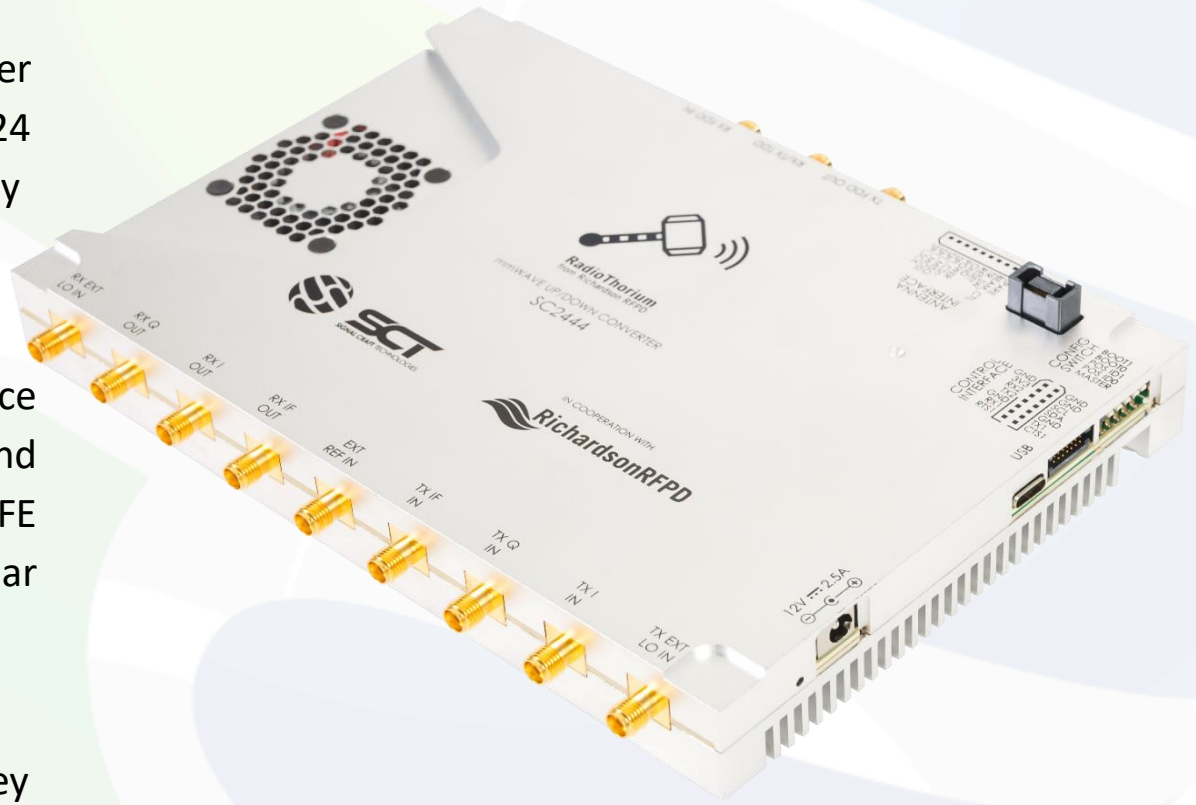
SIGNAL CRAFT TECHNOLOGIES

Radio Thorium Overview

October 20th, 2022

Overview

SCT created the SC2444 in partnership with RichardsonRFPD and Analog Devices. The SC2444 mmWave Converter is a stand-alone solution for use in the 24 to 44 GHz range. It is the first in a family of RadioThorium Branded Modules.



The module is designed to interface directly with an external baseband platform, such as Analog Device's MxFE (Mixed-Signal Front-End) or similar Software Defined Radios.

The modules are designed such that they can be cascaded to create complex 4x4 MIMO radio applications.

Features

Control of the card is provided via either SPI or USB interfaces. The control interfaces can be cascaded (in series) to support a single, external controller. An API Control Interface Specification is provided with detailed command and timing information. Two control modes are available. The first is a console API based on SCPI/488.2. The second is a 32-bit binary structure, for automated control and timing critical applications.

On the low frequency side, both up and down conversion paths support I/Q and IF interfaces. On-board I/Q buffers allow direct connection to external, single-ended ADC/DACs operating at up to 6 GHz. Programmable low pass filters (LPFs) in the buffers help reduce out of band spurious signals.

The IF ports are designed for the 2 to 6 GHz range. Onboard user selectable filter banks provide 20, 50, 100, 200, 400, 800, 1400 MHz bandwidths along with a bypass path option.

The SC2444 can used for either Time Division Duplex (TDD) or Frequency Division Duplex (FDD) systems. The UC and DC paths have separate, high-performance, local oscillators (LOs). Inputs on each path are also available for injection of external LO sources.

Both onboard and external frequency references are supported. The reference source is shared with both the UC and DC paths to provide phase coherence.

SIGNAL CRAFT TECHNOLOGIES

Key Features

24 to 44 GHz Ports

Fan

Design supports stacking of 4 modules and maintaining performance up to 35C.

IF, I/Q, and LO Ports

Antenna Interface

Spare interface with SPI and GPIO pins to provide control for external devices such as antenna arrays or other front-ends.

Expansion Port

The port routes SPI, UART, and reference clock, and other control lines to other cascaded units that are mechanically stacked on top of each other. Up to 4 units can be controlled simultaneously via this port.

Config Port

Device Addressing and Boot Mode Settings.

Auxiliary Control Interface

Dual UARTS for use with external devices that don't support USB. An I2C Port is also available to power and control the optional external I/Q Filter Bank.

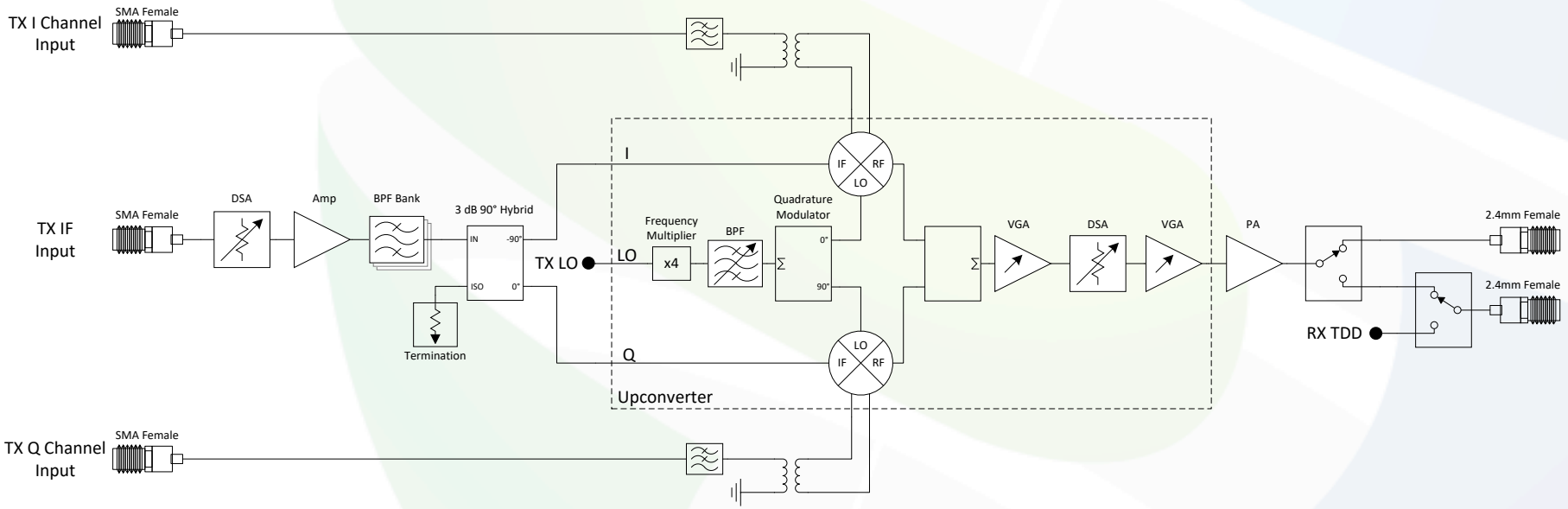
USB Control Interface

USB 2 Type-C High Speed Device

Power Input

Wall cube 12Vdc input.

Upconverter Chain Block Diagram



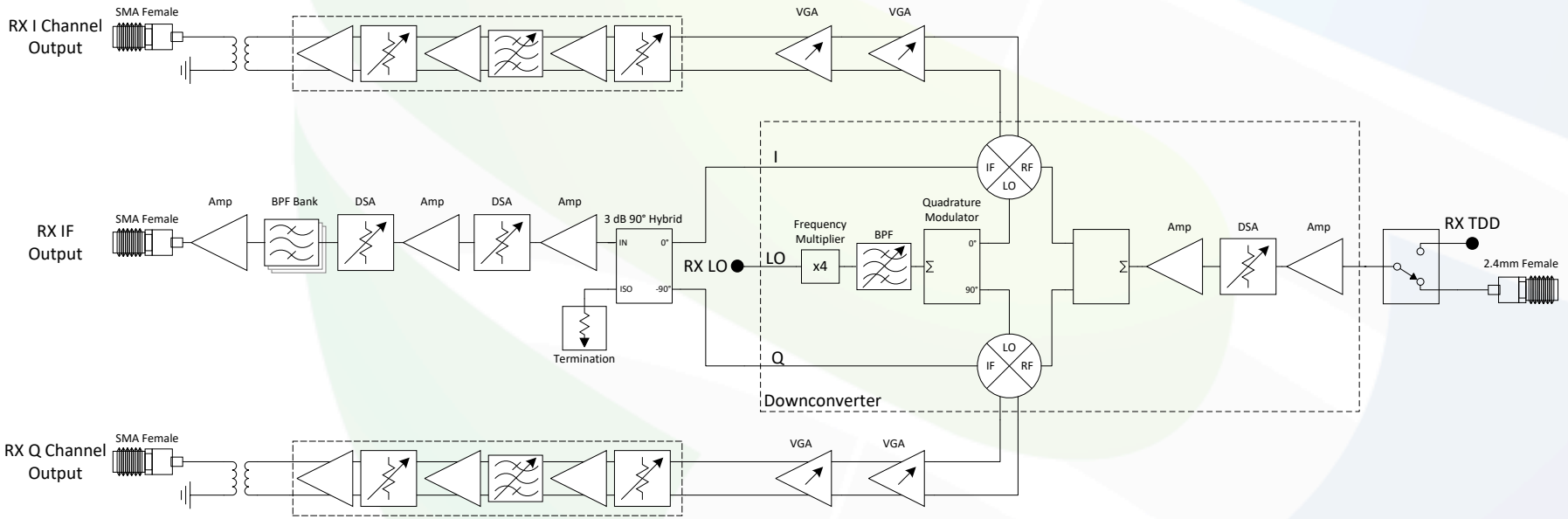
ADMV1013 Wideband, Microwave Upconverter

- Wideband RF input frequency range: 24 GHz to 44 GHz
- 2 upconversion modes
  - Direct conversion from baseband I/Q to RF
- Single-sideband upconversion from real IF
- LO input frequency range: 5.4 GHz to 10.25 GHz
- LO quadrupler for up to 41 GHz
- Sideband suppression and carrier feedthrough optimization

ADPA7002 Power Amplifier

- Output P1dB: 28 dBm (typical at 34 GHz to 44 GHz)
- PSAT: 29.5 dBm (typical at 24 GHz to 34 GHz)
- Gain: 15 dB (typical at 34 GHz to 44 GHz)
- IP3: 38 dBm (typical)
- Integrated power detector

Downconverter Chain Block Diagram



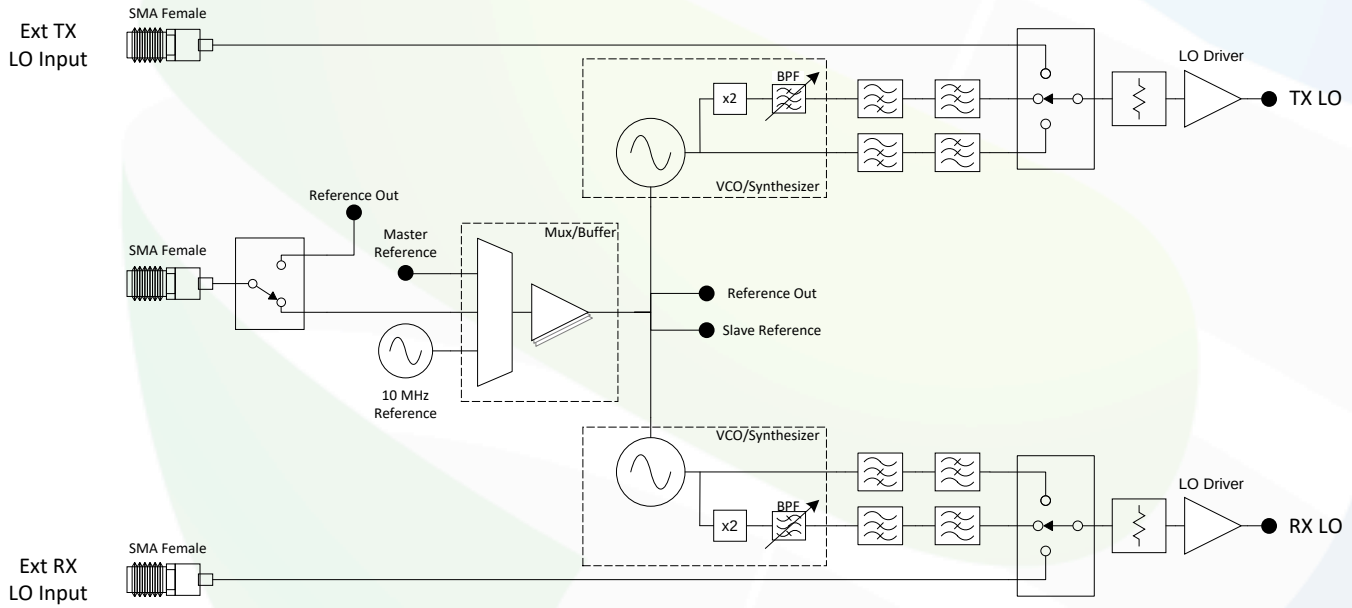
ADMV1014 Wideband, Microwave Downconverter

- Wideband RF input frequency range: 24 GHz to 44 GHz
- Image rejecting downconversion to complex IF
- LO input frequency range: 5.4 GHz to 10.25 GHz
- LO quadrupler for up to 41 GHz LO
- Adjustable output common-mode voltage level
- Image rejection optimization
- Square law power detector for setting mixer input power
- Variable attenuator for Downconverter power control

ADRF5024 SPDT Reflective Switch

- Ultrawideband frequency range: 100 MHz to 44 GHz
- Reflective design
- Low insertion loss with impedance match
  - 1.4 dB typical to 40 GHz
- High input linearity
  - P1dB: 27.5 dBm typical
  - IP3: 50 dBm typical

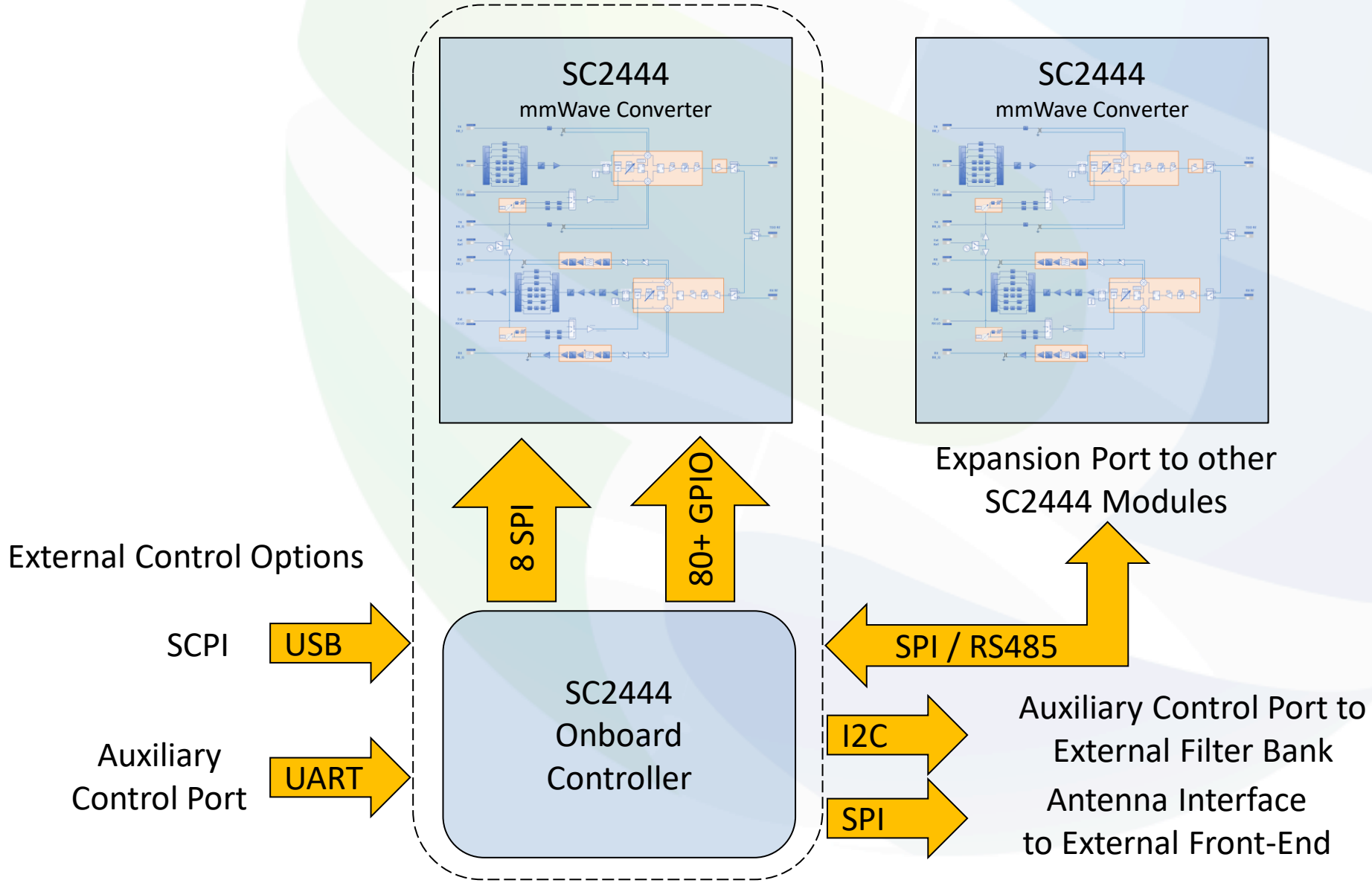
On-Board Oscillators Block Diagram



ADF4372 Wideband Synthesizer with VCO

- RF output frequency range: 62.5 MHz to 16,000 MHz
- Fractional-N synthesizer and integer-N synthesizer
- High resolution 39-bit fractional modulus
- Typical spurious fPFD: −90 dBc
- Integrated rms jitter: 38 fs (1 kHz to 100 MHz)
- Normalized phase noise floor: −234 dBc/Hz
- fPFD operation to 250 MHz
- Reference input frequency operation to 600 MHz
- Programmable divide by 1, 2, 4, 8, 16, 32, or 64 output

Control Interfaces



Controlling the SC2444

Two distinct application protocols are incorporated into the SC2444.

1. Console Protocol
   - Available via USB and UART (TTL-levels) ports
   - Targeted at command console or automated test environments
   - Similar to SCPI / IEEE488.2
   - Supports high level (ie. Set Synth Frequency) and low level (ie. Set Synth N Register) functions
   - ASCII-based commands follow SCPI/IEEE488.2 structure
   - Query command are terminated with a '?' character
   - Example
     - High level command to set the Tx LO frequency to 10.25 GHz using current configuration parameters (ie ext ref freq, comparison frequency, etc)

       format SYN:OUT <channel ID> <direction> <output frequency>

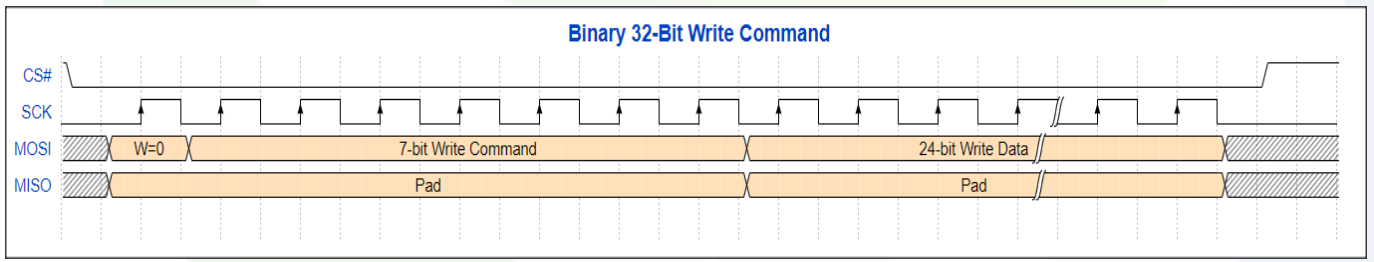
       SYN:OUT TX 10250000
     - Low level command to set the synthesizer registers directly

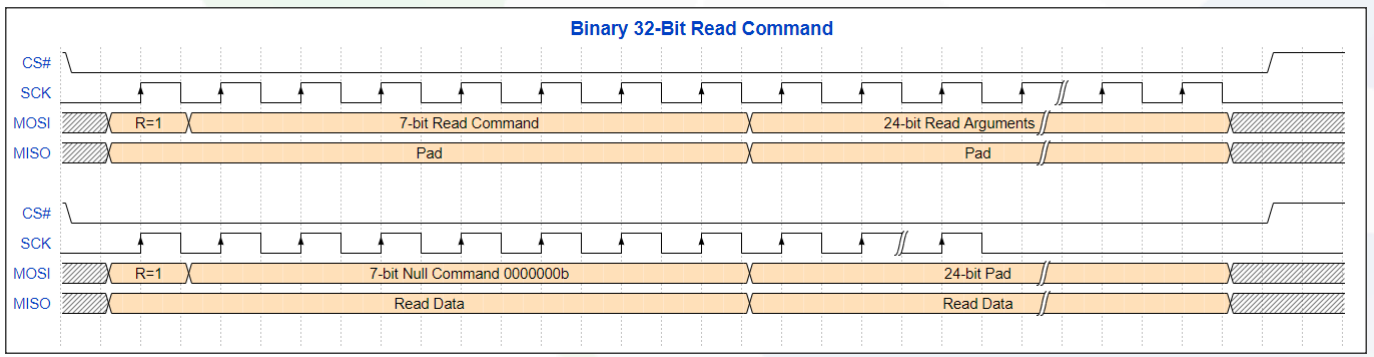
       format SYN:RFSET <channel ID> <direction> <INT> <FRAC1> <FRAC2> <MOD2> <RF Divider>

       SYN:RFSET 0 TX 260 26039637 512 1536 2

Controlling the SC2444

2. Binary Protocol
   - Available via SPI port
   - Targeted at FPGA, or similar, controllers
   - Low level functions via 32-bit register-based interface
   - Supports both write and read operations





Demo Setup Script

```
// Setup the system as a Master with 1 Channel
SYS:ROLE 0 MASTER
SYS:NCHAN 0 1

// Configure the System Reference to 10 MHz
SYS:REF 0 10000
LOCLK:REF 0 INT OFF

// Configure the Synthesizer PFD to 20 MHz
SYN:PFDSET 0 TX 1 1 0
SYN:PFDSET 0 RX 1 1 0

// Configure the LO Frequency
LOCLK:FREQ TX 24650000
LOCLK:FREQ RX 24650000

// Configure the Converter Mode
CV:MODE 0 TX IF
CV:MODE 0 RX IF

// Configure the IF Filters
IFPATH:FLT 0 TX 50
IFPATH:FLT 0 RX 50

// Configure the Converter Gain
// Assumes: TX input power <= -40 dBm
CV:VGAIN 0 TX 1.8
CV:VGAIN 0 RX 0.0

// Configure the IF Attenuation
// Assumes: TX input power <= -40 dBm
IFPATH:ATTN 0 TX 0
IFPATH:ATTN 0 RX 22 22

// Configure the RF Path
RFPATH:PATH 0 FDD
```

Reference:

- Configure the reference signal to use internal 10 MHz
- Configure the Synthesizer PFD for 20 MHz

Upconverter:

- IF input of 2.345 GHz with a bandwidth of 50 MHz
    - Configure IF input filter to 50 MHz
- RF output of 26.985 GHz (upper sideband)
- Configure the internal synthesizer for an LO of 24.650 GHz
    - Enables the RF8 output of the synthesizer
    - Switches the RF8 output to the Converter LO input
    - Configures the Synthesizer output to 6.160 GHz
        - The converter multiplies the LO by 4x
        - (*Frequency / PFD) = Integer Value* for best performance
    - Configures the Converter to use the LO Filter *5.4 GHz – 7 GHz*

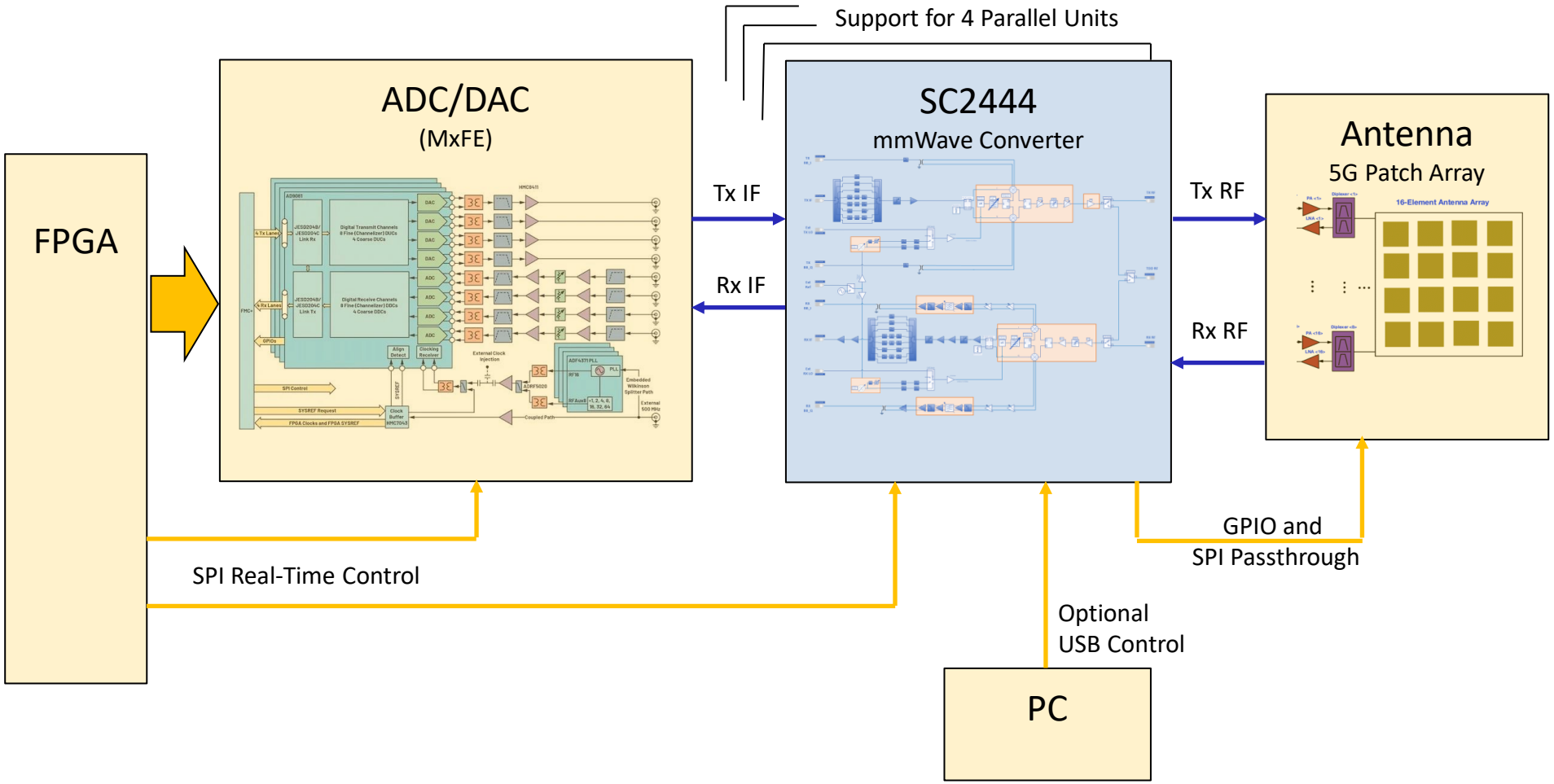
Downconverter:

- RF input of 26.985 GHz (upper sideband)
- IF output of 2.345 GHz with a bandwidth of 50 MHz
    - Configure IF output filter to 50 MHz
- Configure the internal synthesizer for an LO of 24.650 GHz
    - Enables the RF8 output of the synthesizer
    - Switches the RF8 output to the Converter LO input
    - Configures the Synthesizer output to 6.160 GHz
        - The converter multiplies the LO by 4x
        - (*Frequency / PFD) = Integer Value* for best performance
    - Configures the Converter to use the LO Filter *5.4 GHz – 7 GHz*

Output:

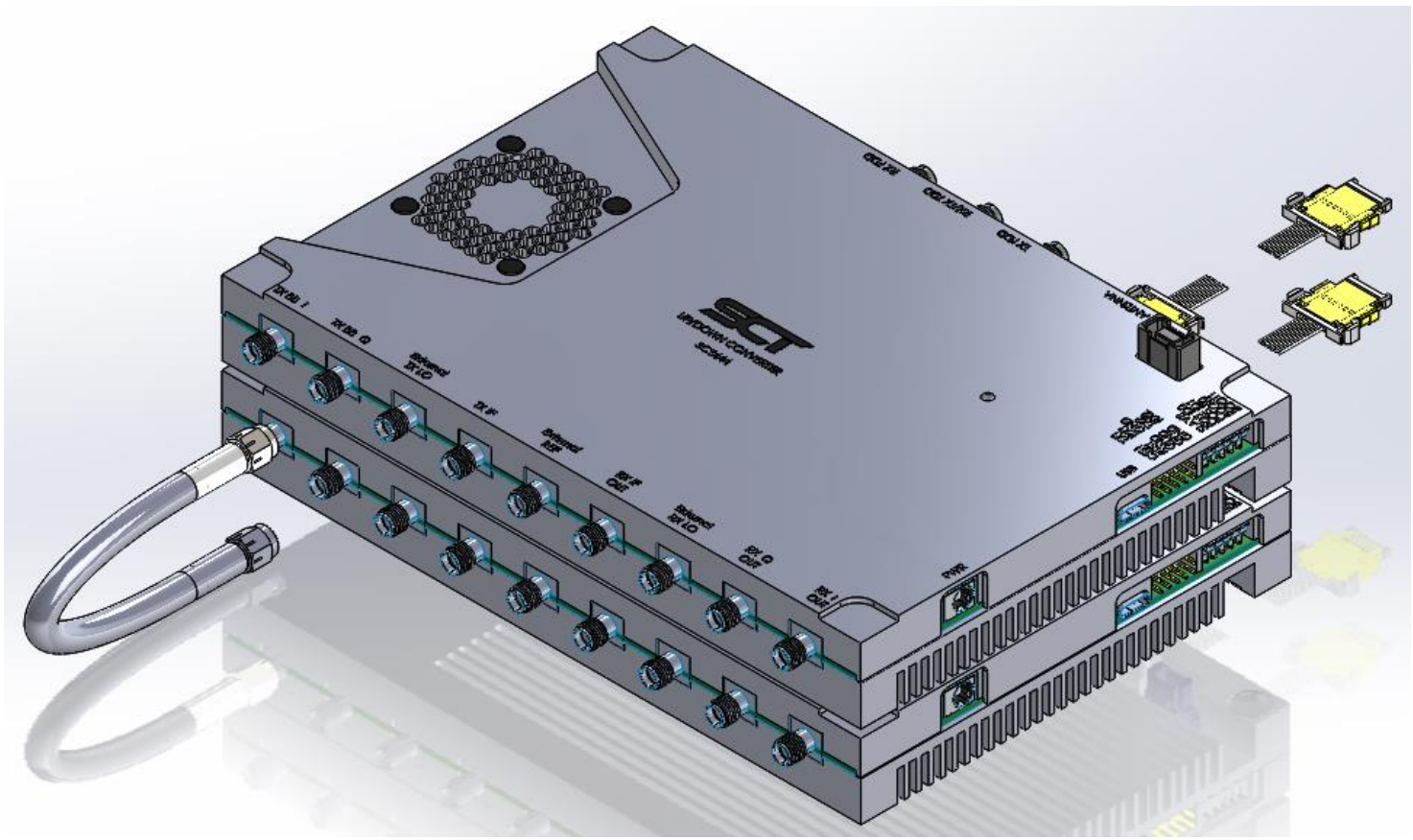
- Select FDD mode.

Typical Application



Multi-Module Support

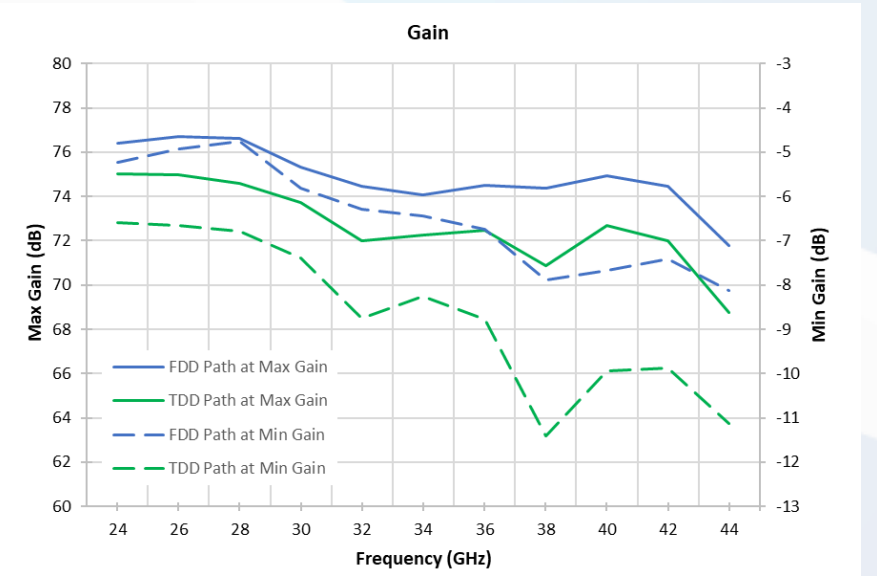
Architecture supports operation of 4 modules in parallel.

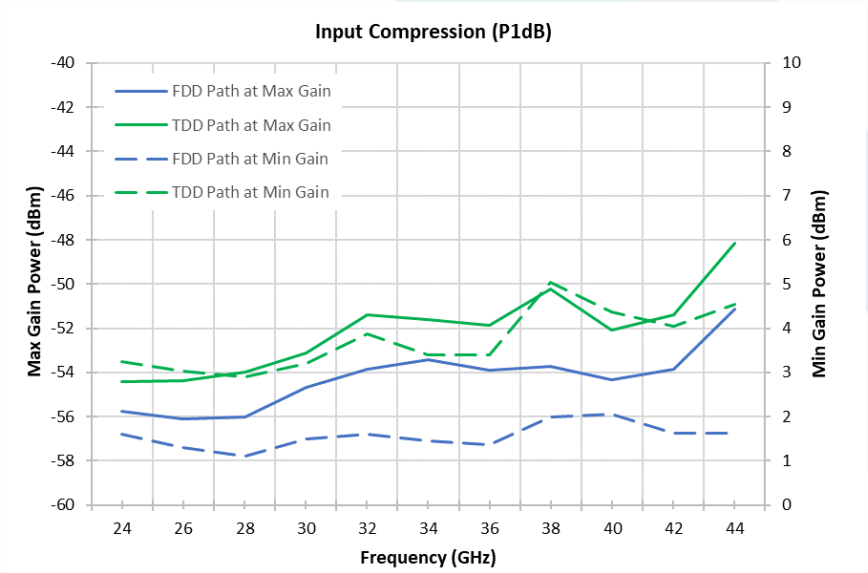


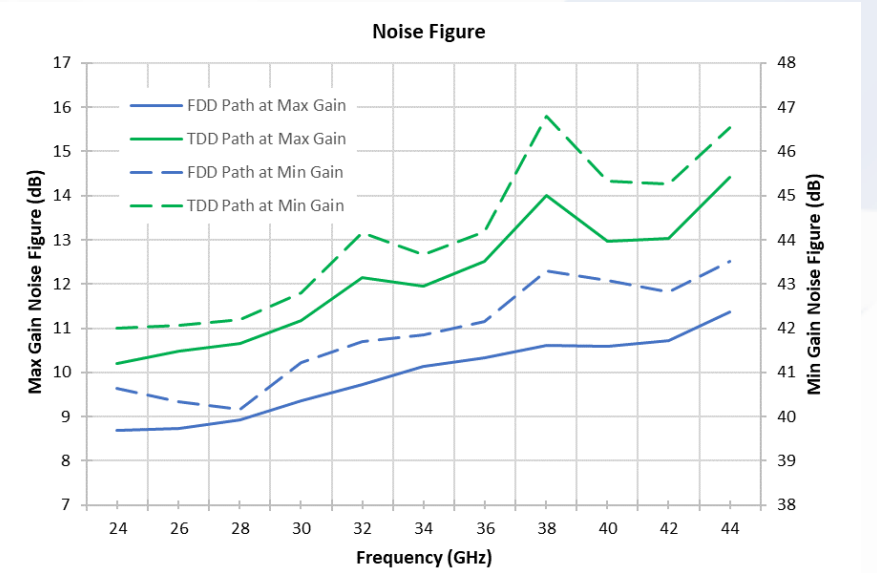
Down-Conversion Path (IF Output)

The Down-Conversion (UC) path in FDD mode has an input P1dB of 0 dBm (min gain) and max gain of 75 dB at 40 GHz.

In TDD mode, the input P1dB at 40 GHz is 0 dBm and has a gain of 72 dB.





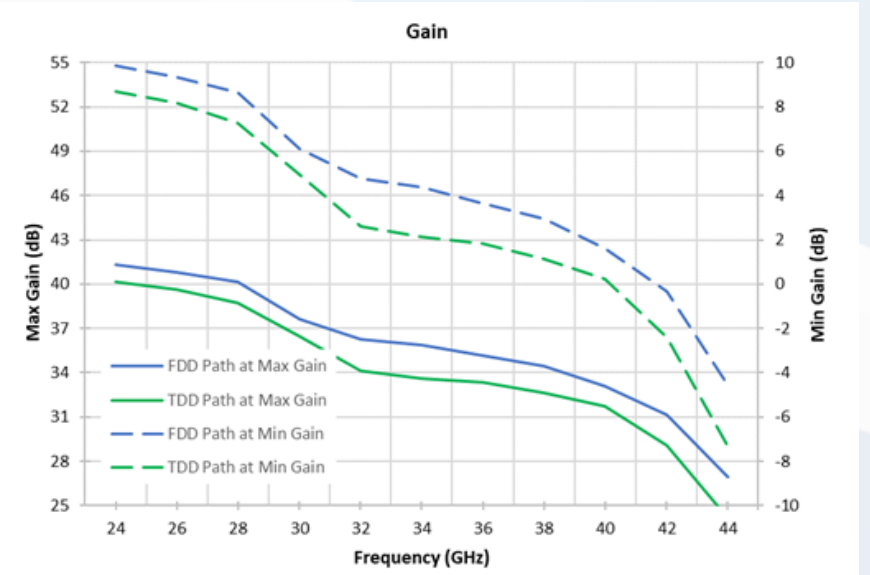


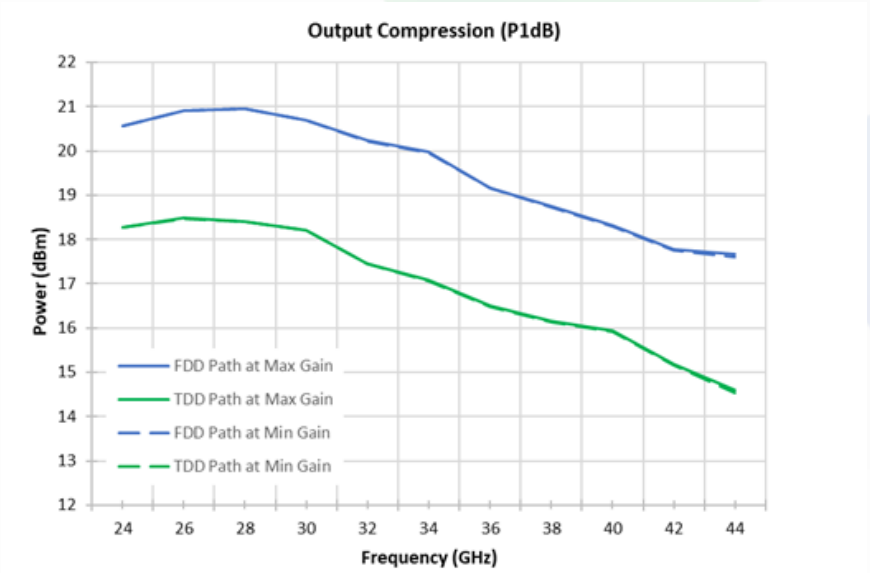
Up-Conversion Path (IF Input)

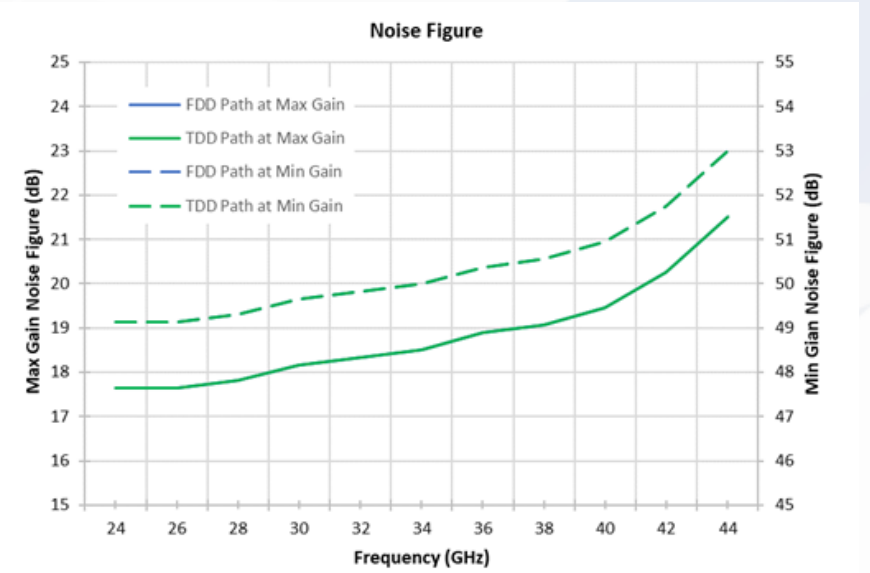
The Up-Conversion (UC) path in FDD mode has a gain of 33 dB and output compression point (P1dB) of 18 dBm at 40 GHz.

In TDD mode, the P1dB at 40 GHz is 16 dBm at a gain of 32 dB.

The Power Amplifier (PA) is biased using an on-board controller, giving the user some control over its operating conditions.

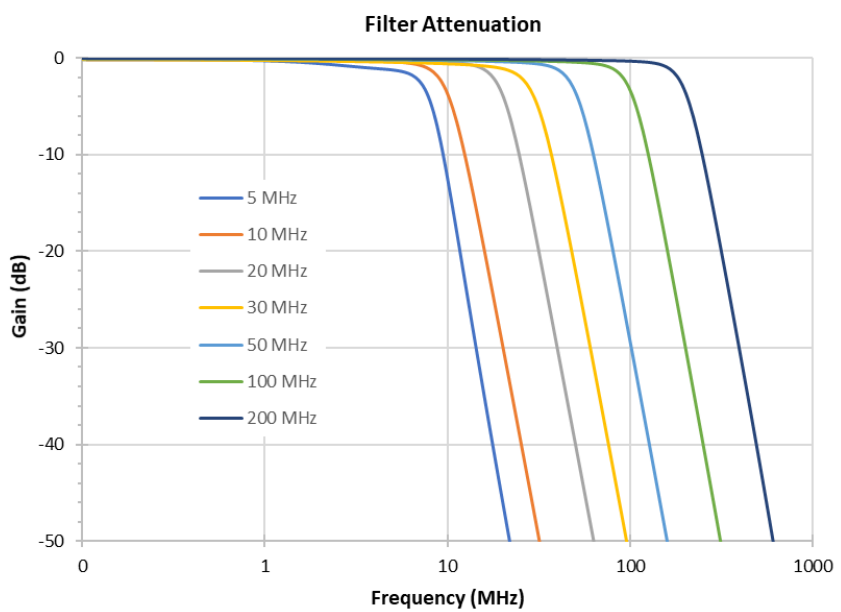






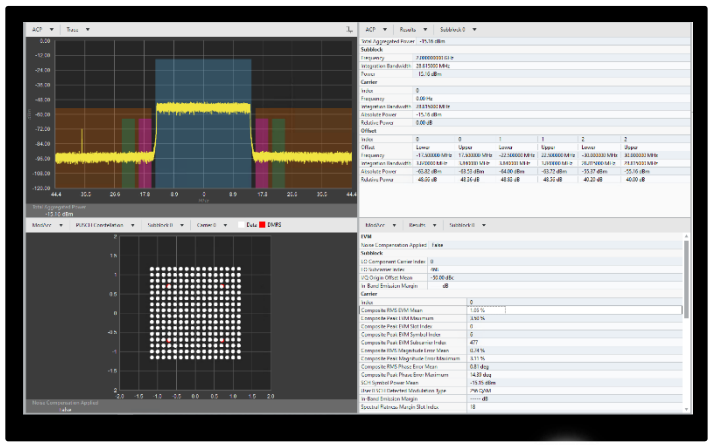
Optional I/Q Filter Bank

The SC4710 in an external Switched Filter Bank that can be used to clean In-Phase and Quadrature signals prior to injection to the converter. It can be controlled directly by the SC2444 via I2C on its Secondary Control Interface.

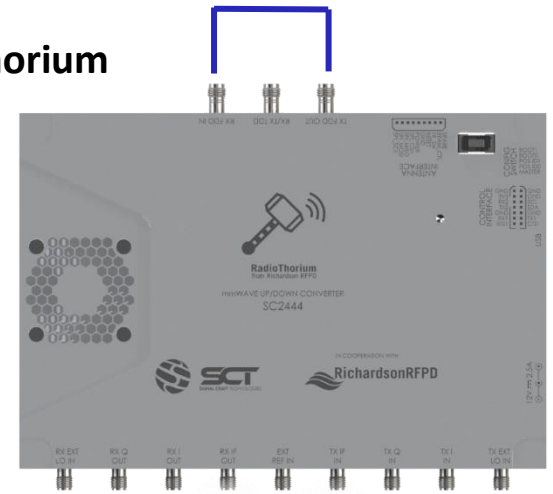


Demo

External Monitor



Radio Thorium



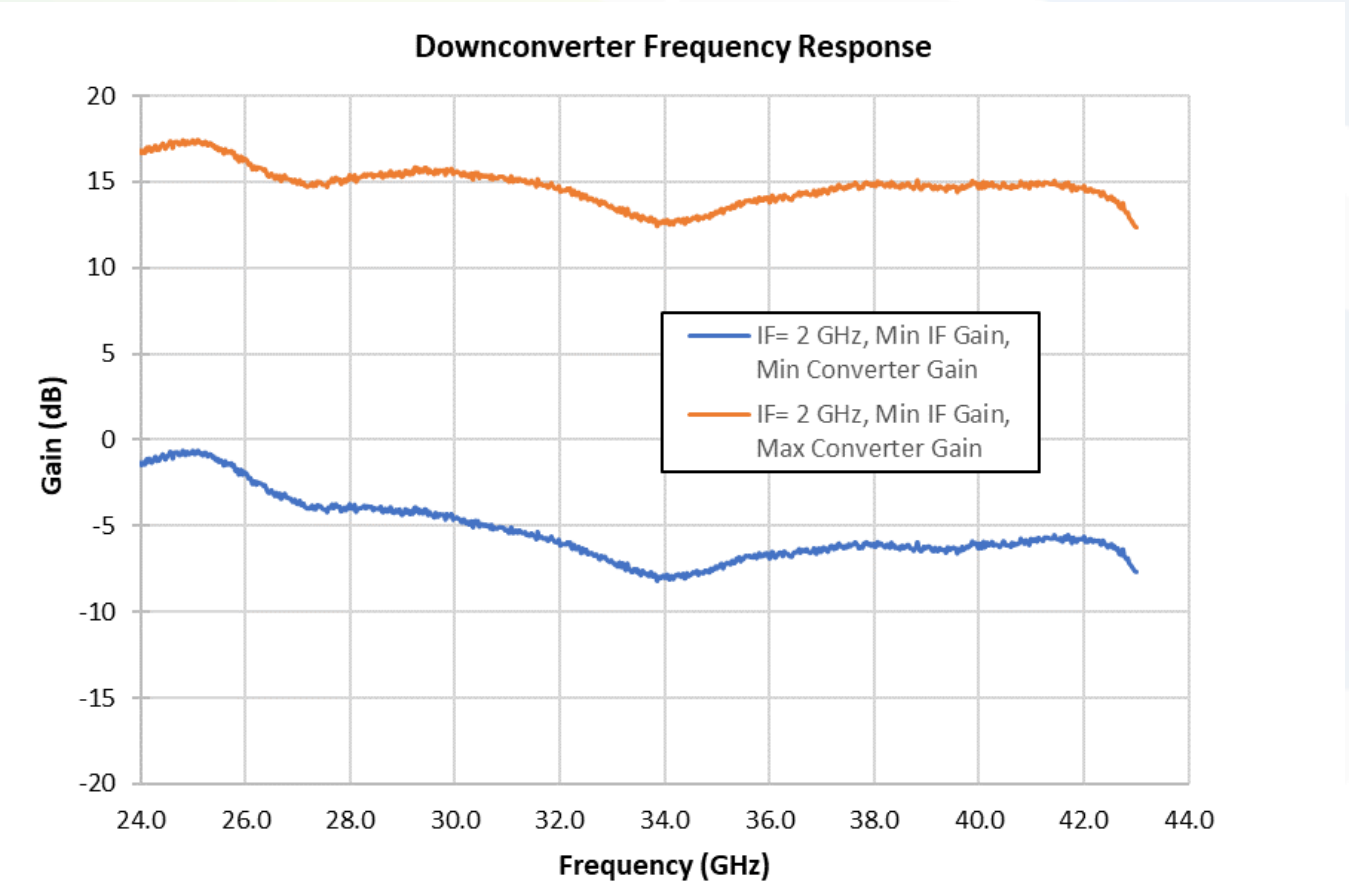
Laptop
(Optional)

Vector Signal Transceiver (SDR)
And PXI-based Controller

Baseband Filter Bank
(Optional)

Downconverter Response

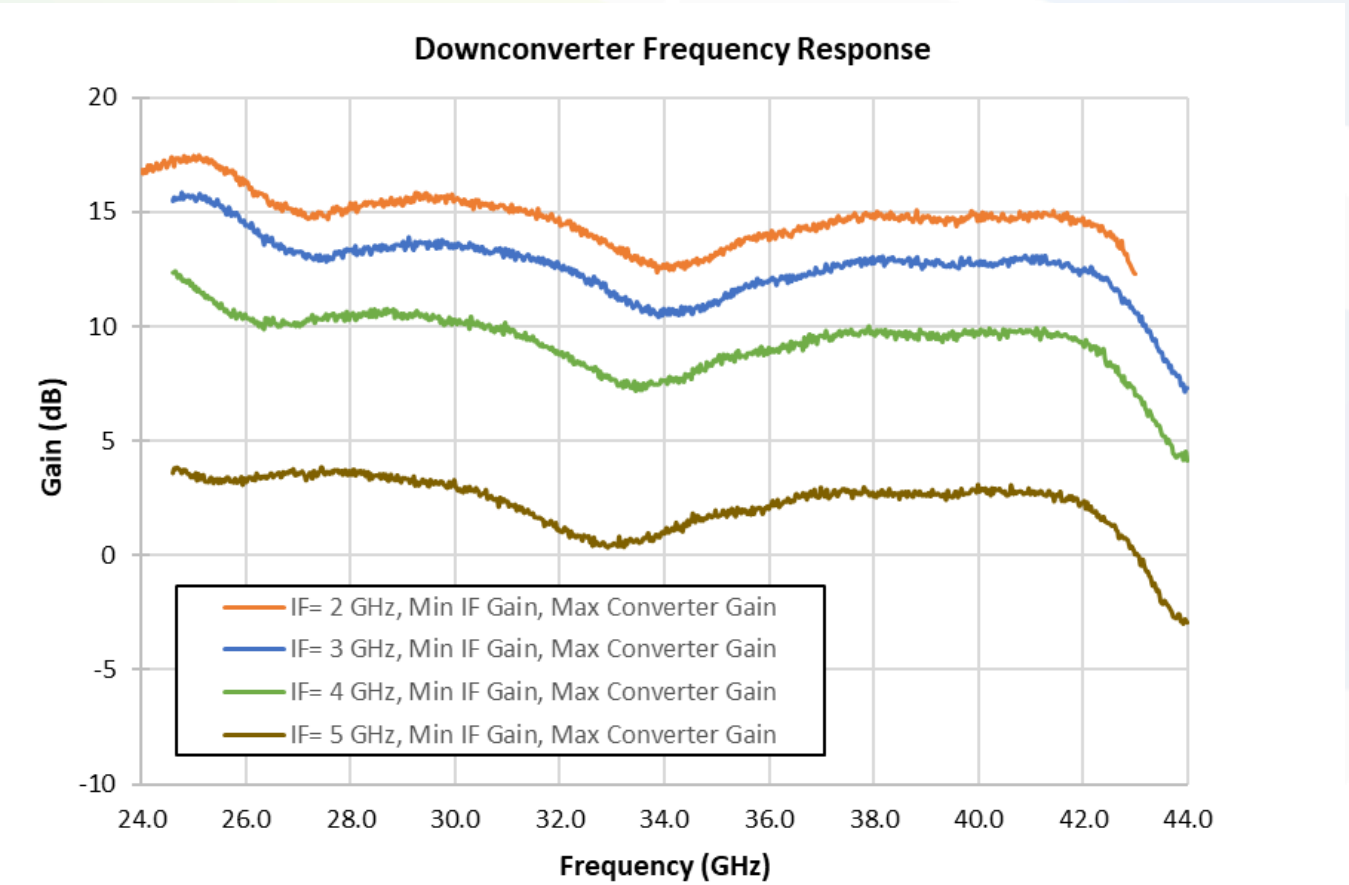
Settings	
RF Frequency	24 to 44 GHz
LO Power	-3.0 dBm
RF Input Power	-30 dBm
RF Gain	Min/Max
IF Frequency	2 GHz
IF Gain	0 dB



Notes:
Rev 1 Hardware (S/N 8D619006)

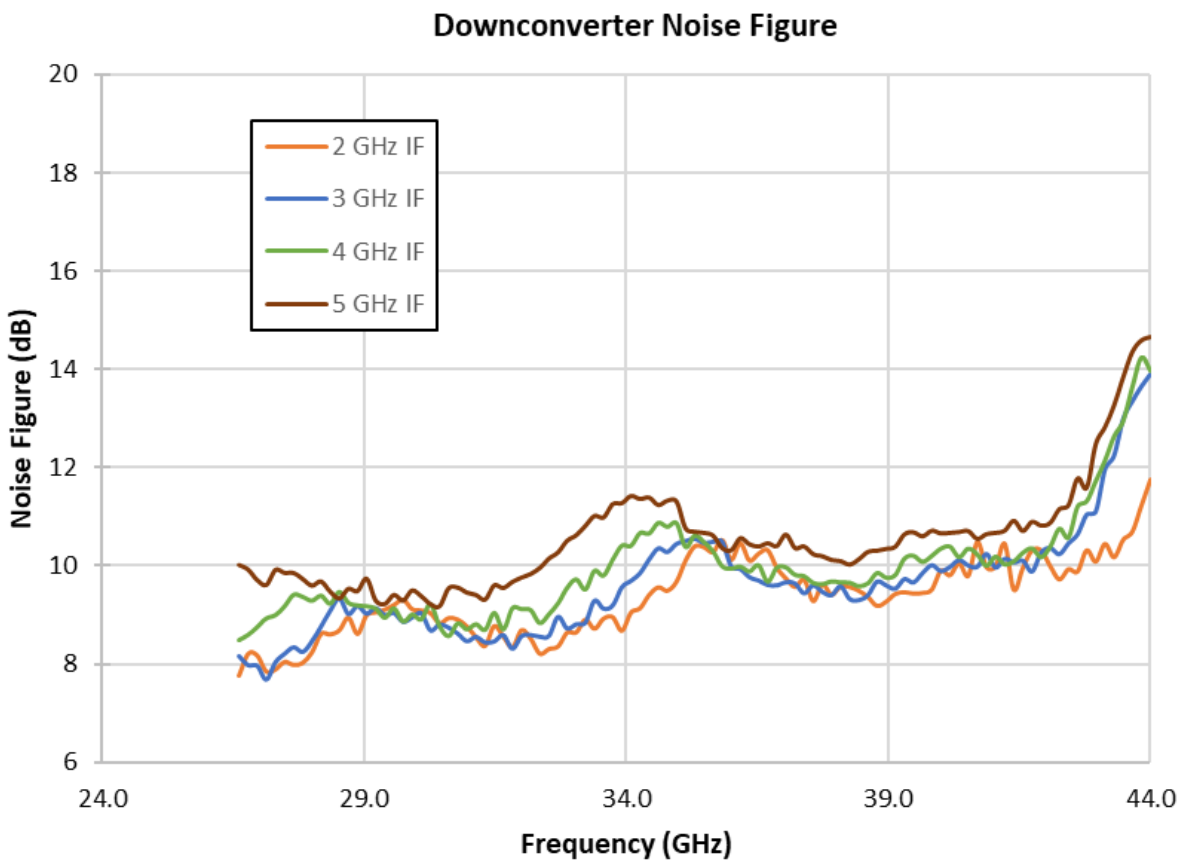
Downconverter Response

Settings	
RF Frequency	24 to 44 GHz
LO Power	-3.0 dBm
RF Input Power	-30 dBm
RF Gain	Max
IQ Frequency	2,3,4,5 GHz
IQ Gain	0 dB



Notes:
Rev 1 Hardware (S/N 8D619006)

Downconverter Noise Figure

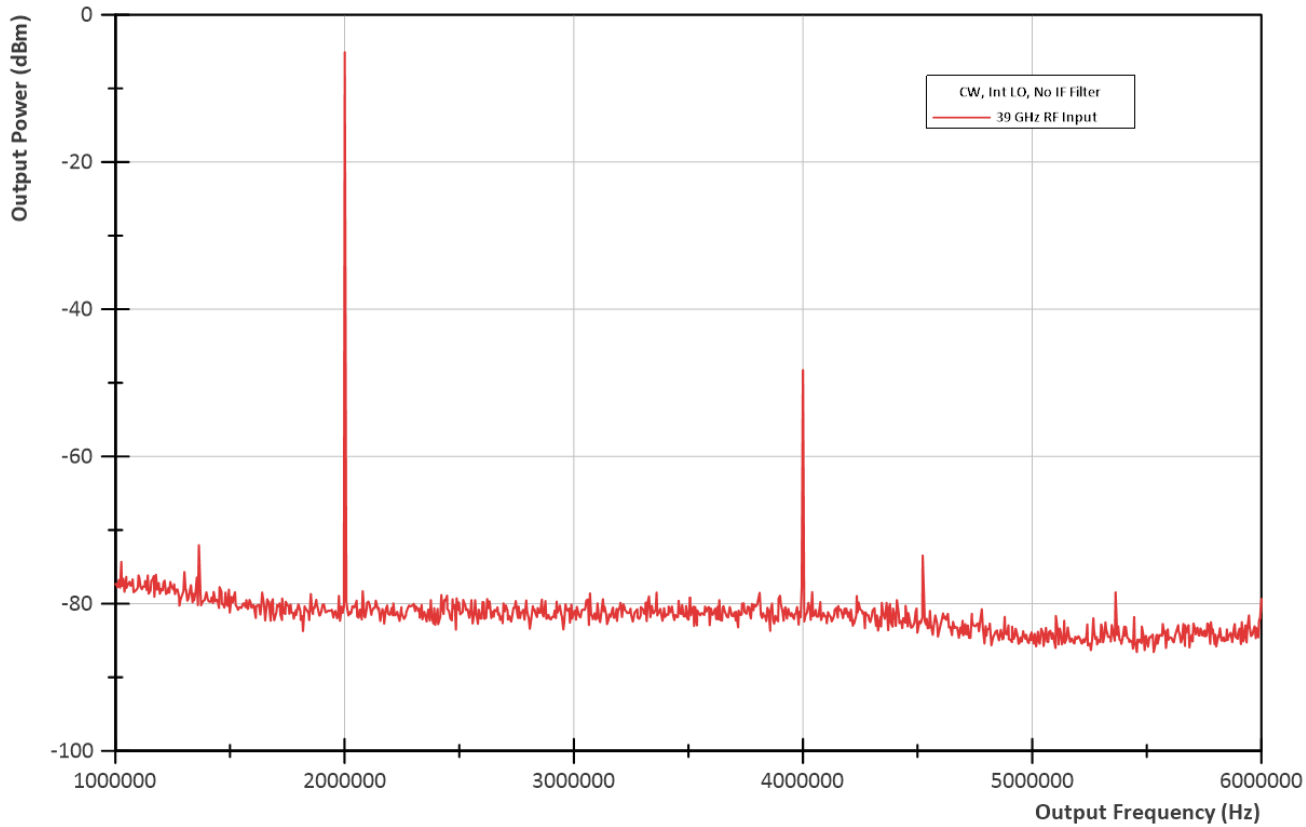


Settings	
RF Frequency	24 to 44 GHz
LO Power	-3.0 dBm
RF Input Power	-30 dBm
RF Gain	Max
IF Frequency	2,3,4,5 GHz

Notes:
Rev 1 Hardware (S/N 8D619006)

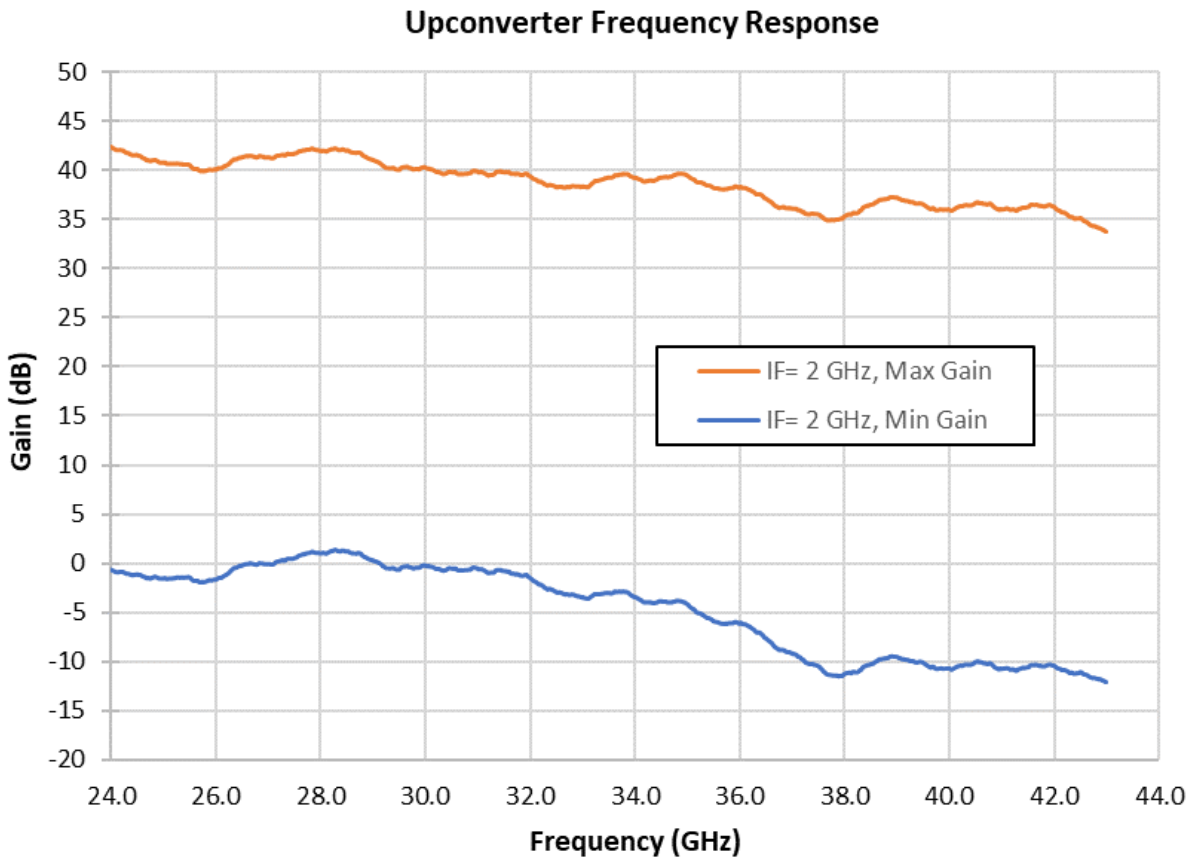
Downconverter IF Output Spectrum

Settings	
RF Frequency	39 GHz
LO Power	-3.0 dBm
RF Input Power	tbd
Gain	Max
IF Frequency	2.35 GHz
IF Gain	0 dB



Notes:
Rev 1.1 Hardware (S/N 8D619006)

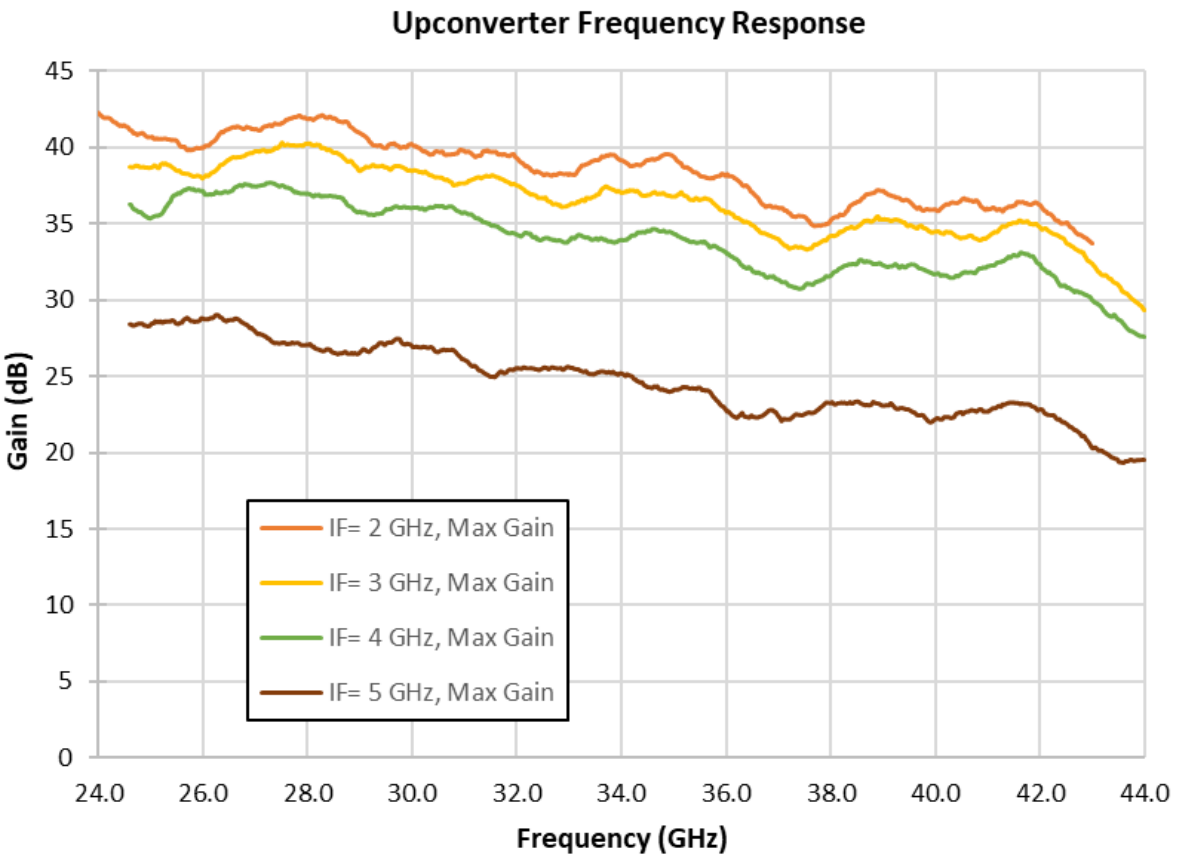
Upconverter Response



Settings	
RF Frequency	24 to 44 GHz
LO Power	-3.0 dBm
IF Input Power	-30 dBm
Gain	Min/Max
IF Frequency	2 GHz

Notes:
Rev 1 Hardware (S/N 8D619006)

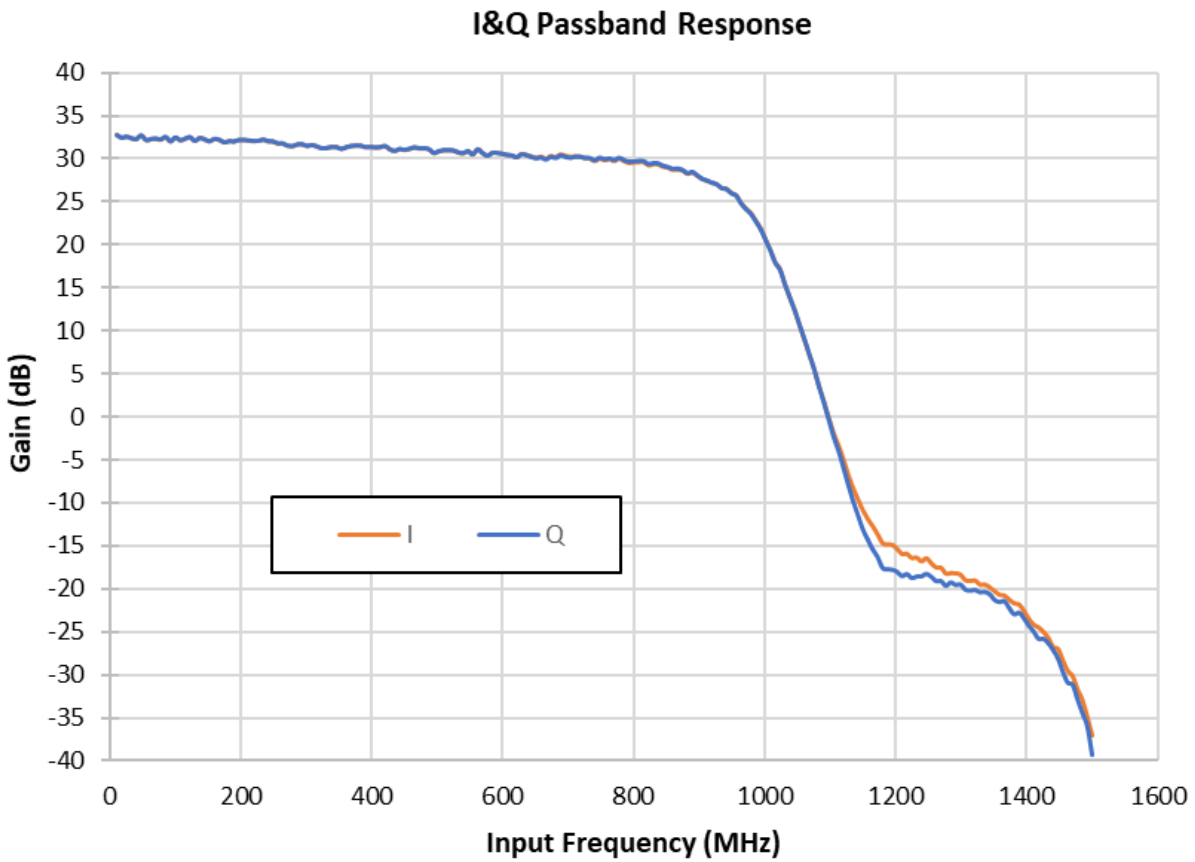
Upconverter Response



Settings	
RF Frequency	24 to 44 GHz
LO Power	-3.0 dBm
IF Input Power	-30 dBm
Gain	Max
IF Frequency	2, 3, 4, 5 GHz

Notes:
Rev 1 Hardware (S/N 8D619006)

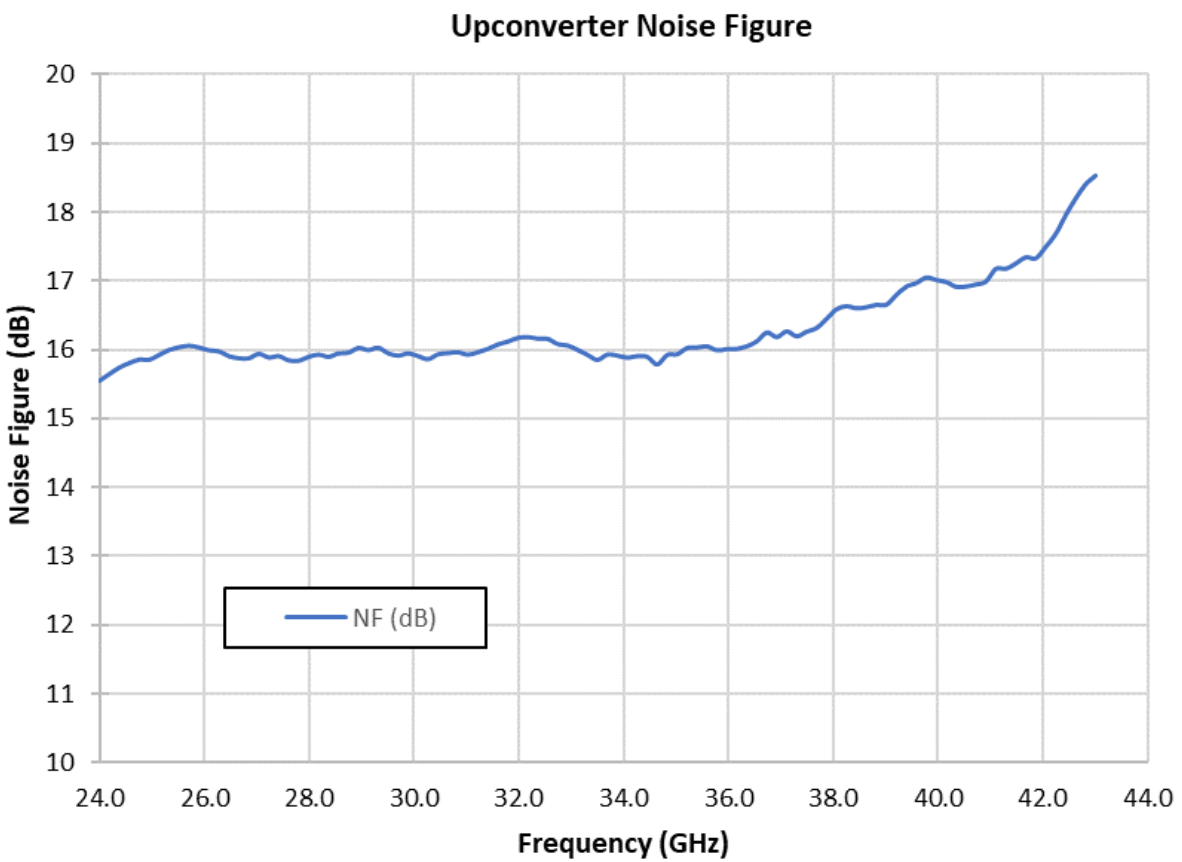
Upconverter IQ Passband Response



Settings	
RF Frequency	24 GHz
LO Power	-3.0 dBm
IQ Input Power	-30 dBm
Gain	Max
IQ Frequency	Variable

Notes:
Rev 1 Hardware (S/N 8D619006)

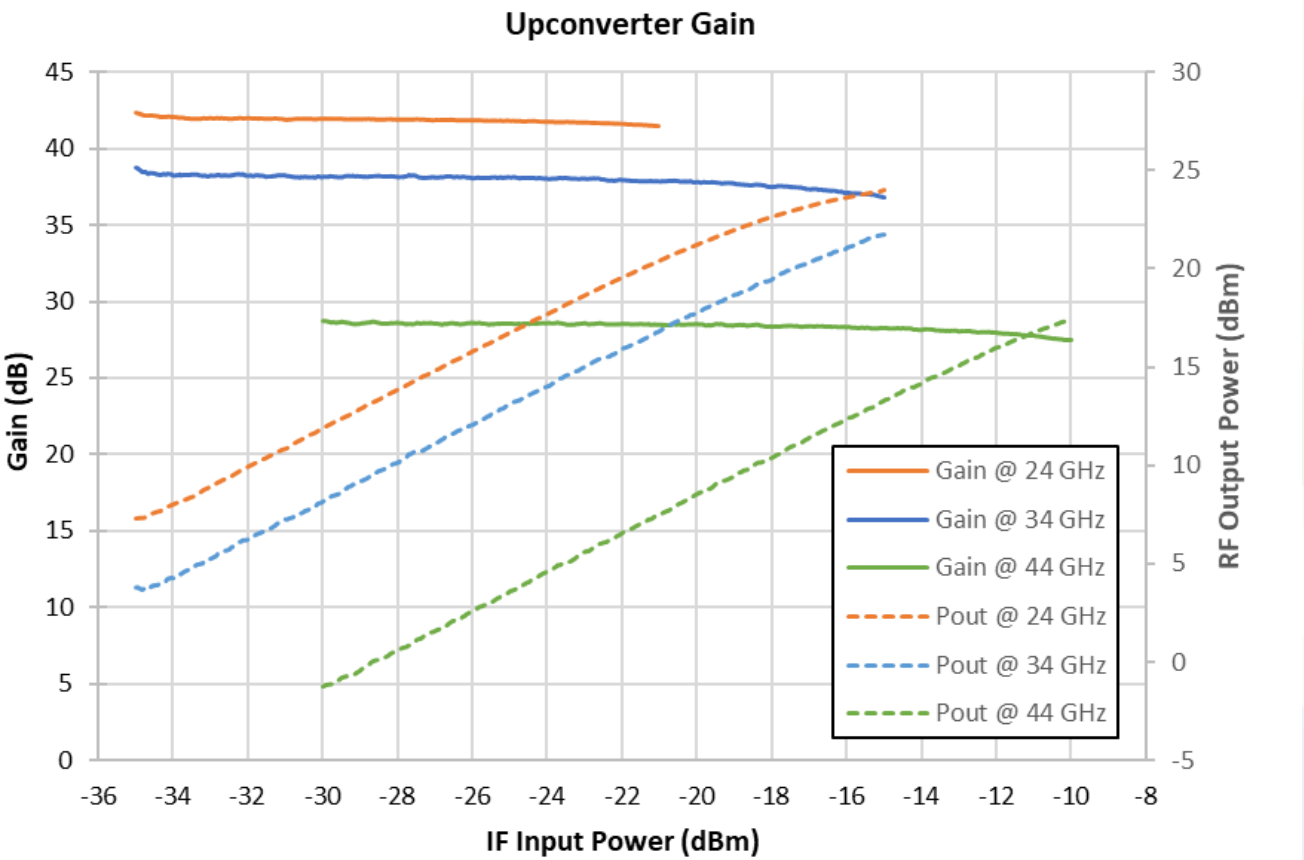
Upconverter Noise Figure



Settings	
RF Frequency	24 to 44 GHz
LO Power	-3.0 dBm
IF Input Power	-30 dBm
Gain	Max
IF Frequency	2 GHz

Notes:
Rev 1 Hardware (S/N 8D619006)

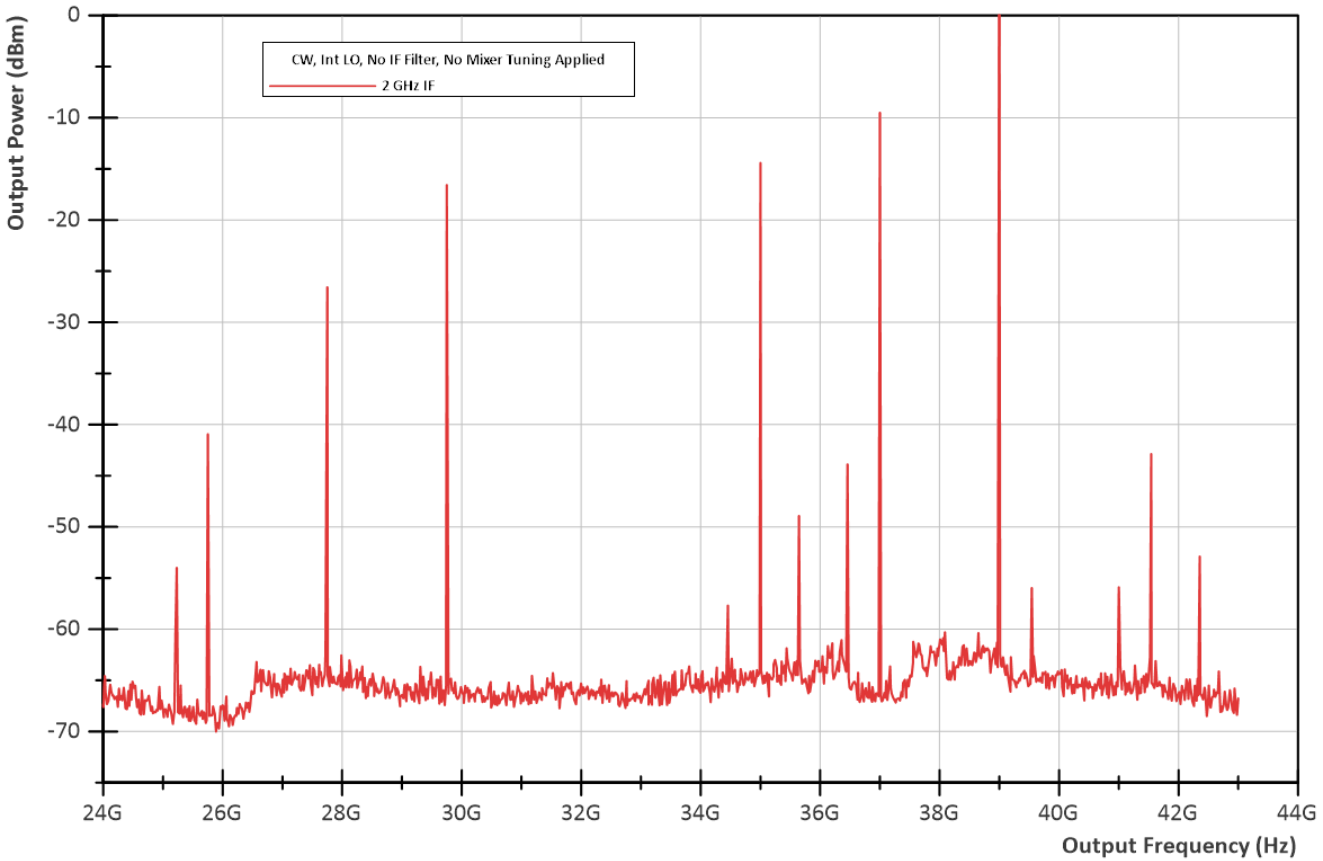
Upconverter Gain



Settings	
RF Frequency	24, 34, 44 GHz
LO Power	-5 dBm
IF Input Power	variable
Gain	Max
IF Frequency	2 GHz

Notes:
Rev 1 Hardware (S/N 8D619006)

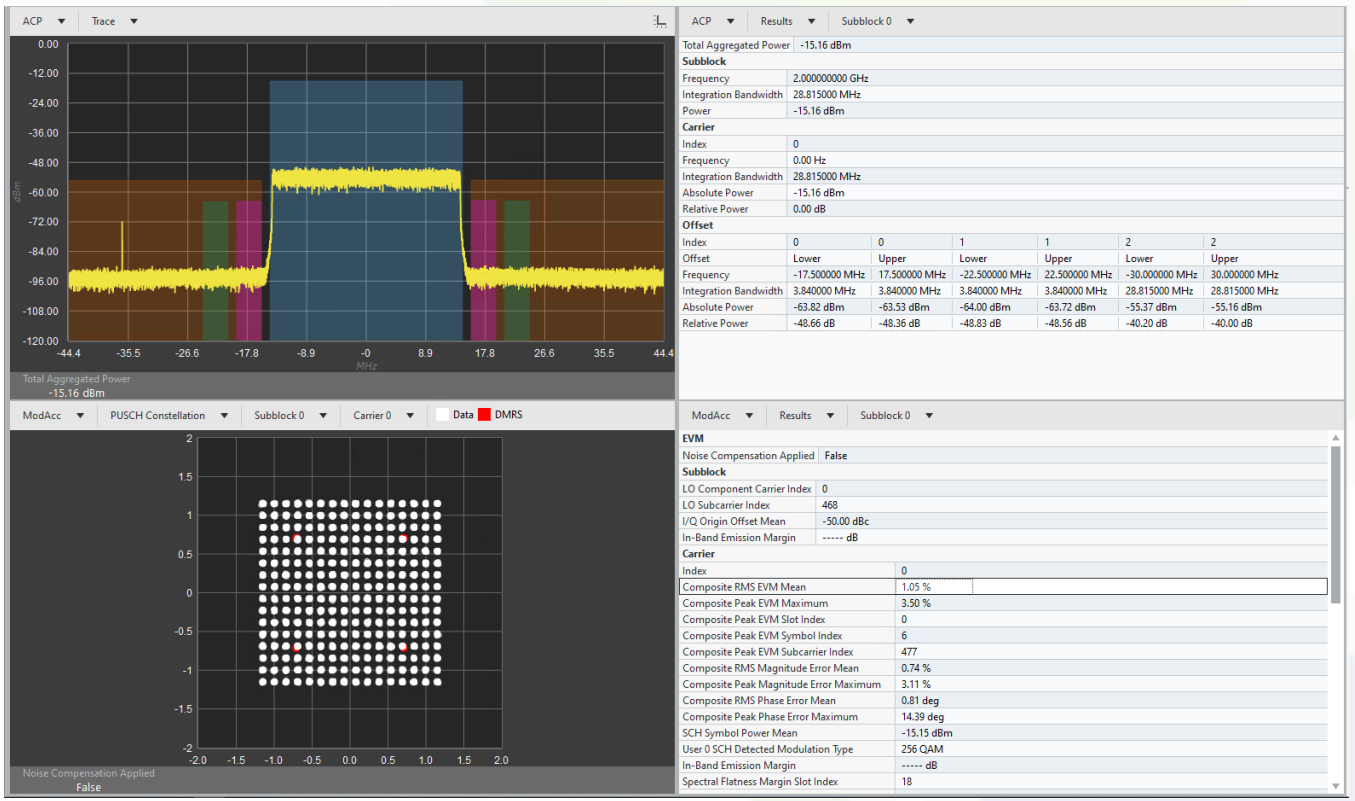
Upconverter Harmonic and Spurious Output



Settings	
Output Freq	39 GHz
Filtering	None
Mixer Tuning	None
LO Power	-5 dBm
IF Input Power	variable
Gain	Max
IF Frequency	2 GHz

Notes:
Rev 1 Hardware (S/N 8D619006)

Example EVM Measurement

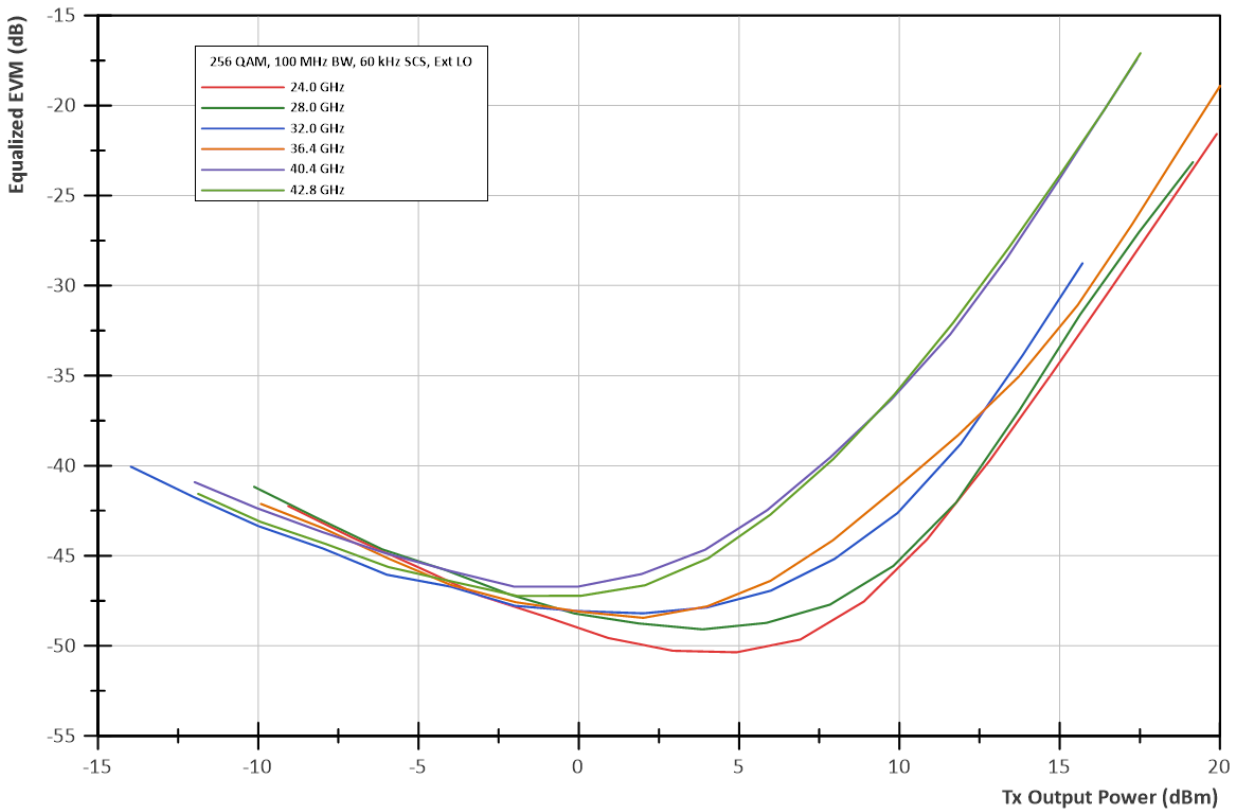


Settings	
Modulation	5G BW=30MHz SCS=30kHz 256 QAM
RF Frequency	24 GHz
Tx Output Power	0 dBm
Tx IF Input Power	-20 dBm
Tx IF Gain	Max
Tx RF Gain	Max
IF Frequency	2 GHz

Notes:
Rev 1 Hardware (S/N 8D619006)
Test Signal NR_FR1_UL_FDD_SISO_BW-30MHz_CC-1_SCS-30kHz_Mod-256QAM-OFDM

Upconverter Composite EVM vs Frequency

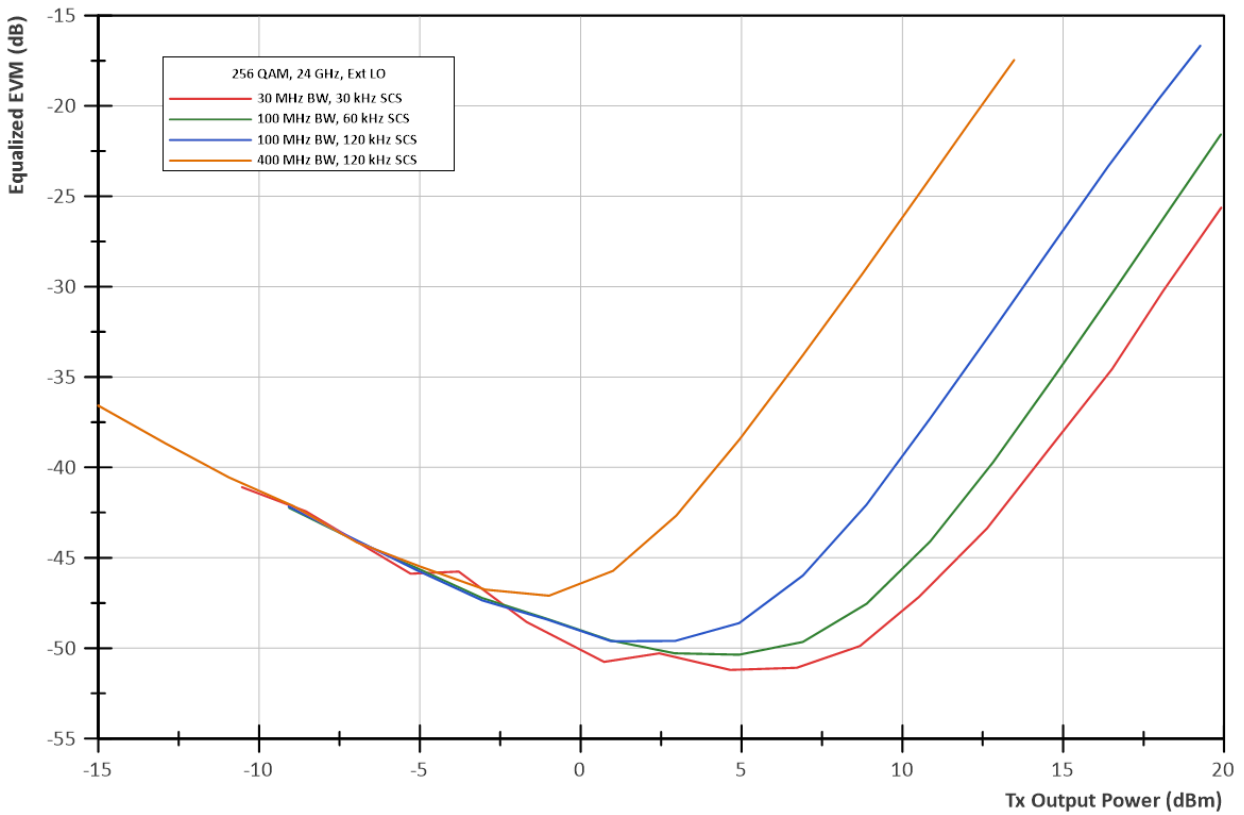
Settings	
Modulation	5G BW=100MHz SCS=60kHz 256 QAM
RF Frequency	Varied
IF Input Power	Swept
Gain	Max
IF Frequency	2 GHz
LO Config	PNA



Notes:
Rev 1.1 Hardware (S/N 8D619010)
Characterized with Keysight PNA-X using Equalized Mode
Test Signal NR_FR1_UL_FDD_SISO_BW-100MHz_CC-1_SCS-60kHz_Mod-256QAM-OFDM
EVM
- Equalized EVM of the DUT (non-linear contribution)
- Un-equalized EVM of the DUT (Includes non-linear and linear distortion due to frequency dispersion)

Upconverter Composite EVM vs BW

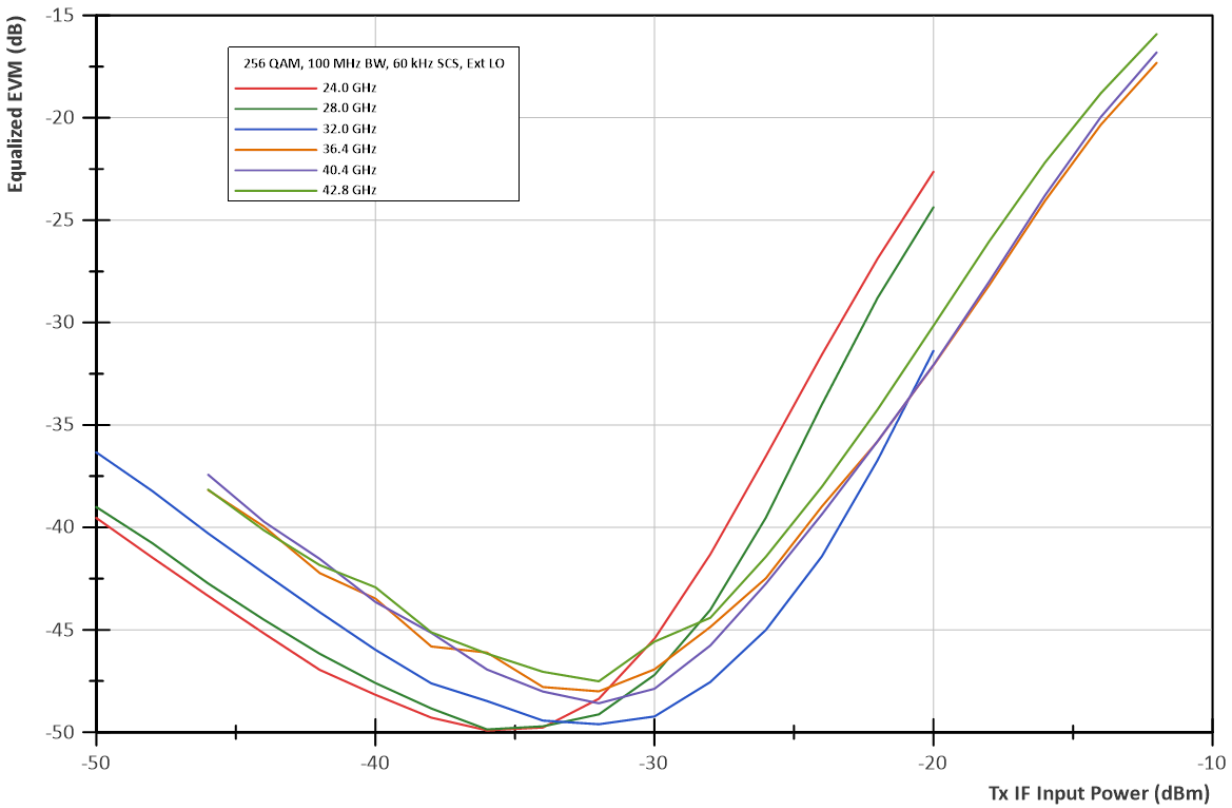
Settings	
Modulation	Varied
RF Frequency	24 GHz
IF Input Power	Swept
Gain	Max
IF Frequency	2 GHz
LO Config	PNA



Notes:
Rev 1.1 Hardware (S/N 8D619010)
Characterized with Keysight PNA-X using Equalized Mode
Test Signal NR_FR1_UL_FDD_SISO_BW-100MHz_CC-1_SCS-60kHz_Mod-256QAM-OFDM
EVM
- Equalized EVM of the DUT (non-linear contribution)
- Un-equalized EVM of the DUT (Includes non-linear and linear distortion due to frequency dispersion)

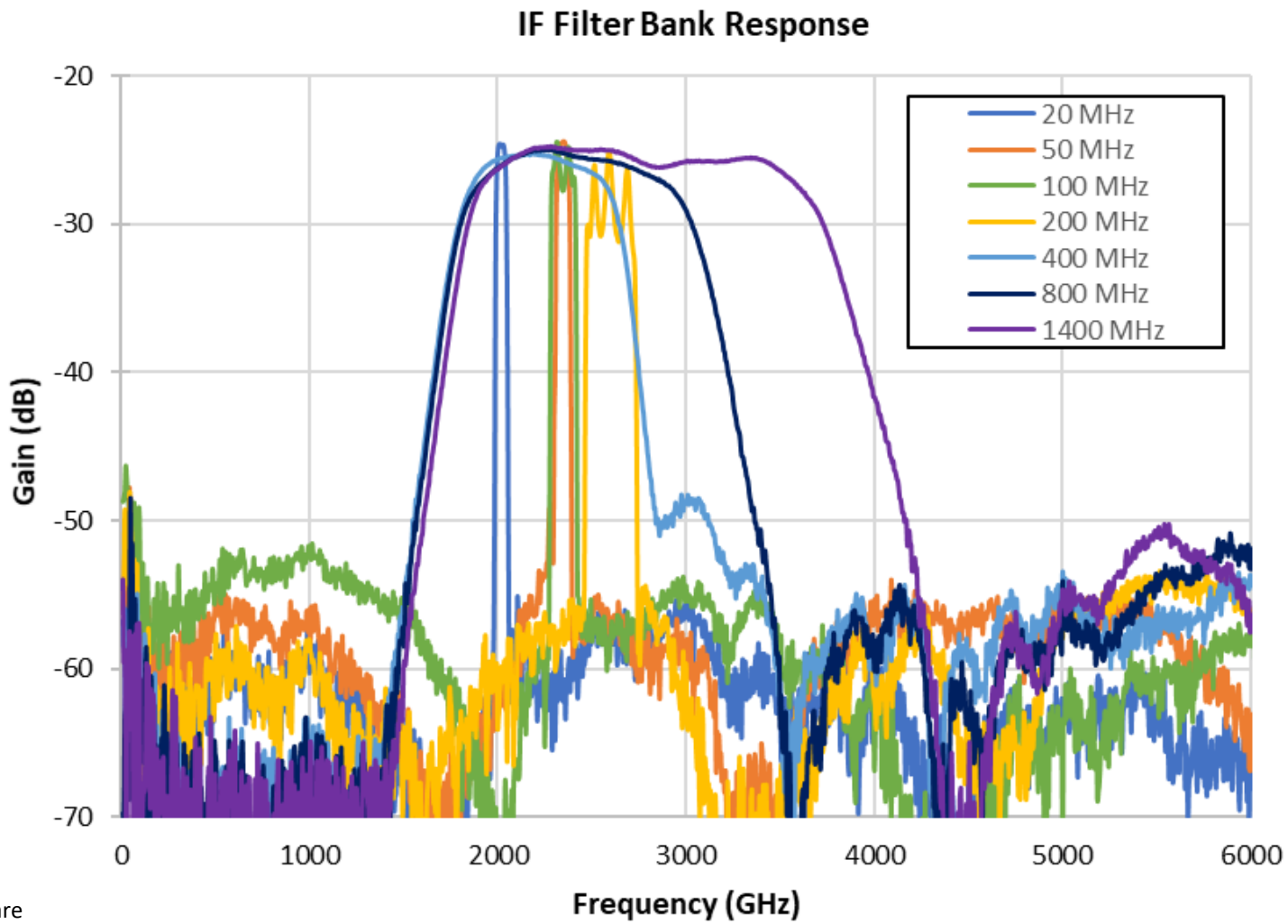
Loopback Composite EVM

Settings	
Modulation	5G BW=100MHz SCS=60kHz 256 QAM
RF Frequency	Varied
IF Input Power	Swept
Gain	Max
IF Frequency	2 GHz
LO Config	Independent Internal



Notes:
Rev 1.1 Hardware (S/N 8D619010)
Characterized with Keysight PNA-X using Equalized Mode
Test Signal NR_FR1_UL_FDD_SISO_BW-100MHz_CC-1_SCS-60kHz_Mod-256QAM-OFDM
EVM
- Equalized EVM of the DUT (non-linear contribution)
- Un-equalized EVM of the DUT (Includes non-linear and linear distortion due to frequency dispersion)

IF Filter Bank Responses



Notes:
Proto A Hardware