Understanding and Improving Measurement Uncertainty in ACPR Measurements

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Abstract

Adjacent channel power ratio (ACPR) measurements are a critical performance measure for transmitters in today's crowded spectrum. Making measurements where the circuit performance is similar to that of the spectrum analyzer is especially challenging, demanding an optimized mixer level and understanding of the interaction of the adjacent channel interference of the circuit and that of the analyzer. This paper explores that interaction, giving examples of the resulting measurement uncertainty and a way to set the optimum mixer level in the spectrum analyzer.
Agenda

• ACPR background
• Implications of DUT-analyzer ACP coherence
• Determining optimum mixer level
• Measurement uncertainties
• Optimizing accuracy vs. optimizing dynamic range
• Conclusions, references
Critical Role of ACP Measurements

• Fundamental measure of ability to share spectrum
• A universal regulatory requirement
• Offenders cause more trouble and are more easily noticed in today’s crowded spectral environment
• Some limits now more stringent
Role of ACP Measurements in Reducing Out-of-Band Emissions

- Isolating the problem parts of a design or circuit
- Perfecting circuit designs
- Optimizing operating points of amplifiers, etc.
  - Trading off performance, efficiency, cost
  - “Just good enough” ACPR performance
- Evaluating advanced techniques such as distortion cancellation
  - Cancelers incorporate the equivalent of analyzers
Measurement Limits due to Analyzer ACPR

- Internally-generated ACP a concern any time it is not much (10-15 dB) lower than DUT ACP
- Internally-generated ACP generally presumed incoherent with DUT
  - Sometimes implicitly (powers assumed to add)
- Incoherence assumption is generally not valid
- Cannot perform noise power subtraction/compensation because of coherence between DUT and analyzer
- Minimizing measurement errors a multi-faceted challenge
  - Error magnitude due to interaction of several factors
  - Errors may produce optimistic or pessimistic results
Adjacent Channel Power Example
Spectrum Analyzers and ACPR Measurements

• Spectrum analyzers generally the tool-of-choice for ACPR meas.
  • Selectivity, accuracy, dynamic range
  • Averaging, band power calculations, noise power BW corrections
  • Dedicated ACPR personalities, ACPR in std.-based personalities

• Analyzer error sources
  • IMD or internal ACP, thermal & phase noise, scale fidelity
  • Flatness, absolute error not typically a concern

• Vector signal analyzers, transmitter testers are similar
Optimum Mixer Level

- Best accuracy and dynamic range depend on optimum mixer level
  - Lowest analyzer-generated ACP, best measurement accuracy
  - May not be the same conditions!
- Instantaneous voltages always add—a vector sum
- Power varies with square of the resulting voltage
Coherent Signals Add as a Vector Sum
Equal Magnitude Examples

I/Q or polar/vector diagrams

- DUT ACPR
- Analyzer ACPR

2X voltage, power +6 dB
Vectors cancel, result is zero power

Two extremes, plus all possible values in between
Incoherent vs. Coherent Signals

• Instantaneous voltage is always a vector sum

• Incoherent signals (random phase of analyzer and DUT) average over multiple cycles of RF carrier and powers are added (in Watts, not dB)

• Coherent signals have a non-random relationship; therefore conditions are not met for a linear addition of power

• Simplified sinewave example:
  Analyzer (internally-generated) and DUT have same ACP
  • Equal signals in phase produce +6 dB power when combined
  • Equal signals out of phase produce zero power when combined
  • Equal incoherent signals produce +3 dB power when combined
Example of ACP in the Analyzer

Analyzer ACP itself is a sum of powers

Intermodulation, coherent with DUT, and power may add or subtract

Phase noise and thermal noise, incoherent with DUT, and power adds linearly
For the Most Reliable Measurements, Assume Worst Case

• Accuracy depends on relative power of different analyzer ACP components, (not simply analyzer ACP) because one adds coherently and the others do not

• If relative phase and thermal noise contributions unknown, use worst case, where analyzer ACP causes largest ACPR shift

• Shift may be positive or negative (thermal and phase noise always positive)
Worst Case Conditions

• Worst case—Positive:
  • Thermal and phase noise at maximum (analyzer specification)
  • DUT and analyzer intermodulation products in phase

• Worst case—Negative:
  • Thermal and phase noise are negligible
  • DUT and analyzer intermodulation products out of phase
Example of Accuracy Bounds, DUT ACLR = -60 dBc

Equal Analyzer and DUT ACP

Coherent sum, +6 dB

Coherent cancellation
Best Accuracy vs. Best Dynamic Range

- Mixer level that minimizes analyzer ACP is not typically same as mixer level that provides greatest DUT ACLR measurement accuracy
- Coherent addition shifts the minimum error point
- Error varies slowly around a minimum

Relationship between mixer levels for best accuracy and best dyn. range

\[ ML_{\text{accuracy}} - ML_{\text{ACLR min}} \approx \frac{1}{3} \left( \text{ACLR}_{\text{DUT}} - \text{ACLR}_{\text{analyzer}} \right) \]
Comparing Best Accuracy & Best Dynamic Range

![Graph showing the comparison between worst-case error and ACLR (Adjacent Channel Leakage Ratio) for ML from Eq. 3 Approximation and ML_{opt} for Accuracy and Dynamic Range.](image)
**Conclusions**

- ACPR (ACLR) is a critical measurement, and the spectrum analyzer is an excellent tool for making it.
- Measuring very low ACPR is a challenge, when signal analyzer ACPR is not much lower than DUT ACPR.
- Measurement errors are larger for very low ACPR.
- DUT—analyzer coherence should be assumed.
- This coherence changes accuracy and operating point assumptions.
- Mixer level for best accuracy is not mixer level for best dynamic range.
- Simple method exists to determine accuracy/dynamic range tradeoffs.
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3. The author has prepared a more detailed treatment of this topic, which has not yet been published. Please contact the author for more information.