Evaluating Emissions of Your New IBOC Transmitter

Measuring Digital Signals Requires New Methods

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So you are putting in your IBOC transmitter and want to be sure you've got your numbers right. How does a broadcast engineer do a "proof of performance" on a new IBOC transmitter? In this article I will walk through some of the measurement techniques for "proofing" a hybrid IBOC station.

As we all know, the FCC has some basic requirements for making sure a new analog transmitter is not a source of interference (Part 73.1590, Equipment performance measurements).

Analog FM rules require a simple RF bandwidth occupancy test against the RF mask, with little guidance on how to measure. Analog AM rules also have an RF mask test, with specified spectrum analyzer settings. The key measurement criteria for AM measurements are a 300 Hz resolution bandwidth ("RBW"), no video filtering, and ten minutes of collecting peak hold samples. On the FM side, it is customary to employ a 1 kHz resolution bandwidth. Peak hold is a convenient way to capture intermittent spurs that might exceed the mask.

Now IBOC comes along, and everything you know about analog spectrum occupancy measurements won't be enough. Digital waveforms have peculiar characteristics. Fundamentally, they are engineered to be as noise-like as possible. That is, the distribution of energy in the bandwidth over time is made as uniform as possible. Digital signals are more spectrally efficient the more (pseudo)randomly they behave. They tend to have flat tops and steep sides on a spectral display. This contrasts with the "triangular" spectral occupancy of AM and FM signals where there is more energy closer to the carrier frequency than at the band edge.

Setting the Reference Level

How does this affect our measurement on a spectrum analyzer?

With an analog signal, it is pretty easy to obtain a power measurement. With a digital signal, the spectral characteristics are less user-friendly. The simplest way to measure an analog station's power on a spectrum analyzer is to remove all modulation from the carrier (AM or FM) and look at the carrier frequency on the center of the display.

FM signals have (nominally) constant power, when considering the entire bandwidth of the signal. If it is inconvenient to interrupt modulation on the FM station, the modulated signal can be measured with the spectrum analyzer resolution bandwidth set to look at the total power of the FM sidebands.

I have had good results setting the RBW to a common value available on spectrum analyzers, 300 kHz. This works because the FM carrier is modulated +/- 75 kHz and the vast majority of the station's power is contained in the 200 kHz channel. In contrast, a 100 kHz RBW would miss some energy, while a wider RBW of 1 MHz might take in undesired energy.

To set the carrier level as a reference, it is just a matter of centering the display at carrier frequency, choosing the RBW for a modulated or not-modulated signal, and using the instrument's reference level setting to adjust the center point of the trace to the top of the analyzer display.

Figure 1 shows three traces. One is the modulated hybrid FM IBOC signal at 1 kHz RBW, from which no reference level can be set. The other two traces, the unmodulated carrier at 1 kHz RBW and the modulated carrier at 300 kHz RBW, produce identical reference levels. The top of the display becomes the analog FM signal power reference level for analog mask and IBOC measurements.

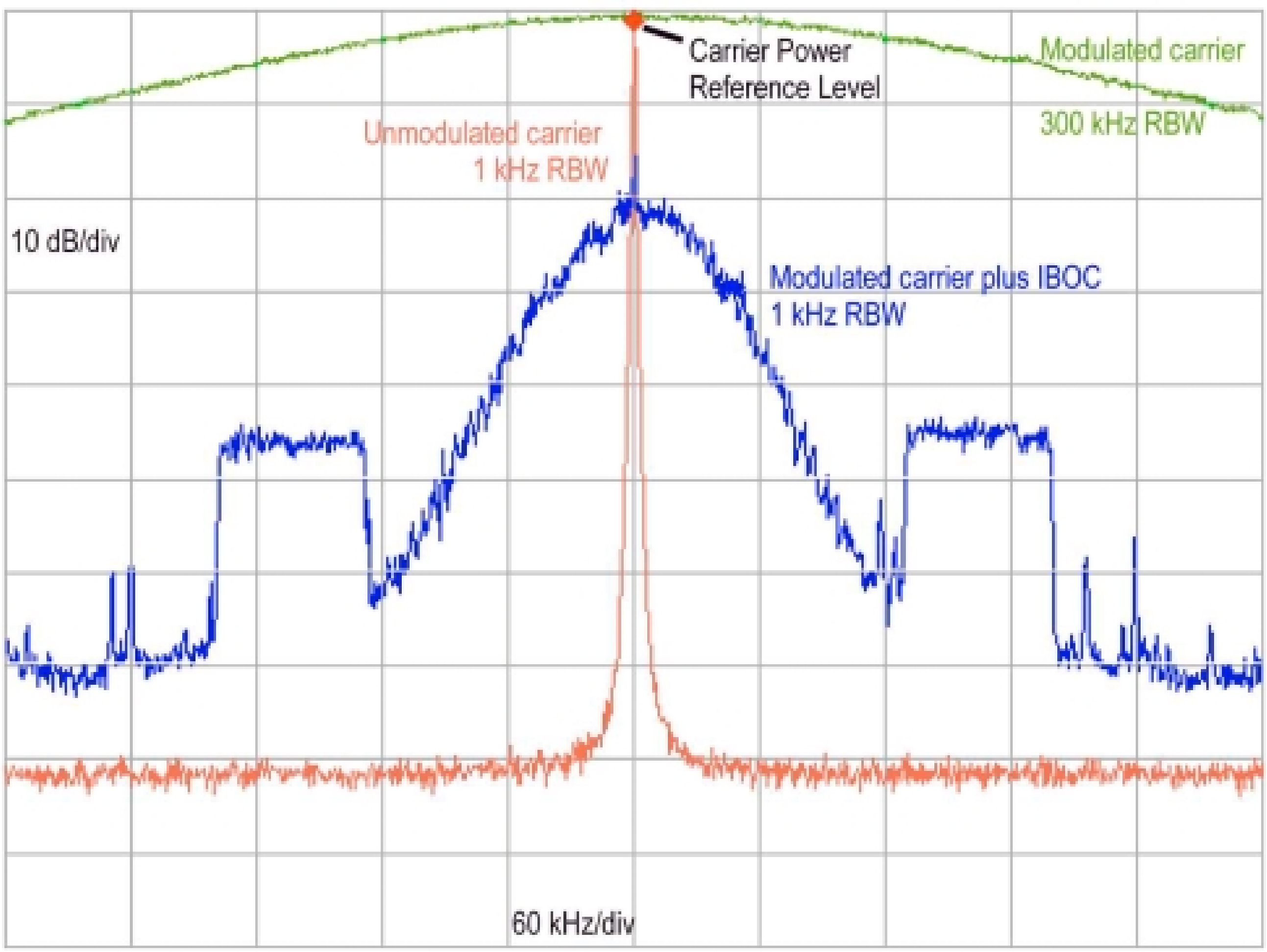

Figure 1
FM hybrid IBOC signal, 1 kHz resolution bandwidth, sample detector averaged over 40 sweeps, taken 15 miles from transmitter (elevated noise floor).

With AM signals, the carrier is at licensed power when there is no modulation. Of course, with modulation the power varies, and it may vary asymmetrically (positive versus negative peaks) so time-averaging the power within the entire modulated bandwidth will not produce a reliable reference power level. Peak hold overstates the level. Time averaging a narrow RBW (300 Hz or less) at center frequency is most representative of the reference power level. With care, this can produce a reasonable power reference level on your analyzer without interrupting modulation. Adjust the analyzer reference level to put this value at the top of the display.

Proceed with Caution

Before we get into sampling IBOC energy, let's pause for an important industrial hygiene message. Your spectrum analyzer needs the electrical equivalent of safety glasses. Whenever sampling RF signals in a new environment, it is crucial that the analyzer not be fed more power than it can handle. Understand the nature of the energy on your point of sampling, whether it be a line tap or an antenna. The whole RF spectrum arrives at your analyzer's front end, unless you pre-filter it. Consequently, another station at the same site, or one using the same transmission line, or one being received incidentally via your transmitting antenna, or some RF source you didn't count on, could pollute your measurements or toast your instrument.

Good spectrum analyzer hygiene includes testing your new sampling point, if need be, with a power meter, or by using a good quality broadband coaxial pad. The pad becomes your instrument's "safety glasses" protecting it from too much power. Even though the instrument has its own internal stepped attenuator, it is wise to put on a sacrificial external pad with an unfamiliar signal source. Your first order of business is to look at the entire spectrum to see if the total incoming RF power is low enough that you can get a good picture of the signal under test.

From Offset	To Offset	Measured power spectral density shall not exceed
kHz	kHz	(dBc in 1 kHz Resolution Bandwidth)
100	200	Target -41.4; Suggested mask -40 dBc
200	215	[-61.4 - (|offset frequency in kHz| - 200) x 0.867] dBc
215	540	–74.4 dBc
540	600	[–74.4 - (|offset frequency in kHz| - 540) x 0.93] dBc
600	And up	–80 dBc
Source: iBiquity Digital Corporation		

Table 1: FM Hybrid IBOC Spectral Density Mask

Spectrum analyzers have a compression figure that indicates how much incoming signal level causes the instrument to compress the incoming signal and give erroneous results. Check your manual. The compression level might be in the vicinity of -5 dBm while the maximum safe input to the instrument might be +20 or +30 dBm. Be sure that the *total* power input to the analyzer's mixer is less than the compression level. It is tempting just to set the desired signal level to the top of the display without regard for the other signals on the input that you can't see on the display. Take care with this step; input compression causes exaggerated intermodulation artifacts products that might be mistaken for the real thing.

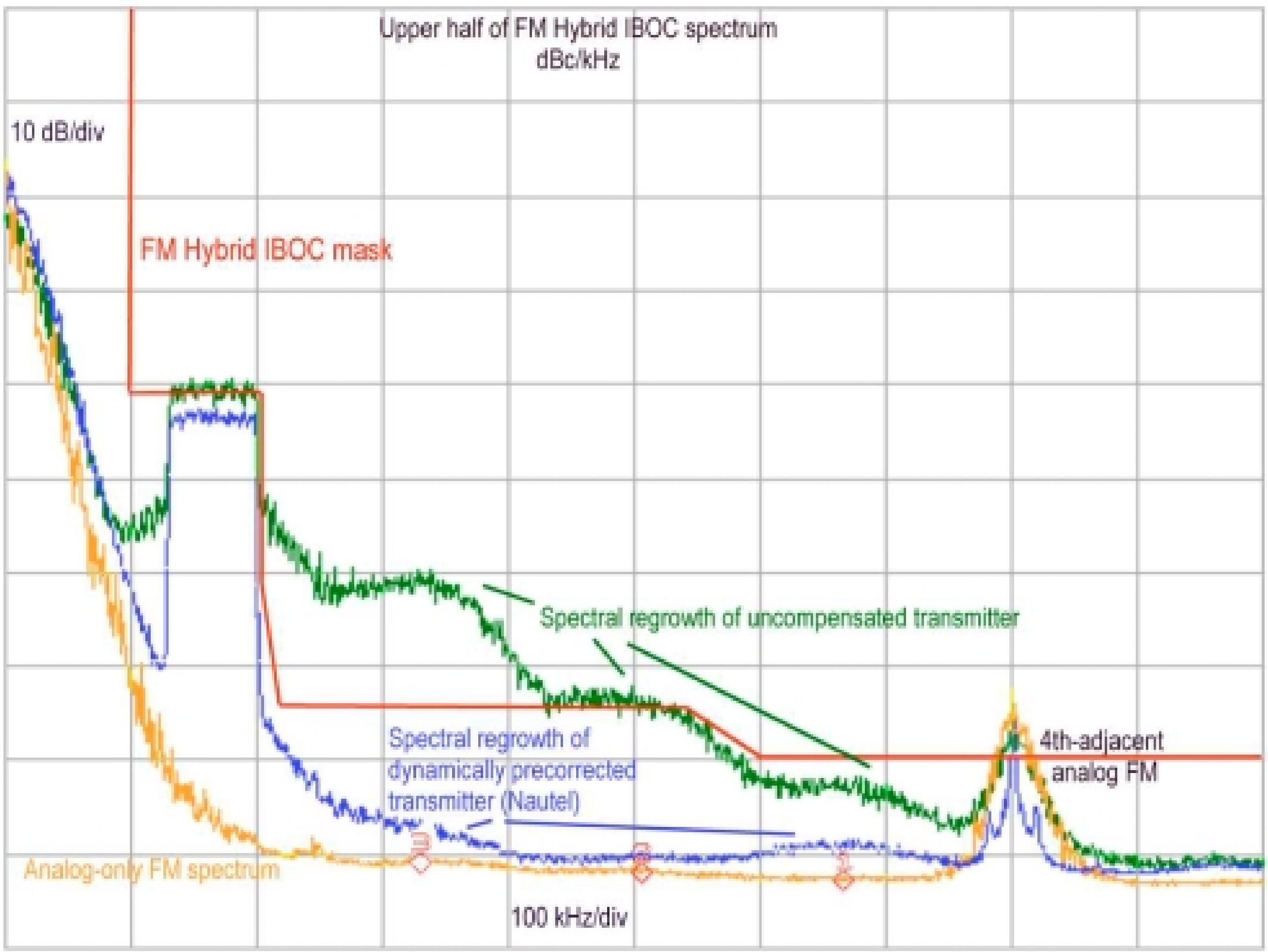

Figure 2
Current version of the FM Hybrid IBOC 1kHz power spectral density mask (upper half of spectrum) with FM Hybrid IBOC spectral regrowth comparisons— analog only, hybrid IBOC through an uncompensated transmitter, and hybrid IBOC through a Nautel dynamically pre-corrected transmitter.
Thanks to Mike Pappas at KUVO

If in doubt about compression, measure a high signal level on the display and then add, say, ten dB of input attenuation. If the level of the signal on the display changes by less than ten dB, the input levels are driving compression. When a one-to-one correlation occurs between a change in the input attenuation and in the measured signal level, compression is avoided. If you are operating on a multi-station combiner, this is a particularly important thing to check. Sometimes it is advisable to insert a filter to reduce unwanted energy. Care must be taken to account for the impact of any filtering on the signals under test.

Power Ratios

Finally, the analyzer is safely and accurately set up with the carrier power of the station under test set as the reference level. (By the way, since the total digital power on hybrid FM IBOC is only 1% of the analog power, it is OK to set the analog FM carrier reference level with or without the IBOC digital signal on.)

Now it is time to take a peek at the power ratios in hybrid IBOC operation. The term “hybrid IBOC” refers to the combined transmission of the analog signal and the digital saddlebags hanging on either side of the analog energy.

The ratio between the analog FM power and the digital sideband power is the first thing to check in your station proof. The FCC has not established any explicit proof requirements yet, but requires stations to adhere to the iBiquity specifications. (See Table 1)

On an FM station, the digital portion of the hybrid signal consists of hundreds of low level digital carriers, each transmitting a fairly low rate. In combination, the raw symbol rate of these carriers running in parallel is 344.5 symbols per second times 382 carriers, or 131.6 kilosymbols per second. (One hybrid FM symbol equals two bits of information).

These digital carriers comprise two groups of digital sidebands, called the Primary Main (“PM”), upper (“USB”) and lower sidebands (“LSB”). (Visible in Figures 1 & 2) There are also additional optional carriers that can be added, squeezing closer to the station’s analog spectrum. These are the Extended hybrid carriers, and are ignored for this discussion.

There are 191 PM carriers in one FM IBOC PM sideband. Each carrier is transmitted at an average power level that is 45.8 dB below the FM analog carrier. However, with a spacing of 363.4 Hz, a single modulated carrier from the PM sideband will not be readily resolved by the spectrum analyzer. Instead, a 1 kHz resolution bandwidth will capture the energy of almost four carriers in one sampling “bin.” That amounts to 4.4 dB more power in 1 kHz bandwidth than in the 363.4 Hz bandwidth. A spectrum analyzer set at 1 kHz RBW should show the FM PM carrier power spectral density at –41.4 dBc/kHz. That is, with the FM analog power reference at the top of the screen, the average level of the PM sidebands in any 1 kHz bin should be about 41.4 dB down.

One entire PM sideband is 69.4 kHz wide. The total power of that sideband is therefore 69.4 times the power within 1 kHz. Converting to decibels,

$$10 \text{ Log } (69.4/1) = 18.4 \text{ dB}$$

Hence, the total power of one PM sideband is 18.4 dB greater than in 1 kHz of bandwidth. The total power in one PM sideband, then, is

$$-41.4 \text{ dBc/kHz} + 18.4 \text{ dB} = -23 \text{ dBc/69.4 kHz}.$$

If your analog and digital signals reside in the same pipe (low, intermediate, or high level combining), take a sample off the combined transmission line. If you have separate antennas, or dual-fed antennas there is no transmission line point to sample. It may be sufficient to measure the power on each transmission line, account for line losses and antenna gain, and arrive at an indirect power measurement of the hybrid IBOC power with respect to analog FM power. Be certain your IBOC power meter is accurate with a digital signal. Alternatively, a carefully placed test antenna can receive a reliable sample of the analog-to-digital ratio. Be sure to be close enough to keep signal levels within the dynamic range of the instrument, keeping the PM sideband energy well above the noise floor of the measurement (better than ten dB is advisable). Figure 1 was taken off the air 15 miles from the station, and the noise floor is only -80 dBc/per kHz. This should be enough to resolve the PM sideband performance, but is insufficient to accurately measure intermodulation products that might appear on adjacent channels.

Channel Power Measurement

Now the instrument is set up, and it is time to measure the PM sidebands. What's the best way to do it?

There are so many options—trace averaging, video bandwidth, peak hold, max/min, and more. Each technique has its errors and uncertainties. A good way to measure the full bandwidth of a PM sideband is to use an analyzer that has a *channel power* measurement utility.

I set my analyzer to show about 500-600 kHz of the band centered on the FM frequency (see Table 1). Then I set the channel power utility to measure the ~70 kHz bandwidth of the PM carriers on one of the sidebands (FM frequency +129 kHz to +199 kHz for the upper sideband, and –129 to –199 kHz for the lower sideband). If no such utility is available, trace averaging or video averaging can accomplish the task, with a little more wiggle room in the results.

A word about digital spectrum analyzer detectors is in order. The "bin" referred to above is the data point on the display that represents a certain frequency. As the analyzer sweeps up in frequency, the RBW filter establishes the bandwidth of each bin and the sweep rate determines how long the analyzer lingers in each bin. From a set of data points in the bin the analyzer's detector picks a value to display. *Peak* and *pit* (i.e. *max* and *min*) detectors look for the greatest and least voltage in the bin's data. The *sample detector* just grabs the n^{th} data point in each bin. Newer detectors rely on the availability of cheap processing power, such as the *average detector*, which runs a computation on all the data points in the bin to produce a result for the display.

Measuring a complex waveform challenges the accuracy of a spectrum analyzer. With a more traditional detector, such as the peak, the analyzer assumes it sampled a sinusoidal signal and makes a conversion to RMS, which is the value shown on the display. If you average several sweeps of peak values of a modulated waveform, the average of the peaks could overstate the power in the bin. The sample detector gets around this by behaving as a random sampler of the waveform in each bin. Averaging samples from several sweeps produces a better estimate of average power in the bin. This is most accurate with sinusoidal signals. However, depending on the nature of the digital waveform, there could be as much as a 2.5 dB understatement of level when using these detectors. The more noise-like the sample, the more the average of several sweeps will deviate from the true RMS value.

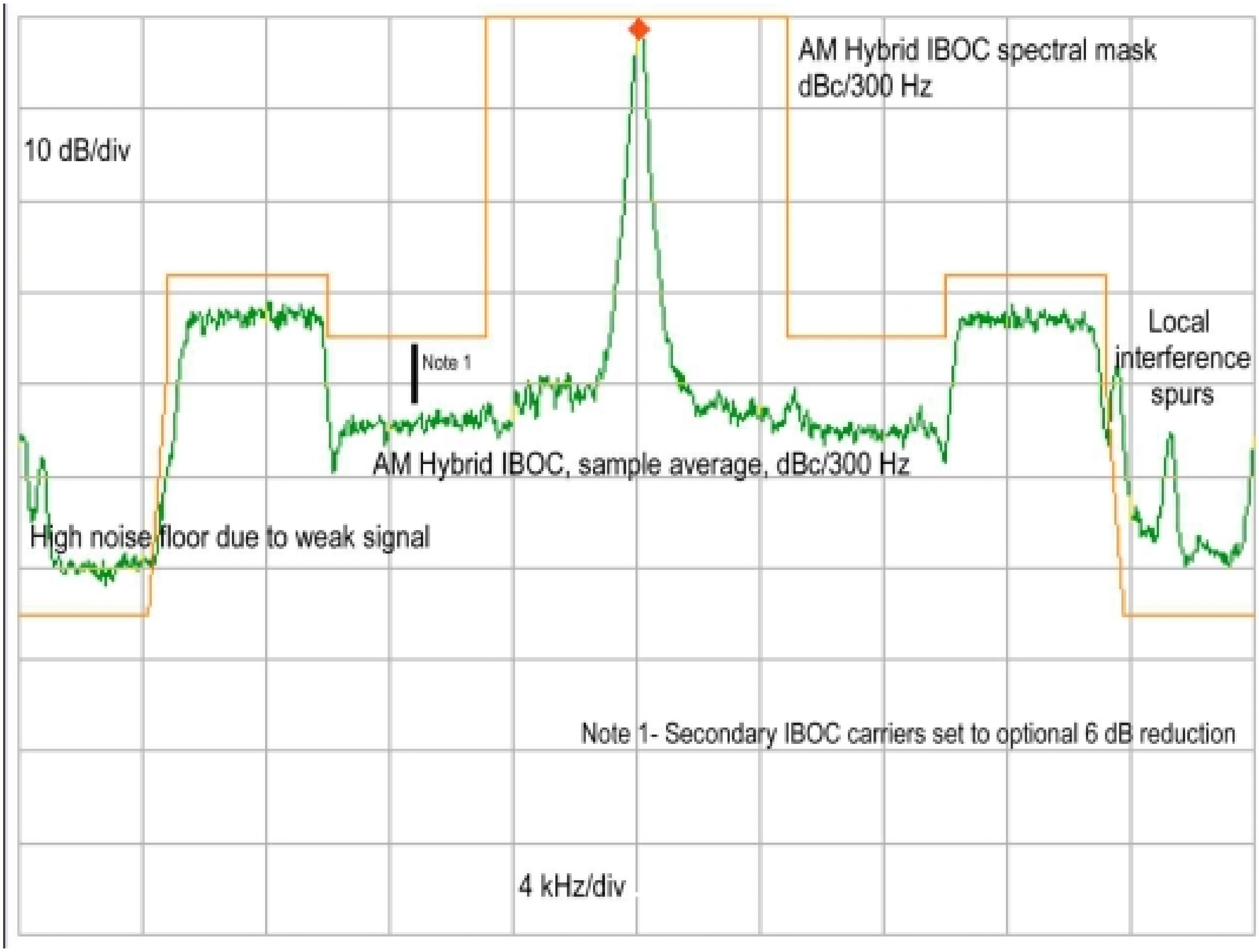

Figure 3
Current version of the AM Hybrid IBOC 300 Hz power spectral density mask close to carrier frequency. AM hybrid IBOC signal recorded 20 miles from transmitter (elevated noise floor and interfering signals)

Averaging multiple sweeps is called *trace averaging*. Trace averaging is not the same as the average detector. While the average detector computes the average power or voltage in each bin, trace averaging takes a series of sweeps, no matter how the bins are detected, and averages them to produce an average of the sweeps. The *video filter* averages in a different way, effectively averaging all the data points in one bin at a time using a low pass filter.

Table 2 shows some suggested settings for common spectrum analyzers. These methods tend to produce results within a couple of dB of each other. The stations I have measured with these methods so far have been entirely at or below the -41.4 dB/kHz spec.

Suggested Setup for Hybrid IBOC Measurements		
	AM	FM
Analog carrier frequency set to center of display (f_0)	Span 40-50 kHz	Span 500-600 kHz
Set trace avg. analog carrier level to top of display (0 dBc)	300 Hz RBW	300 kHz RBW
RBW for digital measurement	300 Hz RBW	1 kHz RBW
Channel Power utility (If available)		
Detector mode, display mode, Video Band Width	Auto, Log, $\geq$1kHz	
Centers of channel power measurements	$f_0 \pm 12.5$ kHz, Primary $f_0 \pm 7.5$ kHz, 2nd-ary	$f_0 \pm 164$ kHz, Primary
Bandwidth of channel power measurements	5 kHz	70 kHz
Target channel power value of a Primary sideband	-15.6 dBc/5 kHz	-23 dBc/70 kHz
Target channel power value of a 2nd-ary sideband (two optional power levels)	-22.6 (or -28.6) dBc/5 kHz	---
Measuring from trace		
Trace Averaging		
Detector mode, display mode, Video Band Width	Sample, Log, >1kHz	
Number of sweeps averaged	25-100	
Video Filtering		
Detector mode, display mode, VBW	Sample, Log, 10 Hz	
Single sweep	No trace averaging	
Average Detection (If available)		
Detector mode, display mode, VBW	Average *Power* Det., Log, >1kHz	
Single sweep	No trace averaging	
Target Values: 1 kHz/300 Hz RBW Measurements		
Primary IBOC carriers	Target: -27.8 Limit: -25 dBc/300 Hz	Target: -41.4 dBc/kHz Limit: -40 dBc/kHz
Secondary IBOC carriers	Target: -34.8, (or -40.8) Limit: -32 dBc/300 Hz,	

Table 2: Suggested Spectrum Analyzer Settings

AM IBOC Measurements

Measurements of the Primary and Secondary sidebands of a hybrid IBOC AM station are similar to those of the FM PM sidebands. The differences are: 1) Analyzer RBW should be 300 Hz; and 2) The digital carrier levels are separated into three groups, each with different level criteria. See Tables 2 and 3, and Figure 3.

When taking an AM measurement off the air, use the same location at which you make the FCC-mandated occupied bandwidth measurements in FCC Part 73.1590 and 73.44. Be sure there is enough signal to noise ratio to resolve the digital signals above the in-band noise and the analyzer noise. A good loop antenna, such as the scott-inc.com LP-3, will aid in capturing a clean strong signal.

Hybrid AM signals also have a tertiary component that resides under the occupied bandwidth of the analog signal. To test for occupied bandwidth compliance with the mask, it is not necessary to determine the actual level of these digital carriers; it is only necessary to show that the emissions remain below the mask. This is helpful because analog modulation would have to be interrupted to see the tertiary carriers well.

In both the cases of AM and FM hybrid operation, there is the potential for intermodulation among the digital carriers and with the analog host. These products, sometimes called *spectral re-growth*, appear at regular intervals up and down the band from the station's frequency. On the FM band, these products can appear at 164-kHz intervals. (Figure 2) On AM, they are most likely to be seen at 12.5 kHz intervals. Once the power level of the analog host and the PM sidebands is established, it is a simple matter to scoot the analyzer over to the location of the spectral re-growth and measure the levels. Just leave the RBW at the 1 kHz or 300 Hz levels already employed on the initial measurements. Leave the reference level alone. Refer to the hybrid IBOC RF masks for the power spectral density limits outside the bandwidth of the hybrid signal. (Figures 2 and 3; Tables 2 and 3) It is helpful to use a spectrum analyzer that has a 100-dB vertical display, to enable a full view from reference level to system noise floor.

From Offset kHz	To Offset kHz	Measured power spectral density shall not exceed (dBc in 300 Hz Resolution Bandwidth)
0	5	Tertiary carriers -41.8 to -47.8 dBc, beneath analog bandwidth. Not addressed in detail in this article.
5.0	10.0	Target -34.8 (optionally -40.8); Suggested mask -32 dBc
10.0	15.0	Target -27.8; Suggested mask -25 dBc
15.0	15.2	–28 dBc
15.2	15.8	–39 – (|offset frequency in kHz| -15.2) x 43.3 dBc
15.8	25.0	–65 dBc
25.0	30.5	–65 – (|offset frequency in kHz| -25) x 1.273 dBc
30.5	75.0	–72 – (|offset frequency in kHz| -30.5) x 0.292 dBc
75.0	And up	-85 dBc
Source: iBiquity Digital Corporation		

Table 3: AM Hybrid IBOC Spectral Density Mask

This article has covered a wide range of measurement topics with just a little bit of depth. Countless manufacturers' application notes and operation manuals were the sources of information on the inner workings of spectrum analyzers. To accurately measure power spectral density of digital signals requires more careful attention to the way spectrum analyzers work. Hybrid IBOC signals marry high-level analog waveforms having triangular power spectral density footprints with low-level digital waveforms having flat-topped power spectral density footprints. Care must be taken to insure signal levels are set to provide the necessary dynamic range between noise floor and compression. With a good analyzer and proper precautions, the measurements that appear on the analyzer display will provide valuable information about the spectral occupancy of the hybrid IBOC signal.