# A 1.8V to 5.25V, 400MHz Quadrature IF Demodulator with 90dB Linear RSSI Range

Min Zou and Vladimir Dvorkin

## Introduction

The LT5502 is a high performance limiting amplifier and quadrature IF demodulator with 70MHz to 400MHz input frequency range, operating over the widest supply voltage range in the industry - from 5.25V down to 1.8V - an industry first. This allows the LT5502 to operate directly from a single Lithium Ion battery, or from two or more NiCad batteries. In combination with an appropriate RF front end and RF/IF bandpass filters, it forms a wideband receiver for applications at 900MHz, 1.8GHz, 2.4-2.5GHz, or other frequencies. The LT5502 can even be used as a self-standing receiver at frequencies below 400MHz.

## LT5502 Primary Features

- Supply voltage range from 1.8V to 5.25V
- Input IF frequency range from 70MHz to 400MHz
- 84dB limiting IF gain
- Receive signal strength indicator with 90dB linear range
- 7.7MHz 5$^{th}$-order lowpass filters on baseband I and Q outputs
- Shutdown mode (1µA supply current), and power saving, fast turn-on standby mode

## Circuit Description

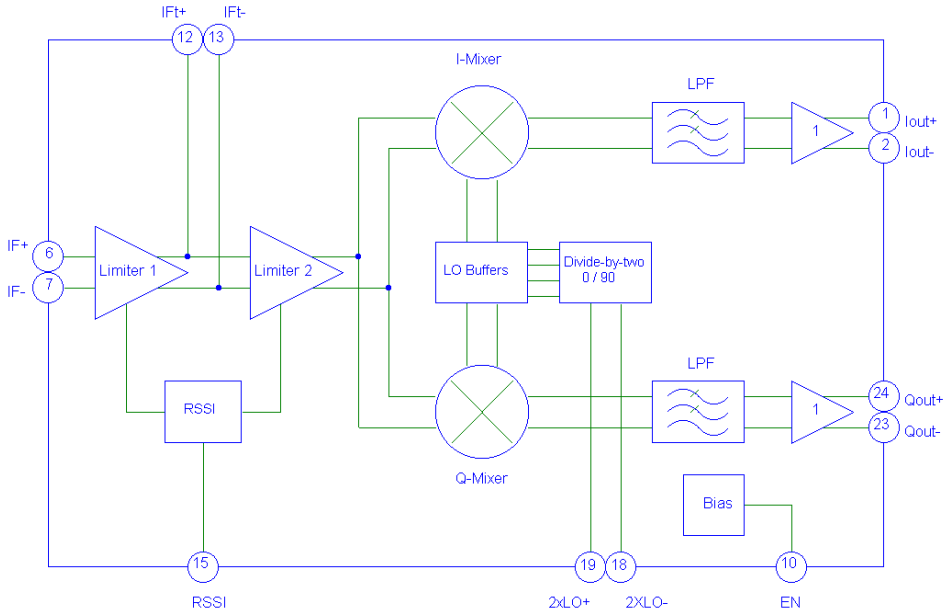



**Figure 1. LT5502 block diagram**

The LT5502 consists an IF limiting amplifier with 84dB small signal gain, quadrature-converting mixers, integrated 5$^{th}$-order low pass filters, and an RSSI section with 90dB IF signal detecting range. Figure 1 shows the LT5502 block diagram. In operation, an IF signal is fed to the inputs of the IF limiting amplifier. The limiting IF signal is then demodulated into in-phase (I) and quadrature (Q) baseband signals by mixing quadrature local oscillator (LO) carriers that are generated on-chip from the external 2xLO signal. The demodulator I/Q baseband signals are passed through fully integrated 5$^{th}$-order low pass filters (LPF) and output drivers.

The LT5502 has 4dB noise figure. That provides an excellent sensitivity for the IF receiver. Various means of input coupling, single-ended or differential, may be used, as well as interstage filtering in-between IFt+ and IFt-, depending upon the sensitivity of the receiver, and the cost requirements of the user. Sensitivity of –86dBm is achievable. Figure 2 shows the baseband I/Q output voltage swing versus IF input power at IF input frequency of 280MHz. The receive signal strength indicator (RSSI) is built into the IF limiter. The input IF signal is detected in a current output proportional to the IF input power. The current outputs from two cascaded stages of IF amplifiers/limiters are summed and converted into the RSSI voltage. The RSSI output has an excellent linear range of 90dB. The characteristic of RSSI output voltage versus input IF power is very stable over the temperature. Only one off-chip capacitor is needed to make the RSSI operate properly. The high performance of RSSI function simplifies the wireless system design. The excellent performance of the RSSI output voltage versus the IF input power is shown in Figure 2.

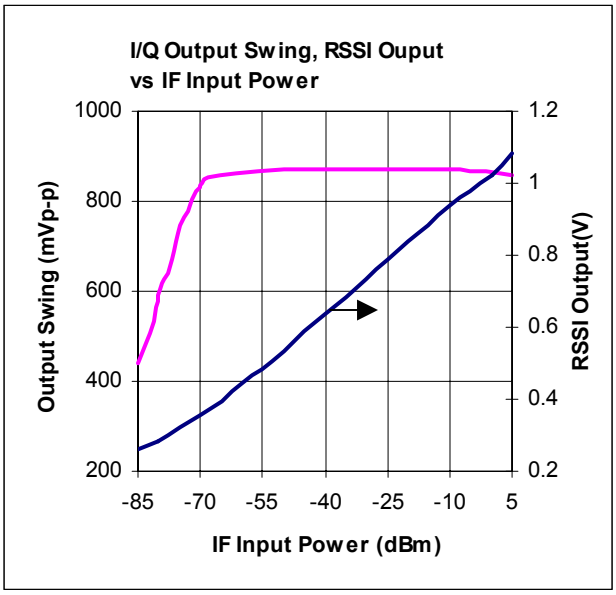



**Figure 2. Baseband I/Q differential output voltage swing and RSSI output versus IF input power; IF Frequency = 280MHz, with 1:4 IF input transformer, without IF interstage filtering**

The quadrature demodulators are double-balanced mixers. The quadrature LO carriers are obtained from on-chip divide-by-two circuit. For this reason, the external 2XLO signal must be twice the LO frequency.

The 5$^{th}$-order integrated lowpass filters are used for filtering the down-converted baseband outputs for both the I-channel and the Q-channel. They serve as anti-aliasing and pulse-shaping filters. The I/Q filters are well matched in gain response and group delay. The 3-dB corner frequency is 7.7MHz and the group delay ripple is less than 17ns. The characteristic of the filters is very stable over the full temperature range from -40°C to +85°C. The high performance of the filters eases the radio system requirement on off-chip filtering.

The capability of 1.8V operation can't be seen from any competitions in the industry. Even at this low supply voltage, it only consumes 25mA. The extremely low power consumption is desirable for most wireless system. The chip has two reduced power modes of operation. In the shutdown mode, power is reduced to less than 1µA. In standby mode with current consumption of 2.6mA, the baseband outputs are pre-biased at their nominal quiescent voltages. This allows rapid turn-on with minimum delay when the LT5502 is AC interfaced with a baseband chip with large AC coupling capacitors.

**Applications and implementation issues.**

The LT5502 can be implemented on 2-layer, 4-layer or multiplayer PCB depending on actual product circuit complexity and other considerations. FR-4, GETEK and other PCB materials can be used. Product designers should provide solid ground plane on the top layer of the PCB and multiple ground vias around the IC's ground pins. Ground plane on the top layer of the PCB should be connected to the designated RF ground plane (located on the second layer) with multiple ground vias. All the RF bypass capacitors should be placed next to designated IC pins. Bypass capacitors and IC ground pins should not share ground vias to avoid ground loops. IF input single ended to differential conversion/matching circuit should be placed as close as possible to pins 6 & 7 of LT5502. LO input single ended to differential conversion/matching circuit should be placed as close as possible to pins 18 & 19 of LT5502.

**Application Example**

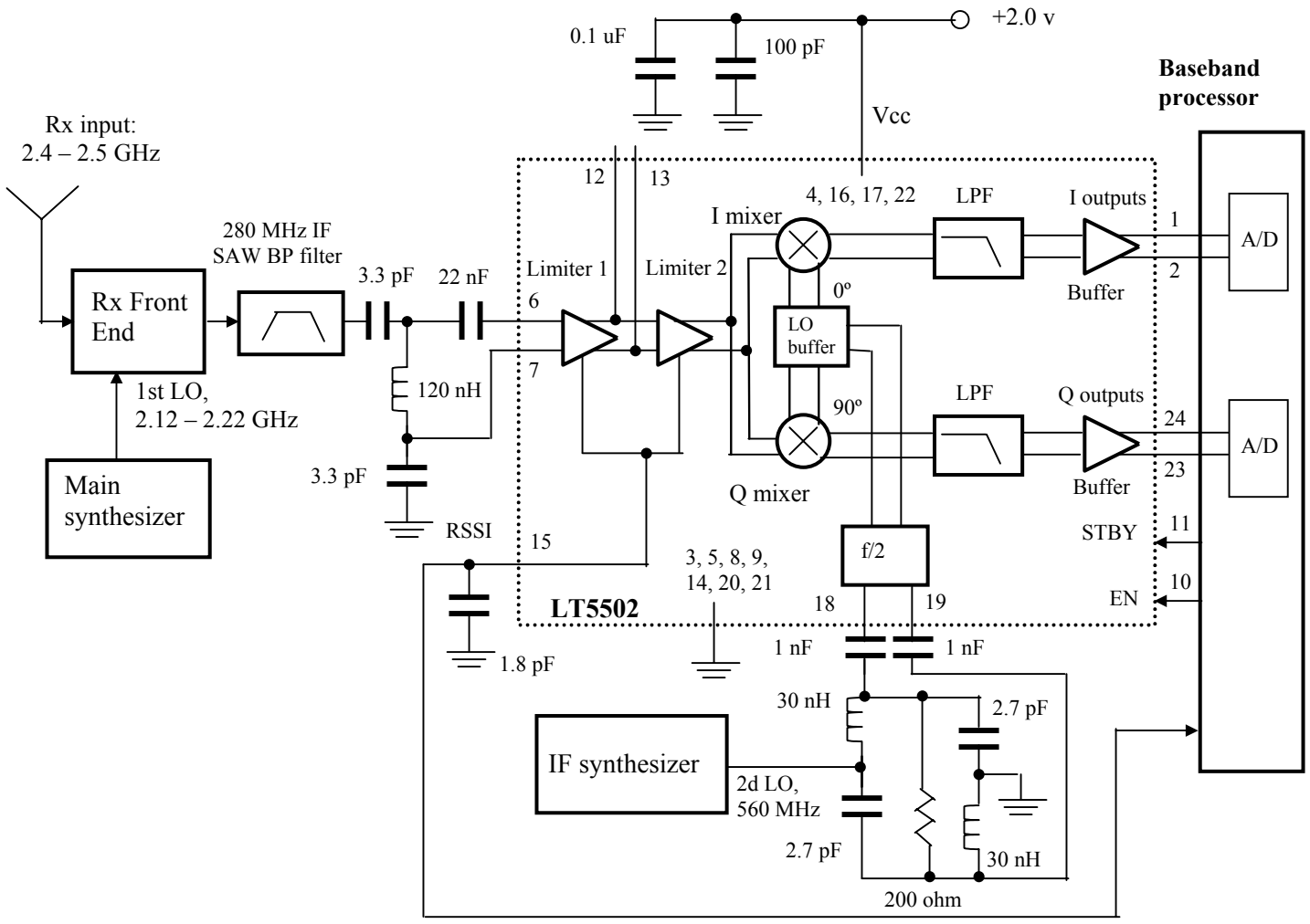



**Figure 3. Example of 2.4 – 2.5 GHz receiver application (Rx IF = 280 MHz)**

In this example, an input signal of 2.4 to 2.5 GHz is converted to a popular 280 MHz IF frequency. Rx front end (refer to Figure 4) typically consists of input bandpass filter to provide image frequency rejection, LNA (Low Noise Amplifier) to establish low Noise Figure in order to meet sensitivity requirements followed by down converting mixer. Main LO is low side injection (cost consideration). A 280 MHz IF SAW bandpass filter provides protection from strong interfering signals in adjacent, alternate channels and out of band. The LT5502's 5th order I/Q LP filters offer very good protection at the baseband outputs. Product designers can relax requirements for the IF SAW filter performance and use lower cost parts. Limiting IF amplifier needs no AGC function and dedicated RSSI output offers unfiltered signal in real time with no delay. This simplifies requirements for BB and DSP portion of the product. Discrete single-ended to differential converters circuits are employed at IF and LO inputs. Direct termination of IF input with a 50Ω resistor is possible with small sensitivity degradation.

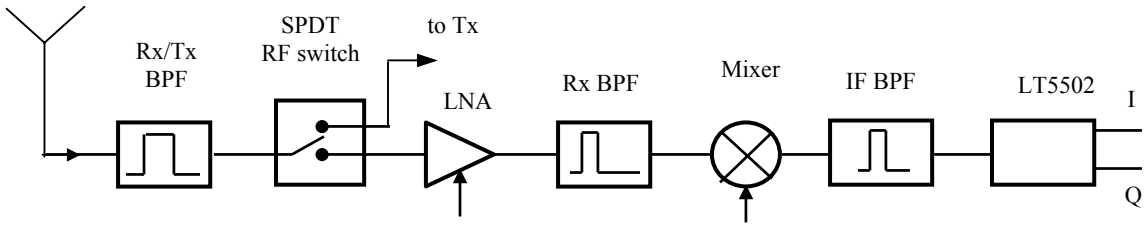



**Figure 4. Example of 2.4 – 2.5 GHz receiver.**

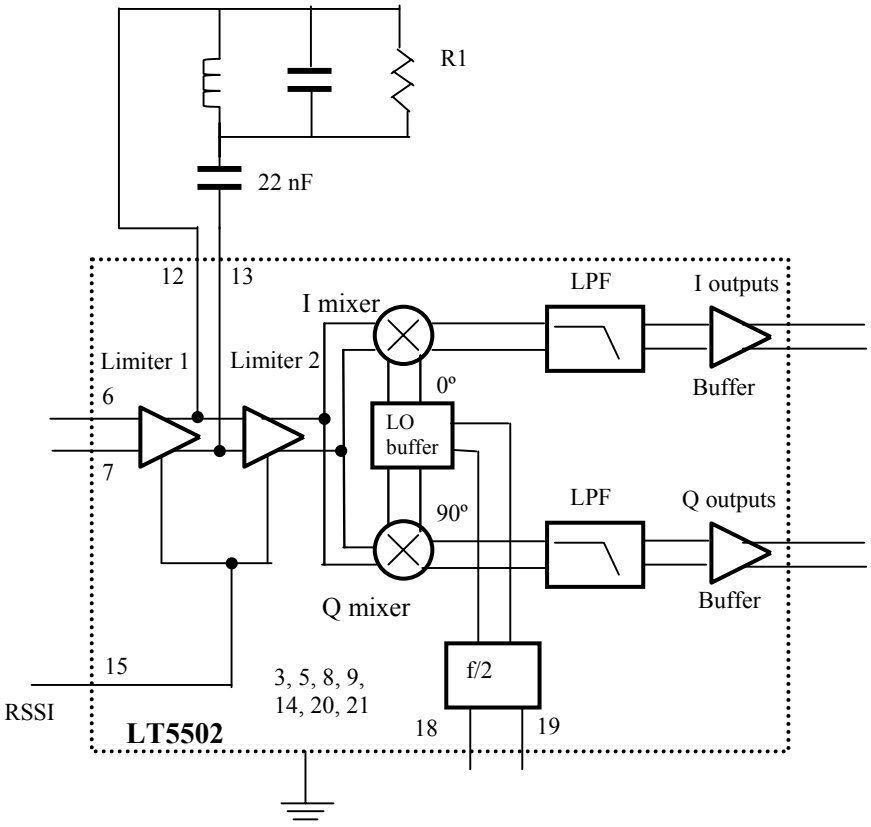
For TDD or half duplex receive/transmit applications (IEE 802.11 and other) receiver front-end shares input BP filter and antenna with transmitter. LNA is followed by optional BPF (depends on image rejection requirements of particular application), mixer and an IF filter. Typically for IEE 802.11 applications LNA has two gain settings: HIGH gain (15 to 20 dB) and LOW gain (0 to –15 dB) to satisfy input signal ranges from –80.0 to –4.0 dBm.

**Typical Rx NF performance (High gain)**

| | 1st BPF | RF switch | LNA | 2nd BPF | Mixer | IF BPF | LT5502 | **Cascaded:** |
|---|---|---|---|---|---|---|---|---|
| Noise Figure, dB | 2.5 | 0.75 | 4.0 | 2.5 | 14.0 | 10.0 | 7.0 | **9.86** |
| Gain, dB | -2.5 | -0.75 | 15 | -2.5 | 6.0 | -10.0 | 84.0 | **89.25** |

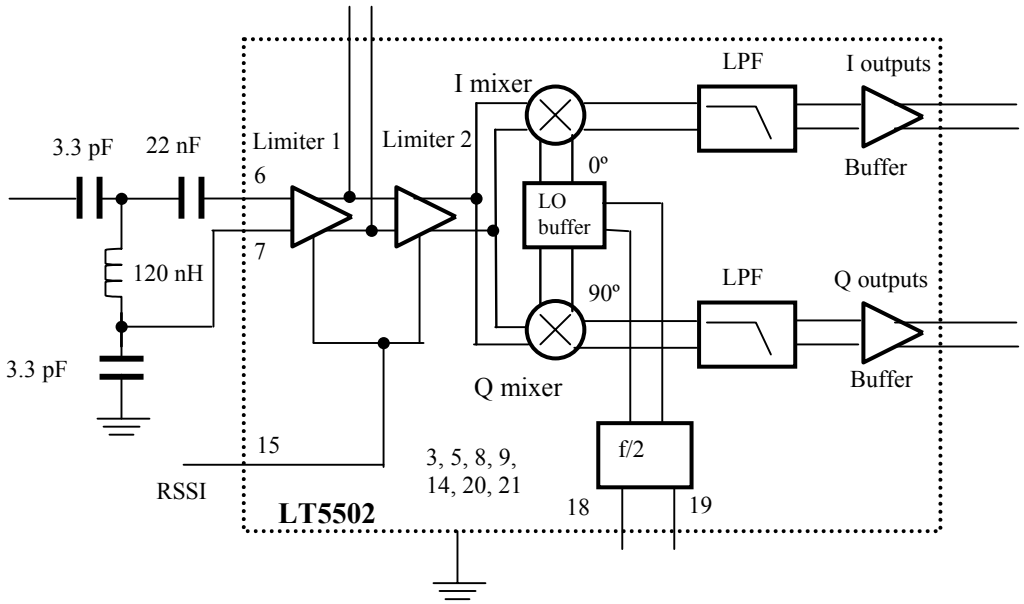
Considering IF noise BW= 22 MHz, S/N = 10 dB, the receiver sensitivity is equal:
KTB + NF + S/N = -100.58 dBm + 9.86 + 10.00 = -80.7 dBm, which satisfies sensitivity requirements of IEE 802.11 with conservative S/N = 10. NOTE: Actual receiver sensitivity is about 4.5 dB better due to the 7.7 MHz 3 dB bandwidth of LT5502 baseband filters. Product designers have to select trip point for LNA HIGH/LOW gain switching depending on actual applications. Intermodulation performance of the whole receiver is determined by receiver front-end circuitry performance.

**Interstage IF filter.**
LT5502 IC has provisions (pins 12 & 13) for optional interstage IF filter.
This filter can be implemented with or without shunt resistor R1. The interstage filter gives product engineers ability for additional sensitivity increase of 2 to 3 dB depending on Q-factor of the tank circuit. Implementing of the interstage filter may result in a group delay ripple increase at baseband outputs.

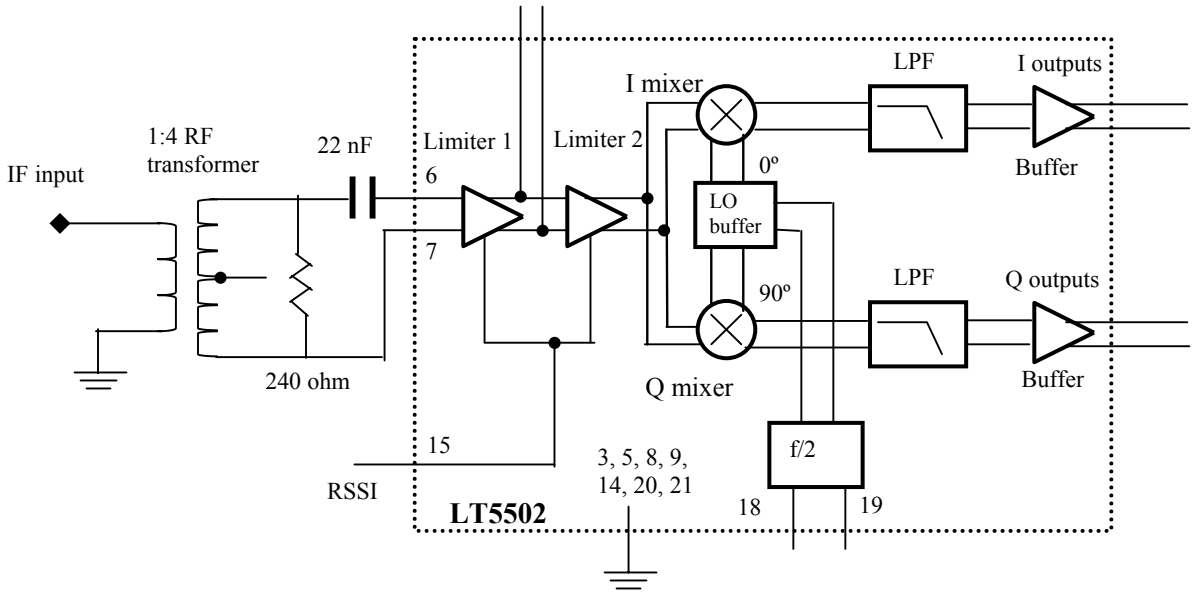


**IF input external circuitry.**
IF input circuitry of LT5502 can be configured by several different ways depending on cost, available PCB space and performance considerations.

1. Discrete single ended to differential circuit (values shown for 280 MHz IF frequency).
This circuit provides narrow band single ended to differential conversion and impedance matching. Cascaded NF is degraded by factor of the input matching circuit loss (.75 to 1.5 dB). This circuit provides maximum sensitivity and gain for IF portion.

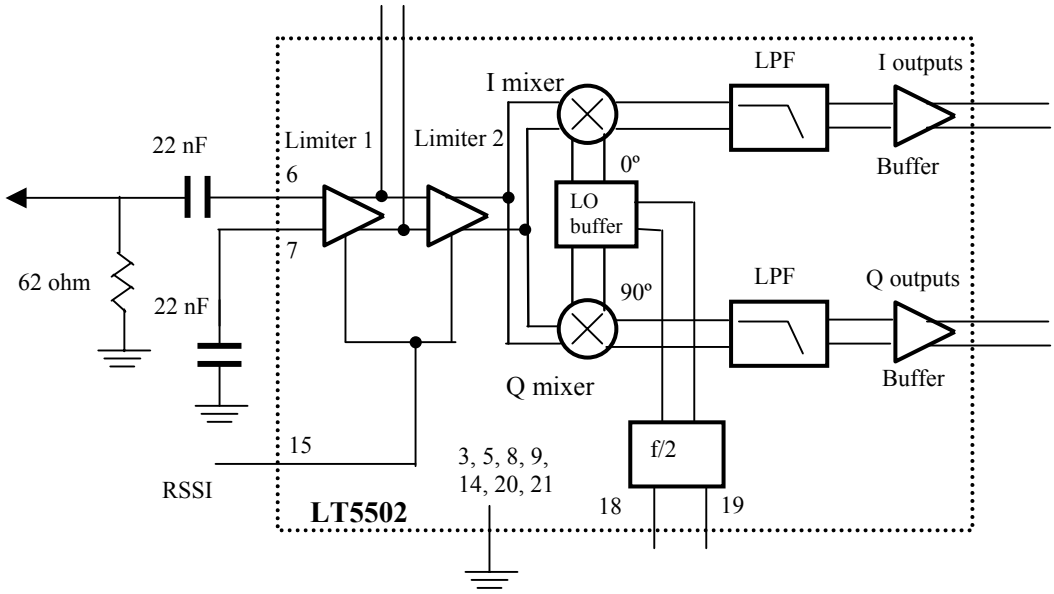



2. 1:4 RF transformer.
1:4 RF transformer with 240-ohm resistor in secondary provide broadband 50-ohm impedance matching at primary. Mini-Circuits JTX-4-10T 1:4 RF transformer and similar transformers from other manufacturers can be used. 1:1 RF transformer can be used as well with 50 to 62 ohm terminating resistor in secondary of transformer. Cascaded NF is degraded by the factor of the transformer loss (1.0 to 2.0 dB). This circuit provides maximum sensitivity and gain for IF portion.



3. Direct 50-ohm termination.

This circuit offers simple and most economical solution for single ended to differential conversion. 62 ohm resistor provides broadband 50-ohm impedance matching. Cascaded NF is degraded by the factor of 2.0 dB. Sensitivity of the IF portion is degraded by factor of 5 .0 to 6.0 dB.

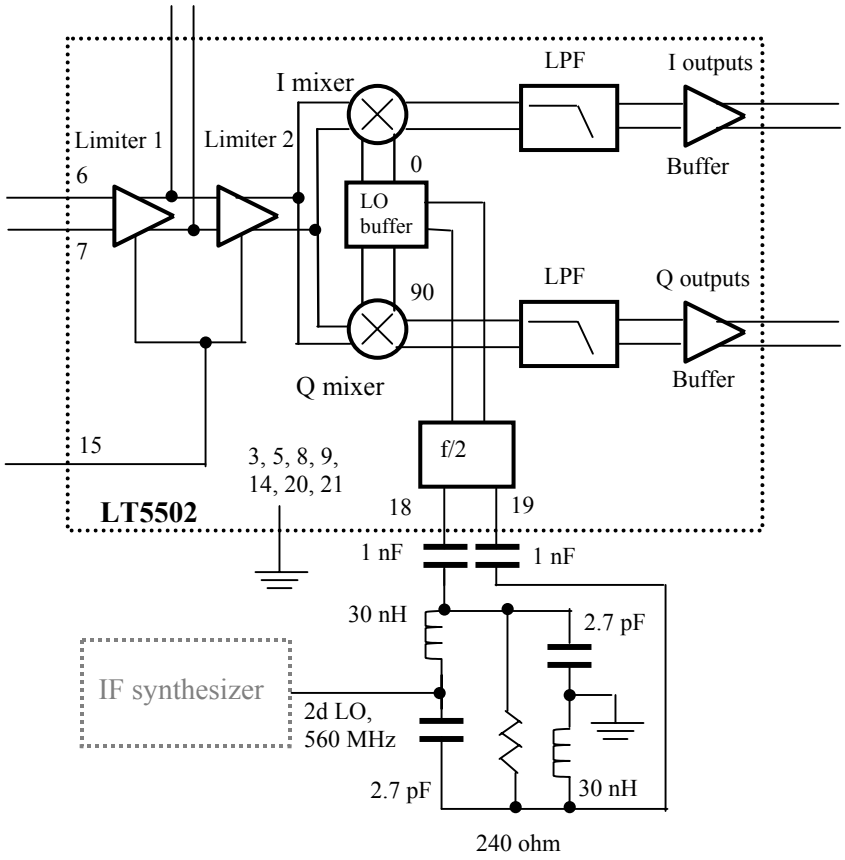



**LO input external circuitry.**

LO input of LT5502 can be configured by two different ways depending on cost, available PCB space and performance considerations. Direct 50-ohm resistive termination is not recommended because it would lead to increase of LO leakage, which in turn may cause sensitivity degradation.

1. Discrete single ended to differential circuit (values shown for 560 MHz LO frequency to support 280 MHz IF frequency).

This circuit provides relatively broadband single ended to differential conversion and impedance matching. LO leakage to the IF input is minimal due to common mode rejection.




2. 1:4 RF transformer.

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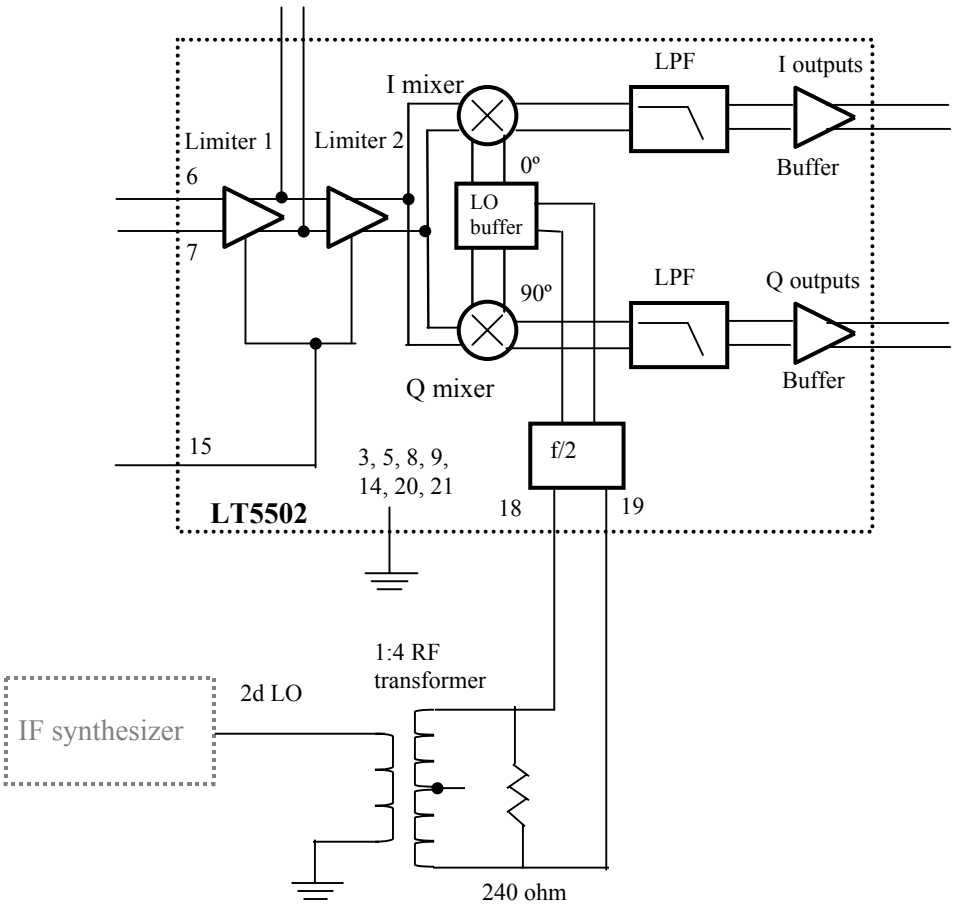


**Conclusion**

The LT5502 is the first part in the industry to offer 1.8V operation. With the lowest power consumption, it also provides the best RF performance from the competition. For a wireless receiver system where simplicity of implementation is desirable, the LT5502 is clearly the best solution. The high performance of RSSI function and integrated lowpass filters further simplify the RF system design.