Evaluation Board Documentation

TRF1500 Integrated Dual-Band RF Receiver User’s Guide

APPLICATION BRIEF: SWRA004A

Wireless Communications Business Unit

Digital Signal Processing Solutions
July 98

TEXAS INSTRUMENTS

IMPORTANT NOTICE

Texas Instruments (TI) reserves the right to make changes to its products or to discontinue any semiconductor product or service without notice, and advises its customers to obtain the latest version of relevant information to verify, before placing orders, that the information being relied on is current.

TI warrants performance of its semiconductor products and related software to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are utilized to the extent TI deems necessary to support this warranty. Specific testing of all parameters of each device is not necessarily performed, except those mandated by government requirements.

Certain application using semiconductor products may involve potential risks of death, personal injury, or severe property or environmental damage ("Critical Applications").

TI SEMICONDUCTOR PRODUCTS ARE NOT DESIGNED, INTENDED, AUTHORIZED, OR WARRANTED TO BE SUITABLE FOR USE IN LIFE-SUPPORT APPLICATIONS, DEVICES OR SYSTEMS OR OTHER CRITICAL APPLICATIONS.

Inclusion of TI products in such applications is understood to be fully at the risk of the customer. Use of TI products in such applications requires the written approval of an appropriate TI officer. Questions concerning potential risk applications should be directed to TI through a local SC sales office.

In order to minimize risks associated with the customer's applications, adequate design and operating safeguards should be provided by the customer to minimize inherent or procedural hazards.

TI assumes no liability for applications assistance, customer product design, software performance, or infringement of patents or services described herein. Nor does TI warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right of TI covering or relating to any combination, machine, or process in which such semiconductor products or services might be or are used.

TRADEMARKS

CONTACT INFORMATION

PIC TELEPHONE	(972) 644-5580
PIC FAX	(972) 480-7800
HP SUPPORT LINE	(972) 480-7872
PIC email	sc-infomaster@ti.com

Contents

Contents

Figures

Tables

TRF1500 Integrated Dual-Band RF Receiver User's Guide

Abstract

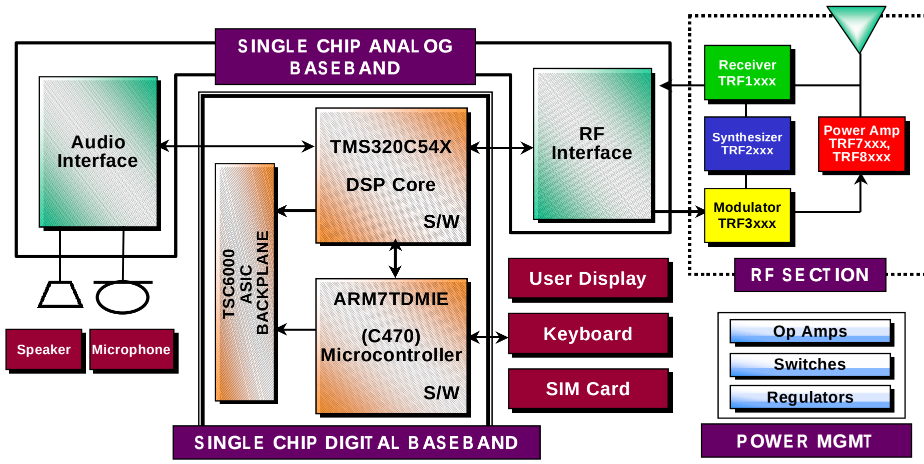
The dual-band handset market is expanding very rapidly due to the increase in customers requiring roaming capability. The customer also demands that handsets have an increase in features while keeping the size compact. These dual-band handset requirements put pressure on the integrated circuit manufacturer to be innovative while keeping costs low.

To meet this demand, Texas Instruments (TI) has developed the TRF1500 receiver. The TRF1500 is a fully-integrated dual-band receiver in a single package. The selection of the external components and the layout of the system board required to complete a transceiver design are critical to achieve maximum performance.

This application report discusses the implementation and impedance matching of each section of the TRF1500 to keep the required board area to a minimum and minimizing external components while maximizing performance. It also discusses parameter measurement techniques.

Product Support

The TI Advantage Extends Beyond RF to Every Other Major Wireless System Block



Digital Baseband

TI's single-chip Digital Baseband Platform, combines two high-performance core processors – a digital signal processor tailored for digital wireless applications and a microcontroller designed specifically for low-power embedded systems. The customizable platform helps wireless digital telephone manufacturers lower component counts, save board space, reduce power consumption, introduce new features, save development costs and achieve faster time to market, at the same time giving them flexibility and performance to support any standard worldwide.

Analog Baseband

TI analog baseband components provide a Mixed-signal bridge between the real world of analog signals and digital signal processors, the key enabling technology of the digital wireless industry. Using a seamless architecture for wireless communications technology, TI matches its baseband interfaces, radio frequency ICs and power management ICs to digital signal processing engines to create complete DSP Solutions for digital wireless systems.

Power Management

TI provides power management solutions with integration levels designed to meet the needs of a range of wireless applications. From discrete LDOs and voltage supervisors to complete power supplies for the baseband section, TI power management solutions play an important role in increasing wireless battery life, time-to-market and system functionality.

For more information visit the Wireless Communications web site at www.ti.com/sc/docs/wireless/home.htm.

Related Documentation

The following list specifies product names, part numbers, and literature numbers of corresponding TI documentation.

- *Dual-Band/Dual-Mode PCS Receiver*, Literature number SLWS041A

World Wide Web

Our World Wide Web site at www.ti.com contains the most up to date product information, revisions, and additions. Users registering with TI&ME can build custom information pages and receive new product updates automatically via email.

Email

For technical issues or clarification on switching products, please send a detailed email to sc-infomaster@ti.com. Questions receive prompt attention and are usually answered within one business day.

Introduction

The TRF1500 is a dual-band/dual-mode Personal Communications System (PCS) receiver for cellular telephones operating dual mode (analog and digital) in the 800 MHz band and single mode (digital) in the 1900 MHz band. The TRF1500 consists of a low noise amplifier (LNA) and mixer for each band. For image rejection, the low-band receiver relies on an off-chip image rejection filter between the LNA and mixer while the high-band receiver uses an image rejection mixer. The device operates from a single 3.75 volt supply and is controlled by six digital CMOS control lines. The digital control offers a wide range of control states, including a sleep mode where the device typically draws less than 5µA.

Additionally, the local oscillator (LO) inputs have buffered outputs that can be used in either single-ended or differential mode for a phase-locked-loop (PLL) configuration. A state is also available that allows the low-band LO to serve as the high-band LO through a mode-selectable frequency doubler.

A wide-band mixer is also available for transmit loop architectures which are commonly used in advanced mobile phone systems, global systems for mobile communications and other digital systems.

The TRF1500 is available in a 48-pin plastic thin quad flatpack package and is characterized for operation from -40C to 85C operating free-air temperature.

Please refer to the data sheet for the TRF1500 (TI literature number SLWS041A) for detailed information on the device specifications and refer to the users guide for test instructions (TI literature number SWRA004A).

Design Considerations

The successful integration of a TRF1500 receiver device into a design is dependent upon the performance of the external components and the quality of the board design and layout.

External Components

Component tolerance and Q specifications (where applicable) should be observed during the selection of any external components. The TRF1500 data sheet, TI literature number SLWS041A, includes a Bill of Materials (BOM) detailing components with proven performance, that are used on the evaluation board. The location and orientation of components should also be taken into consideration for maximum performance and manufacturability. For example, the low-band image rejection is dependent on an external Surface Acoustic Wave (SAW) component. This filter is used to reject signal outside the band of the receiver and has been chosen to maximize the TRF1500 performance, while maintaining minimum size and cost.

Board Design and Impedance Matching

The quality of the board layout is also critical to the TRF1500 performance. Correct transmission line impedances must be maintained throughout the design to insure maximum performance. Correct transmission line impedances can be maintained by using proper line widths and board stack-up in relation to the dielectric constant of the board material.

Utilizing the correct external component to match the device impedance to board transmission line impedance is also very important.

For measurement simplicity, the evaluation board utilizes RF Balun transformers for impedance matching selected differential inputs and outputs to single-ended inputs and outputs. Please note that the Baluns are used only for evaluating the device on the evaluation board and do not have to be included in the end user’s application.

To minimize unwanted signal interference and coupling, digital lines should be routed around and away from the receiver. On a multi-layer board, running a separate plane for the digital lines is highly recommended. Power supply lines should be filtered and regulated as close as possible at the device terminal.

TRF 1500 Dual-Band Receiver

A block diagram of the TRF1500 dual-band receiver front end down converter is shown in Figure 1. Pin names and descriptions are provided in Table 1. The device operates from a single 3.75 volt supply and its operation is controlled by 6 digital CMOS control lines the TRF1500 operates in 18 different states. The control codes and the corresponding active circuits are given in Table 2.

Figure 1. TRF1500 Dual-Band Receiver Block Diagram

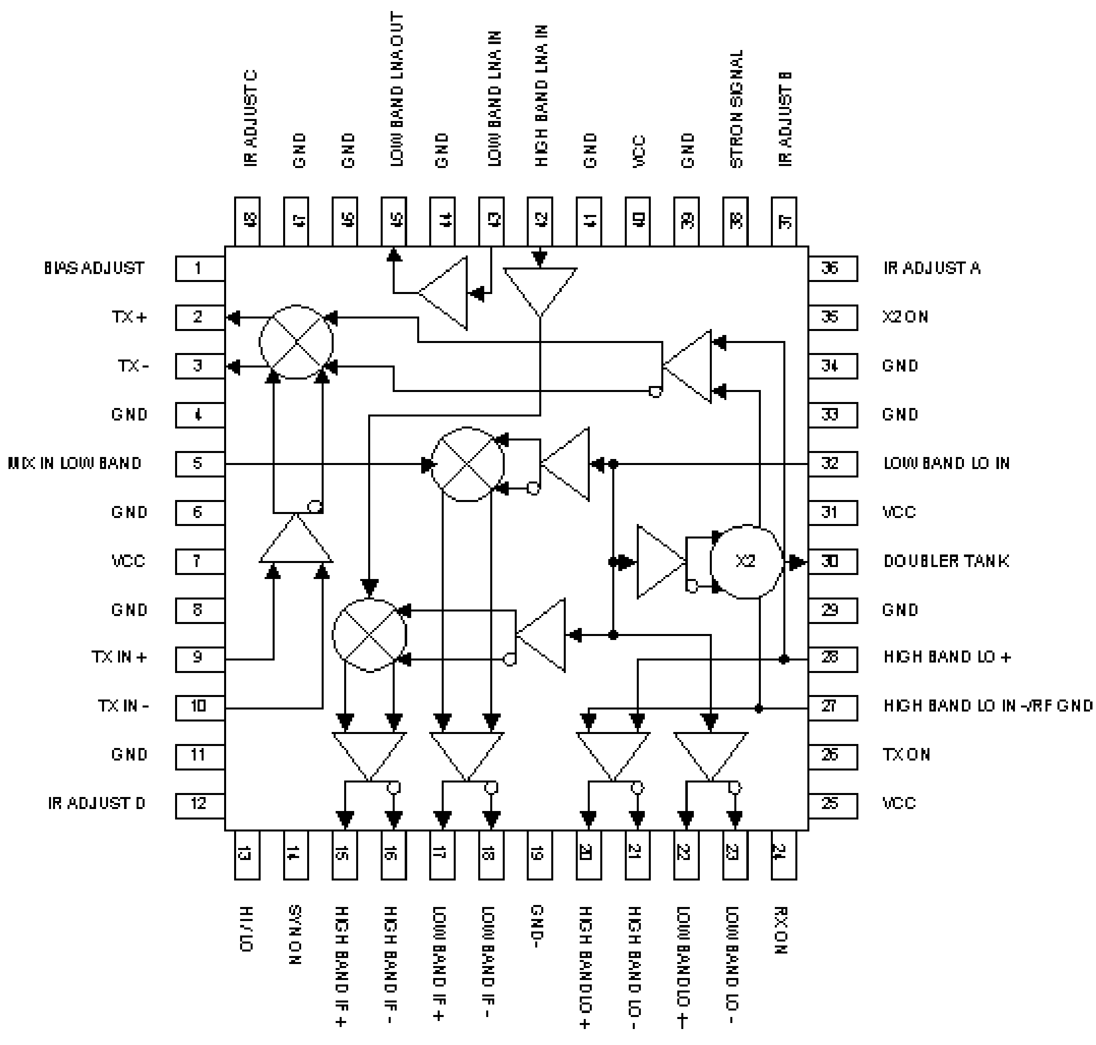


Table 1. Pin Descriptions

Pin Number	Name	Description
1	Bias Adjust	Bias adjust
2	TX IF +	Transmit IF, noninverting output
3	TX IF -	Transmit IF, inverting output
4	GND	ground
5	MIX IN LOW BAND	Low band mixer input
6	GND	ground
7	VCC	Vcc
8	GND	Ground
9	TX +	Transmit, noninverting input
10	TX -	Transmit, inverting input
11	GND	Ground
12	IR ADJUST D	Image rejection adjustment
13	HI/LO	High band/low band select
14	SYN ON	VCO power control
15	HIGH BAND IF +	High band IF noninverting output
16	HIGH BAND IF -	High band IF, inverting output
17	LOW BAND IF +	Low band IF noninverting output
18	LOW BAND IF -	Low band IF, inverting output
19	GND	ground
20	HIGH BAND LO +	High band noninverting LO output
21	HIGH BAND LO -	High band, inverting LO output
22	LOW BAND LO +	Low band noninverting LO output
23	LOW BAND LO -	Low band, inverting LO output
24	RX ON	Low noise amplifier/mixer power control
25	VCC	Vcc
26	TX ON	Transmit mixer/driver power control
27	HIGH BAND LO IN -/RF GND	High band LO inverting input/RF GND
28	HIGH BAND LO IN +	High band LO noninverting input
29	GND	ground
30	DOUDLER TANK	Doubler output
31	VCC	VCC
32	LOW BAND LO IN	Low band LO input
33	GND	ground
34	GND	ground
35	X2 ON	Doubler power control
36	IR ADJUST A	Image rejection adjustment
37	IR ADJUST B	Image rejection adjustment

38	STRONG SIGNAL	Strong signal indication
39	GND	ground
40	VCC	VCC
41	GND	ground
42	LNA IN HIGH BAND	High band LNA input
43	LNA IN LOW BAND	Low band LNA input
44	GND	ground
45	LNA OUT LOW BAND	Low band LNA output
46	GND	ground
47	GND	ground
48	IR ADJUST C	Image rejection adjustment

TRF1500 Control State

The TRF1500 operates in 18 different states: The control code and active circuits are given in Table 2.

Table 2. Control State and the Corresponding Active Circuits

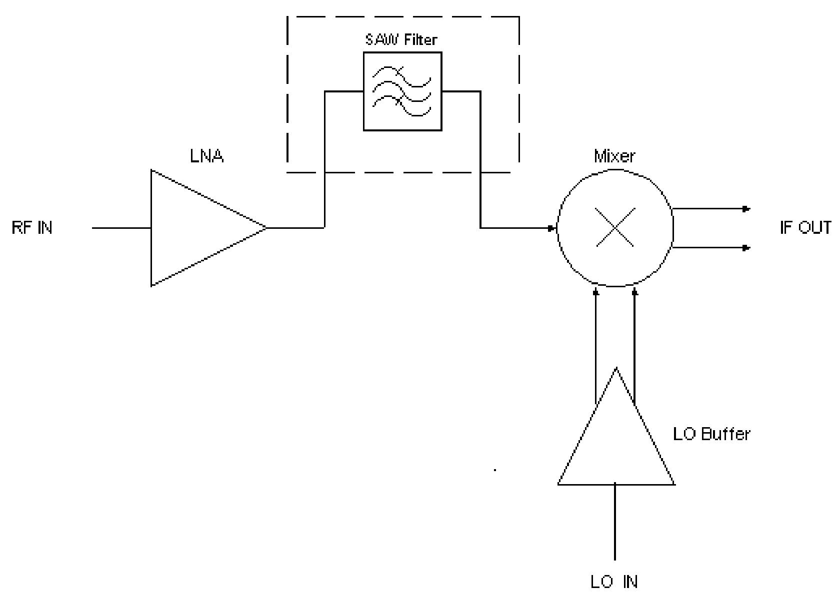
Control Code **(HI/LO, SYN ON, RX ON, TX ON, STRONG SIGNAL, X2)**		**Active Circuits**
000000	Sleep Mode	
010000	Low-Band LO Input Buffer On	LB LO Buffer
011000	Low-Band Receive Normal	LB LO Buffer, LB LNA, LB Mixer
011010	Low-Band Receive Strong Signal	LB LO Buffer, LB Mixer
010100	Low-Band Transmit Mixer	LB LO Buffer, LB TX Mixer
011100	Low-Band Receive and Transmit Mixer	LB LO Buffer, LB LNA (On High), LB Mixer, LB TX Mixer
011110	Low-Band Transmit Mixer	LB LO Buffer, LB LNA (On High), LB Mixer
010001	Doubler On	LB LO Buffer, Frequency Doubler, HB LO Buffer
011001	Low-Band Receive Normal, Doubler On	LB LO Buffer, LB LNA, LB Mixer, Frequency Doubler
011011	Low-Band Receive Strong Signal, Doubler On	LB LO Buffer, LB Mixer, Frequency Doubler
011111	Low-Band Transmit, Doubler On	LB LO Buffer, LB LNA (On High), LB Mixer, LB TX Mixer
111011	High-Band Receive Strong Signal, Doubler On	HB LO Buffer, HB Mixer, Frequency Doubler
110000	High-Band LO Input Buffer On	HB LO Buffer
111000	High-Band Receive Normal	HB LO Buffer, HB LNA, HB Mixer
111010	High-Band Receive Strong Signal	HB LO Buffer, HB Mixer
111001	High-Band Receive Frequency, Doubler On	LB LO Buffer, HB LO Buffer, HB LNA, HB Mixer, Frequency Doubler
110100	High-Band Transmit Normal	HB LO Buffer, HB TX Mixer
110101	High-Band Transmit Frequency, Doubler On	HB LO Buffer, HB TX Mixer, Frequency Doubler, LB LO Buffer

Low Band Cascaded Receiver Section: LNA, External SAW Filter, Mixer, and LO Buffer Amplifier

The TRF1500 low-band receiver section, shown in Figure 2, is an integrated front-end down converter designed to operate in the 800 MHz frequency range. The low-band down converter consists of an LNA, mixer, LO buffer amplifier and an off-chip image reject filter. The digital control allows the low-band to operate in three different states to compensate for the environment in which the TRF1500 is operating. The device can be operated in the normal state, where the LNA, mixer and buffer amplifier are on, the strong signal state, where the LNA is off and the mixer and buffer amplifier are on, or the transmit state, where the LNA bias current is increased to prevent compression when the transmitter is on.

The low-band receiver has low typical current consumption of 21mA at 3.75V supply. The cascaded gain is typically 26dB while providing good dynamic range with approximately a -10dBm third order input intercept point (IIP3). The low-band receiver has a typical system noise figure of approximately 2.5 dB for excellent sensitivity.

Figure 2. Cascaded Block Diagram of the Low-Band Receiver Section



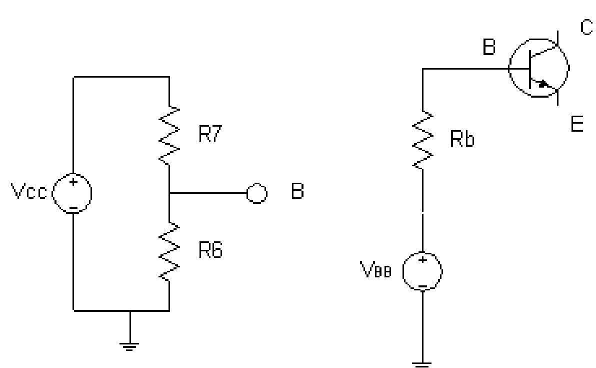
Low-Band LNA

In a typical down-conversion receiver, the LNA is usually placed directly after the antenna and a band-select filter. The purpose of the LNA is to amplify the desired signal being received while adding as little undesired noise and distortion as possible. The TRF1500 LNA is a common emitter amplifier, designed to operate on a single 3.75 volt supply. The LNA has two selectable gain states, normal state or strong signal state, which are controlled with the digital CMOS control lines. The strong signal state, which disables the LNA, is provided for operation in a high signal environment such as near the base station. Operating near the base station in the normal state could cause an increase in the intermodulation product levels and thus cause undesired noise and distortion in the receiver. Stand-alone LNA performance can be ascertained by reconfiguring the evaluation board as noted on the datasheet.

Low-Band LNA Turn on Time

The turn on time can be adjusted by changing the values of C10, R6 and R7, as shown in Figure 3 and Figure 4. The resistors form a voltage-divider network across the supply, Vcc. The function of this network is to provide a bias condition near the ideal operating region at the base of the common emitter amplifier. By providing this bias condition, the charge time of the series capacitor, C10, can be adjusted. Changing the value of resistors should not affect gain, IIP3 or noise figure (NF) performance.

Figure 3. Voltage Divider at Low-Band LNA Input



$V_{BB} = (R6/R6+R7)Vcc$

$Rb = R6R7/R6+R7$

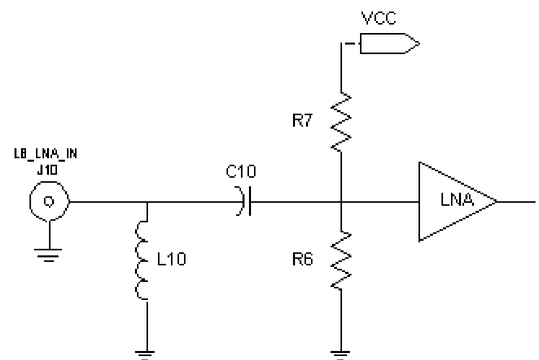
$R6 = Rb/(1-V_{BB}/Vcc)$

$R7 = Rb(Vcc/V_{BB})$

Low-Band LNA Input

Figure 4 details the low-band LNA input configuration. The LNA input impedance matching network primarily determines the cascaded gain, noise figure, and input return loss performance of the low-band receiver section. A simple high-pass shunt-L (L10) impedance matching network is used for optimum noise figure performance. The trade off for this optimization is a lower input return loss in the pass-band, but with sufficient attenuation in the stop-band. C10 has minimal effect on matching and is used mainly to optimize the turn-on time.

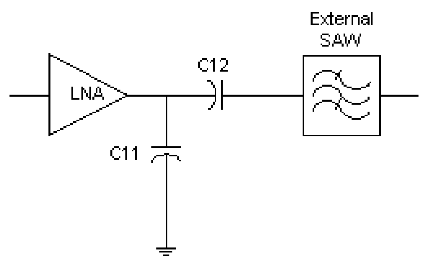
Figure 4. Low-Band LNA Input Configuration



Low-Band LNA Output

Figure 5 details the LNA output configuration. The LNA output impedance matching network has several functions. The matching network optimizes the third order input intercept point (IIP3) performance while also matching the LNA output impedance to the Surface Acoustic Wave (SAW) filter input impedance. A shunt-C (C11) is used to match the LNA output to the SAW filter input. Increasing the value of the shunt capacitor will improve the gain and noise figure performance but will degrade the third order input intercept point. The end user can adjust the LNA input and output matching network to optimize a particular parameter of interest.

Figure 5. Low-Band LNA Output Configuration



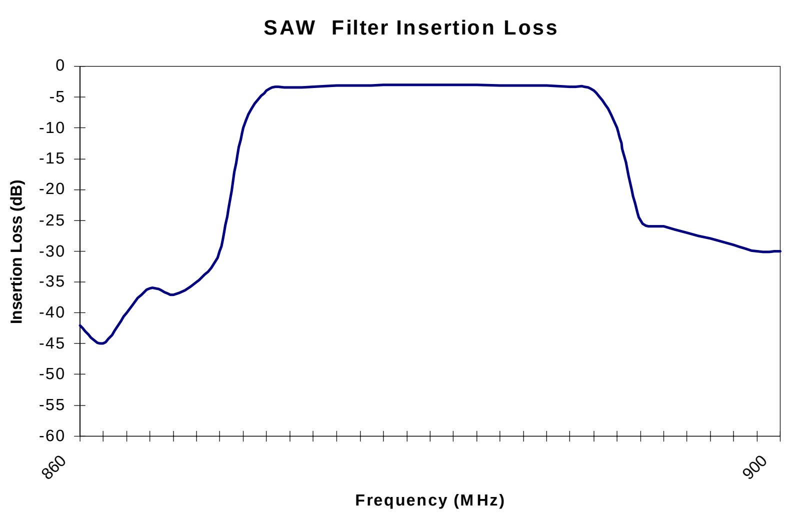
Surface Acoustic Wave (SAW) Filter

The SAW filter is used primarily as an image-reject filter (IRF). The image frequency (f_{IM}) is located at the desired channel frequency (f_{CH}) plus two times the IF frequency (f_{IF}); $f_{IM} = f_{CH} + (2 \times f_{IF})$. The image frequency acts as an interferer to the system. During the down-conversion process, the image and the desired channel are both converted to a common IF. Left unfiltered, the image could completely mask the desired signal. The IRF rejects this image before the RF signal is introduced to the mixer.

By minimizing the image before it reaches the mixer, the sensitivity of the receiver is enhanced. To further minimize potential interferers, a band-select filter is typically used at the front of the receiver, before the LNA. The band-select filter passes only those frequencies that fall within the system receive band. In many TDMA systems, the duplexor acts as the band-select filter.

The off-chip SAW image-reject filter used on the TRF1500 applications board has a 3dB nominal insertion loss and a 25 MHz bandwidth at a center frequency of 880 MHz as shown in Figure 6.

Figure 6. SAW Filter Insertion Loss



Low-Band Mixer

The purpose of the mixer in a down-conversion receiver is to translate incoming signals from one frequency to another. The low-band mixer in the TRF1500 is a three port high-side injected circuit. The mixer takes two known input signals, a radio frequency (RF) signal and a local oscillator (LO) signal and mixes them together to create a sum and difference intermediate frequency (IF). High-side injection means the LO is higher in frequency than the RF by the IF frequency. The output of the mixer is the IF and contains the difference and the sum of the RF and LO signals.

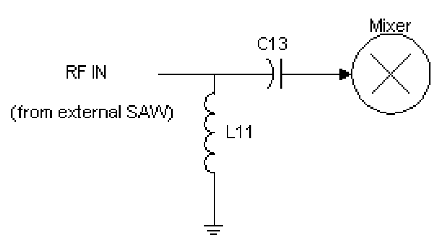
The difference of the RF and LO signals is the desired IF frequency in a down-conversion receiver. The undesired signal, the sum of the RF and LO frequencies, can be attenuated by using a low pass filter. The low-band mixer section of the TRF1500 is a Gilbert cell design with open collector outputs. The Gilbert cell structure was used for its robust isolation and harmonic suppression characteristics.

The TRF1500 mixer typically achieves a noise figure of 7.5 dB with an input third order intercept point of 3.5 dBm. Stand-alone mixer performance can be ascertained by reconfiguring the evaluation board as noted on the datasheet.

Low-Band Mixer RF Input

Figure 7 details the mixer RF input configuration. The signal from the LNA passes through the external image-reject SAW filter and back into the device’s low-band mixer input terminal (MIX_IN_LOW_BAND). Minimal mixer input impedance matching is required. A high-pass shunt-L (L11) and series-C (C13) network are used for impedance matching the SAW filter output to the mixer RF input. The shunt inductor presents a short at the IF frequency. This configuration minimizes the IF leakage and prevents unwanted interfering signals at, or near, the IF frequency from degrading the mixer’s noise figure performance.

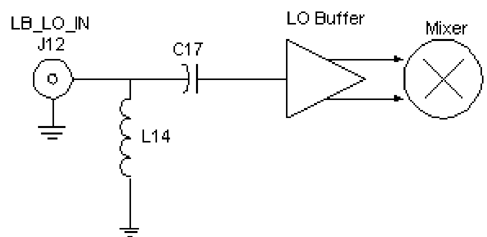
Figure 7. Low-Band Mixer RF Input Configuration



Low-Band Mixer LO Input

Figure 8 details the low-band mixer LO input configuration. The input power range level for the LO buffer amplifier is flexible enough (-3 dBm to -7 dBm) to drive the mixer without entering compression. The LO signal is injected through an internal LO buffer amplifier and into the mixer. A high pass shunt-L (L14) and series-C (C17) network is used for impedance matching. The inductor also shunts to ground any undesired noise that could be injected to the mixer.

Figure 8. Low-Band Mixer LO Input Configuration

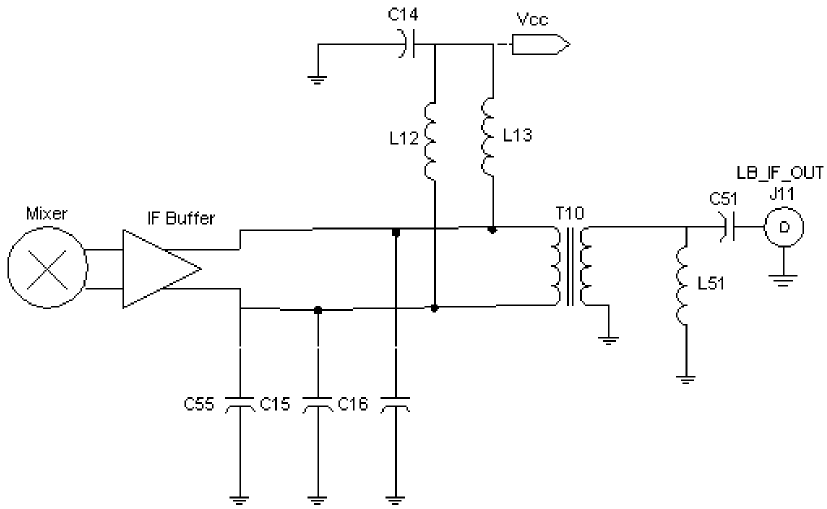


Low-Band IF Output

Figure 9 details the low-band IF output configuration. The low-band mixer has a differential IF output with a 1kΩ differential output impedance. For evaluation, a 16:1 transformer balun, with a insertion loss of 1.8 dB, is used to transform the 1kΩ differential output to a single-ended output which is then matched to 50Ω. In the actual application, the IF output is usually connected to a narrow band channel select filter with a differential input and the transformer balun is not required.

The supply voltage (VCC) is applied to the IF pins with pull up inductors (L12, L13). A low-pass filter network is provided prior to the balun. The filter also acts as part of the impedance matching network. During optimization of the output matching network, it was found that mismatching the differential output, accomplished with C55, gives the best IIP3 performance with minimum effect on the gain and noise figure performance. C55 also helps to decouple the digital CMOS control line from the LO signal. The IF response is shaped by the shunt-L (L51) after the transformer balun. L51 is also used to block unwanted noise that could be reflected back to the mixer. The series capacitor (C51) near the LB_IF_OUT port is used as a dc block for evaluation purposes and does not have to be implemented in the end-users system.

Figure 9. Low-Band IF Output Configuration



Low-Band LO Buffer Amplifier Output

Figure 10 details the low-band LO buffer amplifier configuration. The low-band LO buffer amplifier can be used in either single-ended or differential mode for a phase lock loop (PLL) configuration. The buffer is digitally controlled and requires a operating drive level ranging from -3 to -7 dBm. For evaluation purposes, a 1:1 transformer balun, with an insertion loss of 2.7 dB, is used to convert the differential output to a single-ended output. The series capacitors at the buffer output are used for dc blocking.

The transmission line on the output of the buffer amplifier are used to convert the 100Ω differential to 50Ω differential.

The transmission lines on the output of the buffer amplifier can be modeled as microstrip lines. The values used for the calculations depend on the PCB substrate, the board stackup and the required impedance. The physical dimensions of the microstrip lines can be calculated using standard microstrip transmission line equations using the following values:

Frequency = 990 MHz

ER = 4.400 (FR4), Height = 12.0000 mils , Thickness = 1.5000 mils (Copper)

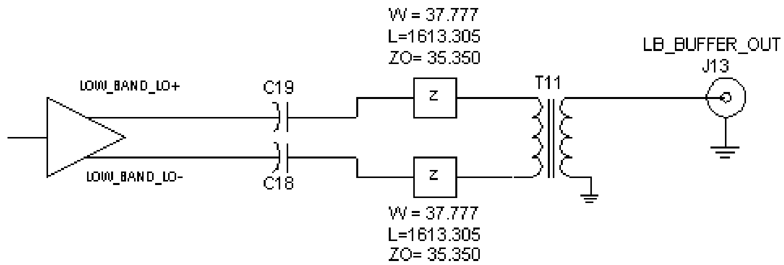
Electrical Parameters:

ZO = 35.350 Ohms, E_EFF = 90.000

Physical Parameters:

Width = 37.777 mils , Length = 1613.305 mils

Figure 10. Low-Band Buffer Amplifier Output Configuration



Low-Band Cascaded Test Guide

This section involves measuring the cascaded performance of the Low Band LNA, Low Band MIXER and Low Band IF Amp. An external SAW filter is utilized to complete the RF receiver section. All tests apply for an IF output terminated into a 1 kΩ differential load. To match the differential IF output to the 50 Ω test equipment a transformer balun is used. All unused ports are terminated into 50 Ω.

Table 3. LB LNA, LB Mixer, SAW Filter, and LB IF Amp Parameters

PARAMETERS	Min	Typ	Max	UNIT
RF Frequency Range	869	881.5	894	MHz
LO Frequency Range	979.52	992.02	1004.52	MHz
IF Frequency		110.52		MHz
RF Input Power		-30		dBm
LO Input Power		-5		dBm
Power Conversion Gain		26.0		dB
Power Conversion Gain Reduction		19.0		dB
Noise Figure		2.5		dB
RF Input Return Loss		5.6		dB
LO Input Return Loss		16.5		dB
LO Buffer Output Power		-10.3		dBm
Power Leakage LO In to RF In		-53.0		dBm
Third Order Input Intercept Point (IIP3)		-9.7		dBm
1dB RF Input Compression Point		-21.0		dBm
1dB Blocking Point		-18.0		dBm

LOW-Band Cascaded: Power Conversion Gain

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

The low band power conversion gain (dB) is the measured power (dBm) at the IF frequency minus the RF source power (dBm). It is measured using a RF source and a spectrum analyzer.

1) Set the RF source power (RF P_{in}) and the desired frequency (see Table 3). Connect the RF source to the EVM RF port, J10.

2) Set the LO source power (LO P_{in}) and the desired frequency (see Table 3). Connect the LO source to the EVM LO input port, J12.

3) Set the spectrum analyzer to measure at the IF frequency (see Table 3).

4) Connect the EVM IF output port, J11, to the spectrum analyzer.

5) Measure the IF output power (IF P_{out}) at the IF frequency with the spectrum analyzer.

6) Calculate the Cascaded Gain as:

   Gain = (IF P_{out} - RF P_{in}) + Transformer Loss. The transformer loss is 1.8dB.

   Example: (-5dBm - (-30dBm)) + 1.8dB = 26.8dB.

The turn on time can be adjusted by changing the values of C10, R6 and R7, as shown in Figure 21 and Figure 22. The resistors form a voltage-divider network across the supply, Vcc. The function of this network is to provide a bias condition near the ideal operating region at the base of the common emitter amplifier. By providing this bias condition, the charge time of the series capacitor, C10, can be adjusted. Changing the value of resistors should not affect gain, IIP3 or noise figure (NF) performance.

Low-Band Cascaded: Power Conversion Gain Reduction

Control state: 011010

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

The Power conversion gain reduction is the delta between the cascaded IF Pout and the strong signal IF Pout when the strong signal is enabled. Enabling the strong signal turns off the LNA. It is measured using a RF source and a spectrum analyzer.

1) Set the RF source power (RF P_{in}) and the desired frequency (see Table 3). Connect the RF source to the EVM RF input port, J10.

2) Set the LO source power (LO P_{in}) and the desired frequency (see Table 3). Connect the LO source to the EVM LO input port, J12.

3) Set the spectrum analyzer to measure at the IF frequency (see Table 3).

4) Connect the EVM IF output port, J11, to the spectrum analyzer.

5) Measure the output power at the IF frequency (IF P_{out}) with the spectrum analyzer.

6) Enable the strong signal. Measure the output power at the IF frequency (SS IF P_{out}) with the spectrum analyzer.

7) Calculate Power conversion gain reduction as:

   Power Conversion Gain Reduction = (IF P_{out} - SS IF P_{out}).

Low-Band Cascaded: Noise Figure

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 22

The cascaded Noise Figure (NF) is measured at the EVM Low Band IF output port, J11. The measurement is performed using an HP8970B Noise Figure Meter. The IF output of the mixer is converted from differential to single ended using a transformer balun. The noise figure meter requires a special setup and calibration since the RF source and receive frequencies are different.

Set up the noise figure meter as follows:

1) Special Function 1.4 sets the noise figure meter to measure variable IF and fixed LO frequencies.

2) The IF start, stop, and step size frequencies are set to 100MHz, 120MHz, and 5MHz respectively.

3) Set the smoothing to 16 or above.

4) Ensure that the Excess Noise Ratio (ENR) Table on the Noise Source head in use is entered on the NF meter.

   a) On the front panel, press the ENR button.

   b) Check the ENR value by pressing the Enter button or enter the ENR value for each frequency.

   c) After entering the ENR for the desired frequency, press the Frequency button on the front panel to exit.

5) To calibrate the NF Meter:

   a) Connect the Noise Source directly to the NF meter; press the calibration twice

b) Next, press the Noise Figure and Gain Button. The corrected LED just above the button should be lit.

c) Calibration is complete. Enter the desired IF frequency to measure.

Next, the external equipment Loss is considered (RF cable, Transmission line, filter and circulator).

6) The losses are entered in the Noise Figure Meter by using special function 34.x.

   a) Special Function 34.1 turns on the loss compensation factor.

   b) Special Function 34.2 is used to enter the loss before the DUT.

   c) Special Function 34.3 is used to enter the room temperature in Kelvin (300°K).

   d) Special Function 34.4 is used to enter the loss after the DUT.

   e) Special Function 34.0 is used to turn off the loss compensation factor.

The noise figure is measured as follows:

7) Connect the noise source directly to the EVM RF input port, J10.

   a) A circulator between the noise source and RF input port may help minimize any mismatches between the EVM board and test equipment.

8) Connect the LO source to the EVM LO input port, J12.

   a) Set the LO source at the nominal power and frequency (See Table 3).

   b) Each LO frequency being tested is entered in the Noise figure meter by using Special function 3.1. If the source has excessive broad band noise, a filter at the LO port, J12, may be necessary to eliminate the broad band noise during testing.

9) Connect the EVM IF output port, J11, to the noise figure meter input port.

   a) A bandpass or low pass filter may be necessary on the IF port to eliminate the LO signal interference and get an accurate noise measurement.

10) Measure the Noise Figure.

Low-Band Cascaded: RF Input Return Loss

Control state: 011000

The input return loss of the low band receiver is measured at the EVM low band RF input port, J10. The measurement is performed using a network analyzer.

Set up the network analyzer as follows to measure the RF input return loss:

1) Set the network analyzer to measure the low band RF frequency (see Table 3).
2) Set the power range to -35 dBm through -20 dBm, and then set the input power to -30 dBm.
3) Perform a full one-port calibration on port 1 of the network analyzer.
4) Set the network analyzer to measure S11.
5) Connect the EVM RF input, J10, to port 1 of the network analyzer.
6) Measure the RF input return loss.

Low-Band Cascaded: LO Input Return Loss

Control state: 011000

The cascaded LO input return loss of the Low Band is measured at the EVM low band LO input port, J12. The measurement is performed using a network analyzer.

1) Set the network analyzer to measure the low band LO frequency (see Table 3).
2) Set the power range to -35 dBm through -20 dBm, and then set the input power to -30 dBm.
3) Perform a full one-port calibration on port 1 of the network analyzer.
4) Set the network analyzer to measure S11.
5) Connect the EVM LO input port, J12, to port 1 of the network analyzer.
6) Measure the LO input return loss.

LOW BAND: LO Buffer Output Power

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

This section involves measuring the Low Band LO Buffer Output. All unused ports will be terminated into 50 Ω. The LO buffer output power is measured at the EVM low band LO output port J13. A transformer balun is used to convert the differential output to a single ended output. The measurement is performed using a RF source and a spectrum analyzer.

1) Set the LO source frequency and input power (see Table 3). Connect the LO source to the EVM LO input port, J12.
2) Set the spectrum analyzer to measure at the LO frequency (see Table 3).
3) Connect the EVM LO buffer port, J13, to the spectrum analyzer.
4) Measure the LO buffer output power.

Low-Band: Power Leakage LO In to RF In

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 23

The LO leakage at the RF port is measured at the low band RF input port J10. Power leakage is a measure of power in dBm that couples to the RF port. The measurement is performed using a RF source and a spectrum analyzer.

1) Set the LO source frequency and input power (see Table 3). Connect the LO source to the EVM LO input port, J12.
2) Set the spectrum analyzer to measure at the LO frequency (see Table 3).
3) Connect the RF Port, J10, to the spectrum analyzer.
4) Measure the LO leakage power.

Low-Band Cascaded: Third Order Input Intercept Point (IIP3)

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 21:

The third order input intercept point is the level of the RF input power at which the output power levels of the undesired intermodulation products and the desired IF products are equal. The measurement is performed using three RF sources and a spectrum analyzer.

1) Set the first RF source input power (RF P_{in}) and frequency (F_1) (see Table 3).

2) Set the second RF source frequency to the first RF frequency plus 60kHz; F_2.

3) Using a RF combiner, connect the RF sources to the EVM RF input port, J10.

4) Set the LO source frequency and input power (see Table 3). Connect the LO source to the EVM LO input port, J12.

5) Set the spectrum analyzer to measure at the IF frequency (F_{IF}) (see Table 3).

6) Connect the EVM IF output port, J11 to the spectrum analyzer.

7) Measure the Fundamental output power at the IF frequency (F_{Fund}).

8) Measure the Intermodulation products ($2F_2 - F_1$ or $2F_1 - F_2$) at $F_{IF} \pm 60$ kHz

9) Calculate the Intermodulation Suppression as:

   Intermodulation Suppression = F_{Fund} - Intermodulation product

10) Calculate the Input Third -Order Intercept Point as:

   Input Third-Order Intercept = ((Intermodulation Suppression/2) + (RF P_{in}))

Low-Band Cascaded: 1dB RF Input Compression Point

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

The 1 dB input compression point is the RF input power at which the gain compresses 1 dB. Gain compression is when an increase in P_{in} causes no further increase in the output power (P_{out}). The measurement is performed using two RF sources and a spectrum analyzer.

1) Set the RF source frequency (see Table 3) and the input power (P_{in}) to -35 dBm. Connect the RF source to the EVM RF input port, J10.
2) Set the LO source frequency and input power (see Table 3). Connect the LO source to the EVM LO input port, J12.
3) Set the spectrum analyzer to measure the output power at the IF frequency.
4) Connect the EVM IF output port, J11, to the spectrum analyzer.
5) Measure the output power (P_{out}) at the IF frequency
6) Calculate Gain as:

   $$Gain = P_{out} - P_{in}$$

7) To determine the 1 dB compression point, the RF P_{in} is increased in steps of 1 dBm until the gain compresses by 1 dB. Repeat step 4 and 5 until the gain compresses by 1dB.

RF P_{in}	P_{out}	Gain
-35	-10	25
-34	-9	25
-33	-8	25
-32	-7	25
-31	-6	25
-30	-5	25
-29	-4	25
-28	-3	25
-27	-2	25
-26	-1.2	24.8
-25	-0.4	24.6

-24	0.4	24.4	
-23	1.2	24.2	
-22	2.2	24.2	
-21	3.0	24.0	←1dB Compression Point
-20	3.0	23.0	

Low-Band Cascaded: 1dB Blocking Point

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 21

The 1dB Blocking Point is a measurement of the power (dBm) of the interfering signal, measured at the EVM IF output port J11. The measurement is performed using three sources and a spectrum analyzer.

1) Set the RF source frequency and input power (see Table 3).
2) Set the RF Blocking source frequency to the RF frequency minus 45 MHz at -30dBm input power.
3) Using a RF combiner, connect the RF sources to the EVM RF port, J10.
4) Set the LO source frequency and input power (see Table 3). Connect the LO source to the EVM LO input port, J12.
5) Set the spectrum analyzer to measure the output power at the IF frequency.
6) Connect the EVM IF port, J11, to the spectrum analyzer.
7) To determine the 1dB Blocking Point, increase the RF Blocking source input power until the output power at the IF frequency is decreased by 1dB.
8) Disconnect the Blocking source.
9) Connect the Blocking source directly to the spectrum analyzer, and change the spectrum analyzer's frequency to the frequency of the Blocking source.
10) Measure the power of the Blocking source.

High-Band Cascaded Receiver Section: LNA, Mixer, LO Buffer Amplifier

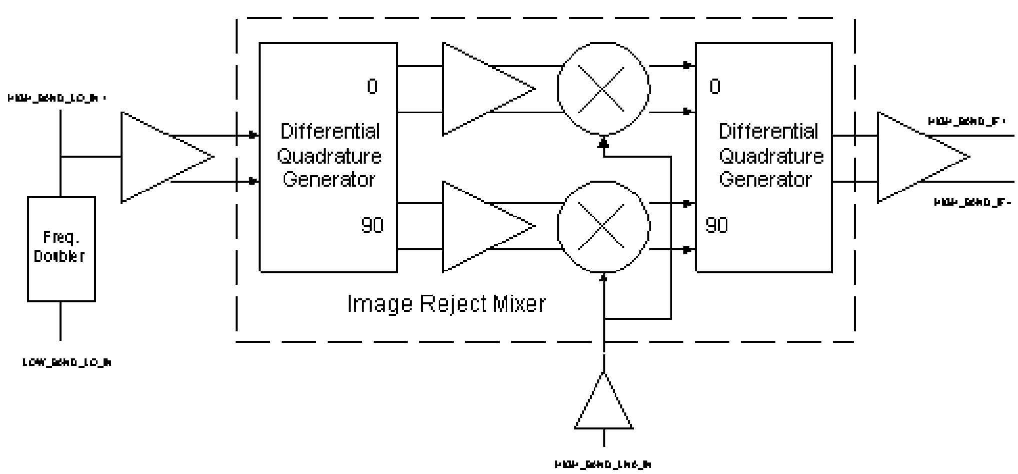
Cascaded High-Band Receiver Section: LNA, Mixer, and LO Amplifier

The TRF1500 high-band receiver section, shown in Figure 11, is an integrated front-end down converter designed to operate in the 1900 MHz frequency range. The high-band down converter consists of an LNA, an image-reject mixer, and LO buffer amplifier circuitry. Figure 11 details the cascaded block diagram with the image reject mixer detailed inside the dotted box.

The digital control allows the high-band receiver to operate in three different states to compensate for the environment in which the TRF1500 is operating. The high-band receiver can be operated in the normal state, where the LNA, mixer and buffer amplifier are on, the strong signal state, where the LNA is off and the mixer and buffer amplifier are on, or the transmit state, where the LNA bias current is increased to prevent compression when the transmitter is on.

The high-band receiver has a typical nominal gain of 26 dB, an IIP3 of -17.7 dBm and a noise figure of 4.66 dB when the receiver LO doubler is used and 4.35 dB when the high-band LO is directly driven.

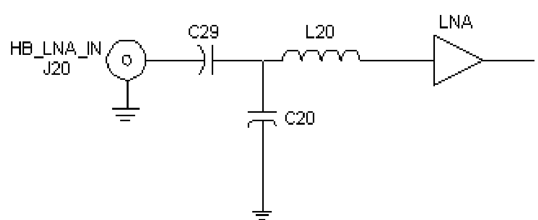
Figure 11. Block Diagram of the High-Band Receiver Section



High-Band RF Input

Figure 12 details the high-band RF input configuration. The cascaded noise figure and input return loss performance of the high-band receiver section is determined primarily by the input matching network. The input matching network is designed for optimum noise figure performance, while maintaining good input return loss. A low-pass shunt-C (C20) series-L (L20) network is used for the input impedance matching. The series capacitor (C29) on the input port is used for dc blocking purposes. The end-user can optimize the input matching network for better input return loss but obtaining a better input match may degrade the overall cascaded noise figure performance.

Figure 12. High-Band RF Input Configuration



High-Band LO Input

The high-band LO signal is fed through a buffer amplifier into a differential quadrature generator, which is realized using a polyphase network. The signals generated by the polyphase network are used to drive two mixers which are injected with a common RF signal. The IF signals out of these mixers will have a 180° phase shift of the image frequency as compared to the wanted RF frequency. As a result of this 180° phase shift, the IF signals at the image frequency will cancel in the quadrature combiner. The IF signal at the desired frequency will add in the quadrature combiner.

The TRF1500 offers several methods for providing high-band LO drive. The high-band LO terminal may be directly driven either single-ended or differentially. Alternately, the high-band LO terminal may be driven by using the low-band LO output and the integrated frequency doubler.

Figure 13 details the TRF1500 configured to utilize the low-band LO input and doubler as the high-band LO. The high-band LO signal is injected into the low-band LO input. The buffered signal is then routed through the doubler. The output of the doubler is routed through an external capacitor (C40) and into the single-ended high-band LO input.

Figure 14 details the TRF1500 configured to utilize the high-band LO. The signal is directly injected into the high-band LO input which directly drives the high-band down converter.

> **Note:** To use the high-band LO input, remove C40 and L40, and change the value of C41 to 1pF and populate C24.

Figure 13. High-Band LO Frequency Doubler Driven Configuration

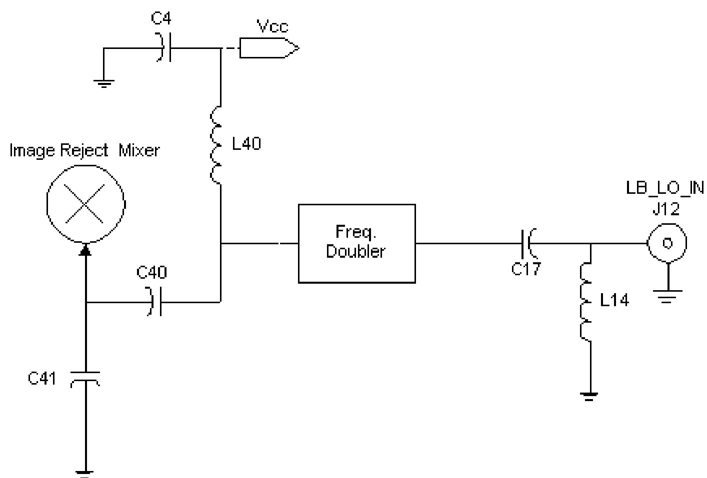
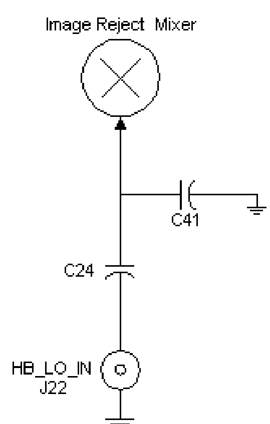


Figure 14. High-Band LO Directly Driven Configuration

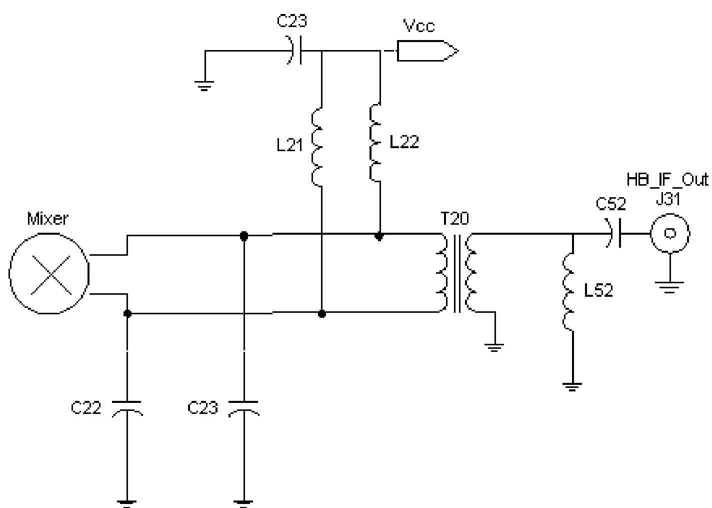


High-Band IF Output

Figure 15 details the high-band mixer IF output configuration. The high-band mixer has a differential IF output with a 1kΩ differential output impedance. For evaluation purposes, a 16:1 transformer balun, with an insertion loss of 1.8 dB, is used to transform the 1kΩ differential output to a single-ended output which is then matched to 50Ω. In the actual application, the IF output is usually connected to a narrow band channel select filter with a differential input and the transformer balun is not required.

The supply voltage (VCC) is applied to the IF terminals with pull-up inductors (L21, L22). A low-pass filter network is provided prior to the balun. The filter also acts as part of the impedance matching network. The IF response is shaped by the shunt-L (L52) after the transformer balun. L52 is also used to block unwanted noise that could be reflected back to the mixer. The series capacitor (C51) near the HB_IF_OUT port is used as a dc block for evaluation purposes and does not have to be implemented in the end-users system.

Figure 15. High-Band IF Output Configuration



High-Band LO Buffer Amplifier Output

Figure 16 details the high-band LO buffer amplifier configuration. The high-band LO buffer can be used in either single-ended or differential mode for a phase lock loop (PLL) configuration. The buffer is digitally controlled and requires an operating drive level ranging from -3 to -7dBm. For evaluation purposes, a 1:1 transformer balun, with an insertion loss of 2.7 dB, is used to convert the differential output to a single-ended output. The series capacitors at the buffer output are for dc blocking.

The transmission line on the output of the buffer amplifier are used to convert the 100Ω differential to 50Ω differential.

The transmission lines on the output of the buffer amplifier can be modeled as microstrip lines. The values used for the calculations depend on the PCB substrate, the board stackup and the required impedance. The physical dimensions of the microstip lines can be calculated with standard transmission line equations using the following values:

The following information are used to calculate the microstrip transmission lines:

Frequency = 2.070 GHz

ER = 4.400 (FR4), Height = 12.0000 mils, Thickness = 1.5000 mils (Copper)

Electrical Parameters:

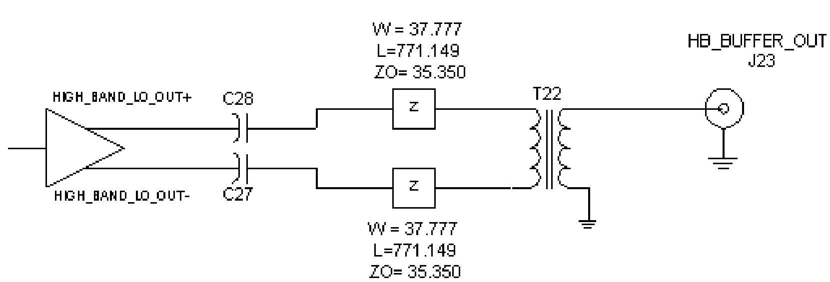
ZO = 35.350, E_EFF = 90.000

Results:

Physical Parameters:

Width = 37.777, Length = 771.149

Figure 16. High-Band LO Buffer Amplifier Output Configuration



High-Band Cascaded Test Guide

This section involves measuring the cascaded performance of the High Band LNA, High Band Mixer and High Band IF Amp using the Frequency Doubler. All tests apply for an IF output terminated into a 1 kΩ differential load. A transformer balun is used to match the IF output to the 50 Ω test equipment. All unused ports are terminated into 50 Ω.

Table 4. HB LNA, HB mixer, HB IF amp

PARAMETERS	Min	Typ	Max	UNIT
RF Input Frequency Range	1930	1960	1990	MHz
Direct Drive LO Frequency Range	2040.52	2070.52	2100.52	MHz
Doubler Drive LO Frequency Range	1020.26	1035.26	1050.26	MHz
IF Frequency		110.52		MHz
RF Input Power		-30		dBm
LO Input Power		-5		dBm
Power Conversion Gain		26.3		dB
Power Conversion Gain Reduction		43.5		dB
Image Rejection		22.5		dB
Noise Figure		4.66		dB
RF Input Return Loss		14.2		dB
LO Buffer Output Power		-14		dBm
Power Leakage LO In to RF In		-50		dBm
Third Order Input Intercept Point(IIP3)		-17.7		dBm
1dB RF Input Compression Point		-23.7		dBm
2X2 Spur Performance		69		dBc
3X3 Spur Performance		81		dBc

High-Band Cascaded: Power Conversion Gain

Control state: 111001

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

The high band power conversion gain (dB) is the measured power (dBm) at the IF frequency minus the RF source power (dBm). It is measured using a RF source and a spectrum analyzer.

1) Set the RF source power (RF P_{in}) and the desired frequency (see Table 4). Connect the RF source to the EVM RF port, J20.

2) Set the LO source power (LO P_{in}) and the desired frequency (see Table 4). Connect the LO source to the EVM LO input port, J12.

3) Set the spectrum analyzer to measure at the IF frequency (see Table 4).

4) Connect the EVM IF output port, J21, to the spectrum analyzer.

5) Measure the IF output power (IF P_{out}) at the IF frequency with the spectrum analyzer.

6) Calculate the Cascaded Gain as:

   Gain = (IF P_{out} - RF P_{in}) + Transformer Loss. The transformer loss is 1.8dB.

High-Band Cascaded: Power Conversion Gain Reduction

Control state: 111011

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

The Power conversion gain reduction is the delta between the cascaded IF Pout and the strong signal IF Pout when the strong signal is enabled. Enabling the strong signal turns off the LNA. It is measured using a RF source and a spectrum analyzer.

1) Set the RF source power (RF P_{in}) and the desired frequency (see Table 4). Connect the RF source to the EVM RF input port, J20.

2) Set the LO source power (LO P_{in}) and the desired frequency (see Table 4). Connect the LO source to the EVM LO input port, J12.

3) Set the spectrum analyzer to measure at the IF frequency (see Table 4).

4) Connect the EVM IF output port, J21, to the spectrum analyzer.

5) Measure the output power at the IF frequency (IF P_{out}) with the spectrum analyzer.

6) Enable the strong signal. Measure the output power at the IF frequency (SS IF P_{out}) with the spectrum analyzer.

7) Calculate Power conversion gain reduction as:

   Power Conversion Gain Reduction = (IF P_{out} - SS IF P_{out}).

High-Band Cascaded: Image Rejection

Control state: 111001

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

Image Rejection is a signal that appears at twice the IF distance from the desired RF signal, located on the opposite side of the LO frequency from the desired RF signal. The measurement is performed using two RF sources and a spectrum analyzer.

1) Set the RF source power (RF P_{in}) and the desired RF frequency (F_{RF}) (see Table 4). Connect the RF source to the EVM RF input port, J20.

2) Set the LO source power (LO P_{in}) and the desired LO frequency (F_{LO})(see Table 4). Connect the LO source to the EVM LO input port, J12.

3) Set the spectrum analyzer to measure at the IF frequency (F_{IF})(see Table 4).

4) Connect the EVM IF output port, J21, to the spectrum analyzer.

5) Measure the output power at the IF frequency (IF P_{out}) with the spectrum analyzer.

6) Set the RF Frequency to F_{RF} + 2 F_{IF}.

7) Measure the output power at the IF frequency (IF P_{out}) with the spectrum analyzer

8) Calculate the Image Rejection as

   Image Rejection = Δ between the IF output power at (F_{RF}) and the IF output power at F_{RF} + 2 F_{IF}

High-Band Cascaded: Noise Figure

Control state: 111001

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 22

The cascaded Noise Figure (NF) is measured at the EVM Low Band IF output port, J21. The measurement is performed using an HP8970B Noise Figure Meter. The IF output of the mixer is converted from differential to single ended using a transformer balun. The noise figure meter requires a special setup and calibration since the RF source and receive frequencies are different.

Set up the noise figure meter as follows:

1) Special Function 1.4 sets the noise figure meter to measure variable IF and fixed LO frequencies.

2) The IF start, stop, and step size frequencies are set to 100MHz, 120MHz, and 5MHz respectively.

3) Set the smoothing to 16 or above.

4) Ensure that the Excess Noise Ratio (ENR) Table on the Noise Source head in use is entered on the NF meter.

    a) On the front panel, press the ENR button.

    b) Check the ENR value by pressing the Enter button or enter the ENR value for each frequency.

    c) After entering the ENR for the desired frequency, press the Frequency button on the front panel to exit.

5) To calibrate the NF Meter:

    a) Connect the Noise Source directly to the NF meter; press the calibration button twice.

    b) Next, press the Noise Figure and Gain Button. The corrected LED just above the button should be lit.

    c) Calibration is complete. Enter the desired IF frequency to measure.

Next, the external equipment Loss is considered (RF cable, Transmission line, filter and circulator).

6) The losses are entered in the Noise Figure Meter by using special function 34.x.

a) Special Function 34.1 turns on the loss compensation factor.

b) Special Function 34.2 is used to enter the loss before the DUT.

c) Special Function 34.3 is used to enter the room temperature in Kelvin (300°K).

d) Special Function 34.4 is used to enter the loss after the DUT.

e) Special Function 34.0 is used to turn off the loss compensation factor.

The noise figure is measured as follows:

7) Connect the noise source directly to the EVM RF input port, J20.

   a) A circulator between the noise source and RF input port may help minimize any mismatches between the EVM board and test equipment.

8) Connect the LO source to the EVM LO input port, J12.

   a) Set the LO source at the nominal power and frequency (See Table 4).

   b) Each LO frequency being tested is entered in the Noise figure meter by using Special function 3.1. If the source has excessive broad band noise, a filter at the LO port, J12, may be necessary to eliminate the broad band noise during testing.

9) Connect the EVM IF output port, J21, to the noise figure meter input port.

   a) A bandpass or low pass filter may be necessary on the IF port to eliminate the LO signal interference and get an accurate noise measurement.

10) Measure the Noise Figure.

High-Band Cascaded: RF Input Return Loss

Control state: 111001

The cascaded input return loss of the high band is measured at the high band RF input port, J20. The measurement is performed using a network analyzer.

Set up the network analyzer as follows to measure the RF input return loss:

1) Set the network analyzer to measure the low band RF frequency (see Table 4).

2) Set the power range to -35 dBm through -20 dBm, and then set the input power to -30 dBm.

3) Perform a full one-port calibration on port 1 of the network analyzer.

4) Set the network analyzer to measure S11.

5) Connect the EVM RF input, J20, to port 1 of the network analyzer.

6) Measure the RF input return loss.

High-Band: LO Buffer Output Power

Control state: 111001

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

This section involves measuring the Low Band LO Buffer Output. All unused ports will be terminated into 50 Ω. The LO buffer output power is measured at the EVM low band LO output port J23. A transformer balun is used to convert the differential output to a single ended output. The measurement is performed using a RF source and a spectrum analyzer.

1) Set the LO source frequency and input power (see Table 4). Connect the LO source to the EVM LO input port, J12.

2) Set the spectrum analyzer to measure at the LO frequency (see Table 4).

3) Connect the EVM LO buffer port, J23, to the spectrum analyzer.

4) Measure the LO buffer output power.

High-Band Cascaded: Power Leakage LO In to RF In

Control state: 111001

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 23

The LO leakage at the RF port is measured at the low band RF input port J20. Power leakage is a measure of power in dBm that couples to the RF port. The measurement is performed using a RF source and a spectrum analyzer.

1) Set the LO source frequency and input power (see Table 4). Connect the LO source to the EVM LO input port, J12.
2) Set the spectrum analyzer to measure at the LO frequency (see Table 4).
3) Connect the RF Port, J20, to the spectrum analyzer.
4) Measure the LO leakage power.

High-Band Cascaded: Third Order Input Intercept Point (IIP3)

Control state: 111001

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 21

The third order input intercept point is the level of the RF input power at which the output power levels of the undesired intermodulation products and the desired IF products are equal. The measurement is performed using three RF sources and a spectrum analyzer.

1) Set the first RF source input power (RF P_{in}) and frequency (F_1) (see Table 4).
2) Set the second RF source frequency to the first RF frequency plus 120kHz; F_2.
3) Using a RF combiner, connect the RF sources to the EVM RF input port, J20.
4) Set the LO source frequency and input power (see Table 4). Connect the LO source to the EVM LO input port, J12.
5) Set the spectrum analyzer to measure at the IF frequency (F_{IF}) (see Table 4).

6) Connect the EVM IF output port, J21 to the spectrum analyzer.

7) Measure the Fundamental output power at the IF frequency (F_{Fund}).

8) Measure the Intermodulation products ($2F_2 - F_1$ or $2F_1 - F_2$) at $F_{IF} \pm$ 120 kHz

9) Calculate the Intermodulation Suppression as:

   Intermodulation Suppression = F_{Fund} - Intermodulation product

10) Calculate the Input Third -Order Intercept Point as:

   Input Third-Order Intercept = ((Intermodulation Suppression/2) + (RF P_{in}))

High-Band Cascaded: 1dB Input Compression Point

Control state: 111001

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

The 1 dB input compression point is the RF input power at which the gain compresses 1 dB. Gain compression is when an increase in P_{in} causes no further increase in the output power (P_{out}). The measurement is performed using two RF sources and a spectrum analyzer.

1) Set the RF source frequency (see Table 4) and the input power (P_{in}) to -35 dBm. Connect the RF source to the EVM RF input port, J20.

2) Set the LO source frequency and input power (see Table 4). Connect the LO source to the EVM LO input port, J12.

3) Set the spectrum analyzer to measure the output power at the IF frequency.

4) Connect the EVM IF output port, J21, to the spectrum analyzer.

5) Measure the output power (P_{out}) at the IF frequency

6) Calculate Gain as:

   Gain = P_{out} - P_{in}

7) To determine the 1 dB compression point, the RF P_{in} is increased in steps of 1 dBm until the gain compresses by 1 dB. Repeat step 4 and 5 until the gain compresses by 1dB.

RF P_{in}	P_{out}	Gain	
-35	-10	25	
-34	-9	25	
-33	-8	25	
-32	-7	25	
-31	-6	25	
-30	-5	25	
-29	-4	25	
-28	-3	25	
-27	-2	25	
-26	-1.2	24.8	
-25	-0.4	24.6	
-24	0.4	24.4	
-23	1.2	24.2	
-22	2.2	24.2	
-21	3.0	24.0	←1dB Compression Point
-20	3.0	23.0	

High-Band Cascaded: 2X2 Spur Performance

Control state: 111001

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

2X2 Spur Performance is measured at IF output port J21. The measurement is performed using two sources and a spectrum analyzer.

1) Set the RF source frequency (F_{RF}) and input power (see Table 4). Connect the RF source to the EVM RF input port, J20.

2) Set the LO source frequency and input power (see Table 4). Connect the LO source to the EVM LO input port, J12.

3) Set the spectrum analyzer to measure the output power at the IF frequency; F_{IF}

4) Connect the EVM IF output port, J21, to the spectrum analyzer.

5) Measure the output power (1 P_{out}) at the IF frequency.

6) Set the RF source Frequency to (F_{RF} + ½ F_{IF}) and P_{in} to -50dBm.

7) Measure the output power (2 P_{out}) at the IF frequency.

8) Calculate 2 X 2 spur performance as 2 X 2 spur performance = 1 P_{out} - 2 P_{out}.

High Band: 3X3 Spur Performance

Control state: 111001

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

3X3 Spur Performance is measured at IF output port J21. The measurement is performed using two sources and a spectrum analyzer.

1) Set the RF source frequency (F_{RF}) and input power (see Table 4). Connect the RF source to the EVM RF input port, J20.
2) Set the LO source frequency and input power (see Table 4). Connect the LO source to the EVM LO input port, J12.
3) Set the spectrum analyzer to measure the output power at the IF frequency; F_{IF}.
4) Connect the EVM IF output port, J21, to the spectrum analyzer.
5) Measure the output power (1 P_{out}) at the IF frequency.
6) Set the RF source Frequency to (F_{RF} + 2/3 F_{IF}) and the source power to -50dBm.
7) Measure the output power (2 P_{out}) at the IF frequency.
8) Calculate 3 x 3 spur performance as:

   3 x 3 spur performance = 1 P_{out} - 2 P_{out}.

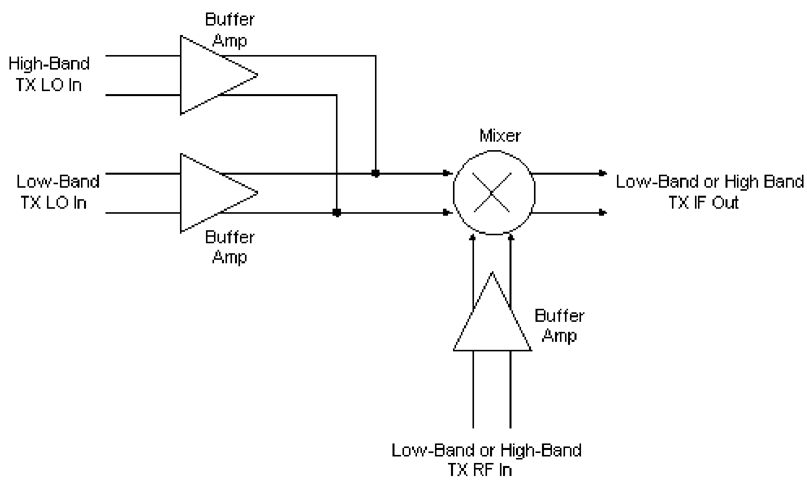
Low-Band and High-Band Transmit

Low- and High-Band Transmit Mixer

Figure 17 details the block diagram of the transmit mixer. The TRF1500 provides a transmit mixer for down converting the system transmit signal (low-band or high-band) to a common IF for loop-back testing. The LO input for this mixer can be selected from either the low-band LO input or the high-band LO input by means of the digital control. The RF input of the transmit mixer provides a broad-band 200Ω differential input impedance over a band of 800 MHz to 2GHz and thus requires minimal external matching.

The mixer is a double-balanced Gilbert cell design with open collector outputs. The Gilbert cell structure was implemented for its robust isolation and harmonic suppression characteristics.

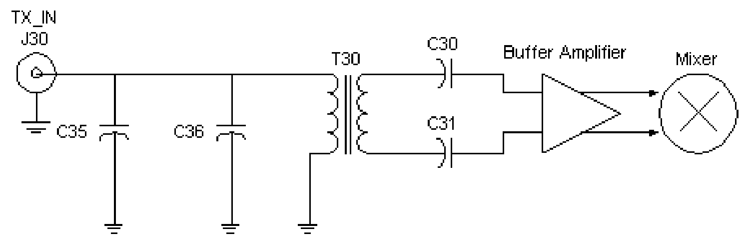
Figure 17. Transmit Mixer Block Diagram



Low-Band and High-Band Transmit Mixer RF Input

Figure 18 details the transmit mixer RF input configuration. The transmit mixer can be either driven single-ended or differentially. For evaluation purposes, a 4:1 transformer balun is used on the EVM to drive the transmit mixer single-ended. The input requires very little external matching. A shunt capacitor (C35) near the input port (J30) and a shunt capacitor (C36) near the transformer balun (T30) are the only input impedance matching components required.

Figure 18. Low- and High-Band Transmit Mixer RF Input Configuration

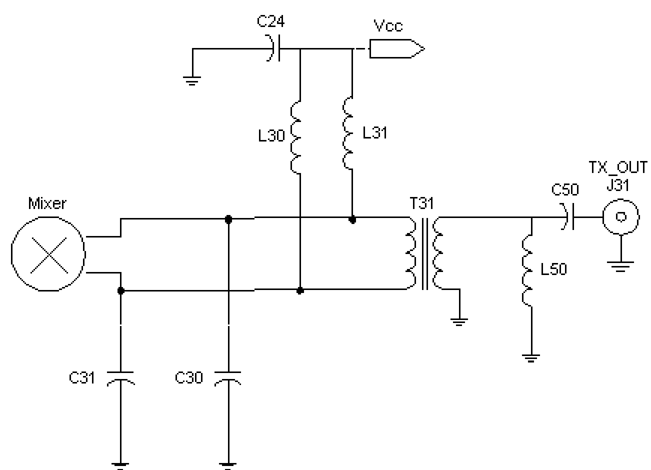


Low- and High-Band Transmit Mixer IF Output

Figure 19 details the transmit mixer IF output configuration. The transmit mixer has a differential IF output with a 1kΩ differential impedance. For evaluation purposes, a 16:1 transformer balun, with an insertion loss of 1.8 dB, is used to transform the 1kΩ differential output to a single-ended output which is then matched to 50Ω.

The supply voltage (VCC) is applied to the IF pins with pull up inductors (L30, L31). A low-pass filter network is provided prior to the balun. This filter also acts as part of the impedance matching network. The IF response is shaped by the shunt inductor (L50) after the transformer balun. L50 is also used to block unwanted noise that could be reflected back to the mixer. The series capacitor (C50), near the TX_IF_OUT port, is used as a dc block for evaluation purposes and does not have to be implemented in the end-users system.

Figure 19. Low- and High-Band Transmit Mixer IF Output Configuration



Low-Band Transmit Mixer Test Guide

This section involves measuring the Transmit Mixer performance. All tests apply for an IF output terminated into a 1 kΩ differential load. To match the IF output to the 50 Ω test equipment a transformer balun is used. All unused ports are terminated into 50 Ω.

Table 5. Low-Band Transmit Performance Parameters

PARAMETERS	Min	Typ	Max	UNIT
Tx Mixer Input Frequency Range	824	836.5	849	MHz
LO Input Frequency Range	941	953.5	966	MHz
Tx Mixer IF Frequency		117		MHz
RF Input Power		-30		dBm
LO Input Power		-5		dBm
Power Conversion Gain		19		dB
Noise Figure		7.8		dB
Input Return Loss		9.8		dB
Power Leakage LO In to Tx In		-49		dB
Power Leakage Tx In to LO In		-70.6		dB
1dB Input Compression Point		-20		dBm
Second Order Input intercept Point (IIP2)		29.5		dBm
Third Order Input Intercept Point(IIP3)		-11.5		dBm

Low-Band Transmit Mixer: Power Conversion Gain

Control state: 010100

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

The low band transmit mixer power conversion gain (dB) is the measured power (dBm) at the IF frequency minus the RF source power (dBm). It is measured using a RF source and a spectrum analyzer.

1) Set the RF source power (RF P_{in}) and the desired frequency (see Table 5). Connect the RF source to the EVM RF port, J30.

2) Set the LO source power (LO P_{in}) and the desired frequency (see Table 5). Connect the LO source to the EVM LO input port, J12.

3) Set the spectrum analyzer to measure at the IF frequency (see Table 5).

4) Connect the EVM IF output port, J31, to the spectrum analyzer.

5) Measure the IF output power (IF P_{out}) at the IF frequency with the spectrum analyzer.

6) Calculate the Cascaded Gain as:

   Gain = (IF P_{out} - RF P_{in}) + Transformer Loss. The transformer loss is 1.8dB.

Low-Band Transmit Mixer: Noise Figure

Control state: 010100

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 22

The cascaded Noise Figure (NF) is measured at the EVM Low Band IF output port, J31. The measurement is performed using an HP8970B Noise Figure Meter. The IF output of the mixer is converted from differential to single ended using a transformer balun. The noise figure meter requires a special setup and calibration since the RF source and receive frequencies are different.

Set up the noise figure meter as follows:

1) Special Function 1.4 sets the noise figure meter to measure variable IF and fixed LO frequencies.

2) The IF start, stop, and step size frequencies are set to 114MHz, 120MHz, and 3MHz respectively.

3) Set the smoothing to 16 or above.

4) Ensure that the Excess Noise Ratio (ENR) Table on the Noise Source head in use is entered on the NF meter.

   a) On the front panel, press the ENR button.

   b) Check the ENR value by pressing the Enter button or enter the ENR value for each frequency.

   c) After entering the ENR for the desired frequency, press the Frequency button on the front panel to exit.

5) To calibrate the NF Meter:

   a) Connect the Noise Source directly to the NF meter; press the calibration button twice.

b) Next, press the Noise Figure and Gain Button. The corrected LED just above the button should be lit.

c) Calibration is complete. Enter the desired IF frequency to measure.

Next, the external equipment Loss is considered (RF cable, Transmission line, filter and circulator).

6) The losses are entered in the Noise Figure Meter by using special function 34.x.

   a) Special Function 34.1 turns on the loss compensation factor.

   b) Special Function 34.2 is used to enter the loss before the DUT.

   c) Special Function 34.3 is used to enter the room temperature in Kelvin (300°K).

   d) Special Function 34.4 is used to enter the loss after the DUT.

   e) Special Function 34.0 is used to turn off the loss compensation factor.

The noise figure is measured as follows:

7) Connect the noise source directly to the EVM RF input port, J30.

8) Connect the LO source to the EVM LO input port, J12.

   a) Set the LO source at the nominal power and frequency (See Table 5).

   b) Each LO frequency being tested is entered in the Noise figure meter by using Special function 3.1.

9) Connect the EVM IF output port, J31, to the noise figure meter input port.

10) Measure the Noise Figure.

Low-Band Transmit Mixer: Input Return Loss

Control state: 010100

The cascaded input return loss of the low band transmit mixer is measured at the EVM low band RF input port, J30. The measurement is performed using a network analyzer.

Set up the network analyzer as follows to measure the RF input return loss:

1) Set the network analyzer to measure the low band RF frequency (see Table 5).
2) Set the power range to -35 dBm through -20 dBm, and then set the input power to -30 dBm.
3) Perform a full one-port calibration on port 1 of the network analyzer.
4) Set the network analyzer to measure S11.
5) Connect the EVM RF input, J30, to port 1 of the network analyzer.
6) Measure the RF input return loss.

Low-Band Transmit Mixer: Power Leakage LO In to TX In

Control state: 010100

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 23

The LO In leakage at the TX In port is measured at the low band TX input port J30. Power leakage is a measure of power (in dBm) that couples to the TX port. The measurement is performed using a RF source and a spectrum analyzer.

1) Set the LO source frequency and input power (see Table 5). Connect the LO source to the EVM LO input port, J12.
2) Set the spectrum analyzer to measure at the LO frequency (see Table 5).
3) Connect the TX In Port, J30, to the spectrum analyzer.
4) Measure the LO leakage power.

Low-Band Transmit Mixer: Power Leakage TX In to LO In

Control state: 010100

SEE APPENDIX A: TEST BENCH SETUP

Test setup Figure 24

The Power leakage from TX IN to LO IN is measured at the LO in port, J12. A leakage is a measure of power (in dBm) that couples to the LO IN port. The measurement is performed using a RF source and a spectrum analyzer.

1) Set the TX source frequency and input power (see Table 5). Connect the TX source to the EVM TX input port, J30.

2) Set the spectrum analyzer to measure at the TX frequency (see Table 5).

3) Connect the LO In Port, J12, to the spectrum analyzer.

4) Measure the TX leakage power.

Low-Band Transmit Mixer: 1dB Input Compression Point

Control state: 010100

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

The 1 dB input compression point is the TX RF input power at which the gain compresses 1 dB. Gain compression is when an increase in P_{in} causes no further increase in the output power (P_{out}). The measurement is performed using two RF sources and a spectrum analyzer.

1) Set the TX RF source frequency (see Table 5) and the input power (P_{in}) to -35 dBm. Connect the RF source to the EVM RF input port, J30.

2) Set the LO source frequency and input power (see Table 5). Connect the LO source to the EVM LO input port, J12.

3) Set the spectrum analyzer to measure the output power at the IF frequency.

4) Connect The EVM TX IF output port, J31, to the spectrum analyzer.

5) Measure the output power (P_{out}) at the IF frequency

6) To determine the 1 dB compression point, the TX RF P_{in} is increased in steps of 1 dBm until the gain compresses by 1 dB. Repeat step 4 and 5 until the gain compresses by 1dB.

7) Calculate Gain as:

$$Gain = P_{out} - P_{in}$$

RF P_{in}	P_{out}	Gain
-35	-16	19
-34	-15	19
-33	-14	19
-32	-13	19

-31	-12	19
-30	-11.2	18.8
-29	-10.2	18.8
-28	-9.2	18.8
-27	-8.4.	18.6
-26	-7.6	18.4
-25	-7.8	18.2
-24	-6.0	18.0←1dB Compression Point
-23	-5.5	17.5

Low-Band Transmit Mixer: Second Order Input Intercept Point (IIP2)

Control state: 010100

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 21

Input intercept point is the level of input RF power at which the output power levels of the undesired intermodulation products and IF products are equal. The second order intercept point is measured at the IF output port, J31.

1) Set the RF source input power (RF P_{in}) and frequency (see Table 5).
2) Set the LO source input power and frequency (see Table 5). Connect the LO source to the EVM LO input port, J12.
3) Set the spectrum analyzer to measure at the IF frequency (see Table 5).
4) Connect the EVM IF output port, J31 to the spectrum analyzer.
5) Measure the IF output power (IF $1P_{out}$) at the IF frequency.
6) Increase the RF frequency by half the IF frequency.
7) Measure the IF output power (IF $2P_{out}$) at the IF Frequency.
8) Calculate IIP2 as: $IIP2 = RF\ P_{in} + [IF\ 1P_{out} - IF\ 2P_{out}]$

Low-Band Transmit Mixer: Third Order Input Intercept Point (IIP3)

Control state: 010100

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 21

The third order input intercept point is the level of the RF input power at which the output power levels of the undesired intermodulation products and the desired IF products are equal. The measurement is performed using three RF sources and a spectrum analyzer.

1) Set the first RF source input power (RF P_{in}) and frequency (F1) (see Table 5).
2) Set the second RF source frequency to the first RF frequency plus 60kHz; F_2.
3) Using a RF combiner, connect the RF sources to the EVM RF input port, J30.
4) Set the LO source frequency and input power (see Table 5). Connect the LO source to the EVM LO input port, J12.
5) Set the spectrum analyzer to measure at the IF frequency (F_{IF}) (see Table 5).
6) Connect the EVM IF output port, J31 to the spectrum analyzer.
7) Measure the Fundamental output power at the IF frequency (F_{Fund}).
8) Measure the Intermodulation products ($2F_2 - F_1$ or $2F_1 - F_2$) at $F_{IF} \pm 60$ kHz
9) Calculate the Intermodulation Suppression as:

   Intermodulation Suppression = F_{Fund} - Intermodulation product
10) Calculate the Input Third -Order Intercept Point as:

   Input Third-Order Intercept = ((Intermodulation Suppression/2) + (RF P_{in}))

High-Band Transmit Mixer Test Guide

This section involves measuring the High Band Transmit Mixer performance. All tests apply for an IF output terminated into a 1 kΩ differential load. To match the IF output to the 50 Ω test equipment a transformer balun is used. All unused ports are terminated into 50 Ω. Testing the performance of the high transmit mixer can be performed two ways. One being the LO Doubler driven, no EVM modification needed. Two LO is directly driven, before measuring the high band transmit mixer performance the EVM board must be modified as follows: Remove L40 and C41, add C24. This enables the high band transmit to be directly driven by an LO source.

Table 6. High-Band Transmit Mixer Performance Parameters

PARAMETERS	Min	Typ	Max	UNIT
Tx Mixer Input Frequency	1850	1880	1910	MHz
LO Frequency Directly Driven	1733	1763	1793	MHz
LO Frequency Doubler Driven	983.5	998.5	1013.5	MHz
Tx Mixer Output Frequency		117		MHz
LO Input Power		-5.0		dBm
RF Input Power		-30		dBm
Power Conversion Gain		9.9		dB
Noise Figure		12.7		dB
RF Input Return Loss		16.6		dB
Power Leakage Tx In to LO In		-55.5		dB
Power Leakage LO In to Tx In		-69.5		dB
1dB Input Compression Point		-15.7		dBm
Second Order Input Intercept point (IIP2)		27		dBm
Third Order Input Intercept Point(IIP3)		-6.7		dBm

To test the High Band Transmit Mixer parameters use the procedure for the Low Band Transmit Mixer, with the following exception: Control state mode 110100 and when testing the Third order intercept point the RF signal separation is 120kHz.

Low-Band LNA Stand-Alone Test Guide

This section involves measuring the Low Band LNA by itself. All unused ports are terminated into 50Ω. Before measuring the low band LNA by itself the EVM board must be modified as follows: Remove C12 and place C53. The EVM board is now modified to use J15 as the output port of the LNA.

Table 7. Low-Band LNA Parameters

Parameters	Min	Typ	Max	Units
RF Frequency Range	869	881.5	894	MHz
RF Input Power		-30		dBm
Gain		15.5		dB
RF Input Return Loss		-6.5		dB
RF Output return loss		-14		dB
Isolation		-17.2		dB
Noise Figure		1.8		dB
Third Order Input Intercept Point(IIP3)		-3		dBm
1dB Input compression Point		-13.5		dBm

Low-Band LNA: Gain

Control state: 011000

The LNA gain is measured from the input port J10 through the output port J15. The measurement is performed using a network analyzer.

1) Set up the network analyzer to measure the low band RF frequency range (see Table 7).
2) Set the power range to -35 dBm to -20 dBm,
   a) Set the input power to -30 dBm.
3) Perform a full two-port calibration.
4) Connect the low band LNA input port J10 and output port J15 to the S11 and S22 port of the network analyzer respectively.
5) Set the network analyzer to measure S21.
6) Measure the gain

Low-Band LNA: Input Return Loss

Control state: 011000

The LNA input return loss is measured at the input Port J10. Using the calibration performed above, set the network analyzer to measure S11.

Low-Band LNA: Output Return Loss

Control state: 011000

The LNA output return loss is measured at the output port J15. Using the calibration performed above, set the network analyzer to measure S22.

Low-Band LNA: Isolation

Control state: 011000

The isolation of the Low Band LNA is a measure of the attenuation between the output of the LNA and the input of the LNA. . Use the calibration performed above; set the network analyzer to measure S12.

Low-Band LNA: 1dB Input Compression Point

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 27

The 1 dB input compression point is the RF input power at which the gain compresses 1 dB and when an increase in P_{in} causes no further increase in the output power (P_{out}). The measurement is performed using two RF sources and a spectrum analyzer.

1) Set the RF source frequency (see Table 7) and the input power (P_{in}) to -35 dBm. Connect the RF source to the EVM RF input port, J10.
2) Set the spectrum analyzer to measure the output power at the desired LNA frequency.
3) Connect The EVM LNA output port, J15, to the spectrum analyzer.
4) Measure the output power (P_{out}) at the LNA frequency
5) Calculate Gain as:

$$Gain = P_{out} - P_{in}$$

6) To determine the 1 dB compression point, the RF P_{in} is increased in steps of 1 dBm until the gain compresses by 1 dB. Repeat step 4 and 5 until the gain compresses by 1dB.

RF P_{in}	P_{out}	Gain	
-35	-20	15	
-34	-19	15	
-33	-18	15	
-32	-17	15	
-31	-16	15	
-30	-15	15	
-29	-14	15	
-28	-13	15	
-27	-12	15	
-26	-11	14.8	
-25	-10.4	14.6	
-24	-9.4	14.6	
-23	-8.8	14.2	
-22	-7.8	14.2	
-21	-7.0	14.0	←1dB Compression Point
-20	-7.0	13.0	

Low-Band LNA: Noise Figure

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 25

The LNA Noise Figure (NF) is measured at the LNA output port J15. The measurement is performed using an HP8970B Noise Figure Meter.

1) Set up the Noise figure meter as follows:

2) Set start; stop frequency (see Table 7) and the step size to 12.5 MHz.

3) Set the smoothing to 16 or above.

4) Insure that the Excess Noise Ratio (ENR) Table on the Noise Source head in use is entered on the NF meter.

   a) On the front panel press ENR button.

   b) Check the ENR value by pressing the Enter button or enter the ENR value for each frequency.

c) After entering the ENR for the desired frequency, press the Frequency button on the front panel to exit.

5) To calibrate the NF Meter:

a) Connect the Noise Source directly to the NF meter; press the calibration button twice.

b) Next, press the Noise Figure and Gain Button. The corrected LED just above the button should be lit.

c) Calibration is complete.

Next the external equipment loss is considered (RF cable, Transmission line).

6) The Losses are entered in the Noise Figure Meter by using special function 34.x.

a) Special Function 34.1 turns on the Loss compensation factor.

b) Special Function 34.2 is used to enter the loss before the DUT.

c) Special Function 34.3 is used to enter the room temperature in Kelvin (300°K).

d) Finally Special Function 34.4 is used to enter the loss after the DUT.

e) Special Function 34.0 is used to turn off the loss compensation factor.

The noise figure is measured as follows:

7) Connecting the noise source directly to the Low Band LNA input port, J10.

8) Connect the EVM LNA output port, J15, to the noise figure meter input port.

9) Measure the noise figure for each frequency.

Low-Band LNA: Third Order Input Intercept Point (IIP3)

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 26

The third order input intercept point is the level of the RF input power at which the output power levels of the undesired intermodulation products and the desired products are equal. The measurement is performed using two RF sources and a spectrum analyzer.

1) Set the first RF source input power (RF P_{in}) and frequency (F1) (see Table 7).

2) Set the second RF source frequency to the first RF frequency plus 60kHz; F_2.

3) Using a RF combiner, connect the RF sources to the EVM RF input port, J10.

4) Set the spectrum analyzer to measure at the RF frequency (F1) (see Table 7).

5) Connect the EVM IF output port, J11 to the spectrum analyzer.

6) Measure the Fundamental output power at the RF frequency (F_{Fund}).

7) Measure the Intermodulation products ($2F_2 - F_1$ or $2F_1 - F_2$) at $F_{IF} \pm$ 60 kHz

8) Calculate the Intermodulation Suppression as:

   Intermodulation Suppression = F_{Fund} - Intermodulation product

9) Calculate the Input Third -Order Intercept Point as:

   Input Third-Order Intercept = ((Intermodulation Suppression/2) + (RF P_{in}))

Low-Band Receiver Mixer Stand-Alone Test Guide

This section involves measuring the Low Band Receiver Mixer. All unused ports will be terminated into 50 Ω. Before measuring the low band Mixer separately, the EVM board must be modified as follows: Remove C12 and place C54. The EVM board is now modified to use J15 as the input port of the Receiver Mixer.

Table 8. Low-Band Receiver Mixer Parameters

PARAMETERS	Min	Typ	Max	UNIT
Rx Mixer Input Frequency	869	881.5	894	MHz
LO frequency	979.52	992.02	1004.52	MHz
Rx Mixer Output Frequency		110.52		MHz
RF Input Power		-30		dBm
LO Input Power		-5		dBm
Power Conversion Gain		12		dB
RF Input Return Loss		9		dB
Power Leakage LO In at RF In		-50		dB
Noise Figure		7.5		dB
1dB Input Compression Point		-6		dBm
Third Order Input Intercept Point(IIP3)		3.5		dBm

Low-Band Receiver Mixer: Power Conversion Gain

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

The receiver mixer conversion gain (dB) is the measured power (dBm) at the IF frequency minus the RF source power (dBm). It is measured using a RF source and a spectrum analyzer.

1) Set the RF source power (RF P_{in}) and the desired frequency (see Table 8). Connect the RF source to the EVM RF port, J15.

2) Set the LO source power (LO P_{in}) and the desired frequency (see Table 8). Connect the LO source to the EVM LO input port, J12.

3) Set the spectrum analyzer to measure at the IF frequency (see Table 8).

4) Connect the EVM IF output port, J11, to the spectrum analyzer.

5) Measure the IF output power (IF P_{out}) at the IF frequency with the spectrum analyzer.

6) Calculate the Cascaded Gain as:

   Gain = (IF P_{out} - RF P_{in}) + Transformer Loss. The transformer loss is 1.8dB.

Low-Band Receiver Mixer: Input Return Loss

Control state: 011000

The input return loss of the low band receiver mixer is measured at the low band RF input port J15. The measurement is performed using a network analyzer. The network analyzer is set up to measure the low band receiver frequency range (see Table 8). The network analyzer power range is set to 35 dBm to -20 dBm; the input power is set to -30 dBm. Perform a full one-port or two-port calibration. Set the network analyzer to measure S11. To measure the receiver mixer input return loss, connect the RF input port J15 to S11 port of the network analyzer.

The input return loss of the low band mixer is measured at the low band mixer input port, J15. The measurement is performed using a network analyzer.

Set up the network analyzer as follows to measure the RF input return loss:

1) Set the network analyzer to measure the low band RF frequency (see Table 8).

2) Set the power range to -35 dBm through -20 dBm, and then set the input power to -30 dBm.

3) Perform a full one-port calibration on port 1 of the network analyzer.

4) Set the network analyzer to measure S11.

5) Connect the EVM RF input, J15, to port 1 of the network analyzer.

6) Measure the RF input return loss.

Low-Band Receiver Mixer: Power Leakage LO In to RF In

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 23

The LO leakage at the RF port is measured at the low band mixer RF input port, J15. Power leakage is a measure of power in dBm that couples to the RF port. The measurement is performed using a RF source and a spectrum analyzer.

1) Set the LO source frequency and input power (see Table 8). Connect the LO source to the EVM LO input port, J12.

2) Set the spectrum analyzer to measure at the LO frequency (see Table 8).

3) Connect the RF Port, J15, to the spectrum analyzer.

4) Measure the LO leakage power.

Low-Band Receiver Mixer: Noise Figure

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 22:

The low band mixer Noise Figure (NF) is measured at the EVM Low Band IF output port, J11. The measurement is performed using an HP8970B Noise Figure Meter. The IF output of the mixer is converted from differential to single ended using a transformer balun. The noise figure meter requires a special setup and calibration since the RF source and receive frequencies are different.

Set up the noise figure meter as follows:

1) Special Function 1.4 sets the noise figure meter to measure variable IF and fixed LO frequencies.

2) The IF start, stop, and step size frequencies are set to 100MHz, 120MHz, and 5MHz respectively.

3) Set the smoothing to 16 or above.

4) Ensure that the Excess Noise Ratio (ENR) Table on the Noise Source head in use is entered on the NF meter.

a) On the front panel, press the ENR button.

b) Check the ENR value by pressing the Enter button or enter the ENR value for each frequency.

c) After entering the ENR for the desired frequency, press the Frequency button on the front panel to exit.

5) To calibrate the NF Meter:

a) Connect the Noise Source directly to the NF meter; press the calibration button twice.

b) Next, press the Noise Figure and Gain Button. The corrected LED just above the button should be lit.

c) Calibration is complete. Enter the desired IF frequency to measure.

Next, the external equipment Loss is considered (RF cable, Transmission line, filter and circulator).

6) The losses are entered in the Noise Figure Meter by using special function 34.x.

a) Special Function 34.1 turns on the loss compensation factor.

b) Special Function 34.2 is used to enter the loss before the DUT.

c) Special Function 34.3 is used to enter the room temperature in Kelvin (300°K).

d) Special Function 34.4 is used to enter the loss after the DUT.

e) Special Function 34.0 is used to turn off the loss compensation factor.

The noise figure is measured as follows:

7) Connect the noise source directly to the EVM RF input port, J15.

a) A circulator between the noise source and RF input port may help minimize any mismatches between the EVM board and test equipment.

8) Connect the LO source to the EVM LO input port, J12.

a) Set the LO source at the nominal power and frequency (See Table 8).

b) Each LO frequency being tested is entered in the Noise figure meter by using Special function 3.1. If the source has excessive broad band noise, a filter at the LO port, J12, may be necessary to eliminate the broad band noise during testing.

9) Connect the EVM IF output port, J11, to the noise figure meter input port.
   a) A bandpass or low pass filter may be necessary on the IF port to eliminate the LO signal interference and get an accurate noise measurement.

10) Measure the Noise Figure.

Low-Band Receiver Mixer: 1dB RF Input Compression Point

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 20

The 1 dB input compression point is the TX RF input power at which the gain compresses 1 dB. Gain compression is when an increase in P_{in} causes no further increase in the output power (P_{out}). The measurement is performed using two RF sources and a spectrum analyzer.

1) Set the Mixer RF source frequency (see Table 8) and the input power (P_{in}) to -35 dBm. Connect the RF source to the EVM RF input port, J15.
2) Set the LO source frequency and input power (see Table 8). Connect the LO source to the EVM LO input port, J12.
3) Set the spectrum analyzer to measure the output power at the IF frequency.
4) Connect The EVM Mixer IF output port, J11, to the spectrum analyzer.
5) Measure the output power (P_{out}) at the IF frequency
6) Calculate Gain as:

   Gain = P_{out} - P_{in}

7) To determine the 1 dB compression point, the mixer RF P_{in} is increased in steps of 1 dBm until the gain compresses by 1 dB. Repeat step 4 and 5 until the gain compresses by 1dB.

RF P_{in}	P_{out}	Gain
-25	-15	10
-24	-14	10

-23	-13	10
-22	-12.2	9.8
-21	-11.4	9.6
-20	-10.4	9.6
-19	-9.6	9.4
-18	-8.7	9.3
-17	-7.8	9.2
-16	-6.8	9.2
-15	-6.0	9.0 ←1dB Compression Point
-14	-5.5	8.5

Low-Band Receiver Mixer: Third Order Input Intercept Point (IIP3)

Control state: 011000

SEE APPENDIX A: TEST BENCH SETUPS

Test setup Figure 21

The third order input intercept point is the level of the RF input power at which the output power levels of the undesired intermodulation products and the desired IF products are equal. The measurement is performed using three RF sources and a spectrum analyzer.

1) Set the first RF source input power (RF P_{in}) and frequency (F1) (see Table 8).

2) Set the second RF source frequency to the first RF frequency plus 60kHz; F_2.

3) Using a RF combiner, connect the RF sources to the EVM RF input port, J15.

4) Set the LO source frequency and input power (see Table 8). Connect the LO source to the EVM LO input port, J12.

5) Set the spectrum analyzer to measure at the IF frequency (F_{IF}) (see Table 8).

6) Connect the EVM IF output port, J11 to the spectrum analyzer.

7) Measure the Fundamental output power at the IF frequency (F_{Fund}).

8) Measure the Intermodulation products ($2F_2 - F_1$ or $2F_1 - F_2$) at $F_{IF} \pm$ 60 kHz

9) Calculate the Intermodulation Suppression as:

Intermodulation Suppression = F_{Fund} - Intermodulation product

10) Calculate the Input Third -Order Intercept Point as:

Input Third-Order Intercept = ((Intermodulation Suppression/2) + (RF P_{in}))

Appendix A: Test Bench Configuration

Figure 20. Test Bench Setup: Power Conversion Gain, Power Conversion Gain Reduction, 1dB RF Input Compression Point, Second Order Input Intercept Point (IIP2), 2x2 Spur Performance, 3x3 Spur Performance, Image rejection and LO Buffer Output Power

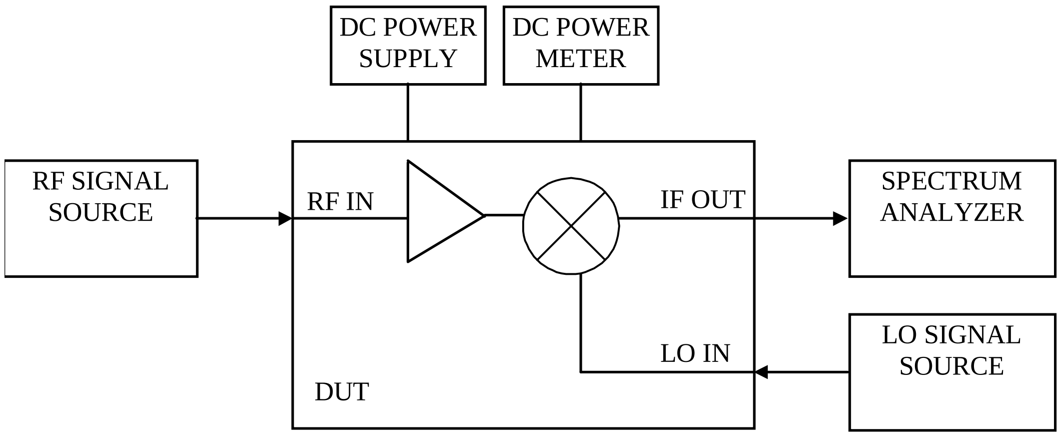


Figure 21. Test Bench Setup: Third Order Input Intercept Point (IIP3), 1dB Blocking Point Measurements

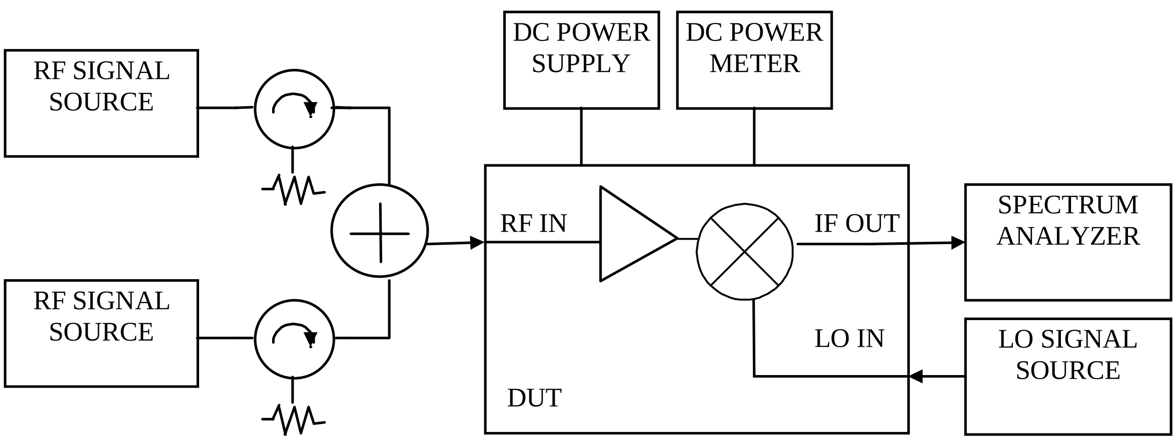


Figure 22. Test Bench Setup: Noise Figure

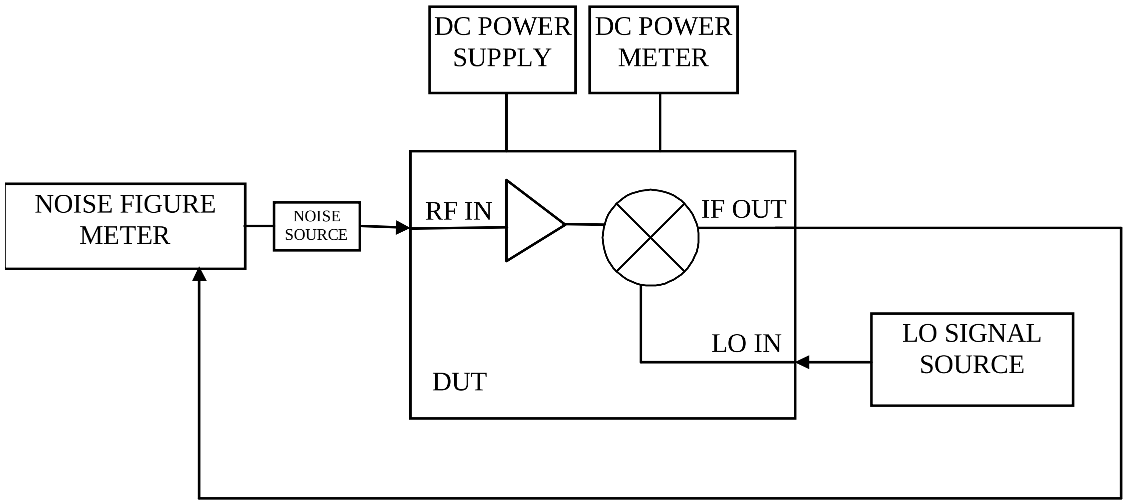


Figure 23. Test Bench Setup: Power Leakage LO In to RF In

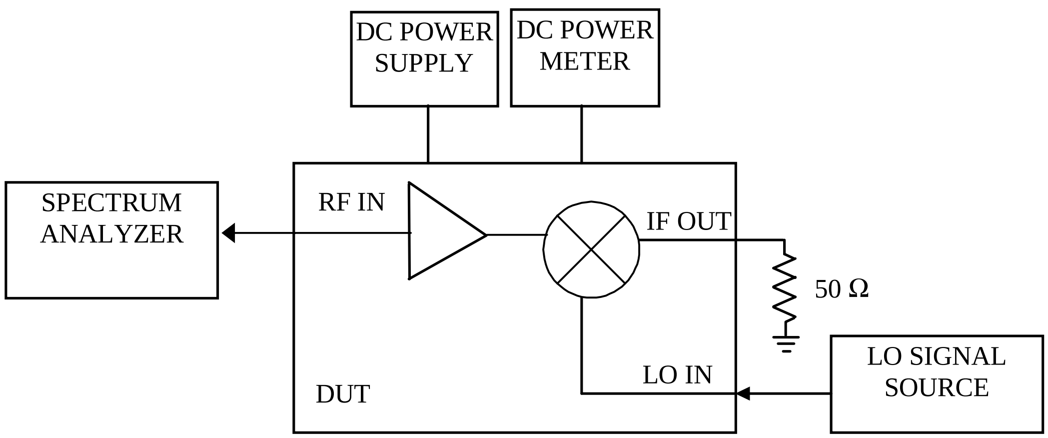


Figure 24. Test Bench Setup: Power Leakage RF In to LO In Measurements

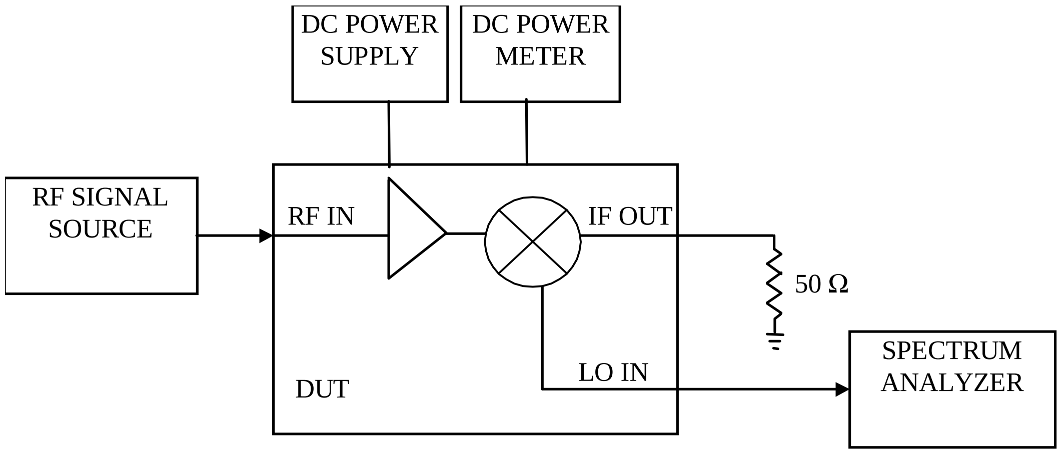


Figure 25. Test Bench Setup: LNA Noise Figure Measurements

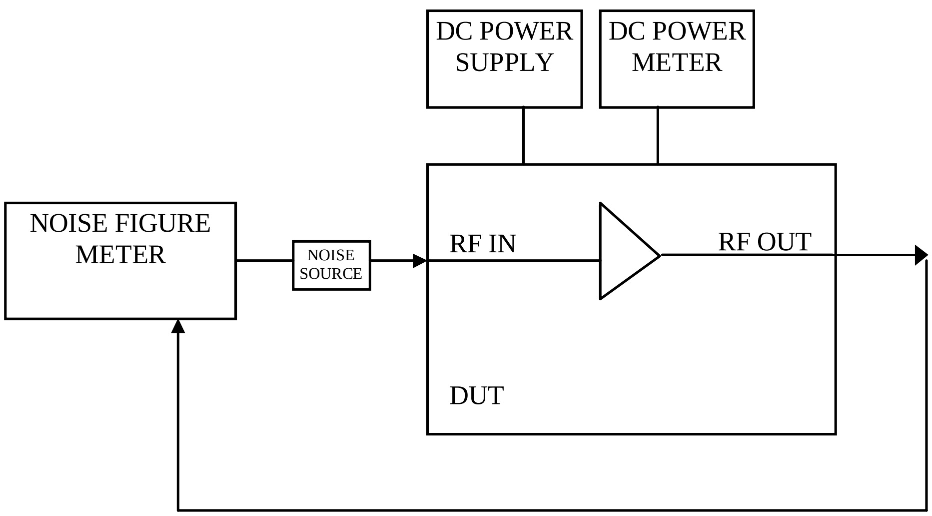


Figure 26. Test Bench Setup: LNA Third Order Input Intercept Point (IIP3) Measurement

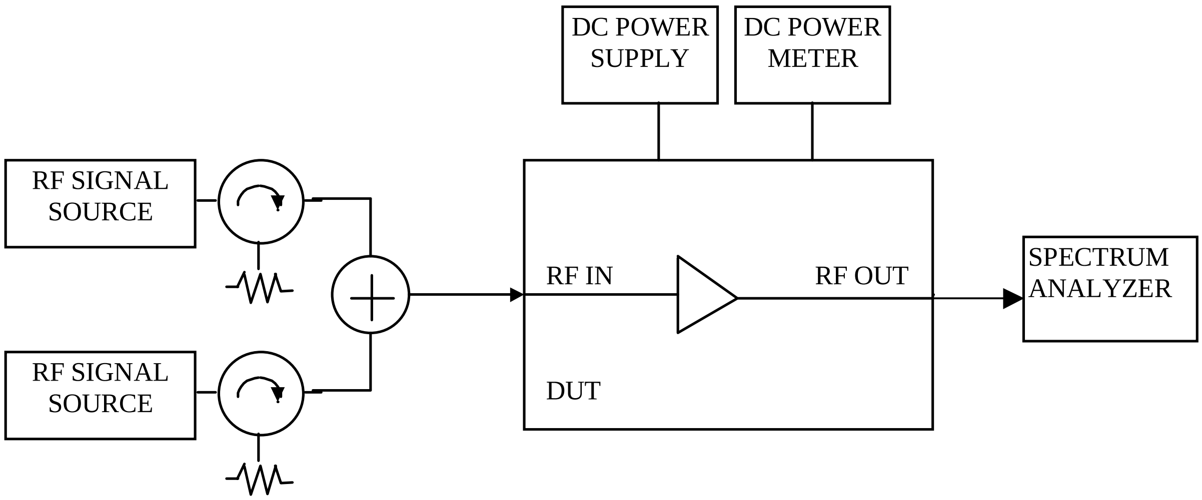


Figure 27. Test Bench Setup: LNA 1dB Input Compression Point