

Circuits from the Lab™ Reference Circuits

Circuits from the Lab™ reference circuits are engineered and tested for quick and easy system integration to help solve today's analog, mixed-signal, and RF design challenges. For more information and/or support, visit www.analog.com/CN0285.

Devices Connected/Referenced

ADF4351	Fractional-N PLL IC with Integrated VCO
ADL5375	Wideband Transmit Modulator
ADP150	Low Noise 3.3 V LDO
ADP3334	Low Noise Adjustable LDO

Broadband Low Error Vector Magnitude (EVM) Direct Conversion Transmitter

EVALUATION AND DESIGN SUPPORT

Circuit Evaluation Boards

[CN-0285 Evaluation Board \(EVAL-CN0285-EB1Z\)](#)

Design and Integration Files

[Schematics, Layout Files, Bill of Materials](#)

CIRCUIT FUNCTION AND BENEFITS

This circuit is a complete implementation of the analog portion of a broadband direct conversion transmitter (analog baseband in, RF out). RF frequencies from 500 MHz to 4.4 GHz are supported using a phase-locked loop (PLL) with a broadband, integrated voltage controlled oscillator (VCO). Harmonic filtering of the local oscillator (LO) from the PLL ensures excellent quadrature accuracy, sideband suppression, and low EVM.

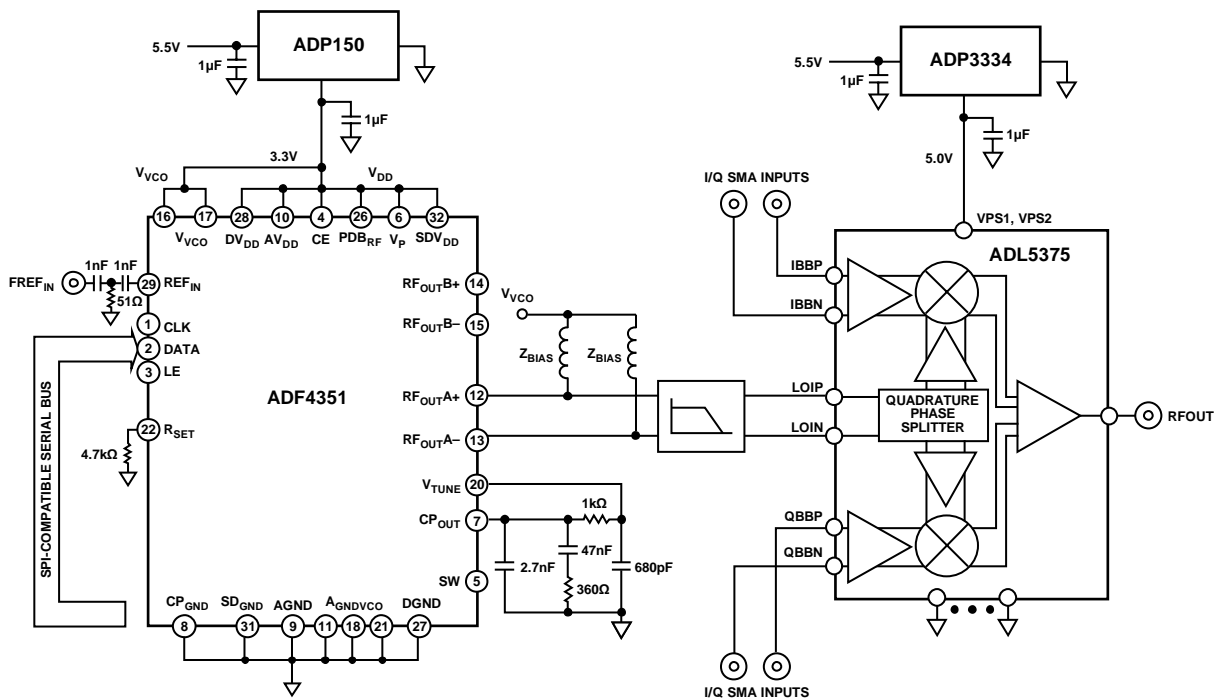


Figure 1. Direct Conversion Transmitter (Simplified Schematic: All Connections and Decoupling Not Shown)

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Figure 2. Evaluation Board for CN-0285 Direct Conversion Transmitter

Low noise, low dropout regulators (LDOs) ensure that the power management scheme has no adverse impact on phase noise and EVM. This combination of components represents industry-leading direct conversion transmitter performance over a frequency range of 500 MHz to 4.4 GHz

CIRCUIT DESCRIPTION

The circuit shown in Figure 1 uses the [ADF4351](#), a fully integrated fractional-N PLL IC, and the [ADL5375](#) wideband transmit modulator. The [ADF4351](#) provides the LO signal for the [ADL5375](#) transmit quadrature modulator, which upconverts analog I/Q signals to RF. Taken together, the two devices provide a wideband, baseband IQ-to-RF transmit solution. The [ADF4351](#) is powered off the ultralow noise 3.3 V [ADP150](#) regulator for optimal LO phase noise performance. The [ADL5375](#) is powered off a 5 V [ADP3334](#) LDO. The [ADP150](#) LDO has an output voltage noise of only 9 μV rms and helps to optimize VCO phase noise and reduce the impact of VCO pushing (equivalent to power supply rejection).

Filtering is required on the [ADF4351](#) RF outputs to attenuate harmonic levels to minimize errors in the quadrature generation block of the [ADL5375](#). From measurement and simulation, the odd-order harmonics contribute more than even-order harmonics to quadrature error and, if attenuated to below -30 dBc, results in sideband suppression performance of -40 dBc or better. The second harmonic (2H) and third harmonic (3H) levels of the [ADF4351](#) are as given in the data sheet and shown in Table 1.

To get the third harmonic below -30 dBc, approximately 20 dB of attenuation is required.

Table 1. [ADF4351](#) RF Output Harmonic Levels Unfiltered

Harmonic Content	Value (dBc)	Description
Second	-19	Fundamental VCO output
Third	-13	Fundamental VCO output
Second	-20	Divided VCO output
Third	-10	Divided VCO output

This circuit gives four different filter options to cover four different bands. The filters were designed with a $100\ \Omega$ differential input ([ADF4351](#) RF outputs with appropriate matching) and a $50\ \Omega$ differential output ([ADL5375](#) LOIN differential impedance). A Chebyshev response was used for optimal filter roll-off at the expense of increased pass-band ripple.

The filter schematic is shown in Figure 3. This topology allows the use of either a fully differential filter to minimize component count, a single-ended filter for each output, or a combination of the two. It was determined that for higher frequencies (>2 GHz) two single-ended filters gave the best performance because the series inductor values are twice the value compared to a fully differential filter and, hence, the impact of component parasitics is reduced. For lower frequencies (<2 GHz), a fully differential filter provides adequate results.

Table 2. [ADF4351](#) RF Output Filter Component Values (DNI = Do Not Insert)

Frequency Range (MHz)	Z _{BIAS}	L1 (nH)	L2 (nH)	C1a (pF)	C1c (pF)	C2a (pF)	C2c (pF)	C3a (pF)	C3c (pF)
500 to 1300 (Filter Type A)	27 nH 50 Ω	3.9	3.9	DNI	4.7	DNI	5.6	DNI	3.3
850 to 2450 (Filter Type B)	19 nH (100 Ω in Position C1c)	2.7	2.7	3.3	100 Ω	4.7	DNI	3.3	DNI
1250 to 2800 (Filter Type C)	50 Ω	0 Ω	3.6	DNI	DNI	2.2	DNI	1.5	DNI
2800 to 4400 (Filter Type D)	3.9 nH	0 Ω	0 Ω	DNI	DNI	DNI	DNI	DNI	DNI

The **ADF4351** output match consists of the Z_{BIAS} pull-up and, to a lesser extent, the decoupling capacitors on the supply node. To get a broadband match, it is recommended to use either a resistive load ($Z_{BIAS} = 50 \Omega$) or a resistive in parallel with a reactive load for Z_{BIAS} . The latter gives slightly higher output power, depending on the inductor chosen. Note that it is possible to place the parallel resistor as a differential component (that is, 100Ω) in Position C1c to minimize board space (see Filter Type B, Table 2).

Design the filter with a cutoff approximately 1.2 times to 1.5 times the highest frequency in the band of interest. This cutoff allows margin in the design, because typically the cutoff is lower than designed due to parasitics. The effect of printed circuit board (PCB) parasitics can be simulated in an electromagnetic (EM) simulation tool for improved accuracy.

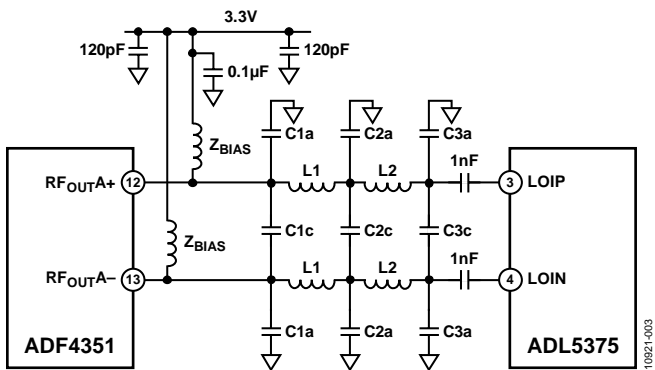


Figure 3. **ADF4351** RF Output Filter Schematic

As can be seen from Table 2, at frequencies lower than 1250 MHz, a fifth-order filter is required. For 1.25 GHz to 2.8 GHz, third-order filtering is sufficient. For frequencies more than 2.8 GHz, filtering is not required because the harmonic levels are sufficiently low to meet the sideband suppression specifications.

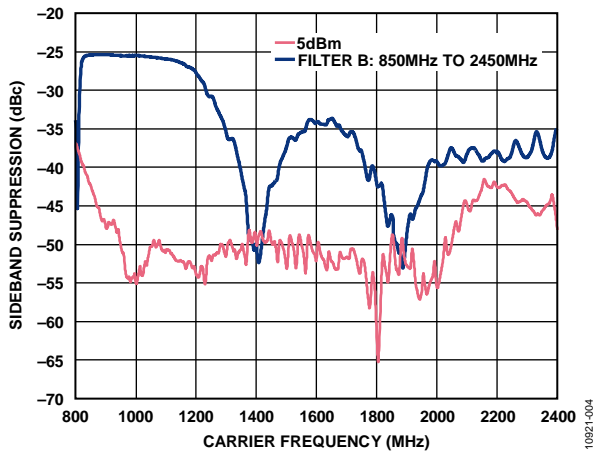


Figure 4. Sideband Suppression for Filter Type B, 850 MHz to 2450 MHz

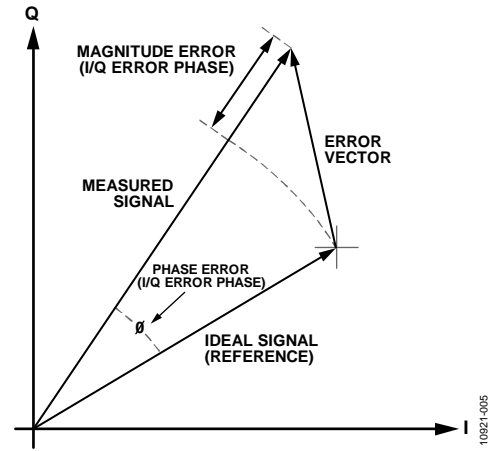


Figure 5. EVM Plot

A sweep of sideband suppression vs. frequency is shown in Figure 4 for the circuit using Filter Type B (800 MHz to 2400 MHz). In this sweep, the test conditions were the following:

- Baseband I/Q amplitude = 1 V p-p differential sine waves in quadrature with a 500 mV (**ADL5375-05**) dc bias
- Baseband I/Q frequency (f_{BB}) = 1 MHz.

EVM is a measure of the quality of the performance of a digital transmitter or receiver and is a measure of the deviation of the actual constellation points from their ideal locations, due to both magnitude and phase errors (see Figure 5).

EVM measurements are given in Table 3 comparing the results with and without the filter. In this case, the baseband I/Q signals were generated using 3GPP Test Model 4 using a Rohde & Schwarz AMIQ I/Q modulation generator with differential I and Q analog outputs. Filter Type B was also used. A block diagram of the test setup for the EVM is shown in Figure 6. For comparative purposes, the **ADF4350** is also measured. Lower EVM due to in-band PLL noise improvements on the **ADF4351** can be seen in Table 3. Other contributing factors to the EVM improvement are the lower phase frequency detector (PFD) spurious levels on the **ADF4351**.

Table 3. Single-Carrier W-CDMA Composite EVM Results Comparing Filter vs. No Filter on ADF4351 RF Outputs (Measured As Per 3GPP Specification Test Model 4)

Frequency (MHz)	ADF4350 Composite EVM No LO Filtering	ADF4350 Composite EVM with LO Filtering, Filter B	ADF4351 Composite EVM with LO Filtering, Filter B
2140	3.27%	1.31%	1.02%
1800	1.46%	1.13%	0.95%
900	10.01%	1.03%	0.96%

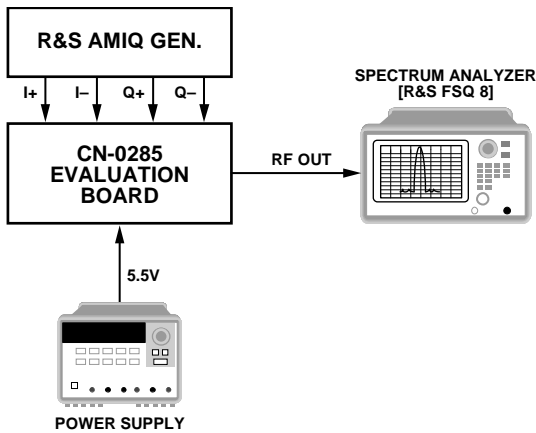


Figure 6. EVM Measurement Setup (Simplified Diagram)

In addition to the improvement in sideband suppression and EVM, there is also a performance benefit to driving the ADL5375 LO inputs differentially. This benefit improves modulator output IP2 performance by 2 dB to 5 dB, compared with single-ended LO drive. Note that most external VCOs only come with a single-ended output, so using the differential outputs on the ADF4351 provides a benefit over an external VCO in this case.

Figure 7 shows sideband suppression results using an 850 MHz to 2450 MHz filter (Filter Type B).

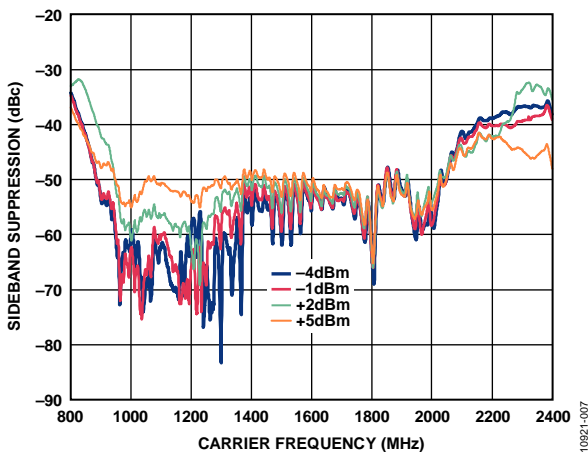


Figure 7. Sideband Suppression Results for 850 MHz to 2450 MHz Filter Type B

A complete design support package for this circuit note can be found at <http://www.analog.com/CN0285-DesignSupport>.

COMMON VARIATIONS

It is possible to use the auxiliary outputs on the ADF4351 to switch between two filter types where wideband operation beyond that possible with one single filter is required (see Figure 8). An RF double-pole, 4-throw switch (DP4T) is used to select the differential outputs of either Filter 1 or Filter 2.

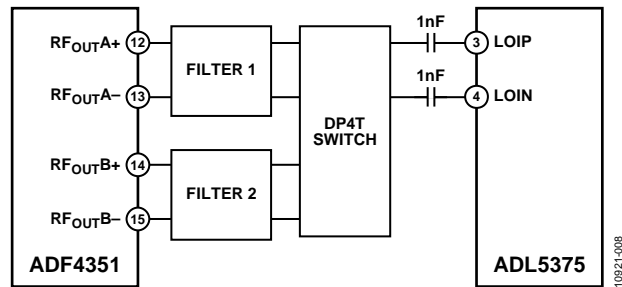


Figure 8. Application Diagram Showing Possibility of Filter Switching Using the ADF4351 Main and Auxiliary Outputs

CIRCUIT EVALUATION AND TEST

The EVAL-CN0285-EB1Z evaluation board contains the circuit described in CN-0285, allowing for the quick setup and evaluation of the performance of the circuit. The control software for the EVAL-CN0285-EB1Z uses the standard ADF4351 programming software located on the CD that accompanies the evaluation board.

Equipment Needed

The following equipment is needed:

- A standard PC running Windows® XP, Windows Vista (32-bit), or Windows 7 with a USB port
- The EVAL-CN0285-EB1Z circuit evaluation board
- The ADF435x programming software
- 5.5 V power supplies
- An I-Q signal source, such as the Rohde & Schwarz AMIQ
- A spectrum analyzer, such as the Rohde & Schwarz FSQ8

For additional details, see the UG-521 User Guide, the ADF4351 data sheet, and the ADL5375 data sheet.

Getting Started

See the [UG-521 User Guide](#) for software installation and test setup. The user guide also includes the block diagram, the application schematic, the bill of materials, and the layout and assembly information. In addition, see the [ADF4351](#) data sheet and the [ADL5375](#) data sheet for additional details.

Functional Block Diagram

See Figure 1 and Figure 6 in this document, and also see the [UG-521 User Guide](#).

Setup and Test

After setting up the equipment, use standard RF test methods to measure the sideband suppression of the circuit.

LEARN MORE

CN0285 Design Support Package:

<http://www.analog.com/CN0285-DesignSupport>

[ADIsimPLL Design Tool](#)

[ADIsimPower Design Tool](#)

[ADIsimRF Design Tool](#)

AN-0996 Application Note. *The Advantages of Using a Quadrature Digital Upconverter (QDUC) in Point-to-Point Microwave Transmit Systems*. Analog Devices.

AN-1039 Application Note. *Correcting Imperfections in IQ Modulators to Improve RF Signal Fidelity*. Analog Devices.

Data Sheets and Evaluation Boards

[ADF4351 Data Sheet](#)

[ADF4351 Evaluation Board](#)

[ADL5375 Data Sheet](#)

[ADL5375 Evaluation Board](#)

[ADP150 Data Sheet](#)

[ADP3334 Data Sheet](#)

REVISION HISTORY

2/13—Revision 0: Initial Version

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