INCREASING THE CHANNEL CAPACITY OF SINGLE ENDED CATV AMPLIFIERS

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PATENT PENDING

Investigations were conducted on an operating cable television system to explore methods of increasing the channel capacity of broadband single-ended amplifiers.

The resulting data indicated that this could be achieved by judicious selection of the carrier frequencies.

An original method of deriving the desired carrier frequencies is presented to enable channels to be added in the midband spectrum 120-174MHz. The equipment requirements are discussed, and test results obtained under dynamic conditions allows a comparison with standard carrier operation.

Introduction

It is well known that when the standard low and high band television carriers are applied to broad band CATV amplifiers intermodulation products are generated which appear in the mid band, and conversely when the standard mid band carriers are introduced, intermodulation products appear in the low and high bands.

One result of this is that many CATV systems, particularly those which are operating with single ended amplifiers are denied the use of all but a small portion of the mid band spectrum. This paper proposes a method of controlling the restrictive second order intermodulation products which will allow the use of the mid band channels in addition to the low and high band channels.

Discussion

The investigation commenced with a measurement of the spurious frequencies generated by intermodulation through a chain of CATV amplifiers. It was decided to use this emperical approach because the results of previous attempts to correlate between the predicted and measured amounts of intermodulation products has in general been poor.

The location chosen for the measurement was a point on the system preceeded by fifty seven amplifiers, all single-ended and comprising fifty one trunk stations, a bridger, and five line extenders. A full complement of standard low and high band carriers was applied, and the tests conducted using a spectrum analyser whose output was recorded on an x, y plotter.

Fig. 1 x, y Plot of Midband Spectrum

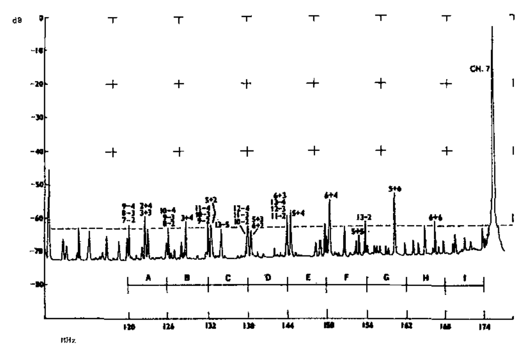


Fig. 1 illustrates how the intermodulation products due to the high and low band channels restricts the mid band use, and it is important to note that the intermodulation products with the highest amplitude and the most critical locations can be identified as the second order sum and difference products.

Fig. 1 suggests that if the positions of the interfering intermodulation products could be relocated such that they would be coincident in frequency with the mid band carriers then perhaps they could be phaselocked and the resulting beats would be eliminated.

To examine this possibility a table of the standard carriers was developed in a form that would permit analysis of the intermodulation products. Introducing the constants x and y and assigning values of 6 and 0.25 to them respectively, the standard carriers can be expressed in analytic form as shown in table 1.

Table 1

Standard TV Carriers

$x = 6MHz$, $y = 0.25MHz$

Channel	Frequency (MHz)	Equation
2	55.25	9x + 5y
3	61.25	10x + 5y
4	67.25	11x + 5y
5	77.25	13x - 3y
6	83.25	14x - 3y
A	121.25	20x + 5y
B	127.25	21x + 5y
C	133.25	22x + 5y
D	139.25	23x + 5y
E	145.25	24x + 5y
F	151.25	25x + 5y
G	157.25	26x + 5y
H	163.25	27x + 5y
I	169.25	28x + 5y
7	175.25	29x + 5y
8	181.25	30x + 5y
9	187.25	31x + 5y
10	193.25	32x + 5y
11	199.25	33x + 5y
12	205.25	34x + 5y
13	211.25	35x + 5y

By examining the values of x and y resulting from the various sum and difference combinations, the positions of the second order products can now be seen at a glance. This can be illustrated with two examples, as follows.

1) Channels 4 + 6 = 25x + 2y

2) Channels 10 - D = 9x

A glance at table 1 shows the sum product of the first example to be troublesome to channel F because its equation is 25x + 5y, hence a 3y or 0.75MHz beat will occur.

The difference product of the second example appears at a distance 5y removed from channel 2 hence a 1.25MHz beat is predictable.

From this it is apparent that the controlling factor in the formulation of beats is the resulting value of the y constant and that by reassigning the values of y, the desired frequency congruence can be accomplished.

Table 2 lists the modified carrier equations, and if the examples are reexamined it is now evident that the sum product of example 1 falls at 25x + 2y and is identical to channel F, and the difference product of example 2 occurs at 9x + 5y which is identical with channel 2.

Table 2

Standard and Modified Television Carrier Equations

Channel	Freq MHz	Standard	New Assignment
2	55.25	9x + 5y	9x + 5y
3	61.25	10x + 5y	10x + 5y
4	67.25	11x + 5y	11x + 5y
5	77.25	13x - 3y	13x - 3y
6	83.25	14x - 3y	14x - 3y
A	121.25	20x + 5y	20x + 2y
B	127.25	21x + 5y	21x + 2y
C	133.25	22x + 5y	22x + 2y
D	139.25	23x + 5y	23x + 2y
E	145.25	24x + 5y	24x + 2y
F	151.25	25x + 5y	25x + 2y
G	157.25	26x + 5y	26x + 2y
H	163.25	27x + 5y	27x + 2y
I	169.25	28x + 5y	28x + 2y
7	175.25	29x + 5y	29x + 7y
8	181.25	30x + 5y	30x + 7y
9	187.25	31x + 5y	31x + 7y
10	193.25	32x + 5y	32x + 7y
11	199.25	33x + 5y	33x + 7y
12	205.25	34x + 5y	34x + 7y
13	211.25	35x + 5y	35x + 7y

It follows that if the values of x and y are resolved and used as the base oscillators in an appropriate synthesizer, the desired output frequencies can be realized.

The values of x and y are derived by solving two of the carrier equations simultaneously. This method allows considerable flexibility as the equations can be selected to produce the least amount of shift off the standard carriers, and may be chosen to allow phaselocking to off-air carriers where on-channel operation is necessary.

As an example of the solution of x and y and to illustrate the flexibility afforded by this method, a situation is assumed where it is necessary to phaselock channels 11 and 6, both offset by 10kHz.

From table 1

Channel 11 = 33x + 7y = 199.26MHz
Channel 6 = 14x - 3y = 83.26MHz

By simultaneous solution the values realized for x and y are 5.9929MHz, and 0.2135MHz respectively.

Substituting these values for x and y in the carrier equations results in the reassigned carriers shown in table 3. The amount of shift from standard carriers is included.

Table 3

Comparison of Standard and Reassigned Television Carrier Frequencies With Two Carriers Phaselocked

Channel	Standard Frequency (MHz)	Reassigned Frequency (MHz)	Frequency Shift Off Standard (KHz)
2	55.25	55.0036	246
3	61.25	60.9965	253
4	67.25	66.9893	260
5	77.25	77.2671	17
6	83.26	83.26	zero (locked)
A	121.25	120.2850	965
B	127.25	126.2779	972
C	133.25	132.2708	979
D	139.25	138.2635	986
E	145.25	144.2564	993
F	151.25	150.2495	1000
G	157.25	156.2422	1007
H	163.25	162.2351	1015
I	169.25	168.2280	1021
7	175.25	175.2884	38.5
8	181.25	181.2813	31.3
9	187.25	187.2742	24.2
10	193.25	193.2671	17.1
11	199.26	199.26	zero (locked)
12	205.25	205.2529	2.9
13	211.25	211.2457	4.2

Table 4

Reassigned Television Carrier Frequencies With No Phaselocking Requirements

Channel	Equation	Reassigned Frequency (MHz)	Frequency Deviation (KHz)
2	9x + v	55.125	-125
3	10x + v	16.125	-125
4	11x + v	67.125	-125
5	13x + u - v	77.125	-125
6	14x + u - v	83.125	-125
A	20x + u	120.25	-1000
B	21x + u	126.25	-1000
C	22x + u	132.250	-1000
D	23x + u	138.250	-1000
E	24x + u	144.250	-1000
F	25x + u	150.250	-1000
G	26x + u	156.250	-1000
H	27x + u	162.250	-1000
I	28x + u	168.250	-1000
7	29x + u + v	175.375	+125
8	30x + u + v	181.375	+125
9	31x + u + v	187.375	+125
10	32x + u + v	193.375	+125
11	33x + u + v	199.375	+125
12	34x + u + v	205.375	+125
13	35x + u + v	211.375	+125

Where there are no phaselocking requirements, the amount of shift from the standard carriers can be minimized by expanding the carrier equations. The y components, 5y, -3y, 2y, and 7y are replaced by v, u-v, u, and u + v and by assigning the values of 6MHz to x, 0.25 MHz to u, and 1.125MHz to v, the second order cancellation objective is achieved with minimal carrier shift, as shown in table 4.

The expansion to three variables permits phaselocking to a maximum of three off-air carriers. The amount of frequency shift is determined by the channels to be phaselocked, as shown in table 5.

Table 5

	Phaselock to	Max freq shift in kHz*						
Channel Groups	one or two out of CH 2 - 4	0	0	0	-167	-250	-167	-125
	one or two out of CH 5 - 6	-250	0	-500	0	0	-167	-125
	one or two out of CH 7 - 13	+250	+500	0	+167	0	0	+125
	none out of CH C - I	-1000	-750	-1250	-917	-1000	-1083	-1000

Use of table 5

a) Decide the channel(s) to be locked to "off-air" signals (max. 3).

b) Determine the channel group(s) to which they belong 2-4, 5-6 and/or 7-13.

c) Select the column(s) which indicate a 0 freq. shift for those channel group(s).

d) The shift in other channel groups is indicated in that same column.

Note: It is not possible to lock three carriers when each one is in a different channel group.

To illustrate the use of table 5.

Assume a lock is required to channels 5, 7 and 9. Channel groups to which they belong are 5-6 and 7-13. The fifth column shows 0 shift for channel group 5-6 and 7-13, it also shows a shift of -250kHz for channel group 2-4 and -1000 kHz shift for channel group C-I.

* Slightly greater values may occur depending on the 10kHz off-sets of the channels to be locked.

Effect of Carrier Reassignment on Second Order Products

Assuming the use of the modified carrier frequencies contained in Table 3, a calculation was made of all second order sum and difference products arising from the inclusion of five lowband, nine mid-band and seven high band channels. The complete results of the channel by channel analysis is appended to this paper, however, it can be summarized as follows.

1. Total possible unwanted products = 108

2. Number locked to wanted carriers = 72

Of the 36 which remain, 18 are located at a position of wanted carrier plus 1.72MHz and 18 are located at wanted carrier plus 4.28MHz.

Comparison of the locations of the un-locked products to the susceptability curve contained in Graph 1 reveals that a product at wanted carrier plus 1.72MHz requires a margin of 46dB. A product located at carrier plus 4.28MHz, or carrier minus 1.72MHz requires a margin of 34dB.

Considering that the product of greatest amplitude was measured at 49dB below nearest carrier as shown in Fig. 1, it can be reasonably expected that no beat interference due to second order inter-modulation will be visible.

Equipment Requirements

To obtain the required modulated RF carriers at the precisely inter related frequencies (based on x, u and v), a master generator was built employing 3 crystal oscillators as shown in Fig. 2.

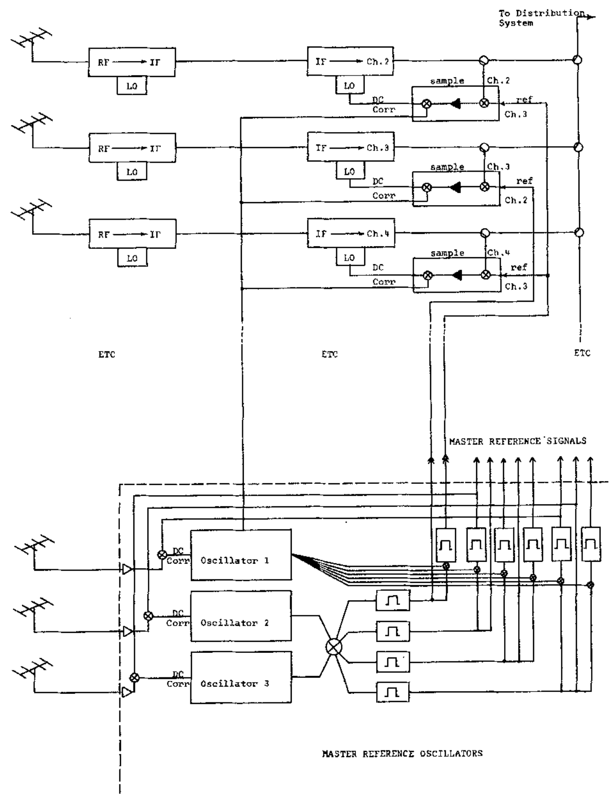
By mixing a sample of the outgoing RF signal of each processor with its adjacent channel signal from the master generator, a "difference frequency" at the approximate value of x is generated. A further comparison between this "difference frequency" and x, produces the DC correction voltage which controls the local oscillator frequency of the processors output converter thereby obtaining a precise lock.

Since either adjacent channel can be used to develop the "difference frequency" only a limited number of reference carriers need to be generated. Fig. 2 illustrates a situation where 15 carriers can be locked to the master oscillator by use of 11 reference signals. Locking to "off-air" signals requires the master generator to be slaved to the "off-air" signals, which is also shown in Fig. 2.

Fig. 2

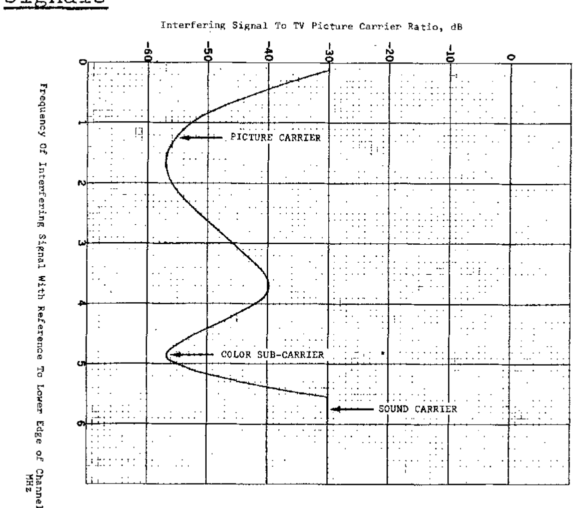
Simplified Block Diagram of Master Carrier Generator

Head-End Processors



Graph 1

Permissible Limits For Intermodulation And Other Undesired Single Frequency Signals



System Tests With The Reassigned Carriers

Measurement of Triple Beat

Recognizing that the coherent aspect of the proposed carrier arrangement would produce the stacking effect associated with third order products, it was decided to measure the amplitude of the triple beat described as $f1 \pm f2 \pm f3$. This could then be directly compared with the non coherent or random carrier use generally encountered in CATV operations.

To conduct this test a carrier generator was built to provide seven carriers tuned to the high band channels (7-13), and spaced at precise 6MHz intervals as shown in Fig. 3. The triple beats appearing in the region of the channel I carrier (168MHz) were recorded using a spectrum analyzer at the same test location described earlier.

The x, y plots given in Figures 4 and 5 indicate that the triple beats resulting from the seven coherent carriers added to produce a single spurious frequency whose magnitude was 10dB greater than the individual triple beat resulting from a random carrier source.

Fig. 3

Coherent Carrier Generator

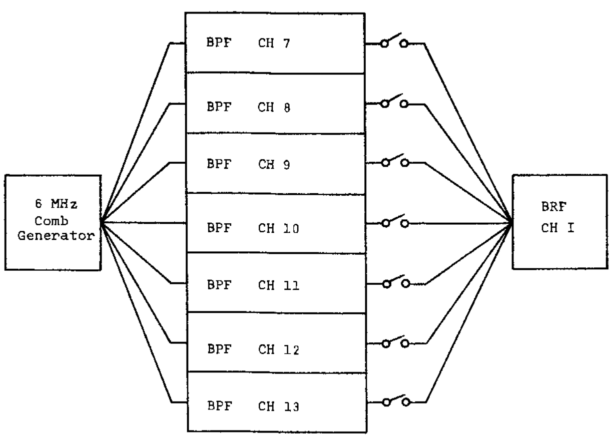


Fig. 4

Triple Beat With Coherent Carriers

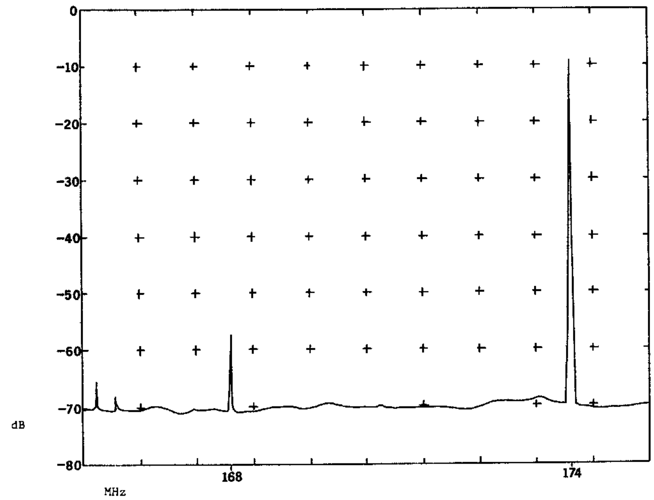
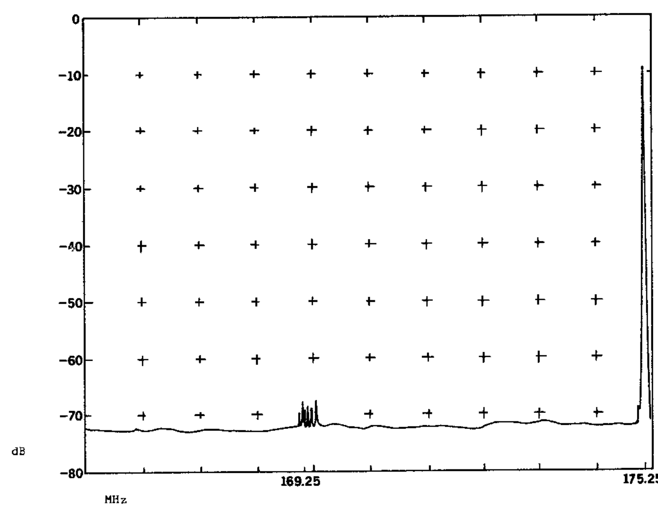


Fig. 5

Triple Beat With Random Carriers



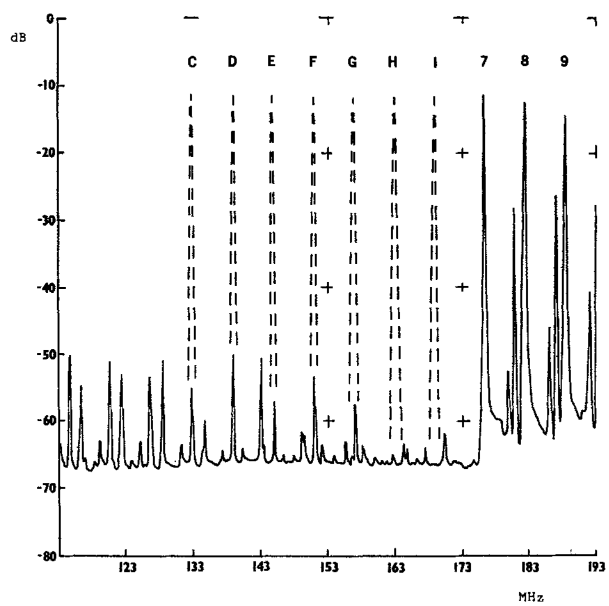
Measurement of Second Order Products

With the output frequencies corresponding to those listed in table 3, a 17 channel head-end was installed and connected to the system. The number of channels used was restricted in deference to the regulation of the Canadian Department of Communications against the use of mid-band channels A and B.

At the same location used to obtain the results shown in Fig. 1, the midband spectrum was plotted and is shown in Fig. 6. This allows direct comparison with the results shown in Fig. 1 and to this comparison, the positions of the reassigned carriers have been superimposed on to Fig. 6. The frequency coincidence of the wanted carriers and unwanted products is self-evident.

Fig. 6

x, y Plot of the Midband Spectrum



The placement of carriers in the midband as an addition to the carriers of the low and high band channels produces second order combinations whose products appear in the low and high band. This aspect was included in the analysis of second order products described earlier in this paper, and to confirm this analysis two of the spurious frequencies which are not congruent with wanted carriers were measured.

Again the same test location was used together with a spectrum analyzer and x, y plotter. The products measured were channel I minus channel 6, which was expected to appear at channel 6 picture plus 1.72MHz, and channel 6 + channel 6 predicted to appear at channel H picture plus 4.28MHz.

Examination of the results which are given in Figures 7 and 8 reveals the channel I - channel 6 beat was not measured and can therefore be considered to be at least 14dB below the permissible level established by Fig. 1. The channel 6 plus channel 6 product was measured at 27dB below the permissible level.

Fig. 7

Spectrum of CH. 6

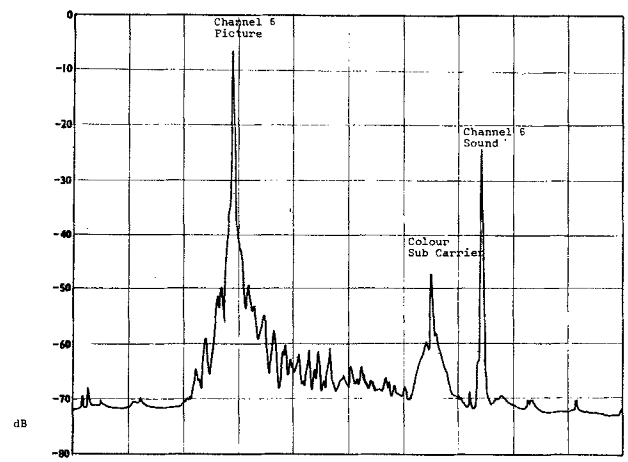
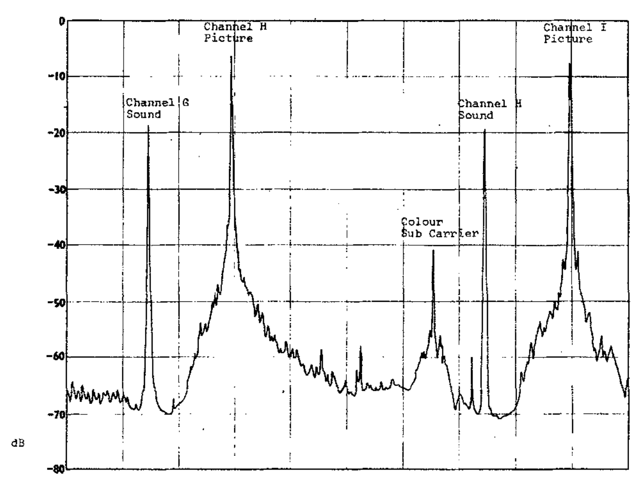


Fig. 8

Spectrum of CH. H



Subjective Tests

The objective tests described previously were supplemented by a critical viewing test of each system channel. The tests were conducted at three system locations, the head-end, a mid point preceeded by twenty two trunk amplifiers plus a bridger amplifier, and finally the deepest point of the system comprising 51 trunks, 1 bridger and 5 line extenders.

Typical broadcast receivers of different manufacture were used to evaluate the picture quality, including two receivers supplied by member representatives of the Electronic Industry Association of Canada. It can be noted that the two receivers referred to are purported to have the tightest A.F.C. ranges of any receivers available to the public.

In relation to the system considerations the tests can be described as follows.

1. When viewed at the systems deepest point, no beat frequency interference was observed.

2. Accompanied by member representatives of the E.I.A.C. tests of the compatibility with receiver fine tuning was conducted by switching back and forth between the standard and reassigned carriers. All receivers required slight adjustment of the fine tuning control. Predictably, the receivers local oscillators could accomodate a 250kHz shift, however, the small amount of adjustment required exceeded expectations, receivers equipped with A.F.C. required no adjustment.

3. No visible evidence of crossmodulation was observed. This was confirmed by conducting a "blank screen" test on the systems community channel, channel 10 by removing the modulation and operating with normal sync and pedastal levels.

Conclusions

The test results indicate that the use of judiciously selected carrier frequencies as a means of circumventing second order intermodulation distortion in order to permit use of the midband is practical.

The amount of carrier shift resulting from the use of this system was demonstrated to be fully compatible with standard television receivers.

The frequency shifts occurring in the midband region, 1000kHz, is not anticipated to be problematic since the number of receivers in use that are equipped with midband tuners is negligible. Hence to accomodate the use of midband channels the standard receivers will be dependent upon an external converter. The tuning range of these converters is more than adequate to meet the prescribed frequency shift.

Because the results were obtained through an operating CATV system with 51 trunk amplifiers, 1 bridger amplifier and five line extender amplifiers in cascade, all single-ended, it can be reasonably assumed that better results will be obtained in systems with a shorter amplifier cascade.

As noted earlier the tests did not include midband channels A and B, however, since these channels are included in the analysis of second order products and in the light of the test results obtained, they can predictably be used.

Circumvention of second order distortion leads logically to a discussion of third order problems. The results of tests described herein suggest that triple beats will not impose a severe constraint on midband use on a typical system. However, as more channels are added the third order distortion products must be considered as the limiting factor to system reach. In particular the effects of coherent carrier operation will require close attention since the amplitude of triple beat was shown to increase dramatically in this mode of operation.

Another third order problem that will be encountered by additional channel operation is crossmodulation. Increasing the number of system carriers will reduce the amount of crossmodulation margin on a CATV system however, this form of distortion is not related to the choice of carrier frequencies.

APPENDIX 1

SECOND ORDER PRODUCTS RESULTING
FROM THE REASSIGNED LOW, MID AND
HIGH BAND TV CARRIERS

LOCATION OF SECOND ORDER PRODUCTS BY CHANNEL

2	3	4	5	6	A	B	C	D	E	F	G	H	7	8	9	10	11	12	13
A-3	A-2																		
B-4	B-3	B-2																	
C-5	C-4	C-3																	
D-6	D-5	D-4	C-2																
7-A	E-6	E-5	D-3	D-2	2+4														
8-B	8-A	F-6	E-4	E-3	3+3	3+4	2+5												
9-C	9-B	9-A	G-5	F-4	7-2	8-2	4+4	2+6	3+6								2+E	2+F	2+G
10-D	10-C	10-B	H-6	H-5	8-3	9-3	9-2	3+5	4+5	4+6						2+D	3+D	3+E	3+F
11-E	11-D	11-C	11-A	I-6	9-4	10-4	10-3	10-2	11-2	5+5					2+C	3+C	4+C	4+D	4+E
12-F	12-E	12-D	12-B	12-A	11-5	12-5	11-4	11-3	12-3	12-2	5+6			2+B	3+B	4+B	5+B	5+C	5+D
13-G	13-F	13-E	13-C	13-B	12-6	13-6	13-5	12-4	13-4	13-3	13-2	6+6	2+A	3+A	4+A	5+A	6+A	6+B	6+C
11	11	10	8	7	7	6	6	5	5	4	2	1	1	2	3	4	5	5	5

TOTALS

(LOCKED PRODUCTS ARE UNDERLINED)