SATELLITE & Cable TV

UNDERSTANDING & CONTROLLING DISTORTION IN A CATV NETWORK

This is the second part of a series of articles. The first part carried a few months ago provided an insight into noise on CATV networks. This article takes a closer look at distortion and means of minimising it.

INTRODUCTION

While most of us have a general idea of distortion and know that it deteriorates the signal, it may be useful to re-state what is distortion. When a signal is processed through an electronic circuit, the output of the circuit often contains unwanted signals which were not part of the input. These unwanted output signal's frequency is usually related to the input signal's frequency. As a simple example, if a 100 MHz signal is fed into a CATV Amplifier, the output signal may contain unwanted signals at 200 MHz, 300 MHz, 400 MHz etc. These signals are referred to as distortion. It is important to note that only active electronic circuits generate distortion. Passive elements or circuits such as coaxial cables or even traps and filters do not generate any distortion.

TYPES OF DISTORTION

Several types of Distortion exist. The example given above with a 100 MHz input signal is demonstrated graphically in Figure 1.
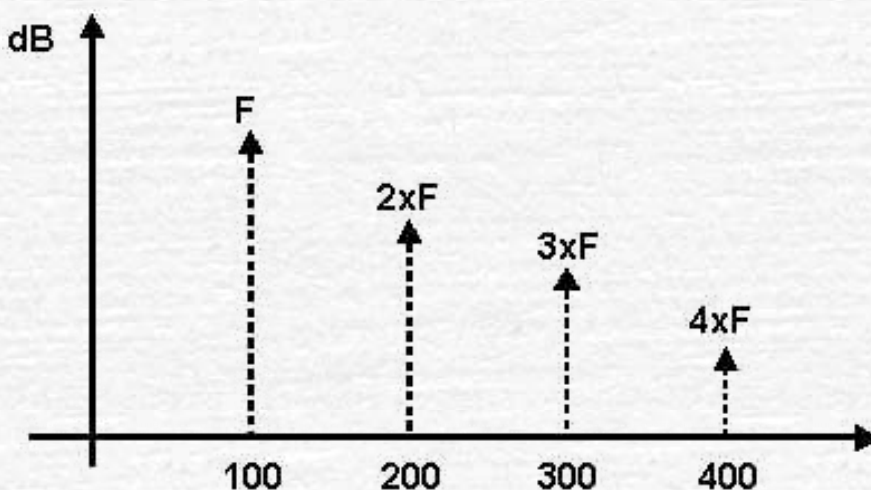

Figure 1:   Frequency (MHz)

The original 100 MHz input signal is referred to as the "Fundamental". The 200 MHz distortion is the "Second Harmonic" since it is twice the frequency of the original. Similarly the 300 MHz distortion is the "Third Harmonic". This example of a single frequency input signal yielding multiple harmonics is the simplest case of distortion and is termed as "Harmonic Distortion" since the distortion products are harmonics or multiples of the original (fundamental) signal.

In the real world, it is unlikely that any amplifier would be fed a single frequency input. Even a single TV channel contains 2 carriers viz the video and audio carriers. Let us assume that 2 frequencies f1 and f2 are fed into the amplifier. Besides simple, harmonic distortion, other types of distortion such as f1 + 2xf2, f2 + 2xf1 and various other multiples of f1 and f2 will be created. These are shown in Figure 2. Lets assume that f1 = 50 MHz and f2 = 80 MHz. Distortion products will be generated at 210 MHz, 180 MHz, etc. These distortion products are collectively termed as "Intermodulation Distortion" since they are the result of the interaction or modulation of both the input frequencies.

Readers will realise that a Cable TV system with even 10 to 12 channels, can very quickly generate a large variety of intermodulation distortion products. It is therefore crucial to maintain a low level of intermodulation distortion.

There are various types of intermodulation products depending on the harmonic multiples that are selected. These are CSO (Composite Second Order) distortion and CTB (Composite Triple Beat)

distortion. In typical CATV networks, particularly those with a large number of channels, CTB is the distortion which rises very rapidly and is the predominant distortion. Therefore, usually the CTB specifications of an Amplifier are to be considered since this is usually the worse case distortion.

Fortunately for technicians involved in the installation (rather than the design) of CATV networks, the measures that reduce CTB are also effective for reducing most other types of distortion such as CSO or ofcourse the Grand Daddy of all distortions - Harmonic Distortions.

As indicated above, harmonic distortion is the simplest form of distortion. The second harmonic of the 450 MHz signal will be at 900 MHz. However, the bandwidth of most cable networks does not exceed 890 MHz. Hence the harmonic distortion of any channel above 450 MHz will not affect the picture quality on a CATV network.

However intermodulation distortion products occur both above and below the input frequencies. Cable networks have now realised that improper setting up of channel X, Y or Z modulators often creates distortion in the picture on channels E2 to E4. Switching off the offending channel x Modulator magically clears the picture on channel E2 !
    Given this basic primer on the different types of distortion, lets take a look at the various types of amplifiers typically used in a cable network.

THE WIDEBAND / BROADBAND AMP
The most basic CATV Amplifier is the Wideband Amplifier sometimes also referred to as the Broadband Amplifier. This is typically constructed using 5 or 6 transistor stages of amplification. Each of these transistor stages uses several discreet components. As a result of this, the characteristics of the amplifier can vary quite significantly from piece to piece. However, these amplifiers are relatively low cost and have proved popular for use in small networks carrying 24 or less CATV channels over relatively short distances.

THE HYBRID AMPLIFIER
Most modern CATV Amplifiers now utilise a Hybrid IC manufactured either by Motorola or Philips. These Hybrid ICs provide all the essentials of a good CATV Amplifier in a easy to use, hybrid module. The manufacturer needs to arrange a few basic components around the Hybrid IC to obtain a quality CATV Amplifier. Ofcourse, considering the very high frequency of operation, the actual component layout, quality of components as well as even the material used for the PCB, effects the performance of the finished product. Nevertheless, Amplifiers manufactured from Hybrid ICs provide very consistent specifications that do not vary significantly from piece to piece. Further, the Hybrid ICs are designed to provide a significantly higher output level for the CATV signal, with low distortion.

POWER DOUBLER AMP
As we will see later in the article, the distortion generated by an Amplifier depends largely on the output signal level. Just as a car would strain to run at a higher speed, an Amplifier generates more distortion if operated at a larger output level. Circuit designers then thought of using 2 amplifier output stages to share the output. As a result, each output stage bears only half the load. Alternatively, for the same distortion, the power doubler amplifier can provide twice the output (i.e. 6 dB more) than a conventional Hybrid IC.

LINE LENGTH & DISTORTION
In a CATV network, the output of 1 amplifier, after being attenuated by the distribution cable feeds the input of another CATV Amplifier. This is referred to as "Cascading" of Amplifiers. In large networks, it is not uncommon to encounter a cascade of 10 to 12 Amplifiers before the signal reaches the end subscriber from the control room. In a cascade, not only the output signal but also the distortion of one Amplifier is feed into the input of the next Amplifier which amplifies both the signal and distortion !

One can very easily appreciate that unless the distortion; particularly in the first few amplifiers; is kept at a minimum, the picture at the customer end will be significantly deteriorated. Because of this larger networks need to pay greater attention to minimising distortion from the Amplifiers.

Again, it is for this reason that large networks require to deploy superior performance "Trunk Amplifiers" on the trunk line. Somewhat lower performance and ofcourse cheaper "Line Extender Amplifiers" can be used on the branch and distribution routes.

ESTIMATING DISTORTION
The distortion of an Amplifier can be calculated quite accurately from the data sheets. Since most Hybrid Amplifiers use similar Hybrid IC modules, the data sheet of the Hybrid IC module is an excellent starting point to calculate and predict amplifier distortion.
The Cross Modulation (X-Mod) distortion in any amplifier is given by the formula
X-Mod = X-Mod Spec + 2(Rated output - Actual output)

Let us try and understand what this formula conveys. The Cross Modulation of the Hybrid IC is specified for a particular output level (usually the maximum output, e.g. 108 dBU) and number of channels on the system (usually 69 channels for 550 MHz). As one can expect the amplifier would generate less distortion for a lower output level. How much lower, is what the formula will reveal.

The formula actually indicates that Distortion deteriorates by 2 dB of every dB increase in the output level !

Note: While referring to the Maximum output level, we refer to the Channel with the highest level. As an example, if the output of the amplifier is 102 dBU at Channel 2 & 92 dBU on channel s-20, the max output for the calculations should be taken as 102 dBU.
Let us assume that the Motorola Hybrid IC 5342 is rated to provide -58 dB distortion with an output level of 108 dBU. Let us assume that all amplifiers in the network are set so that their maximum output is 100 dBU putting these values in the formula, we obtain the X-Mod distortion of the first Amplifier as

X-Mod 1   = 58 + 2(108 - 100)
              = 58 + 16
              = 74 dB

Thus the first Amplifier generates -74 dB of distortion.
The BIS specifications dictate that the customer should not receive more than -54 dB of distortion. Hence more amplifiers can be cascaded till the distortion reaches -54 dB. The formula that yields the maximum number of Amplifiers that can be used before distortion exceeds permissible limits is :
System X-Mod = X-Mod of first Amplifier - 20 log (n) where n is the number of Amplifiers.
Plugging in the values we have obtained above:
54 = 74 - 20 log (n)

Using a scientific calculator yields n = 10 i.e. a maximum of 10 Amplifiers can be used in cascade if the output level of each amplifier is kept within 100 dBU. A cascade of 10 amplifiers is fairly reasonable for most networks. If the distribution network requires more than 10 Cascaded Amplifiers, then the output level of all amplifiers should be suitably reduced. A max output level of 95 dBU will permit a 40 Amplifier cascade !

The use of a scientific calculator may prove daunting for many readers hence we have formulated a simple method for calculation of distortion without the use of anything more than a paper and pencil.

RULE OF THUMB CALCULATIONS
A Rule of Thumb is typically a quick approximation that is accurate enough to use in practice. We have developed such a "Rule of Thumb" for calculating amplifier distortion.
The Cross Modulation of the first Amplifier is fairly simple to calculate. As indicated above
Cross Mod 1 = 58 + 2(108 - Actual Level)

We strongly recommend that for all practical purposes, users maintain a maximum output level from hybrid amplifiers of 100 dBU. Hence for all Hybrid Amplifiers utilising the usual Motorola or Philips Hybrid IC, Cross Mod of the first Amplifier will be
   = 58 + 2(108 - 100)
   = 74 dB
The key "Rule of Thumb" for Amplifier distortion is :
Doubling the Number of Amplifiers Increase distortion by 6 dB
Hence if one Amplifier generates Cross Mod distortion (for 100 dBU output level) of -74 dB, 2 Amplifiers will result in Cross Mod distortion of -68 dB, 4 Amplifiers will result in X-Mod distortion of -62 dB, 8 Amplifiers will yield -56 dB and 16 Amplifiers will yield -50 dB.

However BIS specifications dictate that distortion should not be worse than -54 dB. Clearly we can therefore use between 8 and 16 amplifiers. The exact mathematical calculation yields 10 amplifiers. To calculate distortion follow these simple steps :

STEP 1
Calculate the distortion of the first Amplifier :
X-Mod = 74 + 2(Rated output - Actual output)
STEP 2
In the left hand column list down numbers from 1, that keep doubling viz. 1, 2, 4, 8, 16, etc On the right hand side column against 1, list the X-Mod of the first Amplifier that was calculated in Step 1. Keep reducing this by 6 dB as you progressively move down the column, till you reach -53 dB.

As an example, let us calculate the X-Mod distortion for Hybrid Amplifiers operating at an output

level of 98 dBU.

$$\text{X-Mod of First Amp} = 58 + 2(108 - 98)$$
$$= 78 \text{ dB}$$

1	78 dB	2	72 dB
4	66 dB	8	60 dB
16	54 dB	32	48 dB

This indicates that more than 16 Amplifiers can be used in cascade, if the maximum output level is maintained below 98dBU. All these calculations are ofcourse, only considering distortion. Actually, the noise contribution should also be reviewed. The method for estimating & controlling amplifier noise has already been outlined in the previous article, in this series of articles.

DISTORTION LIMITS
The Bureau of Indian Standards vide their specification IS-14264 dictates that the customer should receive a signal which is atleast 54 dB higher than the total distortion on the signal. Assuming that the headend does not generate a significant amount of distortion, it implies that all cascaded amplifiers on the network from the headend to the subscriber at the furthest point, should not generate more than -54 dB of distortion. Table 1 indicates the effect of various types of distortion on the picture quality. It is interesting to note that CTB also generates a grainy picture which can sometimes be mistaken for a noisy picture.

WIDEBAND AMPLIFIER DISTORTION
The Wideband or Broadband Amplifier, offers poorer performance than a Hybrid Amplifier and is suitable for small distribution networks carrying approximately 24 channels. Such Amplifiers typically yield higher distortion. A good working rule is to operate the Wideband Amplifier at a maximum output level of 95 dBU. Operated at this level, the Wideband Amplifier gives satisfactorily low distortion for use in delivering a quality CATV signal.

MINI HYBRID AMPLIFIERS
The Mini Hybrid Amplifier, as the name suggests, uses a "Mini" hybrid circuit. Various such hybrid circuits are available. Some of these are manufactured in India while others are of Chinese origin. The Mini Hybrid Amplifier offers better performance than a Wideband Amplifier but is not as good as a regular Amplifier utilising the Motorola 5342 / 6342 Hybrid IC or its Philips equivalent.

To obtain good performance from a Mini Hybrid Amplifier, it is recommended that the Amplifier be operated at a maximum output level of 97 dBU.

POWER DOUBLER ICs
As we have seen earlier, increasing the output level by 3 dB increases the distortion by 6 dB i.e. distortion rises very rapidly. An increase of 3 dB in the output level may not seem much to the non technical user but actually implies double the output power level. A new type of Hybrid IC (Philips BGD 502 or 504) that uses a dual output stage offers double or 3 dB higher output, for the same distortion. This family of Hybrid ICs have been called "Power Doublers".

As indicated, increasing output level by 3 dB increases distortion by 6 dB. On the other hand, if the Power Doubler (Hybrid IC) Amplifier output level is not increased by 3 dB, the Power Doubler Hybrid IC will provide 6 dB lower distortion than the Hybrid IC, for the same output level.

Again, reviewing the earlier formula which dictated that distortion increased by 6 dB when the number of Amplifiers used is double. Hence, twice as many Power Doubler Amplifiers can be used in a cascade, compared to regular Hybrid IC Amplifiers, for the same output level of say 100 dBU. Ofcourse, the Power Doubler Hybrid IC and Amplifier are more expensive than the regular Hybrid IC equivalent.

DISTORTION & NUMBER OF CHANNELS
Just as a truck engine would strain to pull a full load compared to an empty truck, similarly a CATV Amplifier would generate higher distortion if it is used to amplify 67 channels instead of 1 channel. Actually there is a formula that links the distortion to the number of channels being amplified. However an easier method is to remember that amplifier distortion increases by 3 dB if the number of channels is doubled. Similarly a Hybrid IC Amplifier that would operate well with 69 channels and 100 dBU output level, can be operated with an output level of 103 dBU if used on an 18 channel CATV network.

However it is apparent that changing the number of channels from 69 to 35 permits the output level to be increased from a maximum of 100 dBU to 101.5 dBU. The difference is not much and 1.5 dB could easily be the caliberation error of your signal level meter measuring a 100 dBU output signal. Hence it best to adhere to the recommended maximum output level of 100 dBU for a Hybrid IC based CATV Amplifier.

CONCLUSION

The article presents a simplified overview of distortion. It also provides an easy, non mathematical method to determine the distortion generated in a chain of CATV Amplifiers.

Further, a simple practice of maintaining a maximum output level of 100 dBU for CATV Hybrid Amplifiers is recommended. This will provide good performance and sufficiently low distortion for use in almost any practical CATV network.

Table 1 : Effects of Excessive Distortion.

CROSS MODULATION DISTORTION (X-Mod) :

Diagonal bars usually running from the top right hand corner to the lower left corner of the screen. This is often termed as "Wind Shield Wiper" effect since it resembles the Wind Shield Wiper across the screen.

A faint picture of another channel is superimposed. This is most prominent when the screen goes blank in between programmes or when text such as titles are scrolled against a dark background.

COMPOSITE TRIPLE BEAT DISTORTION (CTB) :

The picture is "Wormy". Appears as if tiny worms are crawling across the screen !

Grainy picture. The picture will appear with good contrast and colour but consists of grains or tiny dots all over the screen. A grainy picture due to noise will often lack colour and contrast.

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