# CUSTOMIZED BROADBAND – ANALYSIS TECHNIQUES FOR BLENDED MULTIPLEXES

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*Abstract*

*With HFC reaching saturation levels in North America, much of the focus of the vendor community for infrastructure development is in the international arena. As a result, there is a wide variation in frequency plans, bandwidths implemented, transport methods, and cascade requirements. This variation occurs simply because of global differences in demographics, topology, and standards used. As a basic example, it is now quite common to require system analysis and design for deployments featuring a mixed set of analog and digital signals, where digital channels of multiple bandwidth and modulation formats exist between groupings of analog channels, within different segments of the forward band. This situation means that a mechanism for analyzing, characterizing, and understanding the effects on performance of these systems is necessary to optimally develop system solutions in these cases.*

*Because of these needs, a user–friendly tool has been developed that predicts performance based on manual inputs on all of the key system variables – analog and digital frequency multiplexes, relative levels, slopes, output levels, and distortion variables. Perhaps the simulator's most important task is its ability to calculate the distortion performance of any set of channels – from all analog to all digital – at any relative level of each, for any slope and output level, and for any particular distortion baseline. The simulator output can be delivered in numerical tables of every analog and digital distortion component, or plotted. Output plots can be broken down into each individual contributing analog and digital distortion component, by the order of distortion component. They can be combined into a single composite plot that includes both the analog and digital components individually by order. Or, the output can be combined into one composite map. These outputs are critically important to understanding performance characteristics, and ultimately in designing and recommending hardware for such systems.*

## INTRODUCTION

The purpose of this paper is to present a summary of a distortion modeling tool, its capabilities, and applications. The primary function of this simulation tool is to graphically and numerically report the second and third-order distortion at any frequency, for any analog and digital multiplex. Throughout this paper, graphical examples are discussed, and some general relationships regarding the behavior of distortion are given.

## TRADITIONAL LINEUP

A traditional, forward-path, NTSC channel lineup occupies the band from 55.25 MHz to an upper limit of 865.25 MHz. The lower 500 MHz of is usually reserved for 6 MHz wide, analog channels, while the upper 320 MHz is reserved for 6 MHz wide, digital channels. The digital channels are typically operated anywhere from 6-10 dB below their analog counterparts. These lower levels for digital channels are sometimes referred to as digital-derate levels. The entire forward path is tilted, such that the lowest analog channel is 12 dB lower than it's analog equivalent at 865.25 MHz, 6 dB if that high channel is actually digital, with a 6 dB digital-derate. This is a "typical", North American system whose performance can easily be predicted with measured specifications and some generalized rules. General relationships are what allow us to predict the distortion effects of changing RF levels and cascading RF amplifiers.

General Distortion Relationships

Typically, we can expect third-order distortion, CTB, to degrade by about 2 dB for every 1 dB increase in channel level. We can also expect second-order distortion, CSO, to degrade by about 1 dB for every 1 dB increase in channel level. Cascading RF amplifiers requires that we add CTB performance on a 20-LOG scale, though many times it measures less. Cascaded CSO performance adds on a 20-LOG scale, though a 15-LOG scale is more typical. Additionally, changes in distortion level due to changes in channel loading can be approximated. However, calculating changes in the distortion levels requires that the channel frequencies, which see the most number of beats, are known. Generalizations like these create a simple system for predicting CTB and CSO performance and they are all based upon specifications obtained from laboratory measurements and simple analog beat mapping tools.

Classical Analog Beat Mapping Tools

Without the aid of beat mapping algorithms, generalizations regarding distortion behavior would be difficult to make. Beat maps generate the number of beats (frequency tones) that fall at any frequency as well as the distortion magnitude at that frequency. Simons [1] made this easy to determine when he showed how to calculate distortion magnitude and location for second/third-order distortion. The proof is nothing more than an algebraic manipulation of the time-domain representation of the channel spectrum.

Consider channels A and B. Mixing these channels produces second-order harmonic distortion at frequencies 2A and 2B, as well as sum and difference distortion at frequencies A±B. The harmonic distortion is about 6 dB below the sum and difference distortion. CSO is a cumulative sum of all the second-order harmonic and sum and difference distortion that fall at any frequency.

Now consider channels A, B and C. Mixing produces third-order harmonic distortion at frequencies 3A, 3B and 3C, triple-beat distortion at frequencies A±B±C and intermodulation distortion at frequencies 2A±B, 2A±C, 2B±A, 2B±C, 2C±A and 2C±B. Intermodulation distortion is about 6 dB below triple-beat distortion. Third-order harmonic distortion is about 15.5 dB below triple-beat distortion. CTB is the sum of all third-order harmonic, intermodulation and triple-beat distortion that fall at any frequency.

An analog beat mapping tool keeps track of all these distortions by storing them in a table of increasing frequency. This can be easily implemented and plotted in a spreadsheet program such as Microsoft Excel. Figure 1 shows an example plot of all output distortion components throughout frequency. Different colors identify the distortion contributor. Figure 2 is the cumulative sum of the CTB and CSO components.

Both Figure 1 and Figure 2 are relative plots, which means the levels shown are not absolute levels. The levels shown use second-order sum and difference beats, A±B, and third-order triple-beats, A±B±C as a starting point, with all other types of distortions either about 6 dB or 15.5 dB below in order to get the total relative plots you see in Figure 1 and Figure 2

Figure 2 also shows worst case CTB occurring near the middle of the band at 397.25 MHz. Worst case, in band CSO is at the low frequency edge, at 54MHz.

The worst case distortion occurs at frequencies with the greatest accumulation of beats and power. Analog beat mapping tools provide insight on where to expect worst case distortion as well as distortion levels throughout the band.

Real Hardware Considerations

It is valuable to know theoretical analog distortion performance. However, it does not compare to the accuracy of testing in the lab and observing the output on a spectrum analyzer. However, predicting distortion with real hardware has drawbacks. Lab testing takes time, particularly given multiple channel scenarios with different levels and cascades. Therefore, despite the fact that using real hardware is the most accurate characterization of performance, it may not be the most efficient route, especially when considering many scenarios and trying to quickly respond to customer inquiries.

## MODELING DIGITAL MIXING

Accurate modeling is an effective and efficient way to get answers regarding performance. Analog modeling is well understood today, however, that's not enough. A way to incorporate digital channels into the mix as well as making relative distortion models predict absolute distortion levels versus frequency would enhance the modeling required for today's applications.

Modifications to Traditional Tools

Predicting and measuring analog distortion is different from digital distortion primarily in the effect it has on other channels. Digital distortion is noise-like. However, the same rules used to calculate analog distortion still apply to digital distortions. The trick is how to describe the digital channel. A simulator with a frequency domain engine could easily model digital channels as a series of discrete tones. A simulator with a time domain engine could represent digital signals as a sinc or raised-cosine function.

After calculating all the distortions, including mixing between analog and digital signals, the three categories must be distinguished – analog/analog, digital/digital, and analog/digital. The reason will become clear once intermodulation noise is defined.

Composite Intermodulation Noise, CIN

Composite intermodulation noise is the noise-like digital distortion that is generated from mixing analog/digital and digital/digital signals together [2,3]. CIN is the combination of CIN2 and CIN3. CIN2 is the second-order digital distortion and CIN3 is the third-order digital distortion. Carrier-to-Noise ratio, CNR, is thermal noise associated with a specific bandwidth and the noise figure of the RF amplifier. All of these noise ratios combine together into composite Carrier-to-Noise ratio, CCN.

Low Power, Low Bandwidth Digital Loads

You can manage CIN by controlling the amount of power and bandwidth associated with your digital channels. Generally, the lower the power and bandwidth, the lower your CIN will be. This may seem intuitive based on what we know about analog distortion, but may be better understood by considering the total power load of the digitally loaded portion of the forward spectrum.

Total digital power load is the sum of the power of all the individual digital channels. Digital distortion varies as a function of the total power load. Therefore, digital bandwidth and derate can be exploited to reduce total power load, which reduces digital distortion and improves CIN. This will be shown in following two cases.

<u>550 MHz Analog Plus 100 MHz Digital</u>

The analog distortion for this case is shown in Figure 1 and Figure 2. The digital distortion, for about 100 MHz of digital loading, is illustrated in Figure 3 and Figure 4 Figure 3 has the digital channels 10 dB below the highest analog carrier and Figure 4 has the digital channels 6 dB below the highest analog carrier. The total digital power load is roughly 4 dB lower for 10 dB digital-derate than it is for the 6 dB digital-derate. The second/third-order distortion is about 4 dB worse in the 6 dB derate system. Therefore, increasing the digital signal level increases the distortion, which is the same as degrading CIN. The one-to-one correspondence indicates that the dominant CIN3 contribution is from 2A+1D

<u>550 MHz Analog Plus 320 MHz Digital</u>

Adding digital bandwidth shifts the maximum third-order distortion. For 320 MHz of digital bandwidth, the maximum CTB is at 706.5 MHz, compared to the maximum at 544.5 MHz for 100 MHz of digital bandwidth. CSO distortion is at its maximum at 315.25 MHz for 320 MHz of digital loading, while 100 MHz digital loading reaches maximum at 99.25 MHz. Therefore, expect shifts in the maximum and minimum locations of CTB and CSO with changes in the bandwidth.

Increasing the digital bandwidth to about 320 MHz will increase the total digital power load by about 7 dB. This will increase the third-order distortion by about 7 dB and increase the second-order distortion by about 6 dB, as illustrated in Figure 5

In Figure 6, with the digital-derate level changed from 6 dB to 10 dB, the performance is 4 dB better in both CTB and CSO.

These examples show that by increasing the total power load, either through increasing channel level or bandwidth, distortion increases, ultimately degrading CIN.

<u>Models and Measurements</u>

Up to this point, it has been shown that relative changes to total power load results in relative changes in the distortion. Measured performance can be tied to the distortion model through nonlinear gain coefficients [1]. Nonlinear gain coefficients effectively scale the distortion levels from a relativistic to an absolute value. For example, assume an RF amplifier has a measured performance of –60 dBc CTB and –66 dBc CSO. The input levels to the amplifier are 17 dBmV per channel. For 550 MHz worth of analog channels, assume that the gain of the device is 27 dB and there is no tilt, so the output power of the carriers is 44 dBmV. Now, from those values of CTB and CSO, calculation of the intercept points yields [5,6], $IP_2$=128.45 dBmV and $IP_3$=92.86 dBmV. The intercept points enable us to calculate $k_2$ and $k_3$, which are the second/third-order nonlinear gain coefficients. For this case, $k_2$=1.34E-4 and $k_3$=3.14E-6. Approximating the absolute distortion for CTB and CSO requires scaling each second/third-order distortion beat by $k_2$ and $k_3$, respectively. This results in the beat map shown in Figure 7. The maximum CTB is about –16 dBmV (–60 dBc), the maximum CSO is about –22 dBmV (–66 dBc), with the carrier outputs at 44 dBmV.

## CUSTOM MULTIPLEXES

Summarizing, modeling allows prediction of the distortion spectrum for any amplifier of specified performance. However, the real strength of this modeling capability lies mainly in its ability to predict distortion for atypical situations. Custom multiplexes are common in the international arena, offering a wide variety frequency plans, implementation of bandwidths, transport methods, and cascade requirements. The tools described will allow prediction of distortion for any channel configuration. Prediction becomes much more efficient with the aid of a programming language like Visual C++ or Visual Basic, or using MATLAB.

There are some general rules that are valuable to keep in mind. CIN behaves more like a noise floor even though it's generated the same way analog distortion is. Therefore, expect to see a nearly flat spectrum, at least in third order distortion. Also, expect CIN to increase with any increase in total power loading. It may not be a one-for-one increase for all cases, but should increase either way. Predicting performance for custom multiplexes is no different than for the traditional case, just simply a matter of managing the input load and separating the analog and digital components as necessary.

Using programming as described above, simulation time is about 1 minute for every MHz of digital signal. MATLAB provides an output in as little as 4 minutes, regardless of the amount of digital bandwidth. This is because the FFT feature in MATLAB doesn't care what the input spectrum is. It does an FFT based on the number of data-points of the input vector. The only trick with MATLAB simulation is being sure to obey Nyquist.

Using numerical tools, many different scenarios of channel plans can be determined in a reasonable amount of time. This makes for quick turn-around answers with confidence.

Figures 8 and 9 are plots of the relative analog distortion generated for two such cases. Figures 10 and 11 are their respective cumulative distortions. These two cases have digital intermixed with analog throughout the forward band, with digital channel bandwidths of 8 MHz. As indicated, both relative and absolute results can be obtained.

### Frequency Dependent Effects

Despite these conclusions, there is one more wild card at work. With today's RF electronics that are often optimized for performance at particular frequencies, the distortion effects across frequency are not constant. The result is that nonlinear gain coefficients will change over frequency. Therefore, the model must account for how $k_2$ and $k_3$ will change over frequency. Figure 12 shows how two tones, of equal power and separated by 2, 20 and 100 MHz, resulted in varying distortion performance depending upon where they were located in frequency.

## CONCLUSION

Today's link analysis requires very flexible modeling tools. Both relative and absolute second/third-order distortion for any analog and digital multiplex can be modeled. With efficient numerical tools, many variations of an analog and digital multiplex can be predicted. The capability to analyze, characterize and understand the effects of these systems allows development of optimal system solutions.

## REFERENCES


[1] Simons, K. (1968). "Technical Handbook for CATV Systems". Philadelphia: Jerrold Electronics Corporation.

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[3] Waltrich, J. B. (1993). "Distortion produced by digital transmission in a mixed analog and digital system", Communications Technology, 40, 64-76

[4] Matrix Test Equipment. (1998) "Notes on composite second and third order intermodulation distortions". Available http://www.matrixtest.com//Literat/mtn108.htm

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**FIGURE 1. Analog Individual Components**

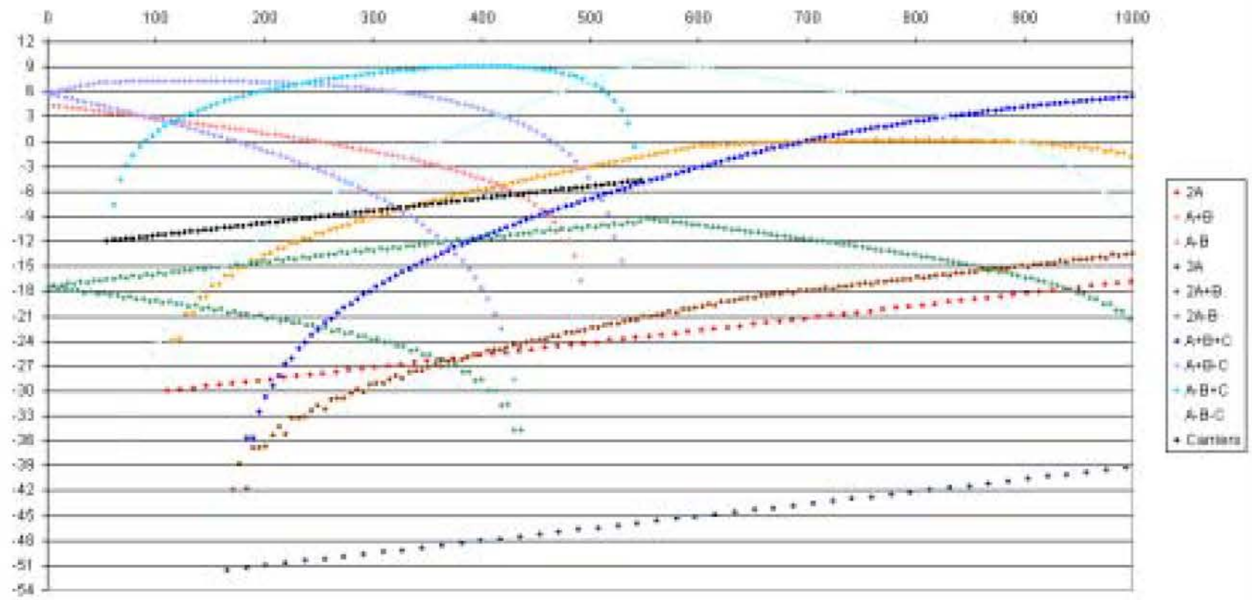


**FIGURE 2. Analog Composite**

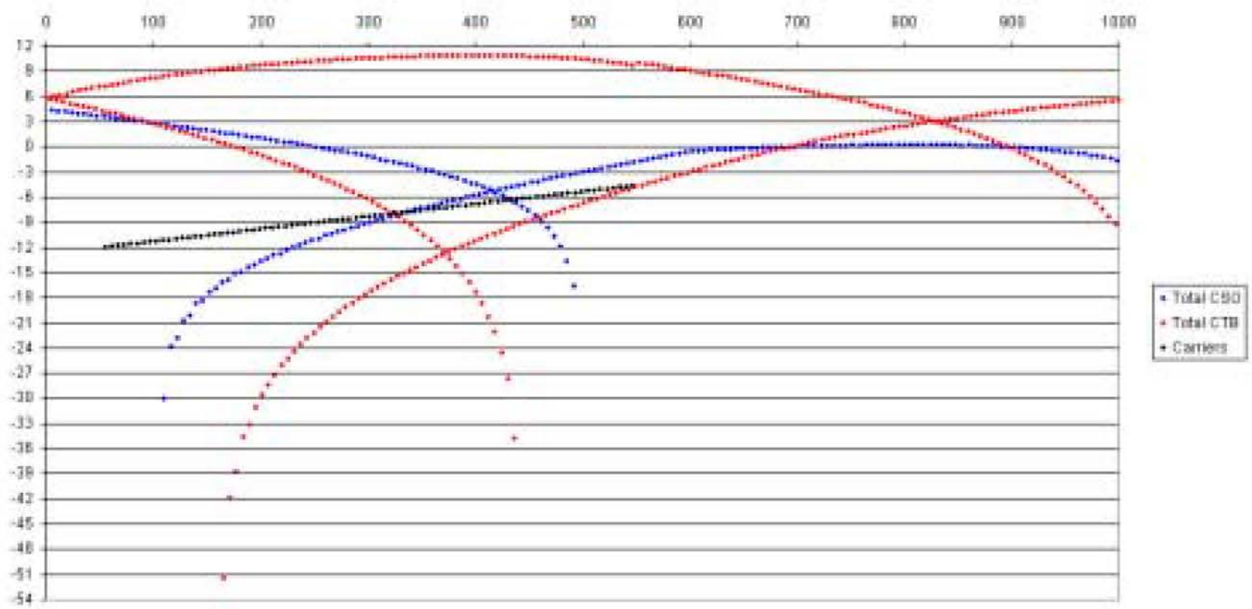

FIGURE 3. Digital Composite

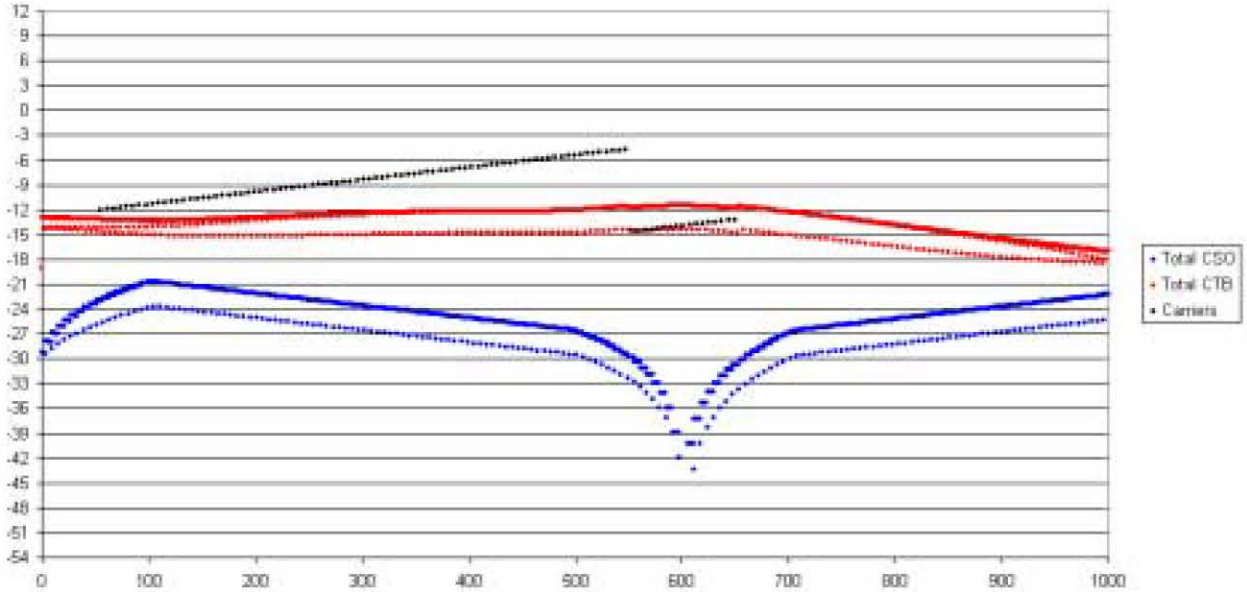


FIGURE 4. Digital Composite

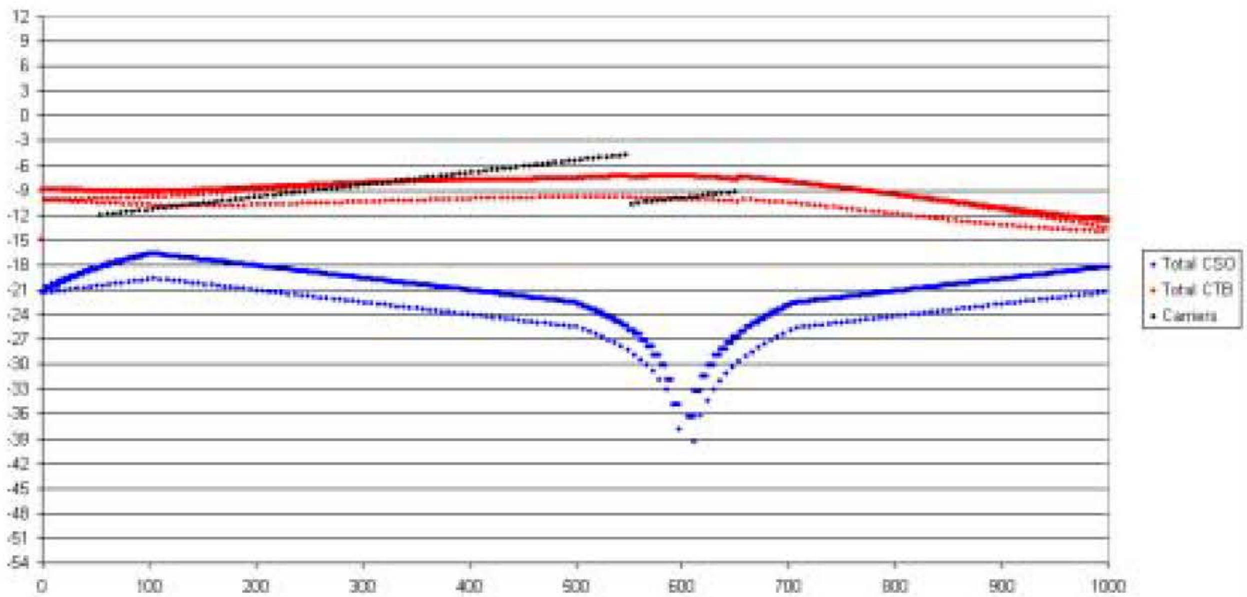

FIGURE 5. Digital Composite

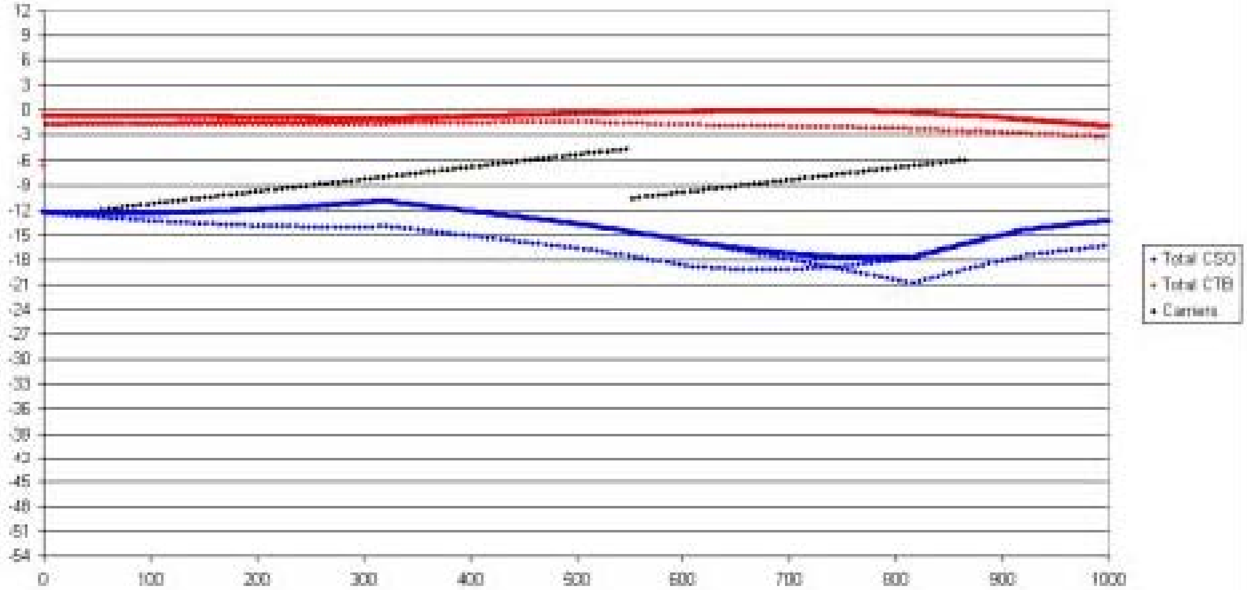


FIGURE 6. Digital Composite

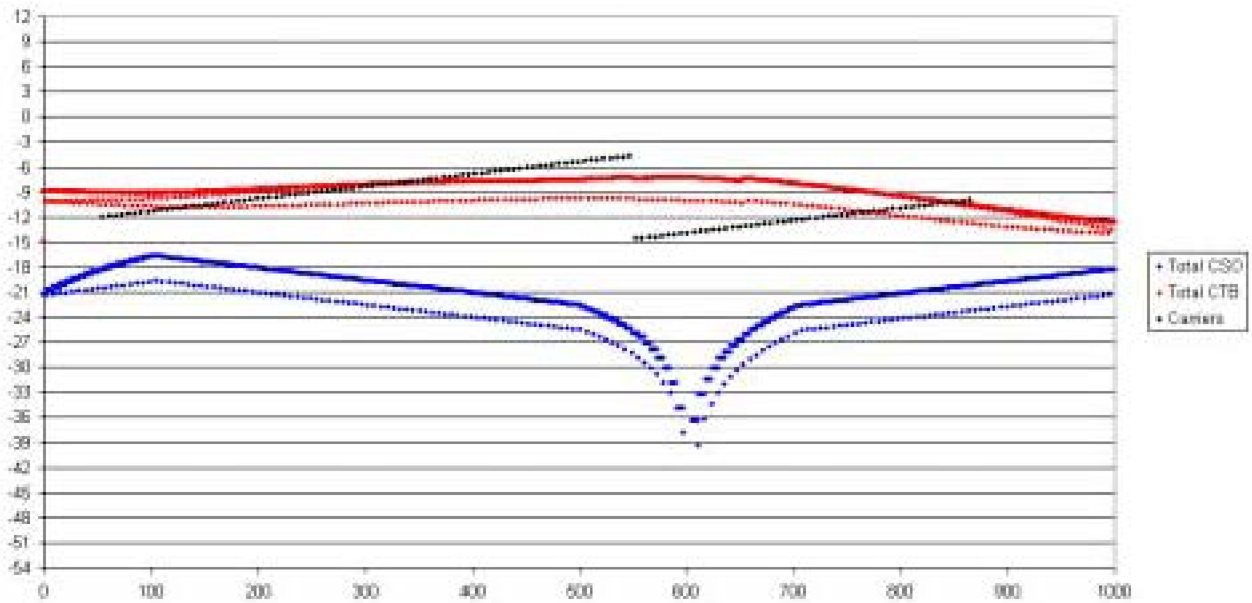

**FIGURE 7. Analog Composite**

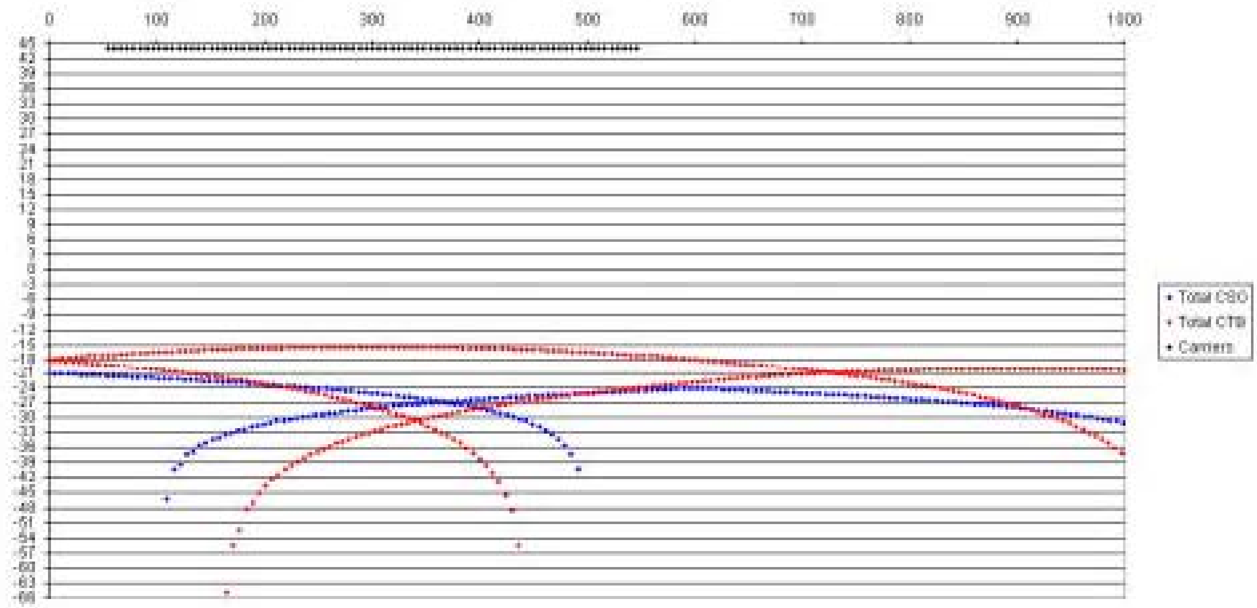


**FIGURE 8. Analog Composite**

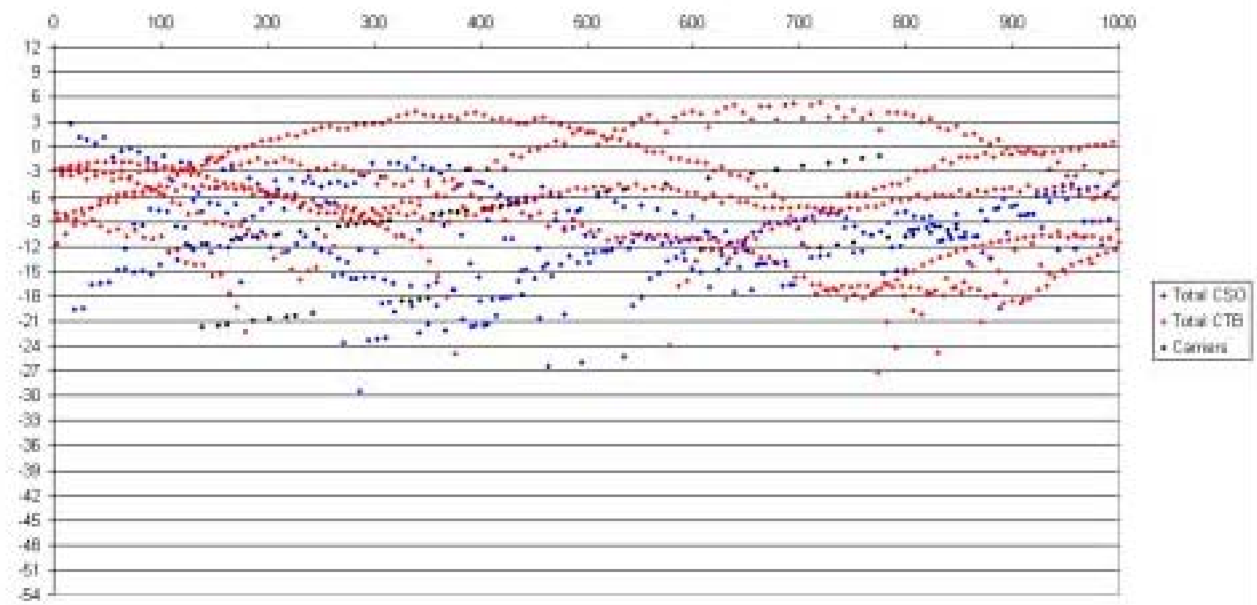

FIGURE 9. Analog Composite

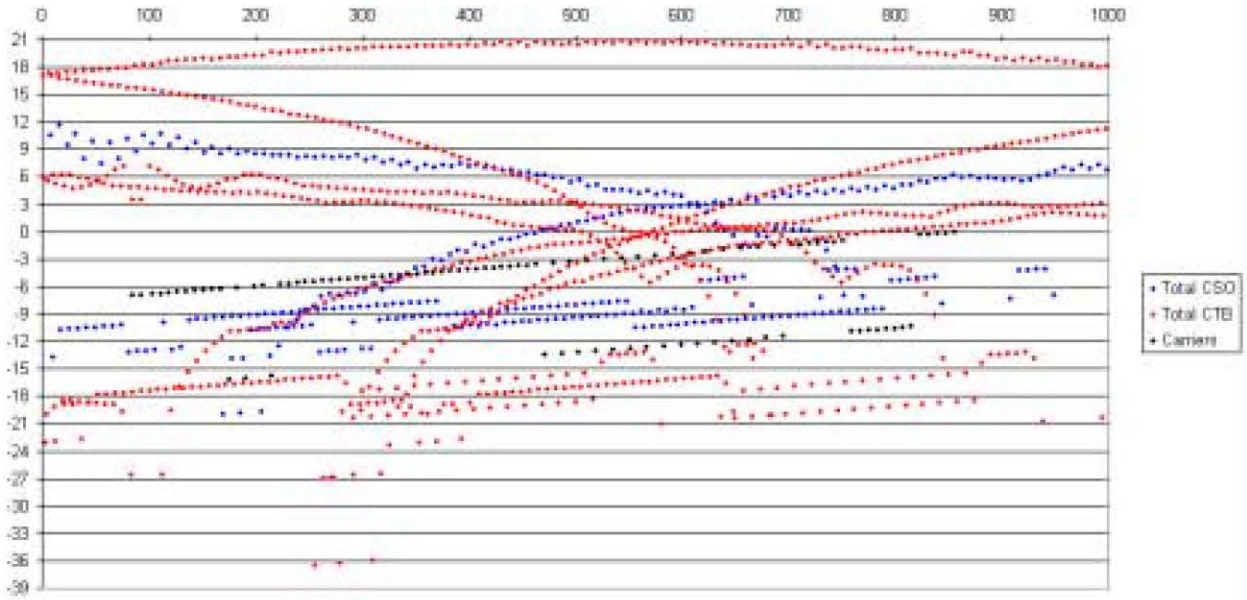


FIGURE 10. Digital Composite

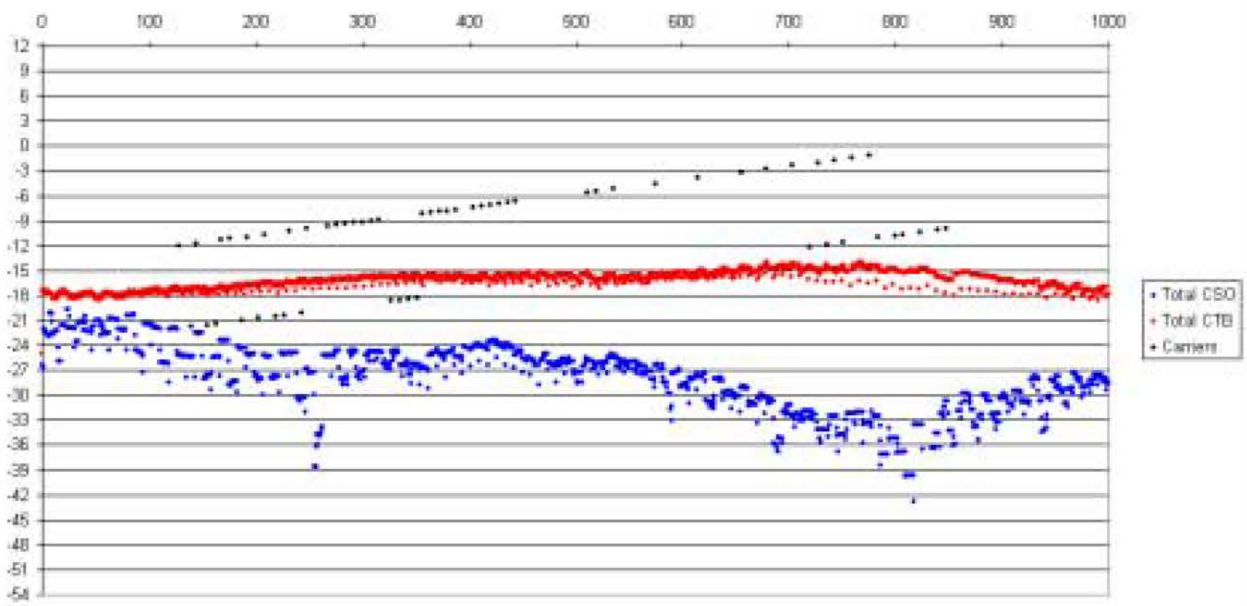

FIGURE 11. Digital Composite

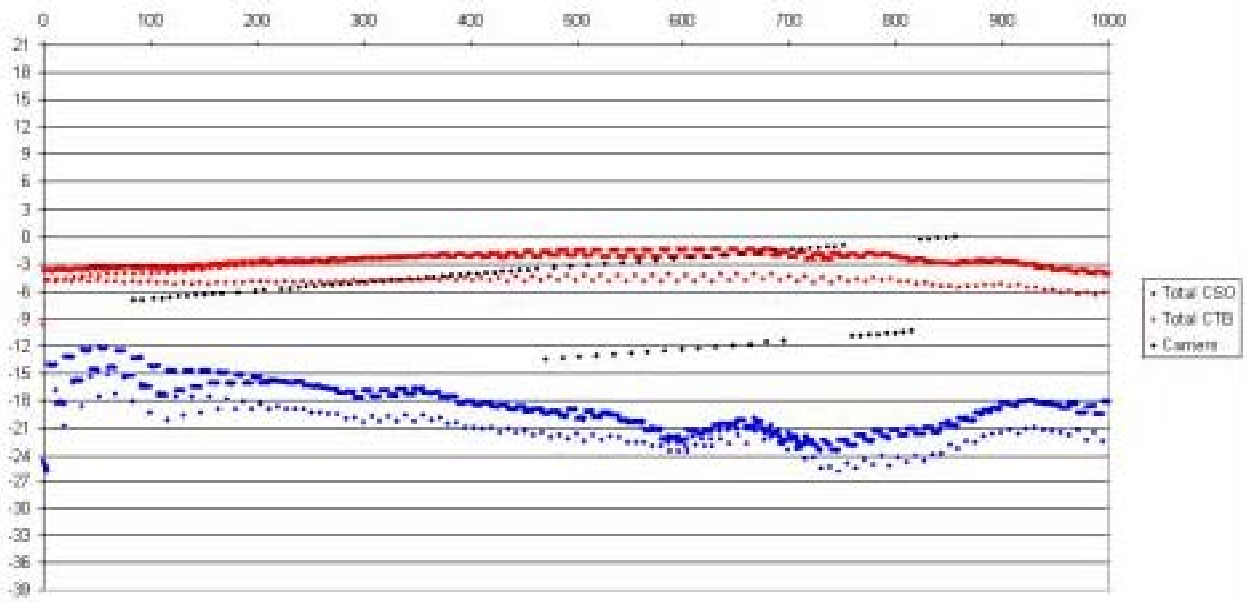


FIGURE 12. 2A Distortion vs. Frequency