High Performance 400MHz Quadrature IF Demodulator Runs from 1.8V Supply

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Introduction

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

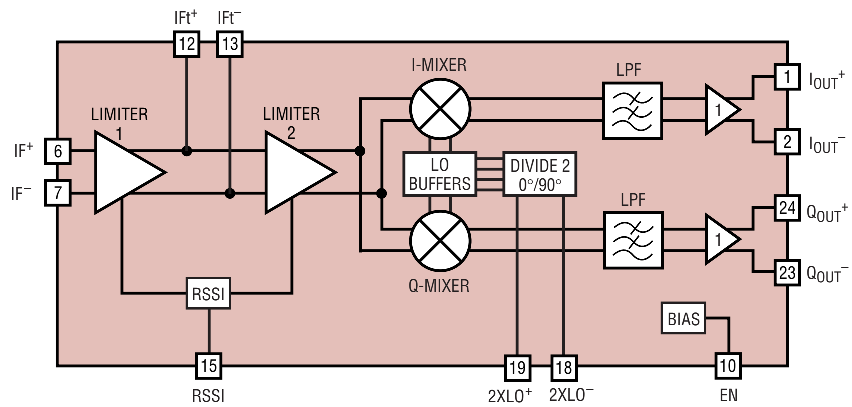

Figure 1. LT5502 block diagram

Circuit Description

The LT5502 consists of an IF limiting amplifier with 84dB small-signal gain, quadrature-converting mixers, lowpass filters and a receive signal strength indicator (RSSI) section. Figure 1 shows the LT5502 block diagram. In operation, an IF signal is limited by high gain amplifiers and is then demodulated into in-phase (I) and quadrature (Q) baseband signals using quadrature local oscillator (LO) carriers that are generated on-chip from an external 2 × LO signal. The demodulated I/Q baseband signals are passed through fully integrated 5th order lowpass filters and output drivers.

The LT5502 has a 4dB noise figure and an achievable sensitivity of –86dBm. Figure 2 shows the baseband I/Q output voltage swing versus IF input power at an IF frequency of 280MHz. The RSSI is built into the IF limiter, and offers a linear IF signal detection range of 90dB.

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

The lowpass filters on the I and Q channels serve for antialiasing and pulse shaping. The 3dB corner frequency is 7.7MHz and the group delay ripple is less than 17ns. The filter characteristics are stable over the –40°C to 85°C temperature range.

The LT5502 has two reduced-power modes of operation. In shutdown mode, supply current is reduced to less than 1µA. In standby mode with current consumption of 2.6mA, the baseband outputs are prebiased at their nominal quiescent voltages. This allows instant turn-on with no delay when the LT5502 is interfaced to a baseband chip using large coupling capacitors.

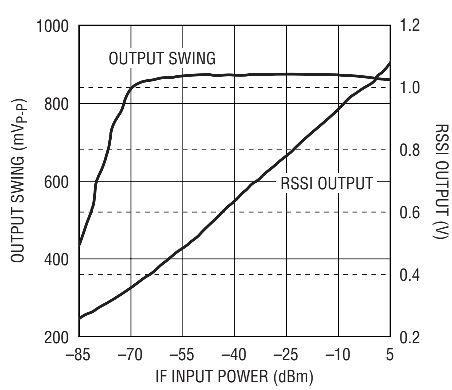

Figure 2. Baseband I/Q differential output voltage swing and RSSI output versus IF input power (IF Frequency = 280MHz, with a 1:4 IF input transformer, and without IF interstage filtering)

Applications and Implementation Issues

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

Table 1: Typical receiver NF performance (high gain mode)

	1st BPF	RF switch	LNA	2nd BPF	Mixer	IF BPF	LT5502	Cascaded
Noise Figure, dB	2.5	1.0	4.0	2.5	14.0	10.0	4	9.77
Gain, dB	–2.5	–1.0	15	–2.5	6.0	–10.0	84.0	89.0

should be placed as close as possible to pins 18 and 19 of the LT5502.

Application Example

In the example of Figure 3, an input signal of 2.4GHz to 2.5GHz is converted to a popular 280MHz IF frequency. The Rx front end (refer to Figure 4) typically consists of an input bandpass filter to provide image frequency rejection and an LNA (low noise amplifier) to establish a low system noise figure to meet sensitivity requirements, followed by a down-converting mixer.

The main LO uses low-side injection. A 280MHz 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 lowpass filters offer very good adjacent channel rejection at the baseband outputs, allowing product designers to relax requirements for the IF SAW filter performance and to use lower cost parts. The limiting IF amplifiers eliminate the need for an AGC function, and the dedicated RSSI output offers an unfiltered signal in real time with minimal delay. This simplifies requirements for the baseband and DSP portions of the product. External single-ended-to-differential converter circuits are employed at the IF and LO inputs. Direct termination of the IF input with a 50Ω resistor is possible, with small sensitivity degradation.

For time-division-duplex or half-duplex receive/transmit applications (IEEE 802.11 et al.), the receiver front-end shares the input bandpass filter (BPF) and antenna with the transmitter (again, see Figure 4). The LNA is followed by an optional BPF (depending on the application's image rejection requirements), a mixer and an IF filter. Typically, for IEEE 802.11 applications, the LNA has two gain settings: HIGH gain (15dB to 20dB) and LOW gain (0dB to –15dB) to satisfy input signal ranges from –80.0dBm to –4.0dBm.

The typical receiver NF performance is shown in Table 1. The cascaded NF of the receiver is 9.77. Considering the case where the noise BW is 7.7MHz and the signal-to-noise ratio (S/N) is 10dB, the receiver sensitivity at room temperature is given by:

$$kTB + NF + S/N = -105.14\text{dBm} + 9.77\text{dB} + 10.00\text{dB} = -85.37\text{dBm}$$

which satisfies the sensitivity requirements of the IEEE 802.11 standard with a conservative S/N of 10dB. Product designers must select the trip

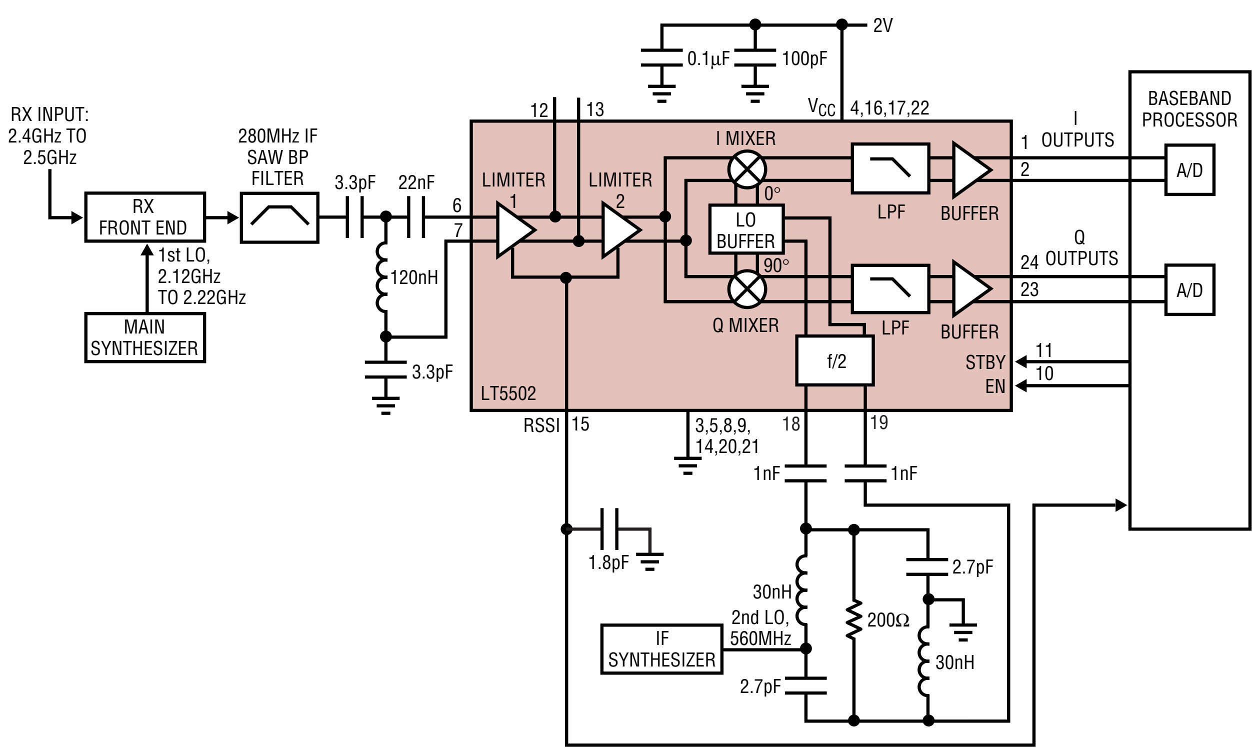

Figure 3. Example of 2.4GHz–2.5GHz receiver application (Rx IF = 280MHz)

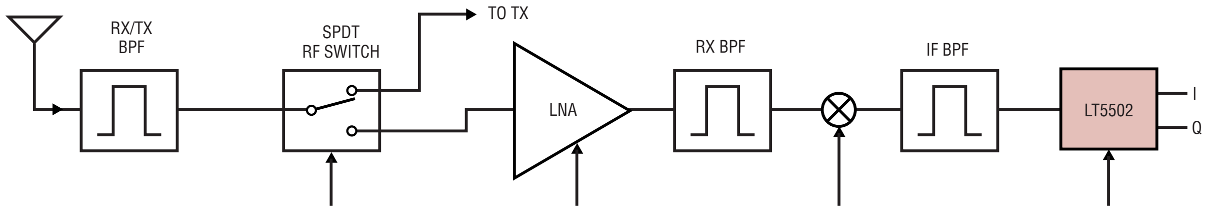

Figure 4. Example configuration of a 2.4 GHz–2.5GHz receiver

point for LNA HIGH/LOW gain switching depending on the actual application. The intermodulation performance of the overall receiver is determined by the front-end circuitry performance.

Interstage IF Filter

The LT5502 has provisions (pins 12 and 13) for an optional interstage IF filter (see Figure 5). This filter can be implemented with or without shunt resistor R1. The interstage filter can provide an additional sensitivity increase of 2dB to 3dB, depending on the Q-factor of the tank circuit. Use of the interstage filter may result in an increase of the group delay ripple at the baseband outputs.

IF Input External Circuitry

The external IF input circuitry to the LT5502 can be configured in several different ways, depending on cost, available board space and performance considerations.

The discrete single-ended-to-differential circuit in Figure 6a provides narrow band conversion and impedance matching. The cascaded NF is degraded by the input matching circuit loss, typically 0.75dB to 1.5dB. The component values shown in Figure 6a are for a 280MHz IF.

A 1:4 RF transformer with a 240Ω resistor in the secondary (Figure 6b) provides a broadband 50Ω impedance match at the primary. A Mini-Circuits JTX-4-10T 1:4 RF transformer or similar transformers from other manufacturers can be used. The cascaded NF is degraded by the transformer loss (1.0dB to 2.0dB). A 1:1 RF transformer can also be used with a 51Ω to 62Ω terminating resistor in the secondary of the transformer.

The circuit in Figure 6c offers a simple and economical solution for single-ended-to-differential conversion, although with a penalty of reduced sensitivity. A 62Ω resistor provides broadband 50Ω impedance matching. The cascaded NF for the IF circuit is degraded by 2.0dB.

LO Input External Circuitry

The LO input of the LT5502 can be configured in two different ways, depending on the cost, the available board space and performance considerations. Direct 50Ω resistive termination is not recommended because it would lead to an increase of LO leakage, which, in turn, may cause sensitivity degradation as well as deg-

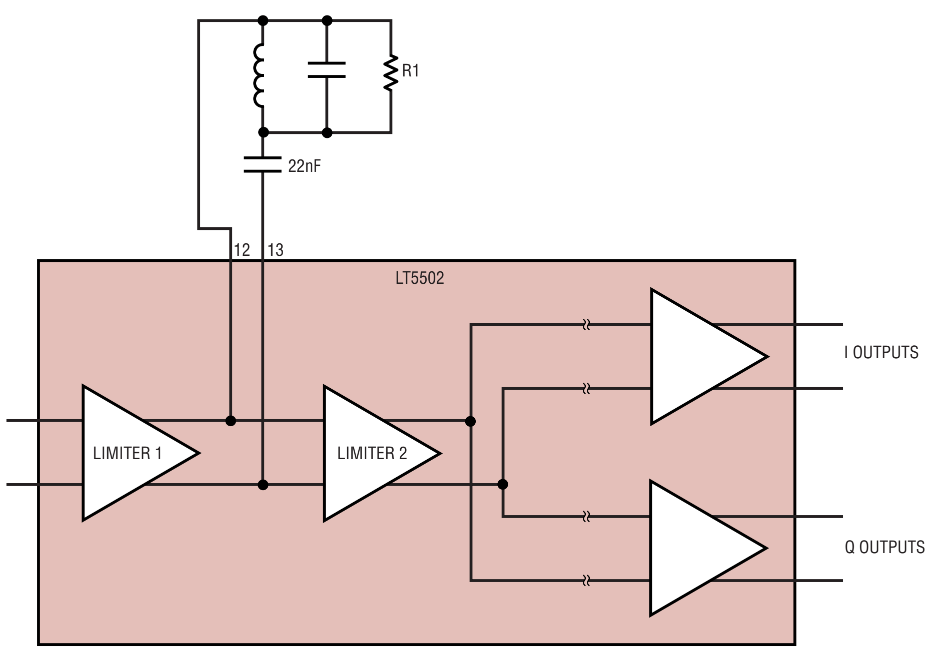

Figure 5. Example of an LT5502 interstage filter

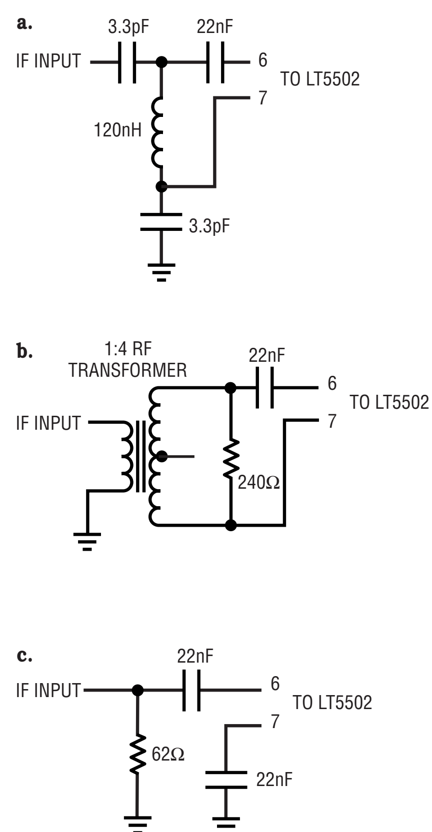

Figure 6. IF single-ended-to-differential input conversion and impedance matching

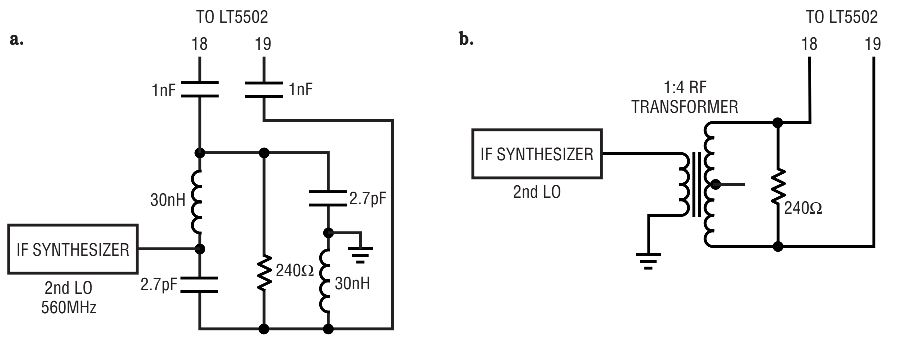

Figure 7. LO single-ended-to-differential input conversion and impedance matching

radiation of the quadrature matching of the I/Q outputs.

The discrete single-ended-to-differential circuit in Figure 7a provides relatively broadband conversion and impedance matching. LO leakage to the IF input is minimal due to common mode rejection. Values shown are for a 560MHz LO frequency to support a 280MHz IF frequency.

A 1:4 RF transformer with a 240Ω resistor in the secondary (Figure 7b) provides a broadband 50Ω impedance match at the primary. LO leakage to the IF input is minimal, due to common mode rejection. A Mini-Circuits JTX-4-10T 1:4 RF transformer or similar transformers from other manufacturers can be used. A 1:1 RF transformer can also be used with a 51Ω to 62Ω terminating resistor in the secondary of the transformer.

Conclusion

The LT5502 is the first IF receiver in the industry to offer high performance with a supply voltage range spanning 1.8V to 5.25V. Its integrated on-chip, lowpass filters and intrinsically low noise operation allow it to meet radio system specifications with a wide variety of input termination options. The LT5502 is designed to simplify the job of the RF product engineer, offering a range of favorable tradeoffs depending on the cost and sensitivity requirements of the application.

Addendum: Input Impedance Matching Procedures for Single-Ended-to-Differential Conversion

1. Turn input impedance into real resistance. The shunt inductor L_{SH} can be divided into two components: L_R and L_M (Figure 8). The L_R is used to resonate out the input capacitance, C_{IN}, of the LT5502, which is about 1.2pF. Its value can be determined by:

$$L_R = \frac{1}{(2\pi f_C)^2 C_{IN}} \bullet \frac{2.11 \bullet 10^{19}}{f_C^2} (nH)$$

2. Calculate L_M, C_{S1} and C_{S2}. After the input capacitive component is resonated out, the input impedance becomes real R_{IN}, which is about 2.2k. The L_M, C_{S1} and C_{S2} are used to convert R_{IN} into 50Ω. The following formulas can be used to calculate their values:

$$C_{S1} = C_{S2} = \frac{1}{\pi f_C \sqrt{50 \bullet R_{IN}}} \bullet \frac{9.6 \bullet 10^8}{f_C} (pF)$$

$$L_M = \frac{\sqrt{50 \bullet R_{IN}}}{2\pi f_C} = \frac{5.288 \bullet 10^{10}}{f_C} (nH)$$

3. Combine L_M and L_R into L_{SH} using the following equation:

$$L_{SH} = \frac{L_R \bullet L_M}{L_R + L_M}$$

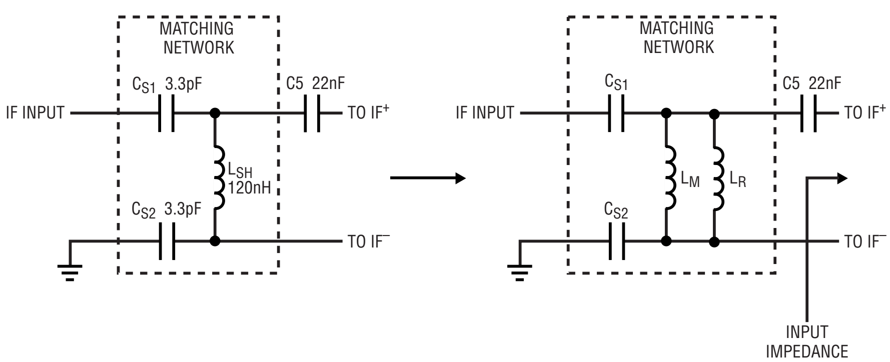

Figure 8. Input matching equivalent circuits