PERFORMANCE ANALYSIS: DOCSIS 3.1 CABLE TV HEADEND COMBINING SYSTEMS

White paper

technetix

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Introduction

Splitters have been used to help build cable networks and combining systems for some time, indeed they are probably one of the most used passive components in a network. Historic knowledge of splitters could make us complacent about technical performance of applications today, particularly in the headend and hub.

The introduction of CCAP and DOCSIS 3.0 & 3.1 demands improved performance of the network, specifically the headend. The key words are speed and cost reduction; which are delivered by CCAP and DOCSIS 3.x. Moving to 1 Gbps/10 Gbps requires optimal technical performance from all parts and sub-systems of the network. Higher modulation schemes on QAM requires improved performance.

This White Paper compares the practical performance of splitters with the theoretical performance and explaining the impact splitter performance will have on overall network performance.

The splitter

There are many types of splitter, variables include mechanical construction, application and number of ports. The 2-way splitter is a good example of a 'typical' splitter.

This paper looks at the commonly used ferrite splitter shown in Fig. 1. A splitter has a common port and two splitter ports which are referred to as I/O 1 and I/O 2.

There is a particular splitter specification that is taken for granted but is dependent on the application of the splitter: the splitter isolation. As a splitter is passive it is bi-directional, meaning the signal can be split in two but we can also use it to combine signals; isolation is important in this application.

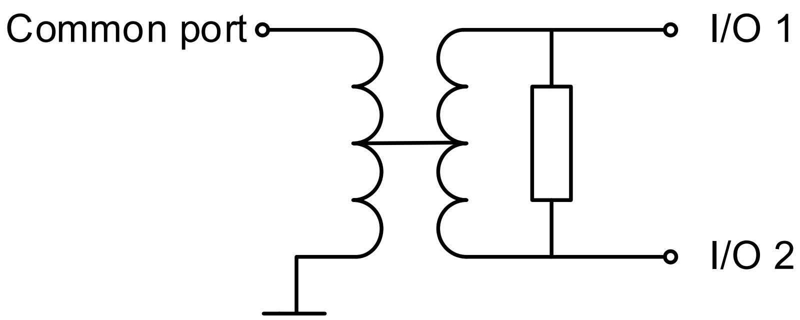

Fig. 1

What is isolation?

In Fig. 1 the isolation is defined as the difference in signal levels in dB between input port I/O1 and input port I/O2, when the common port is terminated.

When we use a splitter to combine two signals this isolation is important as we don't want signal leakage from I/O1 to port I/O2. When modulator signals are combined, the signals are mostly produced by a transistor. A transistor is a nonlinear element, it produces intermodulation, so if an external signal is fed back to the output transistor of a device and the level is high enough, it will generate intermodulation, which we don't want.

What does isolation depend on?

Isolation is dependent on the design and quality of the materials used, in addition to the design of elements such as the PCB board.

The practical isolation of a splitter is mainly determined by the termination of the common port; this can significantly reduce the isolation and create a leakage path (see Fig. 3).

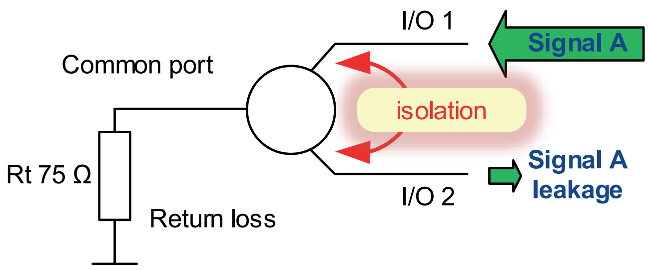

Fig. 2

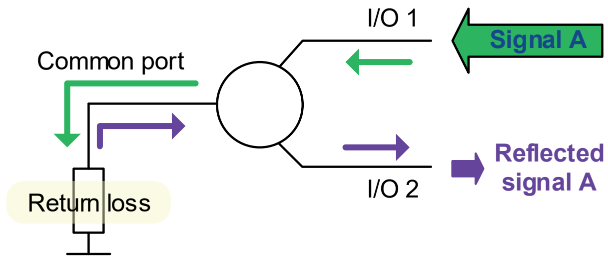

Fig. 3

A signal 'A' is inserted at port I/O1, this loses 4 dB passing the splitter port and faces the termination. The termination has a specific return loss, which is defined as the difference in dB between the power sent towards the termination and the power reflected.

In summary, a part of the signal 'A' is reflected back to the common port, so loses 4 dB passing the splitter port and comes out as the reflected signal on port I/O 2. The return loss of the termination of a splitter directly influences the isolation.

See table 1 for an example.

Termination return loss	Splitter loss	Isolation
40 dB	2 x 4 dB	48 dB (*)
20 dB	2 x 4 dB	28 dB
10 dB	2 x 4 dB	18 dB
6 dB	2 x 4 dB	14 dB

Table 1

(*) This 48 dB isolation cannot be met in splitters and is only theoretical.

Although the data sheets of manufacturers' reference 30 dB isolation, we now know that this is only valid when measured in a laboratory environment with high quality terminators.

The practical isolation of a splitter is twice the splitter loss plus the return loss at the common port.

Measurements

To prove the theory, Technetix took measurements using the following set up (see Fig. 4):

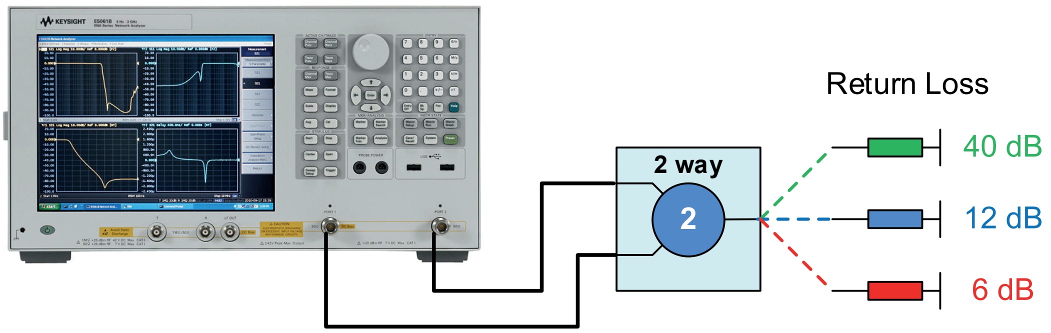

Fig. 4

A Keysight E5061B analyzer was used to measure the isolation with a standard WSP-122-12/D 2-way headend splitter and terminations with 40 dB, 12 dB and 6 dB return loss. The measurements were taken from 50 - 1250 MHz.

Measuring results

First measurement:

A terminator with 40 dB return loss.

The real isolation of the splitter when terminated correctly is measured using this method.

Over 30 dB of isolation between the ports is measured.

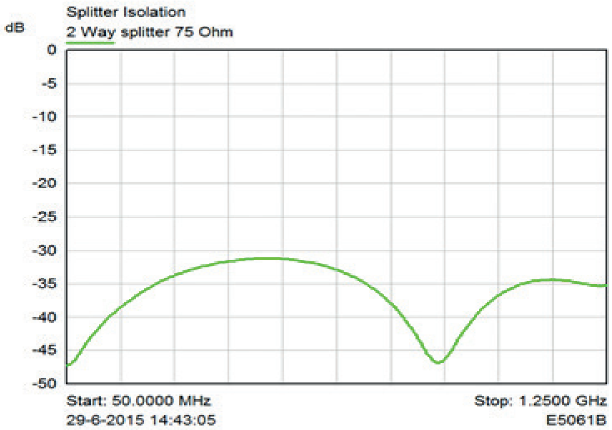

Fig. 5: Termination RL 40 dB isolation 30 dB

Second measurement:

A termination on the common port of 12 dB return loss.

In theory the isolation is:

12 dB + (2 × 4) = 20 dB

The measurement (indicated by the blue line) confirms approximately 20 dB isolation.

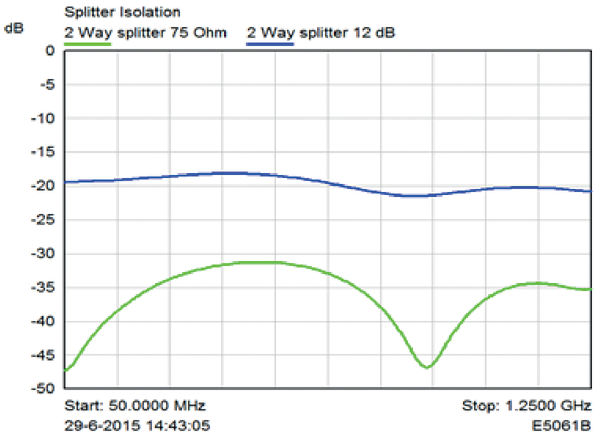

Fig. 6: Termination RL 12 dB isolation 2 × (4 + 12) = 20 dB

Third measurement:

A termination on the common port of 6 dB return loss.

In theory the isolation is:

6 dB + (2 × 4) = 14 dB

The measurement (indicated by red line) shows approximately 14 dB isolation.

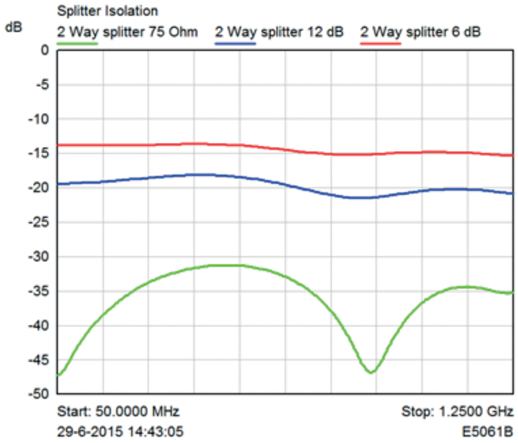

Fig. 7: Termination RL 6 dB isolation 2 × (4 + 6) = 14 dB

In practical applications, when splitters are used they are often terminated without a good return loss over the complete frequency range.

CableLabs specifications for CMTS and CCAP for output return loss is specified in the channel only.

The DRFI from CM-SP-RFIv2.0-I11-060602 specified in CableLabs table 6.16 shows the output return loss as > 14 dB within an output channel up to 750 MHz; > 13 dB in an output channel above 750 MHz.

Checking data sheets from the CCAP and CMTS suppliers tells us that the specification matches CableLab specifications.
To assess the impact of no return loss on the isolation, the following measurement was taken (see Fig. 8):

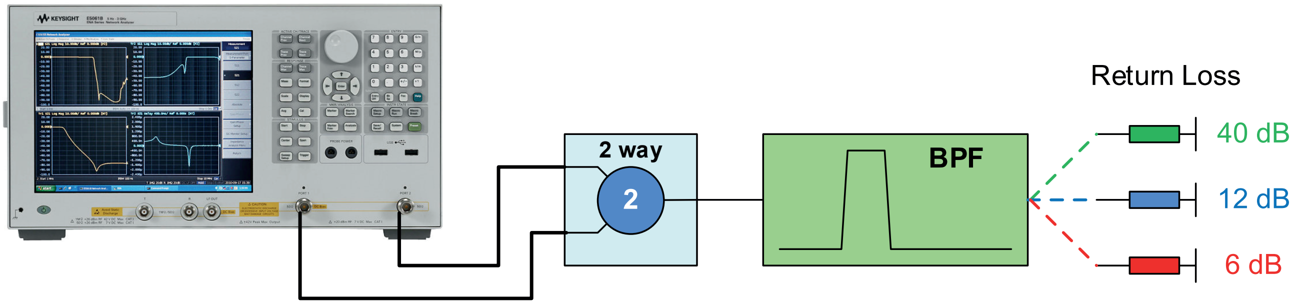

Fig. 8

A band pass filter was placed between the splitter and the termination resistor, so there is only a termination in the pass band of the filter. Outside the pass band of the filter there is no termination and the signal will be reflected. The isolation outside the pass band will be: 0 dB + (2 × 4) = 8 dB.

Fourth measurement:

Termination only in pass band frequency of the filter.

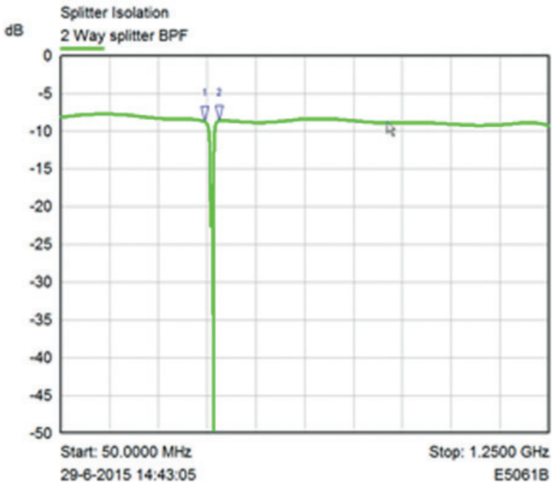

Fig. 9

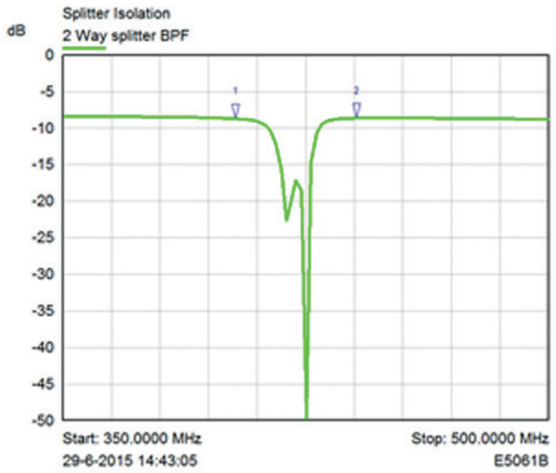

Fig. 10

Fig. 9 is the same splitter (> 30 dB isolation) terminated via a pass band filter with a 12 dB return loss terminator. It can be seen that the isolation is only 8 dB (2 × splitter loss) outside the pass band.

Fig. 10 is zoomed in at the pass band and it can be seen that the isolation is 12 dB + 2 × 4 = 20 dB.

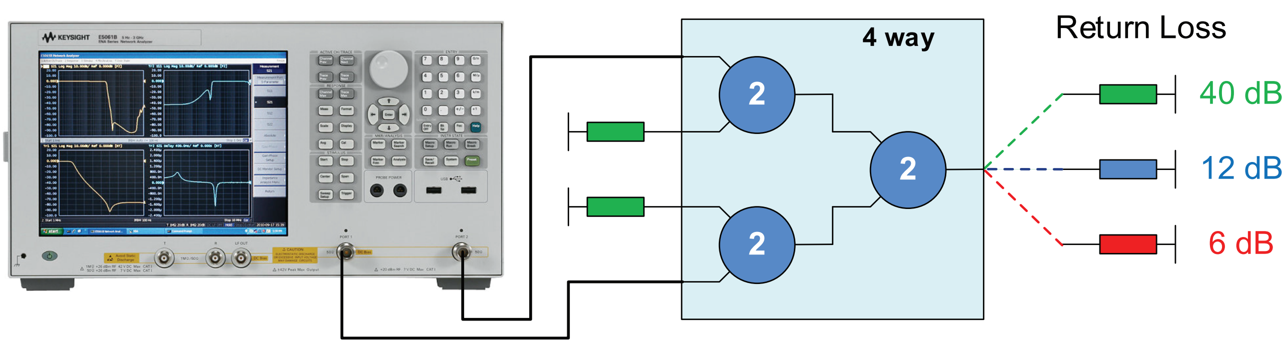

Fig. 11

For comparison purposes, the same test was also carried out with a 4-way splitter. These are built with 2-way splitters, so on adjacent ports we will see similar results.

To measure the furthest port we need more isolation.

Between port 1 and 4 we measure > 32 dB isolation over the frequency range of 50 - 1250 MHz when terminated with 40 dB return loss.

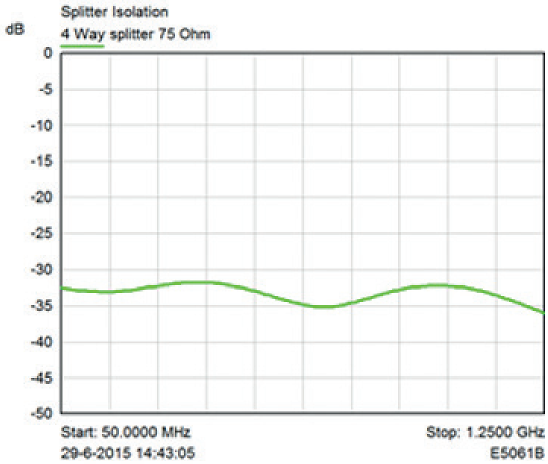

Fig. 12

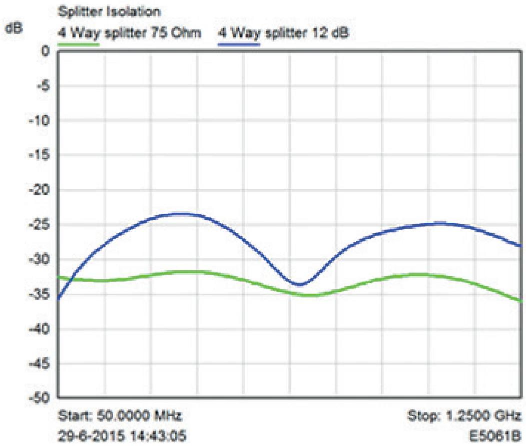

Fig. 13: Termination with 12 dB would give us (4 × 4 dB) insertion loss plus 12 dB return loss = 28 dB

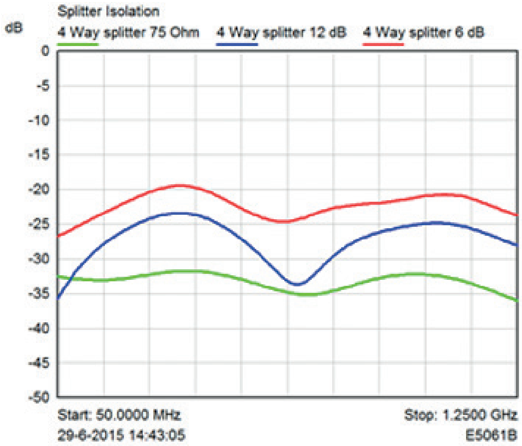

Fig. 14: Termination with 6 dB would give us (4 × 4 dB) insertion loss plus 6 dB return loss = 22 dB

These measurements confirm that isolation in practice is less than the theoretical isolation.

28 dB in theory, is 25 dB in practice and 22 dB in theory is 20 dB in practice.

How does this affect our passive combining system?

To assess the impact of low isolation in combining systems made with passive components, both the signals combined and the design require examination.

As the QAM signals from CCAP, CMTS and other services are being combined, a test was made to see what effect low isolation has on the quality of QAM signals.

The following test setup was used (see Fig. 15):

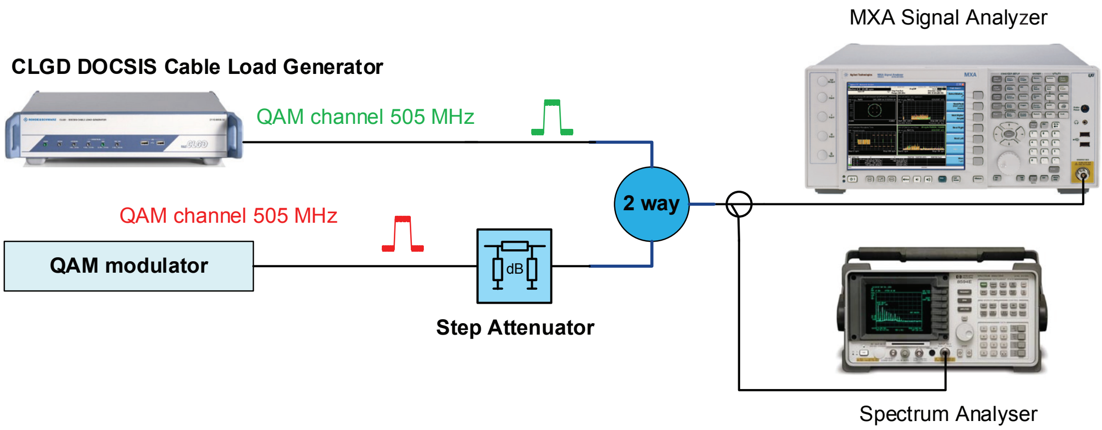

Fig. 15

There are two QAM signals at 505 MHz, the first is achieved with a fixed level from the cable load generator (CLGD) at the MXA analyzer by measuring the BER. The other QAM signal is varied in level using a step attenuator; both signals are combined in a splitter.

By changing the level the different isolation distances can be simulated in the splitter and the effect on the MER of the original channel can be measured.

Test signals

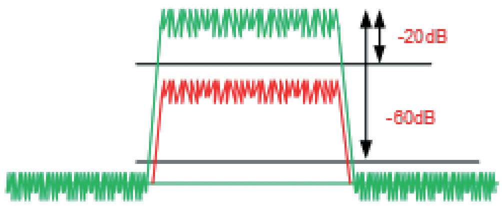

Fig. 16

The test results of the measurements are found in table number 2.

The base figure is a MER of 48.5 dB at an isolation of 60 dB.

When the isolation is reduced by 10 dB to 50 dB, a 1 dB degradation of the MER can be seen. Another 6 dB degradation of the isolation gives a 3.5 dB lower MER value.

Isolation level (dB)	64 QAM MER (dB)	256 MER (dB)
60	48.5	48.5
58	48.5	48.4
56	48.3	48.2
54	48.1	48.1
52	47.9	47.8
50	47.5	47.5
48	47.1	47
46	46.1	46.2
44	45.1	45.2
42	44.2	44.3
41	43.6	43.6
40	42.9	43
39	42	42
38	41	41.1
37	40.2	40.3
36	39	39.1
35	37.9	38
34	37.1	37.3
33	36	36
32	34.7	35
31	33.8	33.9
30	32.9	33.1
29	31.7	31.9
28	30.6	30.4
27	29.6	29
26	28.5	27.2
25	27.1	24.2
24	26.1	22
23	24.6	20
22	23.1	20
21	22	20
20	20	20

Table 2

A graph of the results shows that with 50 dB or lower isolation the MER reduces quite quickly.

A basic combining design

An additional aspect to consider is the design of the combining system.

A typical design for the combining system is shown:

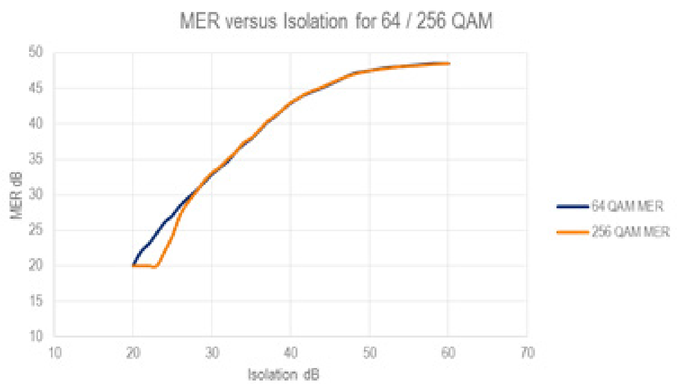

Fig. 17

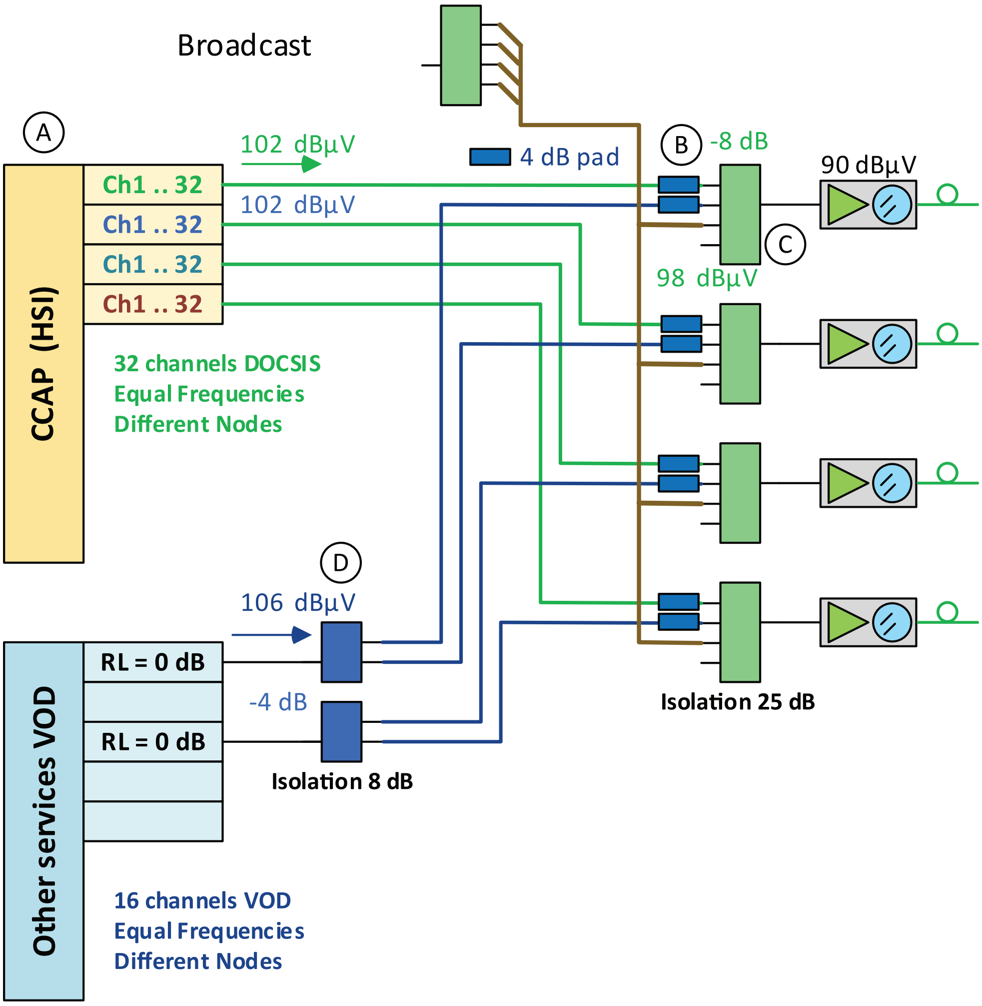

Fig. 18

The optical transmitter has a 4-way splitter at the input point to combine the broadcast and narrowcast signals; the broadcast signals are split and connected to all optical nodes. Input level for the optical transmitter (C) is 90 dBµV.

A CCAP modulator (A) is used to make the DOCSIS channels (32 channels at a maximum level of 102 dBµV).

As the CCAP modulator has multiple outputs and every output port is feeding a different node, the same frequencies will be used for every node.

Video on demand (VOD) is, in many instances, split into two and feeds two nodes. As there are 16 channels there is a maximum level of 106 dBµV per channel. These are naturally different frequencies than the CCAP DOCSIS channels.

It is assumed that attenuators (B) are used at the input splitter of the optical transmitter to make the correct level, although several headend/hubs have been seen where no attenuator was used and the output level of a CMTS was adjusted to obtain the correct input level on the transmitter.

Splitter loss is 4 dB for a 2-way and 8 dB for an 4-way splitter. Isolation of the 4-way splitter is 25 dB, which in reality is hardly achieved.

The isolation on the 2-way splitter (D), in the frequency range of the DOCSIS channels, is 8 dB as there is no termination on the VOD modulator in the frequency range outside the produced channels.

Calculating the levels:

DOCSIS/CCAP: 102 - 4 dB (pad) -8 dB (8-way) = 90 dBµV

VOD: 106 - 4 dB (2-way) -4 dB (pad) – 8dB (4-way) = 90 dBµV

When combining signals there can be a signal leakage path, meaning that signals for node 1 are getting to node 2 and interfere. The leakage path is shown in red.

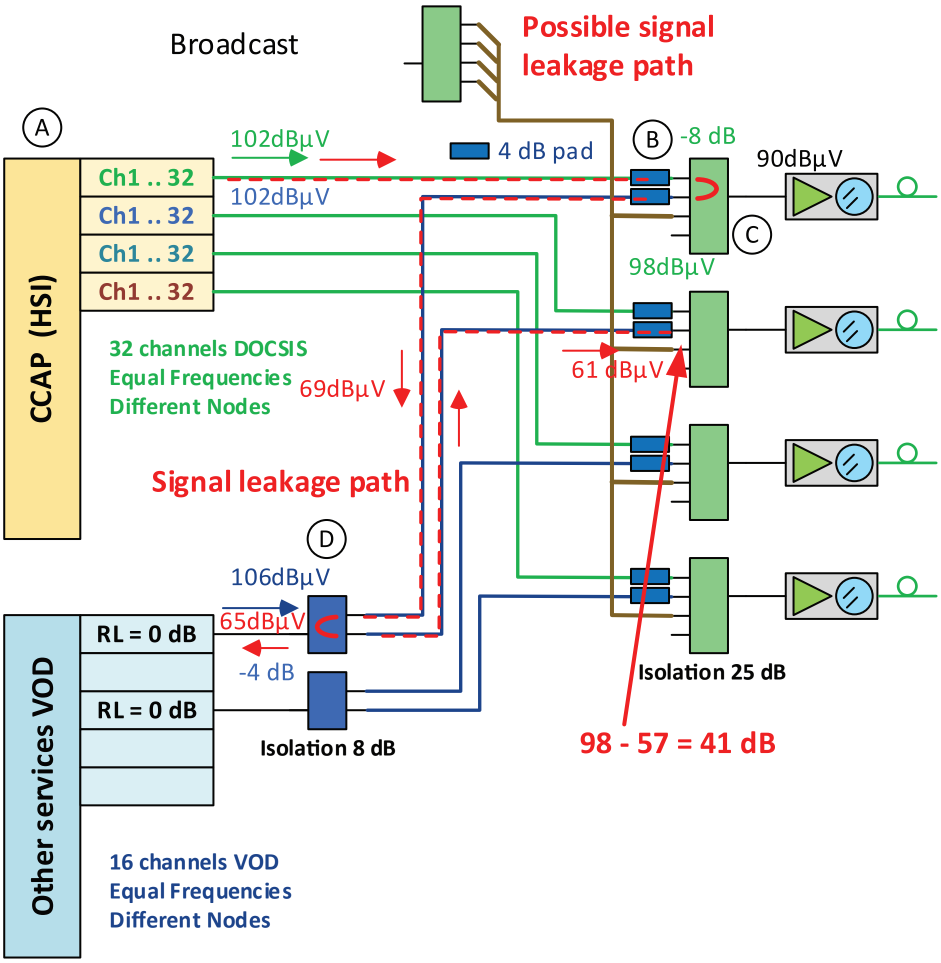

Fig. 19

The DOCSIS output channels from the CCAP device port 1 are for node 1, CCAP port 2 feeds node 2. When the level is calculated from CCAP port 1 via the leakage path to node 2, it is shown that there is enough isolation to avoid interference.

The signal level from the CCAP port 1 (which is also at the input port 2 of the combining splitter for node 2):

102 dBµV – 4 dB (pad) – 25 dB (4-way) – 4 dB (pad) – 8 dB (2-way) – 4 dB (pad) = 57 dBµV
The DOCSIS signals from CCAP port 2 are also in this splitter at a level of 98 dBµV
This means there is only 98 - 57 = 41 dB isolation between the signals with the same frequencies

The QAM measurements taken show that an isolation of 41 dB reduces MER from 48.5 to 43.6 dB - a MER reduction of 4.9 dB

Obviously any dB loss in the MER via the combining system is required as it is needed as overhead to compensate the additional network MER loss from the optical link and amplifiers and also network tolerance. There is potentially a second leakage path via the broadcast splitter which may have a lower isolation, so the interference level could be worse, with even more MER reduction.

Another issue is that a level of 65 dBµV is back feeding into the output section of the VOD modulator. The output level is 106 dBµV so there is only 41 dB difference. As the output section is possibly a transistor this may cause intermodulation in the output stage of the VOD modulator.

This is also back feeding to the CCAP output with a signal of 102 dBµV – 4dB (pad) – 25 dB (4-way) – 4 dB (pad) = 69 dBµV into the output of the CCAP port. There is a 102-69 = 33 dB difference.

Conclusion

Splitter isolation is directly dependent on the return loss of the common port, the isolation is significantly lower in a practical application than that specified on a datasheet. The return loss of CMTS, CCAP ports is only specified within the channel, and outside the channel there is no return loss.

Passive combining systems no longer give sufficient isolation. Higher modulation schemes like 256 QAM, 1K QAM /4K QAM, need > 60 dB isolation on equal frequency interference. With higher levels we can add pads to optimise levels and increase isolation.

CCAP uses equal frequencies on each port to feed nodes. Channel bonding lowers the channel level, meaning the pads get less attenuation, which ultimately means less isolation.

Back feeding in output sections can cause intermodulation, this interference will reduce the MER at the optical transmitter which is unacceptable in a high quality network.

Recommendation

- When introducing CCAP check the combining system, make a simple calculation on the isolation and do a measurement on the isolation.
- A passive combining system on its own could bring unwanted interference and MER reduction. If this occurs the inclusion of an active solution will bring more isolation and overcomes this problem.
- A simple isolation measurement on the existing combining system could save an investment in unusable equipment.

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