Course on Microwave Measurements

Microwave signal generators

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Summary

- Microwave generators types: continuous wave (CW), variable in frequency (sweep), signal generators
- Characteristics and operational schemes
This is the ideal output: most specs deal with deviations from the ideal and adding modulation to a sine wave.
Types of sources

- **CW**
  - generates a single frequency, fixed sine wave
- **Swept**
  - sweeps over a range of frequencies
  - may be phase continuous
- **Signal Generator**
  - adds modulation
  - produces “real world” signal
CW source specifications: frequency

- Range: Range of frequencies covered by the source
- Resolution: Smallest frequency increment.
- Accuracy: How accurately can the source frequency be set.

**EXAMPLE**

\[
\text{Accuracy} = \pm f_{\text{CW}} \times \tau_{\text{aging}} \times \tau_{\text{cal}}
\]

- \( f_{\text{CW}} = 1 \text{ GHz} \) (CW frequency = 1 GHz)
- \( \tau_{\text{aging}} = 0.152 \text{ ppm/year} \) (aging rate = 0.152 ppm/year)
- \( \tau_{\text{cal}} = 1 \text{ year} \) (time since last calibrated = 1 year)

\[\Rightarrow \text{Accuracy} = \pm 152 \text{ Hz}\]
CW source specifications: amplitude

- Range (-136dBm to +13dBm)
- Accuracy (+/- 0.5dB)
- Resolution (0.02dB)
- Switching Speed (25ms)
- Reverse Power Protection

Source protected from accidental transmission from DUT

What is $P_{\text{max}}$ out?

How accurate is this number?

What is $P_{\text{min}}$ out?

Voltage

Frequency
CW source specifications: spectral purity

- Phase Noise
- Residual FM
- Spurious

Residual FM is the integrated phase noise over 300 Hz - 3 kHz BW

- CW output
- Harmonic spur ~30dBc
- Non-harmonic spur ~65dBc
- Sub-harmonics
CW source specifications: Spectral Purity

Phase Noise

Power Spectral Density

frequency

CW output

measured as dBc/Hz

LogMag 5 dBc/div

-75 dBc/Hz

-105 dBc/Hz

-125 dBc/Hz

1k 10k 100k
RF CW block diagram

**Synthesizer Section**

- Reference Oscillator
- Phase Detector
- Frac-N
- VCO

**Output Section**

- ALC Modulator
- ALC Driver
- ALC Detector
- Output Attenuator

**Reference Section**

- Divide by X

**ALC** = automatic level control
RF CW block diagram: reference section

TCXO = Temperature Compensated Crystal Oscillator
OCXO = Oven Controlled Crystal Oscillators

<table>
<thead>
<tr>
<th></th>
<th>TCXO</th>
<th>OCXO</th>
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<tbody>
<tr>
<td>Aging Rate</td>
<td>+/- 2ppm/year</td>
<td>+/- 0.1 ppm /year</td>
</tr>
<tr>
<td>Temp.</td>
<td>+/- 1ppm</td>
<td>+/- 0.01 ppm</td>
</tr>
<tr>
<td>Line Voltage</td>
<td>+/- 0.5ppm</td>
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TCXO:
- Aging Rate: +/- 2ppm/year
- Temperature: +/- 1ppm
- Line Voltage: +/- 0.5ppm

OCXO:
- Aging Rate: +/- 0.1 ppm/year
- Temperature: +/- 0.01 ppm
- Line Voltage: +/- 0.001 ppm
RF CW block diagram: synthesizer section

...produces accurate, clean signals

5MHz

N = 93.1

Frac-N

Front panel control

to output section

931 MHz

465.5 MHz

x 2 multiplier

VCO

5MHz

Phase Detector

from reference section

5MHz

from reference section
RF CW block diagram: synthesizer section

PLL / Fractional - N
...suppresses phase noise

phase noise of source

20logN

reference oscillator

VCO noise

phase detector noise

phase-locked-loop (PLL) bandwidth selected for optimum noise performance

broadband noise floor

frequency

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**RF CW block diagram: output section**

- **ALC**
  - maintains output power by adding/subtracting power as needed
- **Output Attenuator**
  - mechanical or electronic
  - provides attenuation to achieve wide output range (e.g. -136dBm to +13dBm)

*ALC = automatic level control*
Microwave CW block diagram

Reference Section

Synthesizer Section

Output Section
CW: Applications & Critical Specifications

- **Local Oscillator**
  - phase noise
  - frequency accuracy
- **Amplifier**
  - distortion
  - spurious
- **Receiver Testing**
  - spurious
  - level accuracy
As a Local Oscillator

DUT

IF signal

transmitter output

poor phase noise spreads energy into adjacent channels

poor frequency accuracy will cause transmitter to be at the wrong frequency
Amplifier Testing

Intermodulation Distortion

\[ f_1 \]

\[ f_2 \]

DUT

isolator

output RF

test system third order products will also fall here

spurious signals from source can corrupt measurement

f\_L = 2f_1 - f_2

f\_U = 2f_2 - f_1

frequency

amplitude

CW: Applications & Critical Specifications
Receiver Testing

Receiver Selectivity

- **in-channel signal** (modulated signal)
- **out-of-channel signal** (CW or modulated signal)

source output

IF Rejection Curve

spur from source and/or high levels of phase noise can cause a good receiver to fail

Level (dBm)

Frequency
Examples: Agilent CW Generators

RF

Agilent 8662/63 family
- 100 KHz - 2.5 GHz
- Low in channel noise
- AM/FM/Phase/Pulse

Agilent 8664/65 family
- 100 MHz - 6 GHz
- Low out channel noise
- AM/FM/Pulse.

Microwave

Agilent 83711/12B family
- 10 MHz - 20 GHz
- CW only
Sweeper specifications: frequency

- **ramp sweep**
  - accuracy
  - sweep time
  - resolution

- **step sweep**
  - accuracy
  - number of points
  - switching time
Sweeper specifications: amplitude

Frequency Sweep
- Level Accuracy
- Flatness
- Source Match (SWR)

Power Sweep
- Power Sweep Range
- Power Slope Range
- Source Match (SWR)
Sweeper: Applications & Critical Specs

- **Frequency Response**
  - Frequency Accuracy
  - Output Power (Level) Accuracy
  - Flatness
  - Speed
  - residual FM

- **Amplifier Compression**
  - Power Range
Frequency Response Testing

Who Cares About Accuracy?

- Center: 2 450.212 MHz
- Span: 1 099.577 MHz
- BW: 429.600 MHz
- CF: 2405.782 MHz
- Q: 5.60
- Loss: -0.84 dB

1: Transmission

Log Mag

5.0 dB / Ref -15.00 dB

dB

Abs

Ch1

Who Cares About Accuracy?
Amplifier Compression

- **Power Range**

The 1 dB compression point is a common amplifier specification used to identify the linear operating range of an amplifier. Power sweep is available on some sources.
Examples: Agilent Sweep Generators

- **Agilent 83750 Series**
  - Step/Analog sweep
  - AM/FM/Phase modulation
  - 10MHz to 20GHz
  - up to 110GHz with 83550 series
  - modules and amplifier

- **Agilent 8360L Series**
  - Step/Analog sweep
  - 8510/8757 Compatibility
  - 10MHz to 50GHz
  - up to 110GHz with 83550 series
  - modules
Signal generators

- **Calibrated modulation**
  - Analog (AM, FM, PM, Pulse)
  - Digital (I-Q)
  - Format Specific (TDMA, CDMA, etc.)
Modulation

...Where the information resides

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

\[ V = A(t) \sin[\theta(t)] \]
Modulation: analog

Amplitude Modulation

Important Signal Generator Specs for Amplitude Modulation

- Modulation frequency
- Linear AM
- Log AM
- Depth of modulation (Mod Index)
Modulation: analog

Frequency Modulation

\[ V = A \sin[2 \pi f_c t + \beta m(t)] \]

\[ \beta = \Delta \frac{F_{\text{dev}}}{F_{\text{mod}}} \]

Important Signal Generator Specs for Frequency Modulation

- Frequency Deviation
- Modulation Frequency
- dcFM
- Accuracy
- Resolution
Phase Modulation

\[ V = A \sin[2 \pi f_c t + \beta m(t)] \]

\[ \beta = \Delta \phi_{\text{peak}} \]

Important Signal Generator Specs for Phase Modulation

- Phase deviation
- Rates
- Accuracy
- Resolution
Modulation: analog

Pulse Modulation

Important Signal Generator Specs for Pulse Modulation

- Pulse width
- Pulse period
- On/Off ratio
- Rise time
Modulation: digital

...signal characteristics to modify

- Amplitude
- Frequency
- Phase
- Both Amplitude and Phase
Modulation: digital

Polar Display: Magnitude & Phase Represented Together

- Magnitude is an absolute value
- Phase is relative to a reference signal
Modulation: digital

Signal Changes or Modifications

Magnitude Change

Phase Change

Both Change

Frequency Change
Modulation: digital

...Binary Phase Shift Keying (BPSK)

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

\[ \phi(t) = \begin{cases} \phi_1 & f_1 \\ \phi_2 & f_2 \end{cases} \]
BPSK IQ Diagram

One Bit Per Symbol
Symbol Rate = Bit Rate
Modulation: digital

...Quadrature Phase Shift Keying (QPSK)

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

\[ \phi(t) = \begin{cases} 
\phi_1 = 3\pi/4 \\
\phi_2 = \pi/4 \\
\phi_3 = -\pi/4 \\
\phi_4 = -3\pi/4 
\end{cases} \]
Modulation: digital

QPSK IQ Diagram

- Points: 00, 01, 10, 11
- Axes: I, Q
Modulation: digital

\(\pi/4\) DQPSK IQ Diagram
Modulation: digital

Modulation Accuracy

Magnitude Error (IQ error mag)

Error Vector

Test Signal

Ideal (Reference) Signal

Phase Error (IQ error phase)
Signal generators: Apps & Critical Specs

Analog and Digital

- **Receiver Sensitivity**
  - frequency accuracy
  - level accuracy
  - error vector magnitude

- **Receiver Selectivity**
  - phase noise
  - spurious
  - spectral accuracy

- **Spectral Regrowth**
  - ACP performance
Receiver Sensitivity

- **Frequency Accuracy**

Want to measure sensitivity in a channel

Measurement impaired by frequency inaccuracy

**Signal generators: Apps & Critical Specs**

Frequency Accuracy

Signal generators: Apps & Critical Specs

Want to measure sensitivity in a channel

Measurement impaired by frequency inaccuracy

input for signal generator

DUT
Receiver Sensitivity

- **Level Accuracy**

*Customer is testing a -110 dB sensitivity pager:*

<table>
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<tr>
<th>Case 1: Source has +/-5 dB of output power accuracy at -100 to -120 dBm output power.</th>
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<th>Case 2: Source has +/-1 dB of output power accuracy at -100 to -120 dBm output power.</th>
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Receiver Sensitivity

- Error Vector Magnitude (EVM)

- e.g. TETRA Signal
  \( \pi/4 \) DQPSK
  EVM < 1.0%
Receiver Selectivity

- Phase Noise
- Spurious

in-channel signal (modulated signal)

out-of-channel signal (CW or modulated signal)

IF Rejection Curve

spur from source and/or high levels of phase noise can cause a good receiver to fail
Signal generators: Apps & Critical Specs

Receiver Selectivity

Spectral Accuracy:

- EVM
- ACP

GSM Signal
0.3GMSK
Signal generators: Apps & Critical Specs

Spectral Regrowth

- ACP (Adjacent Channel Power) Performance

Diagram:
- Input from signal generator to DUT
- Output from amplifier

Graphs showing spectral regrowth with input and output signals.