Signal Analysis Basics

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Agenda

• Overview
  What is signal, vector and spectrum analysis?

• VSA Theory of Operation
  Vector Signal Analyzer architecture

• Agilent VSA Solutions

• Signal Analysis

• Built-in Applications
  Phase Noise
  Noise Figure
Overview

What is Signal, Vector and Spectrum Analysis?

Spectrum Analysis
- Display and measure amplitude versus frequency for RF & MW signals
- Separate or demodulate complex signals into their base components (sine waves)
Measurements on Digital Radio

Time Domain
(CCDF, pulse shaping, timing)

Frequency Domain
(Channel Power, spectrum mask,...)

Modulation Domain
• Overall Modulation Quality,
• Modulation Quality on individual carriers
• Channel Response, Group Delay
• In Channel Spurious Search

Spectrum Analyzer

Vector Signal Analyzer
Who needs wide analysis BW?

Modern designs demand more bandwidth for capturing high data rate signals and analyzing the quality of digitally modulated bandwidths

- **Aerospace and Defense**
  - **Radar** – Chirp errors & modulation quality
  - **Satellite** – Capture 36/72 MHz BW’s w/high data rates
  - **Military communications** – Capture high data rate digital comms & measure EVM

- **Emerging communications**
  - **W-LAN, 802.16 (wireless last mile), mesh networks**
    - Measure EVM on broadband, high data rate signals

- **Cellular Communications**
  - **W-CDMA ACPR & Multi-carrier Pre-Distortion**
    - High dynamic range over 60 MHz BW to see low level 3rd order distortion for 4 carrier pre-distortion algorithms
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What is a VSA?

- The VSA is an **FFT Analyzer**

- FFT Analyzers are “Block” processors. They take in chunks of data from memory

- This means it takes in **time data** and performs FFT to give the frequency domain data. It retains **phase and amplitude** data

- The retention of phase and amplitude data allows users to view both digital and RF signals in the RF and **Demod domain**
Theory of Operation
FFT Analyzer

ADC speed limits bandwidth

• Nyquist Rule requires sampling rate at 2 times bandwidth
• Number of ADC bits sets Y Axis resolution
• Length or number of samples used in FFT effects noise floor
Theory of Operation
FFT Analyzer

**Windowing** - similar to analog filter shape

**Decimation** - selection of data similar to analog tuning frequency and span

**Re-sampling** - interpolating or reformatting data to align sample clock with signal for precise down conversion
Theory of Operation
Swept Analyzer

Scalar Analysis

Digitizing the Video Signal

Classic Spectrum Analyzer Simplified Block Diagram
Theory of Operation
Modern Spectrum Analyzer – All Digital IF

Auto Alignment
• Temp & time calibration

Digitally Synthesized LO
• Fast tuning
• Close-in phase noise
• Far-out phase noise

Digital IF Filters
• 160 RBW filters
• 1 Hz to 8 MHz
• ±0.03 dB switching error

Digital Detectors
• Normal
• Peak
• Min
• Sample

Digital Log Amp
• ±0.07 dB Scale Fidelity
• >100 dB Dynamic range
• ±0.0 dB reference level error

Digital Video Filters
• Power, voltage, log filtering

Frequency Counter
• Fast (0.1s)
• High resolution (mHz)

Attenuation
2 dB step to 50 GHz

FULL BAND
Pre-amp
Analog IF Pre-Filter

FFT vs Swept
• Faster Sweep w/Max DR

High resolution ADC

FFT

Digital Log Amp

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The sweep speed of FFT versus swept signal analysis basics is illustrated in the graph. The sweep rate of the local oscillator (LO) dominates LO hopping and switching, while acquisition time and narrow resolution bandwidth (RBW) means longer time record, and LO retrace and system overhead are also factors. The graph shows the relationship between measurement cycle time and span for both FFT and swept modes.
Theory of Operation
Block Diagram

Input Signal
ADC Assembly

ADC

Analog IF Filter

F_s

90° phase shift

Digital Local Oscillator

Cos(2\pi f_c n \Delta t)

Digital Filter assembly

Real Part
Incident (I)

Imaginary Part
Quadrature (Q)

-Sin(2\pi f_c n \Delta t)

Digital L. P. Filter

F_s \prime = F_s / n

DSP

Demodulator

Window

FFT

Display

I(t) Time Domain

Modulation time Domain

Q(t) Time Domain

"I"

"Q"

Signal Analysis Basics

VXA

89600

Agilent Technologies
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89600 VSA Software

Teams with Agilent’s instruments to provide superior analysis of satellite, radar & wireless communication signals

• Supports >70 signal standards and modulation types
  
  LTE, WiMAX, GSM, Radar, 2FSK to 1024 QAM....

• Advance tools for VSA analysis
  
  Spectrogram, Constellation, EVM, CCDF, Time gating, signal capture/playback...

• Early support of emerging standards
89600 VSA Software

Signal Sources

Synthetic Instruments

High-Speed Digitizers

Logic Analyzers

Pattern Generators

VSA (89601S)

DigitallO

Oscilloscopes

Spectrum Analyzers

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Signal Analysis Basics
89600 VSA Software – Cross Domain Tool

- Logic Analyzer
- Oscilloscope
- Spectrum Analyzer

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- **Signal Analysis**

- **Built-in Applications**
  Phase Noise
  Noise Figure
Signal Changes or Modifications

- **Magnitude Change**: 0 deg
- **Phase Change**: 0 deg
- **Frequency Change**: 0 deg
- **Both Change**: 0 deg
Basic Constellations Measurements

- Gain Imbalance
- Phase Noise
- Skew-Phase Imb
- AM/AM
- AM/PM
Error Vector Magnitude

What is the EVM Metric?

· Reference Signal
· Measurement Signal
· Vector Difference
· Comparative Measurement
· Degradation Checks
Finding Modulation Impairments with EVM

- VSA Analyzes Modulation
- Find Impairment Source
- Compare Signal Parameters
- Parameter Links to Source
- Diagnose & Reduce Issues
- Shorten Development Cycle
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Basic Phase Noise Concepts

**IDEAL SIGNAL**

\[ V(t) = A_0 \sin 2\pi f_0 \ t \]

Where

- \( A_0 \) = nominal amplitude
- \( f_0 \) = nominal frequency

**REAL WORLD SIGNAL**

\[ V(t) = [A + E_0(t)] \sin [2\pi f \ t + \phi(t)] \]

Where

- \( E(t) \) = random amplitude fluctuations
- \( \phi(t) \) = random phase fluctuations

Signal Analysis Basics

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Phase Noise – Direct Spectrum Measurements

- Easy to configure/use
- Wide carrier frequency range
  - Measures Combination of AM noise and phase noise
  - Sensitivity limited by the analyzer's internal LO
  - Difficult to track drifting signals
Phase Noise Measurement Techniques

Phase detector techniques

Phase Detector converts phase difference between the signals at the input to a voltage signal at the output. When the phase difference is 90° at the input, the output voltage of the detector will be zero volts. This is defined as the "quadrature" condition for the phase detector.

\[ \Delta V_{\text{out}} = K_\phi \Delta \phi_{\text{in}} \]

RF phase detectors require one of the two signals to be a high power signal (typically > +12 dBm) effectively switching the detector "on" and thereby allowing the other signal to be a low power signal (typically > -5 dBm). Microwave detector power levels are typically > +5 dBm and > -5 dBm for the high and lower signal power requirements.
Built-in One Button Phase Noise Measurement
Spectrum measurement technique
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Noise Figure Definition

Noise figure is defined in terms of SNR degradation:

\[ F = \frac{(S_i/N_i)}{(S_o/N_o)} = \frac{(N_o)}{(G \times N_i)} \] (noise factor)

\[ NF = 10 \times \log(F) \] (noise figure)

Test system is assumed to be 50 Ω
Noise Figure Measurement Techniques

Y-factor (hot/cold source)

- Used by NFA and SA-based solutions
- Uses noise source with a specified “excess noise ratio” (ENR)

Cold source (direct noise)

- Used by vector network analyzers (VNAs)
- Uses cold (room temperature) termination only
- Allows single connection S-parameters and noise figure (and more)

Excess noise ratio (ENR) = $\frac{T_{\text{hot}} - T_{\text{cold}}}{290 K}$

Diode off $\Rightarrow T_{\text{cold}}$
Diode on $\Rightarrow T_{\text{hot}}$
## ENR vs. Frequency

**Enter ENR vs. Frequency Table**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>ENR Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00000000 GHz</td>
<td>15.0000 dB</td>
</tr>
<tr>
<td>2.00000000 GHz</td>
<td>15.5000 dB</td>
</tr>
<tr>
<td>3.00000000 GHz</td>
<td>15.1000 dB</td>
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<tr>
<td>4.00000000 GHz</td>
<td>14.7000 dB</td>
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<tr>
<td>5.00000000 GHz</td>
<td>14.3000 dB</td>
</tr>
<tr>
<td>6.00000000 GHz</td>
<td>13.9000 dB</td>
</tr>
<tr>
<td>7.00000000 GHz</td>
<td>13.5000 dB</td>
</tr>
<tr>
<td>8.00000000 GHz</td>
<td>13.1000 dB</td>
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</tr>
</tbody>
</table>
Y-Factor Technique

\[ T_{\text{hot}} \ (\text{on}) \]
\[ T_{\text{cold}} \ (\text{off}) \]

\[ P_{\text{out (hot)}} = kBG_a(T_{\text{hot}} + T_e) \]
\[ P_{\text{out (cold)}} = kBG_a(T_{\text{cold}} + T_e) \]

\[ Y = \frac{P_{\text{out (hot)}}}{P_{\text{out (cold)}}} \]

\[ T_e = \frac{T_{\text{hot}} - Y \times T_{\text{cold}}}{Y - 1} \]

\[ F_{DUT} = F_{sys} - \frac{F_{rcv} - 1}{G_a \ DUT} \]

Calibration:

\[ F_{sys} = 1 + \frac{T_e}{290} \]

Y-factor yields gain and noise figure
Friis Cascade Formula

\[ F_{12} = F_1 + \frac{F_2 - 1}{G_{a1}} \]

\[ \sum F_{N+1} = \sum F_n + \frac{F_{n+1} - 1}{\sum G_N} \]

Where \( \sum F_n \) is cumulative NF up to nth stage
and \( \sum F_{N+1} \) is cumulative NF up to (n+1)th stage
Improvement in Spectrum Analyzer Noise Figure using a Pre-amplifier

Example: Using SA NF of 27dB ($F_2$), add an amplifier with 3dB noise figure ($F_1$), gain 30dB (G)

\[
F_{12} = F_1 + \frac{F_2 - 1}{G}
\]

Noise Fig Total = 2 + \frac{501 - 1}{1000} = 2.5

10 \log 2.5 = 3.98 dB

NFtot = 3.98dB

NF = 3dB
G = 30dB
NF = 27dB
Y-Factor Measurement Assumptions

\[
\Gamma_{\text{src}} \text{(hot)} = \Gamma_{\text{src}} \text{(cold)} \quad \text{(source match of noise source does not change)}
\]

\[
F_{\text{rcv}} \bigg|_{\Gamma_{\text{o(DUT)}}} = F_{\text{rcv}} \bigg|_{\Gamma_{\text{src}}} \quad \text{(no noise-parameter effects of receiver)}
\]

\[
G_a(\text{DUT}) = \frac{P_o \text{ (hot-sys)} - P_o \text{ (cold sys)}}{P_o \text{ (hot rcv)} - P_o \text{ (cold rcv)}} = \frac{\Delta P_{\text{out}}}{\Delta P_{\text{in}}}
\]

True only if \( S_{11} \text{ and } S_{22} \ll 1 \) (So no reflections)

\[
G_a \text{ (available gain)} \text{ is a function of } S_{11}, S_{22} \text{ and } \Gamma_s
\]
Y-Factor Method Example (Spectrum Analyzer)

• “DUT setup” shows a nice diagram how to connect

ENR table is entered automatic (SNS) or manual (346x)
There are 3 NF Display layouts: Graph, Table & Meter
Thank you!

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