Modulated Signal Measurements: Instrumentation and Traceability

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Outline

• Motivation

• Measuring modulated signals
  • Scalar measurements
  • Vector measurements

• Traceability

• Conclusion
Wireless Telecommunication Trends

- Request for a single product allowing several connection capabilities
- Increasing requirements for figures of merit, like *efficiency* and *linearity*
- Space, cost, and power consumption reductions require *new architectures*
Power Amplifier Trends

The Past

Base Band → GSM → PA₁ → WiMax → PA₂ → WiFi

The Future

Base Band → GSM → WiMax → WiFi

Multi-Mode Multi-Band PA

G vs. f

B₁

B₂

G vs. f

B₁

B₂
Objective

• Challenge: measure response of dual-band modulated excitation
  – spectral regrowth
  – cross-channel interference
  – ...
  – typically: \( f_2 - f_1 > 500 \text{MHz} \)
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Measurement Instrumentation

• *Scalar* measurements
  – Spectrum analyzer
  – Peak power sensor

• *Vector* measurements
  – Digital sampling oscilloscope
  – Vector signal analyzer
  – Large-signal network analyzer
Scalar Modulated-Signal Measurements

- Spectrum Analyzer

Input signal +

• good dynamic range
• readily available, inexpensive

LO

Diagram after [1]

• higher uncertainties due to system drift and repeatability
• diode detector: temperature sensitive
Scalar Modulated-Signal Measurements

- Peak Power Meter

Diagram after [2]

+ relatively inexpensive and straightforward to use

- diode detector: temperature sensitive
  - narrowband (~10 MHz)
Vector Modulated-Signal Measurements

**Vector:** Accurate relative phase of all measured components

→ enables time-domain representation

[Graphs from [3]]
Vector Modulated-Signal Measurements

Digital Sampling Oscilloscope: good for waveform meas.

- broadband acquisition
- low dynamic range
- complex calibration
- periodic excitation

trigger and trigger delay

source

DUT
Vector Modulated-Signal Measurements

Digital Sampling Oscilloscope: calibration

→ in-phase/quadrature reference signals create new time base

Ref. [4]
Vector Modulated-Signal Measurements

Vector Signal Analyzer: good for single-band modulated meas.

- modulated signals
- no harmonics
- IF bandwidth ~100 MHz
Vector Modulated-Signal Measurements

Sampler-based Large Signal Network Analyzer: good for multi-sine meas.

- broadband, incl. harmonics
- periodic excitation
- IF bandwidth ~20 MHz
Vector Modulated-Signal Measurements

Dual-band PA characterisation

\[ f_1 \quad f_2 \]

\[ f_{cal} \quad nf_{cal} \quad mf_{cal} \]

800 MHz                WLAN         WiMAX
Vector Modulated-Signal Measurements

Mixer-based Non-linear Vector Network Analyzer: good for multisine meas.

- **wide full bandwidth** (10 MHz – 26.5 GHz)
- **high dynamic range**

- **4-channel VNA required**
- **minimal spacing 40 kHz**
**Multisine Excitation Design**

**Goal:** design multisine to approximate realistic digitally modulated signal

- **Approach**
  - using statistical properties of the signal
    - nonlinear dynamic system of order $n$: multisine should be specified via its *higher order statistics* up to the same order $n$ [6,7]
    - nonlinear memoryless system: *pdf* [8]

→ iterative optimization procedure
Multisine Excitation Design

time waveform of CDMA signal

amplitude [V]

PDF [%]

0 0.1 0.2

-1 -0.5 0 0.5 1
Multisine Excitation Design

From [8]
Phase Detrending

From [9]
Phase Detrending

At $t = t_M$:
- $\theta_1 = 115^\circ$
- $\theta_2 = 345^\circ$
- $\theta_3 = 280^\circ$

From [9]
Phase Detrending

• Approaches [10]
  - **Fundamental alignment**
    = fundamental is aligned to an arbitrary phase
  - **Time-domain signal alignment**
    = estimate time shift between measured and target signal by maximising cross-correlation of measured and target signal
  - **Frequency-domain alignment**
    = estimate phase shift by minimizing least-squared error between measured and target phases
  - **Time-zero cancellation**
    = a linear transform is applied to the phases such that the new phases are independent of time zero
    \[
    \phi_{k,m}' = \phi_{k,m} - (k\phi_c + m\phi_0) \quad f_{k,m} = kf_c + mf_0
    \]
Phase Detrending

Example [10]: 41-tone multi-tone, 172 measurement repeats

- time- and frequency alignment approaches
  - target time domain signal or target phases have to be known
  - standard deviation is lower and fairly constant across bandwidth

- time-zero cancellation approach
  - only arbitrary target phases are required
  - standard deviation increases for frequencies further away
Phase Detrending

\[ 0^\circ \]

\[ \varphi \] ?

\[ \phi \] ?

expected phases (targets)

detrended port 1 phases
detrended port 2 phases

no targets available

From [9]
Application: Dual-Band PA Characterisation

**f_{cal}**

800 MHz

**nf_{cal}**

WLAN

**mf_{cal}**

WiMAX

**31-tone CDMA**

GaN harmonic-tuned dual-band PA

From [11]
Application: Dual-Band PA Characterisation

- Single-tone results

From [11]
Application: Dual-Band PA Characterisation

From [11]
Application: Dual-Band PA Characterisation

- Cross-modulation

From [11]
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**Fundamental Measurement Traceability**

Calibrations tending toward *fundamental traceability* to SI units or calculable physical phenomena

- **power meters, noise sources:**
  → temperature

- **vector network analyzers:**
  → dimension of an air-dielectric transmission line

- **electro-optic sampling systems:**
  → calculable electro-optic effect in materials
Fundamental Measurement Traceability

EOS system

Pulsed Laser

Photo-receiver

Wafer Probe

LiTaO$_3$ wafer

Variable optical delay

Voltage waveform measured here

Optical polarization-state Analyzer

Diagram courtesy D. Williams of NIST [12]

→ Photodiode is transfer standard for oscilloscope calibration

Photodiode is transfer standard for oscilloscope calibration
Derived Measurement Traceability

Calibrations that use a series of *transfer standards*:

- **oscilloscope calibrations**
  → transfer standard: photodiode

- **source calibrations**
  → transfer standard: oscilloscope

- **receiver calibrations**
  → transfer standard: calibrated source
Traceability of Modulated-Signal Meas. Instrumentation

- **spectrum analyzer**
  - calibrated power sensor → temperature

- **peak power sensor**
  - calibrated source → cal. scope → photodiode → physics

- **digital sampling oscilloscope**
  - photodiode → physics

- **vector signal analyzer**
  - calibrated source → cal. scope → photodiode → physics

- **sampler-based LSNA and mixer-based NVNA**
  - calibrated comb generator → cal. scope → photodiode → physics
  - calibrated power sensor → temperature
  - relative calibration → dimension of air-line
Conclusions

• Novel wireless applications stretch characterisation requirements

• Dual-band performance can be studied using LSNA
  – Modulated signal is approximated by multisine
  – Phase detrending is important

• Traceability via transfer standards
Acknowledgements

- NoE TARGET
- EU STREP Project Nano-RF
- FWO, Belgium
- IWT, Belgium
References


References


