DETECTING NONLINEAR DISTORTION IN CABLE SPECTRUM USING A CM OR SDR

And

METHOD AND SYSTEM TO FIND DISTANCE TO A PIM (PASSIVE INTERMOD) DIODE IN WIRING

INVENTORS:

THOMAS HOLTZMAN WILLIAMS

LUIS ALBERTO CAMPOS

KARTHIK SUNDARESAN

D5104 System and Method to Detect Nonlinear Distortion in Cable Plant

Abstract

Sources of CPD can be discovered by their characteristic 2nd order distortion products which cable amplifiers do not normally produce. Previously (Ref 1), a wide block of frequencies was captured in the time domain and analyzed by DSP (digital signal processing) to determine if 2nd order or 3rd order nonlinear distortion was present in a vacant frequency band. This alternate method is for a two-input software defined radios (SDR) to capture on one input the portions of the downstream signal where some distortion products are created and on the second input a resulting distorted spectrum. The two captured signals are processed together to determine if harmonics of a lower-frequency source signal are contained in a higher-frequency target signal. Distance to CPD source can be determined using a cross correlation between the distorted signal giving time difference, if any. A mathematically produced “measured” distortion signal created by squaring or cubing the distortion-producing waveform and this is processed with a captured distortion-producing signal.

Background

See appendix A for discussion of CPD and nonlinear distortion.

This is related to 2013 research which utilized a wideband signal capture and a vacant band in the downstream. This 2013 method used an expensive LeCroy DSO digital sampling oscilloscope. This new method uses a less expensive 2 channel SDR.

In cable plant nonlinear distortion, predominately 2nd and 3rd order, is created by a couple of methods. The expected method is amplifier distortion caused by high operational voltage levels, which produce primarily 3rd order distortion. Push-pull amplifier designs cancel 2nd order distortion. Problematic sources of nonlinear distortion are corrosion diodes causing a problem called common path distortion (CPD) when signals at different frequencies are mixed. CPD produces both 2nd and 3rd (and higher) order distortion.

See Fig. 1 which is a spectral diagram of a cable signal, which may use a mid-split frequency plan. The 5-85 MHz upstream band is illustrated in blue. The downstream 108-1200 MHz spectrum is green. Signals are simultaneously captured in a first low band centered around 158 MHz, and around a second mid band centered around 316 MHz. The signals are from the first band are mathematically processed to see if their 2nd order distortion shows up in the mid band. Processing can occur in the time or frequency domains. Using frequency domain processing is generally more efficient due to the computational efficiency of the FFT. In the frequency domain the signals in the low band are convolved with themselves in the FD (frequency domain) to produce a second order distortion. This convolution process doubles the bandwidth.

This process is repeated between the low band and the high band around 474 MHz to detect third order distortion. A triple convolution of the low band produces a 3rd order distortion.

Fig. 2 is similar to Fig. 1, except that capture bandwidth is wider. A good cross-correlation peak does not require the bandwidth between low, mid and high bands to be doubled and tripled. This is a consideration on the cost of the SDR, since wide band SDRs cost more.

Optionally 3 bands can be simultaneously captured, but hardware costs will be higher.

Processing Steps:

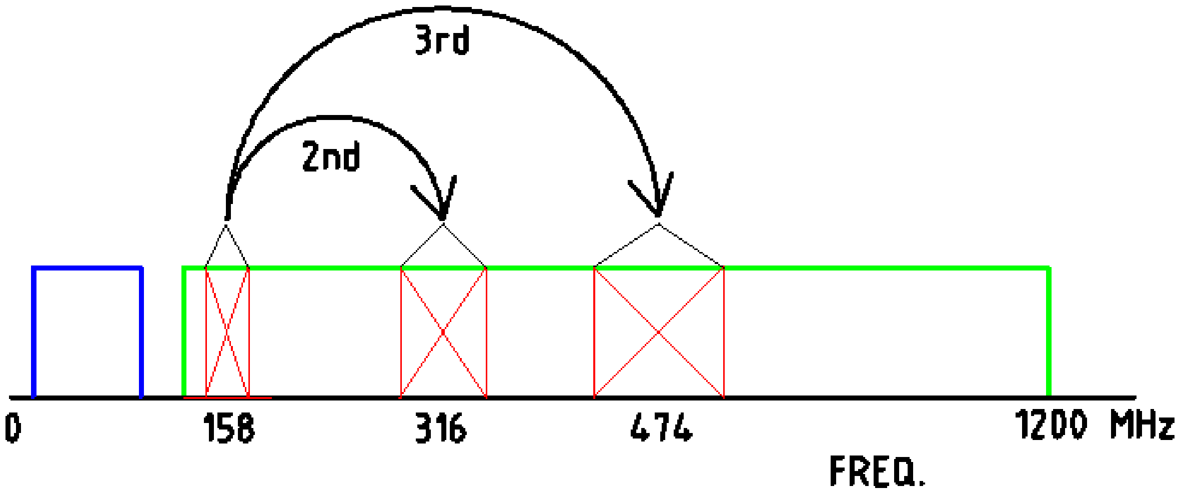
1. Start
2. Program channel 1 SDR to low band
3. Program channel 2 SDR to mid band
4. SDR captures I-Q time samples in low and mid bands at a same time.
5. Samples from low band are squared to make second order “manufactured” distortion in mid band
6. Measured samples in mid band are cross correlated with manufactured samples.
7. A resulting correlation peak indicates the presence of 2nd order distortion
8. Repeat steps 2-7 with high band replacing mid band to find 3rd order distortion.
9. END

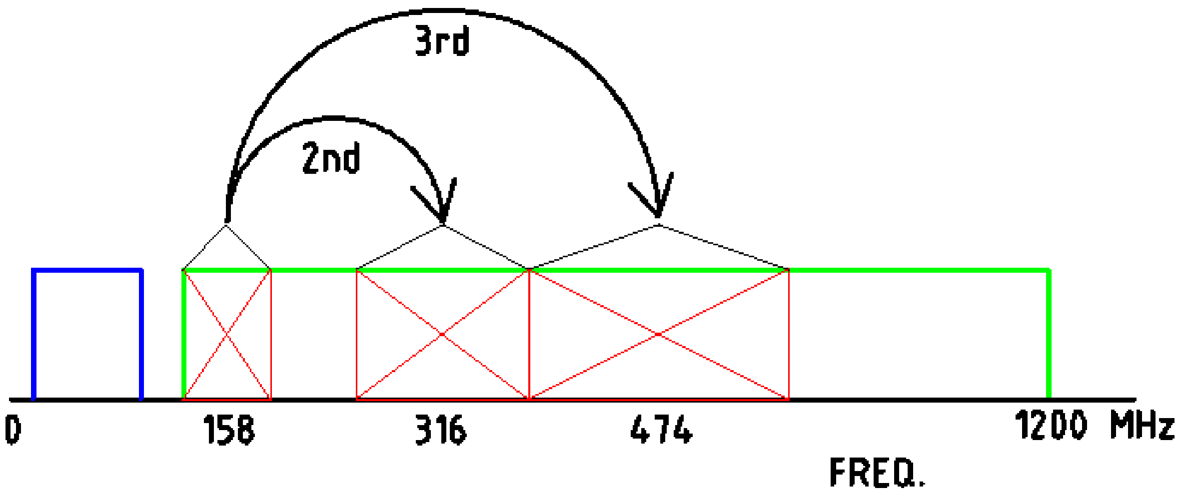
Other Embodiments

1. Karthik suggests having a CM with a Broadcom or MaxLinear chip perform the nonlinear distortion tests in the field. Alternately, the 3 sets of band samples can be uploaded to a PNM server for processing.
2. CPD can be made by home wiring, so this technique is valuable to detect house problems. CPD will most likely be made by high RF level transmissions in the upstream or FDX band.
3. Alberto suggests creating vacant bandwidth with OFDM null subcarriers to reduce noise on cross-correlation plots.
4. On the upstream this method works on burst transmissions. Because of lower frequency and less available bandwidth, 2nd order distortion can be captured as a difference product. For example, an upstream transmission 100-200MHz will produce a 2nd order distortion 0-100Mhz, with 5-100 MHz being visible. This is Fa-Fb distortion. Likewise, third order distortion can be observed in the same 100-200 MHz band as the distortion-creating signal. That is, 2Fa-Fb and 2Fb-Fa components are in the same band as the signal that created them.
5. It is also possible to use a high-speed digital storage oscilloscope, such as the LeCroy DSO series, to capture a full-band spectrum instead of using a 2 input SDR. Digital filtering is then used on the full-band captured data to extract the two bands (158 & 316 MHZ, 158 & 474 MHz) using digital filtering. Frequency domain filtering is more computationally efficient. This digital oscilloscope method uses more expensive hardware, but cost can change in the future. Only 1 full-band field capture is needed. The longer the capture time with either instrument, the better the cross-correlation results.

References

1. US9,590,696
2. US 9,225,387
3. Testing for Nonlinear Distortion in Cable Networks, CableLabs White Paper Oct. 2013 Thomas Willliams, Belal Hamzeh, and Alberto Campos
4. https://www.nti-audio.com/en/applications/evacuation-systems/speech-intelligibility-stipa





Appendix A Nonlinear Distortion in Cable Plant

Nonlinear Distortion on Downstream, including CPD

CPD is a nonlinear distortion that is typically created by corrosion diodes inside cable plant by mixing RF carriers. Corrosion diodes can be created by galvanic corrosion between dissimilar metals. Mixing requires that the signal amplitudes be high enough to make the diodes conduct, so a source of this problem is likely where signals are strong, such as inside hard line near the output of an amplifier. The mixing products are predominately 2nd and 3rd order. While the CPD distortion has been a persistent problem visible on upstream spectrum, it also affects downstream spectrum. When the downstream carriers transitioned from analog NTSC to digital carriers, the upstream CPD went from 3 discrete beats every 6MHz to what appeared to be an elevated upstream noise floor. Many technicians believed that CPD had gone away, but sadly it had only changed appearance.

Wireless carriers also experience this nonlinear impairment and call it Passive Intermod (PIM).

The third order distortion can be modeled as a triple convolution of a signal with itself in the frequency domain, causing spectral regrowth into adjacent frequency bands. See Figure A1. The top diagram is a rectangular-shaped noise-like spectrum of an input signal which is random, such as a single carrier or an OFDM/A signal. The middle spectral diagram shows 2nd order distortion which is a convolution of the input signal with itself. The center frequency of the distortion can be twice the frequency of the input signal (or centered at DC), and the occupied bandwidth is twice the input signal. The bottom spectral diagram shows 3rd order distortion and is a triple convolution of the input signal with itself, and the distortion bandwidth is triple the input frequencies bandwidth. The center frequency of the distortion can be the same as the center frequency or 3X the center frequency.

With two adjacent CW carriers at frequencies Fa and Fb, the predominant 3rd order spectral components will be at Fa+/-Fb+/-Fc, 2Fa+/-Fb, 2Fb+/-Fa. 3Fa, and 3Fb. Self-compression also occurs.

With two adjacent CW carriers at frequencies Fa and Fb, 2nd order distortions occur at Fa +/- Fb, as well as 2Fa and 2Fb.

Third order distortion is normally created at controlled low levels by line amplifiers. Because line amplifiers use push-pull amplification, their second order distortion cancels and should be low.

Now that downstream signals are digital, their nonlinear distortion products appear to be random noise and are mixed with random noise and ingress creating a carrier to composite interference (distortion plus random noise plus ingress), CIN. Energy from both sources is included in a MER per subcarrier ratio available on OFDM carriers.

A UK technical paper by Patel and others [ref 1] indicate CPD has been observed on downstream systems, producing analog TV picture degradation. In the US, downstream CPD is not generally feared.

Another area of concern is strong upstream transmissions originating inside homes from mid-split or high-split plant. No one is expecting home wiring to be free of corrosion diodes. A second or third harmonic of an upstream transmission could produce energy in a downstream band, disrupting services.

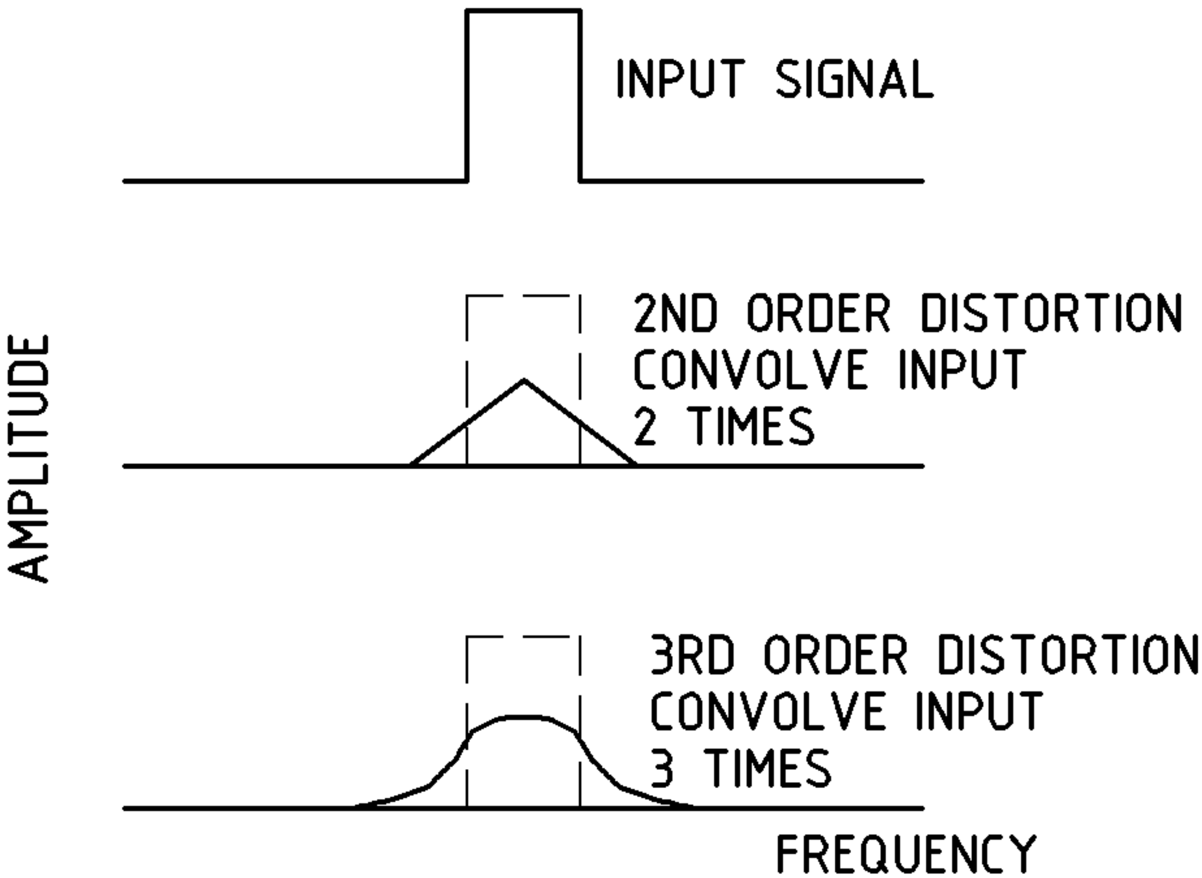


Figure A1. Creation of 2nd and 3rd order distortion in the frequency domain by convolution. Convolution in the frequency domain is mathematically equivalent to multiplication in the time domain.

Testing for Nonlinear Distortion in Cable Networks

CableLabs®

Tom Williams
10-24-2013

Background and Problem Statement

CableLabs Access Network Technologies

- Downstream signals are going to all-digital carriers
- Nonlinear distortion and random noise are expected and budgeted in design.
- Nonlinear distortion with analog video carriers was primarily CTB and could be measured in a vacant channel (and seen in analog TV pictures)
- Now nonlinear distortion products from digital carriers looks like random noise and is generally indistinguishable from random noise.
- So how do you tell if the MER is caused by noise or nonlinear distortion???

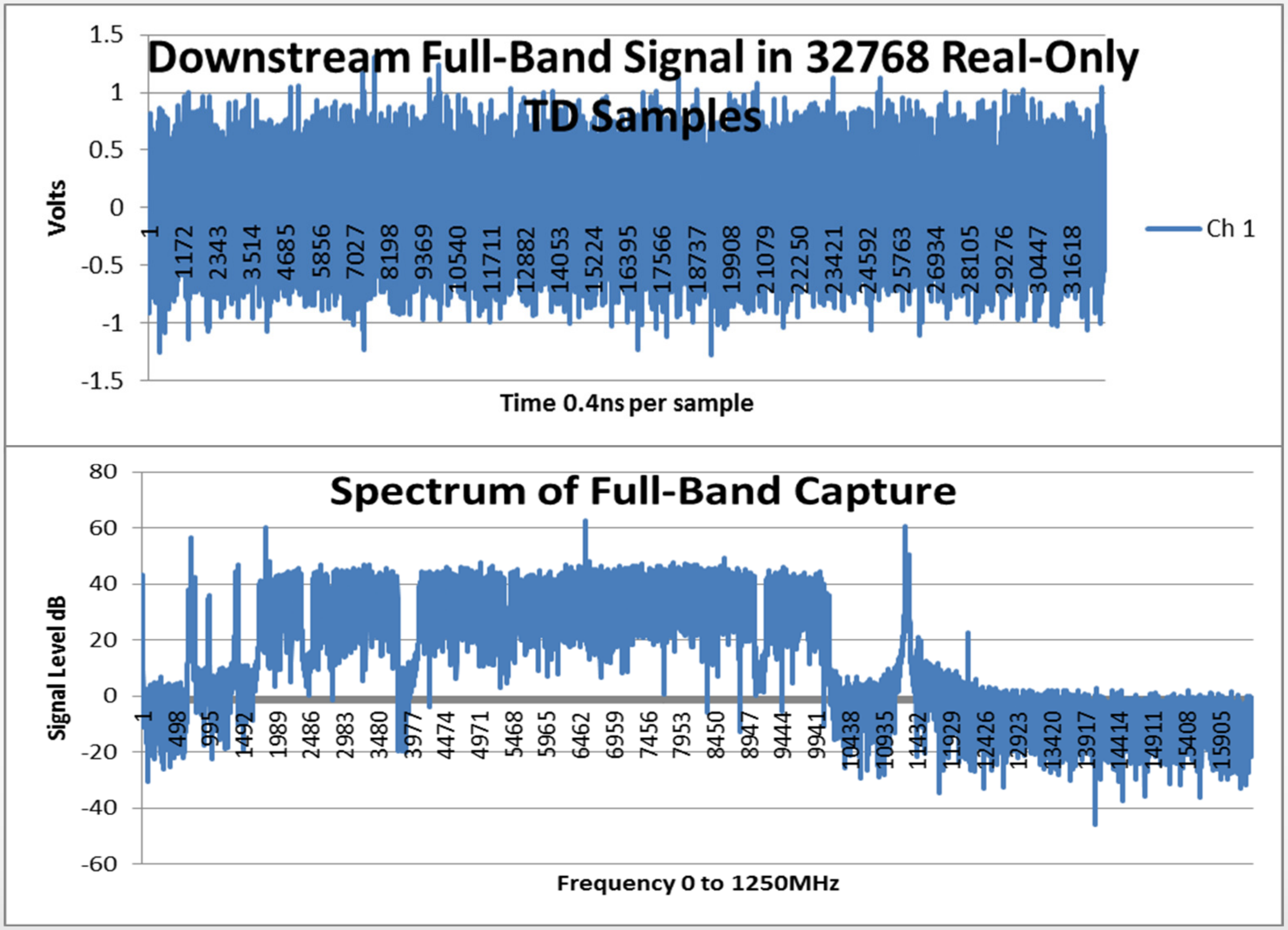
CableLabs®

New Test Method Developed by CableLabs

CableLabs Access Network Technologies

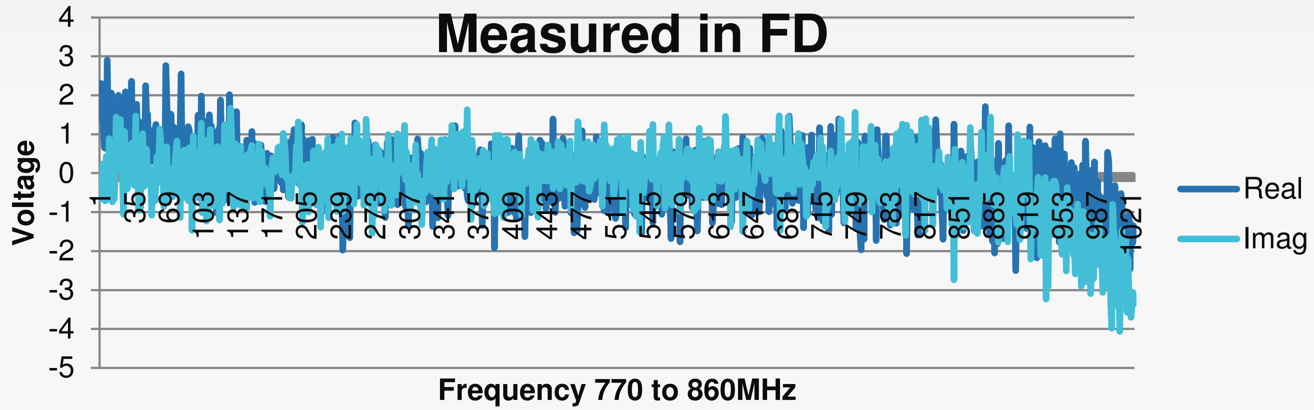
- Identify a vacant band in downstream (in roll-off works)
- Capture the full-band downstream signal with high-speed digital oscilloscope with a 2.5Gigasample rate and 12 bits
- Save the signal in the vacant band. This makes a “measured” signal
- Replace the vacant band energy with all zeroes and mathematically distort the full-band signal
- You now have a “manufactured” distortion signal in the vacant band
- Process “manufactured” signal with “measured” signal and you find out if measured signal is nonlinear distortion or not

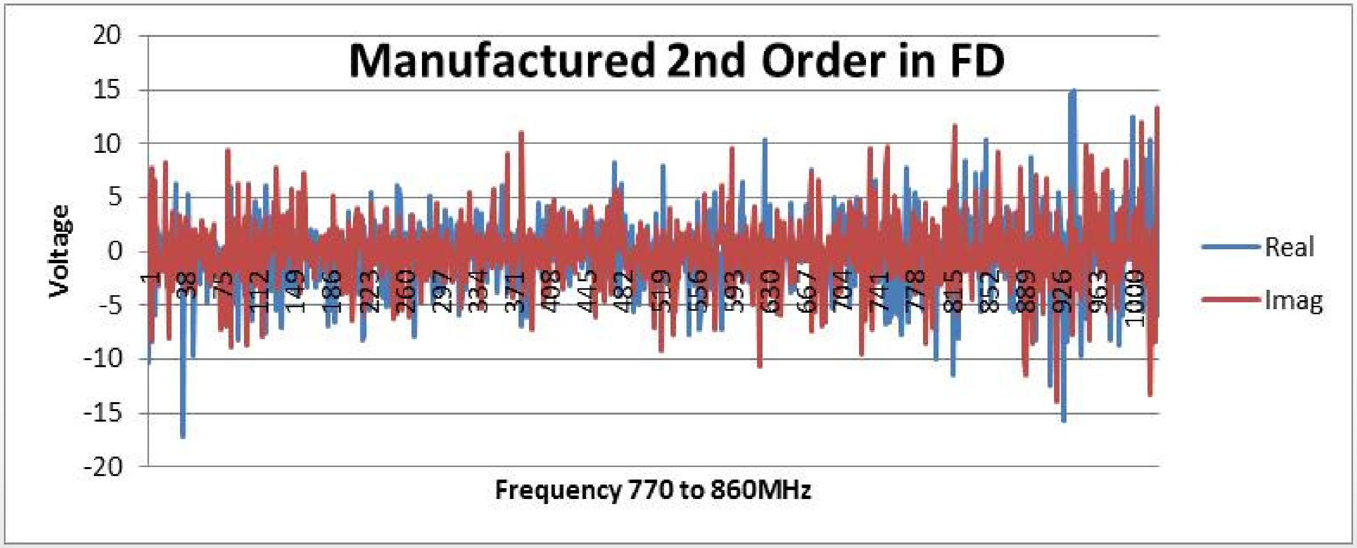
Full Band Downstream in Time and Frequency



Slide 4

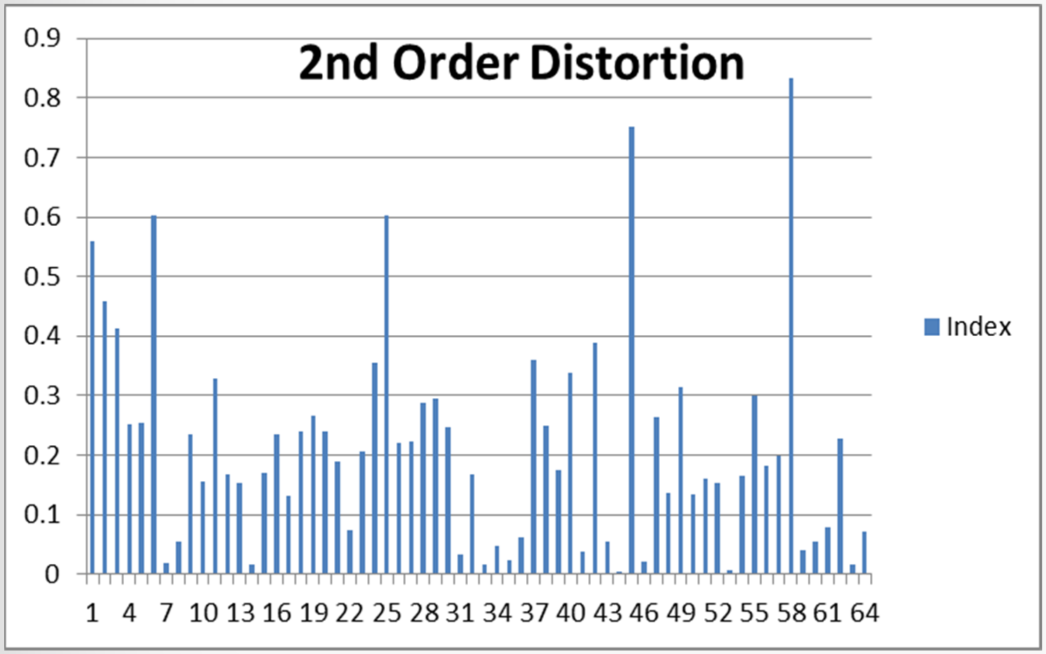
Measured and Manufactured Distortion

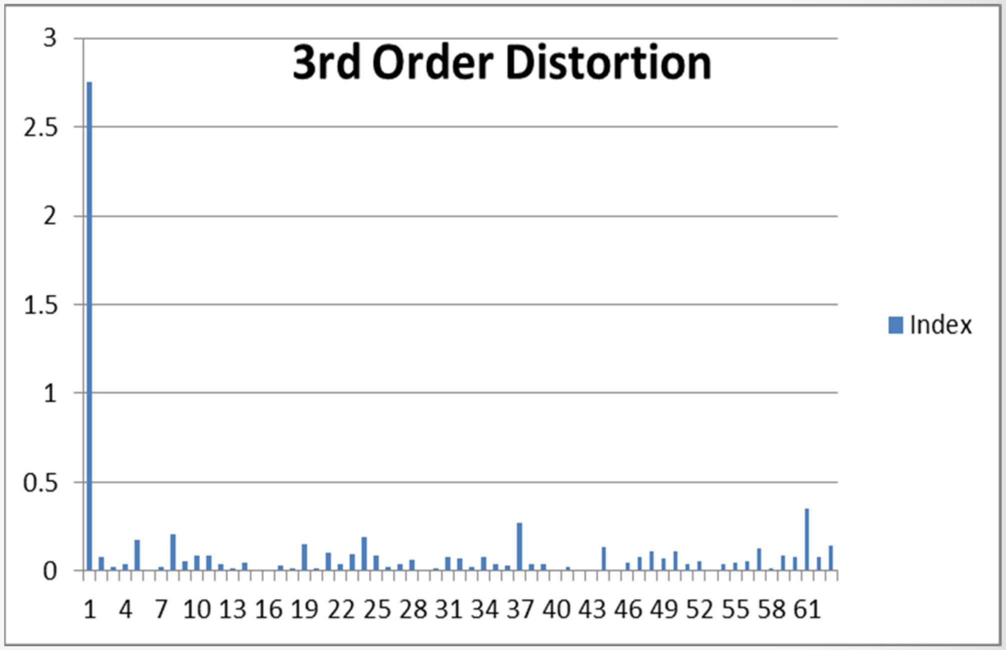




CableLabs®

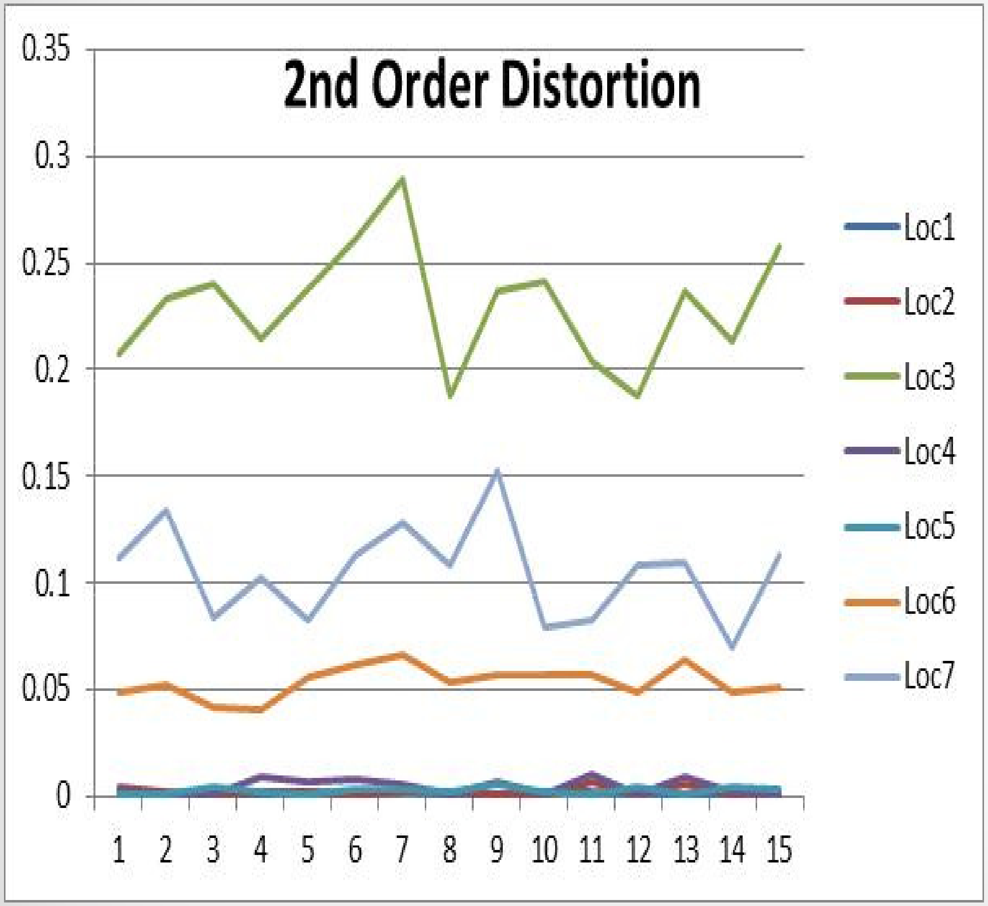
Elevation on Tap 0 Indicates Level of Distortion

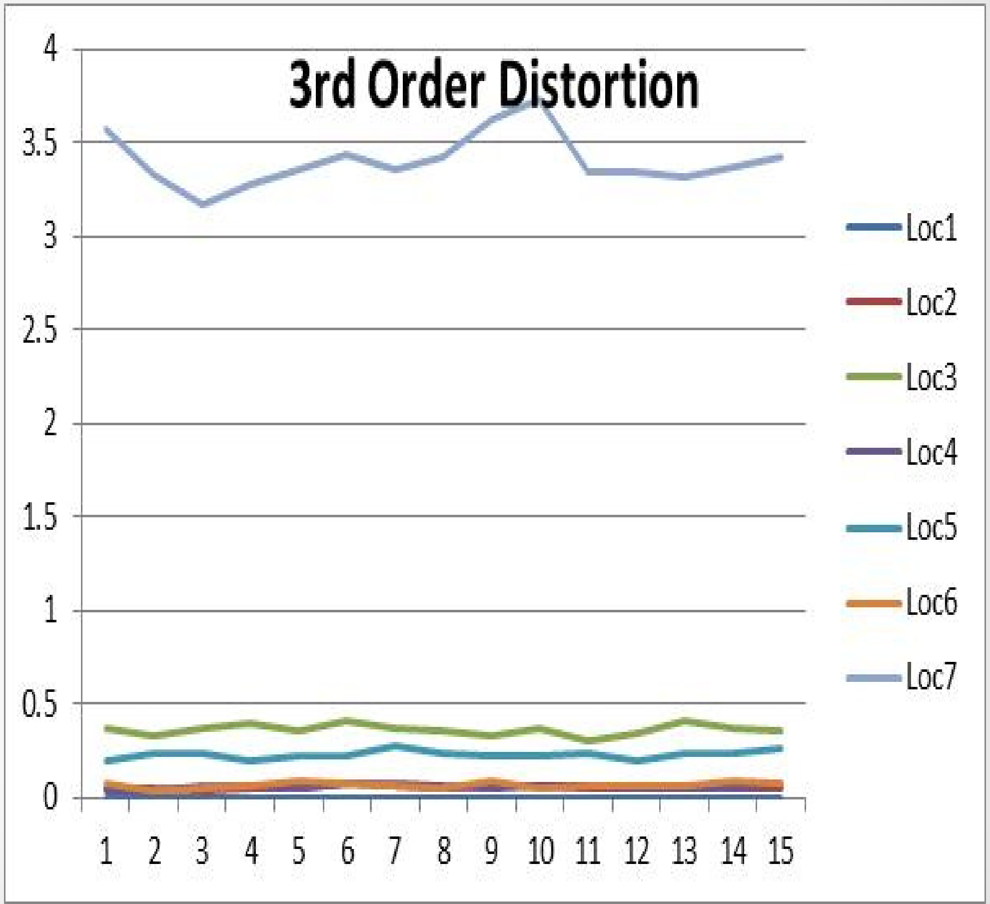




CableLabs®

Test Results on 7 Houses (15 tests each)





CableLabs®

White Paper Available

CableLabs Access Network Technologies

- Contact Cablelabs or t.williams@cablelabs.com

ACCESS NETWORK TECHNOLOGIES

Testing for Nonlinear Distortion in Cable Networks

Prepared by:

Alberto Campos
Principal Architect, Advanced Technology Group
a.campos@cablelabs.com

Belal Hamzeh
Principal Architect, Access Network Technologies
b.hamzeh@cablelabs.com

Tom Williams
Principle Architect, Access Network Technologies
t.williams@cablelabs.com

October 2013

DISCLAIMER

Table of Contents

List of Figures

ABSTRACT

Nonlinear distortion is a well-known problem in electronics. In Cable networks nonlinear distortion presents a limit on RF output levels, which effectively determines Cable signals' maximum reach, and a maximum number of RF channels that can be transported on a downstream plant. This nonlinear distortion constraint, along with random noise, greatly influences plant design. When the plant is transporting analog carriers, the traditional measures of distortion are composite triple beat (CTB) and composite second order (CSO). As plant has transitioned from carriage of analog to digital carriers, the resulting nonlinear distortion has shifted from beats centered at analog video carrier frequencies into a noise-like signal, called CIN (composite intermodulation plus noise), which is generally indistinguishable from random noise. This paper describes a technique for quantifying the level of nonlinear distortion in a vacant band using a full band downstream signal capture, followed by digital signal processing. Improved distortion and noise analysis leads to improved plant alignment, which can allow DOCSIS 3.1 cable modems to operate with a higher order modulation. A higher order modulation will allow higher data rates within the allowed downstream bandwidth. This analysis method will also allow plant problems to be detected and repaired.

1 INTRODUCTION

There has been much written about distortion measurements in the past. Generally one model that has been used is a Taylor series expansion over a range of operation. This is illustrated in Figure 1

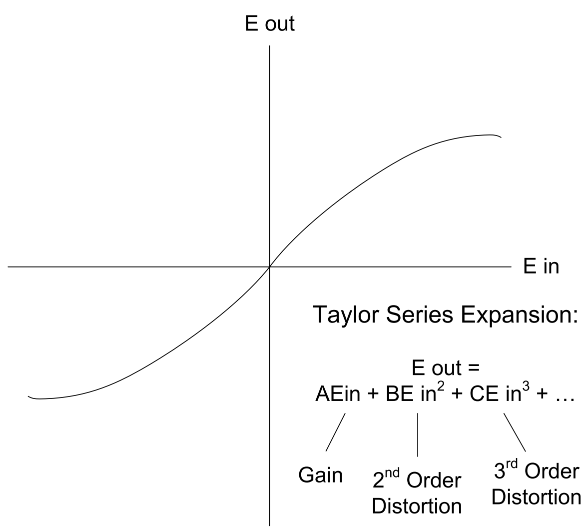


Figure 1 - Taylor Series Expansion Describes Output Voltage vs. Input Voltage

A Taylor series expansion is given by equation:

$$f(x) = Ax + Bx^2 + Cx^3 + \cdots \qquad (1)$$

Where x is a time-varying input signal, f() is a nonlinear operator, such as an overdriven amplifier (or a cascade of overdriven amplifiers). The A term is linear gain, B is a second-order distortion, and C is third order distortion. Even higher terms, such as D, E, and F may also be significant.

$$f(x) + f(y) = f(x + y) \qquad (2)$$

Equation (2) describes a required condition for linearity. Equation (2) will only be valid when:

$$B = C = 0 \qquad (3)$$

One notable differentiator between linear distortion and nonlinear distortion is that linear distortion cannot create distortion energy at new frequencies, but nonlinear distortion can. Likewise, as the operational signal levels are increased, the relative output levels of carriers to distortions will be maintained for linear distortion, but will not be maintained for nonlinear distortions.

One operational test to determine the order (2nd, 3rd) of undesired energy in a vacant band is to elevate the input signal. If the distortion energy increases 3dB for a 1dB step increase on the input signal, the nonlinear distortion is probably third order. If the undesired energy increases 2dB for a 1dB step increase on the input signal, the nonlinear distortion is probably second order.

Appendix B describes the operation of nonlinear distortions on a rectangular block of noise, which can be used as an approximate model for one or more continuous digital carriers.

The nonlinear distortion energy is not random, and can be quantified with knowledge of the input signal that created it. It is particularly easy to quantify in vacant test bands, such as a roll-off region. If a vacant band is not available, one can be created by demodulating the RF signal occupying the band, and then subtracting it mathematically.

There are a few variants of how the detection of signal distortion signal can be done. One method is to capture the same signal twice: one copy of which is a clean undistorted signal at the headend, and the other copy is captured at a test point in the field. This method has the added complexity of requiring synchronized capture and the transfer of data to a central processing point, in addition to removing linear distortion differences between the nonlinearly distorted signal and the pristine headend signal. Another method would be to capture the signal at the input and the output test points of the amplifier, and then determine how much additional distortion was added by the amplifier. The linear distortion of the amplifier, including diplex filters response, tilt, and equalization still make this method non-trivial.

The rest of this paper will describe a test methodology that requires only a signal capture at a single location, where the single full band signal is captured in the field. The captured vacant band signal is stored as a “measured” signal, and processed with a “manufactured” signal. The level of match between the measured and manufactured signals determines how much nonlinear distortion was present in the captured signal’s vacant band.

2 TEST METHODOLOGY

2.1 NONLINEAR 1-SIGNAL DISTORTION TEST METHOD

The new nonlinear 1-signal distortion test method is implemented as follows:

1. Capture a full-band downstream signal with a digital oscilloscope having a sampling rate of at least 2.5 Giga-samples per second and a minimum of 12 bits of A-D resolution for 32,768 samples. That is, the downstream signal is digitized at a rate of at least $2.5 \cdot 10^9$ Hz. A low distortion preamplifier can be used to boost the full band downstream signal prior to capture. This can be necessary because digital oscilloscopes generally have a poor noise figure. Figure 2 illustrates a time domain signal captured by a digital oscilloscope operating at 2.5 Giga-samples per second and 12 bits of A-D resolution. The downstream signal processing requires a vacant band. This 54-860MHz signal was comprised of mostly digital signals, plus a few continuous wave (CW) carriers used as pilots and alignment aids. The signal contains a vacant band between 770 and 860MHz, which is not evident in the time domain trace.

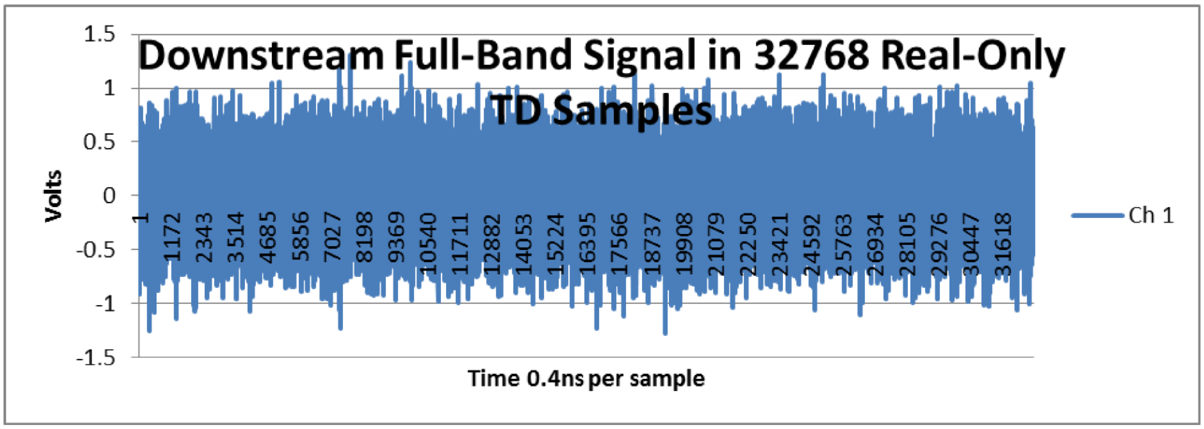


Figure 2 - A Captured Downstream Burst Lasting 16.384 US and Consisting of 32768 Samples

2. Convert the TD signal of Figure 2 into the frequency domain (FD) with a FFT (fast Fourier transform). This FD plot is illustrated in Figure 3. In the frequency domain, the vacant band energy values between 770 and 860MHz, with 1024 FD samples are cut and stored. These 1024 FD samples are called the “measured” vacant band distortion signal, and illustrated in Figure 4. Next, replace the vacant band energy in the FD signal between 770 and 860MHz with 1024 zeroes. This spectral plot is illustrated in Figure 5.

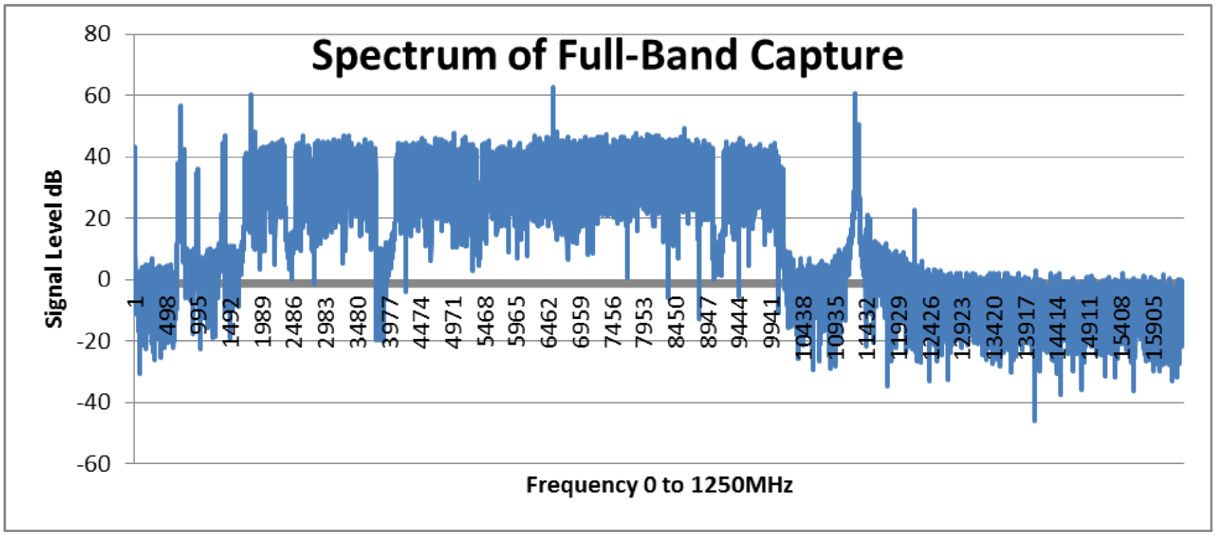


Figure 3 - A Full Band Downstream FD Signal Obtained by Performing an FFT on the Samples Illustrated in Figure 2

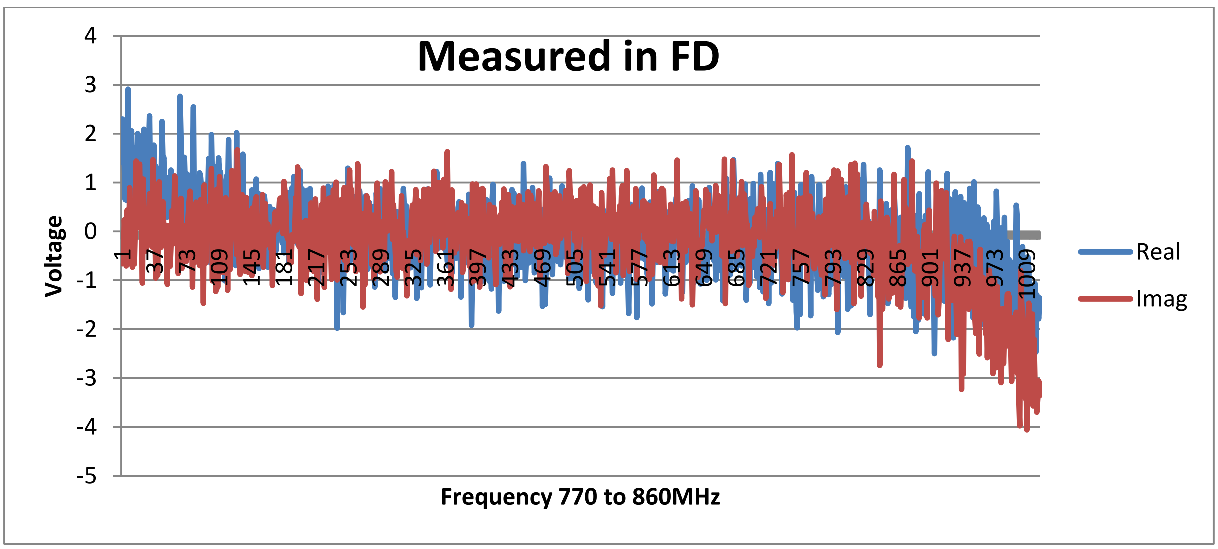


Figure 4 - 1024 Points of Measured Distortion from the Vacant Band

3. Next convert the 54-860 MHz signal of Figure 5 with the newly-vacated band back into the time domain with an IFFT and distort a resulting time sequence with a 2nd and 3rd order nonlinear distortion. This is accomplished by squaring and cubing each term in the time sequence. This creates a 2nd order "manufactured" signal and a 3rd order "manufactured" signal. This distorting manufacturing method gives a good approximate estimate because the nonlinear distortion components are small in cable networks (2). That is:

$$f(x) = Ax + Bx^2 + C^3 \sim Ax \quad (4)$$

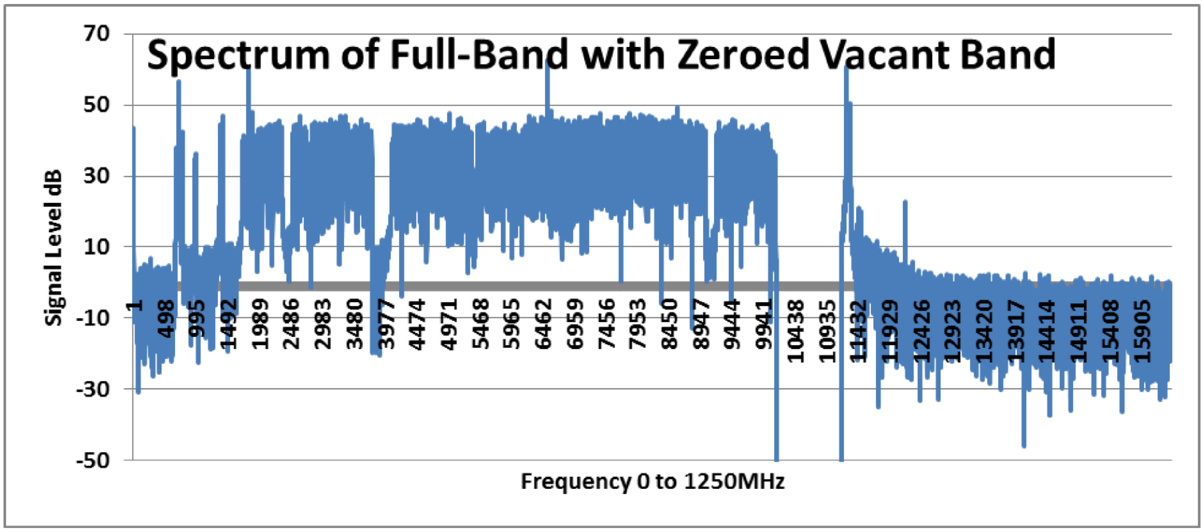


Figure 5 - A Full Band Downstream Signal with a Zeroed-out Vacant Band

4. Convert the "manufactured" signals back into the frequency domain and store only the 1024 distortion components in the vacant band. This is illustrated in Figure 6.

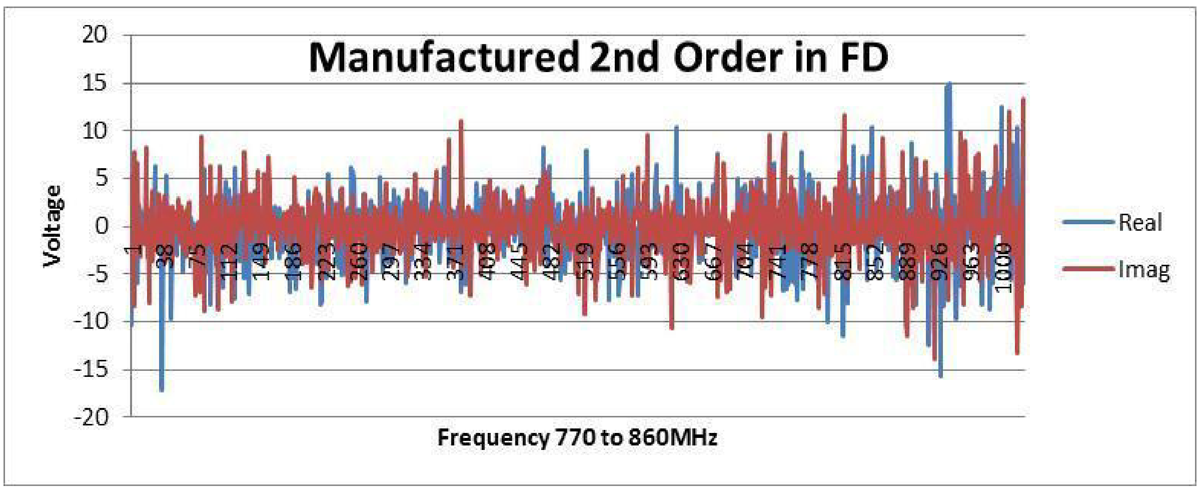


Figure 6 - 1024 Points of Manufactured 2nd Order Distortion from the Vacant Band

5. Process the 1024 point vacant band "measured" signal with the 1024 point vacant band "manufactured" signals. One processing method that has worked well is frequency domain division of the "manufactured" samples by the complex conjugate of the same frequency "measured" samples to produce 1024 FD quotients.

6. Convert the 1024 FD quotients into the time domain. This is illustrated in Figure 7 for 2nd order distortion and Figure 8 for 3rd order distortion. Energy in the first (DC) term indicates a match of the "measured" signal with the "manufactured" signal.

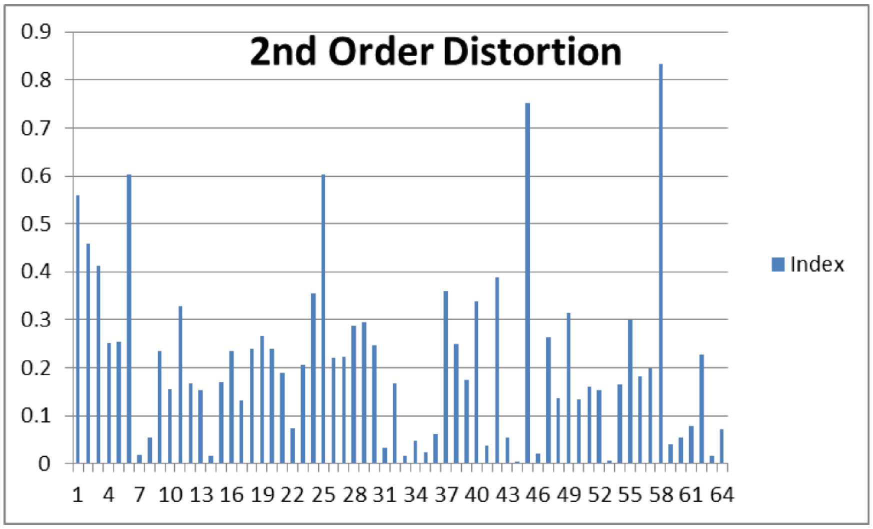


Figure 7 - TD Plot of Quotient Showing Large First Term, Relative to Other Terms, Indicating 2nd Order Distortion

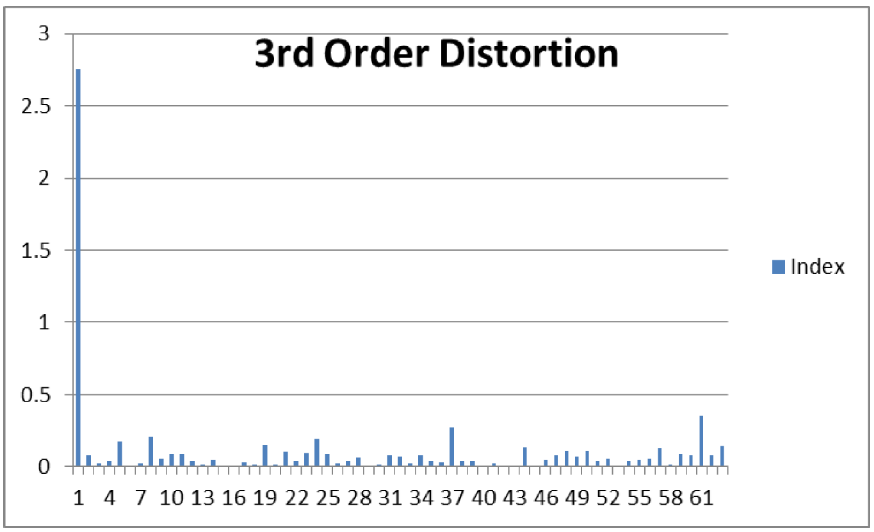


Figure 8 - TD Plot of Quotient Showing Large First Term, Relative to Other Terms, Indicating 3rd Order Distortion

7. If necessary, averaging may be used to better discern the DC term relative to the other terms. Note that the DC terms are correlated vectors that will add, but the other terms are uncorrelated.
8. Repeat steps for other orders of distortion you think might be present.

The plots of Figure 7 and Figure 8 are complex time series and only 64 of the 1024 points are illustrated. As a number of averages increases, the noisy components associated with using a noise-like downstream test signal are reduced. Another improvement to reduce noise in the plots is to use a larger percentage of vacant bandwidth relative to the occupied bandwidth. There is generally a delay (angle) to the distortion, and in most observed tests on distorted Cable amplifiers, the first term (t=0) contains most of the energy. As the amplifier's input drive level increases, both the level of nonlinear distortion and the angle of the DC terms change.

2.2 2ND ORDER DISTORTION DISCUSSION

2nd order distortion in cable networks should be substantially suppressed relative to 3rd order distortion because Cable systems use balanced push-pull amplifiers. These amplifiers cancel even order (2nd, 4th, 6th etc.) distortions. Expected potential sources of 2nd order distortions are imperfect analog downstream linear lasers, damaged, unbalanced push-pull amplifiers, and distortion diodes created by corrosion in the plant.

2.3 3RD ORDER DISTORTION DISCUSSION

3rd order distortion is the dominant nonlinear distortion in cable systems. Generally high powered amplifiers are used to provide needed dynamic range. Cable systems are operated with up-tilt to provide more uniform distortion over the downstream band. The potential sources mentioned above for second order distortion can also contribute to third order distortion.

2.4 TEST RESULTS FROM FIELD LOCATIONS

Figure 9 is a composite plot from different 7 locations for 2nd order distortion test results, and Figure 10 contains 3rd order distortion results. Fifteen separate tests were run to determine if the measurements were repeatable, and 10 averages used. Locations 6 and 7 had downstream high pass filters to pass only data traffic.

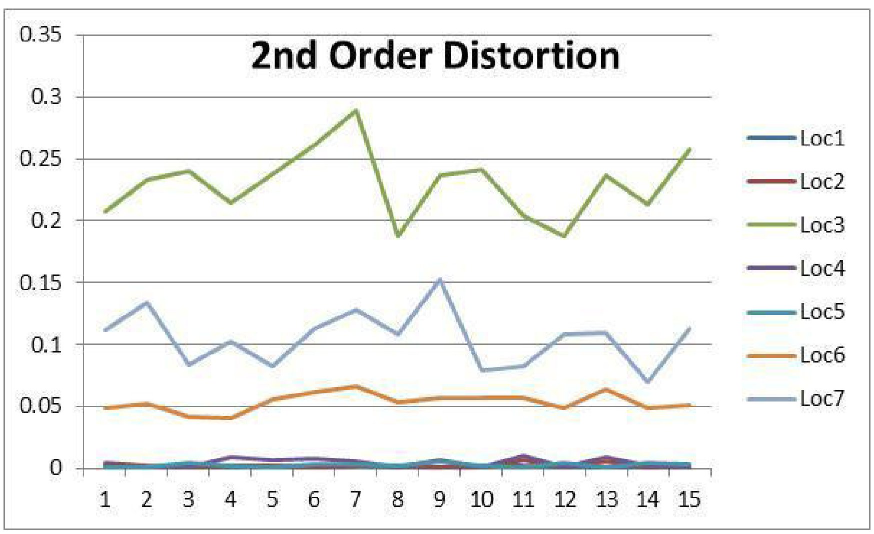


Figure 9 - Second Order Results for 7 Locations (15 Tests Each Location, 10 Averages)

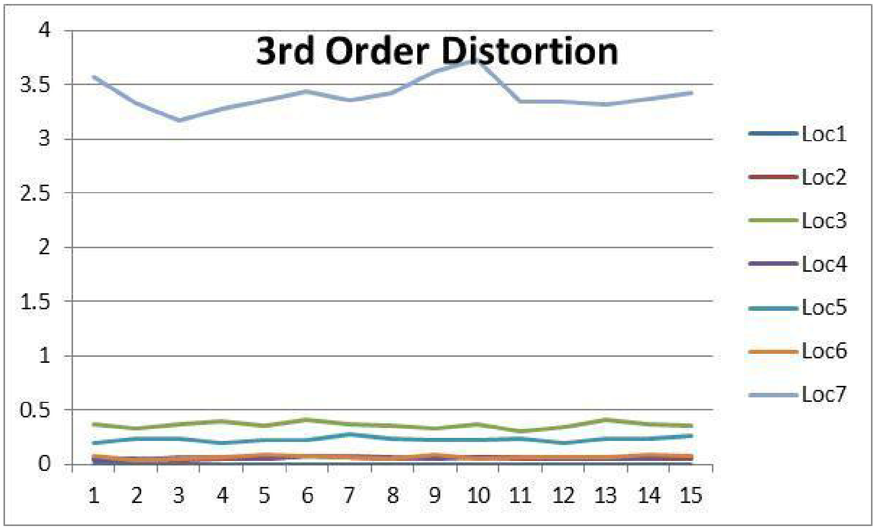


Figure 10 - Third Order Results for 7 Locations (15 Tests Each Location, 10 Averages)

As the nonlinear distortion is created in amplifiers, the amps are generally being operated with an up-tilt as mentioned above. In an attempt to improve the match of the manufactured and measured signals, the input signal used for manufacturing distortion was mathematically tilted by +/- 10dB**.** Figure 10 shows the third order match of the "manufactured" signal improves with input signal up-tilt.

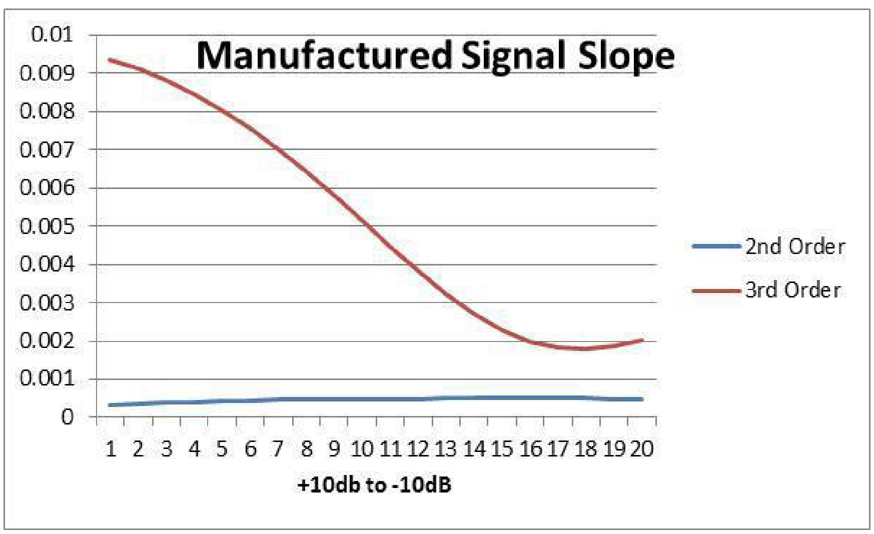


Figure 11 - Curves Showing Improved Matching of Manufactured with Measured Signal, with Tilting of Full Band Signal Used for Manufactured Signals

NOTE: Curve indicates that 3rd order distortion was likely created in amplifier operating with up-tilt.

One observation that can be drawn from the data is that the third order distortion should possibly be somewhat higher than was observed in most of the locations. This could potentially yield improved random noise performance. However, if an error in amplifier alignment levels occurs, it is probably better to run amplifier levels lower rather than higher. This is due to 3rd order distortion rising 3dB for every additional dB of input level, while signal to random noise level will only rise by 1dB for each dB of reduced input level. Another observation was that some locations had second order distortion.

Another observation is that this technique relates percentage of nonlinear distortions to random energy in a vacant band. MER (modulation error rate) could be degraded by either nonlinear distortion or uncorrelated energy, such as random noise. If the MER of the signals are good, the plant probably does not necessarily need to be adjusted.

Other applications for this technology are programming digital pre-distortion circuits that improve the linearity of high power amplifiers, and narrowband amplifier measurements.

3 CONCLUSION

In conclusion, it is now possible measure the undesired energy accompanying Cable signals to determine if they are nonlinear distortion, or some other uncorrelated energy such as random noise or ingress.

APPENDIX A MATLAB CODE FOR NONLINEAR DISTORTION ANALYSIS

```
clear all
close all
clc
lengthFFT=32768;
Ts=.4e-9;   Fs=1/Ts;
N=lengthFFT;
windowFunction=window(@hann,N)
Average_TD_AnalysisSignal_CTB=zeros(1024,1);
Average_TD_AnalysisSignal_CSO=zeros(1024,1);
fid = fopen('trace.txt', 'r');
for count=1:15
      data = fscanf(fid, '%f', [1 lengthFFT]);
      data=data';
      TD_data=windowFunction.*data;
      FD_data=fft(data);
      savedSamples=FD_data(10160:11183);
      FD_data_zeroed=FD_data;
      FD_data_zeroed(10160:11183)=0;
      TD_data_zeroed=ifft(FD_data_zeroed);
      TD_distSignal_CTB=TD_data_zeroed.^3;
      FD_distSignal_CTB=fft(TD_distSignal_CTB);
      CreatedDistortion_CTB=FD_distSignal_CTB(10160:11183);
      FD_AnalysisSignal_CTB=savedSamples.*conj(CreatedDistortion_CTB);
      FD_AnalysisSignal_CTB(1)=0;
      TD_AnalysisSignal_CTB=ifft(FD_AnalysisSignal_CTB);
      TD_distSignal_CSO=TD_data_zeroed.^2;
      FD_distSignal_CSO=fft(TD_distSignal_CSO);
      CreatedDistortion_CSO=FD_distSignal_CSO(10160:11183);
      FD_AnalysisSignal_CSO=savedSamples.*conj(CreatedDistortion_CSO);
      FD_AnalysisSignal_CSO(1)=0;
      TD_AnalysisSignal_CSO=ifft(FD_AnalysisSignal_CSO);
            Average_TD_AnalysisSignal_CTB=Average_TD_AnalysisSignal_CTB+TD_An
      alysisSignal_CTB;
```

```
      Average_TD_AnalysisSignal_CSO=Average_TD_AnalysisSignal_CSO
+TD_AnalysisSignal_CSO;
end
fclose(fid);
Average_TD_AnalysisSignal_CTB=Average_TD_AnalysisSignal_CTB/15;
Average_TD_AnalysisSignal_CSO=Average_TD_AnalysisSignal_CSO/15;
figure(1);
subplot(3,1,1),plot(0:Ts:((length(TD_data)-1)*Ts),TD_data);
subplot(3,1,2),plot(0:Fs/N:.5*Fs-
Fs/N,10*log10((abs(FD_data(1:16384)))));
subplot(3,1,3),plot(0:Fs/N:.5*Fs-
Fs/N,10*log10((abs(FD_data_zeroed(1:16384)))));
figure(2)
stem(abs(Average_TD_AnalysisSignal_CTB))
title('Composite Triple Beat')
figure(3)
stem(abs(Average_TD_AnalysisSignal_CSO))
title('Composite Second Order')
```

APPENDIX B NONLINEAR DISTORTION CREATION BY FREQUENCY DOMAIN CONVOLUTION

Figure 12 is a block of noise in the frequency domain, approximately modeling a single QAM carrier, or a block of contiguous carriers. Figure 13 shows a triangular spectral shape resulting from a second order distortion, and Figure 14 shows a resulting haystack-shaped spectrum from a third order distortion. Figure 15 shows the rectangular block of noise overlaid with the haystack spectrum it created. Observe that nonlinear distortion can be underneath the carrier as well as in adjacent sidebands. The energy in the upper and lower sidebands is sometimes referred to as "spectral regrowth".

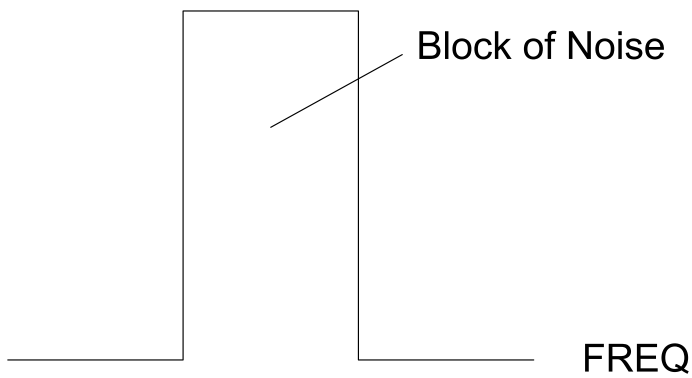


Figure 12 - A Rectangular Block of Random Noise Modeling a Digital Signal, or a Block of Contiguous Digital Signals

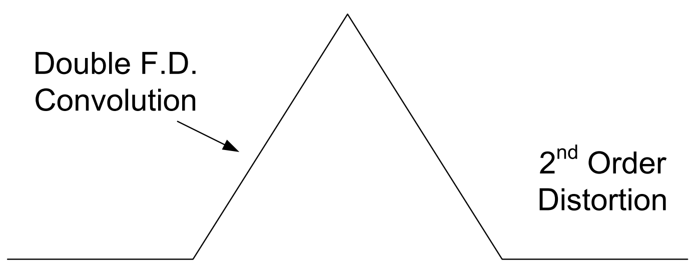


Figure 13 - 2nd Order Distortion Created by a Frequency Domain Double Convolution of the Signal of Figure 2

If the signal of Figure 12 was centered at 100MHz and 10MHz wide, the second harmonic signal of Figure 13 would be at centered at 200MHz and be 20MHz wide.

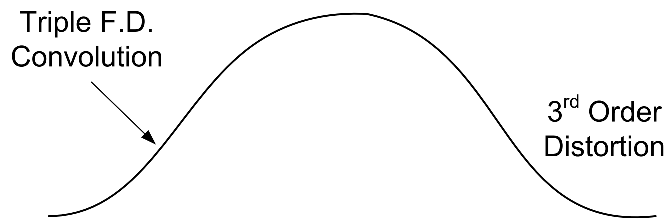


Figure 14 - 3rd Order Distortion Created by a Frequency Domain Triple Convolution of the Signal of Figure 12

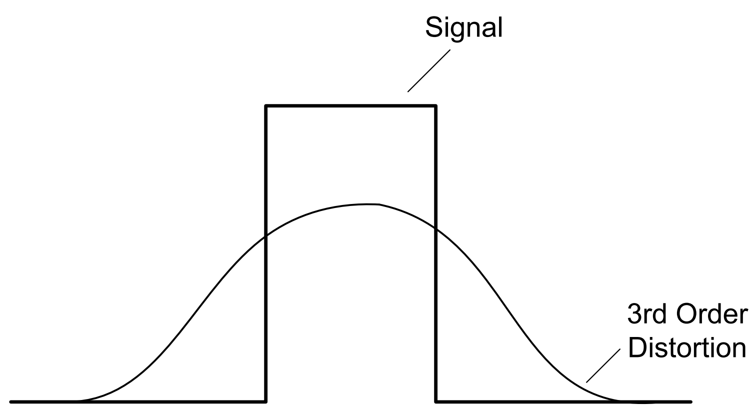


Figure 15 - An Overlay of the Signal of Figure 12 with the Signal of Figure 13

This 3rd order spectrum will be centered over the 100MHz carrier and be 30MHz wide. This spectrum will also appear at the 3rd harmonic frequency of 300MHz.

D5281 Method and System to Find Distance to a PIM (Passive Intermod) Diode in Wiring. Rev 2.

Tom Williams May 24, 2022/Aug 8, 2022

Problem

Some homes have corrosion diodes in the house wiring that are difficult to locate. Even technicians getting into the homes is difficult after COVID pandemic. The diodes mix strong upstream transmission with other signals to produce distortion product in other bands, affecting services for the home itself and other subscribers. They also intermodulate the wideband OFDMA transmissions to produce distortion products at other frequencies, primarily 2 and 3rd order, but higher orders also.

Description:

At the tap, the circuit in Fig. 1 is connected. It can use a conventional network analyzer with an IFFT (inverse fast Fourier transform) option, or the IFFT on the spectral samples can be done external to the analyzer. As an example, the CW transmits at +15dBm at 200 MHz. Some of the CW signal is sampled and sent to a double balanced mixer to act as a LO (local oscillator). The network analyzer is sweeping 220 to 320 MHz (example) and the CW is static at 200 MHz. The two signals are combined and sent into the house to mix in a possible corrosion diode, producing a swept return signal with a frequency 20-120 MHz. A Band Pass filter passes 200-320MHz and keeps out harmonics of the generators, as well as cleans the 20-120 MHz detection band.

The return difference signal from the house is 20-120MHz and it is passed through a Low Pass filter and connected to the RF port of said mixer. The output of the mixer is upconverted and will be returned the original transmit frequency range of the network analyzer, which is 220-320 MHz. The house is swept, and the return response is converted to the time domain with an IFFT, if there is a PIM diode. From the time delay, knowing the cable's velocity of propagation, distance to diode can be computed. The return phasor from the house rotates much faster than the test signal if the diode is far away. The wider the swept frequency, the better the range accuracy.

The invention disclosure (I-only Network Analyzer) can also be used to sweep the house with low cost "Half Network Analyzer" and the Quadrature data can be computed from the In-phase data.

Basically, the PIM diode mixed CW signals are converted back to their original frequencies by the double balanced mixer.

Other frequencies can optionally be used for testing, and other harmonics besides second can be used. A sum distortion product 440-520 MHz can also be used for diode detection and ranging.

Fig. 2 is a block diagram of a method to range the distance to an impedance mismatch, when an impedance mismatch is linear and does not intermodulate signals. The system uses a vector network analyzer, which can be the same convention network analyzer used in Fig. 1. The combiner/splitter connected to the house can alternately be a return loss bridge, or the same device used in Fig. 1.

By overlaying a TDR (time domain reflectometer) or IFFT plot obtained from Fig. 1 test and a time plot obtained from Fig. 2 test, the determination can be made by a technician if an impedance mismatch is linear or is nonlinear. If nonlinear, the impedance mismatch probably has associated corrosion diodes.

The detection of concurrent time peaks can also be done by a computer, using digital signal processing.

Fig. 2 can be obtained from Fig. 1 using switches to remove unnecessary components and connections.

Other methods can be used to make two overlaid time plots, one involving mixing (frequency conversion), and one using no mixing. For example, a chirp signal can be used, with and without frequency mixing. The chirp signal is signal processed with an unimpaired chirp signal. Random noise, impulses, sine(x)/x signals, and pseudo noise signals can also used as reference (test) signals.

This can also be used by wireless industry on their tower to locate their PIM.

July 29, 2022

Another

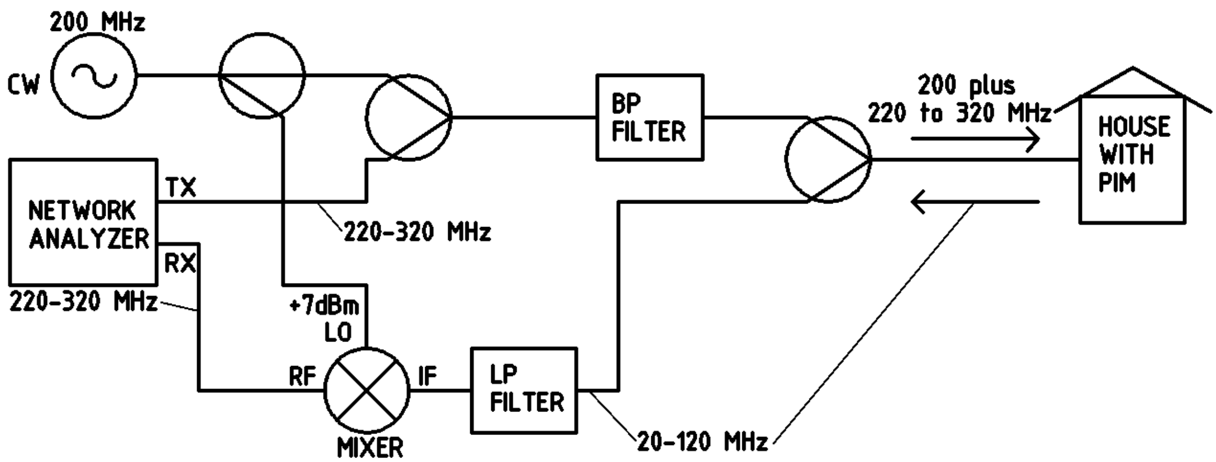


Fig. 1. Circuit to find location of PIM diode by ranging from outside the home.

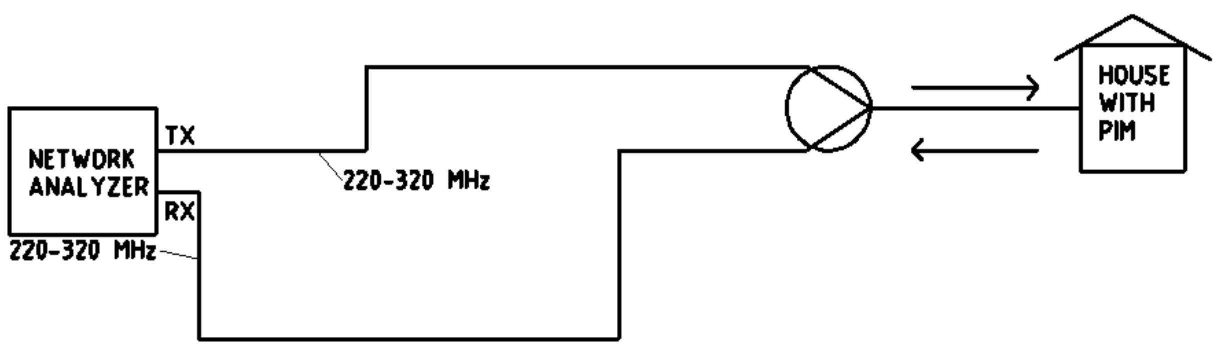


Fig. 2 Circuit to find location of impedance mismatch by ranging from outside home.