Signal Generation Basics

Introduction

- signal generator (signal source) is an instrument which outputs a defined signal (used for various purposes)
  - signal can be an unmodulated (harmonic) sine wave...
  - ... or a modulated signal (analog, digital, pulse, ...)
  - signal can be produced at a given frequency and amplitude
- signal generators can be used for the testing of receivers, various sub-components and systems
  - the goal is to produce precise and stable (repeatable) test signals
  - signal generators can also apply impairments to test the robustness of the DUTs (receivers, ...)

Testing components

- examples of component tests:

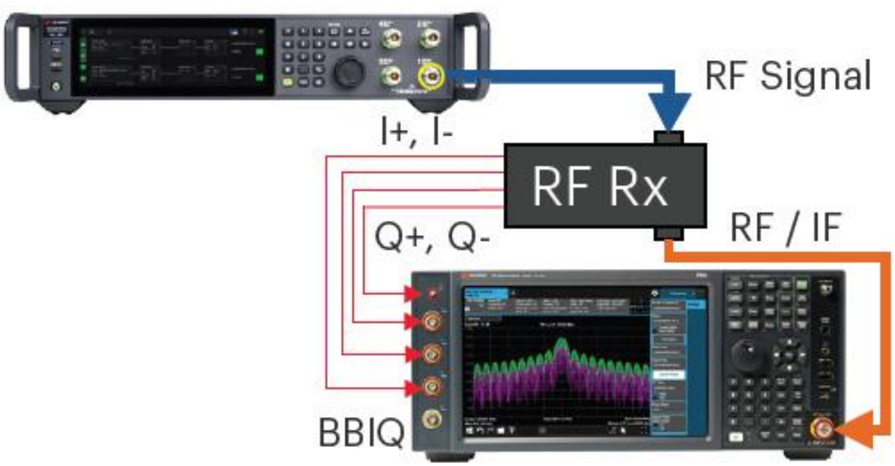
- measuring the influence of the DUT on the input signal
- any passive or active DUT
- modulated/unmodulated signals

- 2-tone tests; intermodulation distortion

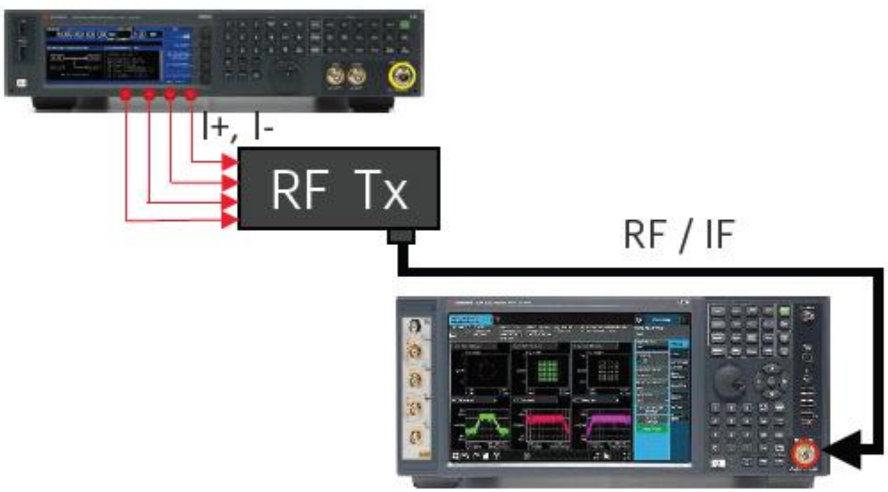
Testing components

- examples of component tests:

- supplying a RF signal to a receiver under test



- generating I/Q baseband signals for a tested transmitter

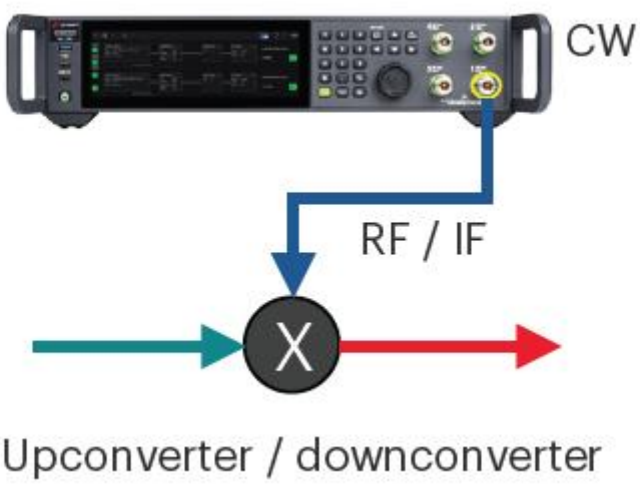


Testing components

- examples of component tests:

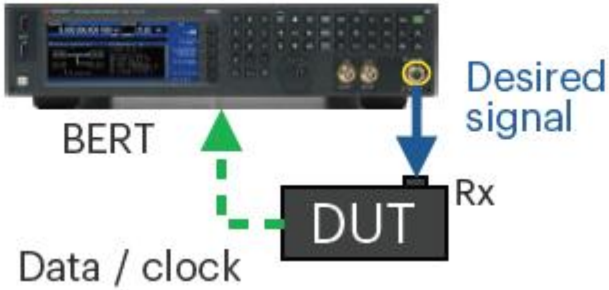
- signal generator as a component (RF modulator):

- signal generator as a component (local oscillator):

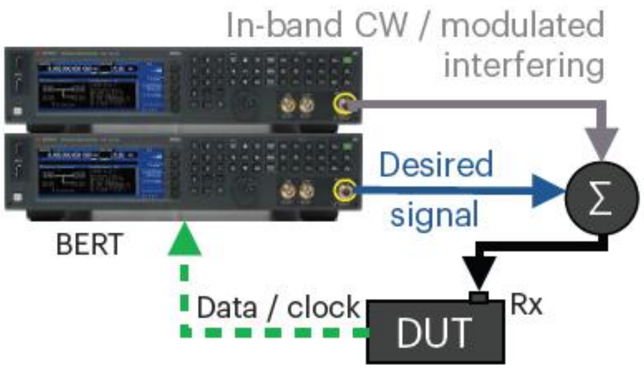


Testing receivers

- sensitivity, dynamic range, accuracy
  - generator produces a test signal at defined level and the receiver has to be able to receive it correctly
  - the receiver should be able to report the level of the received signal

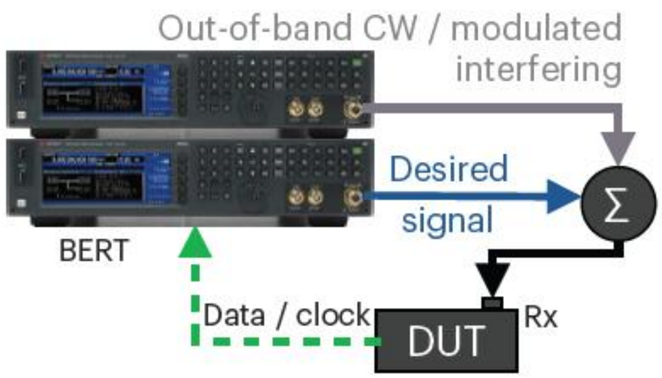


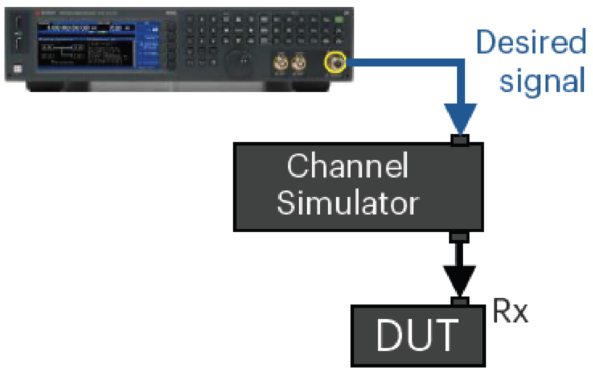
- co-channel rejection
  - two signal generators – the desired signal + in-band interferer
  - testing the immunity of the receiver to other signals present in the same channel



Testing receivers

- immunity to out-of-band signals
  - testing of the sensitivity to out-of band / adjacent band interfering signals
    - signals of the same comm standard present in adjacent channels
    - spurious signals
- fading immunity
  - test signal is put through a channel emulator which can simulate a complex multipath propagation and attenuation of the signal





Types of signal generators

- waveform / function generators
  - lower frequency generators capable of generating various basic shapes of waveforms – sine, square, ramp, pulse, triangle, DC, ...
  - generation of arbitrary (user defined) waveforms
  - output waveforms can be modulated (AM, FM, burst, ...)
  - output is typically very clean with low distortion
  - typical frequency range is from very low frequencies (μHz) up to tens or hundreds of MHz (up to 120 MHz for Keysight generators)
  - Keysight offers the „Trueform“ 33500 and 33600 series AWGs
  - can be used to generate high fidelity low frequency signals, for example for baseband I/Q modulating waveforms

Types of signal generators

- high speed AWGs
  - specialized high speed / high bandwidh / high resolution arbitrary waveform generators
  - up to 256 GSa/s sample rate and 80 GHz of analog bandwidth
  - used typically for generating of:
    - high speed digital signals
    - high bandwidth RF signals (FMCW radars, electronic warfare...)
  - can be used to generate basically any signal which fits into the arb memory and the bandwidth of the instrument
    - like the counterpart of oscilloscopes...

Types of signal generators

- RF signal generators
  - the traditional synthesized RF signal generator use a frequency reference, a PLL, series of frequency multiplexers and dividers and a level control chain (amplifiers/attenuators) to get the desired output signal (frequency and amplitude)

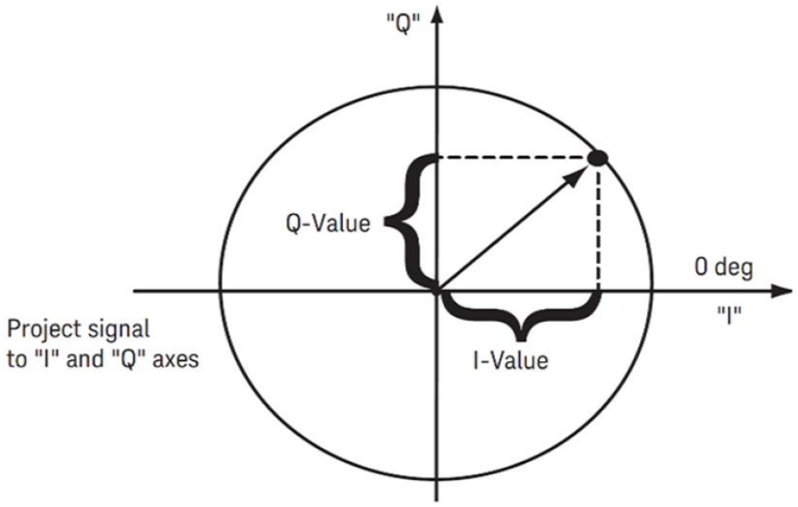
1) analog signal generators
   - can supply sinusoidal continuous wave (CW) signals and several types of analog modulation like amplitude, frequency, and pulse modulation
   - sweep capabilities (frequency / amplidude)
2) vector signal generators
   - all the capabilities of analog SGs + the ability to create digital modulations
   - certain modulation bandwidth around the center/carried frequency
   - basically, the direct counterpart of signal analyzers...

IQ Modulation

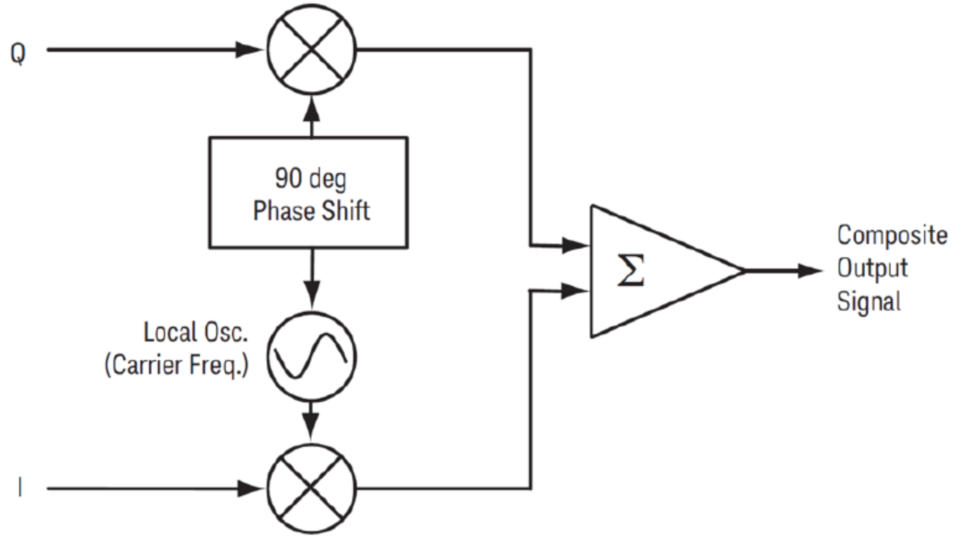
- modulation is the process of varying one or more properties of the carrier signal with the modulation signal that contains information to be transmitted
  - **amplitude**, **phase** and **frequency** of the carrier can be changed
- IQ modulation uses two amplitude modulated carriers – the in-phase (I) and the quadrature (Q) component
  - both components are phase shifted by 90° and are orthogonal
  - by adding these two components, it is possible to create an arbitrarily modulated sine wave
  - the vector signal generators use IQ modulators (block diagram)

IQ Modulation

- I/Q phasor diagram:

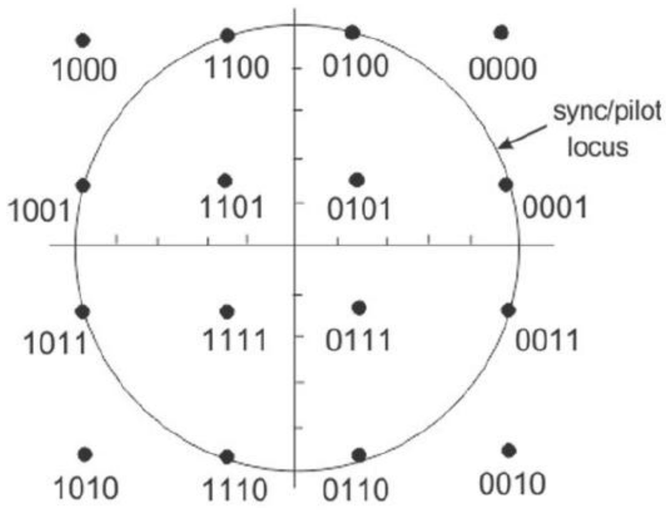


- IQ modulator:

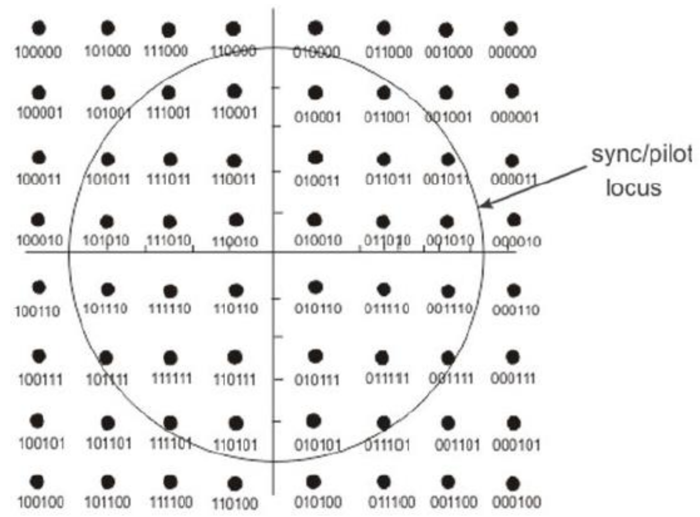


Modulation schemes

- the most common modulation schemes/types are the
  - PSK – phase shift keying
  - FSK – frequency shift keying
  - ASK – amplitude shift keying
  - QAM – quadrature amplitude modulation



16-QAM Symbol Constellation



64-QAM Symbol Constellation

Modulation schemes

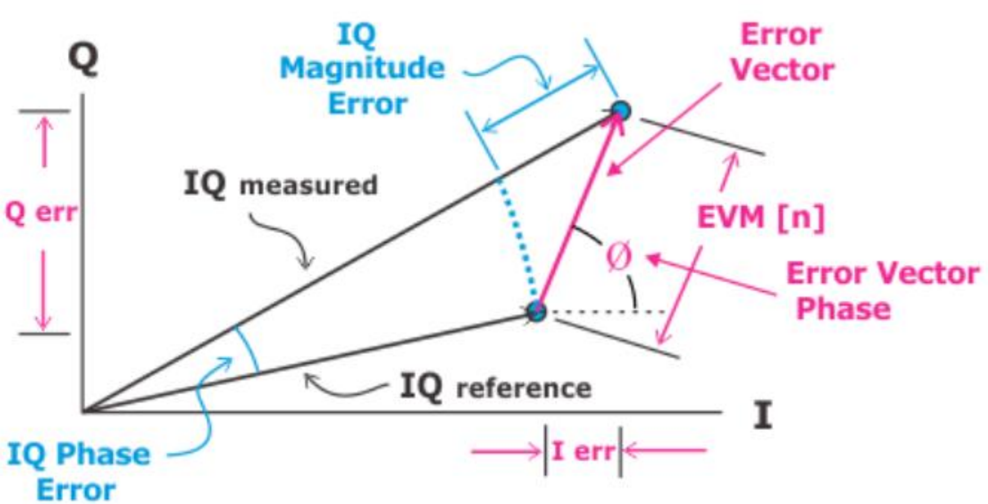
- a constellation diagram shows the available symbols of the particular modulation format
  - in the case of a 16-QAM format, each symbol represents one of the combinations of four bits; for 64-QAM, it’s 6 bits per symbol
  - higher modulation schemes have higher spectral efficiency (more bits per symbol, lower symbol speed and narrower bandwidth)
  - however, as the symbol locations are closer together, the transmission is more prone to errors due to noise and distortion
  - the modern communication technologies can use multiple different modulation schemes and switch between them dynamically as the conditions change

EVM

- an error vector is the vector difference between the ideal I/Q reference signal (constelation point) and the measured signal
  - EVM (Error Vector Magnitude) is the RMS of the error vectors computed and expressed as a percentage of the EVM normalization reference
  - for constellations with constant magnitude (QPSK, BPSK, 8PSK, ...), the „normalization reference“ can be the constellation maximum
  - for constellations with multiple possible magnitudes (QAM, ...), the RMS of reference symbol points is typically used as the normalization reference

$$\%\ \mathbf{EVM} = \frac{\sqrt{\frac{1}{N}\sum_{n=0}^{N-1} \mathrm{Ierr}[n]^2 + \mathrm{Qerr}[n]^2}}{\text{EVM Normalization Reference}} \times 100\%$$

where: n = symbol index
N = number of symbols
Ierr = I Ref - I Meas
Qerr = Q Ref - Q Meas

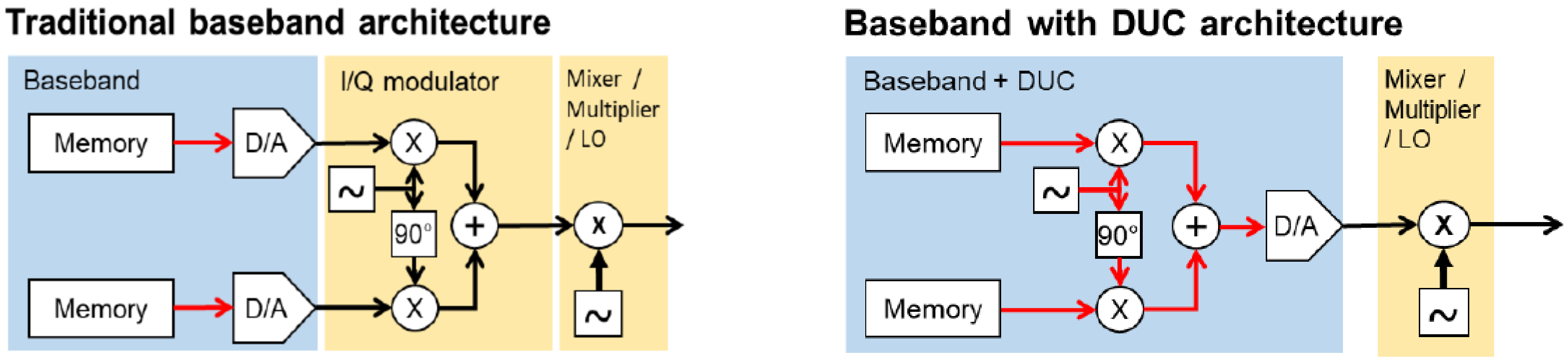


EVM

- vector signal generators can intentionally simulate I/Q impairments to stress-test the DUTs (receivers) or to compensate for imperfections in the signal path
  - **I/Q offset** - DC offsets of the I and Q signals
  - **quadrature angle** – phase offset between the I and Q signals
  - **I/Q skew** - a relative time delay between the I and Q signals
  - **I/Q gain balance** - the amplitude difference between the I and Q
  - **I/Q phase** - the absolute phase of the internal I/Q channel by rotating both I and Q

Types of signal generators

- some of the latest VSGs (**M9484C**) replace the I/Q modulator with direct digital synthesis (DDS) technology
  - up to 8,5 GHz – 14 bit DAC directly to RF (basically a AWG)
  - upconversion for higher output frequencies
  - 2,5 GHz of modulation bandwidth
  - better signal quality than the traditional vector generators – phase noise, modulation quality (EVM), ACP, …



Important parameters

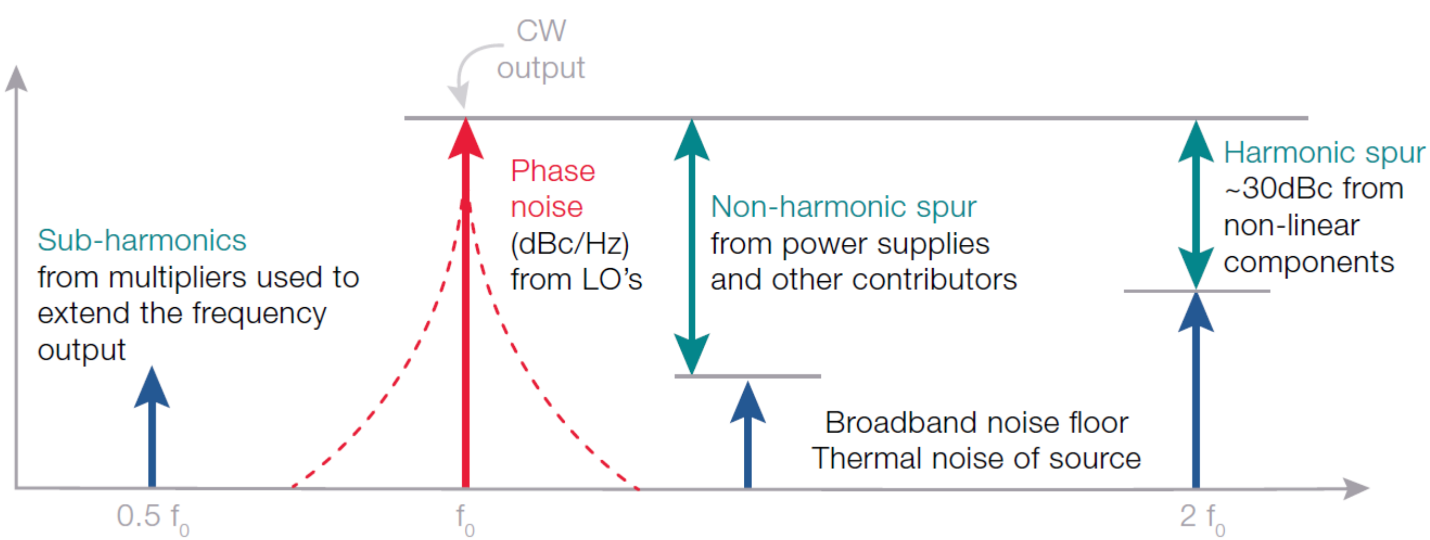
- frequency
  - range typically from 9 kHz up (to 6/7/8 GHz for RF generators and higher for mw instruments)
  - frequency accuracy – defined by the timebase accuracy
  - switching speed – important for certain applications
- amplitude range
  - generators equipped with output attenuators can produce very low levels (< -140 dBm); important for sensitivity testing
  - the maximum output level is a very important parameter for some applications; the rf/mw power is expensive and in some cases, the generator alone can replace an amplifier
    - OTA measurements, receiver tests, compensation of signal path losses

Important parameters

- average and peak envelope power
  - the specified maximum output power applies to CW signal or to the PEP (peak envelope power) for modulated signals
  - modern signals using QAM + OFDM modulation can have large peak to average power ration (PAPR)
  - it is important to know the PAPR and set the output level of the generator so the signal is not clipped in it’s power peaks

Important parameters

- spectral purity
  - a perfect signal generator would generate a sine wave at a single frequency without the presence of noise
  - in practice, there is always noise and distortion:
    - phase noise - a frequency domain view of the noise spectrum around the signal; frequency stability of the oscillator
    - harmonics – caused by nonlinearities and the resulting distortion
    - spurs – other parasitic signals present in the output spectrum



Important parameters

- modulation bandwidth
  - very important for vector signal generators
  - modern communication technologies can use very wide badwidth
    - for example up to 320 MHz for 802.11be
    - UWB, FMCW radars, ...
- modulation quality
  - modern standards (mostly WLAN) use very high level modulation formats (4096-QAM) and require very low levels of EVM
  - in order to be able to test the receivers, the vector signal generators need to be very good (EVM ~ -50 dB)

Important parameters

- when testing any DUT using a signal generator, it is very important that the SG has to be better in the measured quantity than the tested device
  - accuracy and stability of level and frequency
  - harmonic distortion, intermodulation distortion
  - phase noise
    - radar applications
    - digital modulations (phase smearing of the symbols; OFDM leakage)
  - residual EVM
  - ...

Software

- signal creation software is a key thing when working with the vector signal generators
  - the signals in the digital form can be generated „manually“ in some general signal processing software (Matlab, ...) ...
  - ... or, it is possible to use applications specialized for this purpose
- Keysight offers various versions of the „PathWave Signal Generation“ (Signal Studio) software
  - some of the variants are targeted to specific wireless standards and some can be used for creation of general modulated signals
  - software is relatively simple to use and offers configuration options specific for the given application
  - desktop (PC) or embedded (latest SGs – VXG, new MXG) versions

Software

Current model[4]	Communications standard
N7600C	W-CDMA / HSPA+
N7601C	cdma2000® / 1xEV-DO
N7602C	GSM / EDGE / Evo
N7612C	TD-SCDMA / HSPA
N7624C	LTE / LTE-A FDD
N7625C	LTE / LTE-A TDD
N7626C	LTE V2X
N7630C	5GTF (pre-5G)
N7631C	5G NR (New Radio)

Current model[4]	Communications standard
N7606C	*Bluetooth*® (BR, EDR, 4.0 / 4.2, BT5, BT5.1 (AoA and AoD) , BT5.3
N7607C	DFS radar profiles
N7610C	IoT (Internet of Things) (Wi-SUN, ZigBee®, Z-Wave, LoRa, and HRP UWB)
N7615C	Mobile WiMAX™
N7617C	WLAN 802.11 a / b / g / j / p / n / ac / ah / af / ax / be
N7637C	mmWave WLAN 802.11ad / ay

Current model[8]	Description
N7609C	Global navigation satellite systems (GNSS)
N7620B	Pulse building

Current model[8]	Communications standard
N7611C	Broadcast radio (FM Stereo/RDS, DAB, T-DMB)
N7623C	Digital video (w / DOCSIS3.1)
N7640C	Land-mobile radio

Current model[3]	Description
N7605C	Real-time fading
N7608C	Custom modulation (Custom IQ and OFDM)
N7614C	Power amplifier test
N7621B	Multitone distortion
N7622C	IQ toolkit

Software

- compatible instruments:
  - benchtop RF signal generators – CXG, EXG, MXG, VXG, PSG
  - wireless test sets – EXM E6640A, E6680A, E6681A
  - PXIe modular VSGs and transcievers – M9421A, M9410A/11A
  - AXIe arbitrary waveform generators – M8190A, M8195A, ...

Available instruments

- RF/MW benchtop signal generators:

PSG

Metrology Grade

100 kHz to 44 GHz, 80 MHz BW

100 kHz to 67 GHz

VXG

Multi-Channel

1 MHz to 44 GHz, 2 GHz BW

9 kHz to 54 GHz, 2.5 GHz BW

MXG

Pure and Precise

9 kHz to 6 GHz, 160 MHz BW

9 kHz to 40 GHz

N5186A MXG

9 kHz to 8 GHz. 960 MHz BW

Multi-channel

EXG

Cost-effective

9 kHz to 6 GHz, 160 MHz BW

9 kHz to 40 GHz

CXG

Multi-Functional

9 kHz to 3/6 GHz, 120 MHz BW

Available instruments

- PXIe modular VSGs and transcievers:

M9381A

M9410A/11A

M9421A

M9415A

Available instruments

- wireless test sets – EXM E6640A, E6680A, E6681A

E6640A

E6681A

E6680A

Available instruments

- function / arbitrary waveform generators:

M8190A

E336xxA