# TECHNICAL CONSIDERATIONS FOR OPERATING SYSTEMS EXPANDED TO FIFTY OR MORE TELEVISION CHANNELS

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**Phase Lock and Sync Lock are tools that can be used to reduce distortion and favorably change the subjective appearance of the interference seen in the background of a television channel. The use of these tools allows systems carrying fifty or more channels to serve the same geographical area formerly limited to thirty-five channel distribution. Effects of Cross Modulation and Composite Triple Beat will be discussed, and it will be proven that the Triple Beat mechanism is the predominant source of distortion. The phase-lock technique will be explained analytically showing the mechanism which causes the subjective transition of distortion from low frequency beats to sliding video frames. The report will also discuss further additional improvements in system tolerance using sync-lock and sync suppression.**

## INTRODUCTION

Many CATV systems built in the last six or seven years took advantage of the 300 MHz equipment available from suppliers to the industry, and operators planned their layouts to allow for the ultimate carriage of thirty-five television channels. The improved signal handling capability of hybrid IC's and the "quad" circuit, together with larger and more efficient coaxial cables, kept pace with this increased channel loading. Improved system layout approaches, such as hubbing - in conjunction with the use of AML for hub interconnect - were tools used by the CATV operator to deliver quality pictures to their subscribers. Few took advantage of the subjective performance benefits available from phase lock.

Now that CATV is expanding rapidly into systems that will cover significantly larger geographical areas with the increased demand for additional services - thus more channels - the need for techniques to maintain quality performance is evident. Phase lock is such a technique. The incremental cost is low; it is the best performance improvement bargain available today. However, it is evident that the benefits of a phase-locked carrier system are not fully understood by many.

Without phase lock, the major non-linear distortions from system amplifiers that are first apparent on the television screen (assuming well balanced push-pull amplifiers) are the carrier beats from the composite grouping of all the triple beat distortions which fall into the sideband of a desired channel close to its carrier. Even in the older twelve-channel systems it can be shown that the predominant distortion is triple beat, not cross modulation. Now, before I get into trouble with you readers, let me establish a few definitions that I will use throughout this article. I will first state that all the distortions discussed can be derived mathematically from the Power Series expansion of the non-linear transfer characteristics of a typical CATV amplifier. The expression "Cross-Modulation Mechanism" will be used to refer to the 3rd order term in the Power Series expansion, which results in sideband components (and a small carrier component) from one TV channel in the system transferring its signal information symmetrically onto another channel in the system. The small carrier component involved, falls precisely onto the later carrier. The expression "Triple Beat mechanism" will be used to refer to the third order term in the Power Series expansion which results in three separate sideband components and a carrier component from three TV channels transferring their signal information assymmetrically onto a channel in the system. For distortion to occur via the Cross Modulation mechanism, both the distorting and the distorted channels must be in the system. For distortion to occur via the Triple Beat mechanism, at the frequency slot of the channel being distorted, the distorted channel need not be in the system.

The mathematical expressions shown in Figure 1 represent four TV channels (A, B, C, & D) which are 100% amplitude modulated carriers ($f_A$, $f_B$, $f_C$, $f_D$) by a sine wave signal ($f_{sa}$, $f_{sb}$, $f_{sc}$, $f_{sd}$). Figure 2 gives the formula for the Cross Modulation mechanism as derived from the third order component of the Power Series.

$$\text{Unmodulated Carrier} = A \sin 2\pi f_A t$$

$$\text{let } A = A_1\ (1 + m \sin 2\pi f_{sa} t)$$

$$\text{Modulated Carrier} = A_1\ (1 + m \sin 2\pi f_{sa} t) \sin 2\pi f_A t$$

$$A_1 = \frac{A}{1+m}$$

$A$ is the peak level for all values of $m$

$A_1$ is the carrier level

$m$ is the modulation index ($m = 1$ for 100%)

$f_{sa}$ is the modulation signal frequency

$f_a$ is the carrier frequency

$$\text{Channel } A = A_1\ (1 + m_a \sin 2\pi f_{sa} t) \sin 2\pi f_A t$$

$$B = B_1\ (1 + m_b \sin 2\pi f_{sb} t) \sin 2\pi f_B t$$

$$C = C_1\ (1 + m_c \sin 2\pi f_{sc} t) \sin 2\pi f_C t$$

$$D = D_1\ (1 + m_d \sin 2\pi f_{sd} t) \sin 2\pi f_D t$$

*Figure 1*

ONE CROSS MODULATION COMPONENT

$$9/4\ k_3 A_1 B_1^2 \sin 2\pi f_A t$$

CARRIER COMPONENT

$$3/2\ k_3 A_1 B_1^2 m_b \sin 2\pi (f_A \pm f_{sb})\ t$$

SIDEBAND COMPONENT

*Figure 2*

It shows the distortion from channel B, (whose carrier frequency is $f_B$ and whose signal is $f_{sb}$) onto Channel A. Note that the small carrier component from this distortion falls precisely at the frequency of A ($f_A$) and that the sidebands fall symmetrically around the carrier of Channel A. Also, note that Channel A is an integral part of the distortion component and must be in the distorting system (the CATV amplifier system) for this mechanism to occur. Figure 3 graphically represents the result.

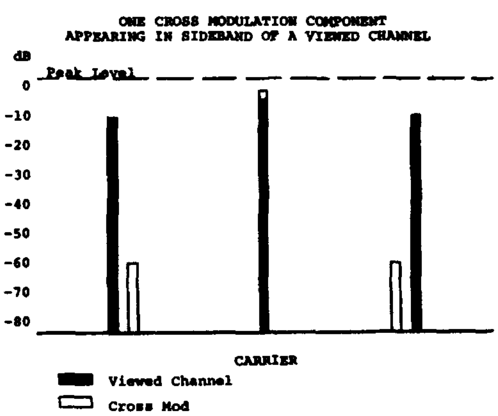


*Figure 3*

The Triple Beat mechanism is defined by the formula in Figure 4 which also derives from the third order component of the Power Series. You can see that there is a carrier component falling at the frequency $f_x = f_B \pm f_C \pm f_D$ and

$$3/2\ k_3 B_1 C_1 D_1 \sin 2\pi (f_B \pm f_C \pm f_D)\ t$$

CARRIER COMPONENT

substitute $f_x$ for $(f_B \pm f_C \pm f_D)\ t$

$$3/4\ k_3 B_1 C_1 D_1 [m_b \sin 2\pi (f_x \pm f_{sb})\ t \pm m_c \sin 2\pi (f_x \pm f_{sc})\ t \pm m_d \sin 2\pi (f_x \pm f_{sd})\ t]$$

SIDEBAND COMPONENTS

*Figure 4*

three sideband components (one set from each offending channel) are symmetrically centered around the above distortion carrier component, $f_x$. An example is given in Figure 5.

LET

| | | |
|---|---|---|
| $f_A$ = Channel 10 | | = 193.250 MHz |
| $f_B$ = Channel 12 (-10KC offset) | | = 205.240 MHz |
| $f_C$ = Channel 9 | | = 187.250 MHz |
| $f_D$ = Channel 11 | | = 199.250 MHz |
| $f_x$ = $f_B$ $+f_C$ $-f_D$ | | |
| | 205.240 + 187.250 - 199.250 | = 193.240 |
| $f_x = f_A$ - 10 KHz | | |

*Figure 5*

The carrier beat from $f_B + f_C - f_D$, given in the example, falls in the sideband of Channel A at 10 KHz below the carrier $f_A$ and the three sideband components from this Triple Beat mechanism fall symmetrically around the distortion carrier, $f_x$ - not around $f_A$. Also, note that Channel A was not involved in the formation of this triple beat component. Figure 6 represents this mechanism graphically.

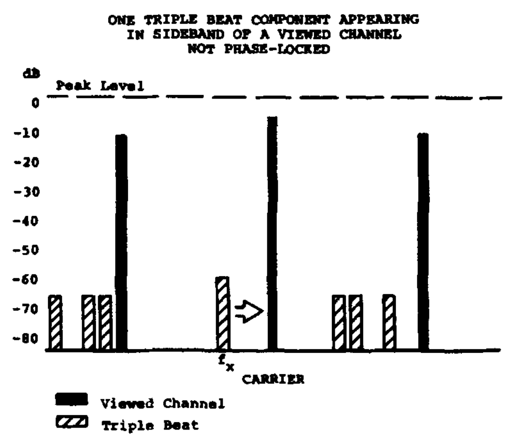


*Figure 6*

Extensive subjective evaluations of distortion in cable systems have been made at the Jerrold engineering laboratory. These studies have included systems carrying twelve, thirty-five and fifty-two television channels. Tests were conducted using both the phase lock and non-phase locked modes. A reference of a "not perceptible" distortion was established. This is typically one dB of system output level below the point where distortion is first seen by a group of trained observers. Results establish that a test system of either thirty-five or fifty-two channels can be driven five dB higher in level when phase-lock techniques are applied to a non-locked system. Similarly, a 52-channel system using phase-lock has the same (or a slightly higher) "not perceptible" reference as the identical system carrying 35 channels non-phase locked. In each case, the specific channel showing most distortion was used as the reference.

It is evident from these studies that the form of the interference changes. In the non-coherent system, the distortion appears as massive low frequency beats in the sideband of the viewed channel. Rarely can a videoframe be identified in the background. In the phase-locked mode, these carrier beats disappear and, at the 5 dB increased level, slowly sliding video frames are apparent. Figure 7 shows that the carrier

ONE TRIPLE BEAT COMPONENT APPEARING IN THE SIDEBAND OF A VIEWED CHANNEL PHASE-LOCKED

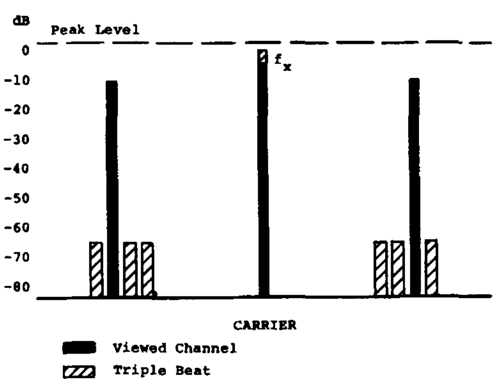


*Figure 7*

component of triple beat distortion depicted in Figure 6 has been shifted in frequency until it coincides with the carrier of the channel being viewed; thus, eliminating the subjective effect of the carrier beats and disclosing the sideband components of this distortion. Note that with phase lock these sideband components are also shifted to become symmetrical about the carrier of the viewed channel. The remaining distortion appears in the same form as pure cross-modulation and deceives some engineers into thinking that triple beat is eliminated and cross-modulation is predominent. Figure 8 is a table showing the number and source of distortions appearing in the worst channel of the three systems.

NUMBER OF DISTORTION COMPONENTS

| | | | |
|---|---|---|---|
| No. Of Channels | 12 | 35 | 52 |
| Channel with Most Distortion | 10 | 11 | 0 |
| Triple Beats $f_A \pm f_B \pm f_C$ | 23 | 347 | 917 |
| 3rd Order Intermod $2f_A \pm f_B$ | 3 | 17 | 28 |
| Second Order | 0 | 6 | 17 |
| Video Sources Triple Beat | 85 | 1126 | 2613 |
| Video Sources Cross Mod | 11 | 34 | 51 |

*Figure 8*

Once the subjective impact of the carrier components of the triple beat is removed by phase-lock, there remains the video components. A single video component from the Triple Beat mechanism is 6 dB lower in level than a single component from the Cross Modulation mechanism. The coefficients shown in Figure 9 indicate this 6 dB relationship.

SIDEBAND COMPONENTS

$$\text{Xmod} = \frac{3}{2} k_3 \, m \, A_1 \, B_1^2$$

$$\text{Triple} - \frac{3}{4} k_3 \, m \, A_1 \, B_1 \, C_1$$

Assumes the carrier level and modulation index are the same for all channels.

*Figure 9*

Referring again to Figure 8, you can see that in a 52-channel system the ratio of video components from triple beat compared to the video components from cross modulation is 2613/51 or 51.2. Similarly, in 35-channel systems the ratio is 1126/34 or 31.1. Converting 51.2 to a power ratio, we get 17.1 dB. Subtracting 6 dB from this to allow for the stronger individual cross modulation components we get an 11.1 dB power ratio or approximately 13 times as much distortion power in the video sidebands from triple beat than from cross modulation. Adding two powers 11.1 dB different in level increases the predominant source by 0.3 dB or impacts the operating level of the system by 0.15 dB. Cross Modulation distortion is clearly incidental.

I mentioned early in this paper that the predominance of triple beat over cross-modulation was easily proven. The test set-up shown in Figure 10 shows 51 channels of a 52-channel system coupled directly to an amplifier cascade. The reference channel being viewed can be switched "THRU" the cascade or can bypass it. In the THRU position, the viewed channel has both cross modulation and triple beat components. In the PASS position, the viewed channel has only triple beat components.

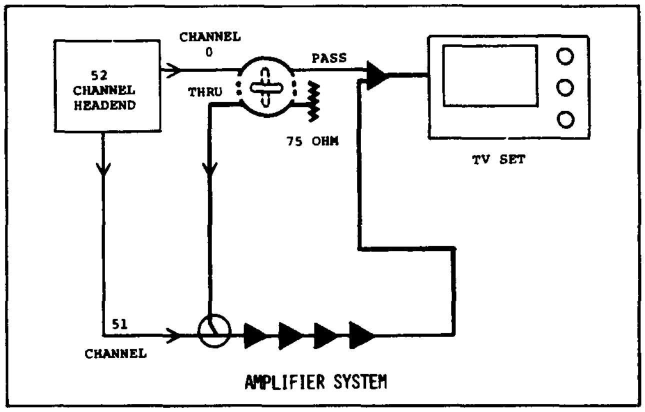


*Figure 10*

Recall that for cross modulation to occur, the viewed channel must be in the distorting system. Subjective tests conducted at Jerrold laboratory show that removal of cross modulation components has no impact on the picture quality, indicating that the real source of distortion is from the Triple Beat mechanism. This proved true even for 12-channel systems.

Another tool that has great promise for reducing distortion and its subjective effect, is a technique I call Sync-Lock. By use of a product called a Frame Synchronizer, a video source can be delayed to have all synchronizing pulses, including the vertical, align precisely with a reference television channel. The simplest way to view the concept is to assume there are N number of channels - then there are N-1 Frame Synchronizers required - each being locked to the same reference. All signals must be at video baseband to create this condition. This entails demodulation of all headend channels received off-air. Headend sources received from satellites and microwave links, plus signals locally generated, are already at baseband. Once sync-locked, all signals are then individually modulated onto the appropriate r.f. carrier. It was brought to my attention that many locally generated video sources can first be gen-locked, reducing the number of Frame Synchronizers required. The major distortion energy in the amplifying system occurs when the television set is blanked vertically and horizontally off-screen. As long as the distortion at the sync pulse period is not sufficient to cause a TV set to roll or tear, the distortion during the viewed portion is reduced with the increased advantage that no sliding interference exists.

The major deterent to this technique is not technical, it is cost. Frame Synchronizers currently sell at $12,000 each. Since these have additional features not required for Sync Lock, it is anticipated that a significant price reduction is possible. A demodulator/modulator combination must substitute for a processor for off-air signal reception.

## SUMMARY

For those large CATV systems which require fifty or more channels, the proven technique of carrier phase-lock is an important tool to maintain quality pictures. In measuring distortion on such systems, the Triple Beat mechanism is of prime importance - cross modulation is incidental. On systems with thirty-five channels and less, phase-lock can be used effectively to significantly improve carrier-to-noise ratio and/or improve system tolerance. In systems so large that the benefits of phase lock are not sufficient, the technique of Sync-Lock holds additional improvement.