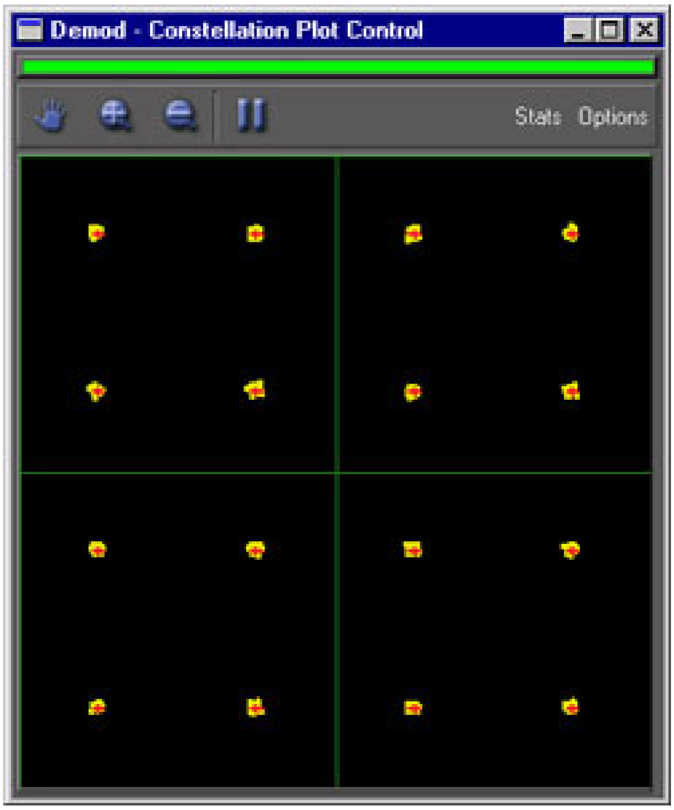
If you build it, you have to test it...



Challenges and solutions in broadband communication systems test.

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Some say broadband is like the weather. Everyone talks about it, but no one can do anything about it. Not exactly true. A hot topic in many circles, broadband means different things to different people. From 3G cellular to Bluetooth&#153, 802.11b, and 802.11a WLANs to cable modem to DSL to MMDS, LMDS, and the towering heights of the newest satellite 'internet in the sky' systems, broadband involves moving data from one place to another... fast. Even though the breakneck wireless build-out seems to have paused to catch a breath, two things are clear: (1) The world's information bank continues to increase at an amazing rate and (2) people want and need instant access to that information. High speed access is addictive and it is hard to relinquish once you've had a taste. Once we have cable modems or DSL in our homes or T1 lines to our offices, using 56k dial-up modems while on the road feels painfully slow and inefficient. The increased access offered by high network data rates is an enabler, changing the way we work for the better.

The challenges presented in moving data fast involve high RF carriers, fast data rates, and advanced modulation schemes. Rates up to 800 million bits per second will soon be broadcast from space to businesses in the Ka band[1], attainable with the same ease as installing a satellite television dish on your rooftop. The Direct Broadcast Satellite (DBS) market, which now boasts more than 18 million subscribers in the United States and more than 80 million subscribers worldwide, makes use of complex digital error correction coding and phase-shift keyed (PSK) modulation to deliver popular shows with digital clarity and quality. Cable modems use quadrature amplitude modulation (QAM) and are moving to synchronous code division multiple access (S-CDMA) to ensure high speed communications over less than ideal cable network infrastructure originally installed for analog, one-way cable television.

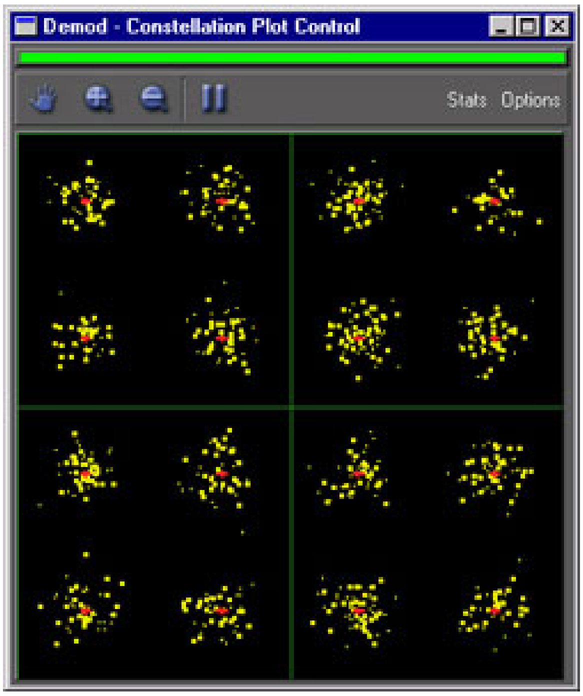

Figure 2. 16 QAM signal with 20 dB CNR.

Developing and manufacturing the broadband chips, boards, and systems to meet the current demand for speed and access places unprecedented demands on today's test and measurement instrumentation. Signal generators, signal analyzers, and channel simulators all need to have higher instantaneous bandwidths, measurement accuracies, processing power, and flexibility. The trend toward more complex modulation schemes such as QAM and code orthogonal frequency division multiplex (COFDM) in new systems pays dividends in higher spectral efficiencies (more data bits per hertz) and better immunity to multipath and interference. But to achieve the dividends, the systems operate closer to the fine line between perfect data and no data, between a great looking high resolution satellite television image and a blue screen. Signal generators and channel simulators must generate and emulate the real world of broadband signals, environments, and impairments with control and precision in order to ensure designs are verified before committing to production.

What are some of the signal characteristics and impairments that need to be simulated and characterized on the new broadband systems? Thermal noise is a good starting point, as its effects on system performance are well understood. But other factors such as I/Q imbalance, phase noise, phase and amplitude distortion, gain linearity, channel loading, multipath, and interference further degrade the real world system performance, and must be considered in order to optimize designs and avoid performance pitfalls. This article describes some of the basic impairments and their impact on system performance.

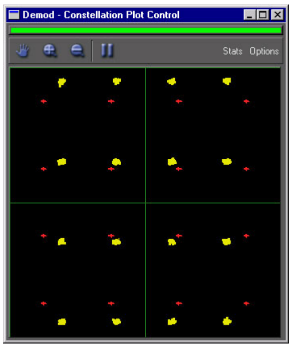

Figure 3. 16QAM signal with 3 dB I/Q gain imbalance.

Thermal Noise

The first and most basic impairment is thermal noise. It is often described in system designs as carrier-to-noise ratio (CNR) or signal-to-noise ratio (SNR). CNR can be described as the ratio of the signal carrier power to the thermal noise power in the analysis bandwidth of the communications receiver, often caused by the noise in the channel or the noise generated by the receiver. Many excellent papers have been written on this subject, and exhaustive theoretical studies have been performed to predict the raw bit error rate (BER) of the communication system as a function of modulation and CNR. As the broadband systems extend the bandwidths up to hundreds of megahertz, move to higher order modulations such as 64QAM and 256QAM, and apply powerful error correction schemes, they push the performance close to the 'blue screen' cliff, making it critical to accurately simulate the thermal noise power. To add to the challenge, the thermal noise may not be spectrally flat across the broadband receiver bandwidth. Figure 1 shows the constellation plot for an ideal 16QAM signal operating at 50 Msymbols per second and 50 dB CNR. Figure 2 shows the same signal with a 20 dB CNR. The noise causes the tight cluster of points designating a symbol to spread out, increasing the chance that one of the points will be interpreted as a neighboring symbol, resulting in a bit errors. The signals were generated with a Celerity Systems CS2540BSG Broadband Signal Generator, a state-of-the-art instrument capable of generating PSK and QAM signals with bandwidths up to 160 MHz. The resulting signals were analyzed with Celerity's CS3540BSA Broadband Signal Analyzer/Recorder which provides spectral, constellation, and eye-diagram plots of signals with bandwidths up to 160 MHz, and demodulated signal parameter measurements including error vector magnitude, I/Q imbalance, carrier offset, symbol rate offset, and carrier power.

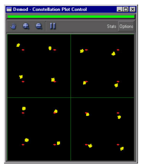

Figure 4. 16 AM signal w/ 10 degree gain i mbala nce I/Q phase i mbala nce.

I/Q Imbalance

I/Q imbalance is an impairment of growing importance to the broadband communications systems designer. A common way to generate broadband signals is to form individual I and Q (complex) signals and then upconvert onto a carrier using an I/Q modulator. As signal bandwidths increase in broadband systems, it becomes more and more difficult to maintain I/Q balance across the entire signal bandwidth, resulting in I/Q gain, I/Q phase, and I/Q DC offset imbalances. If severe enough, I/Q imbalance results in errors in the demodulated data and a higher BER. When combined with other impairments, even a small amount of I/Q imbalance could cause performance degradations. Figure 3 shows the 16QAM signal with 50 dB CNR with a 3 dB difference in gain between the I and Q inputs. Figure 4 shows the 16QAM signal with a 10 degree phase difference between the I and Q inputs. Note that both of these imbalances have distinct error patterns in the constellation plots, with offsets from the ideal QAM position indicated by the red cross marks. These signals were generated with Celerity's CS2540BSG Broadband Signal Generator, which allows precise digital control of all three I/Q imbalances when generating PSK and QAM signals.

Phase Noise

Phase noise, like thermal noise, is unavoidable in communications systems and occurs whenever frequency devices are used. This noise is seen as sidebands around a carrier and is often measured in 1 Hz to 1 MHz offsets. Examples of frequency devices include crystal oscillators, phase locked oscillators and synthesizers, phase locked loops, YIG oscillators and synthesizers, and frequency multipliers. The higher RF carriers, faster time bases, and wider loop bandwidths used for the broadband systems can generate higher phase noise with characteristic continuous and spurious phase noise distributions. Figure 5 shows the constellation plot of the 16 QAM with phase noise starting at &#15040 dBc/Hz 100 Hz from carrier and tailing off to &#15090 dBc/Hz 1 MHz from carrier. The CS2540BSG Broadband Signal Generator was used to generate signals with precise phase noise profiles, including continuous and spurious components, at carrier offsets from 1 Hz to 1 MHz.

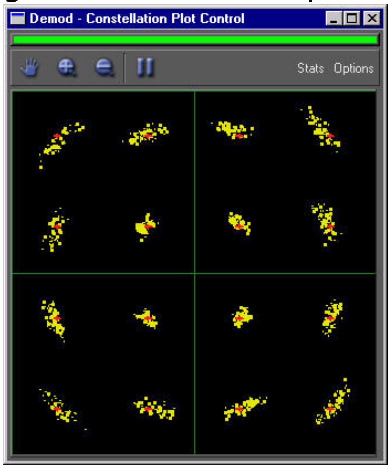

Figure 5. 16 QAM signal with phase noise.

Interference

Interference can be a difficult problem with broadband systems. The wide channel bandwidths required can be home for wayward interferers, either intentional or unintentional. The receivers can be tested for the effects of various forms of interference using the CS2540BSG, which can create a rich environment of signals including CW, PSK, QAM, OFDM, and the full complement of 2, 2.5, and 3G waveforms. Figure 6 shows the effects of a CW carrier 1 MHz away from the 16 QAM carrier.

Amplitude and Linear Phase Deviations

Since broadband signals often use PSK and QAM modulations, amplitude and linear phase deviations (also represented as group delay distortion) over the signal bandwidth can degrade the performance of the system. It is difficult for broadband RF components to maintain passband flatness and phase linearity over the required frequency range. Just how much deviation can be tolerated should be budgeted in the system design, then simulated and measured, if possible. Care must be taken with the design of analog filters close to their band edges, as relatively small deviations in linear phase can result in large system performance degradations. The equalizer designs of the broadband systems can be confirmed with the proper simulated signal impairments. Figure 7 shows the effects of 2 dB of passband ripple on the constellation of the 16QAM signal. Figure 8 shows the effects of 10 degrees of passband phase deviation on the constellation.

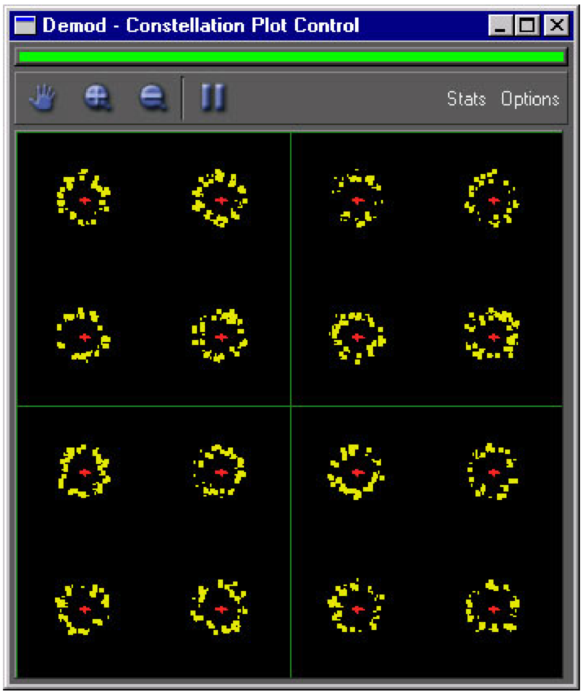

Figure 6. 16QAM CW interferer impairment added 1 MHz offset from QAM carrier.

Intermodulation Distortion or Selectivity

Broadband systems often support multiple broadband signals in the channel, separated either in time (TDM), frequency (FDM), or both. The ability to provide channel loading with realistic signals in multiple adjacent channels adds realism to system testing, and can uncover intermodulation distortion or selectivity issues in the receiver. Figure 9 is an example of a rich environment created with the CS2540BSG across a 160 MHz bandwidth. A 50 MHz 16QAM signal centered at 70 MHz is shown with three 10 MHz 16QAM signals centered at 30, 110, and 125 MHz. Three CW carriers have also been created and inserted into the environment at 138, 140, and 142 MHz. The signals shown were measured with the CS3540BSA Broadband Signal Analyzer.

Multipath

Finally, the effects of Rayleigh and Ricean multipath must be taken into account. Multipath can be minimal in highly directional fixed antenna systems but can have a large impact systems with wider beamwidths, such as mobile applications. In these systems, both flat and frequency selective fading should be generated and used for testing the receiver equalizers, AGCs, and overall system robustness.

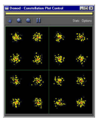

Figure 7.

Conclusion

They say God (or his adversary) is in the details, and this paper we have discussed many of the details to consider in the design of robust broadband communication systems. The effects of thermal noise, I/Q imbalance, phase noise, phase and amplitude distortion, gain linearity, channel loading, multipath, and interference must all be considered in order to optimize the designs and avoid performance pitfalls. With careful attention to these impairments and the use of broadband test and measurement instruments for real world signal generation, channel simulation, and analysis, designs can be proven prior to system production.

The test instruments used for producing the test results in this article include the CS2540BSG Broadband Signal Generator, part of a family of broadband generators from Celerity Systems. These generators produce realistic signals and signal environments over instantaneous bandwidths up to 500 MHz with digital precision and repeatability. Signal memory depth of 512 Mbytes to 4 GBytes supports the signal and environment accuracy required for realistic testing. Powerful signal simulation software, resident on the BSG, generates PSK, QAM, OFDM, 2G, 2.5G, 3G, and CW signals. Signal environments are created that include any or all of these signals. Accurate thermal noise, phase noise, and other impairments can be added for realistic test scenarios. The CS2540BSG is an essential tool for testing and characterizing today's broadband demodulators, receivers, and RF components.

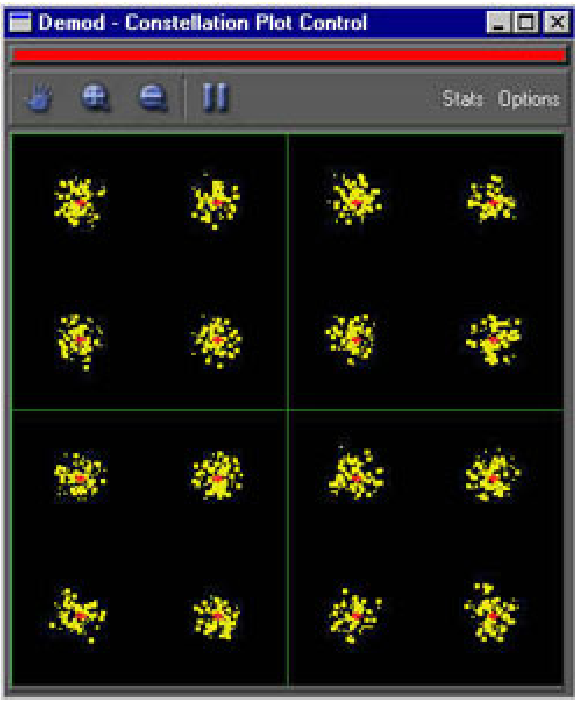

Figure 8.

The CS3540BSA Broadband Signal Analyzer analyzes signals and signal environments with instantaneous bandwidths up to 500 MHz. High speed spectral analysis, ACPR measurement, and PSK/QAM demodulation allow precision measurements of high rate signals, including EVM, IQ imbalance, carrier power, carrier offset, symbol rate offset, and eye closure. As in the broadband signal generators, the analyzer is designed with high performance digital circuitry to ensure precision and measurement repeatability. The CS3540BSA family can measure and characterize the highest bandwidth modulators, transmitters, and RF components.

The CS8016 Channel Simulators from Celerity are used when the entire system link must be tested, including the modulator, RF conversion, antennas, and demodulator elements. These simulators support the bandwidths and impairments for real world testing in the lab prior to production.

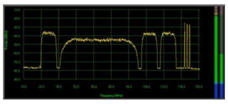

Figure 9.

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