8VSB Measurements Using the RFA300A

8VSB Performance Solutions

The Tektronix RFA 300A 8VSB Measurement Set solves common 8VSB measurement problems, in order to guarantee performance of the transmitter.

Digital television (DTV) transmission produces a near-perfect reproduction of the original picture and sound, or no picture at all if the signal is compromised in some way. Fringe-area viewers who have tolerated poor analog picture quality over the years may find they cannot receive digital signals. Therefore, it is critical to characterize and monitor the performance of DTV transmitters because any degradation in performance can significantly reduce the coverage area.

8VSB is a vestigial sideband digital modulation system that uses eight discrete amplitude modulation levels. These modulation levels are assigned eight different binary numbers or symbol values to convey the MPEG-2 compressed transport stream. Figure 1 shows the basic functions of an 8VSB transmitter.

Measurements of the performance of the system can be taken by the RFA300A before and after the masked filter to quantify the performance of the system. A closed-loop feedback approach can quantify the errors and pre-distort the signal to correct for distortions within the system.

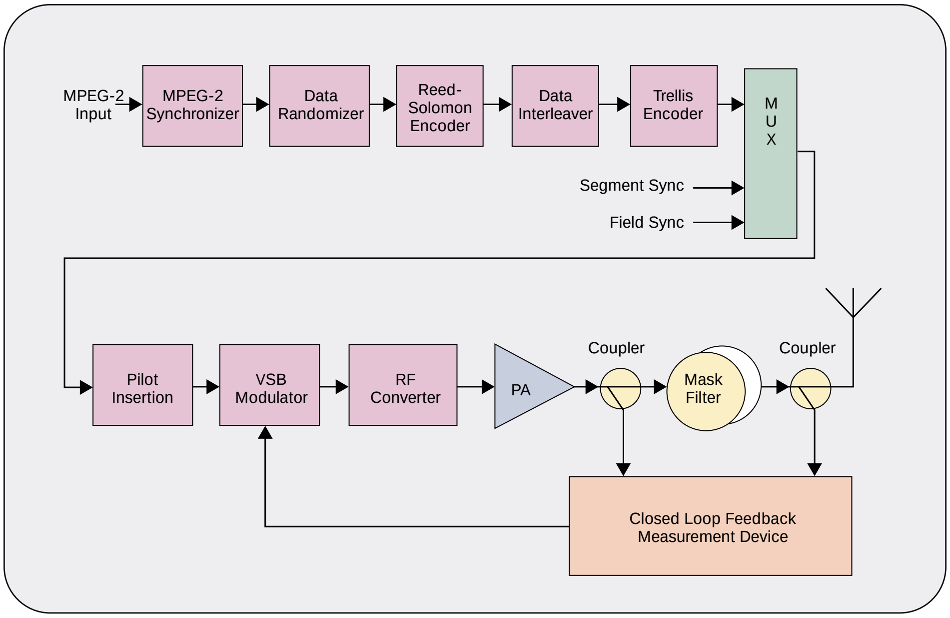

Figure 1. *Block Diagram of 8VSB Transmitter*

Spectrum, Demodulation Measurements Track Transmitter Compliance and Performance

Digital modulation requires new techniques and different methods of measuring the performance of the system. The measurements can be divided into two broad categories:

- RF measurements made by analyzing the RF spectrum.

  RF measurements include Channel Spectrum Peak-to-Average Power and Out-of-Channel Emissions.

  These measurements can be made by a general-purpose spectrum analyzer with suitable performance, or by an instrument such as the Tektronix RFA300A, which provides both spectrum and demodulation measurements.

- Symbol data measurements made by demodulation of the 8VSB signal.

  Symbol data measurements include Constellation Analysis, Signal to Noise, Error Vector Magnitude, Modulation Error Ratio, Frequency and Group Delay Response Error, Phase Error and Phase Noise.

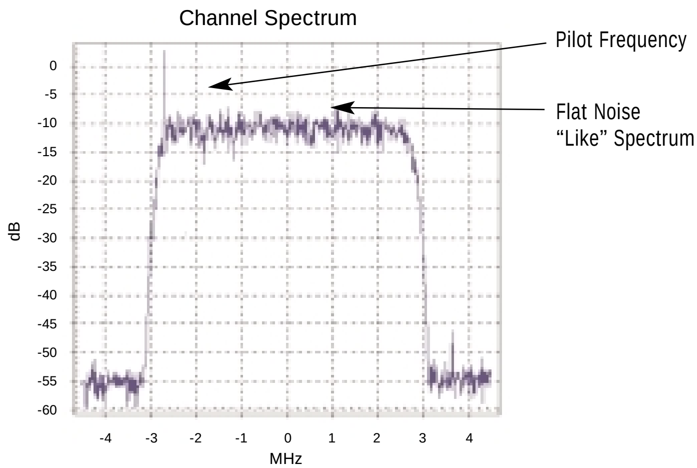

Figure 2. *A High Level View: Spectrum of 8VSB Signal Occupying 6MHz Bandwidth*

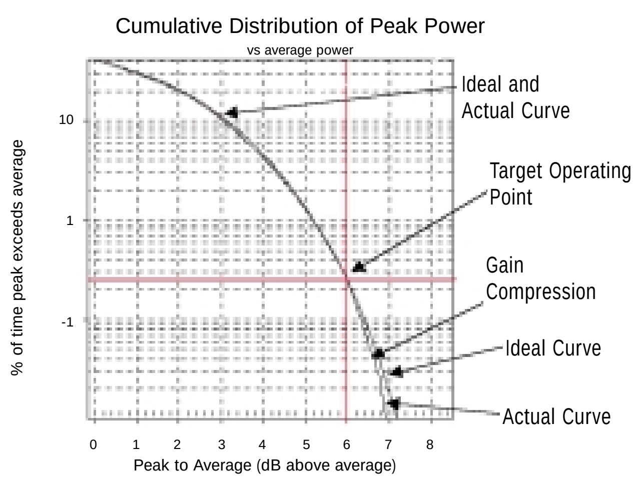

Figure 3. *Cumulative Distribution of Peak Power*

Spectrum Measurements

The display in Figure 2 provides a quick confirmation of the presence of the pilot and also shows whether the transmitted signal is of the appropriate flatness across the 6MHz bandwidth. Any significant deviation would imply that the data values are not being randomized or that another signal is interfering within the channel.

Peak-to-Average Power

A transmitter should spend a certain percentage of its time at various power levels ranging from its average to its peak. The Peak-to-Average Power is the ratio of the peak transient power to the average envelope power. The peak transient power is the maximum value of envelope power occasionally reached by the digitally modulated signal. This is plotted as a statistical distribution of carrier power over time using a Cumulative Distribution Function (CDF).

The percentage of the time the signal is greater than the average amplitude in dB is plotted and compared with the ideal. A properly operating transmitter will track the ideal curve. Using power amplifiers beyond their capability can cause compression of peaks. This distorts the signal, causing out-of-channel emissions and lower signal-to-noise ratio (S/N). Compression can cause the actual curve to fall below the ideal curve.

Figure 3 shows a slight amount of gain compression by comparing the ideal curve with the actual measured curve above 6MHz. The peak power is virtually never attained, and is suppressed by nearly 0.25dB at 7dB. In severe cases this could produce a raising of the sideband shoulders in the out-of-channel spectrum.

Out-of-Channel Emissions

The FCC mandates out-of-channel emissions testing to verify that there is no leakage into adjacent channels and other over-the-air services. The required characteristics are summarized in Figure 4. The power level of emissions on frequencies outside the authorized channel of operation must be attenuated by -47dB at 500kHz from the channel edge. The signals should be attenuated to no less than -110dB at 6 MHz from the channel edge. The specification uses a 500kHz bandwidth, but for measurement purposes a 30kHz bandwidth is used and appropriate correction factors are applied to produce a more accurate measurement.

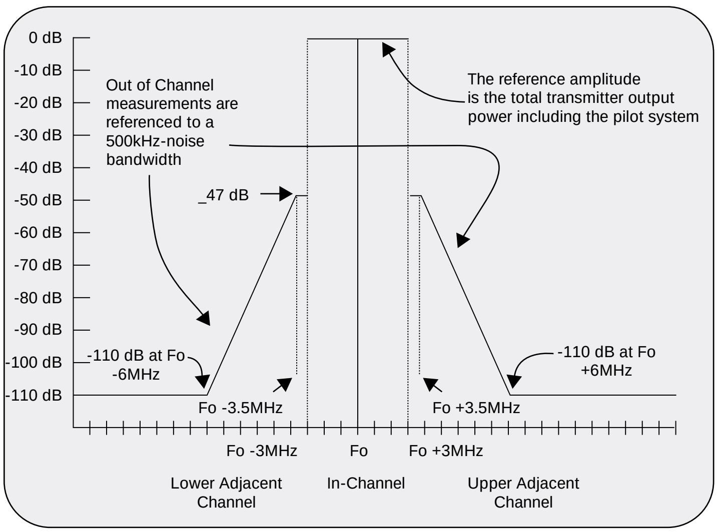

Figure 4. *Out-of-Channel Emissions Mask*

System noise limitations in present-day RF measurement instruments limit direct measurements to -110dB level. Therefore, estimation techniques must be used to make these measurements. One method is to use the transmitter's own bandpass filter as shown in Figure 5. Normal measurements of signal quality and close-in emissions performance are made with a sample of the signal taken at Test Point B. To check the transmitter's extreme out-of-channel emissions amplitude, the measurement equipment is connected ahead of the channel filter at Test Point A. Here the out-of-channel emissions have a much higher amplitude because they have not yet been attenuated by the filter.

After the measurement, the loss of the filter is added to determine the final result. This approach has the advantage of using a filter that is already within the system. However, it requires the characteristics of the transmitter's filter to be known.

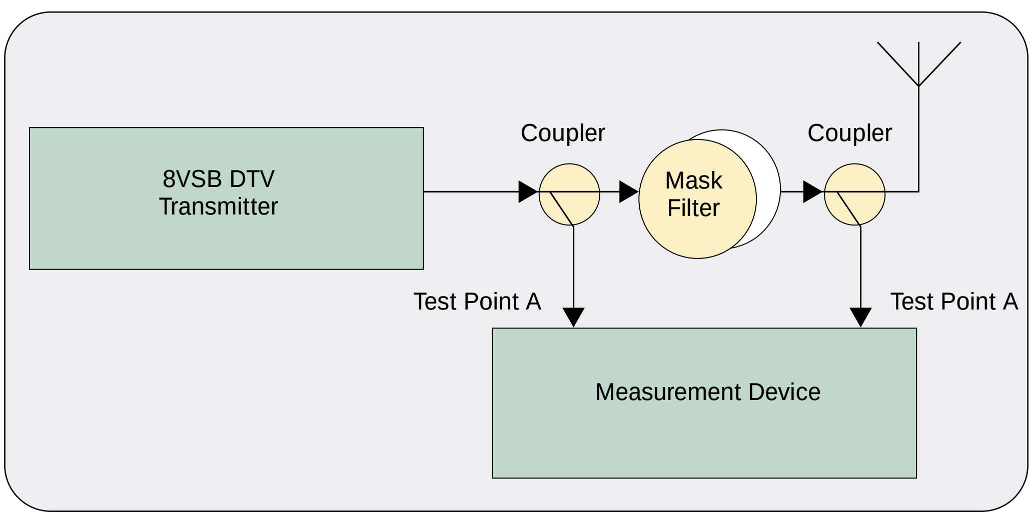

Figure 5. *Characterization of FCC Out-of-Channel Mask*

An equivalence mask can then be calculated from the data taken at test point A and the channel filter response that is superimposed on the FCC mask. The bandpass filter has a small amount of loss. The loss increases as one moves away from the center frequency in either direction. Decreasing the required FCC attenuation by 1dB for every dB of additional loss in the channel filter generates an equivalent mask.

The equivalence mask can then be applied to the out-of-channel measurement to allow estimation to the -110dB FCC mask. It is easy to create an equivalence mask within the RFA300A to check for compliance with the specification. Using a conventional spreadsheet application, define points in the equivalence mask at specific frequency and amplitude values as shown in the example spreadsheet.

Figure 6 shows the results of the Equivalence Mask table calculated from the FCC and Filter Mask tables using the equation above.

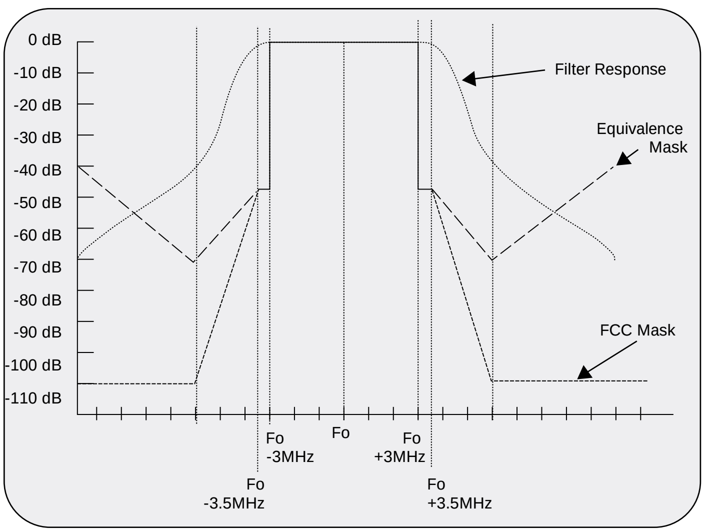

Figure 6. *Reconciling Data from Test Point A, Filter Response and FCC Mask.*

Example "Equivalence Mask" Spreadsheet

FCC Mask	Filter Mask	Equivalence Mask	
Amplitude dB	Amplitude dB	Amplitude dB	Frequency MHz
0	0	0	Fo + 3.0 MHz
0	0	0	Fo - 3.0 MHz
-47	-2	-45	Fo + 3.5 MHz
-47	-2	-45	Fo - 3.5 MHz
-110	-32	-78	Fo + 6.0 MHz
-110	-32	-78	Fo - 6.0 MHz
-110	-70	-40	Fo + 10.0 MHz
-110	-70	-40	Fo - 10.0 MHz

Figure 7 is a spectrum measurement superimposed on a mask template. The pilot frequency is distinct from the flat, noise-like spectrum of the rest of the 6MHz channel. If the outer edges of spectrum are flat, this indicates the system does not have non-linear errors. If a slope is present on channel spectrum display, it indicates the presence of non-linear errors.

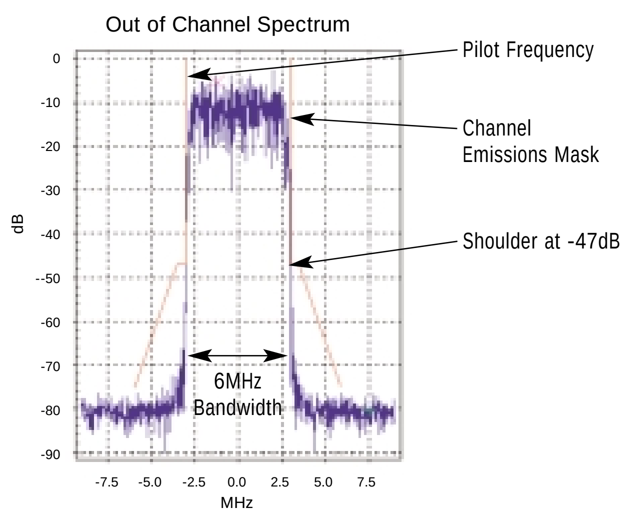

Figure 7. *Out-of-Channel Spectrum*

8VSB Symbol Data Measurements with the RFA300A

Many 8VSB measurements require the measurement device to demodulate the 8VSB signal in order to examine specific symbol data. These measurements are:

- Constellation Analysis.
- Signal-to-Noise.
- Error Vector Magnitude.
- Frequency and Group Delay Response Error.
- Phase Error and Phase Noise.

A conventional spectrum analyzer cannot demodulate the spectral information, and a precision demodulator is required to make these measurements.

Constellation Analysis with the RFA300A

A constellation display plots the relationship between the carrier amplitude and phase of each data symbol. It provides a visual health check of the 8VSB transmitter. The constellation diagram is similar in concept to a NTSC vectorscope display, which visually represents the performance of an analog color TV signal.

There are several different types of digital modulation systems. The simplest of these is Quadrature Phase Shift Keying (QPSK). The phase of the carrier is switched in response to the signal data, as shown in Figure 8.

QPSK modulation is typically used for satellite applications because of its high noise immunity. The distance between symbol values is large, therefore it takes a large amount of noise for the symbol to cross the decision boundary into another quadrant. Two bits of information are sent per symbol.

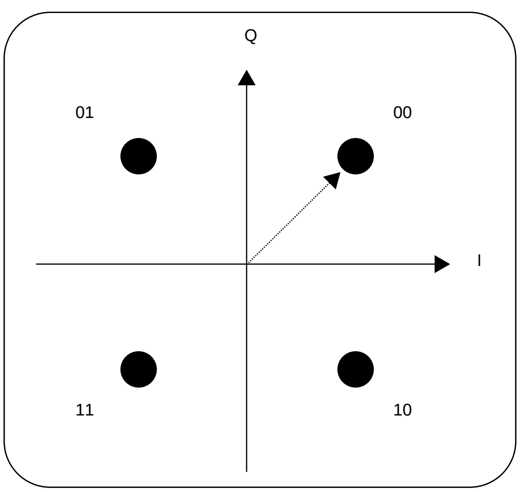

Figure 8. *QSK Constellation Diagram*

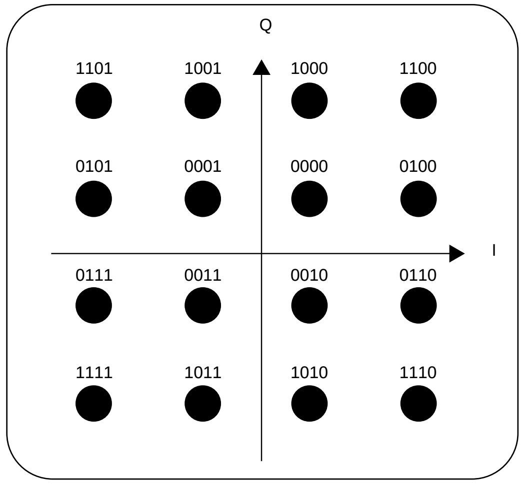

Figure 9. *16QAM Constellation Diagram*

Quadrature Amplitude Modulation (QAM) varies the phase and amplitude of the signal dependent on the signal data, as shown in Figure 9.

QAM modulation is typically used for cable applications because QAM is more susceptible to noise. The distance between symbol values is closer together, therefore it takes a lesser amount of noise for the symbol to cross the decision boundary into another symbol value and produce an error. There are several different forms of QAM. The diagram illustrates 16QAM that uses four bits of information per symbol. Cable systems typically use 64QAM or 256QAM. In this case, the symbols become much closer together.

In 8VSB, we are concerned with the amplitude of the signal which represents the symbol values. The phase of the carrier varies in order to suppress the lower sideband. The eight amplitude levels are recovered by sampling the In-Phase (I channel) only. On the 8VSB constellation diagram, the I-Channel data is displayed along the x-axis (real axis), while the Quadrature (Q channel) follows the y-axis (imaginary axis). Figure 10 illustrates the result.

The 8VSB constellation diagram is a series of eight vertical lines that correspond to the 8 transmitted amplitude levels. In 8VSB, the pilot introduces a 1.25 Constellation Units (C.U.) offset giving a data range of -5.75 to +8.25.

Notice that the position of the symbol in the Q axis does not affect the value of the symbol. Only the In-Phase (I) axis is used to determine the symbol value. Three bits are used for each symbol.

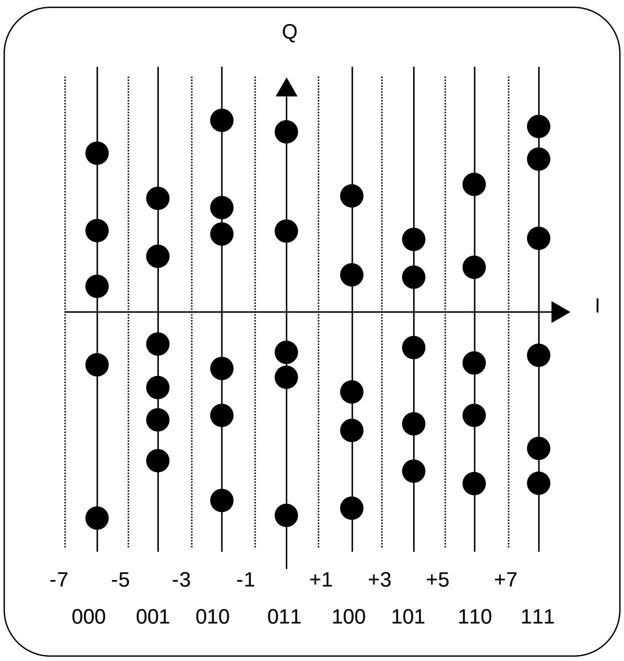

Figure 10. 8VSB Constellation Diagram

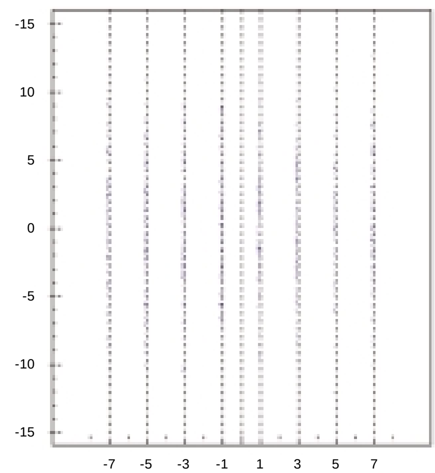

Figure 11. An Ideal Constellation Display

An ideal constellation produces eight thin vertical lines as shown in Figure 11. The symbol dots are very close to the ideal, indicating a low-noise signal with no inter-symbol interference. The pilot offset has been subtracted, yielding a range of -7 to +7 to better visualize the constellation display.

The presence of noise in the system will cause the symbols to deviate from their ideal position. The constellation in Figure 12 shows the effect of some noise in the system. In this example, no symbols have crossed to another level, which would produce inter-symbol interference.

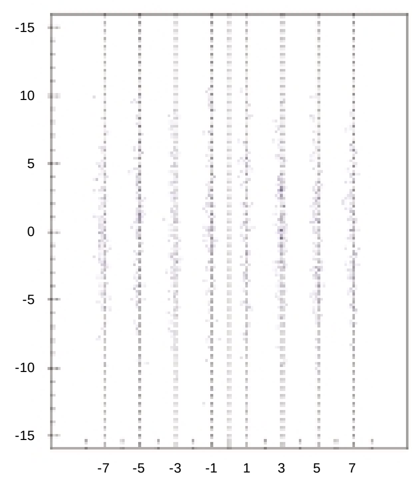

Figure 12. Noise effects on the 8VSB Constellation

Splines Simplify Constellation Analysis

The RFA300A splines function makes it easier to see the average variation of the symbols along each axis and to interpret the type of errors occurring within the system.

The remaining constellation diagrams in this section explain the proper use and interpretation of the RFA300A splines.

When the outer splines curve inward, as shown in Figure 13, too few extreme high-level symbol values are present. This is evidence of amplitude error and gain compression, or clipping, in the transmission. This is known as AM-AM conversion error.

This type of error correlates with the results of the peak-to-average and amplitude error displays.

Similarly, if the outer splines curve outward there is non-linear expansion occurring within the transmitter.

If the splines are S-shaped (Figure 14), a phase error exists. The signal amplitude is modulating the carrier's phase causing the distortion. This is called AM-PM conversion.

Bowtie-shaped splines (Figure 15) indicate phase noise in the transmitter.

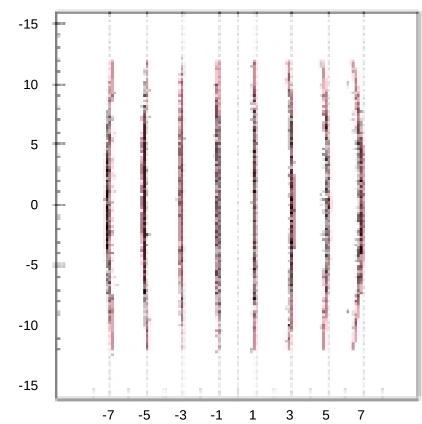

Figure 13. *Clipping Effects in the Transmission*

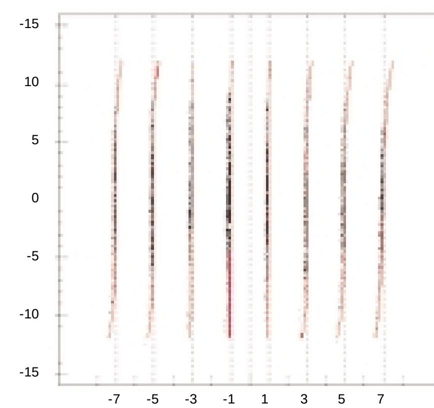

Figure 14. *Phase Error Effects*

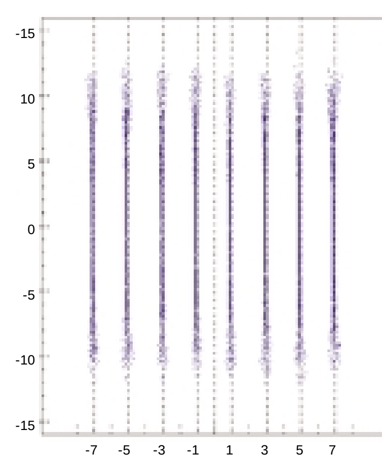

Figure 15. *Phase Noise Effects*

Quantitative Measurements with the RFA300A

The RFA300A can make many measurements that quantify an 8VSB transmitter's operational parameters. These characterize the 8VSB signals' actual performance compared to a theoretical ideal.

Measurements fall into four categories:

Signal to Noise (S/N) is the simple ratio of desired signal to undesired signal power.

Noise is defined as anything that degrades or impairs the signal, including distortion products, intersymbol interference caused by frequency response or group delay errors or ordinary white noise. Poor adjustment of the transmitter will result in a marginal decrease in S/N, which can result in a decrease in coverage area.

Signal to Noise in an 8VSB system should be above 26-27dB and is defined as the average power of ideal symbol values divided by the noise power. This is the difference between the ideal signal and the actual signal as demodulated along the In-Phase real axis.

$$S/N = \frac{\text{Power (ideal I signal)}}{\text{Power (ideal I signal - actual I signal)}}$$

Modulus Error Ratio (MER) is a complex form of the S/N measurement that is made by including the Quadrature channel information in the ideal and error signal power computations.

$$MER = \frac{\text{Power(ideal I-channel and Q-channel)}}{\text{Power (ideal I-channel and Q-channel - actual I-channel and Q-channel)}}$$

MER and S/N will be approximately equal unless there is an imbalance between the I-and Q-channel. If the value of MER is significantly less than S/N, Q-axis clipping is likely to occur. This is because the Q-axis contains most of the amplitude peaks.

Pilot Amplitude Error measurements quantify the pilot carrier's deviation from the ideal.

Error Vector Magnitude (EVM) is the RMS value of the magnitudes of the symbol errors along the real (In-Phase) axis, divided by the magnitude of the real (In-Phase) part of the outermost constellation state. (S_{max} = +7.0 C.U.). See Figure 16.

$$EVM = \frac{\text{RMS(Ideal signal - Actual signal)} \times 100\%}{S_{max}}$$

EVM also includes both I and Q channels and will therefore indicate transmitter clipping slightly before S/N. The transmitter's performance should be in the 4.6 percent range.

EVM is the magnitude of error induced by noise and distortions compared to an ideal version of the signal. EVM is measured as a percentage of the peak signal at the outermost parts of the constellation. Figure 16 illustrates this term. For good performance, the EVM value should be as small as possible.

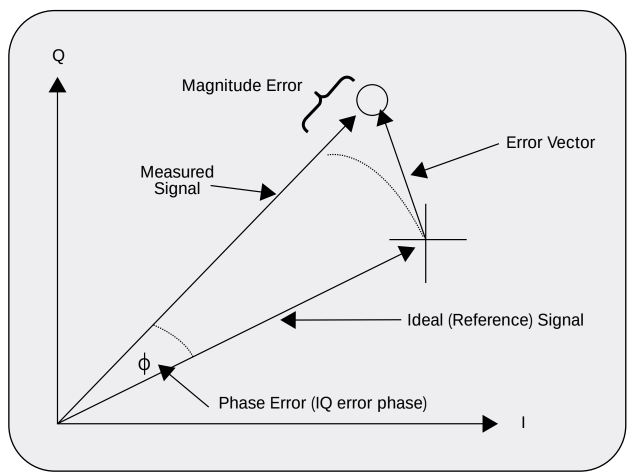

***Figure 16.** Error Vector Magnitude*

When measuring S/N, keep in mind that there are several types of transmitter impairments that can cause degradation on the system. These can be grouped into three areas: **Linear Errors** include Frequency Response, Group Delay Error. **Non-Linear Errors** include Amplitude Error, Phase Error. **Miscellaneous Errors** include Phase Noise, Broadband Noise, Software or DSP Noise.

Identification of Linear Errors

The RFA300A's built-in equalizer corrects for linear errors but is not able to correct for non-linear errors. By comparing the S/N measurements when the equalizer is switched on or off, it is possible to distinguish between linear and non-linear errors, respectively. If the equalizer significantly improves the S/N result, then most of the errors are linear. Otherwise the errors are mainly non-linear.

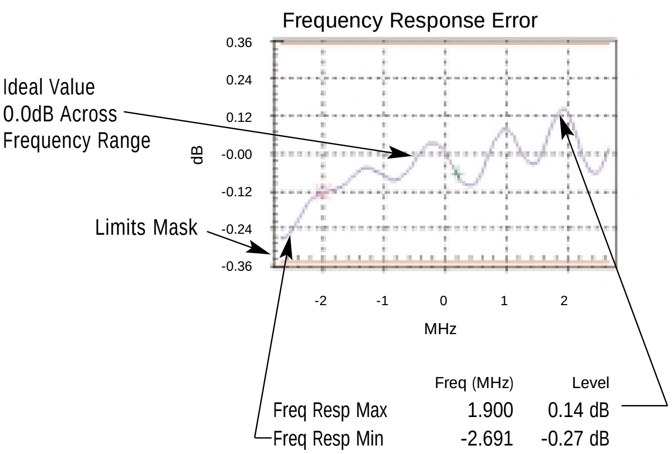

Figure 17. *Frequency Response Measurement*

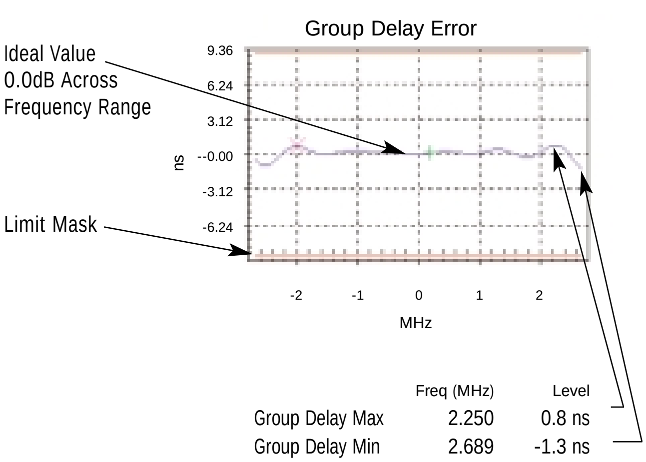

Figure 18. *Group Delay Measurement*

Linear Errors

Transmitter response imperfections and small impedance mismatches can cause linear distortions. Group delay and frequency response problems can cause noise emphasis and inter-symbol interference at the receiver. This may indicate a need for adjustment of the final RF filter or for a pre-correction system.

Frequency Response Error is a frequency domain (spectral) function. It is the difference between the spectral response of an ideal 8VSB signal based on the root-raised cosine frequency response and that of the actual signal. Figure 17 depicts the result of a Frequency Response Error measurement.

Group Delay Error is also a frequency domain function. Group delay is the delay that a specific portion of the spectrum experiences through the transmission path. In this case the ideal curve is a constant (flat) response across the channel. Figure 18 shows a typical Group Delay result.

Non-Linear Errors

Non-Linear errors cause spectral spreading outside the channel band, raising the adjacent channel "shoulders". Amplitude and phase non-linear errors will decrease the transmitter S/N ratio, reducing coverage area. Non-linear error measurements can be used as a guide for adjusting 8VSB transmitter linearity.

Amplitude Errors are a result of gain errors caused by the instantaneous signal amplitude. Typically a transmitter's gain decreases with increasing amplitude, which gives rise to clipping. It is important to measure amplitude error of the transmitter because it is one of the causes of out-of-channel emissions (sometimes called spectral re-growth). Figure 19 presents an RFA300A amplitude error measurement result.

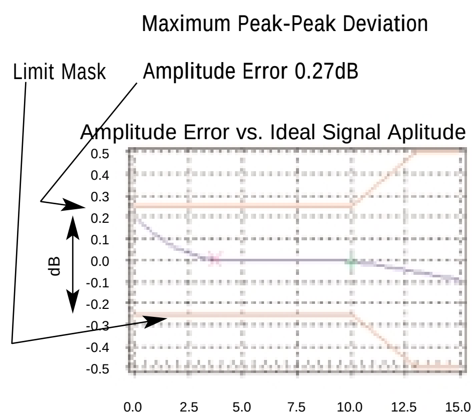

Figure 19. *Amplitude Error Measurement*

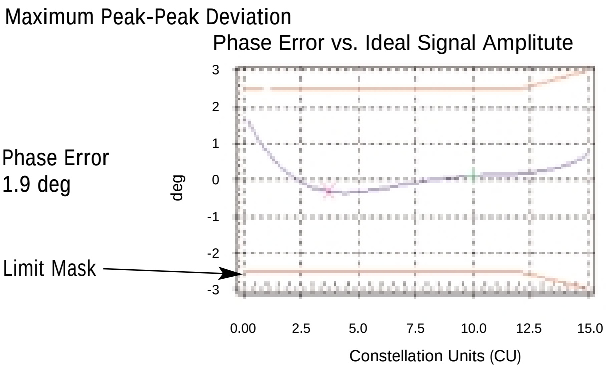

Figure 20. *Phase Error Measurement*

Phase Errors exist in the amplitude domain. A phase shift of the signal passing through the amplifier varies with input signal's amplitude, producing a phase error as shown in Figure 20.

Miscellaneous Errors: Phase Noise

Integrated Phase Noise is a single figure of merit describing the phase variation that the transmitter's frequency synthesizer adds to the digital modulation process. This variation causes phase and frequency deviations and rotates the decision points away from their ideal phase values, reducing the coverage area of the transmitter. The constellation diagram produces a bowtie shape seen in Figure 15, while the RFA300A automated measurement produces the display shown in Figure 21.

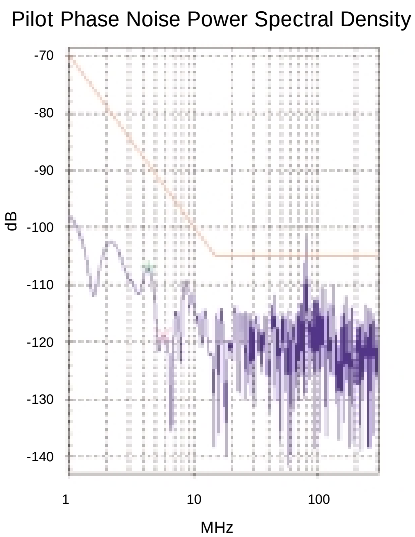

Figure 21. *Phase Noise Measurement Display*

Transmitter Monitoring with the RFA300A 8VSB Measurement Set

The foregoing list of 8VSB measurements should be performed during commissioning of an 8VSB system and at regular intervals over the life of the transmitter. While the sheer number of measurements may seem daunting, the RFA300A 8VSB Measurement Set can be set up to monitor transmitter performance automatically and continuously. It allows the engineer to define performance limits and to set caution and alarm limits for the measurements. When the limits are exceeded, the RFA300A has several ways to notify the engineer, and can also save the measurement results for detailed analysis. Figure 22 shows a typical monitoring screen with its list of tests and results.

Test Name	Result	Time Stamp
Frequency Response & Group Delay		
Freq Resp Max	0.01 dB	10/5/00 11:40:14 AM
Freq Resp Min	-0.02 dB	10/5/00 11:40:14 AM
Freq Resp Pk-Pk	0.03 dB	10/5/00 11:40:14 AM
Freq@ Freq Resp Max	690.401 Mhz	10/5/00 11:40:14 AM
Freq@ Freq Resp Min	687.051MHz	10/5/00 11:40:14 AM
Freq@ Group Delay Max	691.251MHz	10/5/00 11:40:14 AM
Freq@ Group Delay Min	691.690MHz	10/5/00 11:40:14 AM
Frequency Response Mask Test	Pass	10/5/00 11:40:14 AM
Group Delay Mask Test	Pass	10/5/00 11:40:14 AM
Group Delay Max	0.9 ns	10/5/00 11:40:14 AM
Group Delay Min	-0.8 ns	10/5/00 11:40:14 AM
Group Delay Pk-Pk	1.7 ns	
Amplitude & Phase Errors		
Amplitude Error Mask Test	Pass	10/5/00 11:40:40 AM
Amplitude Error Pk-Pk	0.05 dB	10/5/00 11:40:40 AM
Phase Error Mask Test	Pass	10/5/00 11:40:40 AM
Phase Error Pk-Pk	0.6 deg	10/5/00 11:40:40 AM
Out of Channel Emissions		
Outof Chnl Pwr to Avg Power - Lower	-64.4 dB	10/5/00 11:40:43 AM
Outof Chnl Pwr to Avg Power - Upper	-62.0 dB	10/5/00 11:40:43 AM
Out of Channel Mask Test	Pass	10/5/00 11:40:43 AM

Figure 22. *Signal Monitor of RFA300A*

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