EVALUATION OF FEED-FORWARD AMPLIFIERS, MICROWAVE TRANSMISSION AND OTHER LONG-DISTANCE METHODS OF SIGNAL CARRIAGE

Donald Z. Dworkin

NYT CABLE TV, 120 West Merchant St., Audubon, N.J. 08106

ABSTRACT

The advent of 350, 400 and 450 Mhz systems has posed the requirement for improved methods of supertrunk design. The parallel development of feed-forward amplifiers and high channel capacity microwave has opened new possibilities which this paper explores by comparing designs for typical systems by each of these methods. A large range of numbers of channels, bandwidths and numbers of hubs are compared for system performance and costs.

The costs for each type of system are calculated on a per channel basis, per subscriber and per channel, per home. An assessment is made of reliability and operating costs for feed-forward and microwave. A single example each of an FM video and a fiber optic system are included for cost comparison.

INTRODUCTION

Many factors acting in the same direction are driving up the number of channels, bandwidths, geographical size, electronic complexity and performance standards for both new and rebuilt systems. These factors stem from the maturing of CATV, its increasing penetration nationally, particularly in urban areas, the competition of rival technologies such as MDS and DBS, the increased sophistication and demands of city and town councils, and finally the expectation of new services and customers. Therefore, there is a critical need for high capacity, high performance, reliable and economical methods of long-haul transportation which will establish hubs throughout the system area or carry the channels to the system extremities. Once the hub or extremity has been furnished with super high quality signal, local area distribution using traditional CATV hardware suffices to feed high quality signals to the subscribers.

Fortunately, technology seems to be keeping pace with demand in the form of high channel capacity microwave AML and feed-forward amplifiers with their unique distortion-cancelling networks. Both of these methods use AM which is bandwidth efficient and therefore a single link is capable of carrying 35 to 60 channels. Two other methods use FM; namely FM video cable and fiber optics. FM video cable has been proven to carry relatively small numbers of channels (less than half of an equal bandwidth AM system) with superb performance. For this reason as well as the high cost of AM-to-FM (and reverse) processing at each end, this method is considered only for a specific link. The last method, fiber optics, is considered only to compare it to the two AM methods. Both because of cost and lack of experience with large systems at this time, fiber optics is not further evaluated.

TYPES OF SYSTEMS

For cable, four bandwidths and their corresponding number of channels are analyzed; for microwave, two sizes of channel groupings are considered:

Cable

A) 300 Mhz
   1. 35 channels on one cable
   2. 70 channels on two cables

B) 350 Mhz - 44 channels

C) 400 Mhz - 52 channels

D) 450 Mhz - 60 channels

Microwave

A) 40 channels - 38 video channels

B) 54 channels - 52 video channels

Each of these systems was calculated for performance and cost, using comparable numbers of channels. In addition, costs were computed for four groups of system sizes, shown below, each consisting of variation of path lengths to the hubs ranging from 2.5 to 17 miles (See Table I):

	No. of Hubs	Total Miles
A.	5	50
B.	10	95
C.	15	140
D.	20	189

ASSUMPTIONS

A. It was assumed that three channels of reverse transmission were required for both cable and microwave.

B. Supertrunk:

It was assumed that for purposes of reliability and maintenance that status monitoring would be used not only to determine normal parameters but to monitor the condition of the feed-forward gain blocks. Since two identical integrated circuits are used within each gain block, if either should fail, only distortion parameters rise to the level of a standard circuit. Therefore, feed-forward amplifiers have built-in electronic redundance. Status monitoring enables the operator to replace the module before complete failure occurs.

B. A maximum cascade of 30 feed-forward amplifiers would be used, in order to stay within comfortable limits of maintainability.

C. Distribution:
Standard amplifiers such as the Jerrold SJ series (see Table 2) would be used for distribution from the hub with not over 20 amplifiers in cascade, again, in the interest of practical maintainability.

D. Cross-modulation distortion:
Cross-modulation is not specifically mentioned in the discussion since in systems of upwards of 35 channels, triple beat is the limiting factor.

E. Coherent carriers:
Tests demonstrate that coherent and harmonically related carriers provide a 10 db margin in subjective viewing of composite triple beat distortion (1). This is reflected in the Minimum System Specifications, Table 3. However Table 10 gives the end-of-system specifications and maximum length for non-coherent systems of 300 and 350 Mhz; for a 400 Mhz system which could not reach as far as the longest hub required, the specifications and maximum reach are also listed. However, coherent carriers were assumed for this paper.

EQUIPMENT

A. Amplifiers - See Table 2.
1) Feed-forward amplifiers - The Century Model 4102-30-* was used.
2) Standard amplifier - The Jerrold Model 20/* was used for distribution from the hubs in both feed-forward and AML cases.

B. Microwave: The Hughes AML was used in its high-power version, Model AML-STX-141, for downstream application. The STX-151 was used for the upstream channels. The downstream broadband receivers with pilot tone AGC were used. The upstream receivers use composite AGC.

(1) Reference: Jerrold Technical Seminar, 3/26/80

C. Cable: One inch (1") fused disc was used in the calculation for supertrunk simply because, as the lowest attentuation practical cable, the longest cascade and/or best specifications can be attained and therefore mark the practical limits for each design.

COSTS

I. Supertrunk

Actual figures were taken from construction bids and bills for a 300 Mhz feed-forward cascade in the NYT Cable system built by the author with a correction for the use of fused disc cable instead of .750 polyethylene cable actually used. The following Table 4 estimates cost for higher bandwidth systems based upon the increased attenuation. Costs include status monitoring and standby power.

Table 4
Costs Per Foot

System Bandwidth	300		350	400	450
Number of Cables	Single	Dual	Single	Single	Single
Electronics	.61	1.22	.66	.70	.75
Cable	.73	1.46	.73	.73	.73
Construct. Material	.21	.27	.21	.21	.21
Labor	.60	.65	.60	.60	.60
Engineering	.23	.30	.23	.23	.23
Total $/Foot	2.38	3.90	2.43	2.47	2.52
Total $/Mile	12566	20592	12830	13041	13305

System Performance Criteria (Table 5)

The amplifier levels were chosen so that the signal quality delivered to the hub permitted a reasonable standard trunk and feeder stem to emanate from the hub, serve all subscribers within the area and deliver pictures with substantially no observable degradation to the furthest subscriber. The specifications are shown for both supertrunk cable and microwave in Table 5.

System Costs

Costs/Channel/Home in Table 6 and Table 7 were calculated by assuming that each hub served an area of 5,000 homes, and that the penetration would be 50%.

II. Microwave

A.	Assume Existing Tower	$ -0-
B.	Differential tower hardware plus installation per hub	$ 2,000
C.	Antennae and waveguide/hub	$10,300

D.	Incremental tower cost/hub	$ 3,000
E.	Transmit cost/hub minus Transmitter	$15,300

54 Channel Transmitter

52 video channels, 1 pilot tone and 2 FM modules (40 FM channels)

A.	14 8' racks w/multiplexing $2,325/ea.	$ 32,550
B.	38 Standard High power modules $11,850/ea.	$450,300
C.	17 Hyperband High Power Modules $12,975/ea.	$220,575
D.	Transmit Monitor $4,775/ea.	$ 4,775
	Transmitter Total	$708,200

54 channel Receive Cost

A.	54 Channel Receiver	$ 12,980
B.	CATV Interface	$ 1,735
C.	Antennae and Waveguide	$ 7,500
D.	Tower, Land, Building (Average)	$ 50,000
		$ 72,215

40 Channel Transmitter Cost

38 Video channels, 1 pilot tone, 2 FM modules (40 FM Channels)

A.	11 8' racks - $2,325 ea.	$ 25,575
B.	41 high power modules/$11,850 ea.	$485,850
C.	Transmit monitor	$ 4,775
	Transmitter Total	$516,200

40 Channel Receiver Cost

A.	40 Channel Receiver	$ 10,820
B.	CATV Interface	$ 1,445
C.	Antennae and Waveguide	$ 7,500
D.	Tower, Land, Building (Average)	$ 50,000
		$ 69,765

Upstream Transmitters

	3/Hub-Select as required:	Per Channel
A.	STX 451 B: + 10 dbm sites between 1-8 miles	$ 6,380
B.	STX-151C:+17 dbm out (sites between 8-12 miles)	$ 7,580
C.	STX-151D:+ 20 dbm out (Sites greater than 12 miles)	$ 9,215
D.	Rack and Multiplexing/site	$ 2,325

Upstream Receivers

A.	Receiver One required per two hubs	$ 10,820

RELIABILITY

A typical 9 mile path is taken as the basis for comparing the reliability of supertrunk cable and AML.

A. Supertrunk

A 9-mile supertrunk in a 400- Mhz system uses 1.28 feed-forward amplifiers per mile (see table 5). Thus, 12 amplifiers would be used. Modern amplifiers have MTBF's of better than 200,000 hours. Even assuming half of this figure, a cascade of 12 amplifiers would have an overall MTBF of $\frac{100,000}{12} = 8,333$ hours or 1 failure per year per supertrunk. If status monitoring is used with feed-forward amplifiers which contain "redundant" chips (see Assumptions, B) this figure could be greatly improved.

B. AML

The figures used are based upon curves, data and estimates supplied by the manufacturer except for the path reliability figure which was calculated using average terrain and rain figures for the southern New Jersey area with an average transmitter wave guide of 200 feet, a receiver wave guide of 100 feet and circular dual polarized antennas and wave guide, and a duration of 15 minutes per failure.

Table 8

Element	MTBF
Transmitter, High power array	8,800
Path, rain and multi-path	1,666
Receiver, broadband	10,000

Total combined or system MTBF is 1,229 which is equivalent to approximately 7 failure per year. Two factors which should be taken into account are, firstly, that a failure of one transmitter module only causes a single channel failure, all other element failures causing total failure. The second point is that local conditions have a drastic effect on path reliability. Therefore, path calculations serve only as a basic, average guide with variations due to local conditions.

MAINTENANCE COSTS

AML

Taking a 54 channel AML transmitter as reference, the average annual replacement cost for klystrons and miscellaneous parts of $250 per channel would be, assuming klystrons last for 3½ years, costing $2,200 each:

$$54\left(\frac{2,200}{3.5} + 250\right) = \$52,920/\text{year}$$

Adding 1 technician for maintenance, at $18,000 salary, his system cost would be $36,000. The total annual maintenance cost would be $88,920.

Supertrunk

Based upon the MTBF previously calculated and a material cost of $75 per failure, the following costs would be incurred:

Table 9

No. of Hubs	5	10	15	20
No. of Amps	70	140	210	280
No. of Failures	7	14	21	28
$/Parts Cost	500	1,000	1,500	2,000
1 PM Tech.	24,000	24,000	24,000	24,000
¼ DM Tech.	4,500	4,500	4,500	4,500
Total Cost/ Per Year	29,000	29,500	30,000	30,500

Over a one-year period, the cost savings would be approximately $60,000 for supertrunk compared to an AML installation.

Additional Transmission Methods

A. Fiber Optics

The cost of a fiber optic system designed for an 11-hub system, carrying 35 channels is detailed below.

One-Way Electronics, Fiber Optic Cable:	$2,555,000
Fiber-Optic Electronics, Cable for Reverse:	$ 200,000
Demodulators for off-air:	$ 46,000
Remodulators - 35 x 2,000 x 11:	$ 770,000
Buildings at receive sites - 11 x 54,000:	$ 594,000
Installation	$ 350,000
Total	$4,515,000

The costs for an equivalent 35-channel, 11-hub system by AML and feed-forward methods are:

Feed-Forward Supertrunk:	$1,300,000
AML Microwave:	$1,800,000

B. FM Video

A point-to-point, dual cable transmission capable of transporting a total of 44 channels plus FM broadcast signals is estimated for a path length of 10 miles.

Head-end Electronics - 44 x $4,300:	$ 189,200
Receive Electronics - 44 x $4,300:	$ 189,200
Receive Building:	$ 54,000
Cable and Amplifiers, 10 miles x $12,830/mile	$ 128,300
Total	$ 560,700

Equivalent feed-forward and microwave systems' costs for a single 10 mile link are:

44 Channels, feed-forward	$ 120,830
38 Channels, AML	$ 695,000
54 Channels, AML	$ 890,000

CONCLUSIONS

1. Supertrunks can be constructed in 450 MHz systems up to 22 miles in length, using feed-forward amplifiers.

2. a. In all types of systems, feed-forward supertrunk costs approximately $500,000 less than microwave, with the difference remaining approximately the same with increasing number of hubs.

3. Costs per channel per home: These become less for both cable and microwave as:
   a. The bandwidth and number of channels become higher.
   b. The number of hubs increase.

4. Costs per subscriber:
   a. For microwave - decrease by approximately 20% for each doubling of subscribers.
   b. For cable - remain about the same as the number of subscribers increase.

5. Cost per channel:
   a. For microwave -decreases by 25% from 38 channel to 52 channel equipment.
   b. For cable - decreases by 30% from 300 MHz to 450 MHZ.

6. Microwave versus feed-forward supertrunk cable:
   a. Reliability - Mathematical prediction shows a theoretical superiority of cable over microwave, although actual experience and field conditions may considerably modify this.
   b. Maintenance Cost - indicates an annual savings of approximately $60,000 for cable over microwave.

My grateful appreciation goes to Mr. Bruce Adams and Mr. Bill Hindman for their careful work in compiling up-to-date cost figures for feed-forward supertrunk and AML respectively. I, of course, remain responsible for checking and using their data.

TABLE 1

MODEL SYSTEM CONFIGURATIONS

Hub	Ground Miles From Head End	Number of Hubs Selected for Model			
		5	10	15	20
1. Alpha	2		X		
2. Bravo	4.5			X	
3. Charlie	4	X			
4. Delta	6				X
5. Echo	6		X		
6. Fox	6				X
7. George	7.5			X	
8. Hotel	8				X
9. India	8	X			
10. Juliet	8.5			X	
11. Kilo	10		X		
12. Lima	10	X			
13. Mike	10.5			X	
14. Nan	12				X
15. Oboe	12		X		
16. Peter	12	X			
17. Queen	14			X	
18. Romeo	15		X		
19. Sugar	16	X			
20. Tango	17				X
	Total Miles Supertrunk	50	95	140	189

TABLE 2

Amplifier specifications

	Standard Amplifier				Feed-Forward Amplifier			
Bandwidth, Mhz	300	350	400	450	300	350	400	450
Channels	35	44	52	60	35	44	52	60
Gain, db.								
Maximum	26	26	26	26	34	34	34	34
Operating	25	25	25	25	30	30	30	30
Levels, dbmv								
Output	32	32	32	32	40	40	40	40
Input	7	7	7	7	10	10	10	10
Composite Triple Bed, db, at Operating Level	-92	-88	-84	-82	-102	-100	-98	-96
Noise Figure, db. (0 pad)	7	7	7	7	10	10	10.5	10.5
Power								
Watts	30.3	30.3	30.3	30.3				
Amps	0.55	0.55	0.55	0.55	1.0	1.0	1.0	1.0

TABLE 3

MINIMUM SYSTEM SPECIFICATIONS

	HUB		LAST TRUNK		SUBSCRIBER	
	Non-Coherent	Coherent	Non-Coherent	Coherent	Non-Coherent	Coherent
Carrier to Noise, db	47	47	45.2	45.2	45	45
Carrier to Composite Triple Beat, db	67	57	59	49	53	43
Carrier to Second Order, db	66	66	63	63	60	60

TABLE 5

SUPERTRUNK SYSTEM PERFORMANCE

Feed-Forward Amplifiers, Harmonically Related

Bandwidth		300	350	400	450	Microwave (AML)	
Number of Channels		35	44	52	60	38	52
Cable attenuation,db/M', max.		6.3	6.8	7.3	7.8		
Supertrunk(Feed-Forward Amps)							
Number of Amps/ @ 30 db spacing		19	21	22	24		
Number of Amps/ Mile		1.11	1.20	1.28	1.37		
Operating Levels	Sin/Sout	16/46	16/46	16/46	16/46		
	C/N	51	51	50	50	53	53
	C/CTB	64	62	59	57	75	70
Distribution(Standard Amplifier)							
Number of Amps		20	20	20	18		
Operating Levels	Sin/Sout	9/34	9/34	9/34	9/34	9/34	9/34
	C/N	47	47	47	47	47	47
	C/CTB	62	60	54	53	62	54
Total System							
Combined Specs.	C/N	45.5	45.5	45.2	45.2	46	46
for worst case at last trunk amp.	C/CTB	57	55	50	49	60	52.7
Maximum Supertrunk Cascade		45	40	36	31		
Maximum Distance	1.00" cable/miles to still meet: C/N=47 C/CTB=57	40.6	33.4	28.1	22.6	17	17
	.750 cable/ miles: C/N=47 C/CTB=57	28.4	23.3	19.6	15.8		

TABLE 6

SUPERTRUNK COSTS

M=Thousand Dollars
$=Dollars

Number Of Hubs	Total Miles (Actual Ground	Cost Units	Bandwidth, Mhz	300		350	400	450
			No. of Channels	35	70	44	52	60
No. of amp./mile for 1" fused disc cable				1.11	1.11	1.20	1.28	1.37
5	50	M	Total Cost	628.3	1029.6	641.5	652.1	665.3
5	50	M	Cost/Channel	17.8	14.7	14.6	12.5	11.1
5	50	$	Cost/Sub.	50.3	82.4	51.3	52.2	53.2
5	50	$	Cost/Ch/Home	.71	.59	.58	.50	.44
10	95	M	Total Cost	1193.8	1956.2	1218.9	1239	1264
10	95	M	Cost/Channel	34.1	28.0	27.7	23.9	21.1
10	95	$	Cost/Sub.	47.8	78.2	48.8	50	50.6
10	95	$	Cost/Ch/Home	.68	.56	.55	.48	.42
15	140	M	Total Cost	1759.3	2882.9	1796.3	1825.8	1862.8
15	140	M	Cost/Channel	40.3	41.2	40.8	35.1	31.0
15	140	$	Cost/Sub.	46.9	76.9	47.9	48.7	49.7
15	140	$	Cost/Ch/Home	.67	.55	.54	.47	.41
20	189	M	Total Cost	2375	3891.9	2424.9	2464.9	2514.8
20	189	M	Cost/Channel	67.9	55.6	55.1	47.4	41.9
20	189	$	Cost/Sub.	47.5	77.8	48.5	49.3	50.3
20	189	$	Cost/Ch/Home	.68	.56	.55	.47	.42

TABLE 7

MICROWAVE SYSTEM COSTS

All Figures in Thousands Except Cost/Channel/Home and Cost/Subscriber (Designated $)

A) 52 Channels & FM Radio & Pilot

Number of Hubs	5	10	15	20
Downstream				
a. Tower	76.5	153	229.5	290.7
b. Transmitter	708.2	708.2	708.2	708.2
c. Receiver:	361	722	1,083	1,371.8
Upstream				
a. Transmitter	131.3	259.2	382.1	509.9
b. Receiver	32.4	51.4	81.6	108.2
Total	1,309.4	1,893.8	2,484.4	2,988.8
Rounded off cost	1,300	1,900	2,500	3,000
Cost/Channel	25	36.5	48.1	57.6
Cost/Subscriber	$104.72	$75.75	$66.20	$59.78
Cost/Channel/Home	$1.00	.73	.64	.58

B) 38 Channels & FM & Pilot

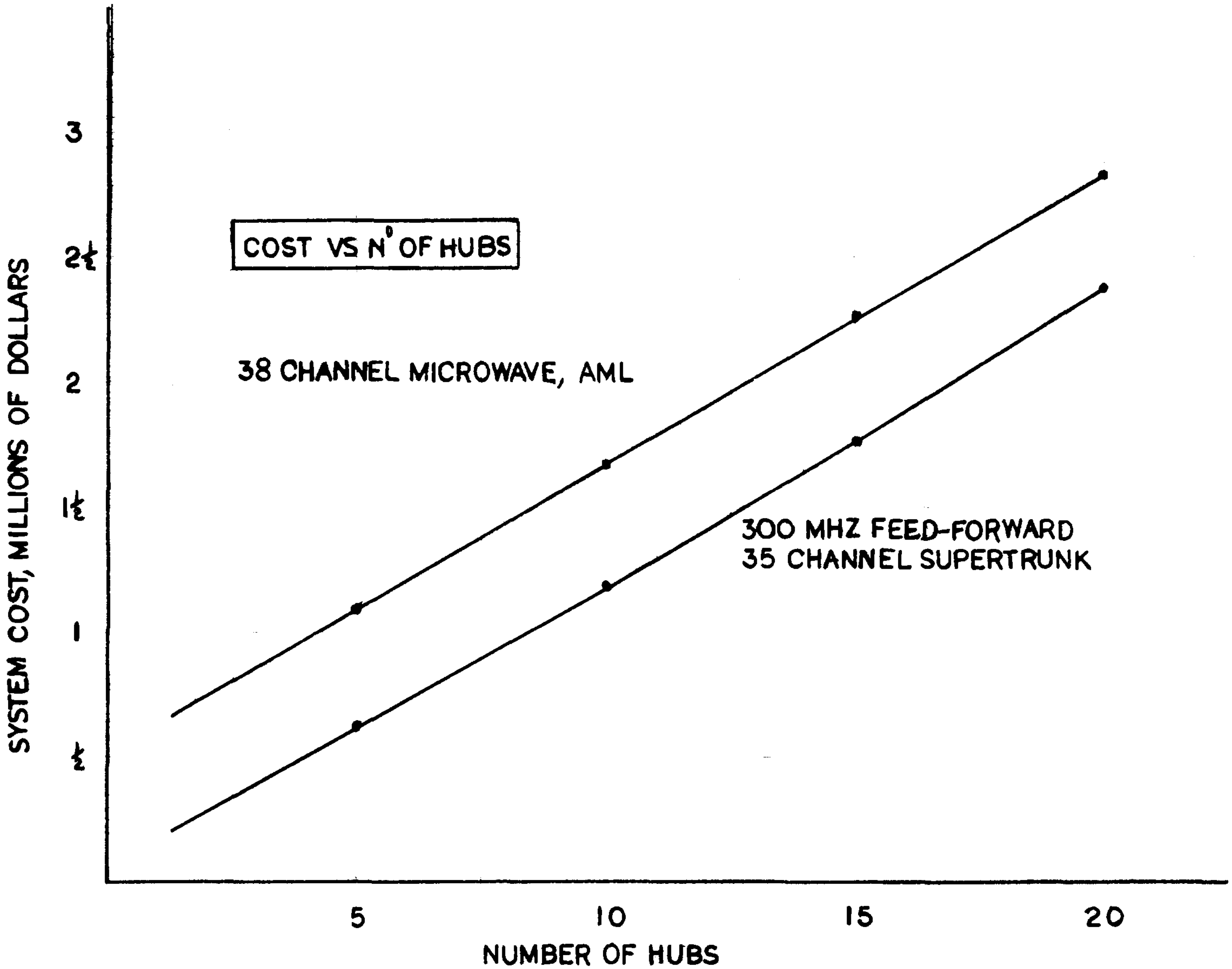
Downstream				
a. Tower	76.5	153	229.5	290.7
b. Transmitter	516.2	516.2	516.2	516.2
c. Receiver	348.8	697.7	1,046.5	1,395.4
Upstream				
a. Transmitter	131.3	259.2	382.1	509.9
b. Receiver	32.4	51.4	81.6	108.2
Total	1,105.2	1,677.5	2,255.9	2,820.4
Rounded Off	1,100	1,700	2,300	2,800
Cost/Channel	29.1	44.1	59.4	74.2
Cost/Subscriber	$88.40	$67.08	$60.16	$56.40
Cost/Channel/Home	$1.16	.88	.79	.74

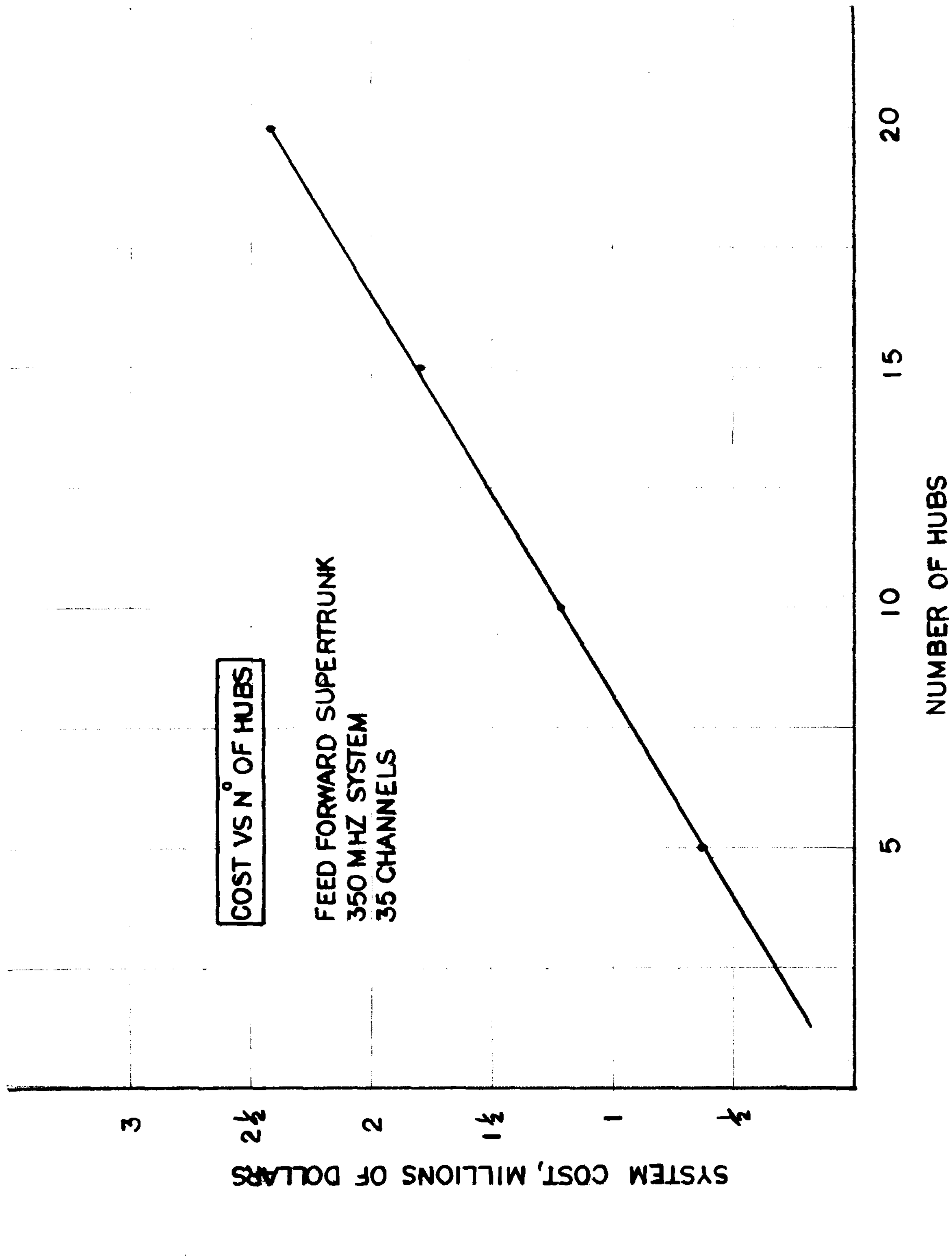
TABLE 10

Supertrunk System Performance; Non-Harmonically Related Carriers

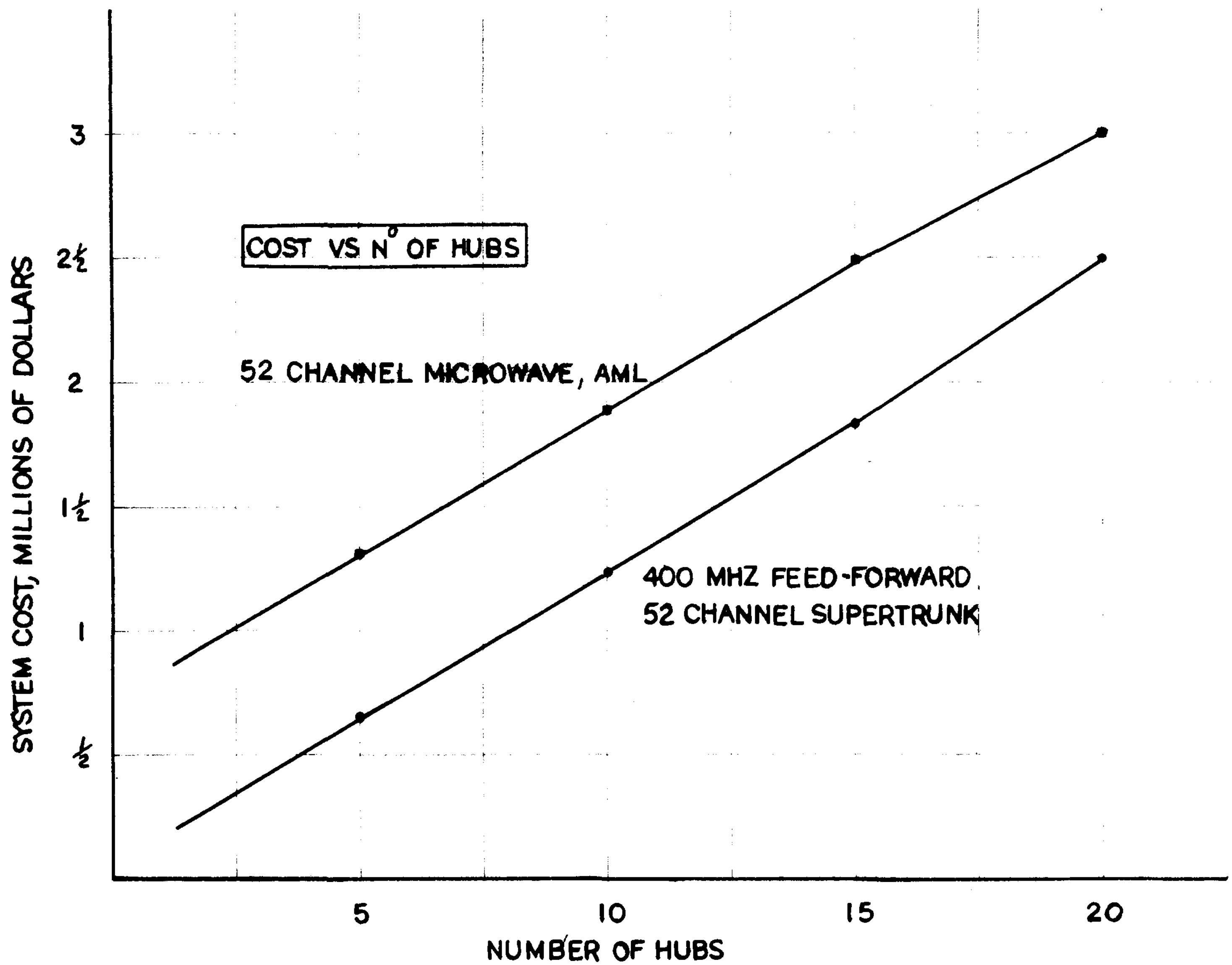
Bandwidth		300	350	400
Number of Channels		38	44	52
System Length, Miles		17	17	
Number of Amplifiers Required		19	21	
Feed Forward Amplifiers	Input/Output	14/44	14/44	
	C/N	49.2	46.7	
	C/CTB	68	67	
Standard Amplifers	#	20	20	
	C/N	47	47	
	C/CTB	62	60	
Combines specifications (Total System)	C/N	45	44.7	
	C/CTB	59	56.7	

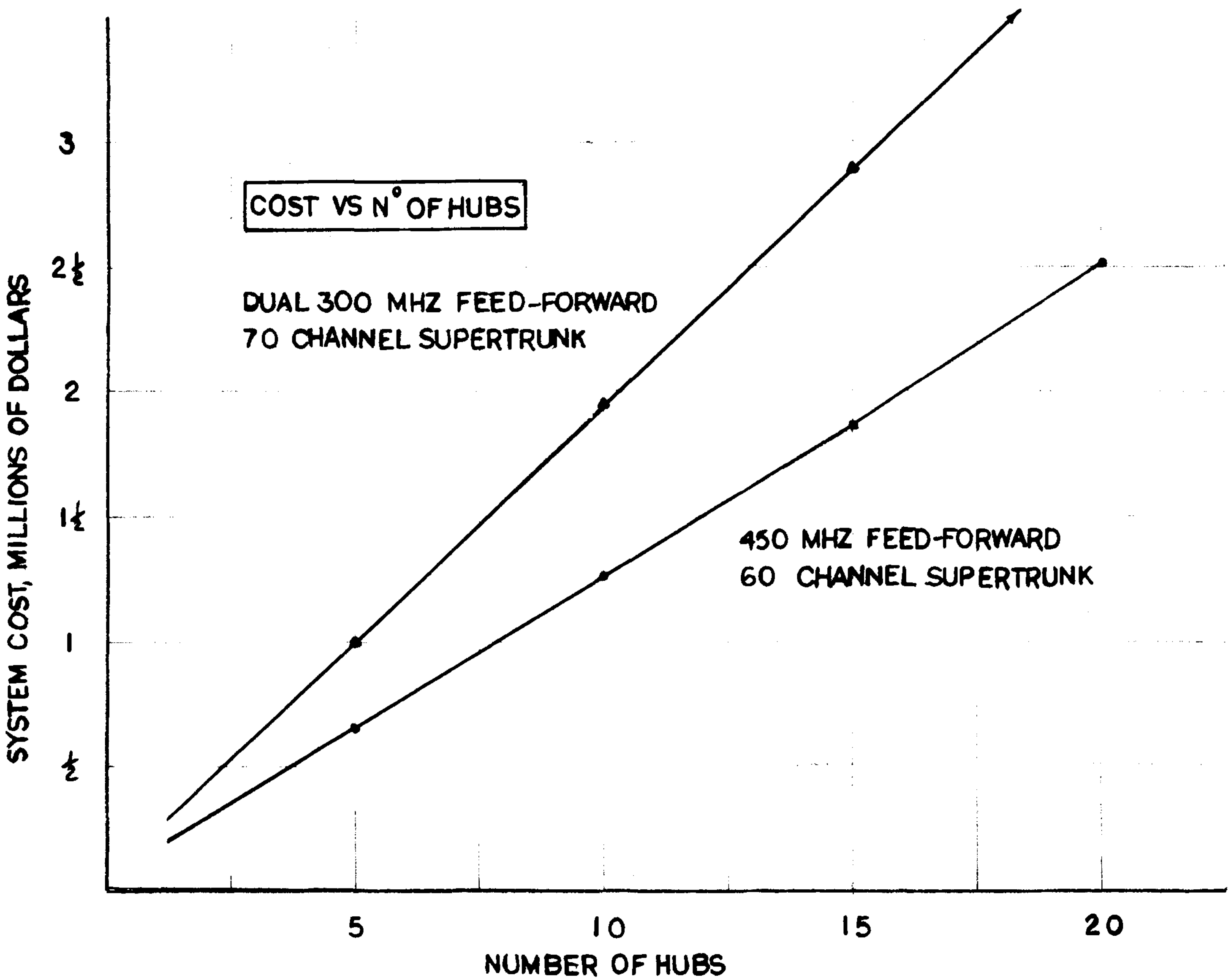
Maximum Miles	1" Disc	24.2	20.	15.6
	0.750	17	14	10.9
Maximum No. of Amps		27	24	20
	C/N	47	47	47
	C/CTB	67	67	67


COST VS N° OF HUBS
38 CHANNEL MICROWAVE, AML
300 MHZ FEED-FORWARD
35 CHANNEL SUPERTRUNK
SYSTEM COST, MILLIONS OF DOLLARS
3
2½
2
1½
1
½
5
10
15
20
NUMBER OF HUBS



COST VS N° OF HUBS
FEED FORWARD SUPERTRUNK
350 MHZ SYSTEM
35 CHANNELS
SYSTEM COST, MILLIONS OF DOLLARS
NUMBER OF HUBS
½
1
1½
2
2½
3
5
10
15
20


COST VS N° OF HUBS
52 CHANNEL MICROWAVE, AML
400 MHZ FEED-FORWARD,
52 CHANNEL SUPERTRUNK
SYSTEM COST, MILLIONS OF DOLLARS
3
2½
2
1½
1
½
5
10
15
20
NUMBER OF HUBS


COST VS N° OF HUBS
DUAL 300 MHZ FEED-FORWARD
70 CHANNEL SUPERTRUNK
450 MHZ FEED-FORWARD
60 CHANNEL SUPERTRUNK
SYSTEM COST, MILLIONS OF DOLLARS
NUMBER OF HUBS
½
1
1½
2
2½
3
5
10
15
20