Saving the DOCSIS 3.1 Network from Passive Intermodulation

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Introduction

This white paper describes the Passive Intermodulation (PIM) phenomena. This may be present in coaxial networks due to saturation of ferrites in taps and splitters or due to corroded connectors. The paper concludes with how to prevent passive intermodulation from degrading DOCSIS 3.1 performance.

Conclusion

In summary, when upgrading for DOCSIS 3.1 distribution, the details in the material selection are critical for the long-term stability and up-time of the HFC network. It is of utmost importance to take care of parameters such as passive intermodulation and CPD robustness.

Selecting coaxial passives with low passive intermodulation, low robustness against transients and other surge pulses, and with die-cast zinc-alloy connectors, places the high bitrates of DOCSIS 3.1 at risk. Unfortunately, these types are commonly seen in cable networks in Europe. To minimize this risk, the DKT Signia Line of distribution passives is a safe choice.

What is the effect of Passive Intermodulation?

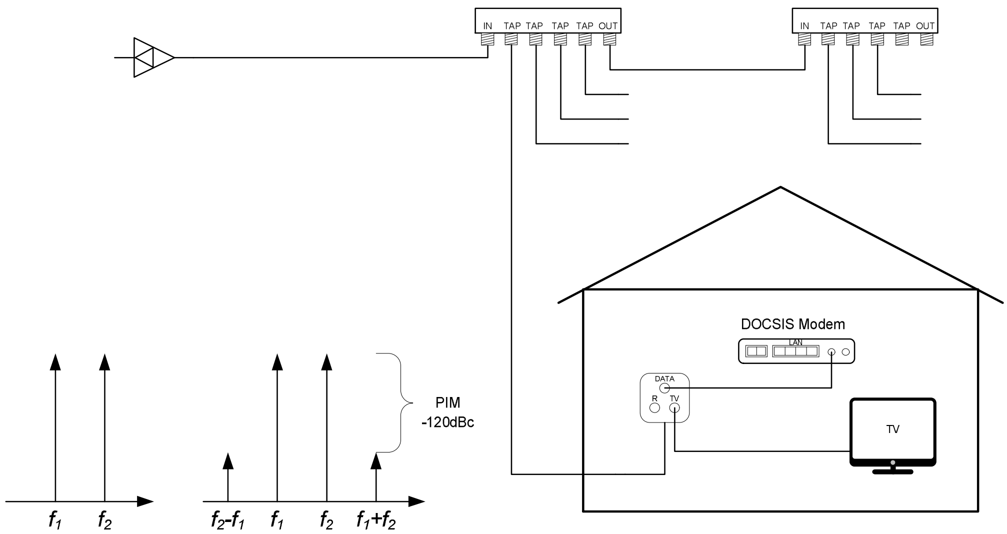

Figure 1 - Coaxial distribution network showing second-order intermodulation in the amplifier.

The transmission of even a single unmodulated carrier through the coaxial part of a HFC network causes it to be distorted; perhaps not much, and perhaps not measurable, but it does become distorted. Also, the stronger the signal, the more it becomes distorted. Most of the

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distortion occurs in the passage through the amplifiers in the network – this is termed *active distortion*. However, even in well-functioning networks, a small part of the distortion occurs in the non-active (passive) components of the network – this is termed *passive distortion*. The main contributors to passive distortion are non-ohmic junctions between male and female connectors and the non-linear characteristic of the ferrite cores inside the distribution passives.

When two or more carriers flow through a coax network, these interact when passing the junctions and ferrite cores. As a result, signals of all combinations of the sum and the differences of the carrier frequencies are generated – this is termed *passive intermodulation*.

Because the DOCSIS 3.1 upstream signal in one block may have up to 3800 sub-carriers (equally spaced by 25 kHz), passive intermodulation generates a plentitude of in-band signals. These act as a rise in the noise floor, hence a decrease in the CNR. The adaptive protocol of DOCSIS 3.1 will attempt to decrease the modulation index. This in order to keep the upstream channel open as the CNR drops from above the QAM1024 threshold of 35.5 dB, to for example 20 dB (the threshold of QAM32), thereby halving the bitrate capacity, or eventually disabling all upstream signaling. This is when the DOCSIS 3.1 is killed by passive intermodulation.

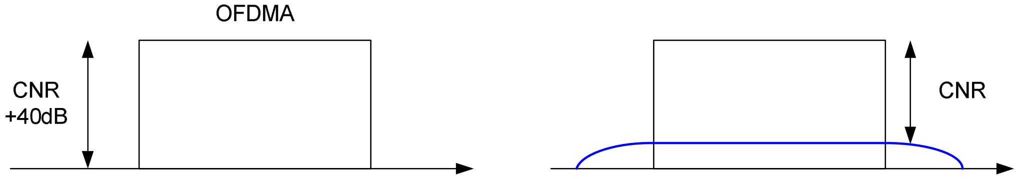

Figure 2 - Intermodulation of a DOCSIS 3.1 upstream signal degrades the CNR.

The second-order intermodulation is typically the strongest intermodulation between two single carriers at frequencies f_1 and f_2. The second-order intermodulation of these two signals generates signals at the sum and difference frequencies f_1+f_2 and f_1-f_2 respectively.

The requirements regarding intermodulation of the distribution passives are only vaguely defined in the IEC60728-4 standard, in which no limits are stated. High-grade distribution passives have second-order intermodulation products that are 120 dB below the carrier frequencies for carrier levels at 120 dBμV; this is denoted as -120 dBc, where the *c* indicates it is below the carrier level.

With DOCSIS 3.1 the intermodulation among the 3800 upstream sub-carriers results in thousands of in-band intermodulation products. For example, with an upstream OFDMA channel in the 10-105 MHz band, the intermodulation product at 100 MHz can be generated in 1600 ways, for example 10 MHz+90 MHz, 22.375 MHz+77.625 MHz, and 49.975

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MHz+50.025 MHz. The factor 1600 equals 32 dB (equivalent to 10*log(1600)). This means that by converting from a measured second-order modulation between just two carriers, for example 40 MHz and 60 MHz of -120 dBc, the summed intermodulation is -88 dBc at 100 MHz.

The second strongest intermodulation involves three carriers, for example with intermodulation products at -140 dBc. These third-order intermodulation products are generated at all frequencies $f_1 \pm f_2 \pm f_3$. Again, using the 3800 DOCSIS 3.1 sub-carriers, more than 7 million combinations can result in a signal at a single in-band frequency. The factor from these combinations equals 69 dB, thus -140 dBc third-order intermodulation adds up to -71 dBc.

Therefore, even if the distortion of a single carrier is non-measurable, the plentitude of intermodulation products arising from the numerous DOCSIS 3.1 sub-carriers might obstruct the Gbit/s bitrates of DOCSIS 3.1.

Preventing Passive Intermodulation

For years – since the introduction of broadband services in HFC networks – it has been known that the junctions between male and female connectors generate passive intermodulation. This phenomenon is termed *Common Path Distortion* (CPD).

The cure for CPD is to use connectors that have corrosion-robust nickel-tin plating. Most F-male connectors for cables are made with this plating. For the counterpart - the F-female connectors on the devices - only a few brands are available with nickel-tin plating and the Signia Line from DKT is one of them.

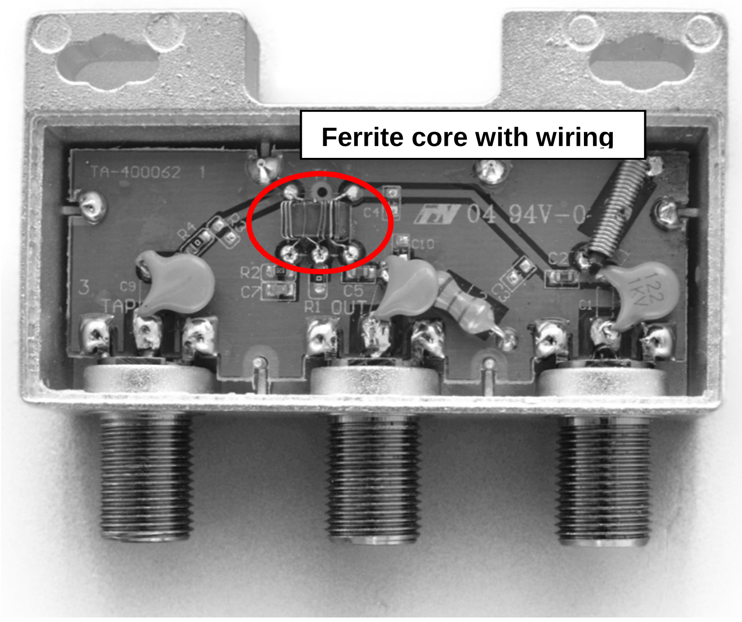

Figure 3 - Ferrite core inside a distribution passive.

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For the most part, distribution passives such as taps and splitters are built around ferrite cores. The wiring around these cores defines the exact performance of each core. The magnetic characteristic of these ferrite cores is not perfectly linear, and the stronger the signal, the closer the ferrite is driven to its saturation limit. Therefore, the sinusoidal waveform of the single carrier is distorted when passing each ferrite core. Also, each tap or splitter may contain several cores. The result is that the slight distortion in a single core sums up through the HFC network.

The ferrite cores are comprised of magnetic material, which has a memory effect. This means that if the ferrite material is brought close to its saturation level, then part of the microscopic magnets constituting the ferrite remain aligned. The effect of this is that the window, of (almost) linear characteristics, becomes narrower.

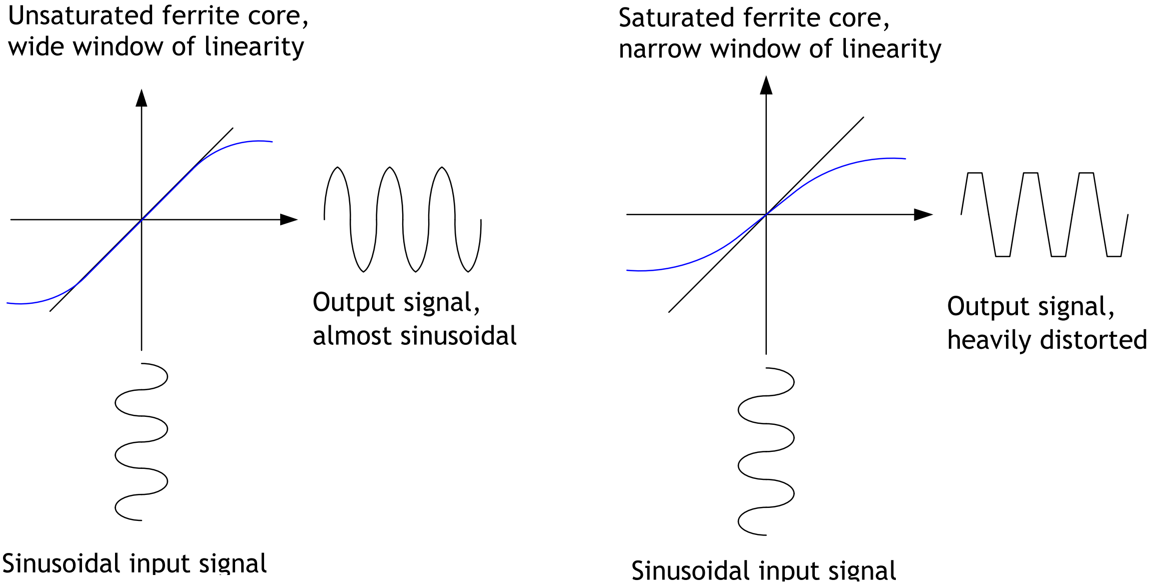

Figure 4 Signal distortion in ferrite cores before and after exposure to surge pulses. The surge pulses saturate the magnetic material and narrow the window of linearity. As a result, the sinusoidal input signal is heavily distorted.

The result is that if a tap with PIM -120 dBc is subject to a high current, the PIM is reduced, for example by 20 dB. With the above examples this gives second and third-order intermodulation products at -68 dBc and -51 dBc respectively. The gap to the threshold for QAM1024 becomes closer, especially in a network with a cascade of distribution passives.

Whenever an active device in a HFC network (an in-home amplifier, a modem, a TV-set, etc.) is switched on or off, a transient is generated in the network. When these transients or surge pulses pass the wiring that is around the ferrite cores, the above memory effect in the magnetic material sets in, reducing the PIM and degrading the network CNR.

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By selecting magnetic material with a high saturation level for the ferrite cores, and building in a protection against surge pulses, distribution passives can have a high level of robustness against surge pulses. The DKT Signia Line has been produced to satisfy these requirements. That is why the Signia Line passives have a low PIM and is robust against surge pulses.

Conclusion - repeated

In summary, when upgrading for DOCSIS 3.1 distribution, the details in the material selection are critical for the long-term stability and up-time of the HFC network. It is of utmost importance to take care of parameters such as passive intermodulation and CPD robustness.

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