Performing GHz wide Multi-Port Spectral Analysis within a VNA

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AGENDA

- VNA-SA theory of operation
- VNA-SA Coherent mode for wideband signal
- Phase consistency between receivers and ports
- Wideband phase stitching for vector spectrum analysis
- Conclusion
VNA-SA Theory of operation 1/3

• Let’s focus on Keysight PNA-X instrument: 4 ports VNA (Keysight PXI and USB VNAs can run SA too)

• VNA design does not feature a hardware pre-selector: we need an image rejection algorithm. 2 cases:
  – Unknown test signal: stochastic image rejection
  – Known repetitive test signal: deterministic image rejection
VNA-SA Theory of operation 2/3

PNA-X Receiver chain for each RF mixer:
- 100 MHz dual ADCs with anti-alias filters and dithering
- Capable up to 33 MHz IF bandwidth

New data process flow for SA option
Image rejection algorithm (4 points, default)

- Step LO frequency by “about” 16 MHz per acquisition
- Perform 5 acquisitions for any frequency point to have at least 4 good hits
- Make decision based on 4 or 5 close enough amplitude values

We suppose the RF signal is stable enough during this process
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VNA-SA Coherent mode for wideband repetitive test signals

Key Assumption: we know the test signal repetition rate

Idea: Align the signal frequency grid and the DFT analysis grid

PNA-SA ADC acquisition time for one LO == k * test signal period

Example:
Repetitive test signal period: 1000
Acquisition = 2000
Vector averaging = k = 2
DFT size = n * 1000 samples
Key benefits of SA coherent mode:

- DFT bins are aligned by design with RF tones
- No need for ADC windowing: faster, phase of tones are kept
- Coherent mode amplitudes are not trigger-dependent
- Harmonic frequencies and intermodulation products derived from the test signal are all landing on the same DFT grid
Coherent deterministic image rejection

List of LO frequencies engineered to separate tones and images:

- The DFT grid is more dense than the RF signal tone spacing but still aligned. No more need for stochastic mode overlap decision.
- Managed dissymmetry of the LO versus the RF signal tones.
- This algorithm can be improved to protect against Nyquist images and harmonic images of the IF chain.

2 obviously bad examples:
- LO sitting on a tone
- LO just in the middle of 2 tones.

At IF side, we will end up with overlapping images of RF tones, with no way to separate them.
Example of a wideband repetitive signal
RF PA going into saturation (R1: input, B: output)

IMD3 and IMD5 intermodulation tones are visible at the output of the PA.

The test signal here is an USMT (unequally-spaced multi-tones) repetitive test signal with 8 tones.
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Phase consistency between receivers and ports for VNA-SA

Good news: VNAs have built-in phase consistency between receivers
- The same LO drives all the RF mixers,
- The same clock and trigger drives all the ADCs,
- This is required for S-parameters measurements.

The SA coherent mode DFT keeps the phase information of the tones and the phase differences between ports.

So, as long as the SA analysis is performed simultaneously on multiple receivers, phase consistency between receivers is achieved.
Wideband phase consistency problem

This SA measurement example needs at least 8 LOs.

The LOs absolute phases and ADC acquisition start time will both change the phases of each chunk (delay and phase offset).

So, even if the signal is repetitive and the SA runs the coherent mode, we need to do some extra work to ensure a stable and accurate wideband phase consistency between all the different LO acquisitions.
Wideband test signal for next examples

4.8 GHz carrier, 4 GHz span, 5 MHz tone spacing, 801 tones, parabolic phases (chirp). This signal acquisition needs 172 LOs.

Full span, frequency amplitude stitching

Zoom in
Amplitudes are nice, but phases are not

Sweep to sweep, phases are randomly moving
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Phase stitching techniques

Two main approaches to get phase continuity over wideband spans of coherent SA:

- Correction of acquisition phase for each chunk from these 3 inputs:
  - LO move timestamp and LO synthesizer model
  - ADC timestamp when acquisition starts
  - An accurate model of IF and LO paths

- Manage acquisitions of RF overlapping areas to align the phases of the chunks
  - Needs more LOs: 372 in our example (this adds averaging)
  - Needs tone energy in overlapping areas:
    - Either from the test signal itself, selecting receiver with highest energy (notches or band guards issues...).
    - From pilot tones or comb signal engineered for that purpose, feeding another synchronized receiver of the VNA

In fact, we often use both approaches together.
Phase stitching settings
The phases of tones now show a pattern
Cumulative phases are now parabolic
Derivative (group delay) looks good too

Sweep to sweep, the slope is now constant
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Coherent SA Wideband Phase stitching: Enabler of new measurements

- Wideband signal demodulation: IQ transformation of vector spectrum sent to VSA software
- AM to PM trajectory plots, wideband group delay measurements
- Modulation Distortion for frequency converters
- Dual input PA studies: wideband phase consistency and accurate phase differences between the PA input ports and the PA output port
Wideband Phase stitching: Conclusion

Under repetitive test signals with SA coherent mode phase stitching, VNAs have the new and unique capabilities to:

• Do arbitrary wide vector spectrum acquisitions

• Have several synchronized SA acquisition ports

• Apply user calibrations, including port match, to an arbitrary wideband vector SA analysis (even in case of external test set)