RMS Communications TECHNICAL BRIEF

BROADBAND

Introducing Intermodulation:

Its Role in Cable Modem and Reverse Path Operation

RF Products Division
RMS Communications

A History of CATV Coaxial Network Design:

Cable Television systems are designed for optimum forward path operation (in one direction only), allowing 6MHz analog video channels to move from the Headend to the home over a Hybrid Fiber/Coax medium. The products used in these networks, from amplifiers to passive's, were designed with forward transmission as the key requirement. As RF travels from the cable system Headend to the home, a number of things happen. For the purpose of understanding Intermodulation and why it occurs, the key thing to remember about RF signals passing through any medium is that they attenuate or loose strength. Cable systems are engineered to ensure that the RF signal present at the entry to every home is optimized to guarantee a minimum video level at the highest frequency of operation. To accomplish this, passive products are designed to attenuate RF signals that pass through them by varying degrees. Depending on how far away a particular home is from the last amplifier (distribution and drop cable length), the dB value of a tap (coupling value) is chosen to ensure that the dB level at all homes fed from that particular amplifier is constant. Homes fed from different taps at different distances from the amplifier should all receive the same signal level in order for the set-top box to work correctly (typically 7dB at the input to the home splitter). Consider the following example (See Figure 1, Page 2).

CATV Coaxial Network Demands Today:

Cable systems today are beginning to utilize their reverse paths extensively. The best example of this is the rapid deployment of cable modems, which allow customers high speed Internet access through their cable television networks. In order for cable modems to operate properly, they rely on being able to receive and transmit data from the home to the Headend over the cable network. As cable systems deploy cable modems, they are learning more about the limitations of passive products in this area. The limitations have primarily to do with the passive product's ability to pass high level RF signals in the reverse direction. From a fundamental design standpoint, RF passes freely through any passive product in either direction. The technical issues have more to do with what happens to the signal as it passes. More specifically, the Intermodulation issue relates to and results from the high RF signal level at which a cable modem must transmit a signal in order to ensure that it reaches the headend accurately and within an acceptable Bit Error Rate range. Just as a RF signal is attenuated through a passive devise in the forward direction, it is also attenuated by the same degree as it passes through that devise in the reverse direction. Consider the following example (See Figure 2):

(continued on page 2)

TECHNICAL BRIEF

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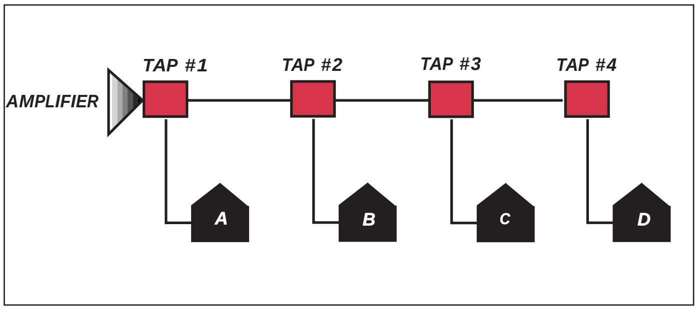

Figure 1. The RF signal level at the entry point to each home must be approximately 7dBmV. The coupling values of Taps 1 through 4 are chosen to ensure this consistent RF level at each home entry port.

In this next example, let's look first at the forward direction. The output level of the amplifier is 50dBmV. This is attenuated by the following losses as it moves towards the home:

- *1.0dBmV Insertion Loss of the first Tap installed on the Amplifier output.*
- *5.0dBmV loss of the distribution cable between Amplifier and Tap #2.*
- *5.0dBmV loss of the drop cable between Tap #2 and Home B.*

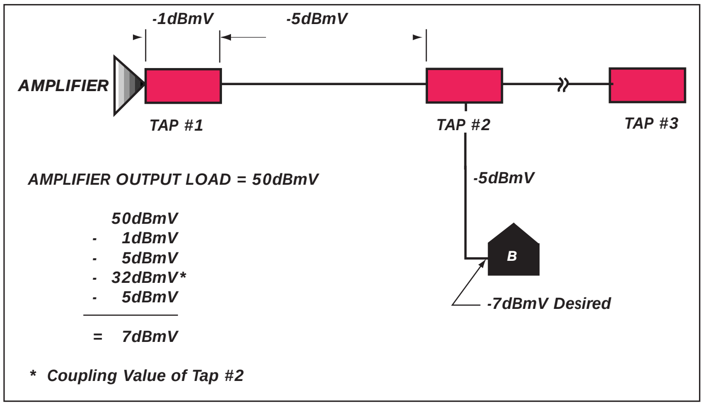

Figure 2. This example shows typical attenuation losses, in the forward direction, of taps and drop cable for a desired 7dBmV at the home.

If a 7dBmV signal level is desired at the home entry point, a 32dB Tap must be selected in order to properly budget the available RF. Amplifier output (50dB), minus Insertion Loss of first Tap (-1dB) minus cable loss (-5dB) minus Tap dB attenuation (-32dB), minus drop cable attenuation (-5dB), equals signal available at the home. [50dB minus 1dB, minus 5dB, minus 32dB, minus 5dB] equals 7dB. This RF budgeting has been carried out with only the forward path considered.

Reverse Path Signal Level Budgeting:

Let's now consider a signal originating at the cable modem and the obstacles it must overcome in order to reach the amplifier, at which point it can be amplified and continue its journey back towards the Headend. Consider the following example (See Figure 3):

In this case, we are looking at a signal originating at the cable modem output. This signal must be transmitted at a level sufficient to overcome interference due to ingress (noise funneling from home appliances etc.), and the losses of passive devices and cable between the modem and

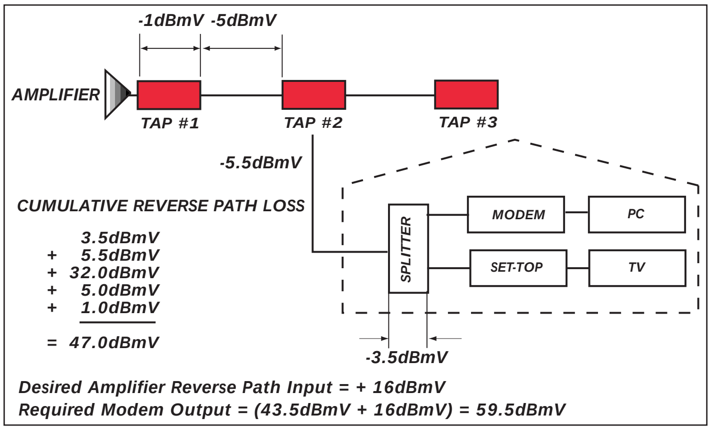

Figure 3. This example shows added attenuation losses of 3.5dBmV due to 2-Way Splitter addition for connection of cable modem.

the first amplifier upstream. These losses are the same as in Figure 2, with the addition of a loss through a 2-Way Splitter inside the home which was added to allow the cable modem to be connected, and the added cable between the entry point to the home and the Indoor Splitter. Beginning at the cable modem, the transmitted signal must overcome the following losses:

- *3.5dBmV loss of the 2-Way Splitter*
- *5.5dBmV loss of the drop cable*
- *32.0dBmV loss of the distribution tap*
- *5.0dBmV loss of the distribution cable between tap and amplifier.*
- *1.0dBmV insertion loss of the first tap on the amplifier output*

TOTAL LOSS = 47.0dBmV

Let's assume that the reverse amplifier requires a minimum input signal level of 13dBmV in order to optimize the carrier to noise and dynamic range. The total output level of the cable modem must now be 60dBmV (47dBmV +

(continued on page 3)

13dBmV) in order to overcome all losses along the way and still reach the amplifier with an acceptable signal strength.

This extremely high cable modem output level of 60dBmV is the root cause of the intermodulation problem we will now discuss.

What Is Intermodulation?:

CATV Passive products are constructed using transformers with ferrite cores and various resistive/capacitive tuned circuits. These circuits function together to ensure that the RF signal is minimally compromised as it passes through the devise in order to redirect, split, reduce it in power by a predetermined factor, or combine it with other signals.
The following circuit diagram depicts a typical 3-Way splitter circuit:

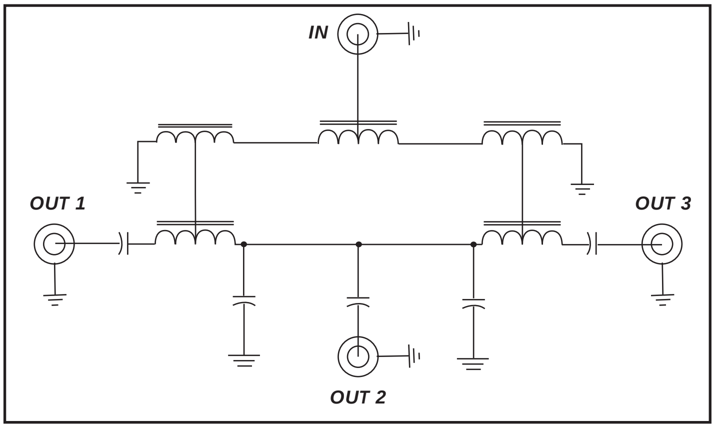

Figure 4. A typical passive device circuit is designed to redirect, split, and/or reduce signal power by a predetermined factor, or to combine it with other signals.

The ferrite core material is particularly sensitive in terms of its magnetic characteristics (linear magnetization curve) and how it allows a broadband (5-1000 MHz) RF signal to pass through it with minimum interference. It is used because of its ability to manage such a broadband signal while continuing to operate linearly or within a predictable and flat range across the entire 5 to 1000 MHz spectrum. The linear operation of a ferrite core is dependent on its magnetic properties remaining within a stable range (linear region). The stable magnetic range of a ferrite can be represented by what is known as a hysteresis curve. This curve depicts the stable operating range of the ferrite's magnetic property which occurs between the upper and lower hysteresis limits (linear region).

The Problem:

As we have demonstrated earlier, a cable modem must output signal levels over a wide dynamic range (25 to 60 dBmV typical) in order to overcome the losses it encounters on its way back to the amplifier. In fact, cable modems are designed to automatically increase their output level until they can verify the signal they are transmitting has been received at the headend within an acceptable bit error rate range. This adds an element of unpredictability to the actual output level of any given modem at any given time.

Assuming the modem output level is a realistic 55 dBmV, the first passive device encountered is the 2-Way Splitter used to connect the cable modem to the CATV network. Depending on where the ferrite material is sitting about the hysteresis curve, the ferrite cores may no longer be capable of operating within their linear range when hit by such a high signal level. The high RF level changes the magnetic properties of the core, and results in operation of that core outside of its stable hysteresis range. This is referred to as "saturation of the core" (non-linear operation).

When saturation occurs, undesired beats or signal sources are generated at harmonic's of the original frequency (fundamental frequency). For example, if the return path signal is being transmitted at 40 MHz and the ferrite saturates due to the high level being transmitted, a second harmonic beat will appear at 80 MHz (twice the fundamental frequency). This second harmonic beat now falls in the forward video band; its level is **unpredictable** and can distort the video channel being transmitted at 80MHz (causing severe interference on the TV picture).

Other lower level beats may appear at higher harmonic frequencies depending on the level of the original beat. Detection of the problem will only occur when the cable modem is operating and a television set close to the modem is tuned to a channel which falls on one of the harmonic frequencies. This makes the interference itself intermittent and difficult to troubleshoot if not understood by the service technician. The following graph depicts this interaction (See Figure 5, Page 4):

(continued on page 4)

TECHNICAL BRIEF

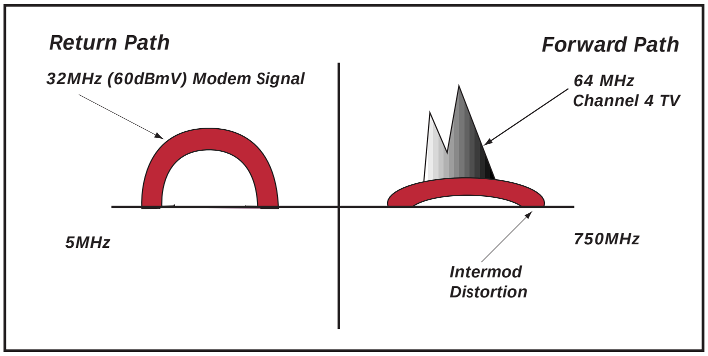

Figure 5. This example shows a return path signal that is being transmitted at 32MHz. As the ferrite saturates, due to the high level signal being transmitted, a second harmonic beat will appear at 64MHz (twice the fundamental frequency).

Common Solutions to the Intermodulation Problem:

Manufacturers have for some time known about this problem and have made some attempts to develop and implement a solution. However, the solutions commonly available all fall short in one fundamental manner. They do not address the problem at the root cause, which is the material composition and linear properties of the ferrite component itself. Other solutions attempt to make the ferrite less susceptible to saturation by merely increasing its size, improving the "as produced" magnetic properties of the ferrite by ensuring it is completely demagnetized on leaving the factory, or adding components which prevent or limit other sources of interference such as impulse noise or other forms of voltage spikes. Manufacturers are attempting to use combinations of the above in order to avoid fundamental redesigns of their staple, existing products. They then market the product as a Low Intermodulation, Modem/Digital Ready product. Let's look at these different solutions and identify some of their inherent drawbacks:

Ferrite Size: *By simply increasing the size of the ferrite, it can become more capable of handling higher signal levels before saturating. However, it is not only physical size that matters, the material composition also plays an important role. Merely increasing ferrite size has a direct negative impact on the broadband performance of the ferrite. In other words, as the size increases it becomes increasingly difficult to maintain desired return loss and frequency response characteristics across the 1000MHz band and the lower and upper portions of the band are most severely affected.*

Demagnetizing Ferrites in Production: *This process is known as "Degaussing" and involves passing the final product through a degaussing chamber just before final packaging at the factory. The resulting ferrite is demagnetized and operating at optimum linearity on leaving the factory. The problem with this solution is that various things can happen in a standard network to re-magnetize the ferrite rendering the product susceptible once again to saturation. The most common re-magnetizing force is a voltage spike caused by impulse noise or lightening. It actually requires rather low voltage levels to change the magnetic properties of the ferrite once again rendering its intermodulation performance unpredictable. Changes in temperature can also vary the magnetization characteristic.*

Adding Components to Prevent Re-Magnetization of the Ferrite: *Many manufacturers are now adding blocking capacitors with various voltage ratings to all ports of an indoor splitter. These blocking capacitors essentially reduce the level of the voltage spike reaching the ferrite, thereby preventing the ferrite from being re-magnetized. This method does help reduce the effects of low voltage spikes, but high voltage spikes can still induce enough magnetic change to cause the ferrite to operate non-linearly. It is therefore at best only a partial solution or defensive measure against the problem.*

The RMS DigiTap™ Low Intermodulation Solution:

The Low Intermodulation solution pioneered by Filtronic & RMS Communications over the past three years and now licensed exclusively to RMS centers on maintaining the actual broadband linearity of the ferrite component itself. Through extensive experimentation and scientific research and development, Filtronic/RMS developed a unique multi-stage solution. The first is a new material composition, which when used with a specific manufacturing process, provides a guaranteed level of linear broadband performance greater than that ever achieved before. Unique circuit designs are used to optimize the broadband RF performance. In addition, some of the performance insurance measures presented above, such as optimizing the physical size of the ferrite and adding blocking capacitors, are incorporated into the final RMS DigiTap™ designs to provide redundant protection.

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TECHNICAL BRIEF

SPECIFICATIONS

RMS DigiTap™ Low Intermodulation Splitters:

Bandpass (MHz)	5-1000MHz	1002DWSBSCTE	1003DWSBSCTE Balanced	1003UBDWSBSCTE Unbalanced		1004DWSB-SCTE
	Frequency (MHz)			Prt 2	Prt 3	
Insertion Loss: (-dB Max.)	5 - 15	4.0	6.3	4.0	8.0	8.0
	16 - 500	3.8	5.7	3.8	7.6	7.6
	501 - 750	4.0	6.2	4.0	8.0	8.0
	751 - 1000	4.5	6.9	4.5	8.8	8.8
	Frequency (MHz)					
Isolation: (-dB Min.)	5 - 10	16	16	16	16	16
	11 - 15	25	25	25	25	25
	16 - 70	35	35	35	35	35
	71 - 1000	20	20	20	20	20
	Frequency (MHz)					
Return Loss Input: (-dB Min.)	5 - 10	16	16	16	16	16
	11 - 500	20	20	20	20	20
	501 - 1000	18	18	18	18	18
	Frequency (MHz)					
Return Loss Output: (-dB Min.)	5 - 10	16	16	16	16	16
	11 - 500	20	20	20	20	20
	501 - 1000	18	18	18	18	18

	Frequency (MHz)	
Tap Distortion (All Ports) (-dBc Min.)	40 - 1000	110 60dBmV One Signal In Return Path
Harmonic Second Order And Higher Second Order Beats (-dBc Min.)	40 - 1000	105 60dBmV One Signal In Return Path
EMC (dB Min.)	30 KHz - 1000 MHz	100
Environmental Operating Range:	-20ºC to +70ºC	

Note: Intermodulation performance results are achieved without degaussing to provide spike immunity.

Isolation and It's Role in Cable Modem Operation:

Isolation refers to the ability of a product to prevent a RF signal from coupling onto adjacent ports and interfering with other subscribers or other sets connected off the same passive product. For example, the signal transmitted by the cable modem, in an ideal situation, travels directly back to the headend and the isolation performance of the passives through which it must pass is sufficient to ensure that it does not interfere with adjacent ports. Unfortunately, once again the high output level of a cable modem places unusual isolation demands on particularly the first passive it encounters, since its signal level is highest at this point. This again will be the indoor splitter used to connect the modem into the CATV network. Because of this, it is not only necessary to prevent intermodulation in the design of the splitter, but also to increase the port-to-port isolation performance of the splitter to protect adjacent ports from the high level cable modem output signal.

The DigiTap™ Splitter line also takes this into consideration in every detail of the design from the printed circuit board material, to tolerances of individual components, to production tuning methods. This has resulted in a significant improvement in the isolation specification of the product. This improvement is in the order of 10dB over conventional splitters in the market, particularly over the important reverse path frequency band where the high level cable modem signal enters the product. ●

For additional product information, contact the RMS Communications office or distributor nearest you:

Office Locations:

UNITED STATES	CANADA	CANADA	EUROPE
11516 Downs Road Pineville,NC 28134 800/223-8312 1-704-588-4008 Fax: 1-704-588-2004	4640 Lancelot Drive Richmond, BC V7C4S3 877/355-2323 1-604-771-3589 Fax: 1-604-271-8384	Telonix Communications 15-305 Industrial Parkway South Auroro, Ontario L4G6X7 888/835-6649 1-905-727-3050 Fax: 1-905-727-2991	TBA