TI Designs
High Efficiency, Low-Noise Buck Converter for WLAN Front End Modules and Transceivers

TEXAS INSTRUMENTS

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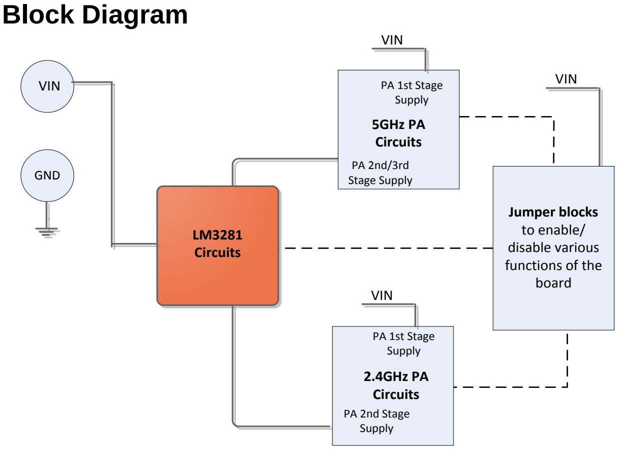
Design Resources

TIDA-00532	Design Folder
LM3281	Product Folder

TI E2E™ Community

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

Block Diagram



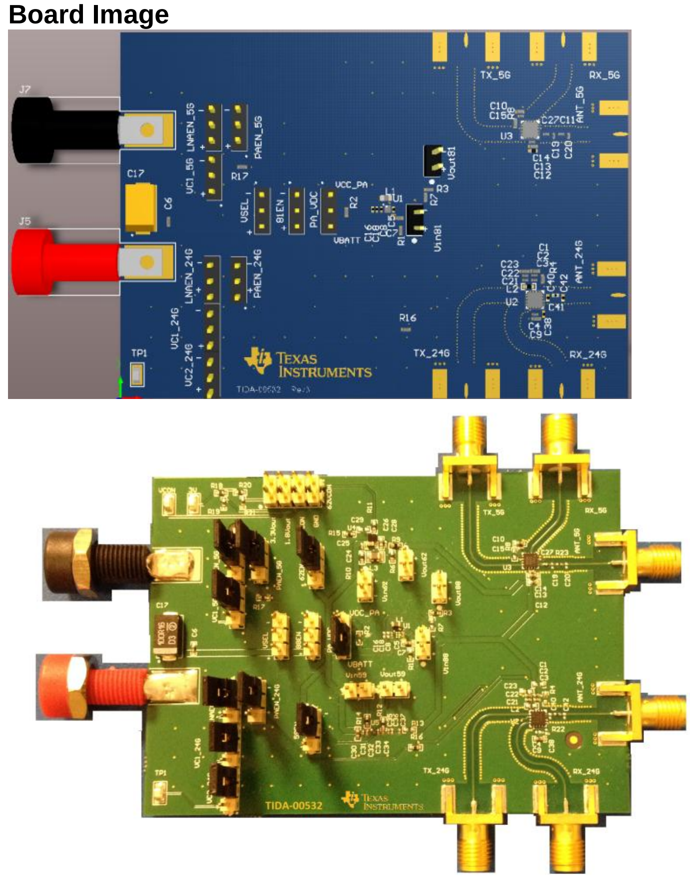
Design Features

- Low noise power supply for power amplifiers (2.4GHz and 5GHz band), RF transceivers and other circuits requiring low noise efficient power conversion.
- Provides long battery life with its ultra low quiescent current.
- High efficiency 94% (at I_{OUT} 300mA)

Featured Applications

- WLAN, Wi-Fi Station Devices
- Wi-Fi RF PC Cards
- Battery-Powered RF Devices
- Always-on applications

Board Image



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Tables

1 System Description

This TI design provides a solution to power two Wi-Fi power amplifiers: one in the 2.4GHz industrial, scientific and medical (ISM) band and one in the 5GHz Unlicensed National Information Infrastructure (UNII) frequency band. Input voltage in the range of 3.0V to 5.5V is provided via the red and black banana jacks on the EVM and LM3281 efficiently converts it to an output of 3.3V which is fed to the power amplifiers. At input voltages below approximately 3.4V, LM3281 smoothly enters the analog bypass mode and provides an output voltage which is input voltage less the dropout across the converter, typically 60mV at 600mA.

TIDA-00532 design provides all the design files and supporting documentation (schematic, Gerber's, and test data) which can be used as a reference for power supplies for RF Front End Modules which require low-noise and excellent transient response. All the files can be obtained from http://www.ti.com/tool/tida-00532

2 Block Diagram

Figure 1 shows a high level block diagram of TIDA-00532 design. Note that it shows two DC/DC converters and one LDO, however this design only covers LM3281 and the other two devices are not used nor populated in the design files.

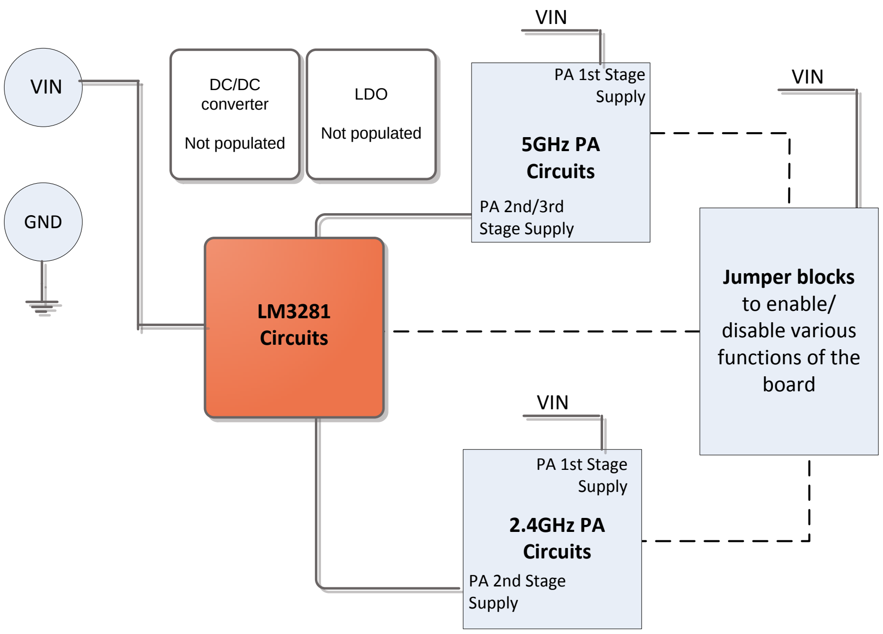

Figure 1 TIDA-00532 design high level block diagram

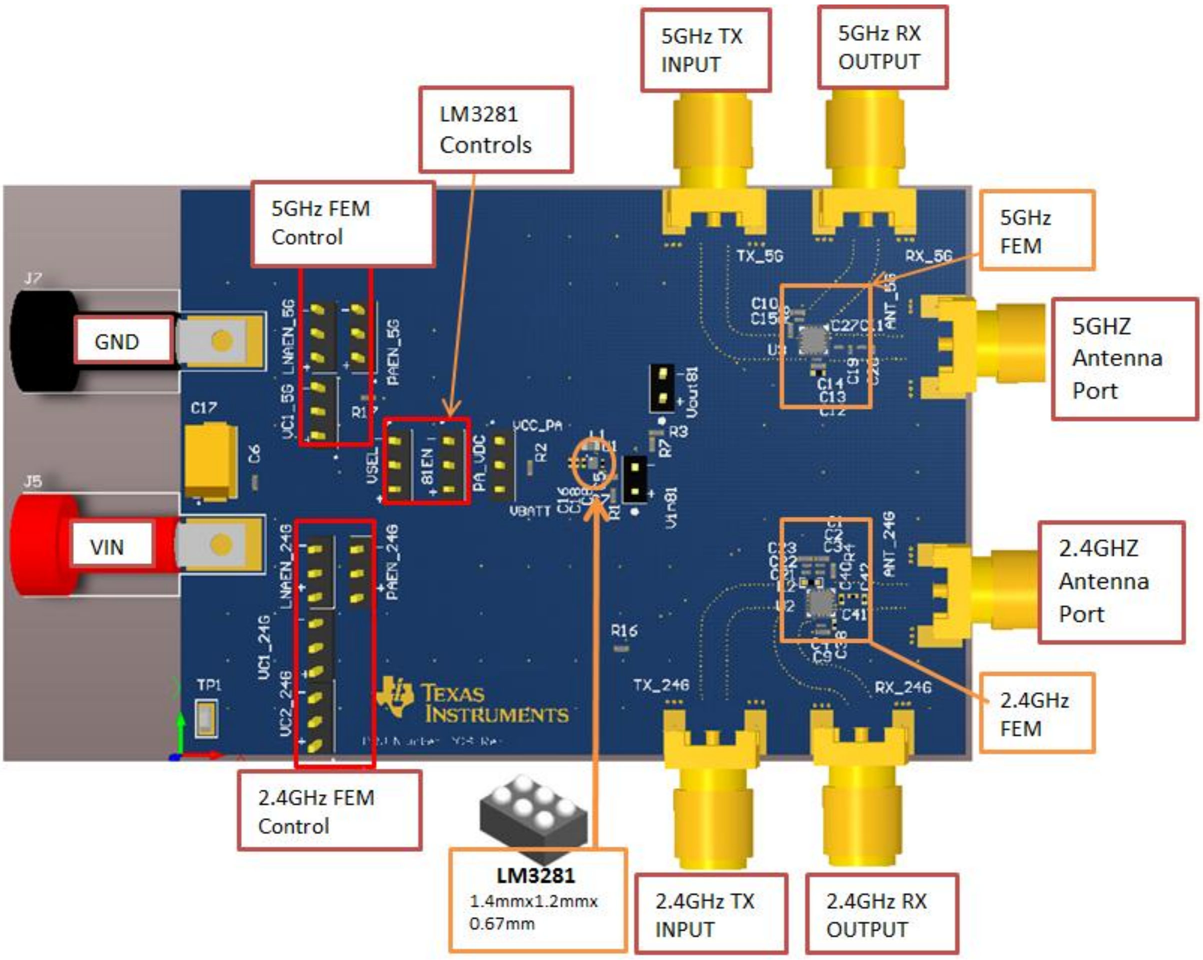

Figure 2 3D view of TIDA-00532 EVM with major connectors and components identified.

Figure 3 Three Pin Header Legend

3 Blocks description

This section describes all the main blocks of **figure 2.**

- LM3281 TI low-noise miniature DC-DC converter
- Banana Jacks (VBATT, GND)
- 5GHz FEM, 2.4GHz FEM
- SMA Connectors

3.1 TI regulator control- LM3281 3.3-V, 1.2-A, 6-MHz Mini Step-Down DC-DC Converter

The LM3281 is a high-efficiency low-noise miniature DC-DC converter optimized for powering noise-sensitive RF Front End Modules (FEMs) from a single Lithium-Ion cell. The LM3281 is ideal for “always on” applications with very low unloaded quiescent current of 16 µA (typ.).

The LM3281 steps down an input supply voltage to a fixed output voltage of 3.3 V with output current up to 1200 mA. Five different modes of operation are used to optimize efficiency and minimize battery drain. In Pulse Width Modulation (PWM) mode, the device operates at a fixed frequency of 6 MHz which minimizes RF interference when driving medium-to-heavy loads. At light load, the device automatically enters into Economy (ECO) mode with reduced quiescent current. In a low-battery voltage condition, a bypass mode reduces the voltage dropout to 60 mV (typ.) at 600 mA. If very low output voltage ripple is desired at light loads, the device can also be forced into PWM mode. Shutdown mode turns the device off and reduces battery consumption to 0.1 µA (typ.).

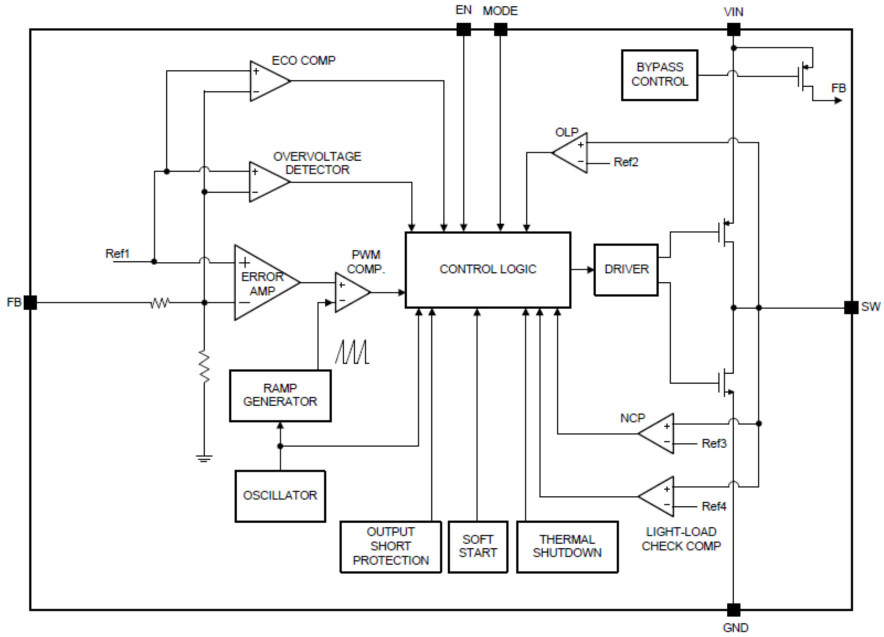

Figure 4 LM3281 functional block diagram

3.1.1 Bypass transition and efficiency

- Analog bypass permits smooth transitions from PWM to bypass mode
  - Smooth VOUT transition avoids disruption of transmission as VIN drops
- Low dropout voltage under heavy load
  - 60mV dropout for 600mA load
  - 120mV dropout for 1200mA load
- High efficiency over the IOUT range
  - Low Iq < 15 µA for 0 mA IOUT
  - ECO mode for < 100 mA IOUT
  - Efficiency optimized at 300 - 600 mA
  - PWM mode up to 1200 mA IOUT

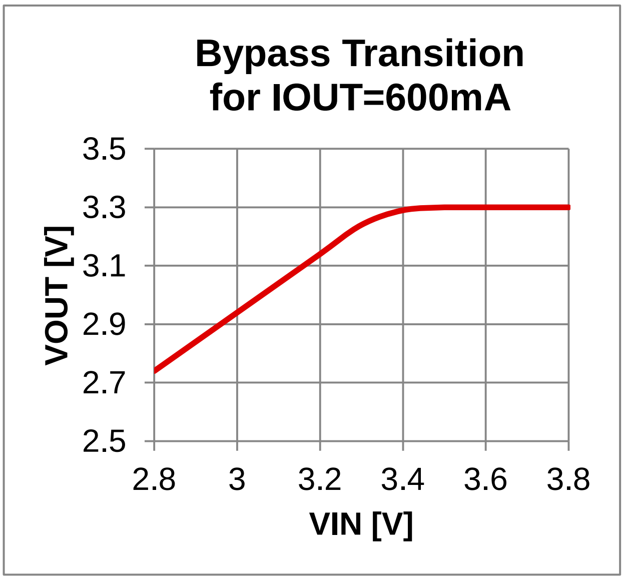

Figure 5 V_{OUT} vs V_{IN}

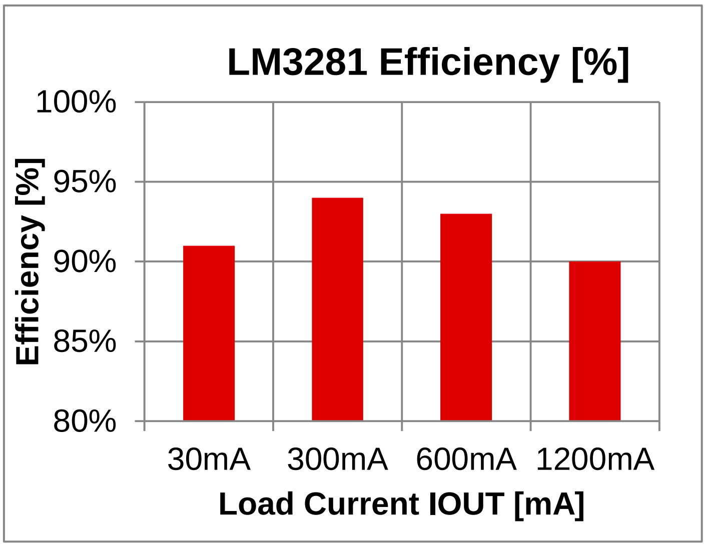

Figure 6 LM3281 Efficiency

3.1.2 LM3281 Solution vs. Standard DCDC

Table 1 LM3281 Solution vs. Standard DC/DC

Feature	Benefit
Low V_{OUT} noise	TI system-level RF testing and support ensures high level of TXVR or PA RF performance. No significant EVM degradation observed when using LM3281 solution.
Fast V_{OUT} transients	VOUT regulates accurately to target to avoid degrading RF performance
Low Iq	Critical for "always-on" applications
Ultra-low dropout bypass	<100mV dropout in bypass mode to extend operating time as battery discharges
Automatic mode transitions	LM3281 optimizes based on VIN, VOUT, IOUT conditions for best system performance without external control
Cost-effective, small-size solution	Competitive advantage in high-volume mobile applications

3.2 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.

3.3 5GHz FEM, 2.4GHz FEM

Blocks labeled 5GHz FEM and 2.4GHz FEM indicate the location of the WLAN front end module circuits that operate in the 5GHz and 2.4GHz frequency bands respectively. These devices normally contain many functions in one IC package such as a power amplifier, a low noise amplifier, a transmit/receive switch, power detector etc.

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

3.4 SMA Connectors (5GHz TX Input, 5GHz Antenna Port, 5GHz RX Output, 2.4GHz TX Input, 2.4GHz Antenna Port, 2.4GHz RX Output)

There are six SMA connectors on the board and their function is as described below.

1. 5GHz TX Input: 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 5GHz PA. A vector signal generator that provides modulated 802.11 a, n or ac signal should be connected to this connector.
2. 5GHz Antenna Port: This SMA connector is used to connect the output of the 5GHz PA to a signal analyzer to make signal quality measurements.
3. 5GHz RX Output: This SMA connector is not used in this design, because the FEM Control was evaluated using the antenna port.
4. 2.4GHz TX Input: RF signal in the 2.4GHz frequency band is input to this SMA connector which in turn connects this signal to TX input pin of the 2.4GHz PA. A vector signal generator that provides modulated 802.11 b, g or n signal should be connected to this connector.
5. 2.4GHz Antenna Port: This SMA connector is used to connect the output of the 2.4GHz PA to a signal analyzer to make signal quality measurements.
6. 2.4GHz RX Output: This SMA connector is not used in this design, because the FEM Control was evaluated using the antenna port.

4 System Design Considerations

As shown in the block diagram of **Figure 1**, TIDA-00532 Board has three separate power conversion devices but only the high-efficacy low-noise **LM3281** is used and populated in the reference design files.

4.1 Component selection for LM3281

The design considerations on this section apply to the given parameters. If your design requires other parameters than the stated in this document, it is necessary to review the ratings and specs on the datasheets of the mentioned devices.

Table 2 Design parameters

Design parameters	Value
Output voltage	3.3V
Input voltage range	3.0V to 5.5V
Maximum output current	1.2A

4.1.1 Typical application schematic

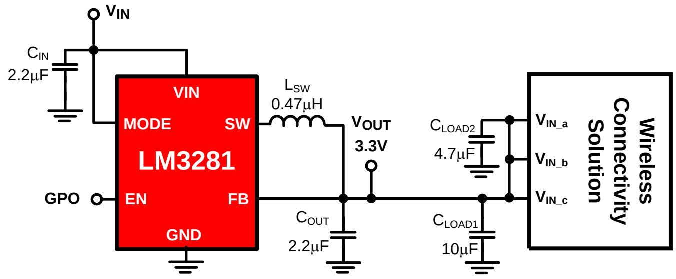

Figure 7 Application schematic

4.1.2 Input/output components

The input filter capacitor supplies AC current drawn by the PFET switch of the LM3281 in the first part of each cycle and reduces the voltage ripple imposed on the input power source.
The output filter capacitor absorbs the AC inductor current, helps maintain a steady output voltage during transient load changes and reduces output voltage ripple. These capacitors must be selected with sufficiently low ESR (Equivalent Series Resistance) to perform these functions. The ESR of the filter capacitors is generally a major factor in voltage ripple.

The LM3281 is designed for use with ceramic capacitors for its input and output filters. Ceramic capacitors types such as X5R, X7R are recommended for both filters. Note that suggested LM3281 solution capacitors are de-rated by 50% to 65% at 3.3-V DC bias.

Table 3 Input/output capacitors

	Capacitance	Capacitance @ 3.3 DC BIAS	SIZE
C_{IN}/C_{OUT}	2.2 µF ± 10%	1.1µF	0402

4.1.3 Compensation components

Inductor

The inductor used in LM3281 designs should have following characteristics over operating temperature range:

- DC resistance (DCR) ≤ 70mΩ
- Inductance at 0-mA current = 0.47µH ±20%
- Inductance at 1.4-A current ≥ 0.29µH
- Inductance at 2-A current ≥ 0.26µH

If an application requires less than 1.4A peak load current, it is possible to trade maximum load current for DCR of the inductor (hence smaller physical size) by using Equation 1:

Equation 1 $DCR\_IND\_MAX = \left(\frac{0.217}{I\_MAX}\right) - 0.085$

Capacitor

Total effective output capacitance including load capacitance (CLOAD1 and CLOAD2) and solution capacitance (COUT), de-rated for 3.3-V DC bias, operating temperature range, aging, etc. must be **3.4 µF to 9 µF**. Suggested load capacitors are de-rated by 55% to 60% at 3.3-V DC bias.

Recommended Load Capacitors

C_{LOAD1} 10 µF ± 10%
C_{LOAD2} 4.7 µF ± 20%

4.2 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. To compensate for the transmission line losses the following traces losses should be applied in measurements for 2.4GHz PA and 5GHz PA.

Table 4 5.5GHz 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

Table 5 2.4GHz trace losses

Measurement Frequency	Input loss (from 2.4GHz TX Input SMA to PA input pin)	Output loss (from PA output pin to 2.4GHz Antenna Port SMA)
2.45GHz	0.25dB	0.25dB

4.3 Component selection summary

Table 6 is a compilation of compensation components selected for LM3281 DC/DC converter.

Table 6 Application component values selection

Component	Value	Size
L_{SW}	0.47uH	0805
C_{IN}	2.2uF	0402
C_{OUT}	2.2uF	0402
C_{LOAD1}	10uF	0402
C_{LOAD2}	4.7uF	0402

5 Getting Started Hardware

NOTE: The TIDA-00532 EVM is not available for purchase; however reference design files can be downloaded at http://www.ti.com/tool/tida-00532

5.1 TIDA-00532 board operation

The following steps detail the operating procedure. Please refer to **figure 2** for location of appropriate headers mentioned in the steps below.

1. Start with all jumper blocks identified in **figure 2** in their disabled position.
2. Move the jumper for the header labelled "VSEL" to enable position for automatics ECO/PWM operation.
3. Provide input supply voltage on V_{IN} and GND banana jacks.
4. Move the jumper for header labelled "81EN" to enable position.
5. Select either 2.4GHz or 5GHz PA operation by putting appropriate jumper in the enable position. If more details are needed on how to select one of the PAs, please see **figure 2** and section on 2.4GHz FEM Control/5GHz FEM Control in this document.
6. Provide WLAN modulated signal on appropriate input SMA connector and perform signal quality measurements on appropriate output SMA connector.

5.2 Enabling the LM3281 Controls

There are two 3 pin headers that control the operation of LM3281:
Header labeled 81EN is used to enable or disable the LM3281 device. Please follow "3 Pin Header Legend" in **figure 3** to put the jumper in appropriate position to enable or disable LM3281 device. Please note that LM3281 should only be enabled after input voltage supply (V_{IN}) to the board has been applied. Enabling LM3281 before input supply has reached 2.5V can lead to un-predictable device operation.

Header labeled VSEL is used to select one of the two selectable operating modes of the LM3281 device. When VSEL = Logic 1, LM3281 switches between ECO and PWM modes automatically depending on the level of load current. When VSEL = Logic 0, LM3281 selects fixed frequency PWM mode irrespective of load current level.

Please refer to **figure 2** to put the jumper in appropriate position.

5.3 5GHz FEM Controls

There are three separate headers that control the operation of 5GHz FEM. Please follow "3 Pin Header Legend" in **figure 3** to put the jumper in appropriate position to enable or disable a particular function block within the 5GHz FEM device.

- Header labeled PAEN_5G is used to enable or disable the 5GHz PA.
- Header labeled LNAEN_5G is for enabling/disabling 5GHz receive mode operation. This jumper should always be kept in the disabled position as the primary purpose of this board is to facilitate PA evaluation with TI power devices.
- Header labelled VC1_5G is used to control a transmit/receive switch inside the FEM. This header should always be kept in the disabled position.

5.4 2.4GHz FEM Controls

There are three separate headers that control the operation of 2.4GHz FEM. Please follow “3 Pin Header Legend” in **figure 3** to put the jumper in appropriate position to enable or disable a particular function block within the 2.4GHz FEM device.

- Header labeled PAEN_24G is used to enable or disable the 2.4GHz PA.
- Header labeled LNAEN_24G is for enabling/disabling 2.4GHz receive mode operation. For TIDA-00532 board, this jumper should always be kept in the disabled position as the primary purpose of this board is to facilitate PA evaluation with TI power devices.
- Header labelled VC1_24G and VC2_24G are used to control a three way transmit/receive/Bluetooth switch inside the FEM. Both of these headers should always be kept in the disabled position on the TIDA-00532 board.

6 Test Setup

LM3281 RF Testing with TQF9046 (2.4GHz) and TQP887051 (5GHz) FEMs

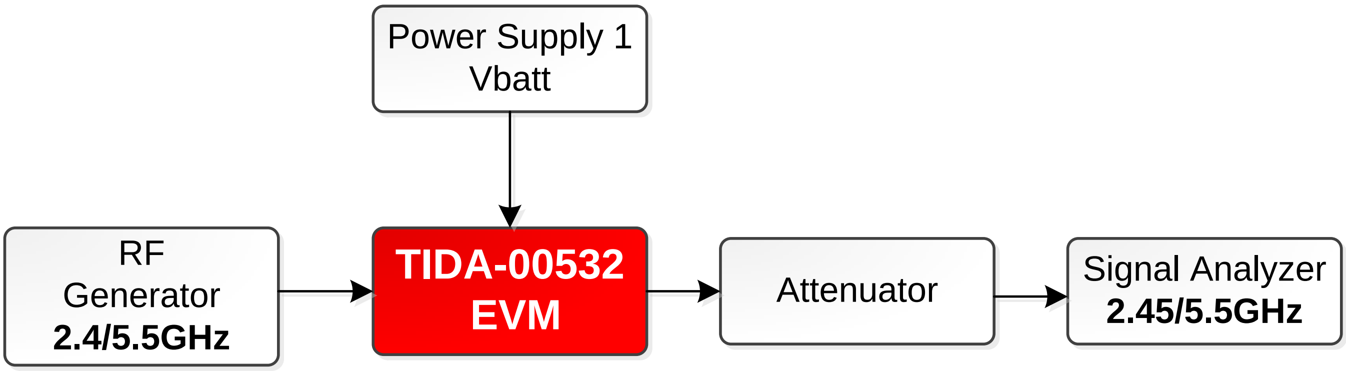

Figure 8 Test Setup Block Diagram

Table 7 Test Signals Conditions

Frequency	Condition
5GHz Band	5.5GHz, 802.11ac, MCS9 VHT80
2.4GHz Band:	2.45GHz, 802.11n, MCS7 HT40

Table 8 Test equipment

Equipment
Agilent – Dual Power Supply (E3631A)
Agilent Voltmeter (34401A) (not shown)
Agilent Ampmeter (34401A) (not shown)
MXA Signal Analyzer 20Hz – 8.4GHz (N9020A)
MXG Vector Signal Gen 9KHz to 6GHz (N5182B)

7 Test Data

7.1 5GHz Band Tests 802.11ac, MCS9, VHT 80

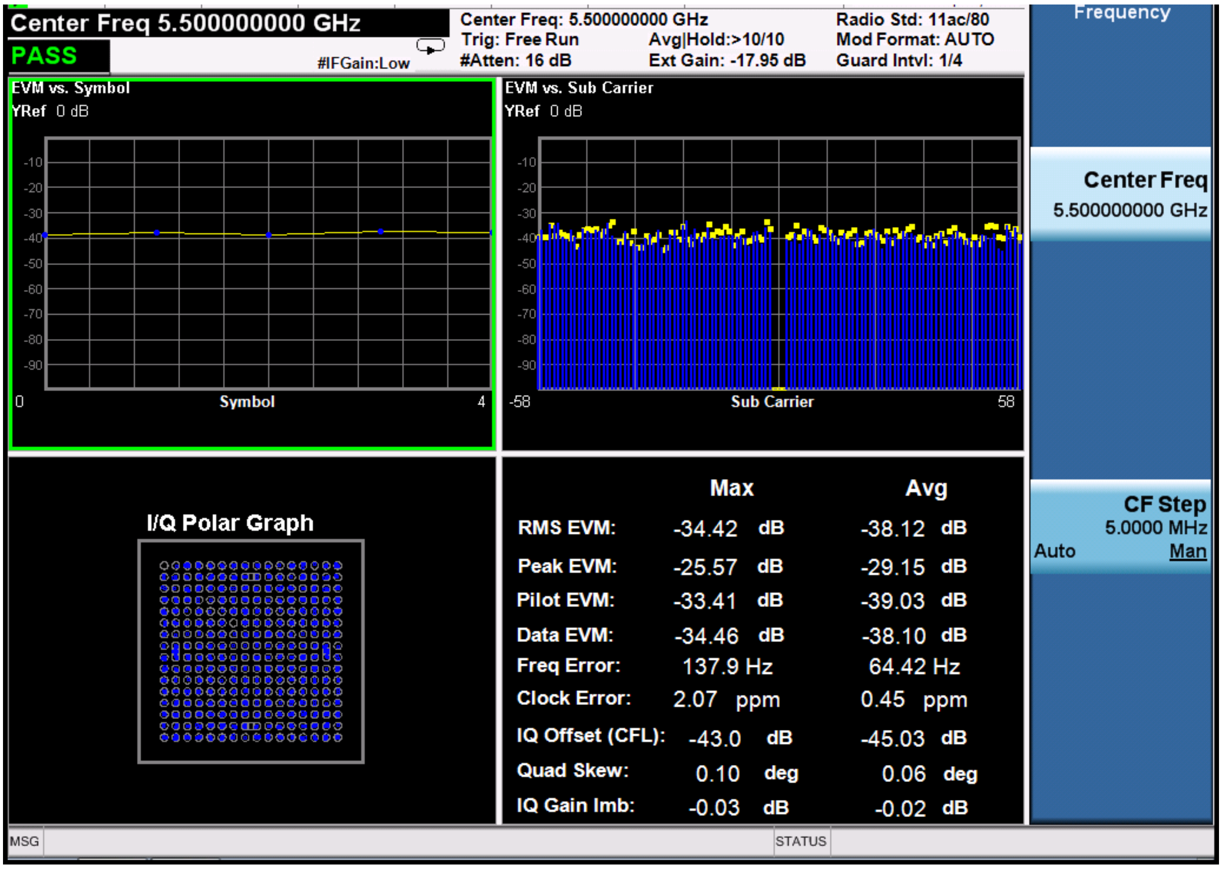

Figure 9 EVM measurements with LM3281 and TQP887051 5GHz FEM

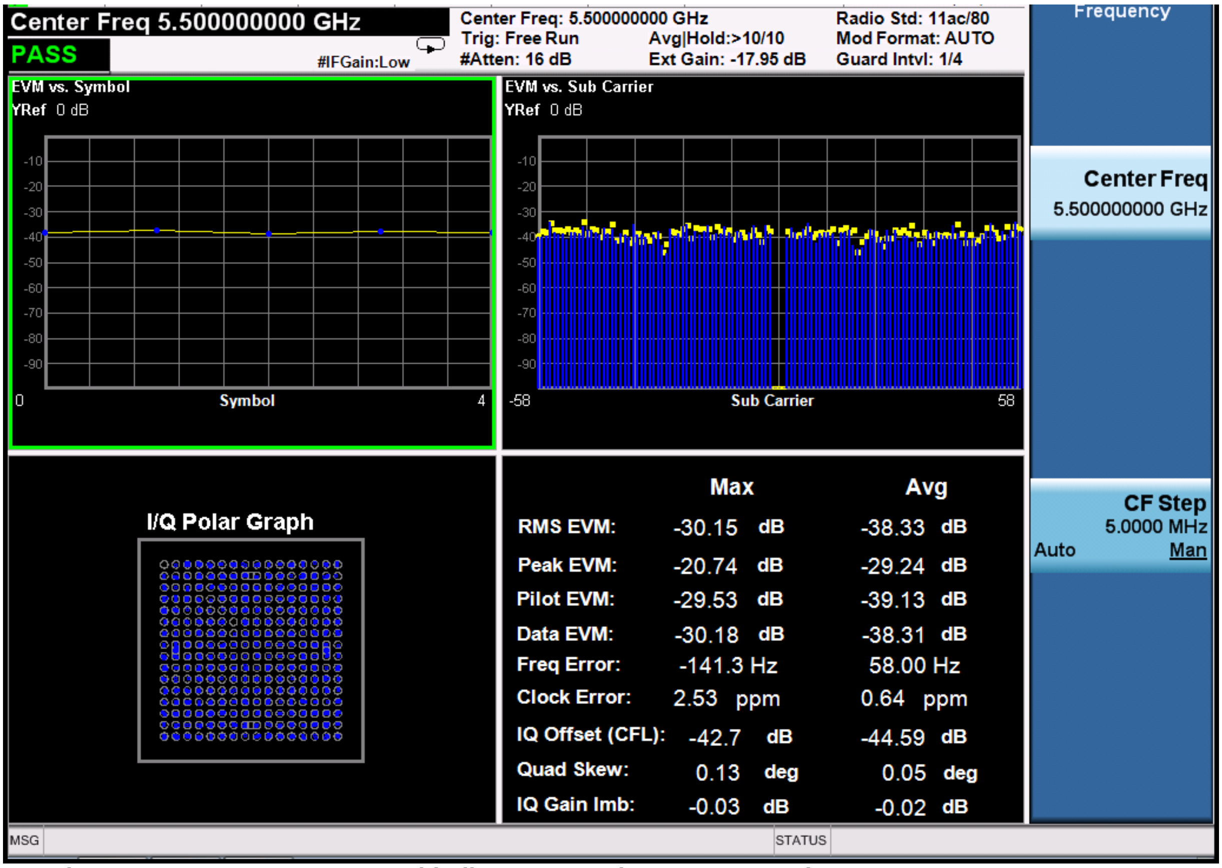

Figure 10 EVM measurements with direct connection to VBATT using TQP887051 5GHz FEM

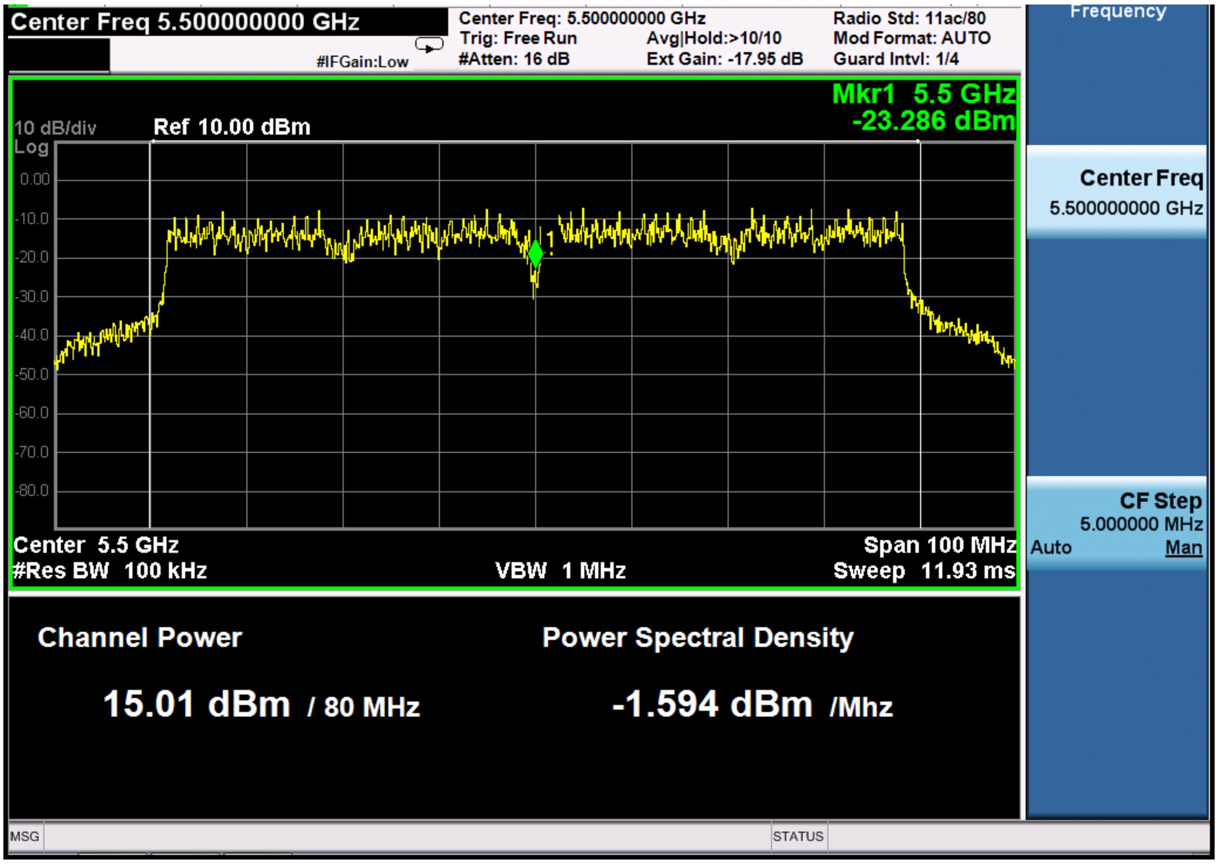

Figure 11 Channel Power measurements with LM3281 and TQP887051 5GHz FEM

7.2 2.4GHz Band Tests 802.11n, MCS7, HT40

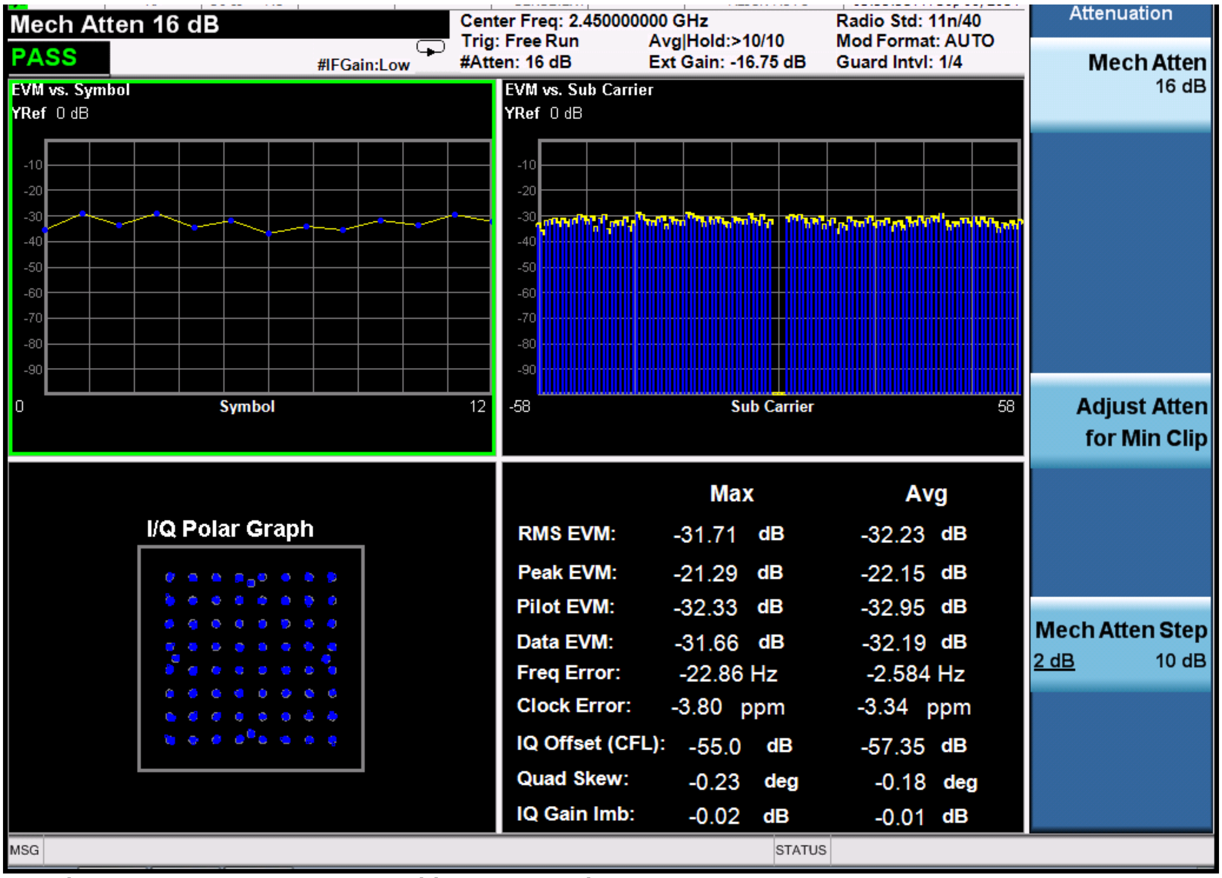

Figure 12 EVM measurements with LM3281 and TQF9046 2.4GHz FEM

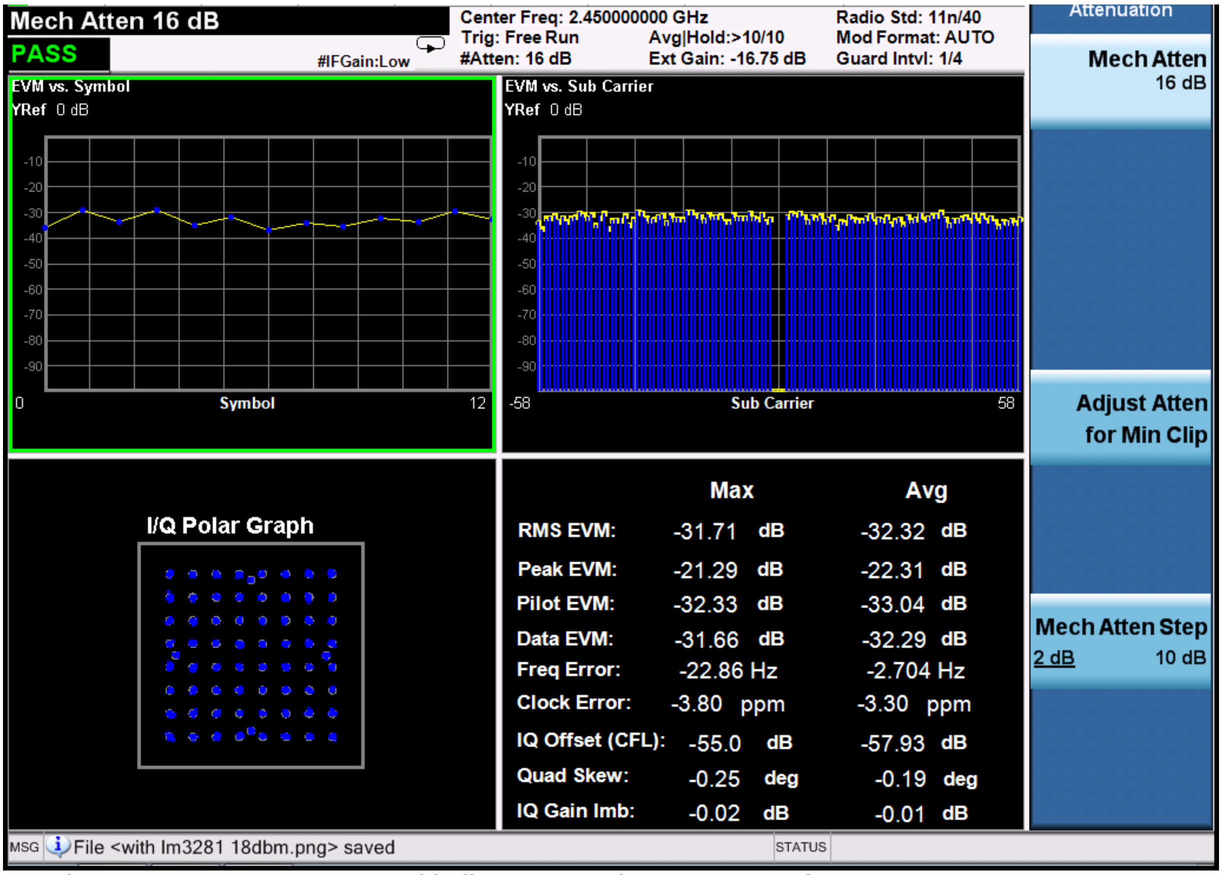

Figure 13 EVM measurements with direct connection to VBATT using TQF9046 2.4GHz FEM

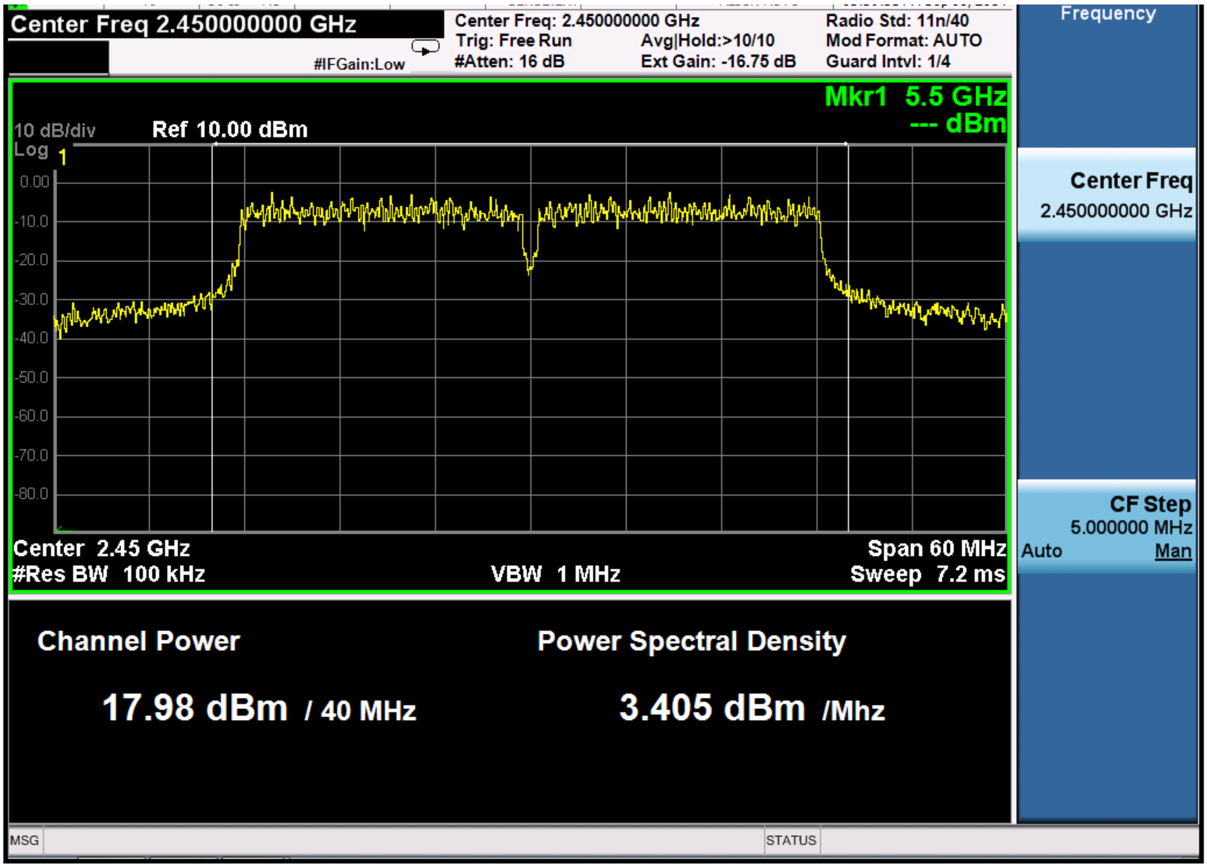

Figure 14 Channel Power measurements with LM3281 and TQF9046 2.4GHz FEM

8 Design Files

8.1 Schematics

To download the Schematics for this board, see the design files at http://www.ti.com/tool/tida-00532

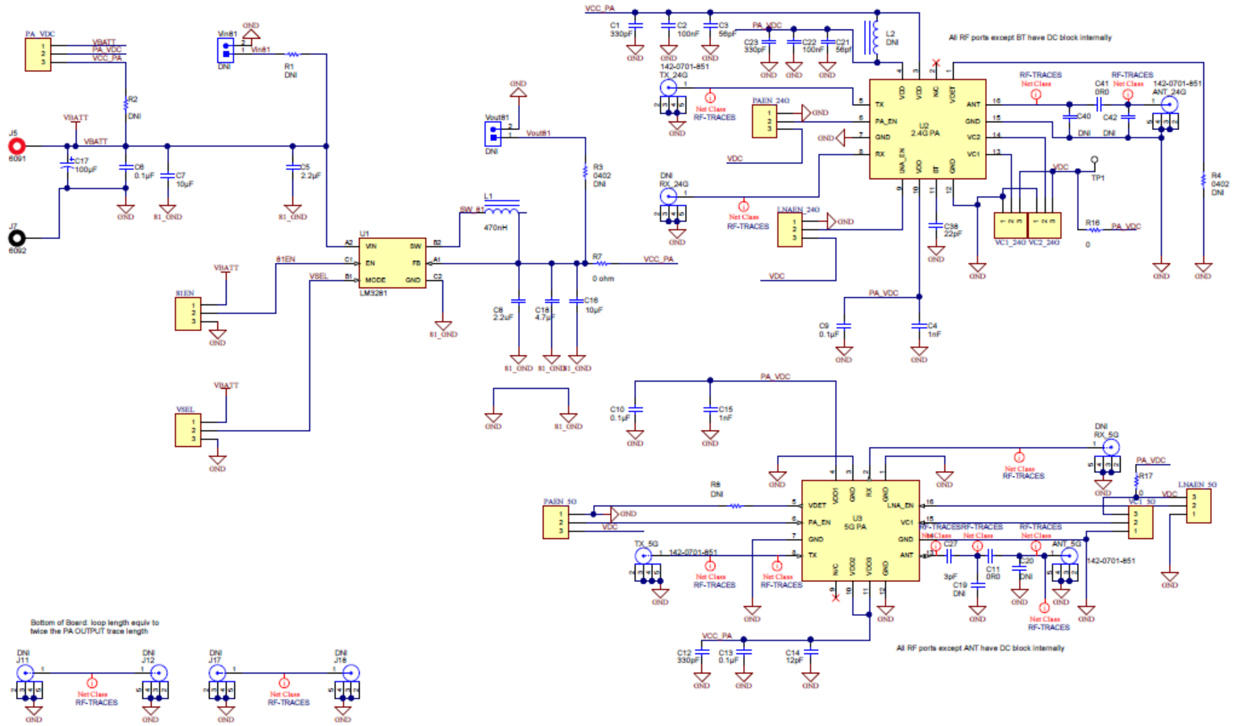

Figure 15 Schematic 1

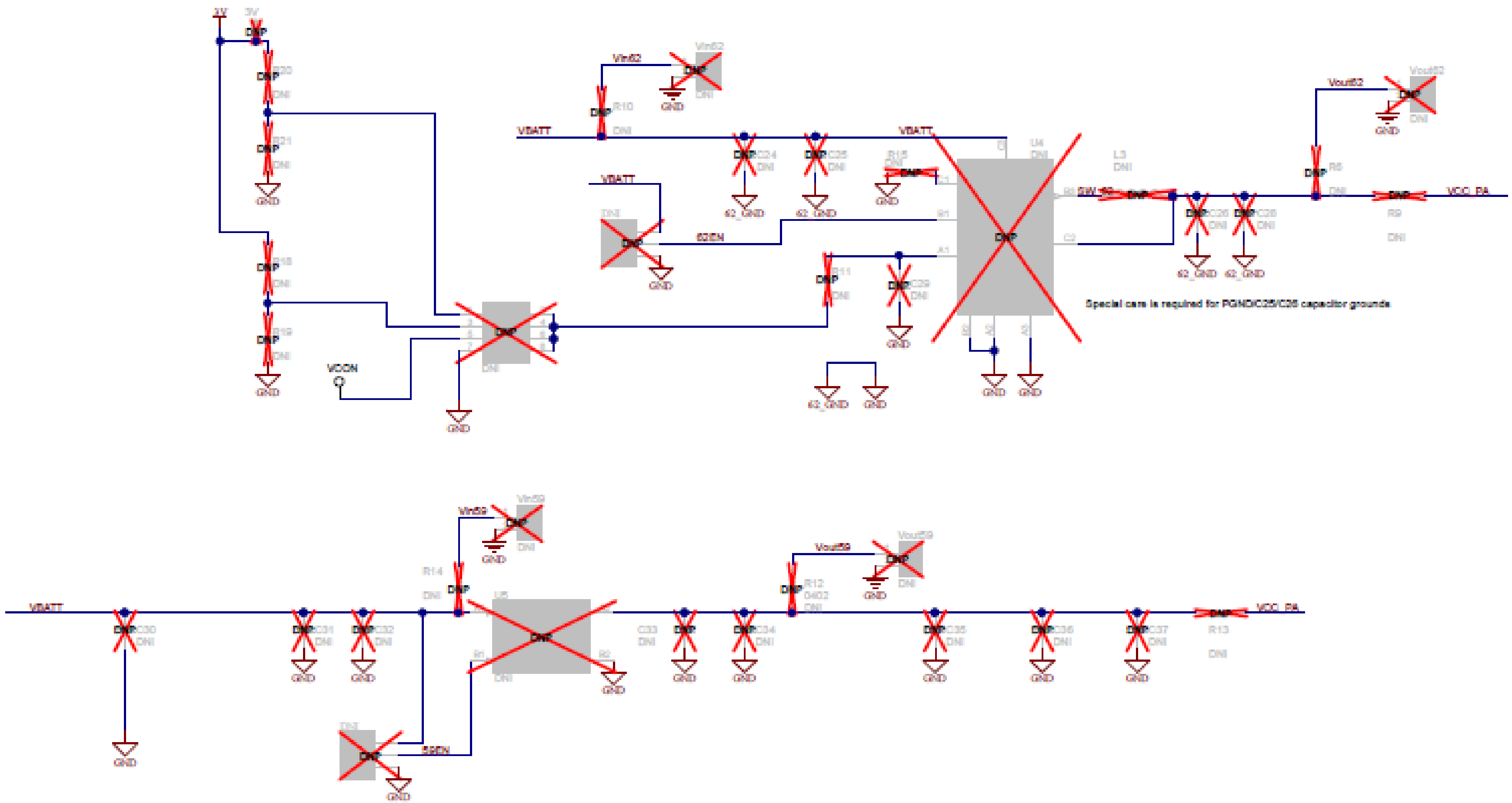

Figure 16 Schematic 2

9 Bill of Materials

To download the Bill of Materials for each board, see the design files at http://www.ti.com/tool/tida-00532

Table 9 Bill of Materials

Quantity	Reference Designator	Description	Manufacturer	Part Number
4	ANT_5G, ANT_24G, TX_5G, TX_24G	Connector, End launch SMA, 50 ohm, SMT	Cinch Connectivity Solutions	142-0701-851
3	C1, C12, C23	CAP, CERM, 330pF, 50V, +/-5%, C0G/NP0, 0402	TDK	C1005C0G1H331J
2	C2, C22	CAP, CERM, 0.1uF, 10V, +/-10%, X5R, 0201	Samsung	CL03A104KP3NNNC
2	C3, C21	56pF, 0201	Murata	GRM0335C1H560JA01D
2	C4, C15	CAP, CERM, 1000pF, 16V, +/-10%, X7R, 0201	Murata	GRM033R71C102KA01D
2	C5, C8	CAP, CERM, 2.2uF, 10V, +/-20%, X5R, 0201	Samsung	CL05A225KQ5NNNC
4	C6, C9, C10, C13	CAP, CERM, 0.1uF, 6.3V, +/-10%, X5R, 0402	TDK	C1005X5R0J104K
2	C7, C16	CAP, CERM, 10 µF, 10 V, +/- 20%, X5R, 0402	Samsung	CL05A106MP5NUNC
1	C14	CAP CER 12PF 25V 5% NP0 0201	Murata	GRM0335C1E120JA01D
1	C17	CAP, TA, 100uF, 16V, +/-10%, 0.1 ohm, SMD	Kemet	T495X107K016ATE100
1	C18	CAP, CERM, 4.7 µF, 10 V, +/- 20%, X5R, 0402	Samsung	CL05A475MP5NRNC
1	C27	CAP CER 3PF 25V NP0 0201	Murata	GRM0335C1E3R0CA01D
1	C38	CAP CER 22PF 50V 5% NP0 0201	Murata	GRM0335C1H220JA01D
1	J5	Standard Banana Jack, Insulated, Red	Keystone	6091
1	J7	Standard Banana Jack, Insulated, Black	Keystone	6092
1	L1	Inductor, 470nH, 2.4A, 0.04 ohm, SMD	Murata	LQM21PNR47MGH
10	LNAEN_5G, LNAEN_24G, PAEN_5G, PAEN_24G, PA_VDC, 81EN, VSEL, VC1_5G, VC1_24G, VC2_24G	Header, 3-Pin	Samtec	HTSW-103-07-G-S
3	R7, R16, R17	RES, 0 ohm, 5%, 0.063W, 0402	Vishay Dale	CRCW04020000Z0ED
2	C11, C41	RES, 0 ohm, 5%, 0201	Panasonic	ERJ-1GN0R00C
1	U1	3.3V, 1.2A, 6MHz, Miniature Step-Down DC-DC Converter	Texas Instruments	LM3281
1	U2	2.4GHz, 801.11n PA	Triquint	TQF9046
1	U3	5GHz, 802.11ac PA	Triquint	TQP887051

9.1 PCB Layout Recommendations

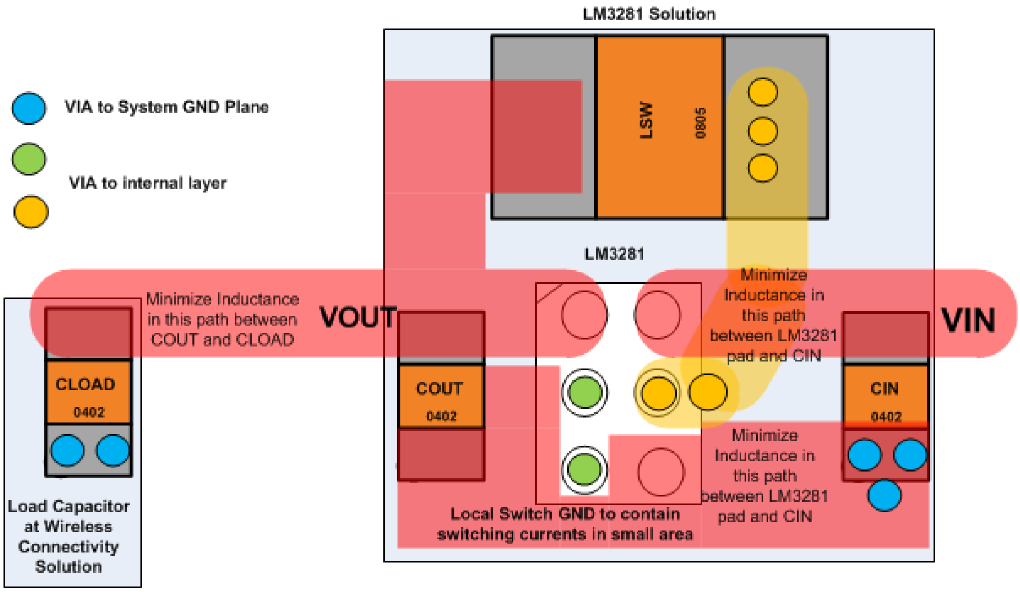

Figure 17 Layout recommendation

- Place input capacitor C_{IN} as close to LM3281 bumps as possible.
- For best performance, it is critical to minimize inductance between input capacitor C_{IN} and LM3281 V_{IN} pad. Similarly, it is critical to minimize inductance between GND side of C_{IN} and LM3281 GND bump.
- It is also important to minimize inductance between LM3281 output capacitor (C_{OUT}) and local capacitor at load (C_{LOAD}).
- To contain switching currents in a small area, a local switch ground plane or, alternatively, a thick trace should be placed out on top layer. This switch ground should be connected to main system GND plane with multiple vias close to C_{IN}.
- Multiple vias should be used to take SW trace to internal layer and to bring it back up to top layer.
- LM3281 FB pad should be connected to top of output capacitor C_{OUT}. Similarly, trace coming out of inductor should also be connected to top of C_{OUT}. This ensures that ripple is maximally filtered before FB voltage is sensed.
- Thick traces should be used for interconnects that conduct heavy current to minimize IR drop (FB trace, connection between inductor and C_{OUT}, VIN trace, and VOUT trace).

9.2 PCB Gerber’

To download the Layout Prints for this board, see the design files at http://www.ti.com/tool/TIDA-00532

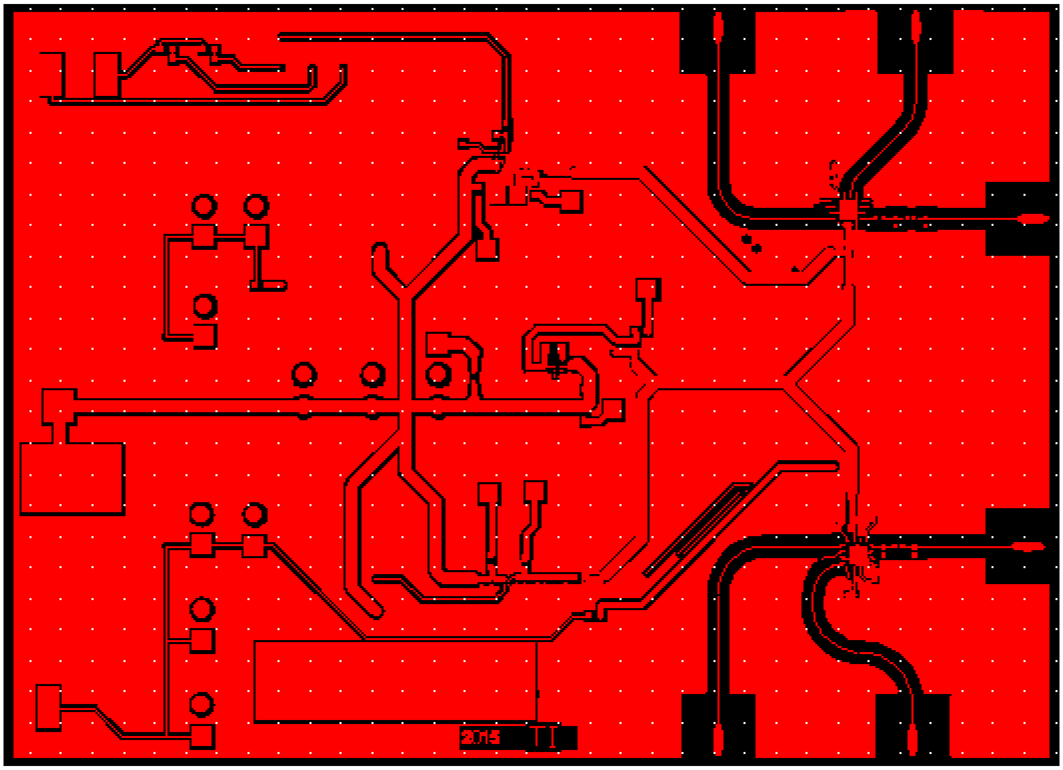

Figure 18 Top layer

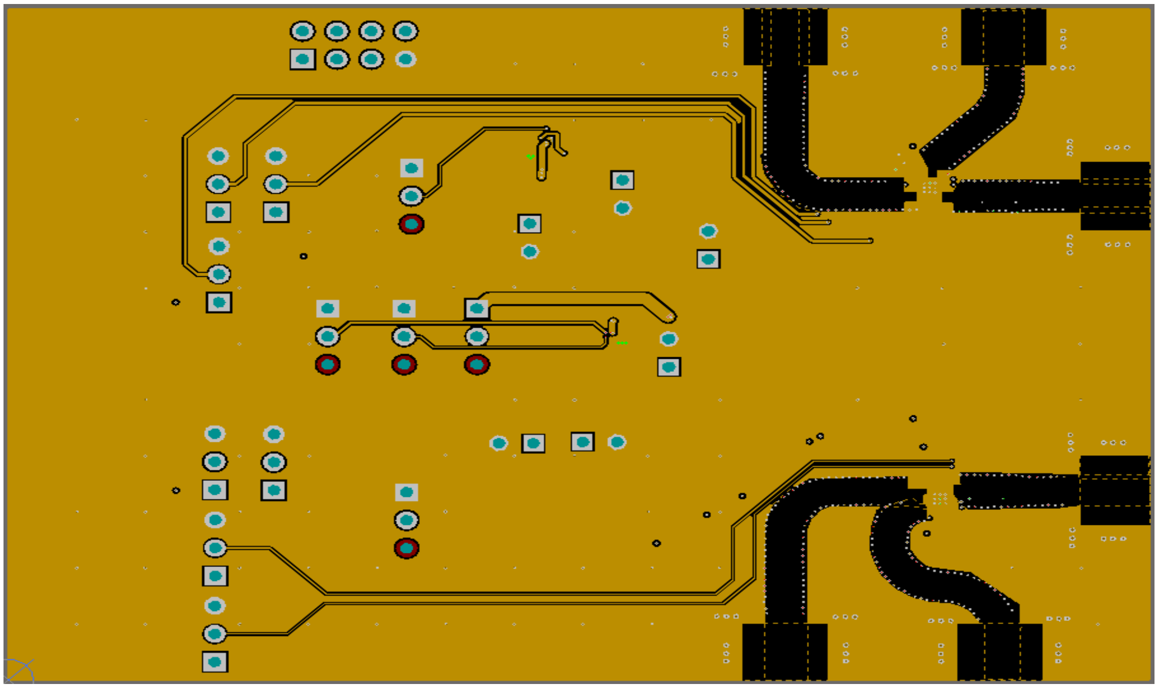

Figure 19 Layer 2

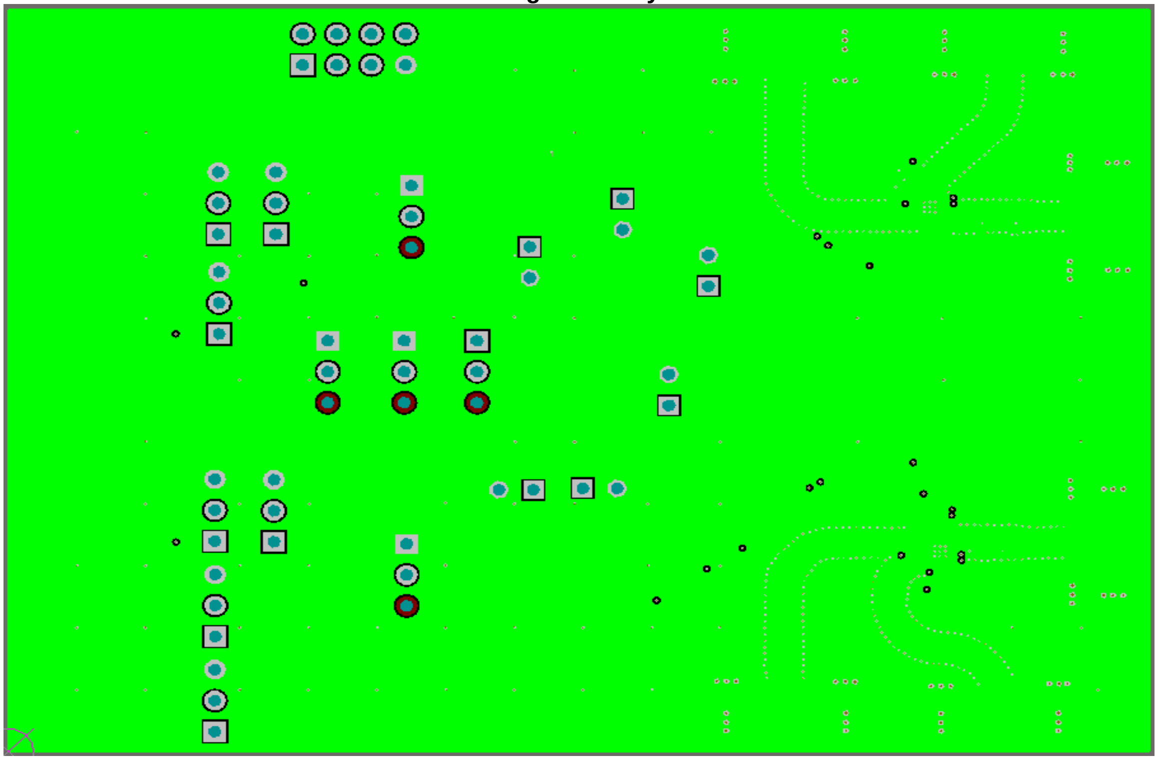

Figure 20 Layer 3

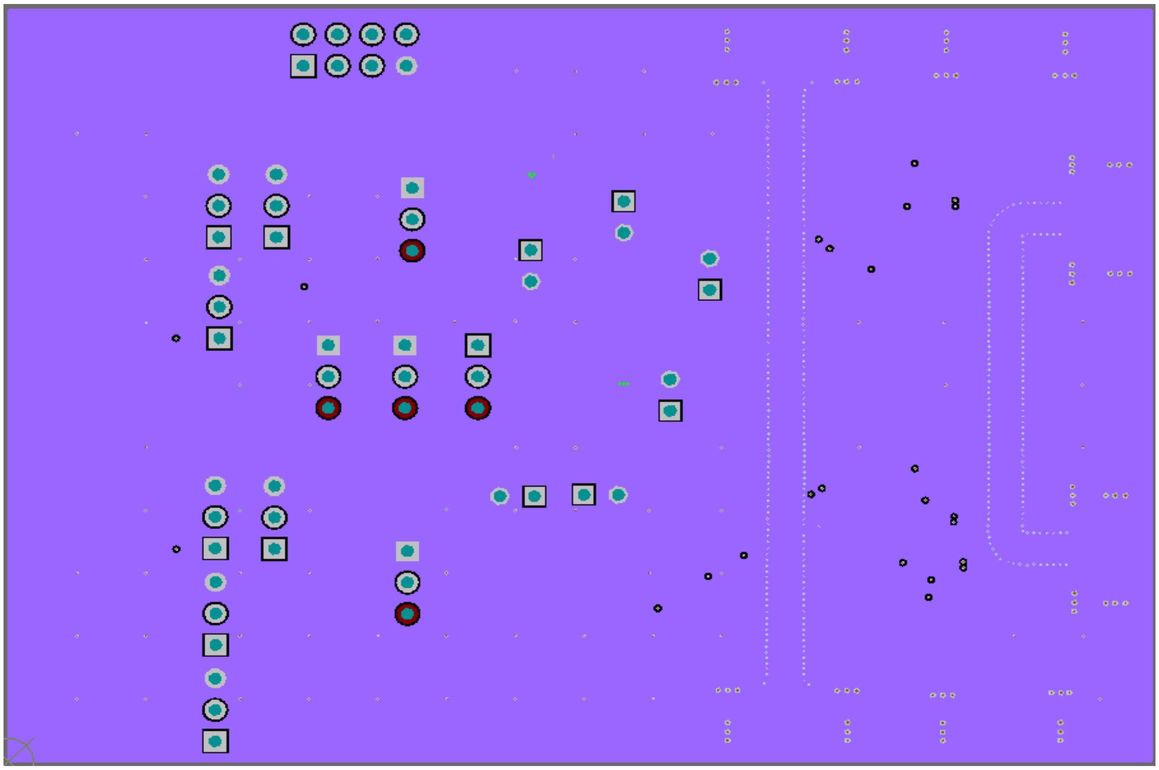

Figure 21 Layer 4

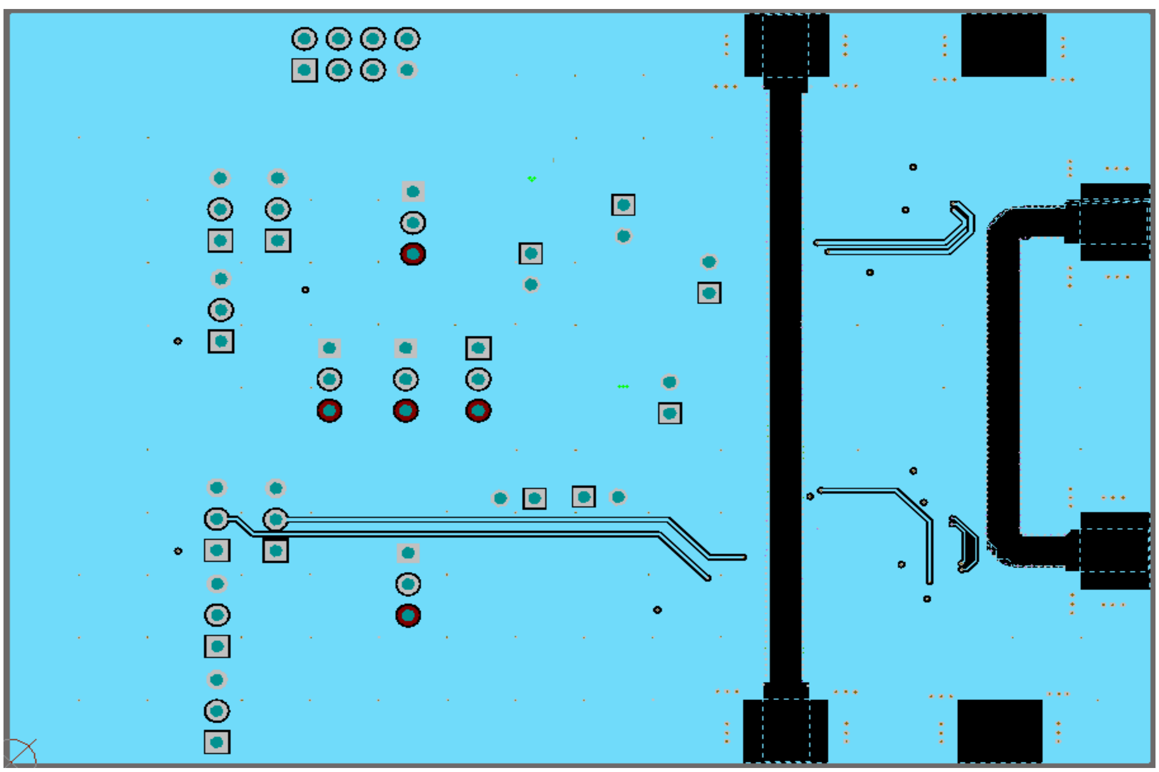

Figure 22 Layer 5

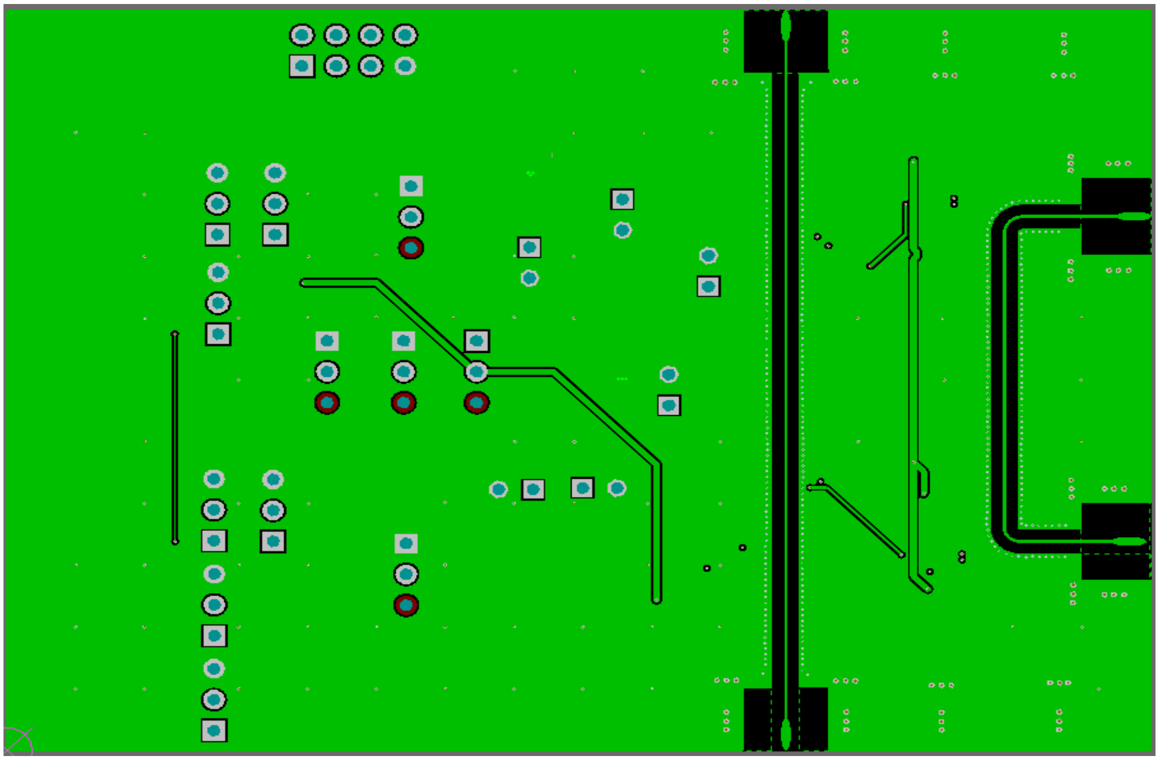

Figure 23 Layer 6

10 About the Author

Liaqat Khan: System design author
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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.