Phase Stability Study of a Harmonic Phase Reference
Outline

- Introduction
- Harmonic phase reference (HPR) and Error Bounds
- Phase alignment
- Measurement Noise
- Warm-up time
- Phase stability study under different external conditions
- Summary
Goal

Presenting the different studies, performed on comb generators to establish a worst-case error bound on their phase characteristic

Motivation

Accurately measuring the voltage and current at the input and output ports of a nonlinear device using a Large-Signal Network Analyser (LSNA), which can be based on a Vector Network Analyser (VNA), e.g. ZVA24 [1]

Requires additional calibrations on top of the relative calibration

Absolute Amplitude calibration: Calibrated Power Sensor

Absolute Phase calibration: Calibrated Harmonic Phase Reference (HPR)

The phase stability of the HPR impacts the phase accuracy of the LSNA measurements
Harmonic Phase Reference

- **What?**
  - a comb generator including proper padding
  - driven by a synthesiser at frequency $f_0$

- **What is important for the absolute phase calibration?**
  - a fixed phase relationship between the combs
  - an arbitrary delay can always be applied to the phase characteristic

![Comb generator diagram with $f_0 = 600$ MHz, input pulse = sine wave, output = pulse, and fundamental and harmonics over GHz frequency range.](image)
Contributions to the Error Bounds on the HPR Phase

- Systematic errors, introduced by the calibration process
  - Traceability to NIST has been established
  - Not discussed in this presentation

- Intrinsic device noise in Comb Generator
  - Always present in the measurements

- Phase stability impacted by external factors
  - Temperature variations
  - Variations in applied input power
  - Variations in applied bias voltage
  - Impact of the nonlinearities of the source
  - Impact due to load variations
Measurement Setup to study HPR Stability

- Study of stability **only** requires a comparison between measurements
- Using the MT4463 [2] which is proven to be very stable after warm-up time to measure incident and reflected waves
- Observing the voltage waveforms $a_1$ and $b_2$ under varying conditions and studying the phase variation of $b_2$

**Two Problems**
- Arbitrary delays in repeatable measurements of $b_2$ require proper phase alignment for correct phase characterisation
- Measurement noise converts into phase uncertainty and hides phase error on HPR
  - Need to estimate the phase error due to the measurement noise
  - This also includes the intrinsic noise generated by the comb generator
Elimination of Arbitrary Delay

- The error bound on the phase as function of frequency under varying conditions is influenced by the method to eliminate the arbitrary delay.

- **Challenge:** for each measurement, determine the delay such that the phase variation across comparable measurements is minimised for all spectral components.

- **Different methods to eliminate the delay**
  - Apply a delay to the signal such that the phase of the fundamental frequency becomes zero.
  - Apply a delay to the signal such that the difference between the signals is minimised for all spectral components.
  - Use system identification for optimal extraction of delay [3],[4].
Phase Alignment

**Blue** = delay signals such that phase of fundamental is zero

**Red** = delay signals to minimise the error for all spectral components

To determine phase error specifications, NMDG applies the latter (red) method.
Estimation of Phase Error Due to Measurement System

- Measurement noise converts into phase error

- This phase uncertainty adds up to the phase variations of the HPR

1000 comb generator measurements
After proper phase alignment:
- Total phase uncertainty
- Phase uncertainty due to measurement noise

Conclusion
Phase variation of comb generator cannot be distinguished from measurement noise
Minimal Warm-up Time

- **Comb Generator**
  - Nominal input power: +10 dBm, nominal biasing voltage: +5V, $f_0 : 600$ MHz

- **Measurement Procedure**
  - Apply nominal input power and nominal biasing voltage
  - Perform 100 measurements after \{0, 1, 3, 6, 10, 15, 21, 28, 36, 45, 55\} minutes
    - Calculate an “average pulse” using the proper alignment at each time slot
    - Compare the 10 “average pulses” against the “average pulse” after 55 minutes after proper alignment

- **Conclusion**
  - After 3 minutes warm-up
  - Phase deviation < 1 degree
Long – Term Stability

- **Comb Generator**
  - Nominal input power: +10 dBm, nominal biasing voltage: +5V, $f_0 : 600$ MHz

- **Measurement Procedure**
  - Apply input power
  - Wait 30 minutes
  - 1000 measurements with interval of 5 seconds
    - Calculate an “average pulse” using the proper alignment
  - Repeat 4 times, spread across 3 days
    - This results in 4 “average pulses” being compared after alignment with each other

- **Conclusion**
  - Phase Variations of 0.5 degrees are observable
Power Sensitivity

• Comb Generator
  • Nominal biasing voltage: +5V, $f_0 : 600$ MHz

• Measurement Procedure
  • Applying nominal input power and nominal biasing voltage
  • Wait 30 minutes
  • Stepping input power from +9 dBm to +11 dBm in steps of 0.1 dBm (21 steps)
  • For each power setting: 1000 measurements
    • Calculate an “average pulse” using the proper alignment
    • Compare the phase of each “average pulse” with “average pulse” for nominal input power of +10 dBm

• Conclusion
  • Power variation needs to be limited to +/- 0.25 dBm to limit phase variation within 1 degree
Bias Sensitivity

- **Comb Generator**
  - Nominal input power: +10 dBm, \( f_0 : 600 \text{ MHz} \)

- **Measurement Procedure**
  - Applying nominal input power and bias voltage
  - Wait 30 minutes
  - Stepping biasing voltage from +4.8 to +5.2 Volt in steps of 0.05 Volt (9 steps)
  - For each bias setting: 1000 measurements
    - Calculate an “average pulse” using the proper alignment
    - Compare the phase of each “average pulse” with “average pulse” for nominal biasing voltage of +5 Volt

- **Conclusion**
  - Bias voltage variation needs to be controlled within 50 mV due to phase variation of second harmonic

![Plot showing phase variations of each harmonic vs. bias voltage and Bias voltage [V] vs. 2f0](image)
Source and Load Sensitivity

- Using the comb generator as HPR requires proper padding
  - Minimising mismatch effects
  - Limiting the peak voltage to avoid compression of LSNA receivers
  - The comb generator used in this study is padded with 20 dB

- Source sensitivity
  - The HPR is driven by the synthesiser used in the LSNA setup
  - The phase characteristic can be sensitive to harmonic distortion (HD)
  - It is assumed that the synthesiser has a HD of -30 dBC in worst case

- Load sensitivity
  - The HPR is connected to different test sets
  - A test set presents a certain load match, which can impact the phase characteristic
  - It is assumed that the test set has a return loss of 20 dB or better

- A special measurement setup is used to inject signals at fundamental and harmonics to simulate different harmonic distortions and return losses
Source and Load Sensitivity: Measurement Setup

Second source ($RF_2$) to inject a waveform
Source sensitivity: inject waveform at $2f_0$ and $3f_0$
Load sensitivity: inject waveform at $f_0$, $2f_0$, $3f_0$
Source Sensitivity

- **Comb Generator**
  - Nominal input power: +10 dBm, nominal biasing voltage: +5V, f₀ : 600 MHz

- **Measurement Procedure**
  - Applying nominal input power and nominal biasing voltage
  - Wait 30 minutes
  - Injecting different powers at second and third harmonic while rotating the phase to simulate all possible harmonic distortion situations up to -30 dBc
  - Processing of measurements in the same way as HPR under nominal conditions
    - Calculate an “average pulse” using the proper alignment for all measurements
    - Determine the uncertainty of all pulses, compared to the “average pulse”

- **Conclusion**
  - Harmonic Distortion of -30 dBc can lead to a phase deviation of 1 degree

![Graph showing source sensitivity, phase uncertainty, and phase deviation due to harmonic distortion and measurement noise.](image)
Load Sensitivity

- **Comb Generator**
  - Nominal input power: +10 dBm, nominal biasing voltage: +5V, f0 : 600 MHz

- **Measurement Procedure**
  - Applying nominal input power and nominal biasing voltage
  - Wait 30 minutes
  - Injecting different powers at fundamental, second and third harmonic while rotating the phase to simulate all possible load mismatches up to 20 dB return loss
  - Same processing as for source sensitivity

- **Conclusion**
  - Mismatch can lead to some small phase deviation
Summary

- Discuss the harmonic phase reference and its phase specification
- Discuss the phase alignment and error contributions to the phase
- Determine the minimal warm-up time
- Discuss the sensitivity to external factors
  - Power sensitivity
  - Bias sensitivity
  - Sensitivity to harmonics generated by the synthesiser
  - Sensitivity to different load matches
- Explain the measurement procedure for each sensitivity study

- For the commercial Phase Reference, these procedures are repeated on a dense grid

For more technical information, please contact info@nmdg.be
www.nmdg.be
References


