TI Designs
High Accuracy, Logarithmic RMS Power Detector for WLAN Applications

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Design Resources

TIDA-00897	www.ti.com/tool/TIDA-00897
LMH2110	www.ti.com/product/LMH2110
LP5912	www.ti.com/product/LP5912

TI E2E™ Community

- Ask The Analog Experts
- Linear Regulators - Forum
- WEBENCH® Design Center

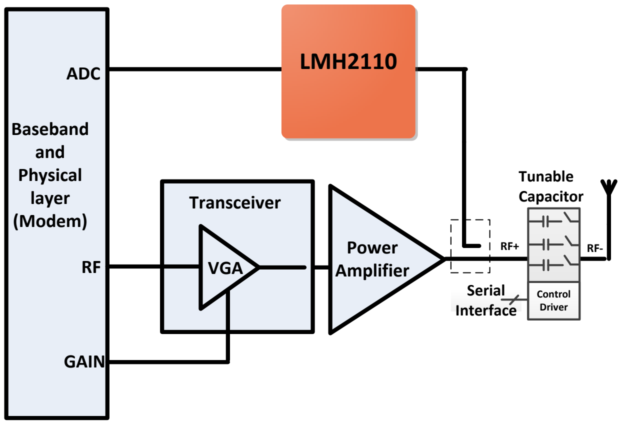
Design Features

- High accuracy logarithmic RMS power detection for WLAN transmit chain at 5GHz – 6GHz.
- 45dB Linear-in-dB power detection range
- LOG conformance better than +/- 0.5dB
- Highly temperature insensitive (+/-0.25db over operating temperature range
- Modulation independent response

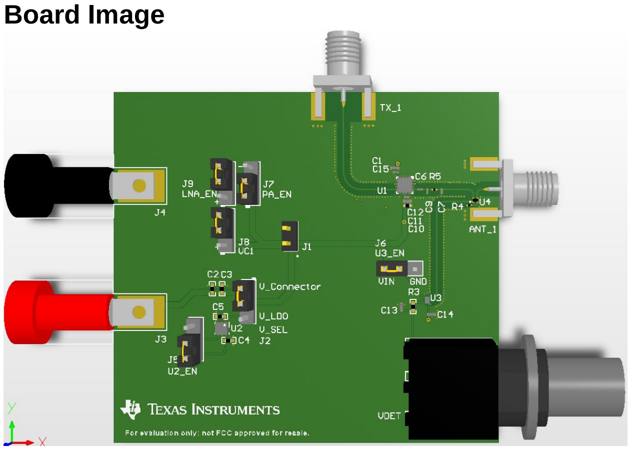
Featured Applications

- WLAN, Wi-Fi Station Devices
- Wi-Fi RF embedded systems
- Wi-Fi automotive applications
- 3G/4G/LTE mobile, automotive and industrial applications

Block Diagram



Board Image



1 System Description

Dynamic transmit-power control is critical for improving spectral efficiency and reducing adjacent channel interference in wireless local area networks (WLANs). In addition, regulatory agencies worldwide require that transmit power be limited to a certain level to reduce interference with other communication equipment. Another benefit of transmit power control in WLAN systems is to prolong battery life by reducing power supply voltage to Power Amplifier. This TI design provides a solution for closed loop dynamic transmit power control for WLAN applications. Although this particular design implements WLAN transmit power control, similar concept can be used to implement power control scheme for other wireless technologies such as 3G/4G/LTE.

As shown in the system block diagram on the first page, a baseband processor and physical layer (modem) maps the digital bits to be transmitted onto a constellation of phase and magnitude vector. This baseband signal is up-converted to RF frequency range (5GHz - 6GHz in this case) by a mixer and scaled to appropriate power level by a Variable Gain Amplifier (VGA) before feeding the final stage of amplification provided by a Power Amplifier block. Both mixer and VGA are normally implemented in the transceiver block. The gains of VGA and power amplifier are subject to part to part variation as well as variation due to temperature and power supply. To account for this variation in gain of the VGA and power amplifier, RF signal power at the output of the power amplifier is measured by power detector that provide a DC output proportional to RF signal amplitude. This DC output from the detector is digitized by an ADC in the modem and becomes an input to an on chip Automatic Gain Control (AGC) algorithm.

TIDA-00897 design provides all the design files and supporting documentation (schematic, Gerber' etc.) which can be used as a reference for implementing a closed loop transmit power control scheme for WLAN systems. All the files can be obtained from http://www.ti.com/tool/tida-00897

Table 1 Key System Specifications

PARAMETER		COMMENTS	MIN	TYP	MAX	UNIT
System Input						
V_{IN}	Operational Input Voltage	Input supply voltage range for EVM operation	3.0	3.8	5.0	V
I_{Load}	Input Current	Current drawn by the EVM when transmitting 16dbm output power.		250	300	mA
$I_{SHUTDOWN}$	Input Current	No transmit power, power amplifier, power detector and LDO disabled.			40	uA
RF Performance (V_{IN} = 3.8V)						
F	Operating Frequency	Operating Frequency range of EVM	5.1		5.9	GHz
P_{OUT}	RF Output Power	RF transmits power range for linear power detection.	-13		17	dBm
P_{COUP}	Coupling factor	Coupling factor of directional coupler on the EVM.	10.2		13.2	dB
V_{DET}	Detector output voltage	Detector output voltage range of EVM	20		1350	mV
$P_{DETACCU}$	Detector Accuracy	Power detection accuracy over temperature			+/- 0.25	dB
Thermals						
T_J	Operating Junction Temperature	LMH2110 Junction Temperature			125	^{o}C

2 Block Diagram

Figure 1 shows a high level block diagram of TIDA-00897 design. Note that LP5912 regulator block is optional. LP5912 is a low noise LDO regulator that can be used to provide supply voltage for power amplifier in applications that have noisy power rails due to switching converters in the system.

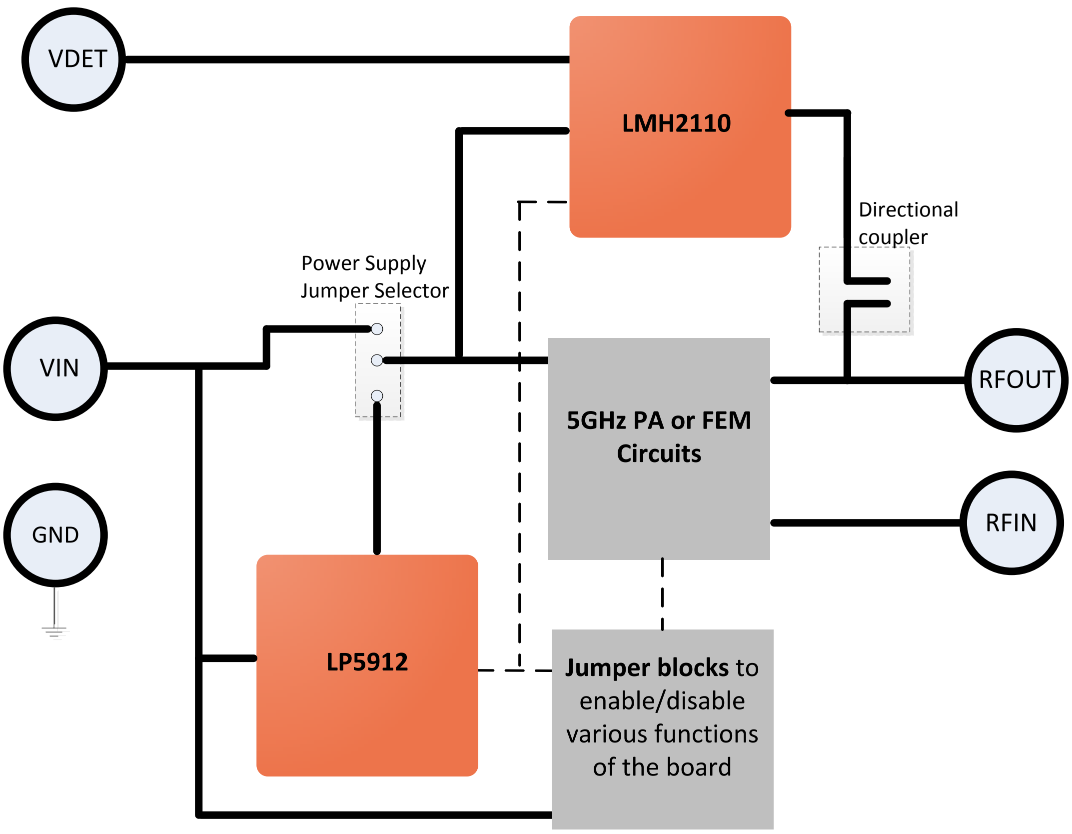


Figure 1 TIDA-00897 Design High Level Block Diagram

3 Block Description

This section describes all the main blocks of Figure 1.

- LMH2110 TI Logarithmic RMS Power Detector
- LP5912 Low dropout linear regulator
- 5GHz FEM
- Connectors and jumpers
  - Banana Jacks (VBATT, GND)
  - SMA Connectors
  - Headers

3.1 LMH2110 8GHz Logarithmic RMS Power Detector

The LMH2110 is a high-performance logarithmic root mean square (RMS) power detector which measures the actual power content of a signal. The device has a RF input power detection range from –40 dBm to 5 dBm and provides accurate output voltage that relates linearly to the RF input power in dBm. This output voltage exhibits high temperature insensitivity of ±0.25 dB. The device has an internal low dropout linear regulator (LDO) making the device insensitive to input supply variation and allowing operation from a wide input supply range from 2.7 V to 5 V. Additional features include multi-band operation from 50 MHz to 8 GHz, shutdown functionality to save power, and minimal slope and intercept variation.

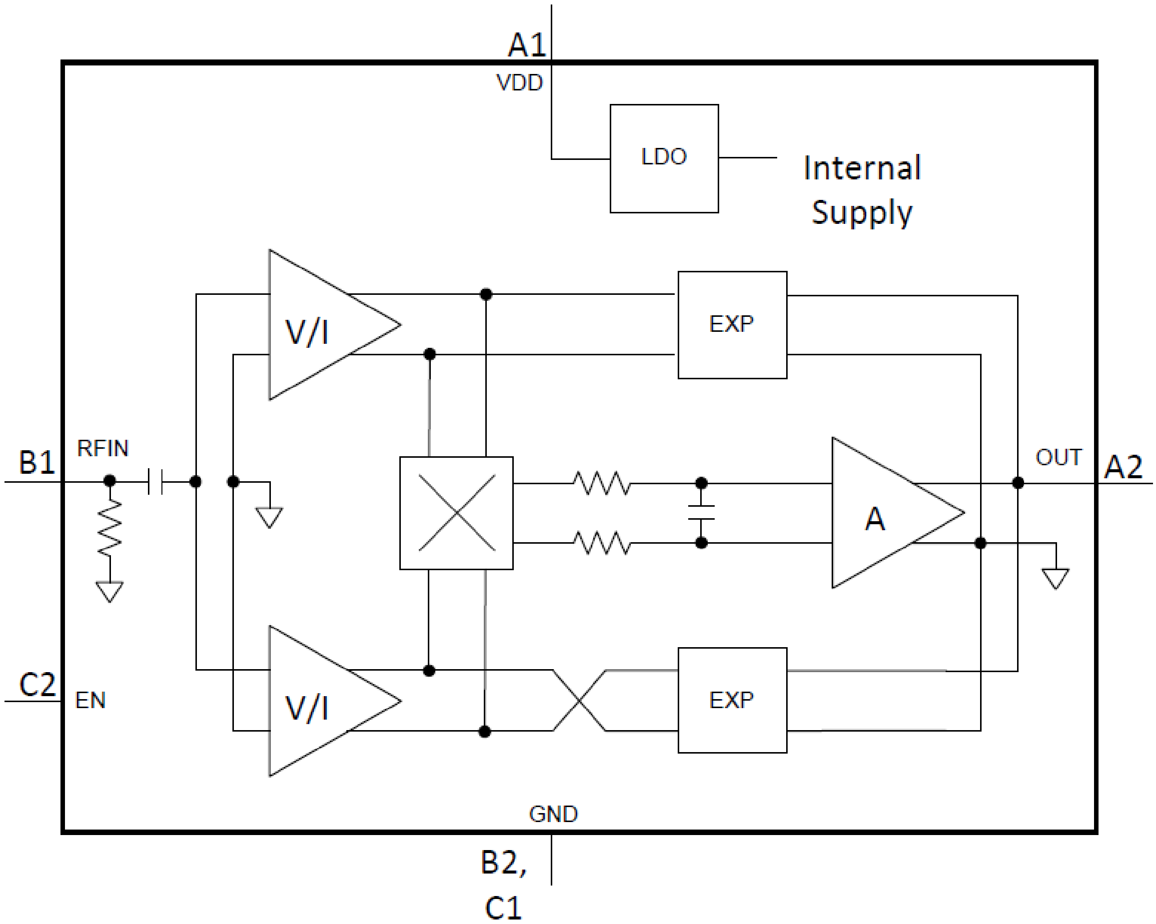


Figure 2 LMH2110 Functional Block Diagram

3.1.1 Accurate Power Measurement

Power is a metric for the average energy content of a signal. By definition it is not a function of the signal shape over time. In other words, the power content of a 0-dBm sine wave is identical to the power content of a 0-dBm square wave or a 0-dBm W-CDMA signal; all these signals have the same average power content.

Depending on the detection mechanism, non RMS power detectors may produce a significantly different output signal in response to more complex waveforms, even though the average power levels of these signals are the same. This error is due to the fact that not all power detectors strictly implement the definition for signal power, being the RMS of the signal. LMH2110 is a true RMS power detector and hence avoids these inaccuracies.

An RMS detector has a response that is insensitive to the signal shape and modulation form. This is because its operation is based on exact determination of the average power, that is, it implements:

$$V_{RMS} = \sqrt{\frac{1}{T}\int v(t)^2 dt} \quad (1)$$

LMH2110 RMS detector is particularly suited for the newer communication standards like Wi-Fi that uses OFDM modulation; W-CDMA and LTE that exhibit large peak-to-average ratios and different modulation schemes (signal shapes). This is an advantage compared to other types of detectors in applications that employ signals with high peak-to-average power variations or different modulation schemes. For example, the RMS detector response to a 0-dBm modulated WCDMA signal and a 0-dBm unmodulated carrier is essentially equal. This eliminates the need for long and complicated calibration procedures and large calibration tables in the baseband due to different applied modulation schemes.

3.1.2 Application With Transmit Power Control

The LMH2110 can be used in a wide variety of applications such as WLAN OFDM, LTE, W-CDMA, CDMA, and GSM. Transmit power control-loop circuits make the transmit power level insensitive to PA inaccuracy. This is desirable because power amplifiers are non-linear devices and temperature dependent, making it hard to estimate the exact transmit power level. If a control loop is used, the inaccuracy of the PA is eliminated from the overall accuracy of the transmit power level. The accuracy of the transmit power level now depends on the RF detector accuracy instead. The LMH2110 is especially suited for transmit power control applications, because it accurately measures transmit power and is insensitive to temperature, supply voltage and modulation variations.

Block diagram on page 1 shows a simplified schematic of a typical transmit power control system. The output power of the PA is measured by the LMH2110 through a directional coupler. The measured output voltage of the LMH2110 is digitized by the ADC inside the baseband chip. Accordingly, the baseband controls the PA output power level by changing the gain control signal of the RF VGA.

To cover for the residual systematic error in the output response of a detector, calibration can be used and a simple look-up table can correct for the residual errors. Depending on the accuracy requirements of the system, multiple look-up tables can be created for different frequency ranges etc.

3.2 LP5912

The LP5912 is a low-noise, high PSRR, low-dropout regulator capable of sourcing a 500-mA load. The LP5912 can operate down to 1.6-V input voltage and 0.8-V output voltage. This combination of low noise, high PSRR, and low output voltage makes the device an ideal low dropout (LDO) regulator to power a multitude of loads from noise-sensitive communication components to battery-powered system.

The LP5912 architecture allows for several important features, including:

- No external output feedback divider resistor, small size and low noise;
- Internal protection circuit, such as current limit, reverse current protection, and thermal shutdown;
- Output auto discharge to fast turnoff;
- Power-good output, with fixed 100-µs delay and no delay option.

3.3 5GHz FEM

Block labeled 5GHz FEM indicates the location of the WLAN front end module circuits that operate in the 5GHz frequency band. This device normally contains many functions in one IC package such as a power amplifier, a low noise amplifier, a transmit/receive switch etc.

Of most interest on this TI design is the power amplifier (PA) function of this device. The PA function is activated by populating jumpers in the appropriate position as discussed in a subsequent section of this document.

3.4 Connectors and Jumpers

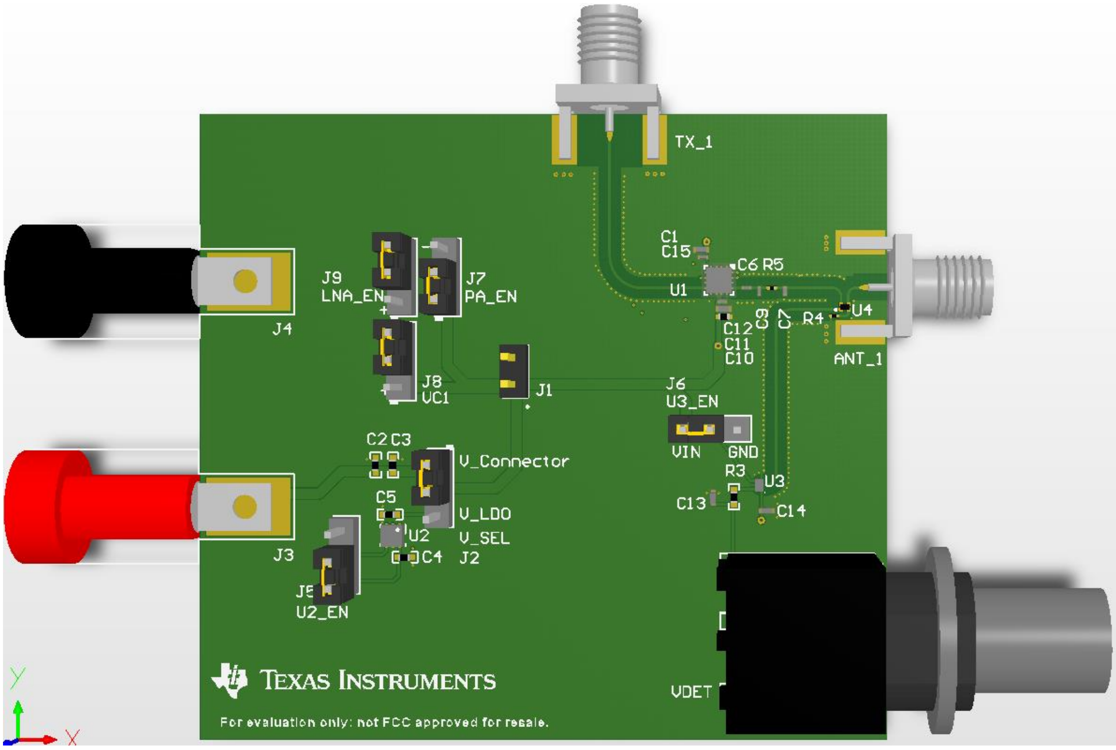


Figure 3 3D view of TIDA-00897 EVM

3.4.1 Banana Jacks (VIN, GND)

Two banana jacks are provided for supplying power to the EVM. Black banana jack is used for ground connection and red banana jack is used for providing input supply voltage. Although the board is capable of operation at lower input voltages, as low as 3.0V, most useful evaluation cases occur at input voltage of 3.8V or higher. Therefore operation at VIN = 3.8V or above is recommended.

3.4.2 SMA and BNC Connectors (TX_1, ANT_1, J6)

There are two SMA and one BNC connectors on the board and their function is as described below.

1. TX Input (TX_1): RF signal in the 5GHz frequency band is input to this SMA connector which in turn connects this signal to TX input pin of the PA. A vector signal generator that provides modulated 802.11 a, n or ac signal should be connected to this connector.
2. Antenna Port (ANT_1): This SMA connector is used to connect the output of the 5GHz PA to a signal analyzer to make signal power measurements.
3. Detector Output (VDET): This BNC type connector provides DC voltage corresponding to the detected RF signal power level.

3.4.3 Headers

Table 2 TIDA-00897 Headers

DESIGNATOR	NAME	FUNCTION
J2	V_SEL	Select system voltage between LDO regulator and directly from the banana connectors.
J5	U2_EN	Connect pin 1-2 to enable LP5912 and pins 2-3 to disable it.
J6	U3_EN	Connect pin 1-2 to enable LMH2110 and pins 2-3 to disable it
J7	PA_EN	Connect pin 1-2 to enable PA of the 5G FEM
J8	VC1_EN	Connect pin 2-3 enable operation in the transmit mode
J9	LNA_EN	Connect pin 2-3 to enable operation in the transmit mode

4 System Design Considerations

The RF input pin of the LMH2110 has an input impedance of 50 Ω. It enables an easy, direct connection to a directional coupler without the need for additional components. For an accurate power measurement the input power range of the LMH2110 needs to be aligned with the output power range of the power amplifier. This can be done by selecting a directional coupler with an appropriate coupling factor.

Because the LMH2110 has constant input impedance, a resistive divider can also be used instead of a directional coupler to couple a fraction of the RF power to input of LMH2110 detector. Resistor R1 sets the attenuation factor before the signal is coupled to detector input using the following formula:

$$R_1 = \left[10^{\frac{A_{dB}}{20}} - 1\right] R_{IN} \tag{2}$$

Where:

A_{dB} is the desired attenuation factor in dB
RIN is the input impedance of LMH2120 (50 ohms)

Although, because of internal averaging mechanism, the output ripple of the LMH2110 is typically low, an optional low-pass filter can be placed in between the LMH2110 output and the ADC input of modem to further reduce the ripple. For some modulation types that have very high peak-to-average ratios, this filtering might be useful.

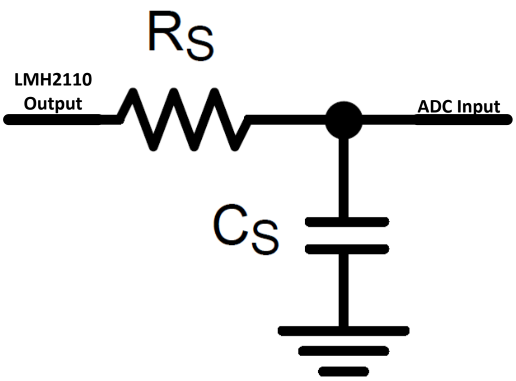


Figure 4: Optional filter configuration at output of LMH2110

Filtering can be applied by an external low-pass filter. Filtering reduces the ripple but increases the response time. In other words, it takes longer before the output reaches its final value. A trade-off must be made between allowed ripple and allowed response time. The low pass output filter is realized by resistor R_S and capacitor C_S. The –3dB bandwidth of this filter can be calculated by:

$$f_{-3dB} = \frac{1}{(2\pi R_s C_s)} \tag{3}$$

4.1 Typical Wi-Fi application schematic

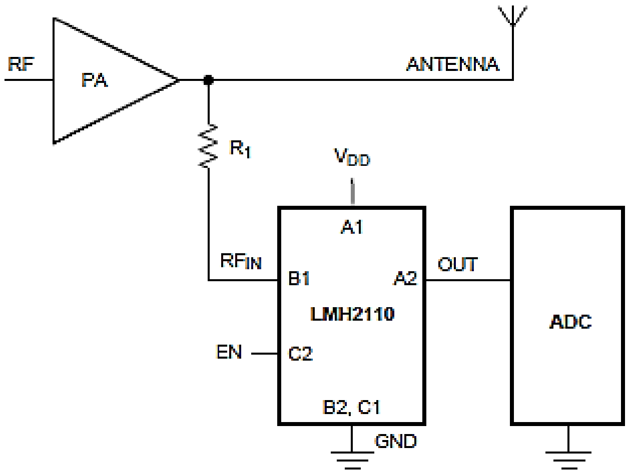


Figure 5 Application schematic

4.2 Other Applications

Applications for transmit power control span a very wide range: from mobile handheld devices to industrial to automotive applications. For example, LMH2110 can be employed in automotive electronics to satisfy transmit power control needs of 3G/4G/LTE communication systems. The block diagram of such a system will be essentially same as that shown in figure 5 for a Wi-Fi system.

4.3 Board Trace Losses

Propagation losses on the micro-strip lines including dielectric and conductor losses must be taken into account to compensate for signal attenuation when making measurements. To compensate for the transmission line losses the following traces losses should be applied in measurements for 5GHz PA.

Table 1: 5.5 GHz Trace Losses

MEASUREMENT FREQUENCY	INPUT LOSS (FROM 5GHZ TX INPUT SMA TO PA INPUT PIN)	OUTPUT LOSS (FROM PA OUTPUT PIN TO 5GHZ ANTENNA PORT SMA)
5.5GHz	0.5dB	0.5dB

5 Getting Started Hardware

Note

The TIDA-00897 EVM is not available for purchase; however, reference design files can be downloaded at http://www.ti.com/tool/tida-00897

5.1 TIDA-00897 board operation

The following steps detail the operating procedure. Please refer to Figure 3 for location of appropriate headers mentioned in the steps below.

1. Provide input supply voltage on V_{IN} and GND banana jacks.
2. If LDO LP5912 is used to provide supply voltage for the PA, place a jumper over pins 1 and 2 of the connector J2. If PA is powered directly from a bench top power supply, place a jumper over pins 2 and 3 of the connector J2.
3. Enable LMH2110 power detector by placing a jumper over pins 1 and 2 of connector J6.
4. Enable 5GHz FEM in the transmit mode. Please see section on 5GHz FEM Control in this document for more details.
5. Provide WLAN modulated signal on input SMA connector labelled TX_1 and perform signal power measurements on output SMA connector labelled ANT_1.
6. Measure detector output voltage (corresponding to RF output signal power at SMA connector ANT_1) on BNC connector labelled VDET.

5.2 5GHz FEM Controls

There are three separate headers that control the operation of 5GHz FEM. This section describes how to put the jumper in appropriate position to enable or disable a particular function block within the 5GHz FEM device.

- Header labeled PA_EN (J7) is used to enable or disable the 5GHz PA. Place a jumper over pins 1 and 2 of this header to enable the PA. Place a jumper over pins 2 and 3 of this header to disable the PA.
- Header labeled LNA_EN (J9) is for enabling/disabling 5GHz receive mode operation. This jumper should always be kept in the disabled position (place a jumper over pins 2 and 3) as the primary purpose of this board is to facilitate PA evaluation with TI power detector.
- Header labelled VC1_EN (J8) is used to control a transmit/receive switch inside the FEM. This header should always be kept in the disabled position by placing a jumper over pins 2 and 3 of this header.

6 Test Setup

LMH2110 RF Testing with TQP887051 (5GHz) FEM

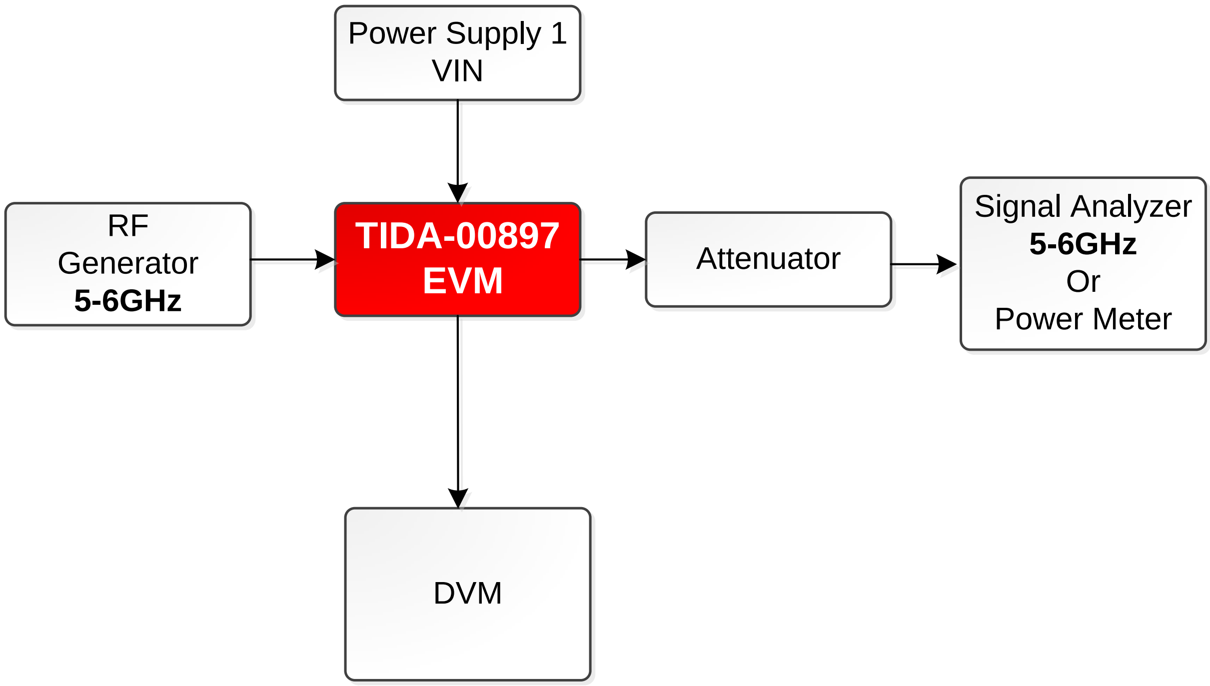


Figure 6 Test Setup Block Diagram

Table 3 Test Signals Conditions

FREQUENCY	CONDITION
5GHz Band	802.11ac, MCS9 VHT80

Table 4 Test Equipment

EQUIPMENT
Agilent – Dual Power Supply (E3631A)
Agilent Digital Voltmeter (34401A)
MXA Signal Analyzer 20Hz – 8.4GHz (N9020A)
MXG Vector Signal Gen 9KHz to 6GHz (N5182B)

7 Test Data

7.1 LMH2110 Detector Response for WiFI 802.11ac Signal

Figures below show response of LMH2110 power detector for 802.11ac Wifi signal.

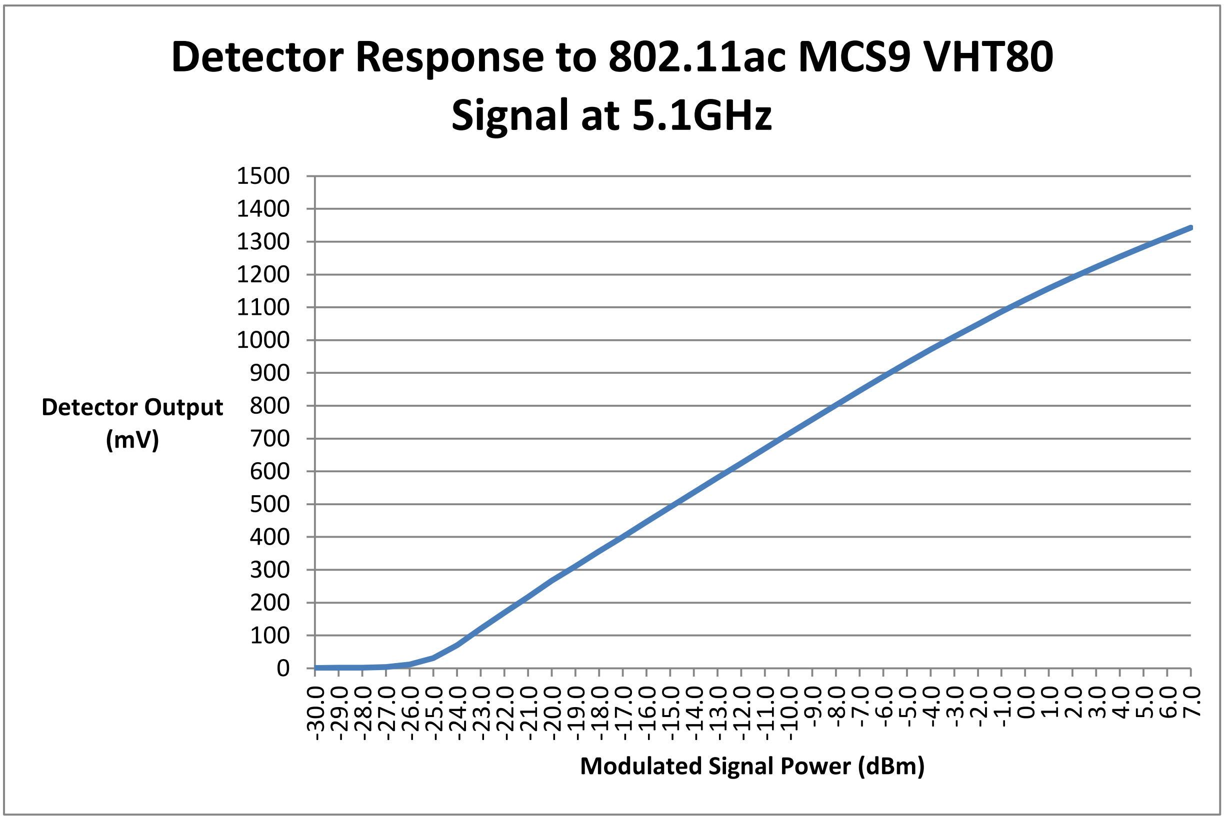


Figure 7: Detector Response at 5.1GHz

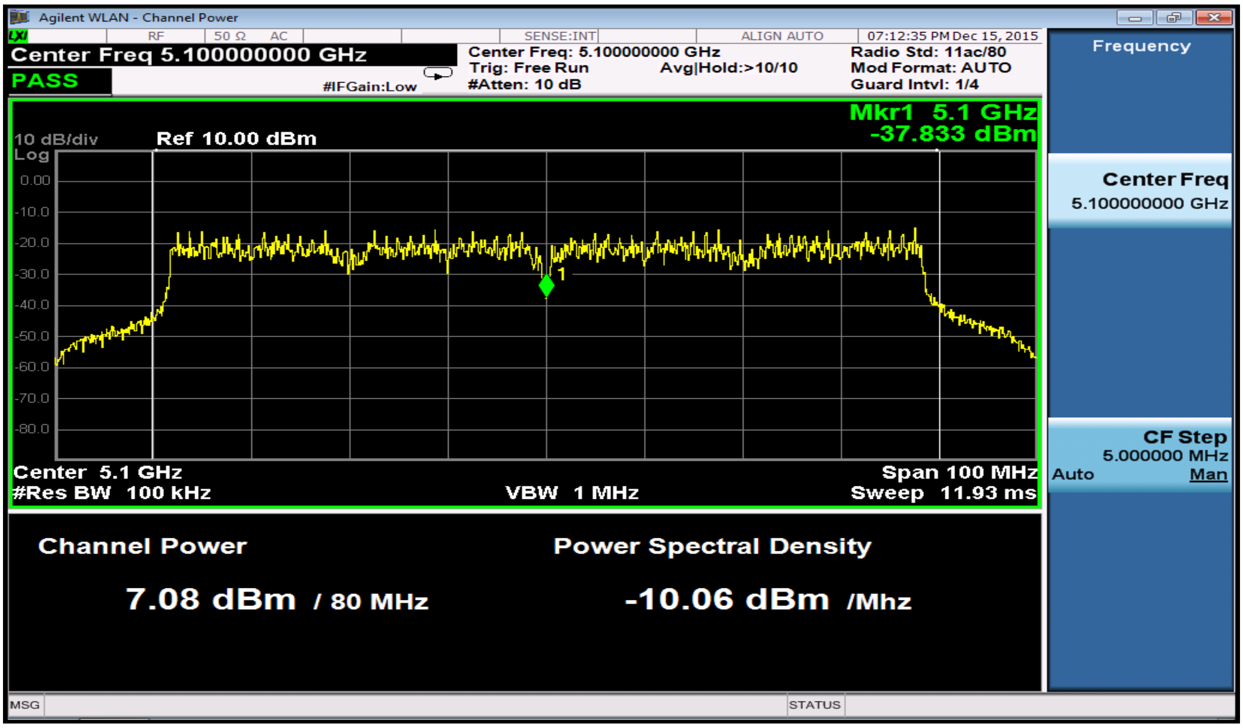


Figure8: 802.11ac Signal 5.1GHz

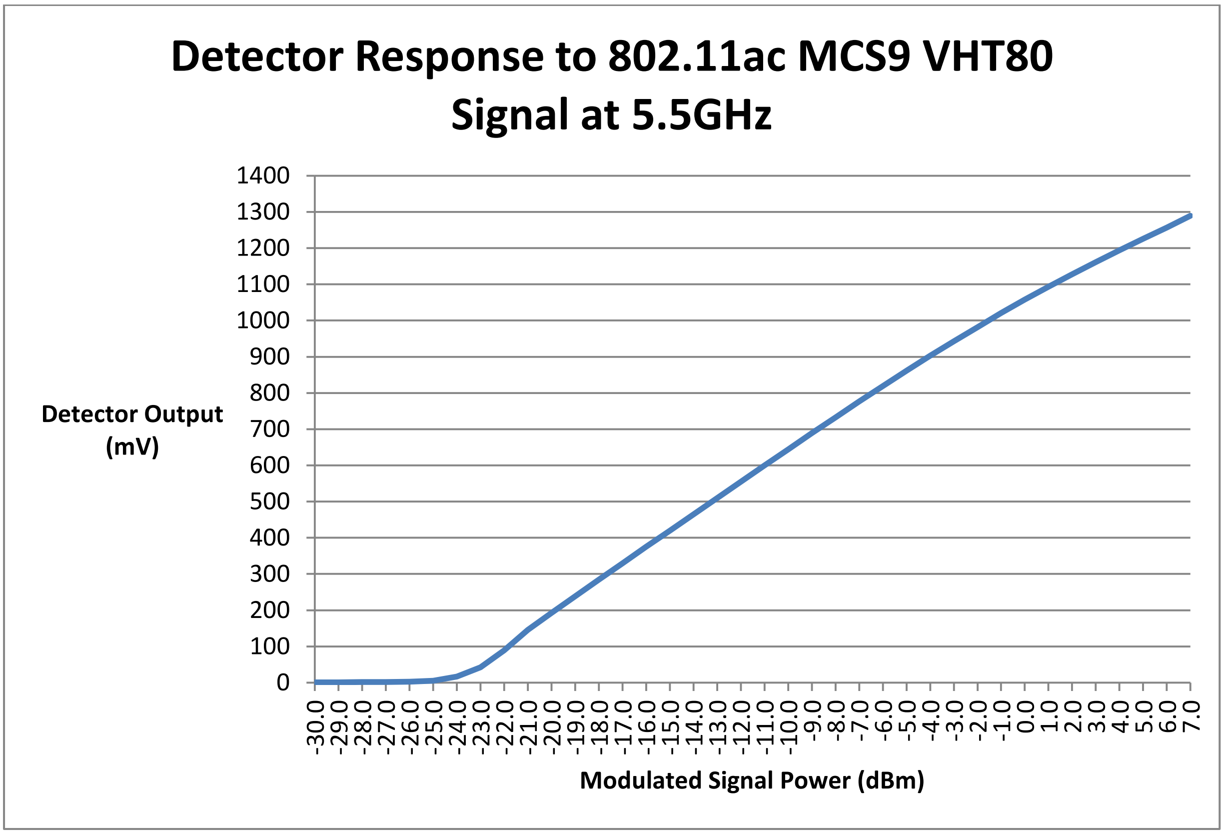


Figure 9: Detector Response at 5.5GHz

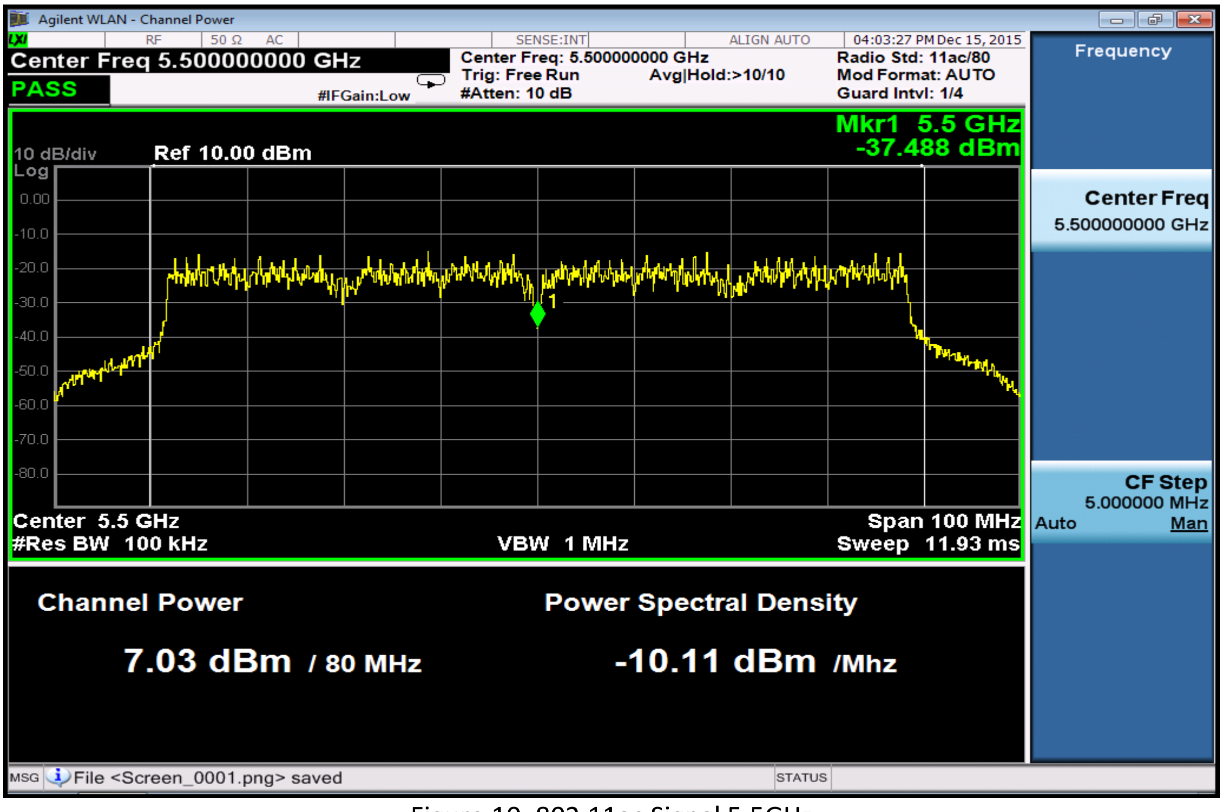


Figure 10: 802.11ac Signal 5.5GHz

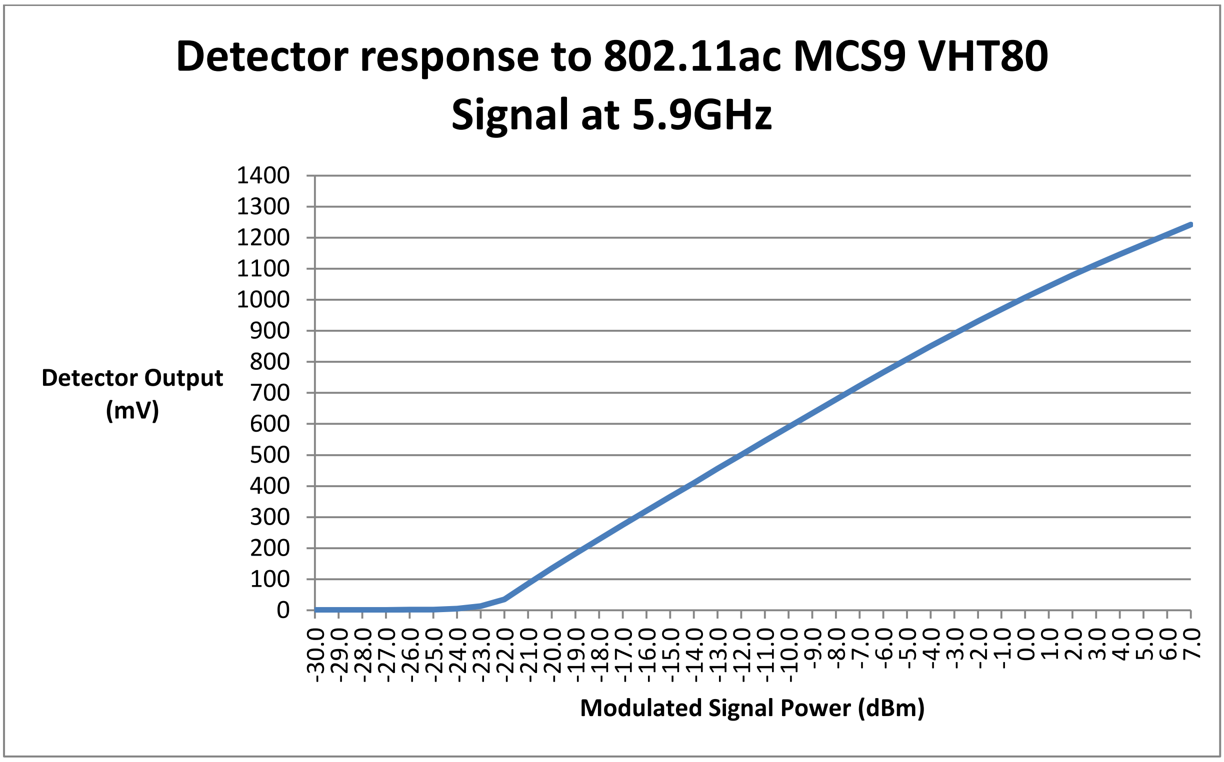


Figure 11: Detector Response at 5.9GHz

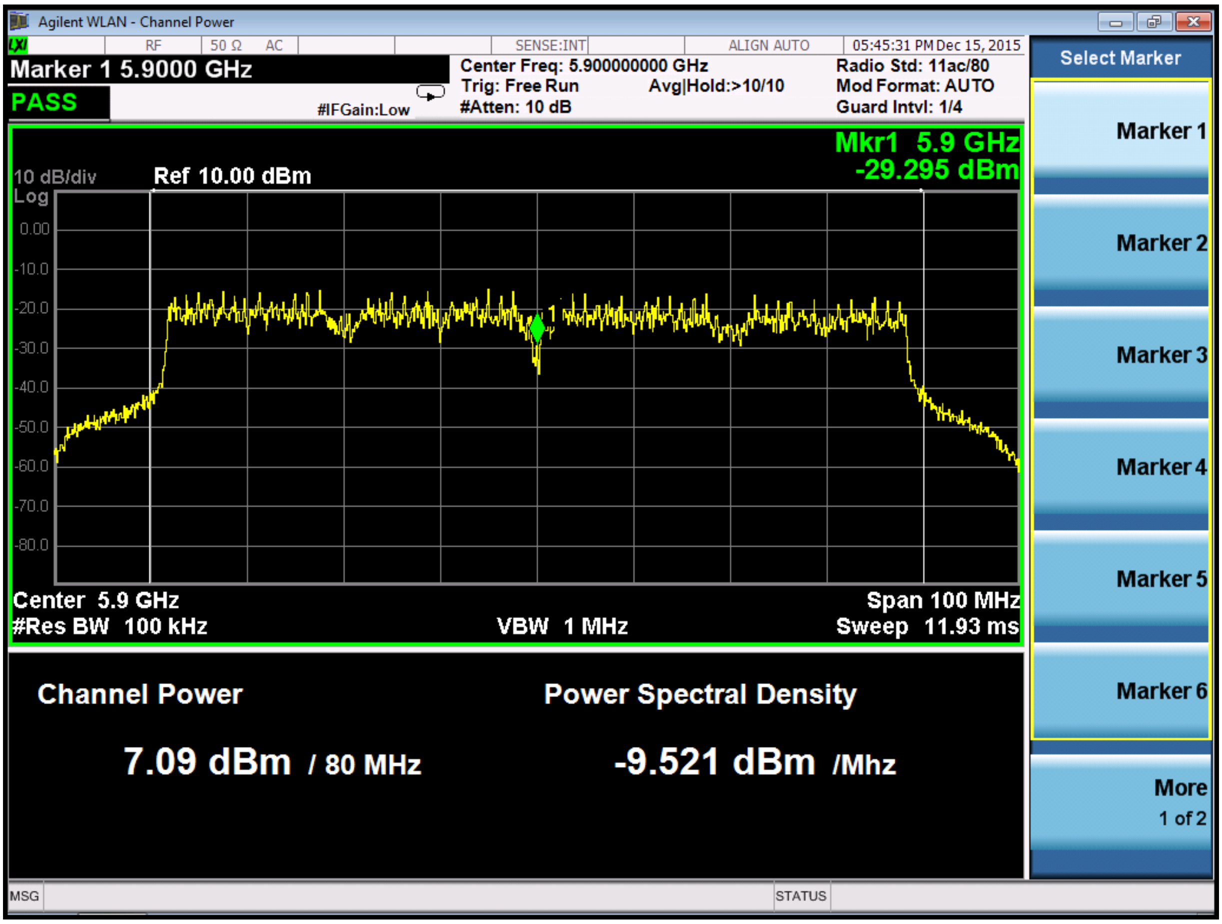


Figure 12: 802.11ac Signal 5.9GHz

7.2 LP5912 Power Supply Rejection Ratio

The output voltage ripple rejection ratio is calculated by comparing the regulated output voltage of the device under test DUT with the input voltage ripple over a frequency range of 10Hz to 10MHz.

Test parameters:

$C_{IN} = C_{OUT} = 1\mu F$

V_{IN_AC} = Sweep from 10Hz to 10MHz

Room Temperature

EN pin tied to V_{IN}

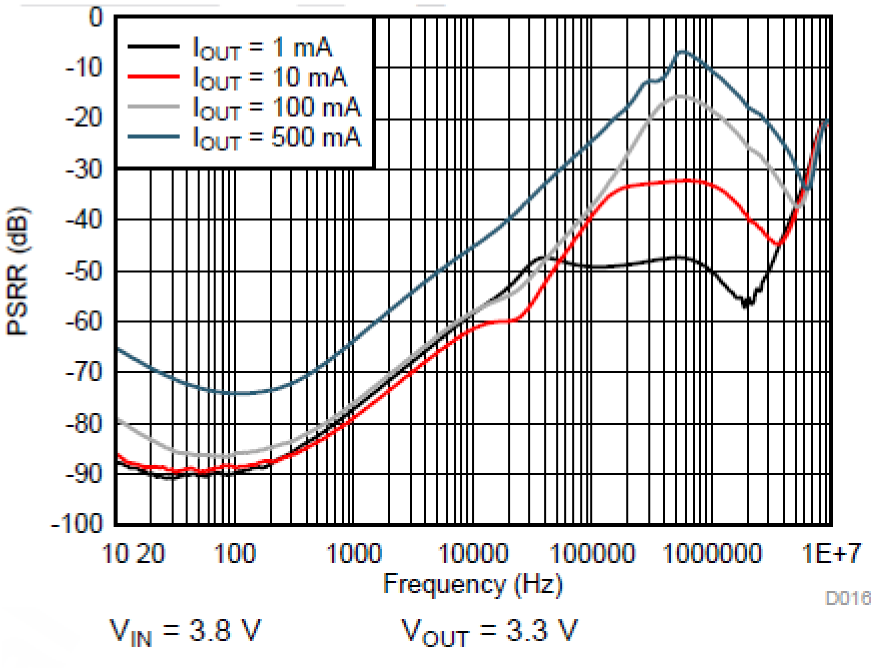


Figure 13: LP5912 PSRR

8 Design Files

8.1 Schematics

To download the Schematics for this board, see the design files at http://www.ti.com/tool/TIDA-00897

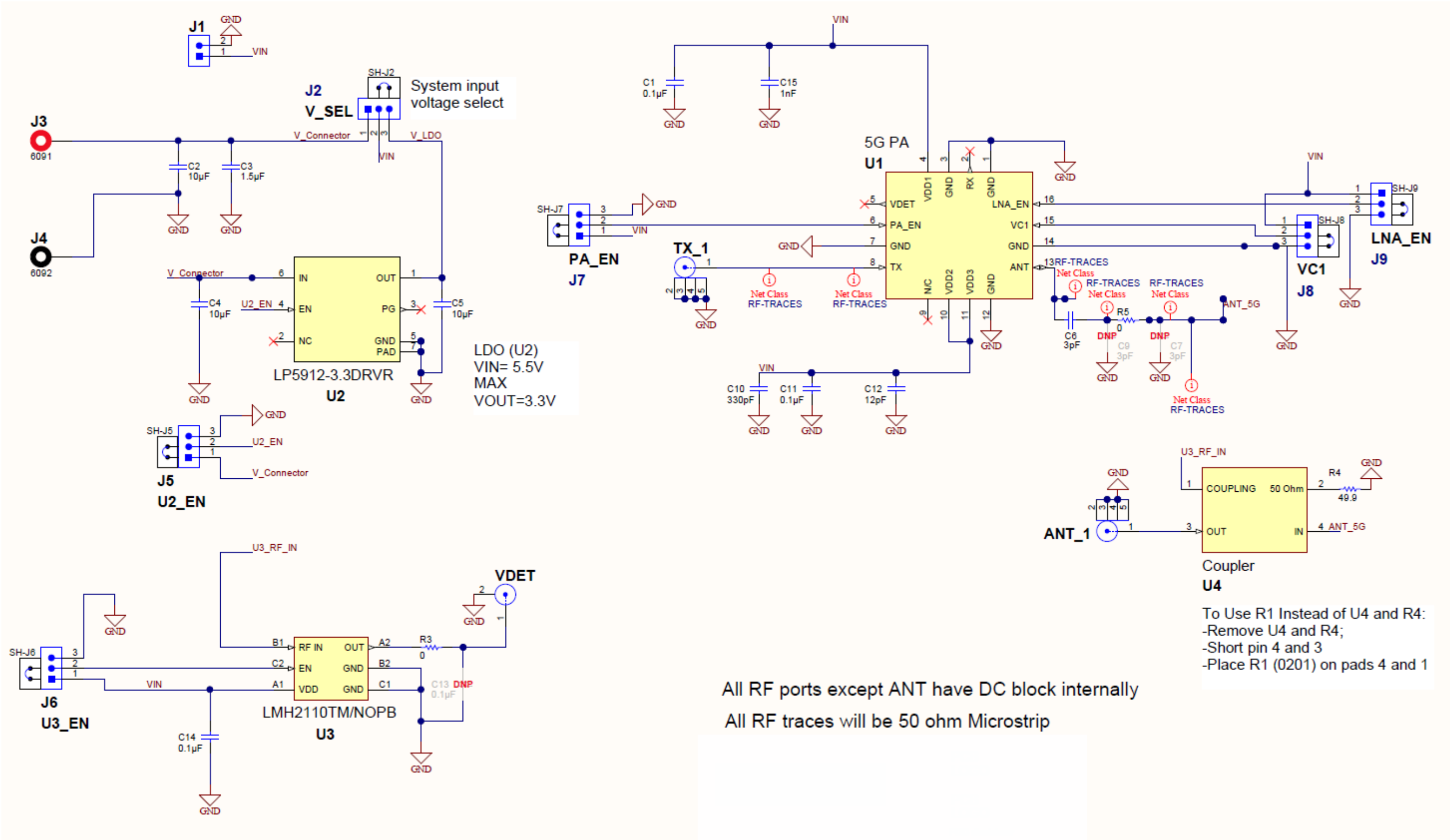


Figure 14: TIDA-00897 Schematic

8.2 Altium Project

The Altium project files can be downloaded at the link below.
http://www.ti.com/tool/TIDA-00897

- Gerber and NC-drills
- Bill of Materials (BOM)
- Layer prints

8.3 PCB Layout Recommendations

Although LMH2110 has a pin out that facilitates easier board layout, as with any RF design, close attention should be paid to board layout. Below are some guidelines to keep in mind as a checklist for layout.

- Ensure 50 ohm impedance for RF traces at the input and output of the PA.
- Place supply decoupling capacitor as close to VDD pin of the devices as possible.
- LMH2110 has input impedance of 50ohm and if a power coupler is employed to couple RF signal to LMH2110 input, input trace should be run as a transmission line with characteristic impedance of 50 ohm.
- If a resistor divider is used to couple RF signal into LMH2110 input, resistor should be placed so that as short a stub is formed in the through transmission line as possible. Please see figure below for an illustration.

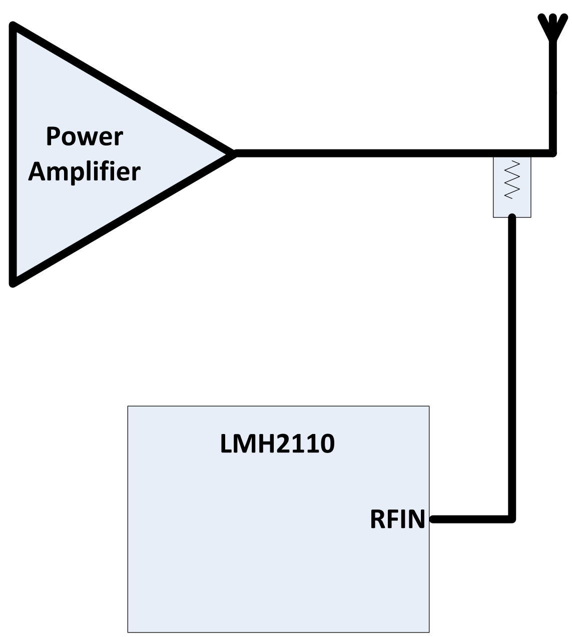


Figure 15: Coupling Resistor Placement

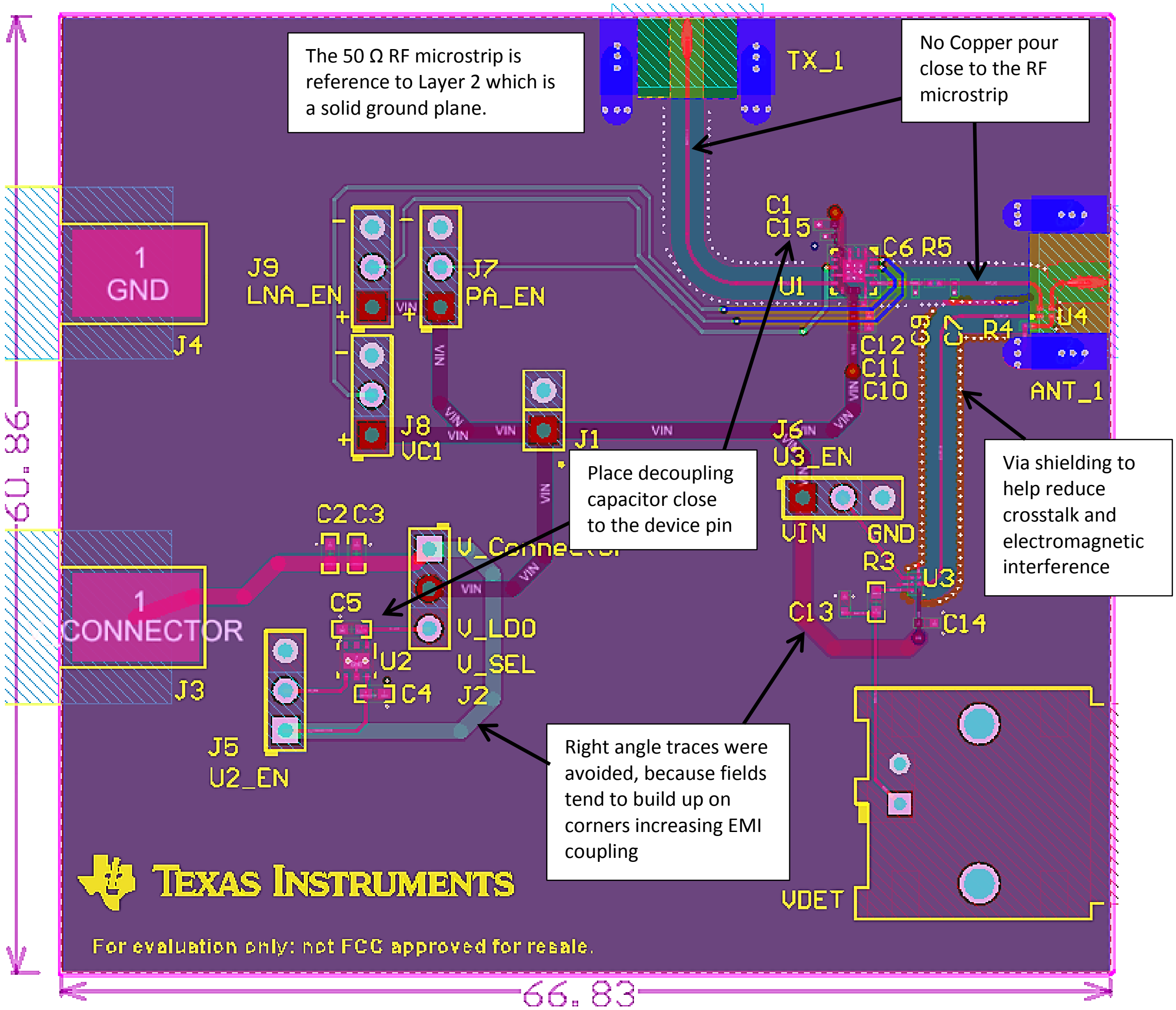


Figure 14 TIDA-00897 PCP Layout

9 Terminology

TI Glossary: SLYZ022 This glossary lists and explains terms, acronyms, and definitions.

10 About the Author

Liaqat Khan is a Senior Applications Engineer at Texas Instruments, where he is responsible for developing power solutions for RF applications. Liaqat brings to this role his extensive experience in RF transceivers, Power Amplifiers, Low Noise Amplifiers, DC-DC converters and other low-noise analog and RF system-level design expertise. Liaqat earned his Master of Science in Computer Engineering (MSCE) from Wayne State University in Detroit, Michigan.

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