µWatt RF Power Measurement System & Methodology

Using a spectrum analyzer adjacent channel power ratio (ACPR) capability to accurately measure RF power from −130 dBm to −50 dBm.

During the development of the SG9000 RF signal generator project, we encountered the challenge of how to accurately measure µW RF power levels down to −130 dBm over a wide range of frequencies. Dismissing the six-figure expense of a measurement receiver, a low-cost alternative was developed that exploits the automated adjacent channel power ratio (ACPR) capabilities available in contemporary spectrum analyzers to make µW RF power level measurements.

ACPR measures output power in a small bandwidth around the center of a known reference level relative to the device under test (DUT) small bandwidth power in the adjacent channel. The benefit of this methodology is that the DUT level is a ratio measurement against a known calibrated reference level, thereby relieving the analyzer of maintaining absolute level accuracy over a wide range of measurement frequencies.

In practice, the ACPR center reference is supplied by an RF signal generator level adjusted to −50 dBm using a calibrated RF power meter such as an Agilent E4418B and appropriate RF power sensor. The center reference level is further attenuated by 50 dB using known-loss fixed attenuators resulting in a calibrated −100 dBm level applied to the input port of a two port combiner. The DUT signal is displaced 2 kHz below the reference and applied to the input port of the combiner through a known loss 3 dB attenuator.

The combiner output drives a low noise-figure 22 dB gain amplifier compensating for combiner and coax cable loss, the resulting composite signal is then applied to the spectrum analyzer in ACPR mode for measurement. The DUT output signal level in dBm can now be calculated by: $DUT\ dBm = ((DUT\ Signal + Ref\ Signal) - DUT\ Attenuator) \times (-1)$.

For example, in Figure-1 ACPR System Confidence Test, DUT $-129.93\ dBm = ((32.93\ dBc + 100\ dBm)) - 3\ dB) \times (-1)$

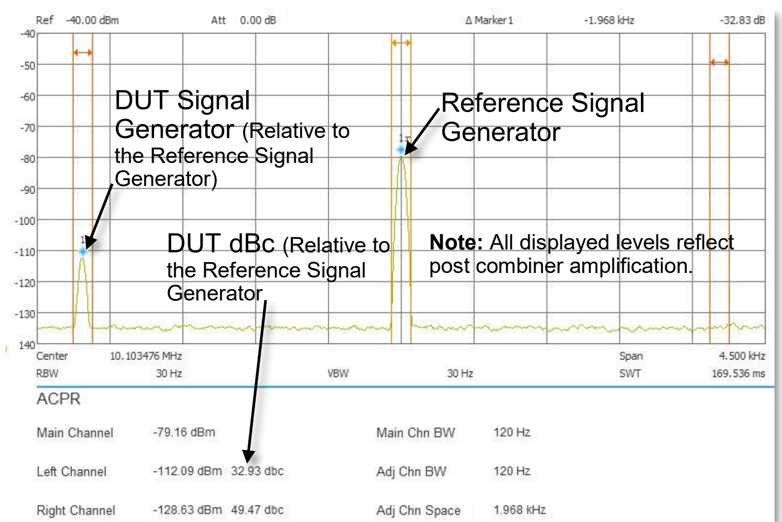

Figure-1 ACPR System Confidence Test Example
DUT Gen HP8657A 10.10150 MHz @ −130 dBm; REF Gen 10.10350 MHz
DUT Measured Level: −129.93 dBm
(HP-8657A Specified Accuracy Below −127 dBm: < ±1.5 dB)

ACPR Measurement Performance Advantages

- **Single Calibrated Instrument:** Allows the use of a single calibrated RF power meter, such as the Agilent E4418B and RF power sensor, to act as an transfer calibration instrument for the measurement of RF power levels from −130 dBm to −50 dBm in the ACPR test environment or direct measurement of levels from −50 dBm to +10 dBm outside the ACPR environment, thereby referencing all RF signal measurement levels to a single calibrated instrument.

- **Convenient Coax Cable Lengths:** The DUT and reference source can be connected by convenient equal-length coax cables to the ACPR test set. Correspondingly, the ACPR output coax to the spectrum analyzer can also be any convenient cable length. As a ratio measurement, loss experienced by the output coax line length/frequency, is automatically compensated for by the ACPR measurement system.

- **Excellent Return Loss**: The DUT RF output connector is directly terminated with a 3 dB attenuator and the reference generator is directly terminated with a 50 dB attenuator, establishing a return loss of greater than −22 dB and −34 dB respectively. This favorable return loss minimizes impedance influenced amplitude variations that may be experienced across the test frequency spectrum.

- **Improved Signal-to-Noise Ratio:** Post two-way combiner amplification of the composite two-tone signal eliminates combiner/cable loss and improves the analyzer signal-to-noise ratio measurement when operating the DUT at levels below −110 dBm.

ACPR Measurement Performance Limitations

It can be argued that a ratio measurement accuracy is subject to the spectrum analyzer's *amplitude precision* specification. For example Siglent's SSA3021X amplitude precision is specified at < 0.7 dB. However, in practice, ACPR measurement results have favorably demonstrated 0.5 dB agreement or better in confidence testing with an HP8657A RF signal generator and a Boonton Model 25A level calibrator.

When measuring RF signal generator low level signals, keep in mind that signal generators specify output amplitude level accuracy or level uncertainty at various power levels and that level uncertainty is greatest at the minimum RF output limit. For example, Keysight N9310A: < 1 dB (not specified below −120 dBm); HP8657A: < 1.5 dB (−127 dBm); Siglent SSG5000X Series: ≤ 1.1 dB (−110 dBm to −130 dBm); Rigol DSG800 Series: ≤ 1.1 dB (−60 dBm to −110 dBm).

Adjacent Channel Power Ratio (ACPR) Test Set

The ACPR Test Set can be easily built using off-the-shelf components. Refer to Figure-2 ACPR interior view, Figure-3 ACPR test set block diagram, and Figure-4 ACPR test configuration.

The ACPR test set as-built selected components are suitable for operation from 1 MHz to 1 GHz. Alternative equivalent components can be substituted recognizing the intended frequency range of operation and amplifier noise figure.

The DUT generator and refence generator outputs are applied to a 2-way 0˚ combiner with a typical port-to-port isolation of 25 dB and an amplitude imbalance of 0.1 dB. The combiner output is followed by an RF amplifier with a typical gain of 22 dB of gain and a typical noise figure of 0.9 dB at 250 MHz. The RF amplifier and can be powered directly by 5 VDC (≈ 170 mA) or indirectly by 12 VDC using a 5 VDC linear regulator enclosure-case-mounted to dissipate the resulting 1.2 Watt. All components are installed in a die-cast aluminum enclosure providing excellent RF shielding properties.

System RF connectivity is established through RG-142 (double-shield) BNC right-angle to BNC straight 36-inch coax cable assemblies ensuring excellent signal integrity and consistent performance.

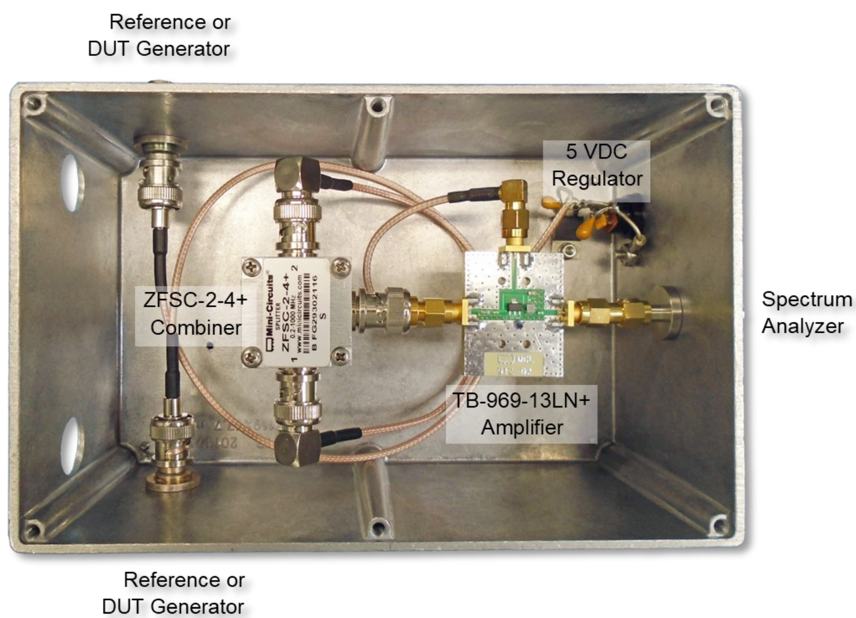

Figure-2 ACPR Test Set Interior Photograph & Component Identification

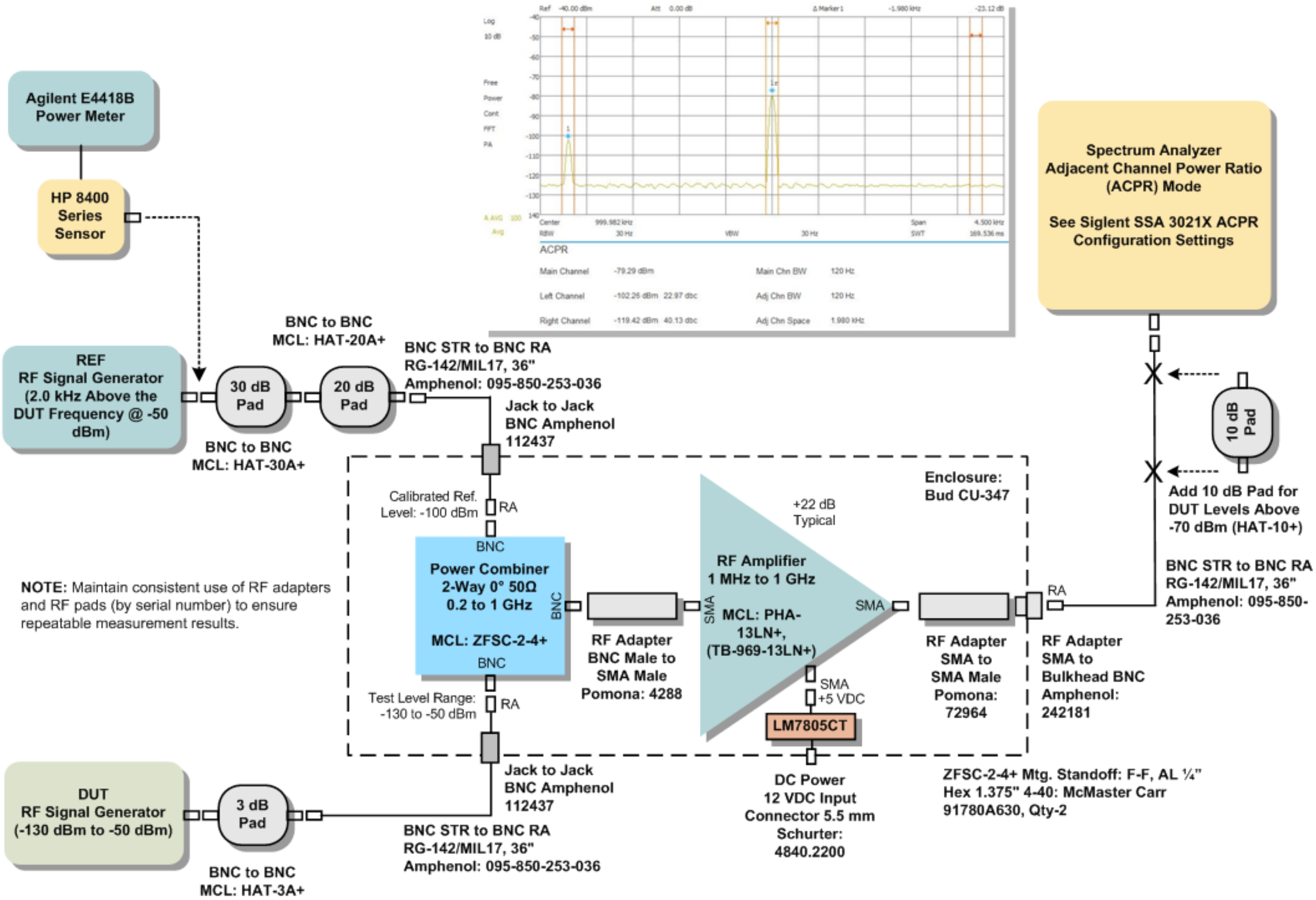

Figure-3 ACPR Test Set Block Diagram & Component Identification (MCL = Mini Circuits Labs)

Figure-4 ACPR Test Configuration Example Spectrum Analyzer, ACPR Test Set, SG9000 REF & DUT RF Signal Generators; DUT: 280.101500 MHz, −100 dBm

Fixed Attenuator Error Correction

The fixed attenuators consists of a 3 dB attenuator applied to the DUT and a 20 dB and a 30 dB attenuator combined applied to the reference generator. Typical attenuator flatness is ± 0.05 to ± 0.3 dB over the frequency range DC to 500 MHz. The calibrated RF power meter is used to measure the actual loss of the individual attenuators at the reference generator calibration frequencies.

The individual attenuator measured loss values are combined to produce an adjusted reference generator calibrated RF output level: $((-20\ dB\ meas.\ value + 20\ dB) + (-30\ dB\ meas.\ value + 30\ dB) - (-3\ dB\ meas.\ value + 3\ dB) + 50\ dB) \times (-1) = reference\ generator\ calibrated\ output\ level.$

For example, at 360 MHz, the measured attenuation values of the individual attenuators are: 20 dB = 20.18 dB, 30 dB = 29.71 dB & 3 dB = 3.05 dB, therefore the reference generator calibrated target level is: $-50.16\ dBm = ((-20.18\ dB + 20\ dB) + (-29.71\ dB + 30\ dB) - (-3.05 + 3\ dB) + 50\ dB) \times (-1)$.

Reference (REF) Signal Generator Frequency and Output Level Calibration

The reference signal generator frequency XXX.10350 MHz is positioned 2.0 kHz above the DUT frequency at −100 dBm (signal generator level −50 dBm + 50 dB fixed attenuation). The reference generator −50 dBm level is verified using a calibrated Agilent E4418B power meter and RF power sensor and subsequently corrected for the fixed −50 dB fixed attenuator error resulting in a calibrated output level of −100.00 dBm for each frequency of interest.

Device Under Test (DUT) Signal Generator Frequency

The DUT is positioned 2 kHz below the reference signal generator with a 3 dB attenuator connected directly to the RF output port.

Spectrum Analyzer ACPR Settings & Configuration

The following spectrum analyzer configuration settings apply to the Siglent SSA3021X with the Advanced Measurement Kit (AMK) firmware option enabled. These settings may also be suitable for similar analyzers as well.

Sweep Mode: FFT

Center Frequency: 2.0 kHz above the DUT (reference signal generator frequency)

Frequency Span: 4.5 kHz (resultant sweep time: 169.536 ms)

RBW & VBW: Auto (resulting in a bandwidth of 30 Hz each)

Amplitude Reference Level: −40 dBm

Amplitude Scale/Div & Type: 10 dB/Log

Attenuator (manual set): 0.0 dB

Preamp (PA): On

System, Auto Cal: On

Measurement (Meas) Mode: ACPR (adjacent channel power ratio)

- **Note:** ACPR mode automatically selects: **AVG Type:** Power; **Detect:** Average Power. ACPR center frequency is automatically selected by the above user center-frequency entry

- **Measurement (Meas) Set-Up, Main & Adjacent Channel BW:** 120 Hz each.

- **Adjust Channel Space (Adj Chn Space):** User marker to center-frequency and delta offset measurement to identify the space frequency

- **Trace Average:** 100 times/measurement event (resultant total measurement time: ≈ 33 seconds).

Determining SSA3021X Analyzer ACPR Frequency Span, Main and Adjacent Channel Bandwidth Values

The SSA3021X in ACPR mode requires that the selected frequency span, main and adjacent channel bandwidth produce an integer value for the proper channel power number of points calculation:

Let: Frequency Span: Hz; SSA3021X Sweep Points: (750); Main Chan BW = Adjacent Chan BW: Hz

Determine:*Frequency Resolution Hz = Frequency Span Hz ÷ 750*

Calculate: *Number of Points Used to Calculate Channel Power = Main Channel Bandwidth (Hz) ÷ Frequency Resolution Hz*

Note: Number of Points must be a integer, 10 or more desired.

Example: 4500 Hz ÷ (750) = 6 Hz

120 Hz ÷ 6Hz = 20 = Number of Points Used to Calculate Channel Power > 10 and an Integer.

The ACPR Settings & Configuration values (Frequency Span: 4.5 kHz and Channel Bandwidth: 120 Hz) meet this criteria.

Measuring DUT Levels Between −70 dBm & −50 dBm

When measuring DUT levels from −70 dBm to −50 dBm install a 10 dB attenuator at the spectrum analyzer input to maintain the DUT level below the spectrum analyzer’s −40 dBm reference level.

RF Level Measurement Example: −130 dBm @ 10.10150 MHz

1.0 Configuration

1.1 Device Under Test (DUT) Signal Generator: Set the DUT to: CW, 10.10150 MHz, and the RF output power −100 dBm.

1.2 Reference Signal Generator: Set the reference generator to CW, a frequency 2 kHz above the DUT test frequency, and adjust the RF output to the −50 dBm attenuator calibrated level.

1.3 Spectrum Analyzer: Set the center frequency to the reference generator frequency. The reference frequency and DUT frequency should visible.

1.4 Using the marker peak and center function, identify the reference frequency and move it to the analyzer center frequency.

1.5 Using the delta peak function to identify the DUT frequency and note the displacement in Hz.

1.6 Enable the ACPR measurement mode and apply the frequency displacement (Hz) in the Adj Chn Space window and set the Main Chn & Adj Chn BW to: 120 Hz.

2.0 Measurement

2.1 Set the DUT RF output level to −130 dBm.

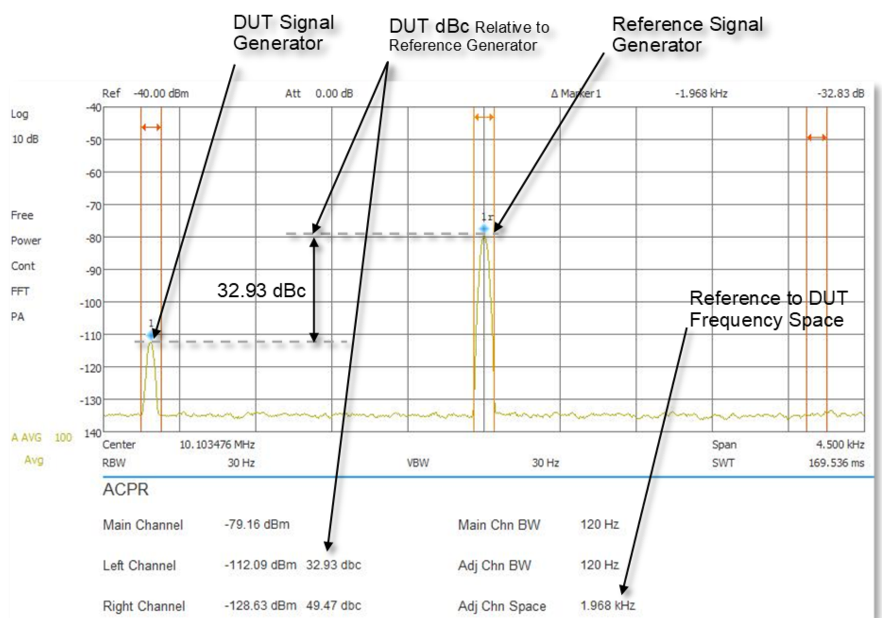

Figure-5 ACPR Measurement Example
DUT Gen 10.10150 MHz −130 dBm; REF Gen 10.10350 MHz
DUT Measured Level: −129.93 dBm

2.2 Set trace averaging to 100X.

2.3 Upon completion of the trace average X100 cycle, read the difference in dBc between the center channel and left channel in dBc. Use that value to compute: $DUT\ dBm = ((DUT\ Signal + Ref\ Signal) - DUT\ Attenuator) \times (-1)$. In this example, the DUT measured: $-129.93\ dBm = ((32.93\ dBc + 100\ dBm)) - 3\ dB) \times (-1)$.

RF Level Measurement Example: −50 dBm @ 10.10150 MHz

1.0 Configuration

Configure the analyzer as in the −130 dBm example with the addition a 10 dB attenuator installed at the spectrum analyzer RF input.

2.0 Measurement

2.1 Set the DUT RF output level to −50 dBm.

2.2 Set trace averaging to 100X.

2.3 Upon completion of the trace average X100 cycle, read the difference in dBc between the center channel and left channel in dBc. Use that value to compute: $DUT\ dBm = ((DUT\ Signal + Ref\ Signal) - DUT\ Attenuator) \times (-1)$. In this example, the DUT measured: $-50.07\ dBm = (-46.93\ dBc + 100\ dBm)) - 3\ dB) \times (-1)$. Note the sign change (−) in the reported DUT dBc relative value.

Interesting to observe, that the DUT signal when measured with the Agilent E4418B RF Power Meter indicated −49.97 dBm, a favorable agreement with the ACPR −50.07 dBm measurement.

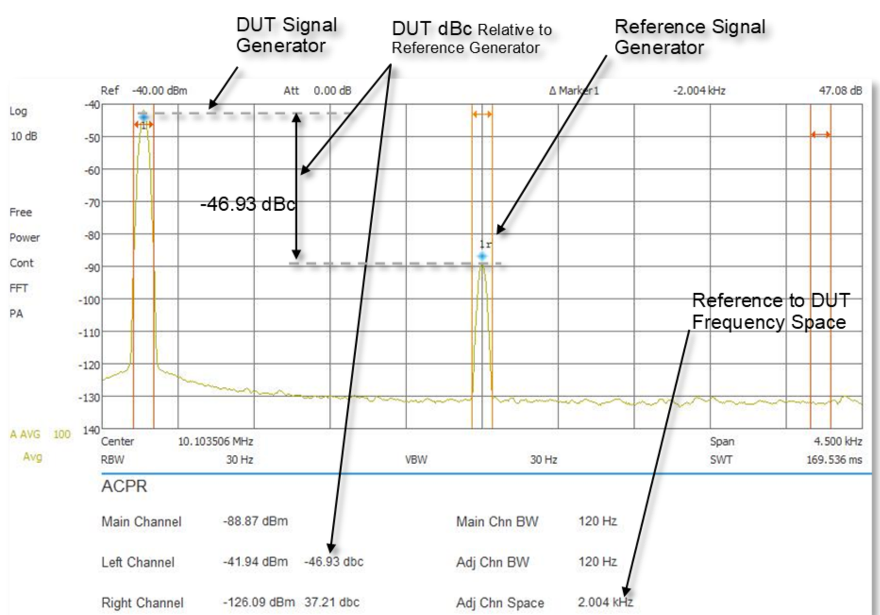

Figure-6 ACPR Test Measurement Example
DUT Gen 10.10150 MHz –50 dBm; REF Gen 10.10350 MHz
DUT Measured Level: −50.07 dBm

Conclusion

The ACPR power measurement system has proven to be a cost effective, accurate, and repeatable methodology for measuring RF power below the −50 dBm to −70 dBm limitations of RF power meters across a wide range of frequencies. In addition, it's readily adaptable to PC automated test platforms using the spectrum analyzer's standard commands for programmable interface (SCPI).

For questions concerning the ACPR test set, the ACPR application or the SG9000 RF signal generator please contact: sales@talonpowersystems.com