Keywords: tube motor, home automation, window blinds, movie screen, receiver, ISM, RF, radio, PCB, layout, Gerber, PADS, schematic, hardware, data rate, ASK, modulation, antenna, impedance

REFERENCE DESIGN 5390 INCLUDES: √Tested Circuit √Schematic √BOM √Description √Test Data √Layout

LFRD014: Tube Motor Receiver Reference Design

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Abstract: This reference design provides a complete demonstration platform for using an industrial/scientific/medical radio frequency (ISM-RF) receiver in a tube motor remote-control application. System structure, BOM, schematics, layout, and test results are provided.

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- Wireless Home
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- EV Kit Software
- Technical Support

General Description

Click here for an overview of the wireless components used in a typical radio transceiver.

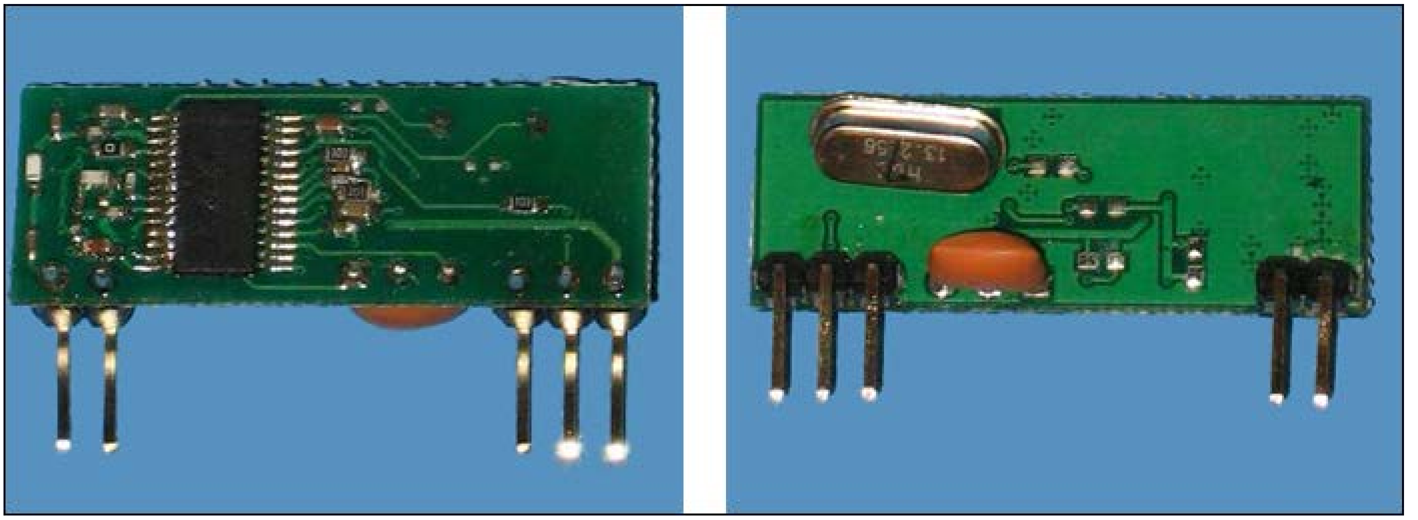
The MAX7034 receiver reference design (RD) is a self-contained evaluation platform for exercising the product as a tube motor receiver module. This receiver (Rx) board includes a simple power supply, data interface, and an antenna connection, all in a small modular form factor that allows the receiver to be placed inside of a tubular enclosure. The Rx board was manufactured to be usable as-is. Gerber files are available for simple cut-and-paste of the radio system design.

Features

- Proven printed circuit board (PCB) layout
- Proven component parts list

Receiver Board Description

The MAX7034 315MHz/434MHz amplitude-shift-keyed (ASK) superheterodyne receiver is configured in a near-standard form similar to the typical application circuit illustrated in the MAX7034 data sheet. The system is targeted for 433.92MHz operation and a 1kbps (NRZ) data rate. Four resistor connections are included in the design to allow flexible use of certain pins. Two connections have resistor footprints but are wired as shorts: R5 connects IR_SEL to VDD and R6 connects EN_REG to VDD. Two other connections are left open (unpopulated): R4 can connect DSP to DATAOUT for hysteresis and R7 can connect DSN to 3V3 for squelch. The module is designed to have a small footprint with minimal connections, to include a pair of pins for antenna/ground connections and a triplet of pins for ground/RX data/power connections. The board uses a 5V power supply.



Populated Rev-A2 board

Form Factor

The LFRD014 is designed as a demonstration platform for the MAX7034 receiver, using a very small form factor. It targets a low-cost, low bill-of-materials (BOM) count RF link—in this case, a tube motor application. The layout incorporates all of the required BOM on a 0.48-inch × 1.32-inch board. The IF filter and crystal both use footprints targeted for older, through-hole mounted components (at a lower cost). A pair of shunt capacitors is included on the crystal pins for minor frequency adjustment. The input network consists of a series cap (C4), series inductor (L1), shunt cap (C5), and a second series cap (C6). A placeholder is provided for the LNA source inductor (L2), but a short-to-ground is recommended. An inductor (L3) capacitor (C7) pair acts as the tank circuit, but it is recommended that the capacitor not be populated.

Antenna, Power, and Data Connections

Power to the Rx board is commonly supplied by a regulated 5V source, such as one generated from line voltage using a wall transformer (**Table 1**).

Table 1. Rx I/O Headers

Header	Signal Description
ANT-1	RX-ANT, antenna connection
ANT-2	GND, antenna ground connection
POWER-1	GND, supply ground connection
POWER-2	RXDATA, module output data connection
POWER-3	V5V, supply 5V power connection

Hardware Details

Receiver Specifications

Supply current (I_{DD}) at f_{RF} = 433MHz, +5.0V	7.2mA (typ)
Shutdown supply current (Iactive-low SHDN) at f_{RF} = 433MHz, +5.0V	8µA (max)
Sensitivity (PRFIN_MIN) (peak power level)	-113dBm (typ)

For testing and debugging purposes, the LFRD014 board was configured with an incorrectly specified crystal and no adjustments were made for parasitic board influences. Initial sensitivity testing for this configuration measured -94.6dBm at a 0.2% bit-error rate (BER) level.

Receiver Antenna Matching

The receiver matching network is similar to the network suggested in the MAX7034 data sheet, which assumes a 50? antenna. A degeneration inductor from the low-noise amplifier (LNA) source pin of the MAX7034 (LNASRC) to ground can be populated in the LFRD014 to adjust the input impedance of the LNA. When the degeneration inductor is present, the LNA input impedance looks like a 50Ω resistor in series with a 2pF to 2.5pF capacitor (without the inductor, the input impedance looks like a 500Ω to 700Ω resistor in parallel with a 2pF to 2.5pF capacitor). These impedance models can be used to design matching networks for any antenna impedance. Note when the antenna impedance is 50?, the matching network is typically a series inductor (with a DC-blocking capacitor). During range testing of the LFRD014 module, a 17.2cm (1/4 wavelength) wire antenna was used.

Selecting the Proper Crystal

One of the most common challenges associated with crystal-based receivers and transmitters is the proper tuning of the radio's oscillation circuit. The oscillator on the MAX7034 is intended to operate using a crystal specified with a 3pF load capacitance. This low value is not a very common specification for crystals; typically customers attempt to design a system using a crystal with a tested load capacitance of 6pF, 8pF, 10pF, or more, often due to cost or supply considerations. Using these crystals is not prohibited, but doing so presents a trade-off since the MAX7034 still only provides about 3.1pF of load to the crystal pins. This loading will cause a 10pF specified crystal to operate at a noticeably higher frequency than intended (see application note 1017, "How to Choose a Quartz Crystal Oscillator for the MAX1470 Superheterodyne Receiver" for further information). To compensate for this shift in frequency, a customer can present a larger load to the crystal by placing capacitors in the circuit. We recommend two shunt capacitors to ground rather than a parallel arrangement for enhanced flexibility and other loading benefits. The trade-off with this "adjusted" load is that too much capacitance connected to the circuit could cause a problem with the oscillation startup.

For demonstration purposes, the LFRD014 was populated with a 13.2256MHz crystal that had a specified C_L of 8pF. A debug measurement was made to investigate the oscillating frequency of the crystal populated on the PCB. To perform this test, an R&S® ZVL3 spectrum analyzer and a "sniffer" antenna were used to probe the crystal frequency. This antenna was held in close proximity to the crystal (or touching one of the leads as needed) to obtain an estimate of the operating frequency. The peak was measured at 13.23049MHz, which is high by 370ppm. This translates to an operating frequency of 434.085MHz (32 × 13.23049 + 10.7), which placed the expected LO and carrier frequency at 165kHz—higher than intended. This off-frequency operation of the crystal oscillator resulted in an incoming ASK carrier and associated sidebands that were pushed to the edge or even past the knee of the IF filter. This caused an unnecessary attenuation of the signal power.

To further test the impact of this error, the passband of the IF was tested. By sweeping the carrier signal in frequency and monitoring the IF filter output with the spectrum analyzer (in max-hold mode) a plot of the filter bandwidth was collected. Marker M1 was placed at 10.7MHz (nominal center of the IF filter) and the delta marker D2 was placed at the frequency spike where the RF signal was tuned to 433.92MHz. The signal generator was set to 434.085MHz when the IF spike was at M1, confirming the shift in LO frequency. The plot illustrated in **Figure 1** shows that the mistuning degrades the carrier by about 7dB. Sideband information needed for ASK demodulation is actually attenuated further, as well as being distorted due to the nonlinear location on the filter curve.

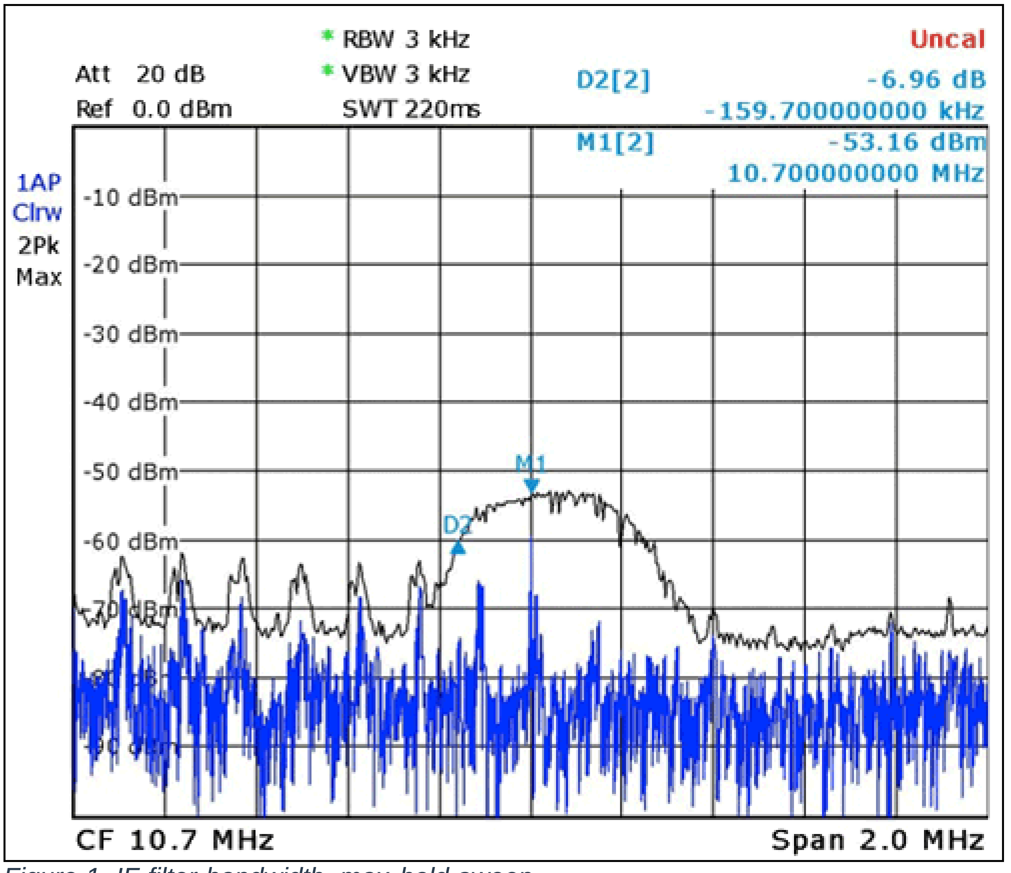


Figure 1. IF filter bandwidth, max-hold sweep.

The following entries were used for the estimates for a specified load capacitance of the crystal at 8pF: MAX7034; C_{PAR} = 1.8pF; C_{SHUNT} = 0pF; C_{SER} = 10000pF; f_0 = 13.2256MHz; C_0 = 2.8pF; C_L = 8.24pF; R1 = 60Ω; C1 = 11.1fF. With these values, the pulling calculation showed an actual RF frequency of 434.0853MHz. Then by adding experimental shunt capacitance values, a pair of 10pF capacitors will adjust the oscillation frequency back to the target value and, assuming the other crystal values are well estimated, the startup margin will be acceptable. The negative resistance calculation was -291.5Ω, compared to 4 × R1 of 240Ω. This left about -50Ω of additional margin.

As a first-order attempt to improve the sensitivity of the demonstration LFRD014 module, two 10pF shunt caps were added at C21 and C22. The resulting crystal oscillator frequency was confirmed to have moved and was now operating at the corrected frequency of 13.226MHz. After adjusting the RF generator to be centered back at 433.92MHz, sensitivity measured in at -107dBm. This 12.4dB improvement resulted from the proper tuning of the reference frequency for the local oscillator.

Tuning the Tank Circuit

The next step to optimize the receiver is to make sure the tank circuit at the LNA output and mixer input is well tuned to the operating frequency. This off-chip inductor-capacitor pair provides a tuned, high-impedance circuit that converts the LNA current output into a voltage, which in turn is fed to the on-chip mixer.

In order to measure the tuning frequency of the tank circuit, a network analyzer is needed. Some of this data can be collected manually with an RF generator and a spectrum analyzer, but a two-port NA is the best tool for the job. The measurement stimulus comes from Port 1 of the NA, which is connected to the LNA input through the antenna feed. The measurement is taken by using a sniffer antenna connected to Port 2 of the network analyzer. This untuned antenna can be held in close proximity to the inductor of the tank circuit, where it will pick up radiated emissions at the circuit's resonant frequency and provide an S21 measurement. The use of a -20dBm or -30dBm source power setting is recommended to avoid putting the LNA input into overdrive.

The suggested component values for the tank circuit are a 27nH inductor in parallel with *no* capacitor, simply to allow the parasitics of the PCB to act as the resonant capacitive element. The resonant frequency of a tank circuit can be calculated from the following equation:

$$\omega_0^2 = (2\pi f_0)^2 = \frac{1}{LC} \text{ or } f_0 = \frac{1}{2\pi\sqrt{LC}}$$

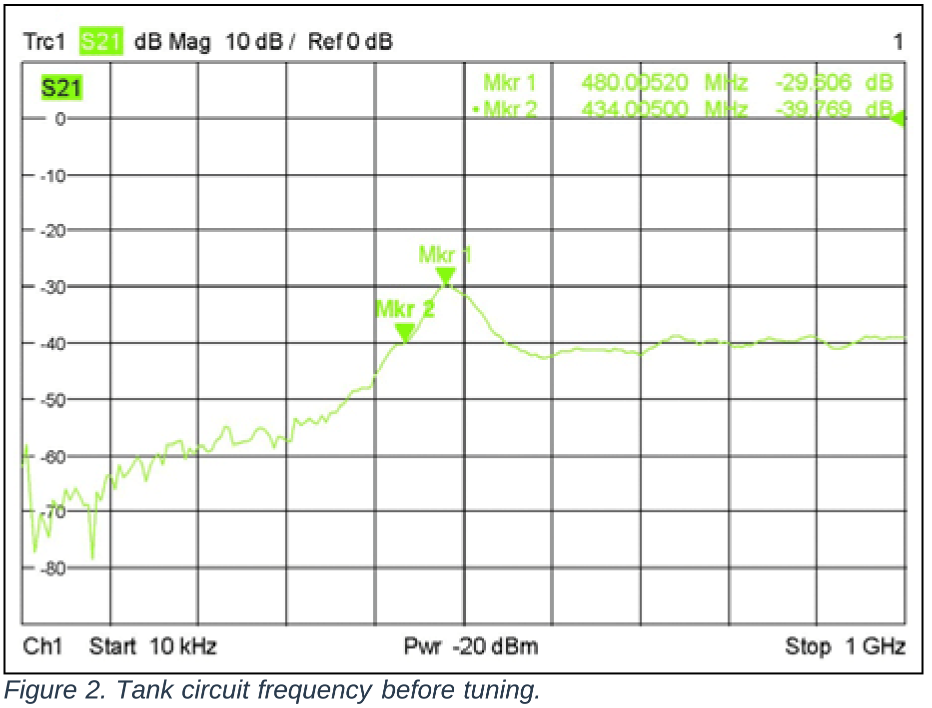


Figure 2. Tank circuit frequency before tuning.

The initial measurements of this tank circuit showed a peak around 480MHz and at the target frequency of 434MHz; the system showed a loss of 10dB from that peak.

Given that L3 = 27nH, the actual parasitic capacitance can be extracted. Then with the same equation, a suggested value for C7 can be calculated.

For the circuit operating at 480MHz, the parasitic capacitance C_P would be about 4.07pF:

$$C_P = \frac{1}{(27nH)(2\pi\ 480MHz)^2}$$

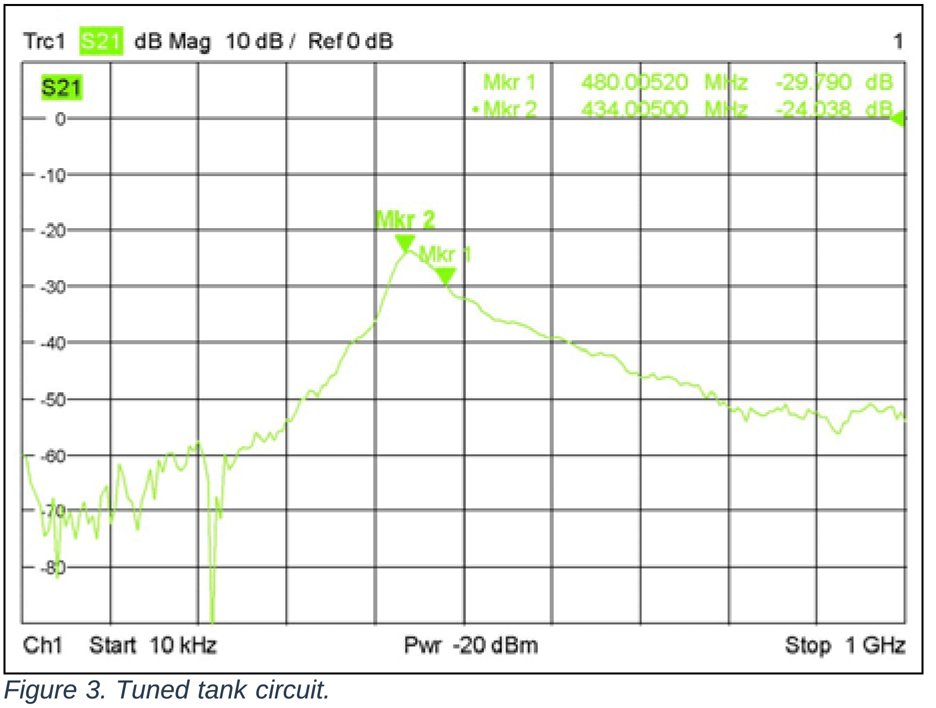


Figure 3. Tuned tank circuit.

With the target resonant frequency of 434MHz, the ideal capacitance becomes 4.98pF and thus the added capacitance need for the tank circuit is about 0.91pF:

$$C7 = \frac{1}{(27nH)(2\pi\ 434MHz)^2} - 4.07pF$$

Adding a 1.0pF capacitor to the C7 location was used as a second step to improve the sensitivity of this demonstration LFRD014 module. With the adjusted tank circuit, the S21 measurement indicated the peak to be very near the target of 434MHz. Once again, sensitivity was measured, now with both the crystal properly tuned and the tank circuit parasitic corrections. Adding three capacitors resulted in a new sensitivity of -111dBm. This is a combined 16.4dB improvement from the original baseline result.

Receiver Baseband

The target data rate of the baseband circuit should be designed with the corner frequency at 1.5 times the fastest expected data rate from the transmitter (as recommended in the MAX7034 data sheet). More information regarding the receiver baseband and data slicing circuitry can be found in application note 3671, "Data Slicing Techniques for UHF ASK Receivers." Since this design was targeting 1kbps NRZ, the corner frequency of the data filter would be 1.5kHz. (Manchester encoding is recommended. See application note 3435, "Manchester Data Encoding for Radio Communications" for more information.)

For a Sallen-Key Butterworth data filter:

$$C13\ (C_{DFFB}) = \frac{1}{141.4k\ \pi\ f_C} = \frac{1}{141.4k\ \pi\ 1.5k} = 1500.7pF$$

Selected 1500pF capacitor value for C13.

$$C12\ (C_{OPP}) = \frac{1.414}{400k\ \pi\ f_C} = \frac{1.414}{400k\ \pi\ 7.2k} = 750.1pF$$

Selected 750pF capacitor value for C12.

The time constant of the RC circuit provides an averaging process that further filters the data filter output to form the threshold voltage of the data slicer comparator. This time constant should be set to approximately 10x the bit interval of the data rate (1kHz). The starting point R1 = 20k?, C17 = 0.47µF was chosen, which is only about a 1-bit interval.

Operational Setup and Use

In this reference design, the transmitter was first emulated using a bench-top RF generator and then implemented for range-testing purposes, using a handheld key fob unit.

Estimated Range

The predicted range in a flat unobstructed outdoor area is based on the following assumptions:

- f_0 = 433.92MHz
- P_{PA} = +10dBm
- G_T = -18dBi (typical value for a small loop antenna)
- h_{TX} = 1m
- h_{RX} = 1m
- G_R = 4.14dBi (ideal 1/4λ antenna = 5.14dBi)
- L_{CONR1} = -0.57dB
- Path loss varies at a rate of R^{-4} because of ground bounce interference
- Rx sensitivity set at -113dBm

The calculated estimate of "open field" range is approximately 370m (see application note 5142, "Radio Link-Budget Calculations for ISM-RF Products" for more information).

Range Testing

Although no baseline data were taken, the system was configured for a "parking lot" range testing using the improved Rx module. A small fixture was assembled to provide power from a 5V DC supply, and the DATA line was configured to be visible on an oscilloscope for assessing a pass/fail distance. The hardware setup was moved outdoors for evaluation using a 12V, discrete key fob transmitter as the signal source.

Figure 4. Range testing setup.

The initial configuration using a 34cm antenna was indicating a square-wave signal out to over 50m. The wire antenna was then swapped with a 17.2cm (1/4λ at 434MHz) antenna and the range test was repeated. The new indicated range was 75m to 80m. The effective operating range is expected to be noticeably farther given an actual decoding system rather than the qualitative, visual "oscilloscope method."

Component List

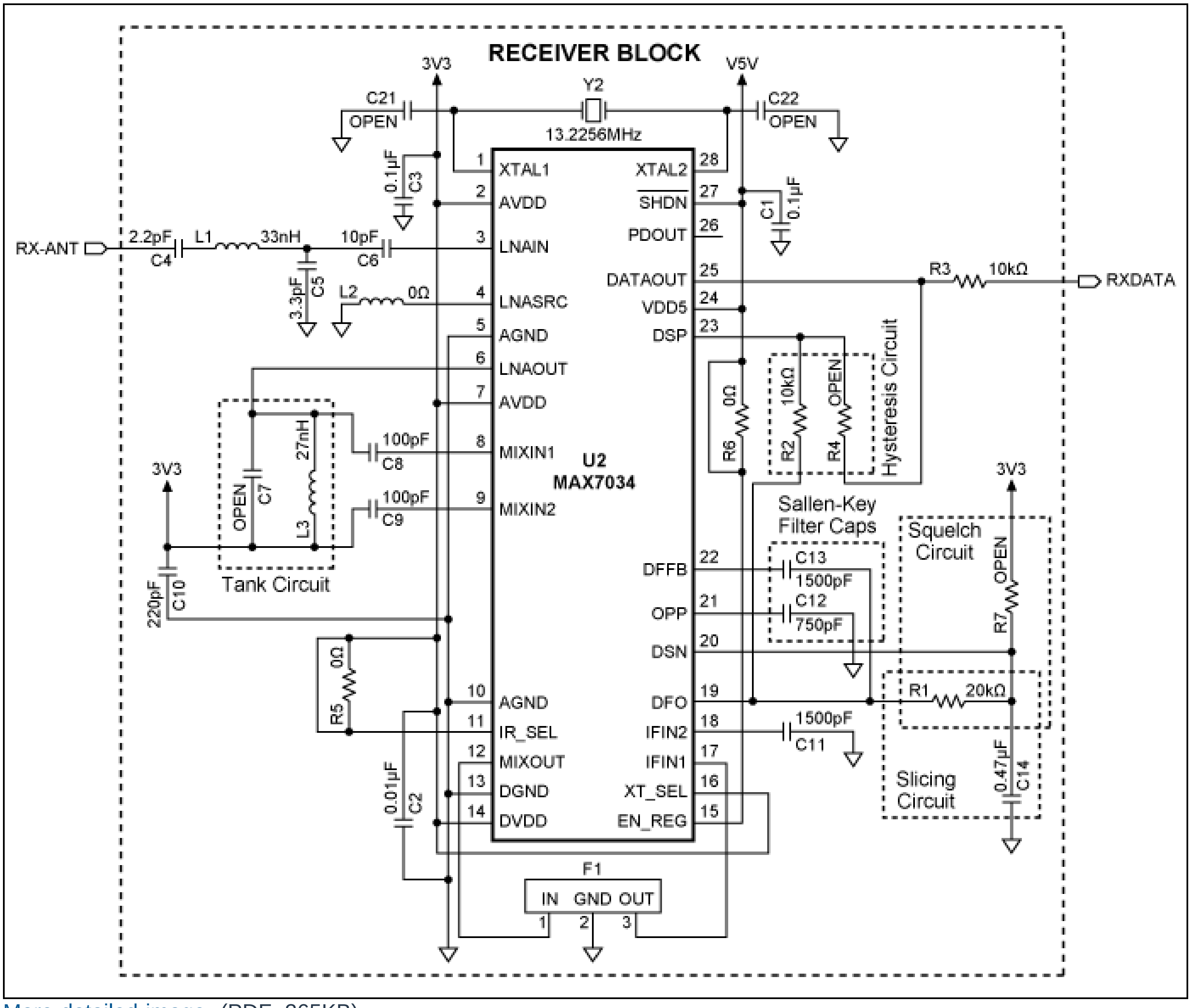
The following table provides a list of components used to populate the Rx board. Maxim recommends high-quality, wire-wound inductors for components used on the board.

Designation	Qty	Description
C2	1	CAP, 0.01µF, 10%
C1 C3	2	CAP, 0.1µF, 10%
C14	1	CAP, 0.47µF, 10%
C8-9	2	CAP, 100pF, 5%
C6	1	CAP, 10pF, 5%
C11 C13	2	CAP, 1500pF, 5%
C4	1	CAP, 2.2pF, 5%
C10	1	CAP, 220pF, 5%
C5	1	CAP, 3.3pF, 5%
C12	1	CAP, 750pF, 5%
C7 C21-22	3	CAP, Open
F1	1	FLT\MURATA\SFTLA10M7FA00-B0, 10.7MHz
L3	1	IND-MOLDED, 27nH, 5%
L1	1	IND-MOLDED, 33nH, 5%
U2	1	MAX7034
R5-6 L2	3	RES, 0Ω
R2-3	2	RES, 10kΩ
R1	1	RES, 20kΩ
Y2	1	XTAL-SMD, 13.2256Mhz

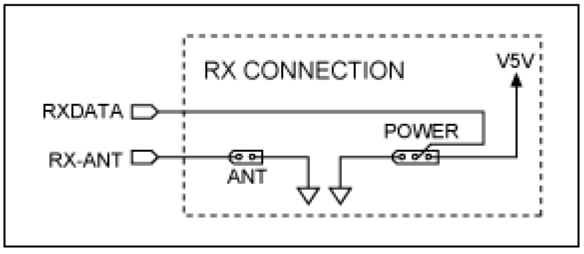
Total Rx Cost (~1k quantities):	Rx BOM	$2.63
	PCB	$0.50
As configured		**$3.13**

Schematics

(Revision A2: a detailed copy is available here.)

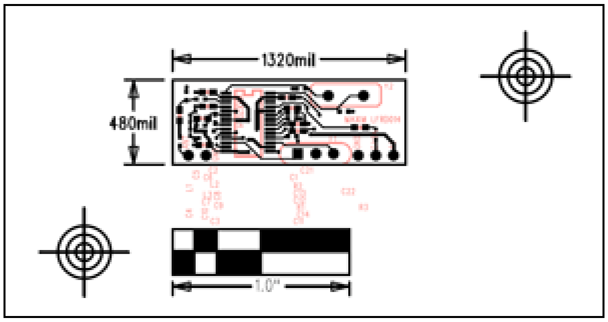


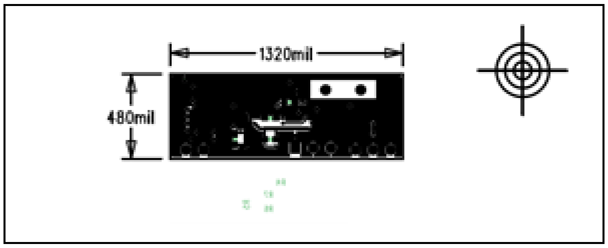
More detailed image. (PDF, 265KB)

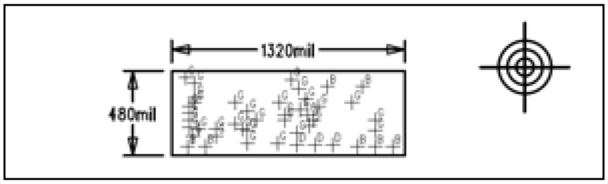


Layout

(Revision A2: detailed scale plots are available here.)





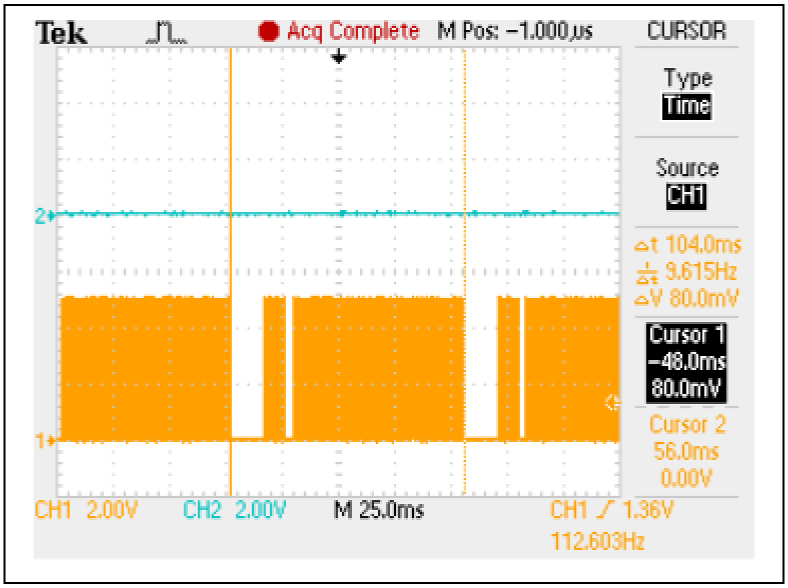


Related Application Notes

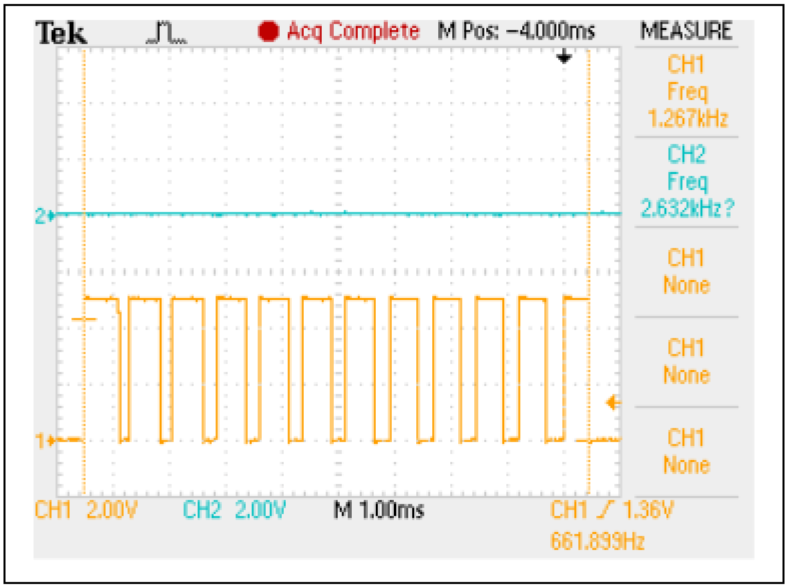
Application note 1017, "How to Choose a Quartz Crystal Oscillator for the MAX1470 Superheterodyne Receiver"
Application note 2815, "Calculating the Sensitivity of an ASK Receiver"
Application note 3435, "Manchester Data Encoding for Radio Communications"
Application note 3671, "Data Slicing Techniques for UHF ASK Receivers"
Application note 4636, "Avoid PC-Layout Gotchas in ISM-RF Products"
Application note 5142, "Radio Link-Budget Calculations for ISM-RF Products"

Appendix I: Tx and Rx Range Testing

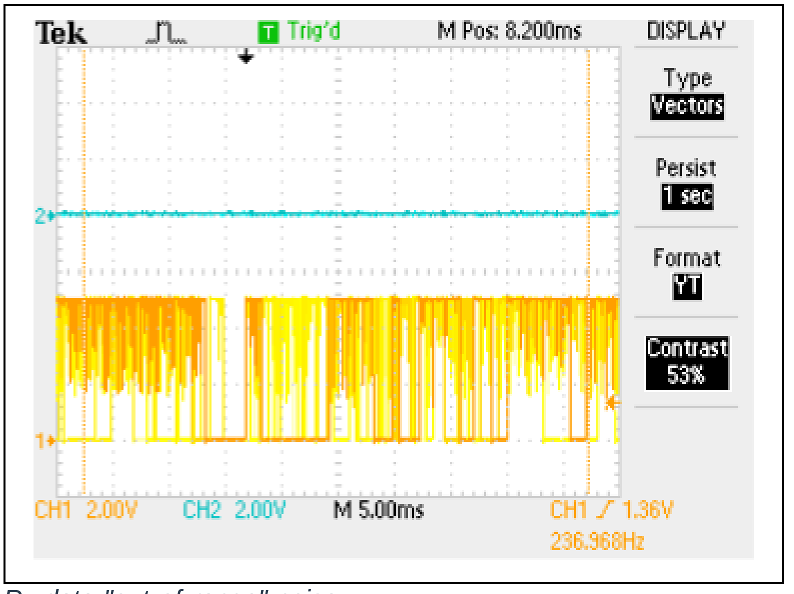
The following plots show the packet transmissions from the key fob as decoded by the LFRD014 receiver. These plots were used to indicate range by qualitatively assessing the signal received by the reference design. Since a matching decoder was not available at the time of testing, a true operating range was not determined.



Rx data oscilloscope capture (zoomed in).



Rx data oscilloscope capture.



Rx data "out-of-range" noise.

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Related Parts		
MAX7034	315MHz/434MHz ASK Superheterodyne Receiver	Free Samples

More Information
For Technical Support: http://www.maximintegrated.com/support
For Samples: http://www.maximintegrated.com/samples
Other Questions and Comments: http://www.maximintegrated.com/contact

Application Note 5390: http://www.maximintegrated.com/an5390
REFERENCE DESIGN 5390, AN5390, AN 5390, APP5390, Appnote5390, Appnote 5390