION				
1. Coaxial Cable				
o 1.0 In. Trunk (1000 Ft)	104	$ 204,200	--	--
o 3/4 In. Trunk (1000 Ft)	--	--	470	$ 651,400
2. Fiber Optic Cable				
o Four-Fiber Bundle (Km)	73	$ 168,000	--	--
SUBTOTAL CABLE AND INSTALLATION		$ 372,200		$ 651,400
TOTAL		$1,724,750		$1,757,926

CONCLUSION

The cost trade-off for the additional trunk reach provided by AM fiber optic technology was examined in three specific, real-life system scenarios. In each case, the focus was solely on the economics of providing the required system performance parameters. On review of the three scenarios we have considered, plus all of our previous experience, there are situations where a hybrid coax-fiber design make economic sense. Especially when one considers the advantages inherent in such a hybrid system in terms of quality, etc., AM fiber optic products need to be given serious consideration on a system by system basis. It has been our experience that there are situations where fiber optics pays for itself or adds only moderate cost without considering the incremental benefits to system performance.

Consideration should also be given to the fact that AM fiber optic products are still in the infancy of their development and are rapidly advancing. Product performance improvements which could dramatically improve the cost vs. performance ratio may happen at anytime. Such changes will alter the economic analyses presented in this document.

It is the opinion of these authors that the new AM fiber optic generation of products should be viewed as another option to be considered for use in system upgrades/rebuilds. Therefore, fiber optics should be added to the list of technology considerations, along with power doubling, Quadrapower™ and feedforward, when considering the economics of system expansions.