Frequency Division Multiplexing and Headend Combining Techniques

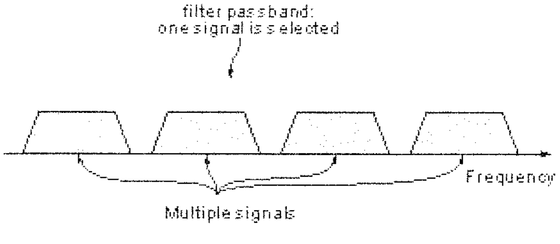
In the 3rdquarter technical report for 2010, I mentioned that the next subject would be wireless link calculations and measurements; however, in my headend testing I continue to find proper FDM (frequency division multiplexing) combining techniques to be a misunderstood subject, in spite of the fact that we've been using these basic techniques since the inception of cable television in the 1940's and 1950's. In the last quarterly technical report we examined OFDM, with a brief examination of FDM. Given the continued general misunderstanding that I see in this basic area of cable television engineering, I've decided to make this area the subject of this first report for 2011.

Introduction.

In frequency division multiplexing, each system carrier is assigned a separate specific frequency and amount of spectrum (bandwidth) to use. At some point, typically in the headend; all of the separate carriers, subcarriers, etc. are combined onto a single coaxial cable before driving the input of a linear laser or coaxial amplifier. The combining (or separating) of these separate carriers requires a fairly complex arrangement of passives, filters, and sometimes actives that we've commonly come to call the 'combining network'. This arrangement of equipment will now be examined in greater detail.

The frequency of most (but not all) carriers is typically related mathematically. For example, if we examine channel 23, the frequency of the luminance carrier is 217.25 MHz and the aural carrier is 4.5 MHz higher (than the visual carrier). Each successive (higher) channel is normally (but not always) exactly 6 MHz higher in frequency. Aeronautical offset requirements will displace some of these frequencies by +12.5 or +25 KHz, but the basic 6 MHz incremental relationship exists for most carriers. And most 'channels', whether NTSC analog or QAM, occupy 6 MHz of bandwidth in the US cable system, or 8 MHz where the PAL system is utilized.

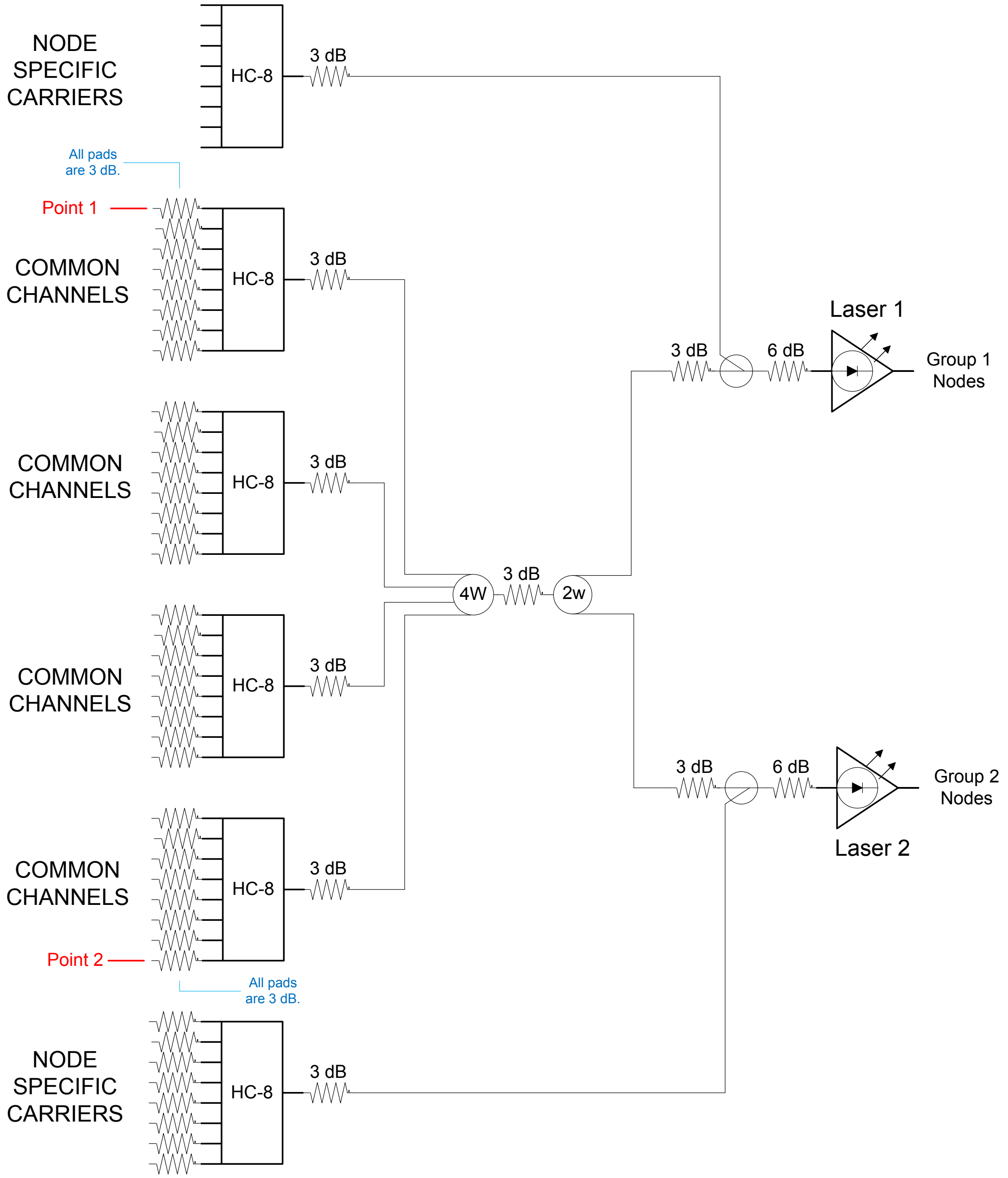
The use of FDM also requires that (any) subsequent amplification be very linear, since if it is not, intermodulation products will be produced that typically land within utilized spectrum, thus degrading the overall performance of those channels and information throughput. Proper combining techniques ensure that the effect of these intermod components is minimized.



Typical FDM Channel Spacing

Basic FDM Combining

First, lets examine a generic combiner diagram *with use of distributed padding*, and discuss some general principals that must be followed to achieve good isolation between equipment and signals, low noise floor, and minimal intermodulation beat introduction.



GENERIC COMBINER CIRCUITRY WITH DISTRIBUTED PADDING

The above generic diagram seeks to combine multiple analog or QAM carriers in such a manner that each carrier has the best possible CCN (analog ‘carrier-to-composite-noise’) or MER (QAM modulation error ratio [digital S/N]), that it does not create or add interfering components within it’s own spectrum or the spectrum of other channels, and makes specific use of ‘distributed padding’ to achieve the above goals. In particular, I will address the issue of distributed padding later in this report, but for now, drawing on years of experience in designing, assembling, and testing downstream and upstream FDM combining networks, let me list the following basic principles that *must be* followed.

1. All modulators, processors, or other equipment that generates an analog carrier(s), including QAM units such as the Motorola SEM, should be operated ‘mid-range’ in terms of RF output levels. This not only ensures that level adjustments (fine-tuning) can be easily performed, it also minimizes noise and distortion generation from individual units. The initial design layout for the FDM network therefore must begin with these mid-range RF levels, as most other components values (pads, combiners, couplers, etc.) will be chosen on the basis of maintaining these output levels mid-range.
2. If time permits during the assembly of the RF headend, use a spectrum analyzer to measure the individual output of each modulator, processor, etc. Some units, even newer ones, may be found to **not** conform to the general specification of all spurious beats being at least 60 dB below the desired signal, and it’s much easier to find and eliminate defective units at this stage than looking for the source of some interfering carrier after all channels or carriers are combined.
3. Never use more than one post amp in cascade unless there is absolutely no other choice. I’ve been in headends where I’ve measured noise levels much higher than should be encountered, and have even measured *composite* 2nd and 3rd order distortions (in the headend!), all due to the unwise use of several post amps in cascade, often coupled with incorrect operating levels. See #5 below. And I have yet to encounter a headend that employed multiple post amps in cascade where a careful FDM redesign did not reduce the post amps in cascade to 1 or even none.
4. If ‘amplified’ 12-way or 16-way combiners are used, they should only be used in the initial combiner stage, where a single carrier or perhaps several carriers are injected at each port. I sometimes encounter a headend where an amplified multi-port combiner has been used ‘downstream’ where a large number of carriers may be present at each input port. The amp stage(s) in these amplified combiners are fairly low in quality, meant for use with only a few carriers, and they *will generate* high distortion levels if used in downstream combiner sections.
5. Be very careful to run post amps at recommended input and output levels; as discrete or even composite distortions, or poor CCN/MER can result if they are not.
6. Use distributed padding! More on this in a later report section, but in general, the use of distributed padding (versus a larger pad at a single location), achieves higher port-to-port isolation.
7. Use of BPF’s. When I began assembling and testing headends in the early 1970’s, placing bandpass filters on the output of all modulators and processors was a common practice, as the equipment of that era tended to generate out of band beats that had to be eliminated, and the use of ‘strip amps’ at that time also necessitated that a BPF be placed before or after the unit. Later designs have pretty much eliminated this practice, but there are times when a BPF will have to be employed (see #9 below). When a BPF is placed, be sure to also place, if at all possible, a low value pad at the input and output of the BPF, as it forces a good impedance match (Z) on what otherwise is a device that is inherently a poor Z match in the network.

8. Be absolutely sure to terminate all unused combiner ports! The specified port-to-port isolation for a splitter or combiner assumes a good 75-ohm match on *all ports*, and even a *single* un-terminated port can affect port isolation.
9. In general, the quality of the modern processor or modulator seems to be declining the past few years, for reasons I'm not entirely sure of (but the manufacturing location is certainly suspect). I'm seeing problems with newer units, just out of the box, that were not seen just a few years ago. For example, one very well known manufacturer of headend equipment has a problem with their newest series agile modulator (550 MHz or 860 MHz), where it just barely passes CLDI (chrominance-to-luminance group delay) when tested new out of the box. In one recent headend that had just received an installed over a dozen of these units, only several would pass the CLDI spec and all were returned for a refund.

   And I'm seeing local oscillator 'bleed-through' on some models, with the cumulative effect of landing a 'composite' beat in one or several channels, rendering them either unusable or requiring the use of a BPF.

Now lets explore the issue of distributed versus 'lumped' padding a bit further.

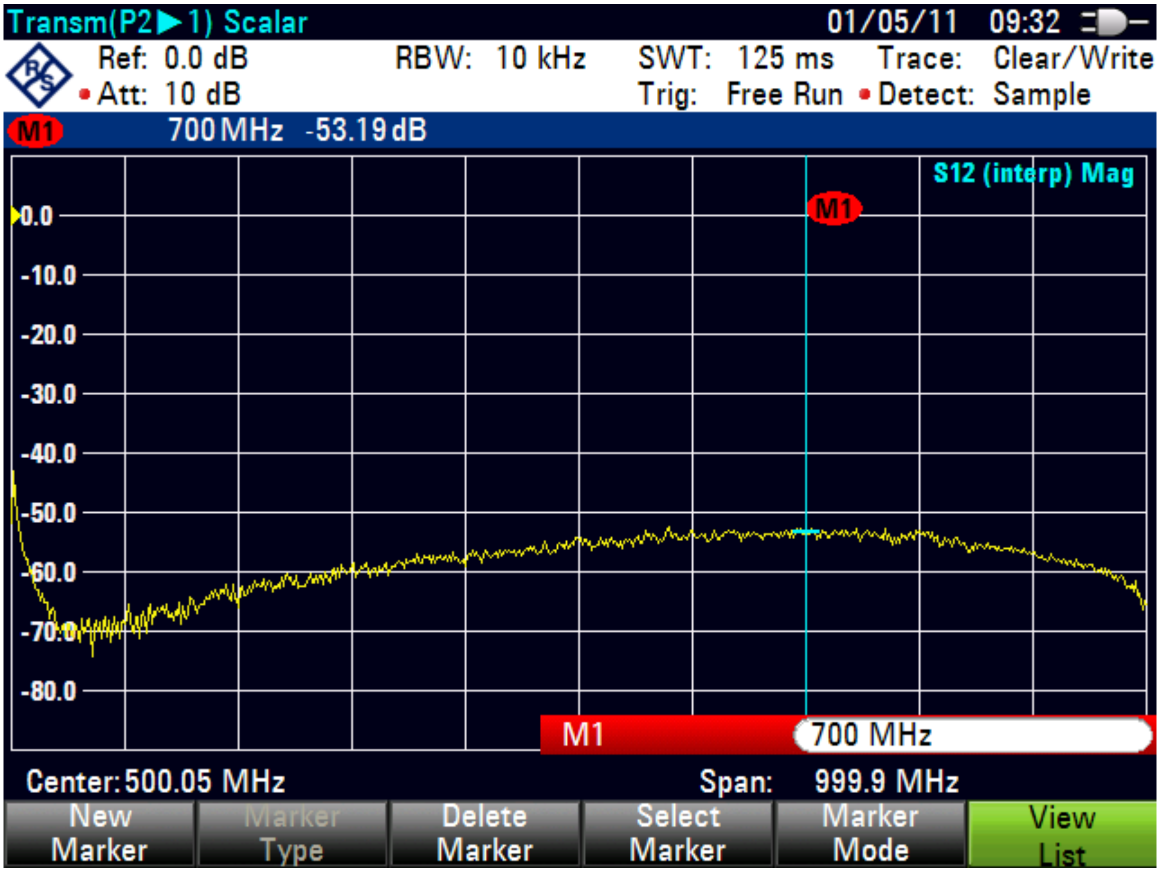
Port-to-Port Isolation

In the first generic combiner diagram shown earlier in this report, padding was distributed throughout the network in small value pads. One might well ask the question "why bother with doing it that way"? Why not just place one or several larger value pads and save the expense of all the smaller ones?

The answer comes by examining port-to-port isolation. If we review the diagram shown earlier, we can 'estimate' the isolation between ports 1 and 2 (labeled on the diagram) as follows.

If one assumes 12 dB of insertion loss between the input and output ports of each 8-way combiner (quality 8-way splitter or headend combiner), 3 dB for each pad, 1 dB for each coaxial cable lead, and 25 dB of port-to-port isolation at the 4-way combiner, the isolation between points 1 & 2 in the diagram should be approximately 63 dB according to the design.

Now let's actually measure the actual isolation using the network wired as shown in the diagram. The following measurement was taken with a Rohde & Schwarz spectrum analyzer with tracking generator, providing for scalar network measurements. The top graticule was normalized to 0 dB to account for losses external to the network under test, such as minimum loss pads, connectors, etc. 1 GHz passives were used, quality cable and connectors were employed, and all ports in the network had a good 75 ohm impedance present.



Transm(P2▶1) Scalar 01/05/11 09:32

Ref: 0.0 dB
Att: 10 dB
RBW: 10 kHz
SWT: 125 ms
Trig: Free Run
Trace: Clear/Write
Detect: Sample

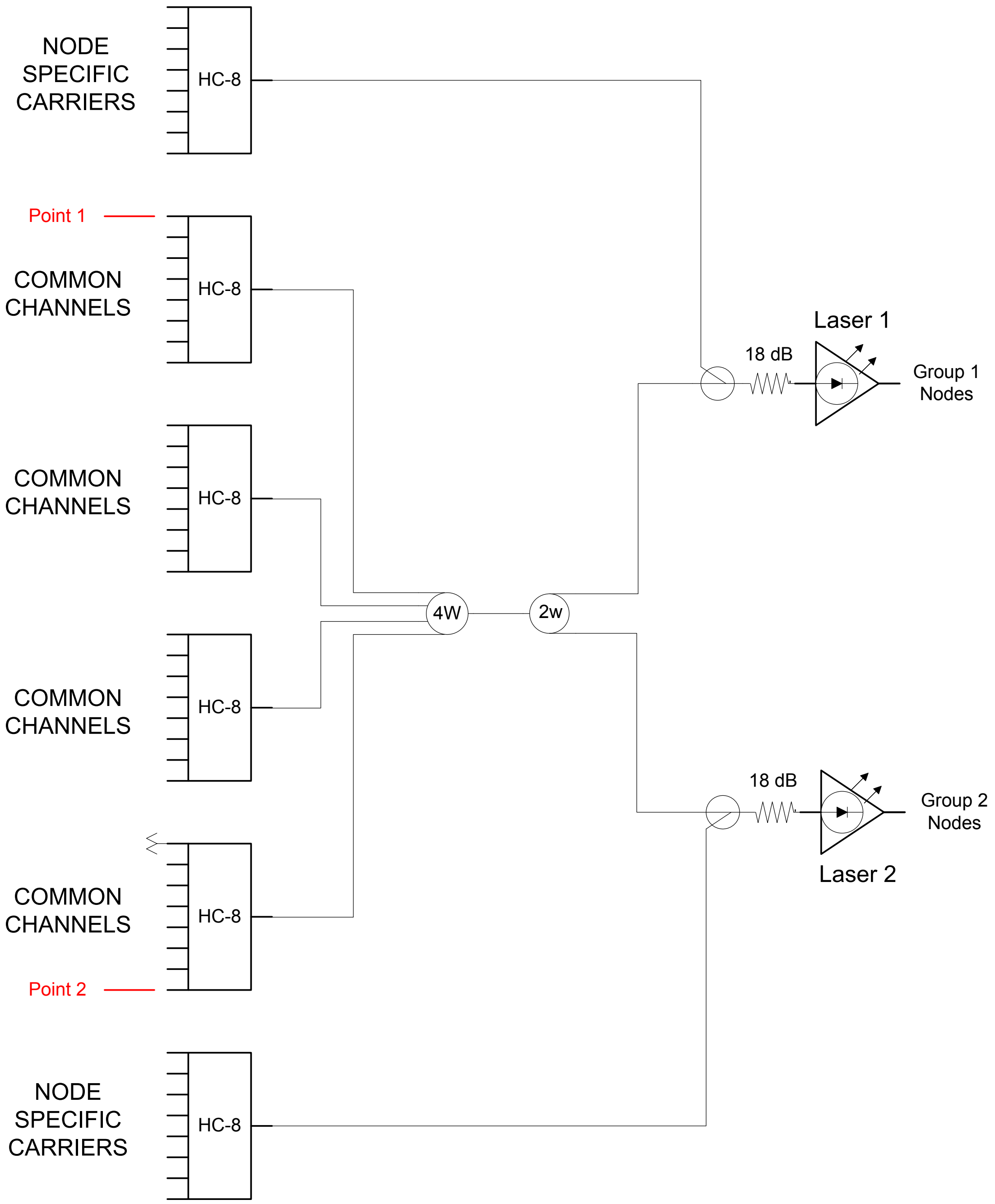
M1 700 MHz -53.19 dB

M1 700 MHz

Center: 500.05 MHz
Span: 999.9 MHz

Worst-case isolation is measured at 700 MHz and is 53.2 dB, or approx. 10 dB worse than our projected isolation value. It is also apparent from the above measurement that the amount of isolation varies considerably depending on frequency, with the best case isolation at 67 to 70 dB below 100 MHz (the tracking generator starts at 100 KHz).

Now what will happen to port-to-port isolation if we simply combine all the pad values to a single lumped value positioned downstream in the network? The combining network under test was changed as shown in the following diagram.

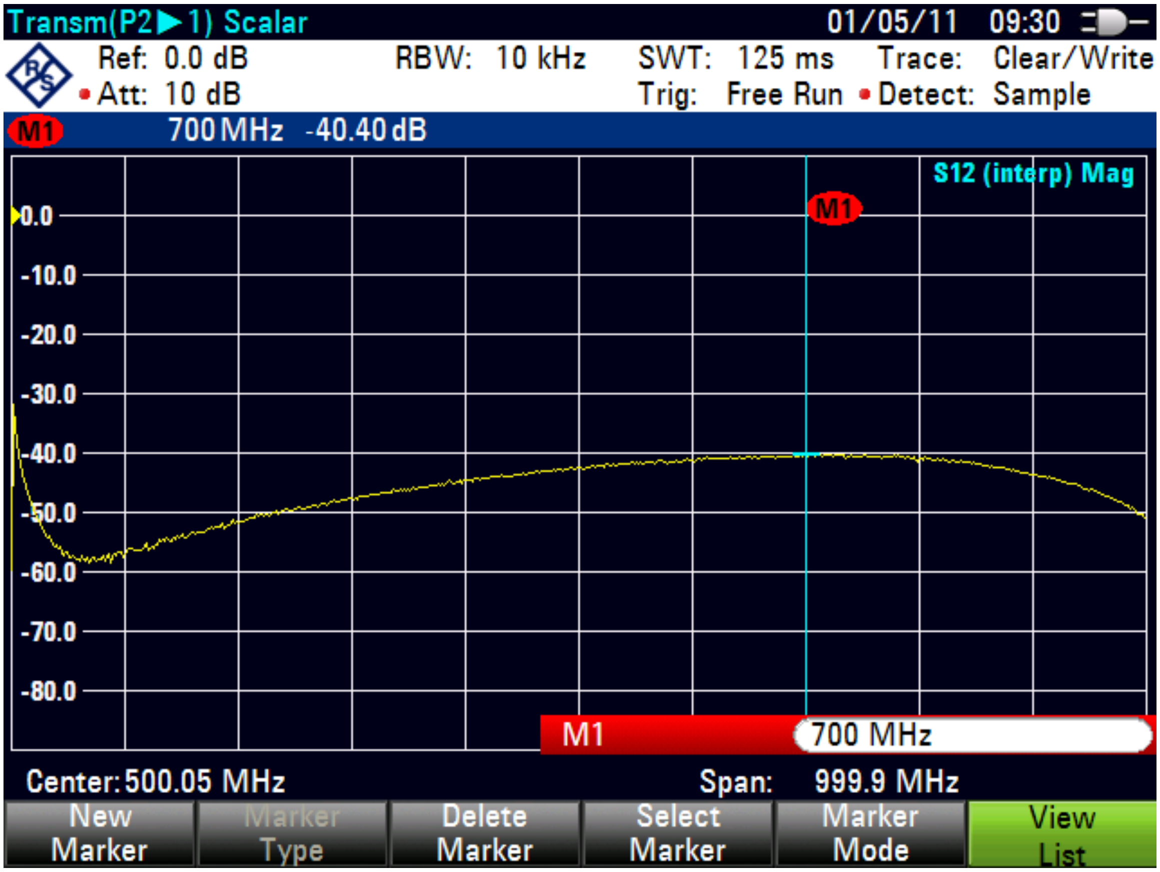


GENERIC COMBINER CIRCUITRY WITH 'LUMPED' PADDING

Note that total padding prior to each laser remains the same; however, now all padding is lumped into a single 18 dB value just prior to each laser.

In this case, we again assume 12 dB of insertion loss between the input and output ports of each 8-way combiner, 1 dB of loss for each coaxial cable lead, and 25 dB of port-to-port isolation at the 4-way combiner. The *projected* isolation between points 1 & 2 in the diagram now drops to 51dB.

Measured worst-case isolation, as seen below, is now 40.4 dB (11 dB worse than projected), and best case (below 100 MHz) is approx. 56 to 57 dB. The important thing to note is that by distributing our padding, rather than lumping it at one or two locations, we gain approx. 13 dB of overall isolation as compared to our first design, and 13 dB could make the difference between 'seeing' or 'not seeing' an analog beat, or a reduction of several dB in MER in a QAM carrier.



Transm(P2▶1) Scalar 01/05/11 09:30

Ref: 0.0 dB RBW: 10 kHz SWT: 125 ms Trace: Clear/Write

Att: 10 dB Trig: Free Run Detect: Sample

M1 700 MHz -40.40 dB

Center: 500.05 MHz Span: 999.9 MHz

M1 700 MHz

And although I could not simulate this in my testing, the actual amount of isolation gained by distributing the padding (in a real headend) is even greater, because the 75 ohm (resistive) pads help all equipment to 'see' a proper impedance match at their inputs and outputs, and improved isolation is achieved when proper impedance match is maintained. In other words, in my test setup I took care to make sure that I maintained a good impedance match at all ports, but this is **rarely the case** in a 'real world' headend combining network, where modulators, processors, filters, etc. often place a partial impedance mismatch at multiple locations in the network.

Conclusion

In the modern cable system, downstream and upstream combining networks have become more and more complex, yet the basic functioning of these networks and reasonable principles to follow in their design and operation seems to be less and less understood. The general principles outlined earlier must be followed if one is to have a headend with quality signals driving downstream lasers; and again, by quality I mean low noise and low intermodulation (discrete or composite) present within the spectrum of interest.

All of the points are crucial to achieving this goal, but I think perhaps the most misunderstood is the proper use of padding. I have, upon occasion, designed combining networks for companies, with the company then building the network and accomplishing the changeover. Later, when I arrive to test and confirm it's overall operation, I find the distributed padding removed with a few large value pads in their place. When I ask why this was done, I get blank stares and the response "why would we spend money and time for all those separate pads, when they can be combined downstream?' Hopefully this article addresses that issue to a reasonable degree, and also highlights the many other important factors involved in this crucial portion of the HFC network.

Unless some new subject 'trips my trigger' during FCC POP testing during January & February of this year, the 2nd Quarter 2011 Technical Report will likely return to the examination of wireless links, how they are designed and implemented, along with some actual measurements on an operational 11.2 mile 2.4 GHz wireless link.

Take care, and best regards for the 2011 New Year season!

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