RFCM 104 – Essential Digital Transceiver Measurements

Agilent Technologies

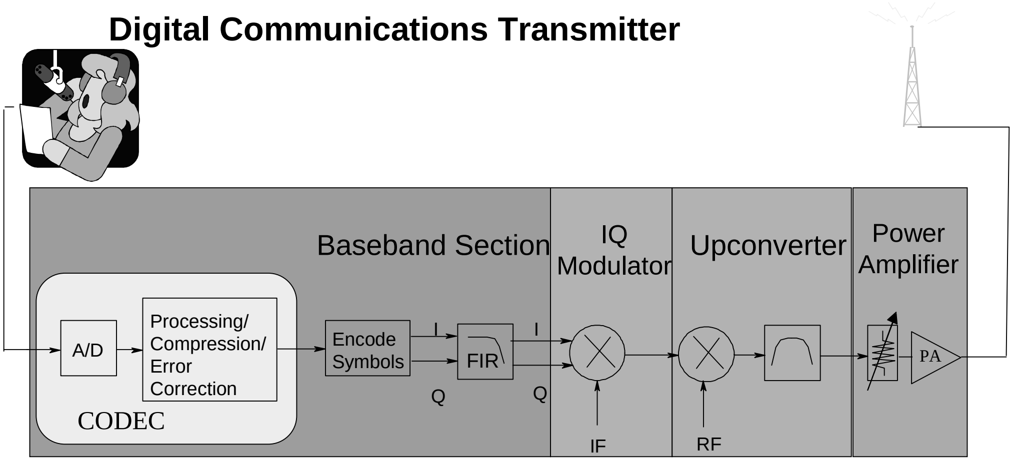
Even as the signals (modulation schemes) become more complex, an essential part of the wireless communications story remains constant: the age-old problems of *transmitters and receivers*. A transmitter has to send a good signal and *modulation quality* is a key measure—for any type of wireless comms. Receivers have to find and lock on to the right signal, and that depends on parameters such *as sensitivity and selectivity,* which are also relevant for any type of wireless comms.

This presentation focuses on impairments that occur to the signal and the measurements that get impacted and the solutions from Agilent Technologies to cope with the challenges of Digital modulation.

Transmitter

We will briefly talk about the digital communications TRANSMITTER and its building blocks.This will help us understand the measurement challenges!

Digital Communications Transmitter



This is a simplified block diagram of a general digital communications transmitter. Typically the transmitter is developed by a number of designers or design teams working on the various sub-assemblies, blocks, or sections. Here, it's shown to be divided into several different sections: CODEC, symbol encoding, baseband filtering (FIR), IQ modulation, upconverter, and power amplifier. CODEC stands for coder/decoder. This is where voice coding may be done for data compression using DSP. Channel coding is also performed by algorithms such as convolutional encoding and interleaving. Convolutional coding duplicates bits for every input bit to add redundancy. These extra bits are used for error correction and adding coding gain. Interleaving further enhances error correction by rearranging the bits so that adjacent bits are no longer adjacent, this spreading of bits over time helps to protect against the impact of unwanted short term duration events like a momentary fade. It provides a more uniform bit error distribution which allows for more efficient error decoding. Symbol encoding is where the data or information is mapped into I and Q signals that together define a symbol for a particular modulation format. Baseband filtering or modulation shaping filtering is low pass filtering which used to provide good bandwidth efficiency by rounding off the sharp edges of the I and Q modulation signals. The I Q modulator mixes the I and Q signals with the same LO, but with a 90 degree phase shift in one path. This is to make the I and Q signals orthogonal to each other, or in quadrature, so they do not interfere with each other. They are then combined to form a single composite output signal at IF. The upconverter translates the IF to a RF signal. This RF signal is then amplified to high power for transmission.

With advances in DSP and ASIC technologies there are higher and higher levels of integration in digital systems. It is possible to find single ICs that could perform part or even all of the functions from the ADC to the modulated IF out. This means the number of RF testing possibilities are reduced at the component and block levels because of fewer test points. So, the ability to test and troubleshoot at the transmitter system level or the antenna port where the final signal is emitted becomes increasingly important.

Key Transmitter Measurements……

In-Band measurements

- **In-Channel**
  - **Channel bandwidth**
  - **Carrier frequency**
  - **Channel power**
  - **Occupied bandwidth**
  - **CCDF**
  - **Timing measurements**
  - **Modulation quality Measurements**
- **Out-of-channel measurements**
  - **ACPR**
  - **Spurious**

Out-of--Band measurements

- **Spurious and harmonics**

These are the measurements needed to ensure the design meets the standards. For details please refer to AN 1313 , Testing and Troubleshooting Digital RF Communications Transmitter Designs

Impairments **Vs Transmitter Measurements!**

Common impairments that will affect a specific measurement when you are testing your design

This is a table of common impairments that show up in measurements at the various test points in a digital communications transmitter/receiver. Transmitter, receiver designs are tested to ensure conformance with a particular standard. However substandard performance may be caused by various parts of the system , so troubleshooting is usually done at several points in the transmit/receive chain.The source of impairments can be difficult to determine.The difficulty is magnified by these practicalities.

•Part of the transmitter is generally implemented digitally

•Some parts of the transmitter may not be accessible

•It may be unclear whether a problem is rooted in the analog or digital section of the system.

And lastly a measurement may be impacted by more than one impairment , for e.g a poor ACP can be caused by one or more of:

•Compression at the amplifier

•Wrong filter coefficient or incorrect windowing

•Incorrect interpolation

•Burst-shaping error

•DAC/DSP error

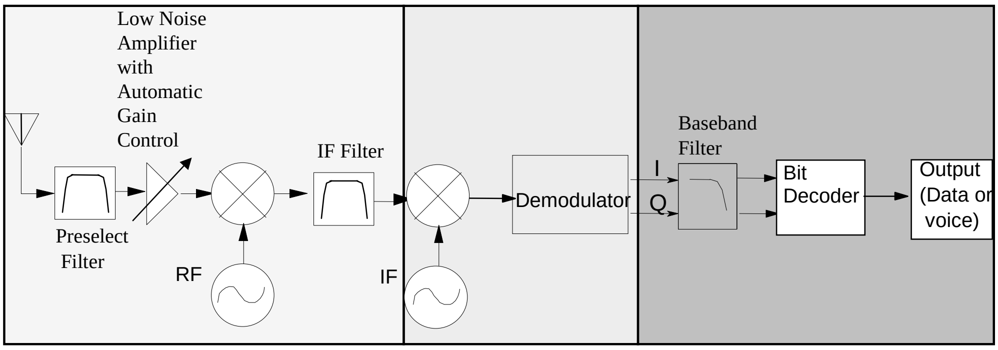
•A severe case of symbol rate error

Let us look at each of these impairments in detail..

Receiver

We will briefly talk about the digital communications RECEIVER and its building blocks.This will help us understand the measurement challenges!

Digital Communications Receiver



Down Converter **Demodulator** **Base band**

To a certain degree, the receiver can be considered a reverse implementation of the transmitter.Consequently the measurement challenges are similar for both parts of the digital radio system (transmitter and receiver). The receiver must extract the RF signal in the presence of the potential interference.Consequently, a pre-selecting filter is the first component of the receiver.It attenuates out-of-band signals received by the antenna.

A Low Noise Amplifier (LNA) boosts the desired signal level while minimally adding to the noise of the radio signal.

A mixer down converts the RF signal to a lower intermediate frequency (IF) by mixing the RF signal with local oscillator (LO) signal.

The IF filter attenuates the unwanted frequency components generated by the mixer and signals from adjacent frequency channels. After the IF filter, the variations in design , manifest themselves.

There are two main ways of implementing a digital receiver, one using I/Q demodulation and the other using sampled IF.

I/Q demodulation implemented with analog hardware is a commonly used digital radio receiver design.The function of the analog I/Q demodulator is to recover the baseband I and Q symbols. Although the I/Q demodulator is a popular design , it has potential problems. Unequal gain in the I and Q paths , relative phase shifts (other than 90 deg) can cause image suppression problems. As such I/Q demodulators are common in single channel base station.

The I and Q data streams are sampled by analog to digital converters(ADCs).They are filter (base band filtering) and decoded to data or voice.

For more details please refer to AN 1314 , Testing and Troubleshooting Digital RF Communications Receiver Designs.

Key Receiver Measurements….

- In-Channel tests
  - Measuring Sensitivity at a specified BER
  - Verifying Co-Channel Rejection
- Out-of-Channel tests
  - Verifying spurious immunity
  - Verifying intermodulation immunity
  - Measuring Adjacent and Alternate Channel Selectivity
- Fading tests

These are the measurements needed to ensure the design meets the standards. For details please refer to AN 1314 , Testing and Troubleshooting Digital RF Communications Receiver Designs

Impairments **Vs Receiver Measurements!**

Common impairments that will affect a specific measurement when you are testing your transmitter design

RECEIVER	I/Q Error	LO Instability	IF filter tilt or ripple	Symbol rate	Interfering tone	Compression	DAC/DSP/ADC Error	AM-PM Conversion
Measurements	Impairments							
Sensitivity	●	●	●	●	●		●	○?
Co-Channel Immunity	○	○	○	○	○	●	●	●?
Spurious immunity (spurious emissions)					●		●	
Spurious immunity (blocking characteristics)	○	○	○	○	●	●?	○	○?
Intermodulation Immunity	○	○	○	○	●	●?	○	○?
Selectivity	○	●	●	○	○		○	○?

● High Probability that impairment affects measurement

○ Severe cases of impairment may affect measurement

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•Burst-shaping error

•DAC/DSP error

•A severe case of symbol rate error

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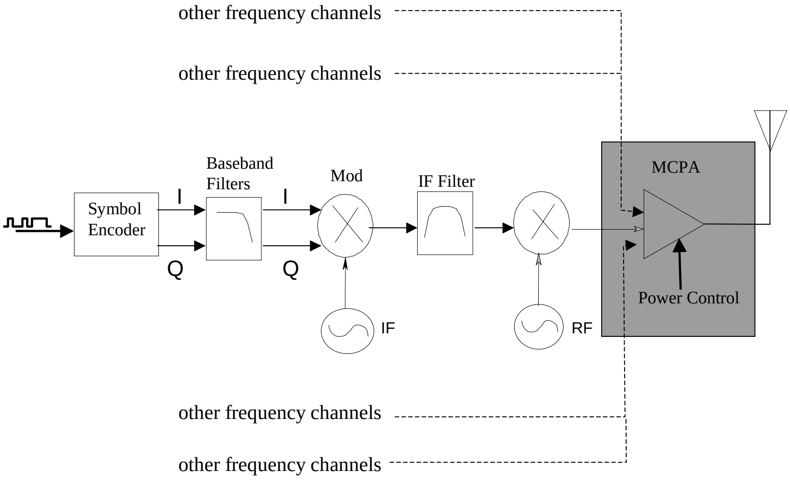
Impairment

Impairment : Compression at the amplifier

This is a common impairment found in transmitters.Let us see how this can be identified and minimized.

Compression at the amplifier

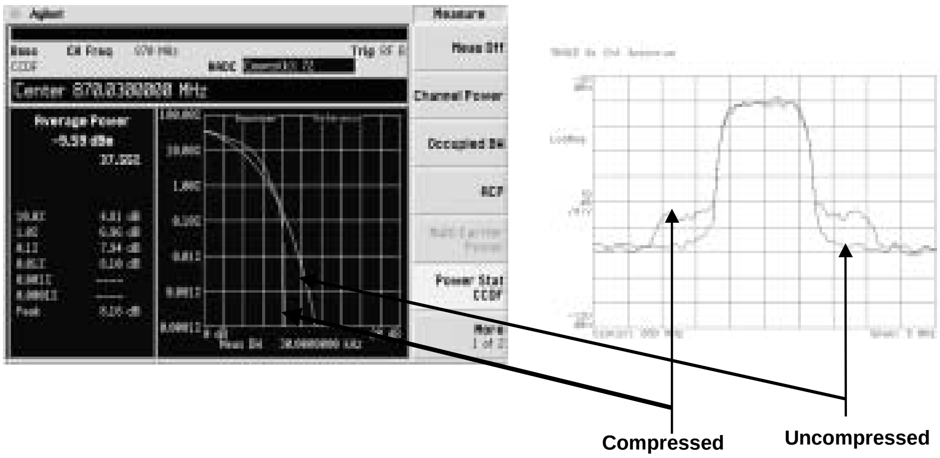


The power amplifier (PA) is the final stage before the signal is introduced to the communication channel to the receiver. Typical characteristics in the PA are frequency and amplitude response, 1 dB compression point and introduction of distortion products. The PA must be selected to accommodate the signal being fed to it. If for example the signals peak power (or peak to average power ratio) is not properly accounted for signal compression can occur. This would restrict the travel of the signals power disabling it to perform the trajectory required to properly represent the data requiring transmission.

Impairments: **Compression at the amplifier**

CCDF curves for signal with and without compression

Adjacent Channel Power increases when compression occurs



Complementary Cumulative Distribution Function (CCDF)

This measurement displays the power statistic of a time-varying modulated signal and can indicate what percentage of time the power exceeds a given level. CCDF is particularly useful for identifying linearity requirements because the percentage of bits or symbols is proportional to the percentage of time shown on the display. CCDF can be measured with a VSA or a spectrum analyzer. **Tip:** Compare the CCDF at the modulator output to that at the output of the transmitter: The difference between the curves is the nonlinear amplitude compression.

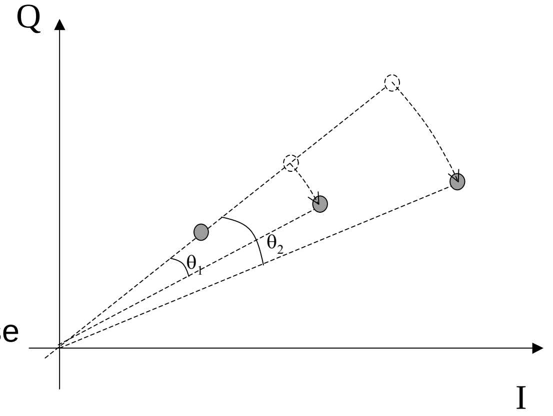
Further Reading — Agilent Application Note 1313, Section 2.3.1.5

Impairment

Impairment : AM – PM Conversion

This is impairment is also associated with amplifier in digital communication transmitters.This impairment is particularly relevant for signals with high peak-to-average ratios,where different amplitude levels suffer different phase shifts. Let us see how this can be identified and minimized.

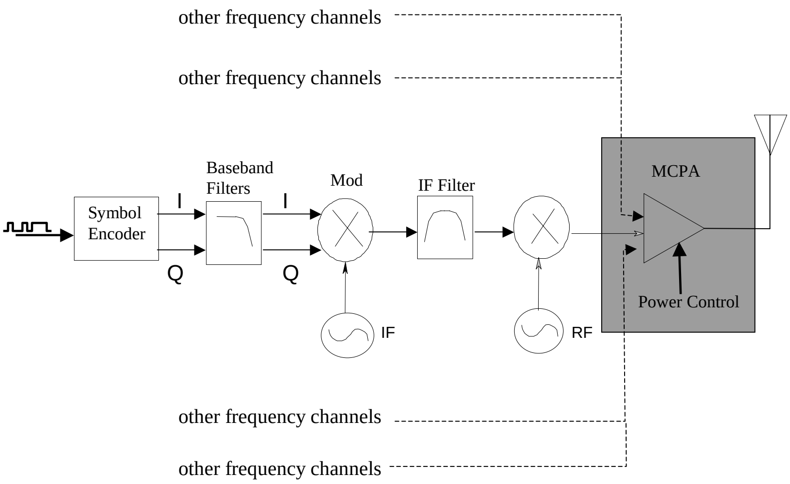
Impairment : **AM-PM Conversion**



Apart from compression (AM-AM conversion) power amplifiers cause phase distortion for high levels of signal amplitude.This effect is known as AM-PM conversion

This slide explains what is AM – PM conversion.Different amplitudes suffer different phase shifts.This can happen at the linear range of the amplifier much below compression point (AM-AM conversion happens at above compression point)

Impairment : **AM-PM Conversion**



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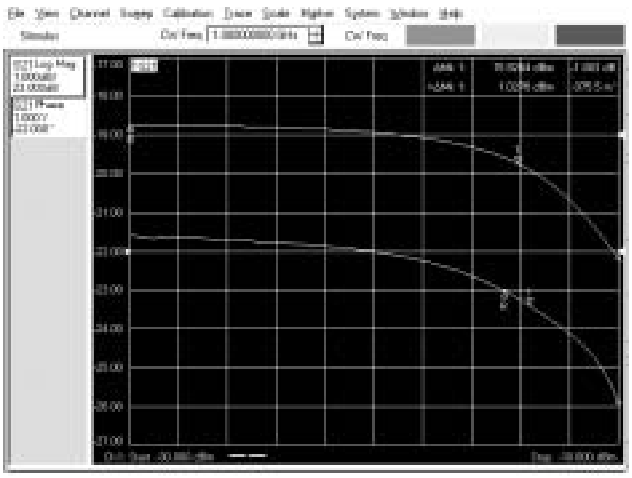
Impairment : **AM-PM Conversion**



Maximizing Power — While Minimizing Distortion

Transmitter power amplifiers play an important role in boosting signals and along with threshold directly affect maximum range and antenna size. As signal levels increase, amps ultimately stop amplifying and start exhibiting the nonlinear characteristics all systems must tolerate to some degree. Nonlinearities typically cause either phase and amplitude distortion that create bit errors, or spectral re-growth that interferes with adjacent channels. Common metrics are AM-AM, AM-PM, IMD, TOI and ACP are covered below. **Tip:** Baseband filtering/equalization is often the distinguishing factor between BER- and spectral re-growth-limited radios. Consider enhancing baseband filters to give the spectrum more room to "grow" before interfering with adjacent channels.

AM-AM (Gain Compression) & AM-PM Conversion (Phase vs. Drive)

As signal amplitudes increase and amplifier power begins to saturate, some amplitude modulation occurs. This is Amplitude Modulation to Amplitude Modulation conversion — also called gain compression a measure deviation from linear performance. It can be measured with a vector network analyzer (VNA) or vector signal analyzer (VSA).

Similarly, as an amplifier begins to exhibit nonlinear characteristics near saturation, its phase shift a constant at low powers, begins to change. This is AM-to-PM conversion, which can be measured with a VNA or VSA.

Further Reading — Agilent Application Note AN1313, Section 3.2.9

Impairment

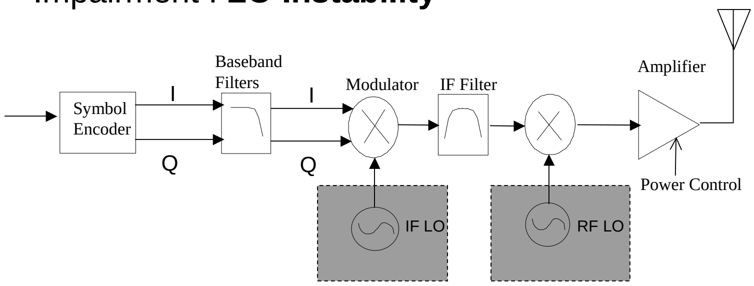
Impairment : LO Instability

LO instability may be caused by digital signals that run close to an analog LO. For instance, data and logic lines (typically CMOS) carry signals with steep edges that can couple RF energy to an LO. This is usually the result of a fault in the final layout design, for example, too-close spacing between lines and/or components.

LO instability can also be caused by poor power supply isolation between the digital and RF sections. In this case, interference from the digital circuitry gets to the analog LOs through the power supply line.

Problems in an LO typically pass on to the final RF signal. If the frequency is unstable, the channel occupation restrictions may be violated and interference with adjacent channels may occur. Close-in phase noise may or may not be a problem, depending on the design of the receiver. Phase noise that is within the loop-bandwidth of the receiver will be tracked. However, it typically results in a loss of margin in the receiver.

Impairment : **LO Instability**



LO instability caused by:

- Data line signals coupling energy to an analog LO
- Poor power supply isolation

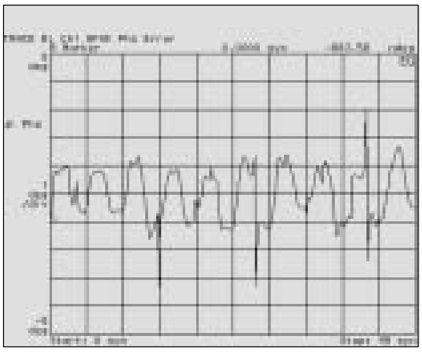
This part of the transmitter affects the signals that appear at the output of the mixer in the transmit path.The RF LO characteristics , like phase noise , phase jitter , residual AM/PM/FM affect the signal characteristics of the input to the amplifier. If the LO frequency is unstable , the channel occupation restrictions may be violated and interference with adjacent channels may occur. Phase noise in any LO in the transmitter can also cause noise in the phase of the recovered I/Q signal.

Let us see what measurements can help to uncover these!

Impairment: LO Instability

Detection and troubleshooting hints:

- **Compare phase and magnitude errors**
- **Use the phase error versus time display**
- **Measure phase noise at isolated LOs**



Vector signal analyzers do not track the phase in the same manner as receivers. Therefore, close-in phase noise appears in the modulation domain as increased error as the result length is increased. This means that the analyzer may detect small phase noise errors that would otherwise go unnoticed by the receiver. Even if the error does not seem to cause a problem in the receiver, the error margin is typically reduced, which may jeopardize high quality communication under more restrictive conditions.

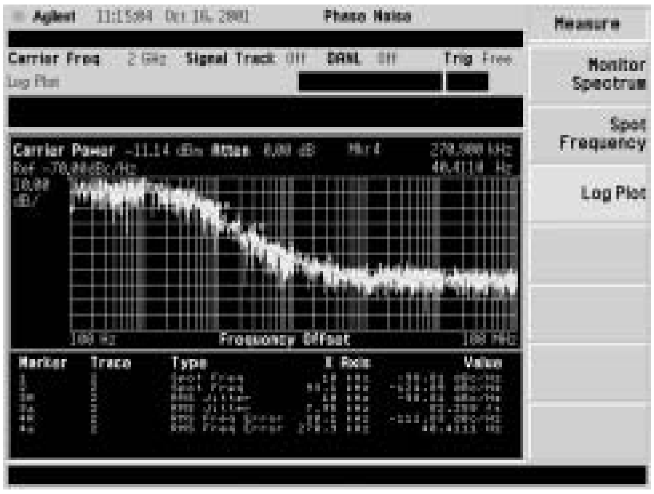
LO instability can be best identified in the modulation domain. A large phase error relative to the magnitude error gives the best indication of instability. The error can be further analyzed by examining the phase error versus time display. This display shows the modulating waveform of any residual or interfering PM signal. Random phase errors indicate random phase noise, which may be created by random data or logic line signals. Sinewave shapes or periodic waveforms indicate interfering PM tones, typically created by periodic logic line signals.

For example, Figure a shows the phase error versus time for a signal with a symbol rate of 50kHz. Since the phase error versus time shows 10 cycles over 50 symbols, the frequency of the interfering PM signal is 10x(50x103)/50 = 10 kHz.

If the LOs in the transmitter are accessible, the problem can be tracked down to a specific LO by making analog PM measurements on the different LOs.

Bad cases of LO interference can also be identified by looking at the constellation (Figure b). The measured symbols preserve the correct amplitude but vary in phase around the ideal symbol reference point.

Impairment : **LO Instability**



Tuning Up Oscillators and Synthesizers

The process of generating signals or converting their frequency requires precise signal sources. Essential tests to asses oscillator and synthesizer compatibility with modulation formats include phase noise, RMS integrated phase noise/jitter, residual AM/FM/PM and spurious.

Further Reading — Agilent Application Note 1313, Section 3.2.7

Phase Noise

Phase noise is a measure of source spectral purity. All sources move randomly about a nominal frequency and minimizing these noise-like variations is essential to preventing degradation of modulation. Typical test instruments are spectrum analyzers for synthesizers or systems, vector signal analyzers (VSA) for modulators, and phase-noise test sets for crystal oscillators and demanding applications. **Tip:** Measuring the scalar EVM of a modulator does not distinguish probabilistic noise from deterministic nonlinearity error sources. The mathematics of these impairments are different so consider also measuring carrier phase noise with your VSA.

Further Reading — Agilent Application Note 1313, Section 3.2.7

Integrated Phase Noise/Jitter

A 1-Hz normalized phase noise measurement at a single frequency offset is rarely sufficient to characterize the effect of phase noise on a broadband communications signal. The integrated RMS phase noise across the band of interest provides a more useful metric that can be applied analytically to constellation geometries. Integrated phase noise can be expressed in degrees RMS, radians RMS or RMS time. Time is particularly useful for evaluating clock jitter. **Tip:** Integrated RMS phase noise and AM/PM are often the primary contributors to residual BER. Low-frequency sources are often regarded as insignificant system contributors; however, their integrated phase noise typically varies substantially, increasing the demands on PA linearity—and system cost.

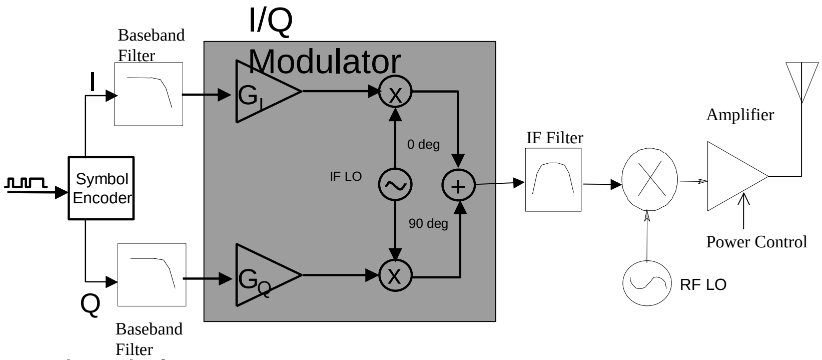
Further Reading — Agilent Application Note 1313, Section 3.2.7

I/Q Impairments

Impairments : I/Q

In this impairment, we look at how the modulator handles I and Q signals fed to it . What are the impairments that can get introduced here. These apply to the I/Q demodulator in the receiver side as well.

Impairments: **I/Q**



I and Q Gain Imbalance

- Gain of I and Q may not be equal
- Integer number of samples delay between I and Q
- Offsets may be added in the amplifiers
- Biasing may be occuring from rounding errors in the DSP
- Quadrature LO may not be at exactly 90 degrees.

When the digitized data is encoded into symbols and the bits are split into parallel paths for creation of the I and Q it is important that the data be properly aligned in phase. Problems in this process can cause delays between I and Q resulting in errors in the final encoded symbols that are transmitted. Since I and Q are two separate signals each will be created and amplified to the right level independently. If there is an equality in this gain the result will be incorrect positioning of each symbol in the constellation causing errors in recovering the data. I/Q offsets can also occur when DC offsets are introduced by rounding errors in the DSP or amplifiers in the signal paths.

The process of mixing the I and Q signals for summing into an IF signal requires shifting the Q signal by 90 degrees. If there is error in the 90 degree phase shift such that the shift is something other than 90 degrees quadrature error will result. This will distort the constellation of the resulting signal once again causing the possibility of errors in the interpreting of the received symbols.

I/Q impairments are not linear errors and therefore cannot be removed by applying equalization.

Impairments: **I/Q**

I/Q Gain Imbalance

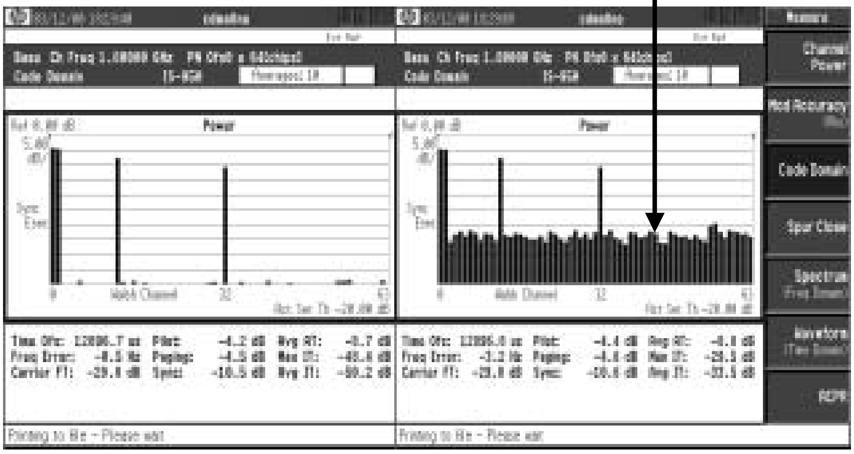
IQ gain imbalance or quadrature errors can be caused by matching problems due to component differences between the I side and Q side of a network. Viewing the signal in the constellation diagram and comparing it to the ideal reference states can determine if these impairments are the causes of the interference. Once again to do this the HP 89441A is set to demodulate using QPSK format for a single code channel.

IQ gain imbalance results in a distorted measured constellation relative to the reference. IQ quadrature errors (other than 90^o between I and Q) result in a skewed constellation.

Note: The constellation is shifted by 45^o.

Impairments: **I/Q**

Increase of code-domain power noise floor



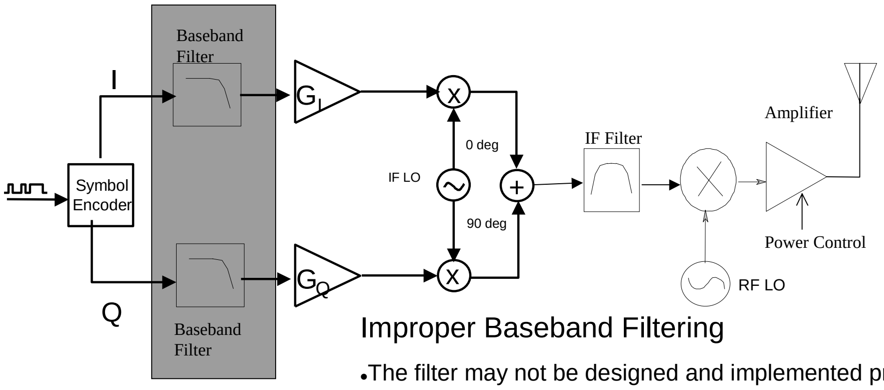
Code-domain power is affected by any I/Q impairment. Basically, any impairment that degrades EVM will cause an increase in the code-domain-power noise floor- that is an increase in the level of non-active channels. The picture shows increase in noise floor for a CDMAone system.

Baseband Impairments

Impairment : Baseband filtering

Here we consider the effect of wrong filter coefficients (alpha) and incorrect windowing on the I and Q signals that go into the modulator.The Error Vector Magnitude versus time is a key indicator of this impairment.This impairment also affects other measurements namely , Channel bandwidth, CCDF, ACP, CDP, Frequency response.

Impairments: **Baseband filtering**

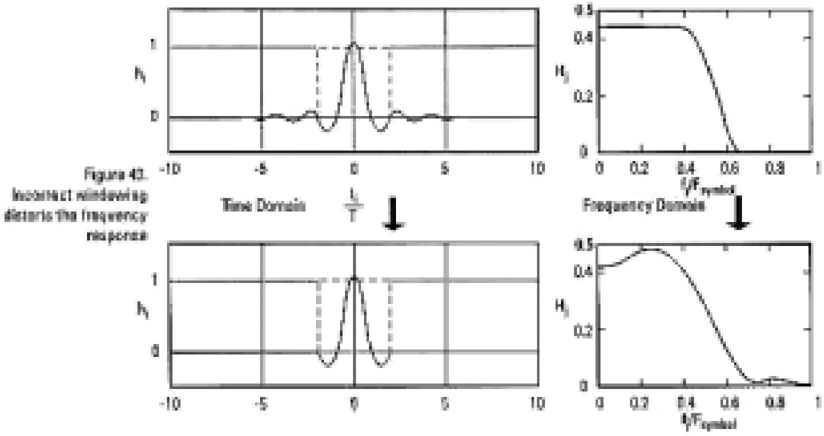


Improper Baseband Filtering

- The filter may not be designed and implemented properly (poor frequency response, etc.)
- The filter parameters (eg. filter roll-off factor) may be improperly specified (the transmitter and the receiver may not match)

The transmitter and receiver both combine with the transmission channel to acheive matched filter detection. This includes the total filtering applied to the signal. Since the filtering is shared between the transmitter and the receiver, it must be compatible and correctly implemented in each. The type of filter and the roll-off factor (alpha) are the key parameters which must be considered. An error in the selection of alpha will potentially result in intersymbol interference (ISI) during fading. It may also cause undesirable amplitude overshoot in the signal.

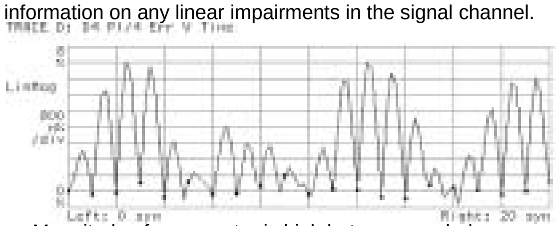
Impairments: **Baseband filtering**



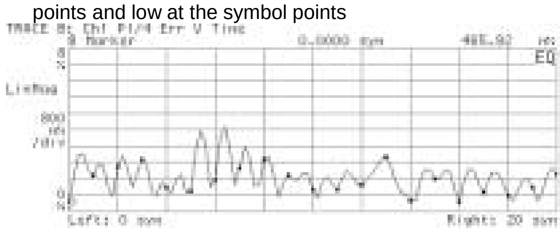
The picture here shows the effect of incorrect windowing of the transmitter filter.The time window applied by the actual filter must be appropriate for the specified alpha to avoid too much distortion of the frequency response,

Equalization improves EVM !

The equalizer will remove any linear impairments to the signal.Examining the equalizer response gives you information on any linear impairments in the signal channel.



Magnitude of error vector is high between symbol points and low at the symbol points



Magnitude of error vector vs. time improves with equalization

Adaptive equalization removes linear errors from modulated signals by dynamically creating and applying a FIR (feed-forward) compensating filter. Linear errors can come from filters in a transmitter or receiver's IF, or from the presence of multiple paths in the transmission path, such as reflections in a cable system. These types of problems appear as group-delay distortion, frequency-response errors (tilt, ripple), and reflections or multipath distortion.

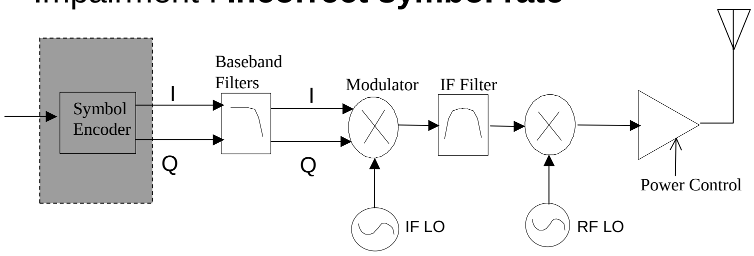
Equalization allows measurement of some impaired channels and can be used to isolate linear from non-linear error mechanisms. Equalization does not require symbol lock or prior knowledge of the signal (such as a training sequence) and is compatible with time-captured data. However, the equalization operation is not real-time and its use is therefore limited to stationary signals.

Symbol Rate Impairments

Impairment : Incorrect symbol rate

Here we will look at the symbol encoder in the transmit chain and the impairments that can affect the I and Q signals it produces.

Impairment : **Incorrect symbol rate**



Symbol clock errors caused by:

- PLL out of lock
- Confusion in oversample ratio specification
- Wrong crystal installed

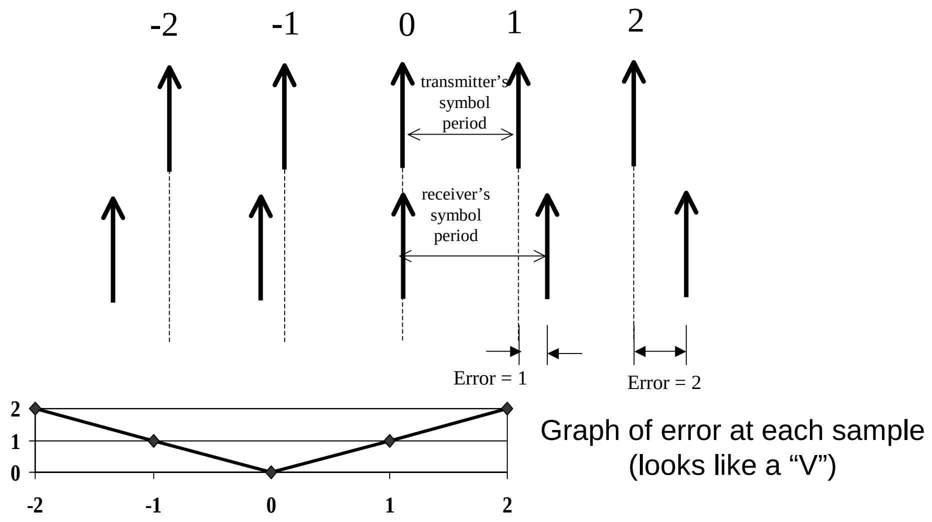
The symbol encoder translates the serial bit steam into the appropriate I and Q baseband signals , corresponding to the symbol mapping on the I/Q plane.

To accurately interpret the symbols and recover the digital data at the receiver, it is imperative that the transmitter and the receiver have the same symbol rate. The symbol clock must be set correctly.

The effect of symbol rate errors on different measurements depends on the magnitude of the error. If it is large, then the modulation measurements get meaningless.You will get an unlock condition in such a case and the signal channel bandwidth measurement is useful.

For smaller errors EVM is useful.

Impairment: Incorrect Symbol Rate

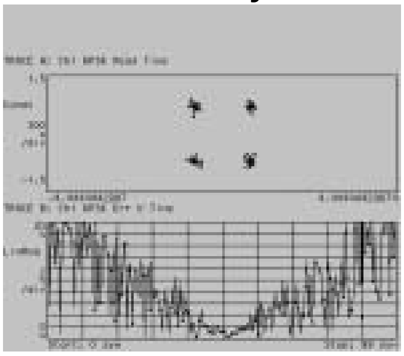


The symbol rate tells the receiver when to sample the transmitted waveform. If the receiver symbol rate is close enough to demodulate the signal but not absolutely correct then the Error Vector Time display shows a characteristic "V" shape.

This slide illustrates the effect of incorrect symbol rate in the demodulation of the signal. In this example, the symbol rate of the transmitted signal is slightly higher than the specified receiver symbol rate (or symbol rate chosen in the analyzer). At one arbitrary reference sample (called 0) the signal will be sampled correctly. Since the symbol rate is slightly off, any other sample in the positive or negative direction will be slightly off in time. Therefore, the signal will deviate by some amount from the perfect reference signal. This deviation or error vector grows linearly (on average) in both the positive and negative directions. Therefore, the magnitude of the error vector versus time shows a characteristic 'V' shape.

Impairment: Incorrect Symbol Rate

a)



b)

Detection and troubleshooting hints:

• Verify the “V” shape of the magnitude of the error vector versus time displa

• For large errors, measure the bandwidth of the signal

This EVM display helps to uncover small symbol rate errors. These are non linear in nature and cannot be compensated by equalization!

The effect of symbol rate errors on the different measurements actually depends on the size of the error and the length of the measurement. If the error and the measurement time are large enough, the analyzer may not be able to demodulate the signal correctly. This means that modulation quality measurements are not useful. Reducing the measurement time can help, unless the symbol error is too large. For instance, for a QPSK system with a specified symbol rate of 1 MHz, an error of 100 kHz (actual symbol rate of 1.10 MHz) causes an unlock condition when making modulation quality measurements, regardless of the measurement time. The best way to verify large symbol rate errors that produce unlock conditions in the measurements is by measuring the signal’s channel bandwidth, which should roughly approximate the symbol rate.

The best way to verify small errors in the symbol rate is by looking at the magnitude of the error vector versus time display. For small errors, this display shows a characteristic 'V' shape, as shown in the slide.

The smaller the symbol rate error, the more symbols are required to detect the error (that is, to form the 'V' shape). For instance, in Figure (a), for a QPSK system with a symbol rate specified at 1MHz, 100 symbols are measured to form a “V” shape in the magnitude of the error vector versus time display for an actual symbol rate of 1.0025 MHz. In the same case, about 500 symbols would be required to form a similar 'V' shape for an actual symbol rate of 1.00025 MHz.

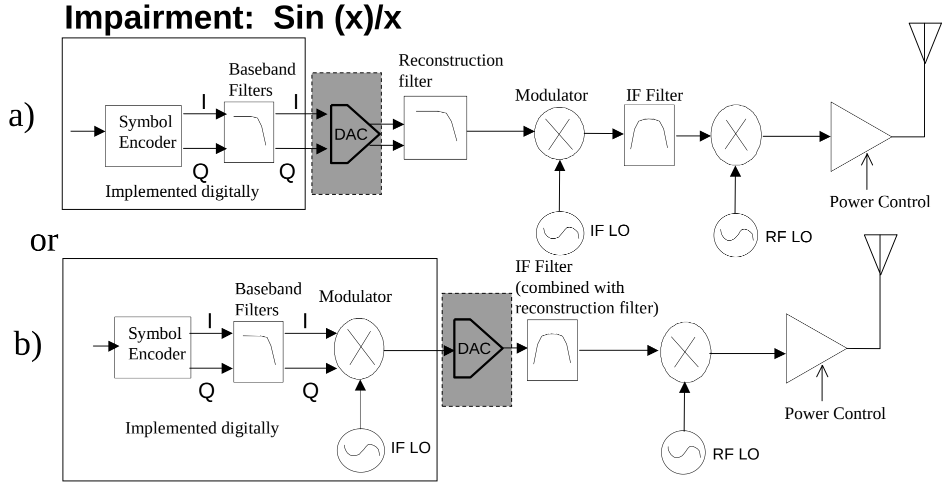
For small errors, the actual transmitted symbol rate can be found by adjusting the symbol rate in the analyzer. This trial and error process is continued until the magnitude of the error vector versus time looks flat.

Sin (x)/x Impairment

Impairment : $\frac{\text{Sin}(x)}{x}$

In this section , we look at impairments that can happen when , we compensate for Sin(x)/x .

Impairment: Sin (x)/x



Sin(x)/x impairment caused by:

- Not compensating for sin(x)/x
- Incorrect oversample ratio or interpolation between sections

Although the ideal output of the DAC is a series of delta impulses that represent the different amplitude levels, in practice the ‘impulses’ have a certain width (t) prior to the reconstruction filter that smoothes the signal. A pulse in the time domain translates into a sin(x)/x function in the frequency domain. In general, for small oversample ratios, the sin(x)/x must be compensated somewhere in the transmitter design.

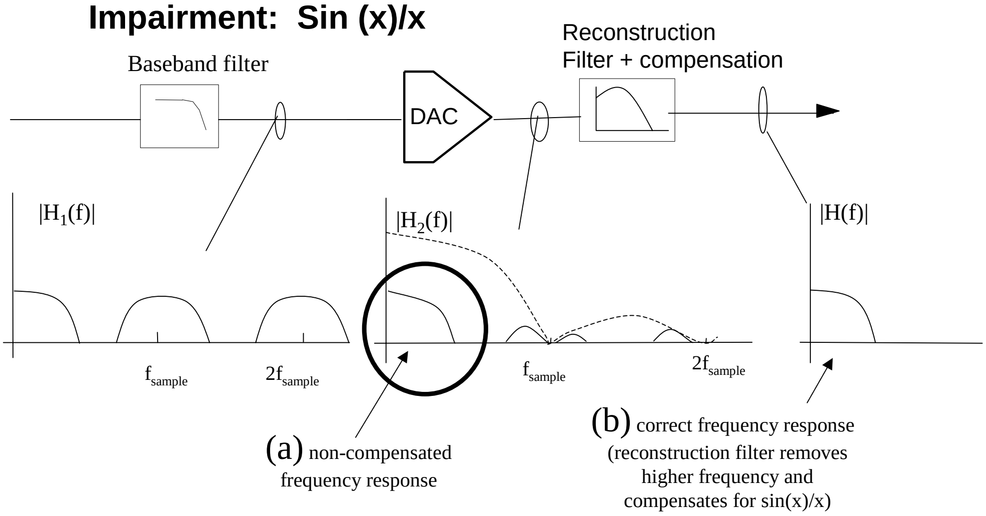
The compensation for the sin(x)/x can be implemented digitally as a pre-distortion function, somewhere before the DAC. It can also be implemented in combination with the analog baseband reconstruction filter or the IF filter.

The sin(x)/x impairment is a common error. Sometimes, it is the result of misunderstanding between the digital and analog teams. For example, each team may assume that the other team’s section is accounting for the error, or both sections may compensate for the error, which also results in a distorted frequency response.

In most cases, the analog team relies on the digital team to implement the compensation as part of their DSP algorithm, for example, as part of the digital baseband filter. The DSP designer may easily forget to apply the correct compensation, especially after changes in the filter design (after applying resample, etc).

The effect of the sin(x)/x on the transmitted signal depends on the oversample ratio. Therefore, an error in the oversample ratio or in the interpolation between sections of the transmitter may also cause an error. For example, if the sample rate in the digital section is four times the symbol rate, and the DACs input rate is only twice the symbol rate, the digital compensating function may be accounting for the wrong sin(x)/x shape.

Impairment: Sin (x)/x



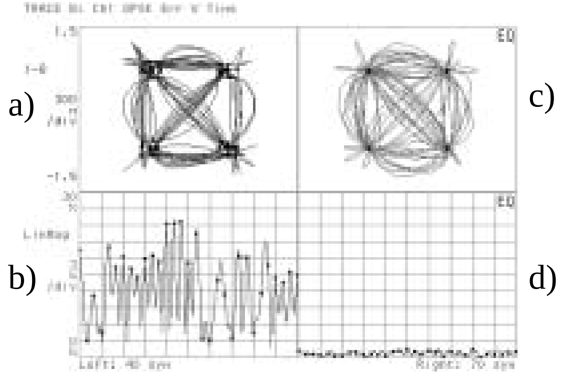
Sin(x)/x is not a problem for high oversample ratios

The importance of the compensation for a transmitter with analog I/Q modulation is illustrated above. In this case, sin(x)/x compensation has been implemented in the analog reconstruction filter (Figure b).

If compensation was not implemented, the spectrum of the transmitted signal would be distorted (Figure a). As mentioned earlier, the amount of distortion depends on the oversample ratio. The width of the sin(x)/x lobes is determined by the sample rate. The higher the oversample ratio, the smaller the effect on the signal's frequency response.

For example, if the sample rate is twice the symbol rate, the sin(x)/x causes an error of 0.91 dB at the 3 dB points, for a root Nyquist filter. For a sample rate four times the symbol rate, the error is 0.224 dB. If the sample rate is sixteen times the symbol rate, the error is only 0.014 dB.

Impairment: Sin (x)/x



Detection and troubleshooting hints:

• Use equalization

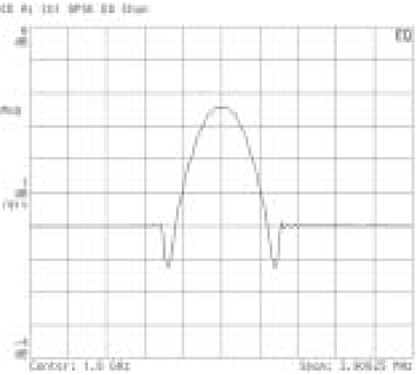
Bad cases of sin(x)/x error have an impact on the signal's spectrum shape. However, the impact of the error in the frequency domain is not always noticeable.

The best way to verify the impairment is by looking at the signal in the modulation domain. Since the sin(x)/x modifies the overall frequency response, intersymbol interference occurs. Therefore, the constellation display and EVM are degraded. The best way to verify sin(x)/x errors is by applying adaptive equalization to remove the effects of these errors in the constellation display and EVM, and by checking the bits-to-RF frequency response, as described later.

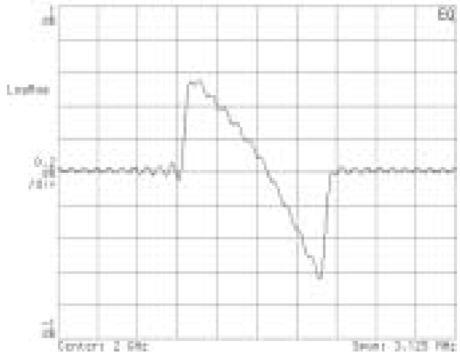
The constellation (Figure a) and display of the magnitude of the error vector versus time (Figure b) of a signal with a sin(x)/x problem are shown above. In this case the sample rate is equal to the symbol rate, and compensation for the sin(x)/x has not been applied anywhere in the design. This results in a very bad case of sin(x)/x error. When equalization is applied, the sin(x)/x error is removed and the constellation (Figure c) and the magnitude of the error vector versus time (Figure d) improve dramatically.

Impairment: Sin (x)/x

a)



b)



Detection and troubleshooting hints:

• Check the bits-to-RF frequency response

Adaptive equalization compensates for linear distortion in the signal. Linear distortion occurs when the signal passes through one or more linear devices having transfer functions containing amplitude unflatness (for example, ripple and tilt), and/or group delay variations over the bandwidth of the signal. From a modeling standpoint, all of the linear distortion mechanisms can be combined and represented by a single transfer function H(f).

When applying equalization, the analyzer must counteract the effects of the linear distortion. To achieve that, an equalizer filter whose transfer function is 1/H(f) is applied over the bandwidth of the signal.

Once equalization has been applied, the inverse transfer function of the equalizer, which represents the linear distortion elements of the device under test, can be displayed and measured. If measured directly at the transmitter's output, the inverse transfer function is basically the bits-to-RF frequency response of the transmitter (or the variations from the ideal frequency response caused by non-linear distortions). The actual frequency response can be displayed and measured as magnitude, phase, and group delay.

Since they are linear errors, sin(x)/x errors can be removed by applying equalization and identified by examining the transmitter's bits-to-RF frequency response. Not compensating for the sin(x)/x creates a frequency response distorted by the sin(x)/x shape. Assuming that there are no other linear impairments in the transmitter, in the case of a transmitter with an analog I/Q modulator, the bits-to-RF frequency response has a rounded top instead of a flat one or, in the worst cases, a sin(x)/x shape (Figure a). In the case of a transmitter with a digital IF, the frequency response is usually distorted by a more linear section of the sin(x)/x. The result is a tilted bits-to-RF frequency response (Figure b).

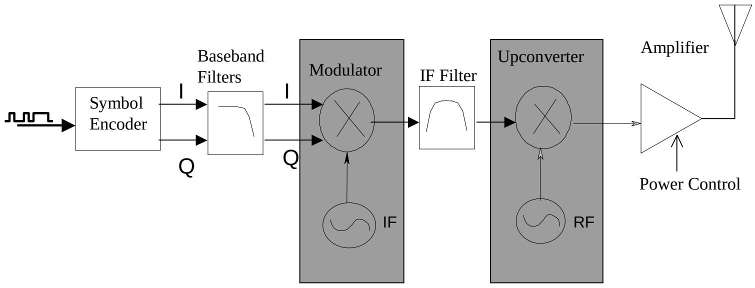
In practice, there are often other linear impairments in the design (for example, other problems in the baseband filtering), which may also be affecting the frequency response.

Interference and spurious

Impairment : Interfering tone or spur

In this section, we look at the mixer portions in the transmit chain and the impairments that can creep in affecting transmitted frequency , interfering with adjacent channel to name a few.

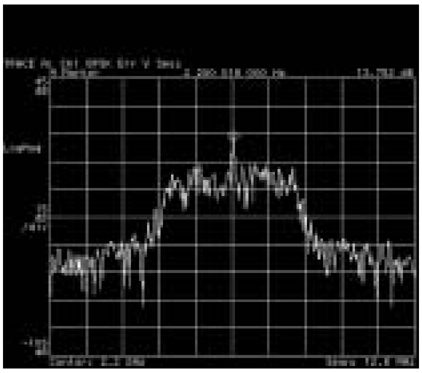
Impairment : **Interfering tone or spur**



A tone or spur generated anywhere in the transmitter can interfere with the transmitted signal if it falls in the signals bandwidth. In-channel interfering tones are usually masked by the signal in the frequency domain. If it is outside of the signal's bandwidth, it can cause interference with other channels or systems.

Interfering tones are typically caused by interactions of internal signals in active devices(such as mixers and amplifiers)

Impairment : **Interfering tone or spur**



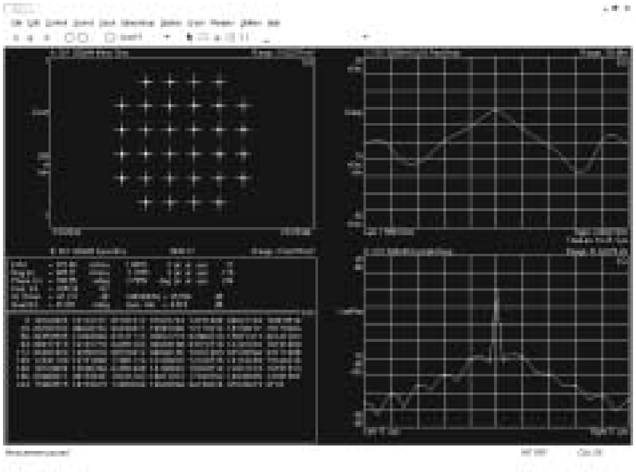
Error Vector Spectrum Identifies Spur Frequency
whereas Signal Spectrum conceals spur!

Threshold-to-Interference Ratio (Blocking), Carrier-to-Interference Ratio (C/I)

Interfering signals hinder proper reception when they degrade the threshold of a victim receiver, blocking its intended signal. The Threshold-to-Interference Ratio (T/I) is highly dependent on the filtering employed in the receiver to block unwanted signals and the frequency offset of the interfering signal. Testing involves observing the victim receiver's threshold performance while an interfering signal is injected at different power levels and frequency offsets, often at adjacent, semi-adjacent and twice adjacent channels. **Tip:** Use a VSA to record an interfering transmitter signal and transfer the recording to a signal source with a large arbitrary memory. Then the interfering signal offset frequency and amplitude can be easily varied while observing the BER of the victim receiver.

Further Reading — Agilent Application Note 1314, Section 2.4

Coping with Channel Impairments and Interference



Coping with Channel Impairments and Interference

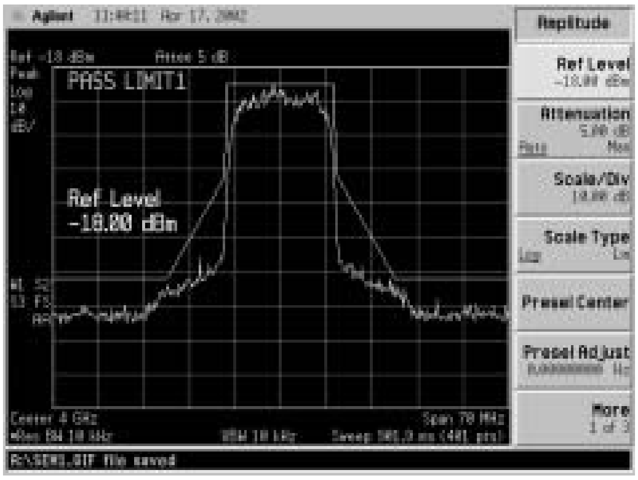
When a signal travels over a channel (path) it usually suffers some impairment from the channel, an interference source, or both. Common impairments are amplitude attenuation, group delay (dispersion) and multipath. Signals from other transmitters and narrowband interferers are common sources of interference.

Group Delay (Dispersion)

Signals with spectrums occupying a finite bandwidth comprise many frequencies. Often the components in the channel between the modulator and demodulator delay each frequency group differently. Thus, at the demodulator, spectral components arrive at incorrect times. Multi-path signals can also sum to create dispersion (group delay). Group delay created in filter and power amplifier components can be measured with a vector network analyzer, or with a signal source and a vector signal analyzer (VSA). **Tip:** Since group delay is highest for narrowband components such as baseband and IF filters, consider using a VSA to measure the delay and supply the impulse response coefficients for digital compensation in the equalizer.

Further Reading — Agilent Application Note 1313, Section 2.3.1.7.4

Verifying Regulatory operation - SEM

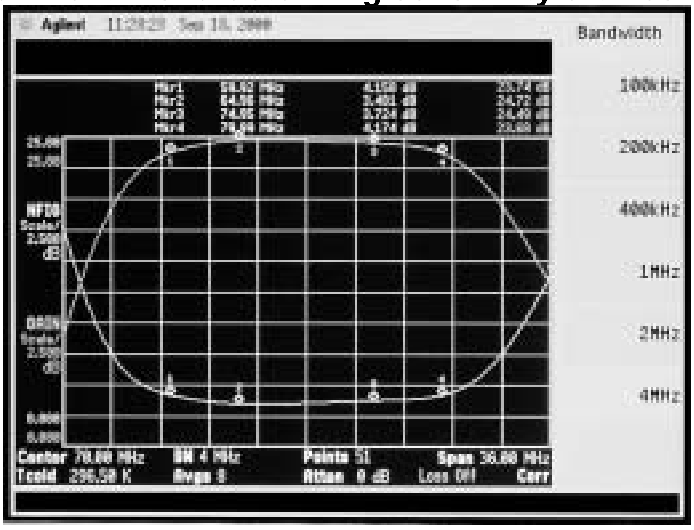


Verifying Proper Regulatory Operation

Transmitter compliance with regulations and standards usually addresses three main elements: Is the emitted spectrum the correct shape?

The SEMs defined by regulatory agencies and standards bodies ensure the usability of radio channels above or below the operating channel. A SEM thus addresses the impossibility of synthesizing or filtering a signal with an infinitely steep frequency response. Measured with a spectrum or signal analyzer, common issues include spurious signals "leaking" into the desired transmit signal path and nonlinearities that cause signal sideband growth (spectral re-growth). **Tip:** Use an analyzer that has built-in limit-line capability or automatic SEM measurements.

Impairment – Characterizing sensitivity & threshold



Characterizing Sensitivity and Threshold

Sensitivity is the minimum signal level at which a change is just detectable, and threshold is the minimum signal at which reliable communication/identification is possible. Most digital communications links are specified in terms of a *threshold received power level* for a given bit-error rate (BER). A few key factors influence threshold received power level:

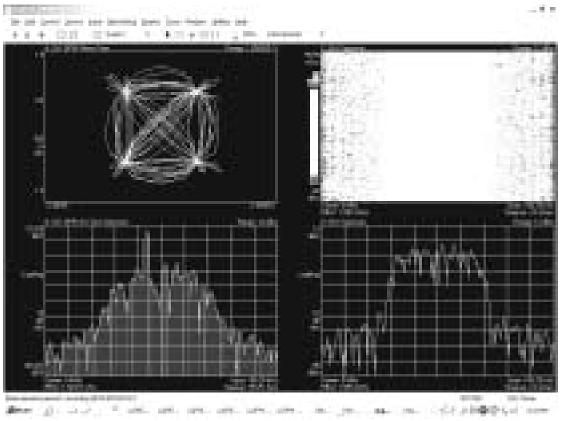
kTB	(Boltzmann's Constant)(System Temperature in Kelvin)(Bandwidth)
	10log(kTB) = -174 dBm @ 290˚K, 1 Hz
BW_{Noise}	Equivalent Noise Bandwidth ($\approx$ Occupied Bandwidth)
NF	Noise Figure
S/N	Signal-to-Noise Ratio or Carrier-to-Noise Ratio (C/N) for a given BER

Noise Figure

Noise figure is the ratio of output signal-to-noise to input signal-to-noise and can be measured with a NF analyzer. System NF can be measured directly or using Friis' formula computed from components:

Tip: Noise figure measurements are sometimes neglected in transmitter power amplifier chains, leading to very high noise power spectral densities that can cause local receiver desensitization. Often in Frequency-Division-Duplex (FDD) systems it becomes necessary to compensate for this by over-engineering expensive, lossy, multi-pole transmitter diplexing filters. As a less expensive alternative, consider monitoring transmitter noise figure.

Enhancing Modulation Quality



Enhancing Modulation Quality

The modulation process of converting signals or data — binary 1s and 0s, on/off voltages — to a signal that can be transmitted through the channel (air) gives rise to the concept of modulation quality. How well does the analog signal and symbols represent the intended data? Common metrics include constellation analysis, EVM, EVM spectrum and CCDF.

Further Reading — Agilent Application Notes 1313, Section 2.3.1.7

Constellation Analysis

A vector signal analyzer (VSA) can display digital modulation formats as a constellation of symbol points. This can help optimize the constellation geometry and is essential to getting the most from any modulation format. Measurements such as quadrature skew (skew of a square constellation), I/Q imbalance (rectangularity of a square constellation), phase noise, distortion and internal interfering signals are visible on a constellation diagram.

Further Reading — Agilent Application Note 1314, Section 3.2.1

Error Vector Magnitude (EVM)

EVM represents the difference between a reference receiver's vector interpretation and the actual transmitted vector, over time. It is a measure of how well the modulator generates the signal. EVM is particularly useful for comparative analysis where a single impairment (noise or distortion) dominates. The measurement can be performed with a vector signal analyzer.

Further Reading — Agilent Application Note 1313, Section 2.3.1.7.1

EVM Spectrum

An EVM spectrum is obtained by taking the Fourier transform of the EVM time record. EVM spectrum, also measured with a vector signal analyzer, is particularly useful for detecting spurious interferers (e.g., power supply noise and clock) or LO leakage embedded beneath the modulated spectrum.

Further Reading — Agilent Product Note 89400-14A, p. 13

Essential Tests & Tips for a better transmit/receive performance

Characterize Sensitivity & Threshold

Cope with Channel Impairment and Interference

Verify regulatory operation

Maximize transmit power but minimize distortion

Enhance modulation quality

Ensure your oscillators are trouble free

These are some good tips to check the quality of your design.You may refer to the poster at our website www.agilent.com/find/testrf .

Q&A

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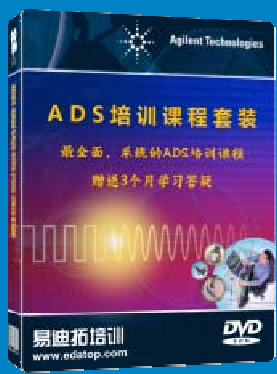

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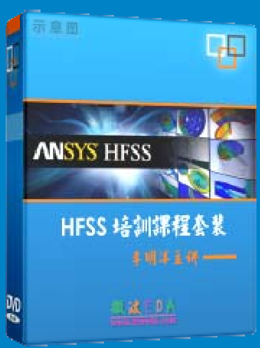

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