



TECHNICAL COLUMNS

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TOTAL POWER AND CHANNEL BONDING

By RON HRANAC

DOCSIS 3.0 is perhaps best known for its support of channel bonding — specifically, logical channel bonding — in which the downstream and upstream data payloads are spread across multiple individual quadrature amplitude modulation (QAM) channels. Channel bonding allows higher data rates between the cable modem termination system (CMTS) and cable modems than can be achieved when using just a single channel in each direction.

The transmission of multiple channels simultaneously between the CMTS and cable modems means that per-channel RF power generally decreases as the number of transmitted channels increases. This has caused a fair amount of confusion, especially because many headend combining networks were designed for single-channel-per-device operation. Most high-speed data installations in the home also were planned around the idea of only one transmitted upstream channel per modem

"The largest impact on upstream CNR is almost always the return fiber links."

Why do CMTS and modem per-channel RF power levels decrease when the number of transmitted channels goes up? The answer has to do with something known as total power.

Power + power

When an RF amplifier or transmitter is designed, one important consideration is the device's total RF output power capability. In the multi-channel world of cable where per-channel signal levels are used to define overall performance, it's sometimes difficult to comprehend the idea of total power. It might help to understand total power by working backwards from single-channel operation to multi-channel operation.

Consider a hypothetical transmitter circuit that's designed to support a maximum RF output average power of +58 dBmV (0.0084128 watt or 8.413 milliwatts) for a single continuous wave (CW) carrier into a 75-ohm impedance load. (Note: One can convert from dBmV to watts using the formula $W = 1/Z * 10^{[(dBmV/10) - 6]}$, where W is power in watts, and Z is the impedance in ohms.) It's assumed that operation at that power level will still be within the linear range of the transmitter's output RF stage(s), leaving headroom to accommodate the carrier's peak power excursions. Further assume that if the transmitter's output power is increased much beyond +58 dBmV, significant compression of the transmitted signal will start to occur.

If the same transmitter is able to be configured to support the simultaneous transmission of two equal-power CW carriers, what's the maximum per-carrier power level? The per-carrier power must follow a $P_{max} - 10 * \log_{10}(N)$ relationship, where P_{max} is the per-carrier maximum power when one carrier is transmitted, and N is the number of carriers.

Since +58 dBmV is the maximum single-carrier power for our hypothetical transmitter, then the combined RF power in the two CW carriers cannot exceed +58 dBmV. In other words, the maximum per-carrier power with two CW carriers must be half of the +58 dBmV single-carrier power, or $+58 \text{ dBmV} - 10 * \log_{10}(2) = +54.99 \text{ dBmV}$ (0.0042064 watt or 4.2064 mW). We can use power addition to confirm that this is correct. In the case



of power in milliwatts, simply add the two lower power levels: $4.2064 \text{ mW} + 4.2064 \text{ mW} = 8.413 \text{ mW}$. To add the two power levels in dBmV: $10 \cdot \log_{10} [10 (54.99/10) + 10 (54.99/10)] = +58 \text{ dBmV}$.

This tells us that the per-carrier maximum power must be 3.01 dB lower than the single-carrier maximum power when two equal-power CW carriers are being transmitted at the same time.

If four equal-power CW carriers are transmitted simultaneously, the per-carrier power must be reduced 6.02 dB from the maximum single-carrier power level, or $+58 \text{ dBmV} - 10 \cdot \log_{10} (4) = +51.98 \text{ dBmV}$ (0.0021032 watt or 2.1032 mW). We can again use power addition to confirm that this is correct. In the case of power in milliwatts, simply add the four lower power levels: $2.1032 \text{ mW} + 2.1032 \text{ mW} + 2.1032 \text{ mW} + 2.1032 \text{ mW} = 8.413 \text{ mW}$. To add the four power levels in dBmV: $10 \cdot \log_{10} [10 (51.98/10) + 10 (51.98/10) + 10 (51.98/10) + 10 (51.98/10)] = +58 \text{ dBmV}$.

Multiple channels vs. a single channel

DOCSIS 3.0 cable modems support the simultaneous transmission of multiple upstream QAM channels, which means the concept of total power just discussed applies to those modems. See Tables 6-7, 6-8, and 6-9 from the DOCSIS 3.0 PHY specification (www.cablelabs.com/cablemodem/specifications/specifications30.html) for summaries of per-channel RF power levels for cable modem upstream transmission.

For instance, the maximum per-channel power for a 64-QAM time division multiple access (TDMA, also called A-TDMA or advanced TDMA in the world of DOCSIS 2.0 and later) signal is +57 dBmV when only one channel is transmitted, while the maximum per-channel power when four channels are transmitted is +51 dBmV. This follows the basic $P_{\text{max}} - 10 \cdot \log_{10} (N)$ relationship.

Impact on CNR and MER

When a DOCSIS 3.0 modem is switched from single-channel upstream TDMA operation to multi-channel TDMA bonded operation, the transmitted per-channel power will drop as discussed previously. As one might expect, the lower per-channel power will cause a reduction in both carrier-to-noise ratio (CNR) and modulation error ratio (MER, also called "upstream SNR"). In order to help compensate for the reduction in per-channel power when multiple channels are transmitted by a cable modem, the DOCSIS 3.0 PHY spec states that cable modems must support 3 dB higher per-channel transmit levels than DOCSIS 2.0 and earlier modems. As well, the allowable minimum RF input levels to the CMTS were reduced.

Given what happens to CNR and MER with decreased upstream per-channel power, it's important that cable and splitter losses in the home wiring — at least those losses "seen" by the cable modem's upstream transmitter — be kept to a minimum. This will help ensure that the modems don't have to transmit at or near their maximum output power, which increases the risk that affected modems' upstream signals will not be able to be received at the CMTS upstream port at the commanded receive level.

Upstream CNR and MER performance are also affected by the alignment of outside plant active devices. While proper alignment of amplifiers is very important and must be maintained, the largest impact on upstream CNR is almost always the return fiber links. One of my colleagues, Frank Eichenlaub, has seen upstream CNR degraded by as much as 16 dB because of misaligned fiber links!

What about the CMTS?

When downstream DOCSIS channels are bonded, the per-channel maximum power also drops. Interestingly, the per-channel reduction doesn't exactly follow the basic $P_{\text{max}} - 10 \cdot \log_{10} (N)$ relationship. Instead, it follows a $P_{\text{max}} - \text{ceil}[3.6 \cdot \log_2 (N)]$ relationship.

When P max is +60 dBmV, the per-channel power is +56 dBmV per-channel for two channels, +54 dBmV per-channel for three channels, +52 dBmV per-channel for four channels, and so on.

This somewhat different relationship has to do with peak-to-average power ratio considerations and the way the multiple QAM signals are "combined" inside the QAM modulator. Since a DOCSIS 3.0 CMTS's multi-channel-per-port QAM modulator circuit effectively combines its channels internally, one can combine the bonded channels deeper — that is, closer to the downstream lasers — in the headend's external combining network. After all, some "combining" has already been done in the QAM modulator!

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