Instrument Fundamentals: Signal Generator Basics
Agenda

► What is a Signal Generator
► Types of signal generators
  ➢ Analog signal generator fundamentals
    – Signal quality
    – Analog modulation
  ➢ Vector signal generator fundamentals
    – About vector signals
    – Modulation types and applications
    – Baseband and IQ
    – Impairments and fading
► Summary
What is a signal generator

► Signal generators play a vital role in test and measurement.
► Generate test signals when applied to components such as filters, amplifier or entire modules.
► Determine the component’s behavior and characteristics.
► Beyond the output of spectrally pure signals.
  – Key functions are analog and digitally modulated signals.
Types of signal generators

- **Analog Signal Generator**
  - Continuous wave (CW) source
  - Basic analog modulation
    - Amplitude Modulation
    - Frequency Modulation
    - Phase Modulation
  - Pulse Modulation
  - Avionics (e.g. VOR, ILS, etc.)

- **Vector Signal Generator**
  - Can create any arbitrary type of digital or analog signal
    - Digital signals (Wi-Fi, LTE, GNSS, etc.)
    - Special signal types (e.g. MCCW)
    - Arbitrary waveform files
    - Impairments and fading
Types of signal generators

Analog Generator

Vector Generator

Ref Osc
Synthesizer Section
Analog Modulation
Output Section

Ref Osc
Synthesizer Section
IQ Modulator
Baseband Generator
Analog Modulation
Output Section
Where are analog signal generators used?

- Analog signal generators applications:
  - High-quality signals (e.g. local oscillator substitution)
  - Measurements of gain, linearity, bandwidth, etc.
  - Component development / testing (e.g. ADCs)
  - Receiver testing (two-tone tests, creation of interfering or blocking signals)
  - EMC testing
  - Avionics applications (e.g. VOR, ILS)
  - Military / radar applications
- Two main advantages of analog over vector:
  - Cost
  - Signal quality
Analog signal quality

Analog signal generators excel at creating high-quality RF signals

**Frequency**
- Range
- Accuracy
- Drift
- Setting time

**Level**
- Range
- Accuracy
- Linearity
- Repeatability
- Setting time

**Spectral purity**
- Phase noise
- Wideband noise
- Harmonics
- Spurious
Unmodulated (CW) signals

- Simple unmodulated carrier (sine wave) signal
- Basic settings:
  - Frequency
  - Level
- High-quality, spectrally pure CW signals are very important in many applications
- List and sweep modes can be used to change frequency and/or level using predefined, user-specified values
Basic analog modulation

- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Modulation (φM)
Simple pulse modulation

- Many analog sig gens can create basic (unmodulated) pulses
- “Unmodulated” means that carrier frequency, amplitude, and phase do not change during the pulse
- Pulses may be sent
  - At fixed intervals
  - At non-fixed intervals based on a user-defined list
- More complex or “modulated” pulses require the use of a vector signal generator
Avionics standards

- Many avionics (navaid) standards can be generated by analog signal generators

VOR

ILS (Localizer / Glideslope)

Marker Beacon
Analog signal generators – selection criteria

- Primary criteria
  - Phase noise
  - Harmonics
  - Output power
- Secondary criteria
  - Switching speed (frequency and amplitude)
  - Amplitude accuracy
  - Modulation support
About vector signals

- An **analog** signal has a magnitude
- A **vector** signal has a magnitude and **phase**
  - Used for sending digital information ("bits")
- Almost all digital modulation schemes (LTE, 5G NR, Wi-Fi, Bluetooth, etc.) use vector modulation
About IQ

- Magnitude and phase can be converted into two magnitude values:
  - In-phase ("real")
  - Quadrature ("imaginary")
- In the RF world, vector signals are usually represented as “IQ” values
  - Pairs of real and imaginary values
  - Greatly simplifies vector signal generation and analysis

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About vector signal generators

- A vector signal generator produces signals using IQ values
- IQ values can be provided by:
  - An internal generator
    - Generated in realtime
    - Pre-generated internally
    - Loaded from a file (externally generated)
  - An external source (analog or digital)
- No industry-wide standard for IQ data format
- The term **baseband** is used to refer to IQ signals before they are converted to RF
Where are vector signal generators used?

- Vector signal generator applications
  - Generating signals for wireless communications, digital broadcast, GNSS, etc.
  - Generating signals for multi-antenna systems (MIMO) and beamforming
  - Simulating signal impairments (noise, interferers, fading, etc.)
**Vector signal generator block diagram**

**Baseband**
- IQ data is loaded / generated, filtering, etc.

**IQ Modulator**
- IQ data is converted to RF

**RF**
- Setting of frequency, level, analog modulation
About generator bandwidth & flatness

• Generator bandwidth represents the maximum “width” of the generated signal
  • 10 MHz LTE signal requires a bandwidth of at least 10 MHz
  • Many modern technologies require bandwidths in the high 100s of MHz or even several GHz
  • Important to choose a generator that has sufficient bandwidth
  • Wide bandwidths present special challenges (e.g. maintaining spectral flatness).
  • Flatness is the gain variation over waveform bandwidth

[Diagram showing a 10 MHz bandwidth signal]
About baseband sources

Realtime generator
Conversion / conditioning
Internally-created ARB
ARB Memory

Baseband

Analog IQ
Digital IQ

External ARB file

Internally-created ARB

Conversion / conditioning
Playing out ARB waveforms

- Waveforms for modulated signals are usually created on a (sub)frame basis
  - e.g. LTE, 5GNR, 802.11 (Wi-Fi), etc.
- Waveforms can be played out
  - Once
  - Continuously
  - Whenever an external trigger is received
Markers

- Some test scenarios require synchronization with the generated signals
- **Markers** can be used to indicate when a waveform (or part of a waveform) is being generated
  - e.g. marker is output at the start of each transmitted frame
- Requires a secondary connection between generator and receiver
Realtime signal generation - general

- Realtime generation of signals based on configured parameters
  - Modulation type (FSK, PSK, QAM, etc.)
  - Modulation parameters (e.g. symbol rate, filter, etc.)
  - Data (file, pattern, PRBS)
- Long sequences can be generated
- Low memory requirement
- Example application: bit error rate tests

Modulation Type

Modulation parameters
10 ksymb/sec
RRC filter 0.3

Data
110010101110
Realtime signal generation - GNSS

• Realistic GNSS (global navigation satellite system) simulation requires long-term signal generation
  • Receivers require time to lock on the signal
  • Receiver testing involves tracking satellites over longer periods of time (minutes, hours, days)
  • Satellites rise and set over time
• Static ARB files can be used to test receiver sensitivity, but not location
• Vector signal generators create realtime GNSS signals from many satellites based on user-supplied data on satellite constellation, time/date, receiver location, etc.
IQ Modulator

- I and Q values are converted to RF using an IQ modulator
- When using IQ for modulation, the signal is split into two paths (I and Q)
  - In the Q path, the oscillator is shifted 90 degrees (“quadrature” means “separated by 90 degrees”)
- The I and Q signals do not interfere with each other when combined and transmitted
- Normally, the IQ modulator settings do not need to be adjusted by the user
RF Block

- Final basic block in a vector signal generator
- Used to define:
  - Frequency
  - Level
  - Analog modulation (AM, FM, ΦM, Pulse)
  - Steps / sweeps of frequency and/or level
Impairments

Baseband

Fading

Noise / Interferers

IQ Modulator

RF

IQ Impairments
Baseband impairments

- Baseband impairments
  - Noise (AWGN)
  - CW interferers
  - Impulse noise
  - Phase noise

![CW interferer](image1)

![Phase noise](image2)

![Noise (AWGN)](image3)

![Impulse noise](image4)
About AWGN

- AWGN = additive white Gaussian noise
  - **Additive** means combined with the useful signal
  - **White** means noise is constant over frequency
  - **Gaussian** describes how the noise changes over time
- Testing under real-world conditions
- Create a controllable signal-to-noise ratio (SNR)
  - Receiver sensitivity testing
  - Bit / block error rate testing
- Possible to generate a “noise only” signal
  - Useful for some types of testing
About CW interferers

- CW = continuous wave (unmodulated carrier)
- Used in many types of receiver blocking tests
- Can be placed near or within the useful signal
- Power level can be adjusted
About impulse noise

- Impulse noise has an on-off or “bursty” pattern
- Many real-world interference sources of impulse noise
  - Unintentional: spark plugs, motors, etc.
  - Intentional: radar or bursty modulation types
- Defined using pulse width, number of pulses, and interval between the pulses
About phase noise

• Phase noise is short term variations in the frequency of a signal
• Excessive phase noise can cause many types of problems
  • High EVM in communications systems
  • Errors in radar systems (masks slow-moving targets)
• We want a signal generator with the lowest possible phase noise
• However, in some cases we want to be able to add a controllable, definable amount of phase noise to a generated signal for device testing.
Adding phase noise impairments

- Phase noise can be added to the baseband signal by defining the amount of phase noise at given frequency offsets.
- Example: adding phase noise to a signal leads to “rotation” of the constellation diagram and increased bit errors.
- This allows us to determine the maximum acceptable level of phase noise in the components, systems, etc.
About fading
Quantifying and simulating fading

- Multiple copies of the signal can arrive with
  - Different delays
  - Different levels
  - Different frequency shifts (Doppler)
- Echoes with similar delays can be modeled as different “taps”
- Each tap’s delay, attenuation, and fading behavior are defined
- A vector signal generator can then “fade” the signal using each tap’s parameters
- Many communications standards require testing with standardized fading profiles.
IQ impairments

- I and Q signals should be (exactly) 90° apart and have identical amplitudes
- Imperfections in the IQ modulator / demodulator can lead to errors
  - Not a function of propagation
- Vector signal generators can (intentionally) create different types of IQ impairments, e.g.
  - Quadrature offset
  - Gain offset
Vector signal generators – selection criteria

- Primary criteria
  - Bandwidth
  - Flatness
  - Low phase noise
  - Low EVM
- Secondary criteria
  - Output power
  - ARB memory length
- Special features or application-specific options
Summary / Q&A

► Analog signal generators
  – Signal quality
  – Analog modulation
► Vector signal generators
  – Digitally modulated signals
  – Baseband → IQ → RF
  – Impairments and fading