TI Designs
A 160-MHz Bandwidth Wireless Signal Tester

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Design Resources

TIDA-00988	Tool Folder Containing Design Files
ADC31JB68	Product Folder
LMH5401	Product Folder
LMK04828	Product Folder
LP3878-ADJ	Product Folder
TPS62130A	Product Folder

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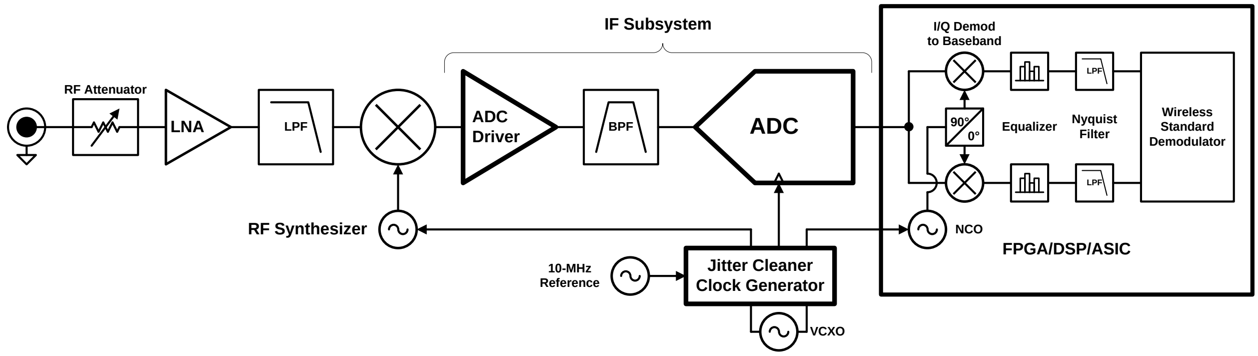
Design Features

- Implements an IF Subsystem for Standard Wireless Signal Tester With 160-MHz Bandwidth
- Support for Most Standard Wireless Signal Data Types

Featured Applications

- Wireless Signal Tester
- Vector Signal Analyzer (VSA)
- IoT Signal Tester
- Spectrum Analyzer (SA)



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1 System Description

This reference design implements an IF subsystem for a standard wireless signal tester with an active balun-amplifier (LMH5401), LC bandpass filter, and 16-bit ADC (ADC31JB68). Measurements using modulated signals demonstrate reception of the signal with high constellation clarity and MER sufficient for testing a wide variety of standard signal types.

2 Motivation

The ability of a RF front-end receiver of a wireless signal tester to reliably measure and characterize a signal is constrained by a number of performance aspects, notably the available demodulation bandwidth, third-order inter-modulation distortion (IMD3), noise spectral density, and phase noise. The bandwidth must accommodate the supported standards with the widest channel, while the noise and distortion must be order(s) of magnitude better than the performance of the Device Under Test (DUT).

Table 1 shows a survey summary of relevant characteristics from a variety of wireless standards. Early standards such as 802.11b, GSM or EDGE and the CDMA-based standards generally occupied less than 25-MHz of bandwidth and used simple modulation schemes, mostly variations of QPSK. However, more recent standards and multi-carrier use cases have driven the tester requirements to higher bandwidths and better performance to support the higher order modulation schemes. Wi-Fi® (802.11 a/c) is an important case that can transmit signals with up to 160 MHz of bandwidth and with a modulation order up to 256-QAM.

Table 1. Characteristics of Wireless Data Standards

STANDARD	CARRIER FREQUENCY	MODULATED CHANNEL BANDWIDTH	MODULATION
Wi-Fi B (IEEE 802.11b)	2.4 GHz	22 MHz Channel	DSSS
Wi-Fi N (IEEE 802.11n)	2.5 and 5 GHz	Channel up to 40 MHz	OFDM, Subcarriers up to 64-QAM
Wi-Fi A/C (IEEE 802.11a/c)	5 GHz	Channel up to 160 MHz	OFDM, Subcarriers up to 256-QAM
WiMAX (IEEE 802.16)	2.3 GHz to 5.8 GHz	Channel up to 20 MHz	SOFDMA, Subcarriers up to 64-QAM
Bluetooth (IEEE 802.15)	2.4 GHz	1 MHz, Frequency hopping across 80 MHz	GFSK (BR), pi/4-DQPSK, 8DPSK (EDR)
Zigbee (IEEE 802.15.4)	850 MHz, 815 MHz, 2,450 MHz	Channel up to 2 MHz (5 MHz spacing)	BPSK, OQPSK
UMTS FDD, WCDMA (3GPP)	0.7 GHz to 3.6 GHz	Channel up to 5 MHz Multi-carrier up to 80 MHz	QPSK, DQPSK up to 64-QAM
LTE FDD (3GPP)	0.7 GHz to 3.6 GHz	Channel up to 20 MHz Multi-carrier up to 80 MHz	OFDM SC-FMDA up to 64-QAM
GSM and EDGE	0.4 GHz to 1.9 GHz	200 kHz Channel Multi-carrier up to 75 MHz	GMSK, 8PSK

Figure 1 shows the basic block diagram of a wireless signal tester receiver, also similar to a vector signal analyzer (VSA). An LNA and RF attenuator condition the signal amplitude, a mixer down-converts the channel (or band) to the intermediate frequency band, the IF subsystem filters and samples the signal, and a digital processor filters and demodulates the signal into symbols dictated by the modulation scheme. The performance of the system is limited by its ability to demodulate standard signals and quantified using popular performance metrics, such as the error vector magnitude (EVM) or Modulation Error Ratio (MER).

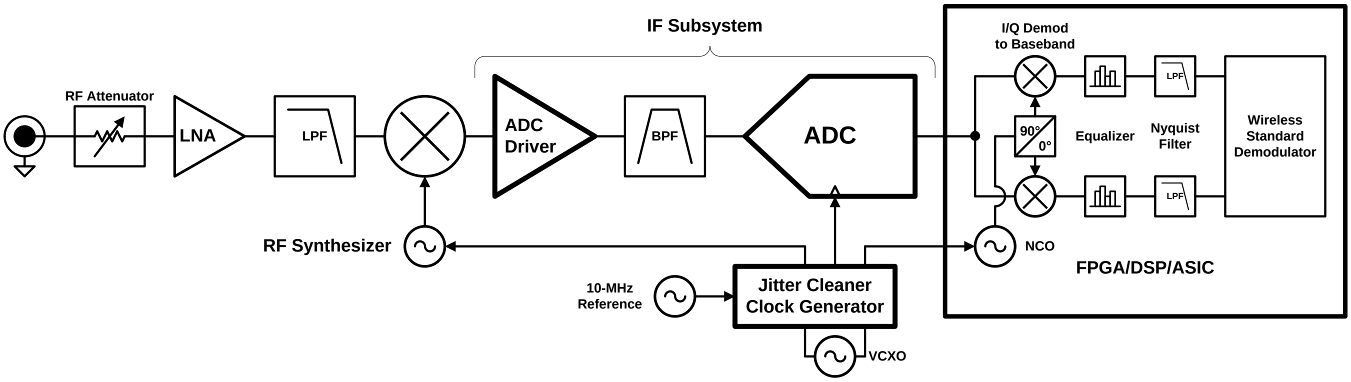

Figure 1. Wireless Signal Tester Receiver Block Diagram

Typically, the demodulation MER performance of a wireless tester must be 10 dB better than the performance requirements of the highest order modulation scheme for a given signal power level to adequately resolve the symbol constellation and quantify the EVM or MER of the unit under test. Here, the following definitions are used for EVM and MER where N is the number of symbols captured, e_k is the magnitude of the respective error vector, and I_k and Q_k are the in-phase and quadrature components of the ideal respective symbol. This EVM definition is consistent with the 3GPP UMTS and LTE standards, and the MER definition is consistent with the ETSI Digital Video Broadcasting measurement guidelines. Both definitions are closely related. The equations for MER and EVM are shown in Equation 1 and Equation 2, respectively.

$$EVM = 100\% \times \sqrt{\frac{\frac{1}{N}\sum_{k=1}^{N} e_k}{\frac{1}{N}\sum_{k=1}^{N} I_k^2 + Q_k^2}} \tag{1}$$

$$MER = 10 \times \log 10\left(\frac{\frac{1}{N}\sum_{k=1}^{N} I_k^2 + Q_k^2}{\frac{1}{N}\sum_{k=1}^{N} e_k}\right) = -20 \times \log 10\left(\frac{EVM}{100\%}\right) \tag{2}$$

Higher order modulation schemes have more closely spaced constellations leading to a higher susceptibility to bit errors for a given MER or EVM value. Figure 2 shows the theoretical Symbol Error Rate (SER) and EVM that corresponds to the given MER (modeled only with AWGN) for a variety of quadrature amplitude modulation schemes.

A wideband 256-QAM signal test signal is a strenuous test case to determine the quality of the tester subsystem, including its functional dynamic range, minimum detectable signal (MDS), and inherent signal integrity before passband equalization. Based on the MER performance requirements to achieve SER<10^–3 shown in Table 2, and assuming the tester's performance must be 10 dB better, the tester must resolve the signal with an MER of greater than 40 dB across a wide range of signal power amplitudes.

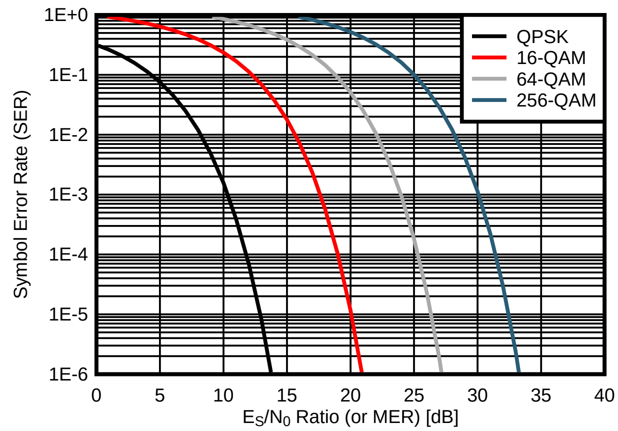

Figure 2. Symbol Error Rate and EVM for a Given MER

Table 2. Theoretical MER and EVM Performance Requirements of Various Modulation Schemes

MODULATION	MER REQUIRED for 10^–3 SER	EVM REQUIRED for 10^–3 SER
QPSK (4-QAM)	10 dB	30%
16-QAM	18 dB	13%
64-QAM	24 dB	6%
256-QAM	30 dB	3.2%

3 System Description

This reference design implements an IF subsystem for a standard wireless signal tester with an active balun-amplifier (LMH5401), LC bandpass filter, 16-bit ADC (ADC31JB68) and clock cleaner and generator PLL (LMK04828), as shown in Figure 3. Measurements using modulated signals demonstrate reception of the signal with high constellation clarity and MER sufficient for testing a wide variety of standard signal types.

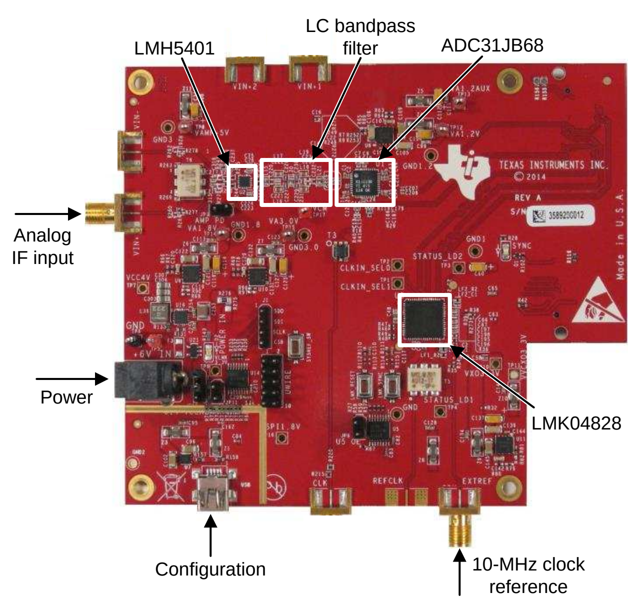

Figure 3. Wideband Receiver Subsystem Reference Design

3.1 ADC31JB68

The ADC31JB68 is a 16-bit ADC sampling at 500 MSPS. The digital outputs are provided on two JESD204B differential lanes, transmitting at 5 Gb per second per lane. The driver-to-ADC interface is AC coupled, thus, the input common mode reference for the ADC is provided through the two 150-Ω termination resistors at the ADC input.

3.2 LMH5401

The LMH5401 is a wide-bandwidth, high-linearity, fixed-gain amplifier that performs a single-to-differential signal conversion. The external components around the amplifier are configured for a 12-dB voltage gain from the SMA connector input to the amplifier output and 50-Ω impedance into the SMA input connector.

3.3 LMK04828

The LMK04828 is a dual-PLL jitter cleaner and clock generator. An on-board 10-MHz reference oscillator (or external signal) can provide the PLL1 input reference, a 100MHz VCXO is used as the VCO of PLL1, and the loop filter bandwidth is set very low to filter the clock noise. PLL2 multiplies the frequency up to approximately 3 GHz and divides down to synthesize the necessary clocks. The ADC is a JESD204B device, so both device clocks and SYSREF clocks are provided to the ADC and to the connector to be used by the downstream signal processor.

4 Block Diagram

Figure 4 shows the TSW31JB68 EVM block diagram.

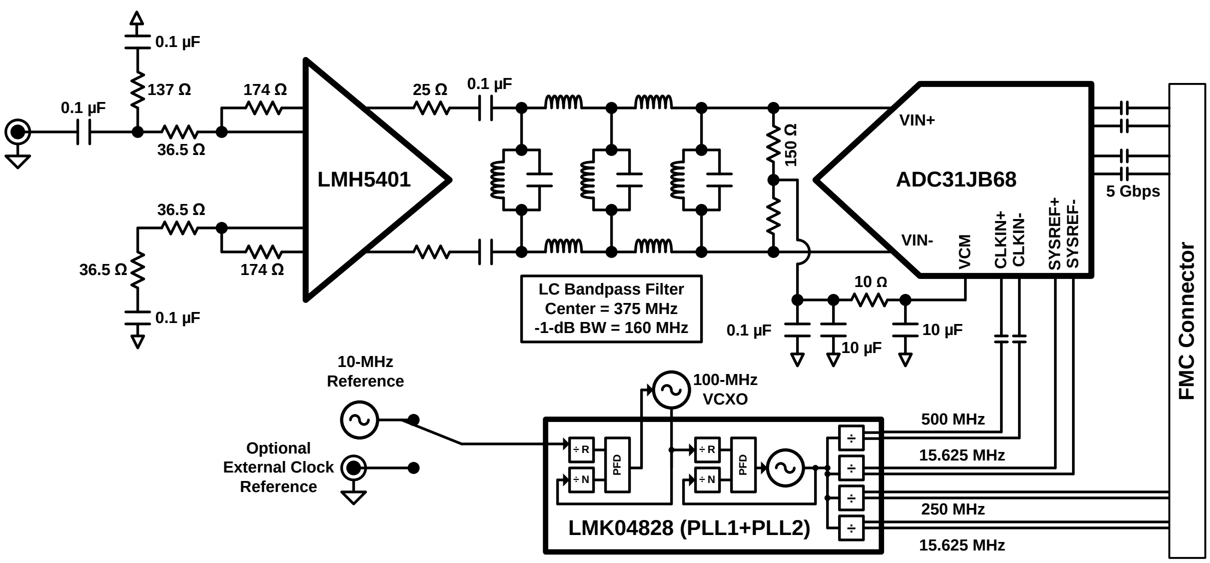

Figure 4. TSW31JB68EVM Block Diagram

5 Measurement Setup

The measurement test bench utilized a Rohde and Schwarz® SMU200A Vector Signal Generator (VSG) to generate the modulated signals, a TSW14J56EVM data capture card to capture the data, the High Speed Data Converter Pro ™(HSDC Pro) software to perform spectral analysis, and Matlab® software to perform demodulation and EVM and MER analysis. Figure 5 shows the bench evaluation setup. Measurements using Continuous Wave (CW) signals used a similar test setup except that a Rohde & Schwarz SMA100A RF signal generator created the signal.

The VSG provided a macro routine for generating a multi-carrier WCDMA signal, as well as a customized modulated signal builder to create a 256-QAM signal with root-raised cosine filter (0.22) pulse shaping. To ensure optimal demodulation performance, the LMK04828 clock chip on the reference design was locked to the 10-MHz clock reference from the SMU200A. The TSW14J56EVM captured data from the ADC31JB68 over a two-lane JESD204B serial data link operating at 5 Gb/s/ane, and delivered the data to the computer. HSDC Pro was used to calculate channel power and peak-to-average ratio of the modulated signals. The 524k-sample data set was then exported to Matlab where it was signal processed to apply the I/Q demodulation to baseband, matched root-raised cosine (alpha= 0.22) filter, and symbol slicer (decimation). De-spreading (code correlation) of the WCMDA signals was not performed so the constellations show the raw QPSK data stream performance and MER is specified before the de-spreading gain.

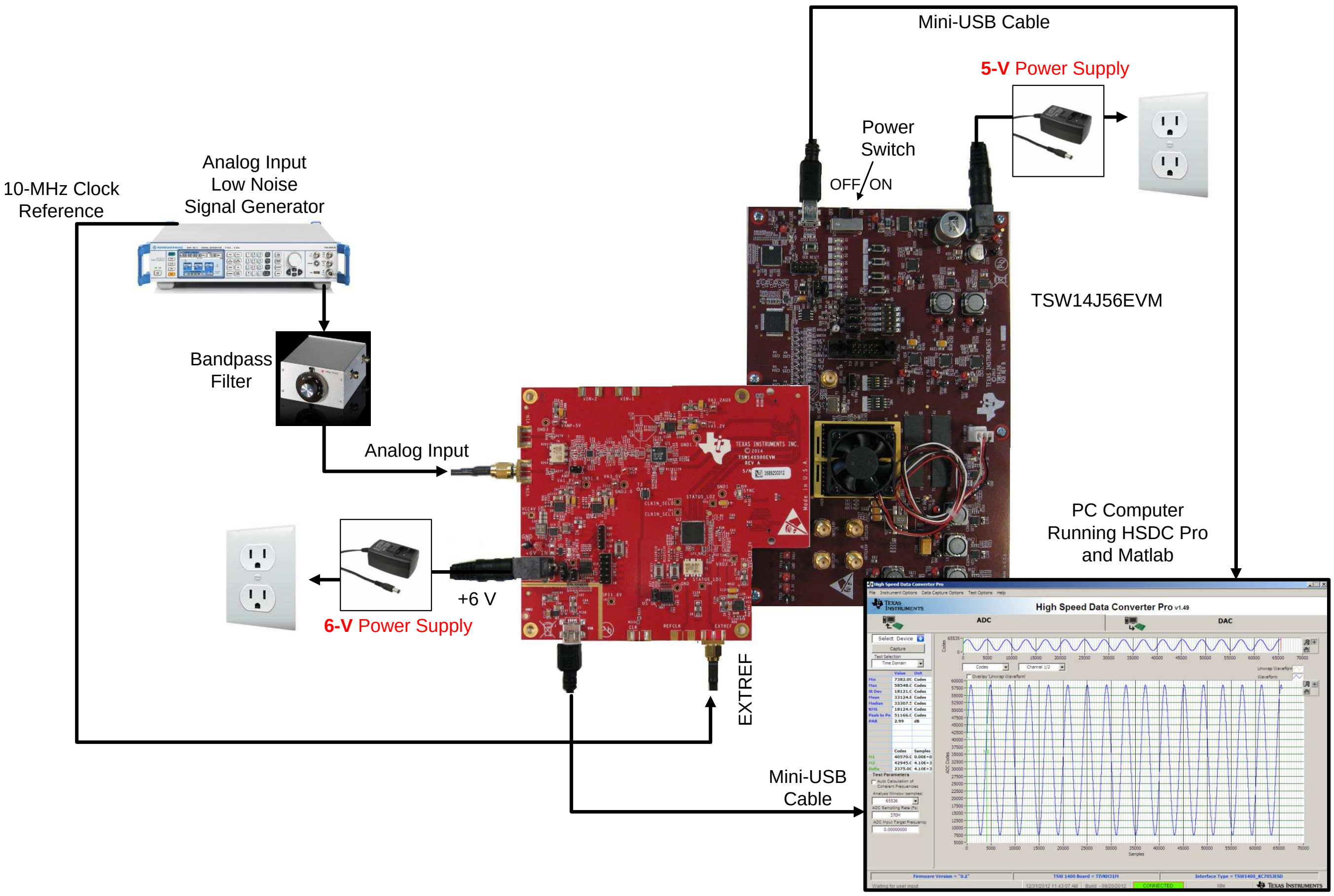

Figure 5. Bench Evaluation Setup

6 Measured Data

6.1 Selectivity

The selectivity is determined by the LC bandpass filter. The chosen topology achieves a high order of roll-off on the upper transition band but sacrifices some unnecessary roll-off on the lower transition to achieve better differential signal balance. The improved differential signal balance across component variation results in better HD2 performance from the ADC. The filter has a 160 MHz -1 dB bandwidth and is centered in the middle of the second Nyquist zone at 375 MHz, as shown in Figure 6. The worst case HD2 occurs at 2×(375–160÷2)= 590 MHz which has approximately 20 dBc of typical suppression.

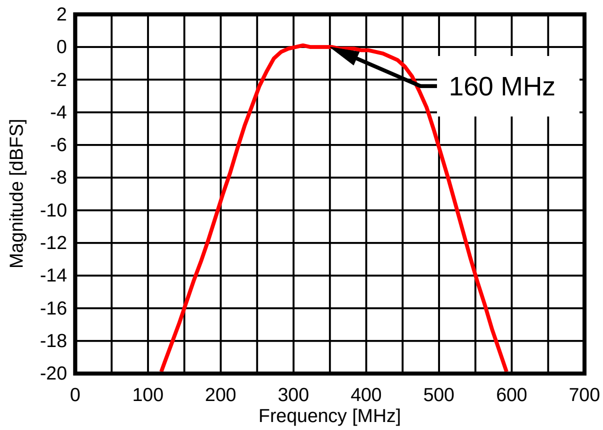

Figure 6. IF Subsystem Frequency Response

6.2 Noise Performance

The total gain of the subsystem is 7.1 dB at mid-band and the input (sinusoidal) power that corresponds to ADC full scale is 1.5 dBm. With no input signal, the subsystem SNR is 70 dBFS, which corresponds to a noise spectral density (NSD) of –154 dBFS/Hz (–152.5 dBm/Hz) at the ADC output. The Noise Figure is approximately 14.4 dB at the SMA connector input.

The SNR and NSD of the subsystem with a –1 dBFS CW tone is shown in Figure 7. The degradation in the noise performance across frequency is due to the phase noise performance of the LMK04828 as well as the additive jitter from the ADC. Based on the noise performance, the sensitivity and dynamic range can be calculated for various standard signals, as listed in Table 3. The 256-QAM, 20-MHz signal has been included as an aggressive test case.

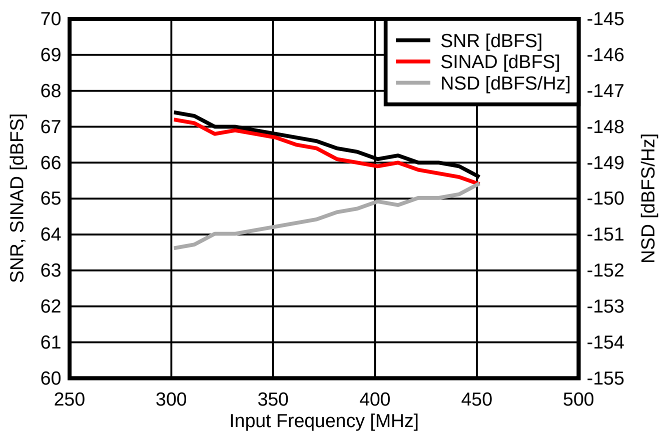

Figure 7. SNR, SINAD, and Noise Spectral Density vs Single-Tone Input Frequency

Table 3. Subsystem Sensitivity and Dynamic Range for Various Standard Signals Based on Noise

SIGNAL TYPE	REQUIRED BASEBAND SNR (E_S/N_0) FOR DEMODULATION [1]	MINIMUM DETECTABLE SIGNAL (MDS) [2]	ASSUMED SIGNAL PAPR	SUBSYSTEM DYNAMIC RANGE
LTE, 5MHz Carrier 16-QAM CR=2/3	11.3 dB	–74.2 dBm	10 dB	Approximately 68.7 dB
WCDMA, 3.84MHz Carrier	–18 dB [3]	–103.5 dBm	11 dB	Approximately 97 dB
256-QAM, 20MHz Carrier	30 dB	–49.5 dBm	9 dB	Approximately 45 dB

[1] Assumes required SER <10–3

[2] Assumes the measured small signal NSD= –152.5 dBm/Hz

[3] Assumes CDMA spreading gain

Equation 3 and Equation 4 show the calculation of MDS and the dynamic range listed in Table 3.

$$MDS_{dBm} = NSD_{dBm/Hz} + SNR_{dB} + 10 \times \log_{10}(BW) \quad (3)$$

$$DR_{dB} = 1.5\ dBm + 3\ dB - PAPR_{dB} - MDS_{dBm} \quad (4)$$

6.3 Distortion Performance

The distortion performance of the subsystem achieves approximately 80 dBFS SFDR for a -1 dBFS input at 375 MHz, as shown in Figure 8. A two-tone test at 380 MHz and 390 MHz and –7 dBFS per tone yields –78 dBc IMD3 as shown in Figure 9.

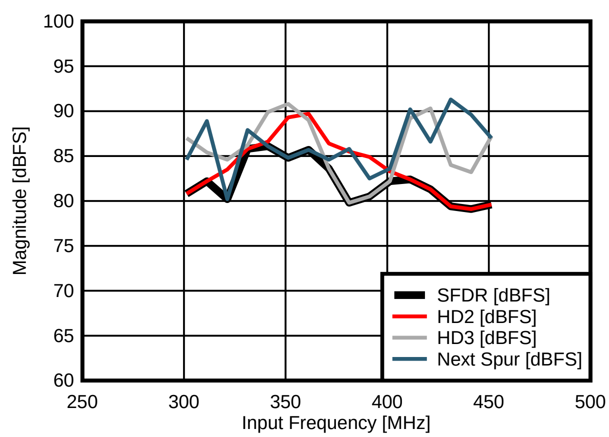

Figure 8. Distortion vs Single-Tone Input Frequency

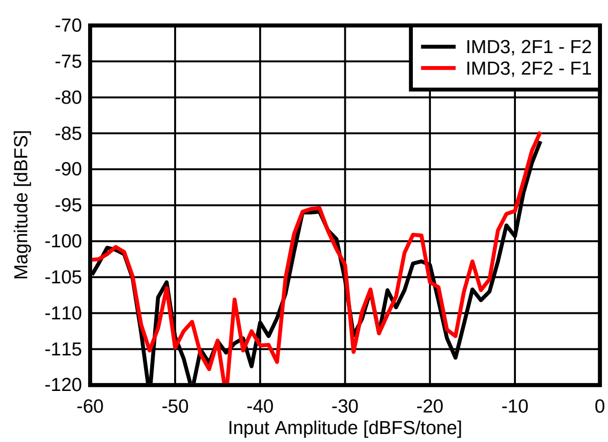

Figure 9. IMD3 vs Two-Tone 380-MHz and 390-MHz Input Amplitude

6.4 Phase Noise

The phase noise of the subsystem is determined by the configuration of the LMK04828. Figure 10 shows the noise density performance at the given frequency offset for a –1 dBFS, 375-MHz input signal. The noise density includes all of the noise from the system, but the in-close phase noise trend coming from the clock source may be clearly distinguished and demonstrates low phase noise for full scale signals within the passband. At the 10-kHz offset, the phase noise is approximately –127dBc/Hz.

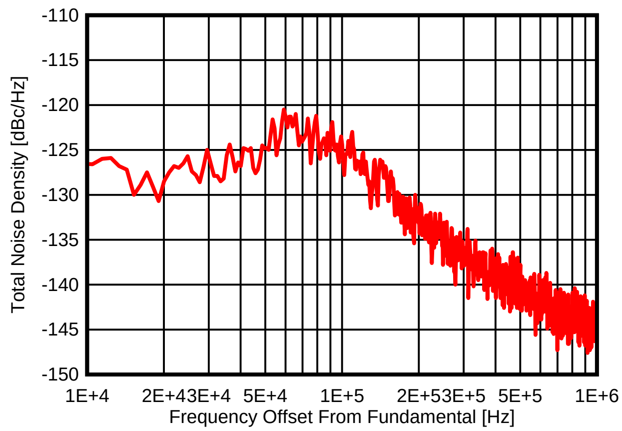

Figure 10. Total Noise Density for 375-MHz of Input

6.5 Multi-Carrier WCDMA Signal Performance

The 5-carrier WCDMA signal spanning 25 MHz with full scale power, as shown in Figure 11, is generated and the center channel is demodulated. The resulting constellation, shown in Figure 12, has an imperceptible error and an MER of 50 dB.

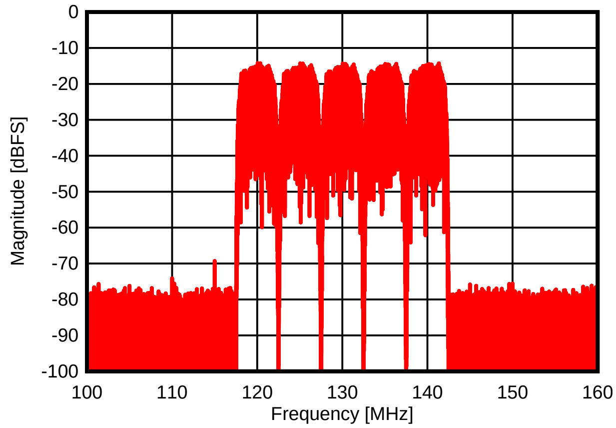

Figure 11. Spectrum fo 5-Carrier –5 dBm WCDMA Signal Centered at 370 MHz IF

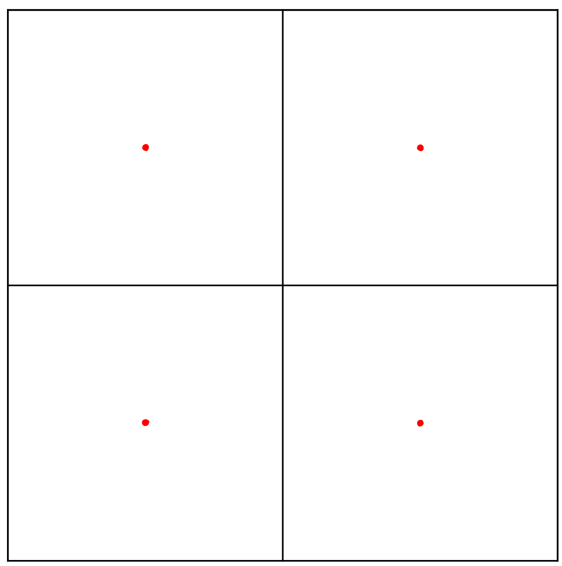

Figure 12. WCDMA Symbol Constellation of Center Channel (MER = 50 dB)

6.6 256-QAM Signal Performance

Measurements of the 20 MHz 256-QAM signal (more correctly, a 20-MHz symbol rate signal with alpha= 0.22 pulse shaping, which results in 24.4 MHz of bandwidth as shown in Figure 13) show good correspondence with the expected theory. Figure 14, Figure 15, and Figure 16 show a clean constellation, eye diagram, and MER performance for a –5 dBm input signal. Figure 17 shows how the MER drops below 30 dB for a –49 dBm MDS and operates up to 4 dBm input power with a very low signal error rate, above which leads to constellation compressions and errors due to ADC over-range. This gives a signal detection dynamic range of 45 dB for symbol error rates <10^–3. The usable dynamic range of this subsystem as a tester is 25 dB for the required MER > 40 dB.

This performance is measured pre-equalizer, which includes amplitude and group delay variation across the 20-MHz bandwidth that degrades the MER. This limitation is usually mitigated by calibration or adaptive equalization in the full tester system. The measurement is also limited by the performance of the signal generator itself.

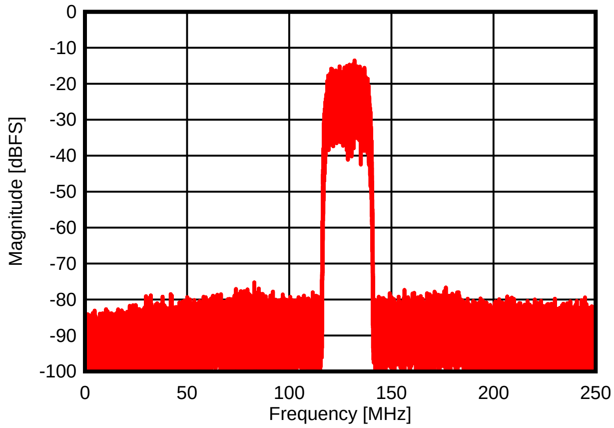

Figure 13. Measured Spectrum of 20-MHz 256-QAM Carrier Centered at 370 MHz

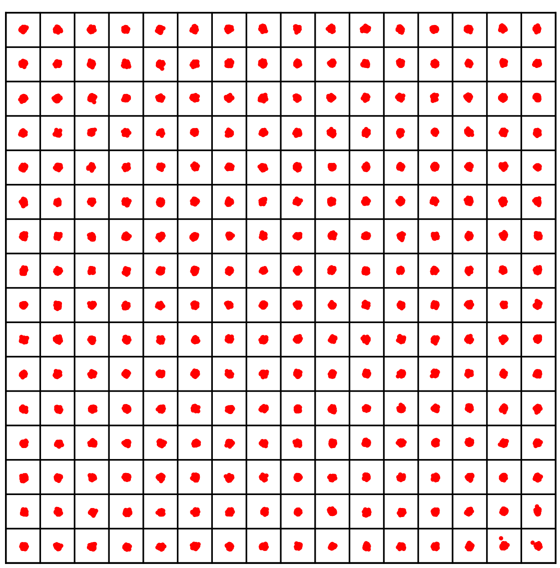

Figure 14. Measured 256-QAM Symbol Constellation (MER = 42 dB)

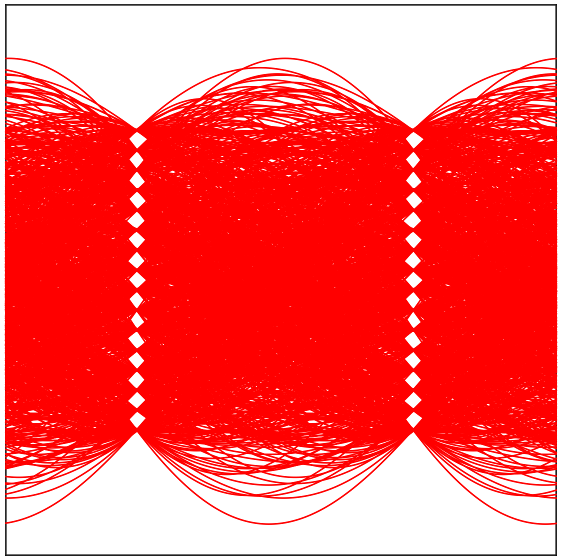

Figure 15. Measured 256-QAM Eye Diagram of the In-Phase Signal Path

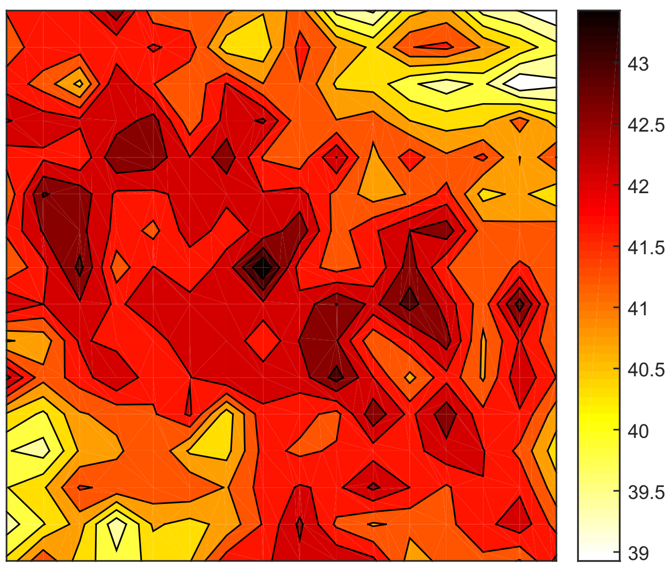

Figure 16. 256-QAM Measured MER Map for Each Symbol

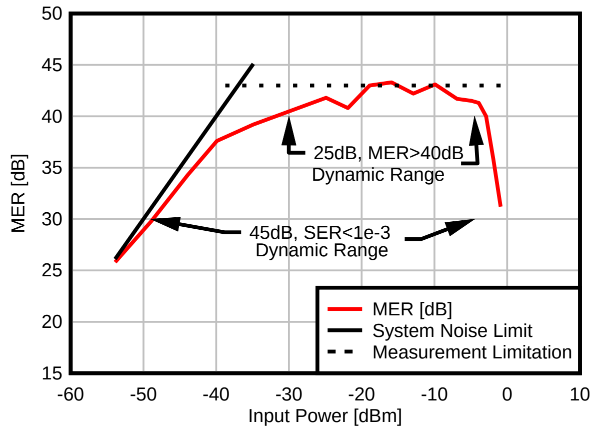

Figure 17. MER for Measured 256-QAM Signal Across Input Signal Power

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