Using the LMX3162 for 2.4-GHz ISM Band

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1.0 ABSTRACT

A monolithic radio transceiver will be demonstrated for the emerging wireless data and voice applications in the unlicensed 2.4-GHz ISM band including Bluetooth, HomeRF and Upbanded DECT standards. The architecture and the functionality of the LMX3162 will be described thoroughly. The circuit blocks and the topology will be discussed to implement the complete radio with the measuring performance. These results illustrate the single-chip LMX3162 is a possible solution to support the various standards in ISM band.

2.0 INTRODUCTION

Higher and higher levels of integration in RF circuits have become the trend over the past decade. For example, the complete receiver on a chip has been available in the industries for many years ago. The LMX3162 integrated circuit (IC) takes radio integration one step further by including receiver, transmitter, and the phase locked loop (PLL) on the same piece of silicon. In accordance with a 1.3-GHz PLL, a frequency doubler is employed and both the receiver and the transmitter can share the same PLL. This reduces the complexity of the system as well as avoiding the problem of injection locking or LO pulling in the VCO. *Figure 1* shows a typical implementation of a 2.4-GHz radio front-end transceiver. In addition to the PLL and frequency doubler, a 2.5-GHz low-noise mixer, intermediate-frequency (IF) amplifier, limiting amplifier, frequency discriminator, and received-signal-strength indicator (RSSI) for the receiver, as well as a buffer amplifier for the transmitter are integrated in LMX3162[1][2]. Only a few of channel selection filters, VCO and loop filters are required external components[1]. The discrete low noise amplifier (LNA) and power amplifier (PA) are optional depending on system requirements for the various standards and applications.

New standards have been developed for the exploding Home PC, handheld service access and information appliance market. For this reason, the unlicensed 2.4-GHz Industrial, Scientific and Medical (ISM) band has been received a great amount of interest in the wireless communications industry worldwide. The common frequency range (2.4 GHz to 2.483 GHz) in Europe, Japan and the USA has also made this band attractive to many product manufacturers. Several companies have their own solutions available in the market today. The open standards will guarantee inter-operability between products of different brands as well as gain customer acceptance and market penetration. Recently, there has been much activity developing products based on Bluetooth and HomeRF protocols.[3][4]

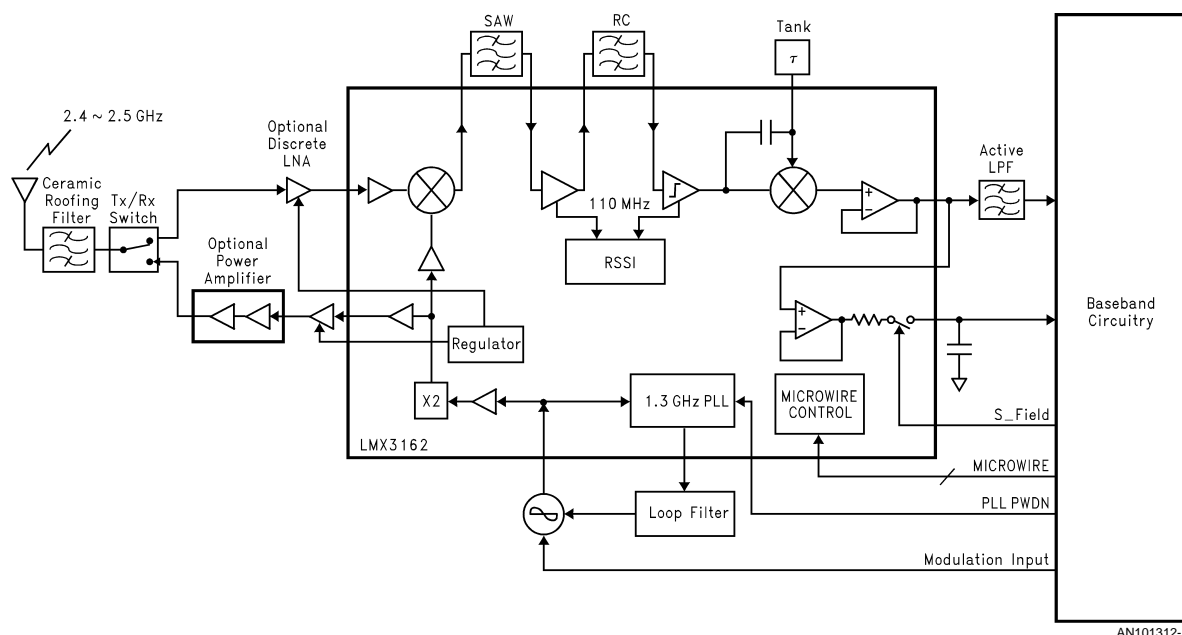[1]The VCO regulator and biasing capacitors are not included here.

FIGURE 1. Transceiver Blocks

3.0 STANDARDS

Bluetooth[2] is a standard for radio-based wireless ports with 10–100 m range as a wireless pico-LAN. In comparison, the Shared Wireless Access Protocol-Cordless Access or SWAP-CA is focused on the home networking with 300 m range. Another option is moving the Digital Enhanced Cordless Telephone (DECT) to the 2.4-GHz band since both Bluetooth and HomeRF are loosely based on the DECT. All these standards are specifically designed with frequency hopping algorithms to work well in the presence of microwave ovens and also include page mode to maximize battery life. An overview of the different standards is shown in *Table 1*.

[2]Bluetooth frequency range is for US only.

The Bluetooth and HomeRF performance requirements are less stringent as the DECT standards. For examples, the sensitivity and the in-band blocking levels are much relaxed. In particular, HomeRF does not need an adjacent channel specification and only requires co-channel interference at the third channel –10 dB below the signal. Moreover, the in-termodulation product (IIP3) requires only –39.5 dBm. Given these relaxed standards, the LNA is an optional device for Bluetooth and HomeRF. Without the LNA, LMX3162 can achieve the sensitivity of –83 dBm. This further reduces the number of external components and power consumption. The power amplifier is also optional because two classes of transmitting power defined in both Bluetooth and HomeRF.

Deploying Bluetooth and HomeRF in accordance with DECT standard, the difference between the masks of transmit spectrum, as FCC part 15[5], should be noticed. In DECT, it is not 20 dB down at 1-MHz offset from the desired channel, where the data rate is 1.152 Mbits/s in GFSK and the BT product equals to 0.5.

There are two ways to resolve this issue. For minimal impact, simply lowering the bit rate to 1 Mbits/s while keeping the same BT product will decrease the bandwidth of the transmit spectrum to meet the requirements. For full DECT data rate, the alternative method is to reduce the BT product to 0.35 so that the spectrum can be met. However, the intersymbol interference (ISI) will be degraded by several dB.

TABLE 1. Parameter Comparison for 2.4-GHz Applications

Parameters		Bluetooth	HomeRF		Upbanded DECT
FREQUENCY					
Band		2.402 GHz–2.480 GHz	2.404 GHz–2.478 GHz		2.40 GHz–2.483 GHz
Channel Spacing		1.000 MHz	1.000 MHz		≥1.000 MHz
Accuracy		±75 kHz	±120 kHz		±50 kHz
Lock Time (est)		220 µs	134 µs		30 µs (416.67 µs w/1 Blind Slot)
Drift		±40 kHz/5 Slots	NA		±40 kHz/ms
MODULATION					
Type		GFSK	2-FSK	(4-FSK)	GFSK
Deviation	Min	±140 kHz	±85 kHz	±135 kHz	±200 kHz nom
	Max	±175 kHz	±177.5 kHz	±190 kHz	(±250 kHz nom)
Burst Bit Rate		1 Mbits/s	0.8 Mbit/s	1.6 Mbit/s	1.152 Mbits/s (1.0 Mbits/s)

TABLE 1. Parameter Comparison for 2.4-GHz Applications (Continued)				
Parameters		**Bluetooth**	**HomeRF**		**Upbanded DECT**
MODULATION					
Accuracy		+/–20 ppm	+/–50 ppm	9	
CONNECTION					
Duplex		TDD	TDD		TDD
Access		Packet (TDMA)	Packet (TDMA)		TDMA
Voice Coder		CVSD/PCM (64 kb/s)	ADPCM (32 kb/s)		ADPCM (32 kb/s)
Data Rate (up to)		721 kb/s Half Duplex + 57.6 kb/s (return)	800 kb/s	1600 kb/s	552 kb/s (479 kb/s) Half Duplex
Maximum Dwell Time		11.25 ms	20 ms		5 ms
TRANSMITTER					
Transmit Power		1 mW (100 mW)	100 mW (1 mW)		250 mW
Transmit Adjacent Channel Power	1st	–20 dBc	–20 dBc		–20 dBc
	2nd	–30 dB	N/A		–34 dB
	3rd	–40 dB	–10 dB		–40 dB
1st Local Oscillator Phase Noise vs Offset Frequency (Rx and Tx)		–80 dBc/Hz @ 550 kHz	–80 dBc/Hz @ 500 kHz		–98 dBc/Hz @ 1.728 MHz
		–101 dBc/Hz @ 2 MHz	–92 dBc/Hz @ 4 MHz		–120 dBc/Hz @ 3.456 MHz
		–111 dBc/Hz @ 3 MHz	–102 dBc/Hz @ 5 MHz		–134 dBc/Hz @ 5.128 MHz
RECEIVER					
Sensitivity (BER=1e-3)		–70 dBm	–76 dBm	–62 dBm	–86 dBm
IIP3		–21 dBm	–39.5 dBm	–54 dBm	–24 dBm
Co-channel Interferer		–11 dBc	–7 dBc		–10 dBc
Max Input Level		–20 dBm	–20 dBm		> –33 dBm
Adjacent Channel Interferers (C/1)	1st	0 dB	N/A		–13 dB
	2nd	–30 dB	0 dB		–34 dB
	3rd	–40 dB	–10 dB		–40 dB

4.0 TRANSCEIVER DESIGN

4.1 Synthesizer

LMX3162 contains a PLL running at one half of the ISM band and utilizes a frequency doubler to synthesize the desired frequencies as shown in *Figure 1*. This architecture alleviates the disturbance to the local oscillator (LO) when the power amplifier (PA) is switched on. The radiation is isolated by "offsetting″ the PA output frequency from the LO frequency.

HomeRF, Bluetooth and Upbanded DECT all are half-duplex TDMA systems. The data is transmitted and received in different time slots. Therefore, the PLL can be shared between transmit and receive sections. Simpler the circuitry also means less power consumption.

4.1.1 Lock Time

The function of the PLL is to hop the desired carrier frequency before data transmission and reception. The time the PLL taken to settle down within an acceptable error is called the lock time. From *Table 1*, it is obviously that the lock time requirement of 134 µs from HomeRF. In comparison, 220 µs for Bluetooth and 416.67 µs for Upbanded DECT with 1 blind slot[3] are much relaxed.

[3]The blind slot operation allows certain latency and provides enough time to acquire lock.

Before solving the lock time problem, another issue should be discussed. To improve performance as well as reduce the cost of implementation, the transceiver transmits and receives data in the open loop mode[6]. The PLL is first locked via MICROWIRE™ programming at the desired carrier frequency and then shut down during the data transmission or reception. *Figure 2* illustrates the timing diagram. In this short duration, the VCO is subsequently modulated by the baseband signal in transmit mode or idling in the receive mode. This implies the drifting of the VCO must be negligible compared to the carrier frequency. In order to achieve low frequency drift (<50 kHz/25 ms), a large capacitor[4] is mandated. This modification limits the loop bandwidth and increases the lock time substantially. (For a complete MICROWIRE programming description, see LMX3162 data sheet and evaluation notes.[1][2].)

[4]The loop capacitors discharge or charge because of the leakage currents associated with the charge pump of the PLL and the varactor of the VCO.

FIGURE 2. Timing for Open Loop Operation

FIGURE 3. Ultra Low Drift PLL

To resolve this issue (in particular for HomerRF), a unity gain op-amp, a CMOS sampling switch and a low-leakage capacitor are employed between the loop filter and the control line of the VCO, as illustrated in *Figure 3*. This configuration handles the lock time and current leakage requirements by using different values of capacitors. With this implementation, a small capacitor in the loop filter is used to provide loop bandwidth and phase margin to achieve the required lock time while a large capacitor (C_S) at the control line of the VCO reduces the frequency drift. The unity gain op-amp duplicates the information (voltage) stored to the low-leakage capacitor (large capacitor) while the PLL is in lock. In the open loop mode, the CMOS sampling switch is used to suspend the operation of the op-amp with sufficient isolation of these capacitors. Once the PLL is closed, the switch resumes the sampling operation. The choice of this capacitor depends on dielectric radiation properties of the material. Polypropylene or even better capacitor is advisable.

The VCO gain (K_{VCO}) is 110 MHz/V referred to 2.4 GHz. The phase detector comparison frequency is 250 kHz[5]. A second order loop filter is designed with the loop bandwidth 40 kHz and the phase margin 50˚. *Figure 3* shows the component values of the filter. The lock time is measured from the falling edge of signal that shuts down the PLL (PLL_PD) to 1225 MHz (2450 MHz at Tx Output) within 5 kHz (10 kHz at Tx output). The lock time is 111 µs as shown in *Figure 4*. This is less than HomeRF required.

[5]Given 1-MHz channel spacing and the IF is at 110.5 MHz, the largest comparison frequency is 0.25 MHz because of frequency doubler.

The frequency drift due to the current leakage is measured starting from the rising edge of PLL_PD. *Figure 5* demonstrates the frequency drift of the VCO at 85˚C. The very low drift of 778 Hz/ms is much less than required for HomeRF. There are two frequency jumps. The first is due to the phase

noise of the PLL and appears as a jump due to the finite response time of the domain modulation analyzer. The second jump is due to the common mode operating range of the op-amp. Since the large VCO gain, the frequency jumps tens of kilohertz even though only a few hundred μVs fluctuates. Placing a 10-MΩ resistor in parallel with loop filter will sink away the bias current of the op-amp and prevent saturation. The occurrence of the second jump depends on the selection of the op-amp and the CMOS switch. In the current design, the second jump occurs only after the loop is open for a long time. (>100 ms). In case of HomeRF, the loop will not be idle or open for such long period.
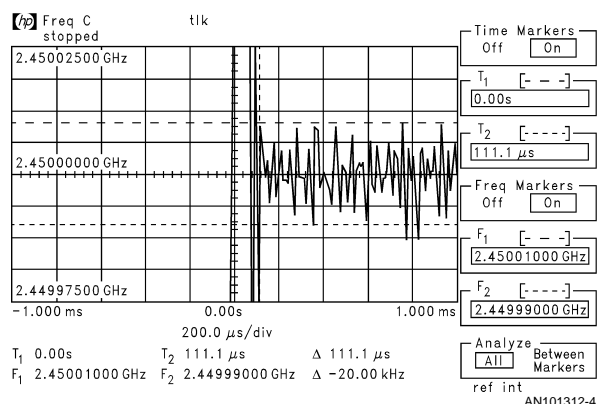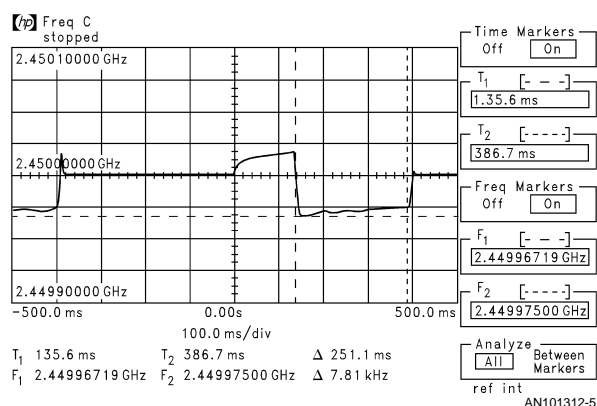

FIGURE 4. PLL Lock Time

FIGURE 5. Open Loop Frequency Drift at 85˚C

For Bluetooth, the maximum continuous transmit time is 5 slots, or 3.125 ms. The total loop filter capacitance of about 7 nF is needed for 180 μs lock time, which including 40 μs budget for margins and programming time. Then, the drift in 3.125 ms is about 34 kHz by

$$\Delta f = I_{leakage} \Delta t \, K_{VCO}/C^6,$$

[6]The typical value of the leakage current is 700 pA at 85˚C.

which meets the Bluetooth requirement of 40 kHz. This calculation tells that LMX3162 meets the requirement even without the additional op-amp, switch and the large capacitor.

Table 1 shows that the maximum dwell time is 11.25 ms for Bluetooth and 20 ms for HomeRF. However, the transceiver is operating in scan mode. (receiving only) Frequency drift can be avoided without additional circuitry by closing the PLL and receiving data. This may result in degradation of bit error rate (BER) by one or two decibel(s), which is acceptable since LMX3162 gives enough design margins on sensitivity.

4.2 Transmitter

In LMX3162, direct VCO modulation scheme is employed as shown in *Figure 7*(a). It is simple and low cost solution in comparison to other options, such as direct RF I/Q modulation or close loop I/O modulation. In this section, LMX3162 will be demonstrated to transmit the data with the open loop modulation for the 2.4-GHz ISM band.

To transmit a signal, a shaped baseband signal is applied to the tuning pin[7] of the VCO to assure bandwidth efficient. The amplitude of the signal from the baseband processor needs to be adjusted to obtain the frequency deviation. Given the VCO gain, a resistive divider can be calculated for the correct amplitude to modulate the VCO. The peak frequency deviation can be measured by a domain modulation analyzer and a spectrum analyzer.

[7]The loop filter or the modulation port of the VCO.

With the correct amplitude of the signal, the VCO output generates the modulated signal and is connected to the input of the frequency doubler inside LMX3162. The 2.4-GHz signal at the transmit output pin (TX_OUT) should be filtered in prior feeding to the power amplifier. Otherwise, a phenomenon called spectra regrowth may occurred.

For Bluetooth in the low power mode, the required transmit power is 0 dBm. The TX_OUT pin provides an output power level of −7.5 dBm. An amplifier of 10.5-dB gain should be sufficient if 1-dB loss in the Transmit/Receive switch and 2-dB loss in the post-amplifier ceramic band pass filter are included. A simple solution is the single stage amplifier with a bipolar transistor[8] biasing at 10 mA with internal voltage regulator supply of LMX3162. For Bluetooth in the high power node, the power range is as of 20 dBm. A high efficiency power amplifier should also be employed. Good candidates are ITT2304 for Bluetooth and HomeRF, ITT2302 for Upbanded DECT.

[8]The same configuration as the LNA, Siemens BFP420, will be mentioned in the receive section.
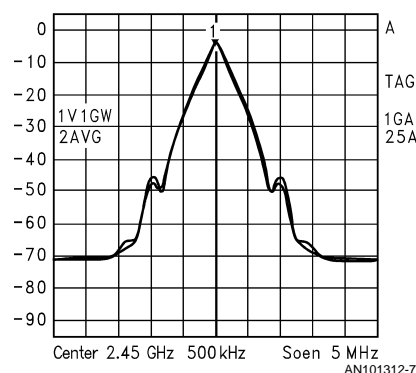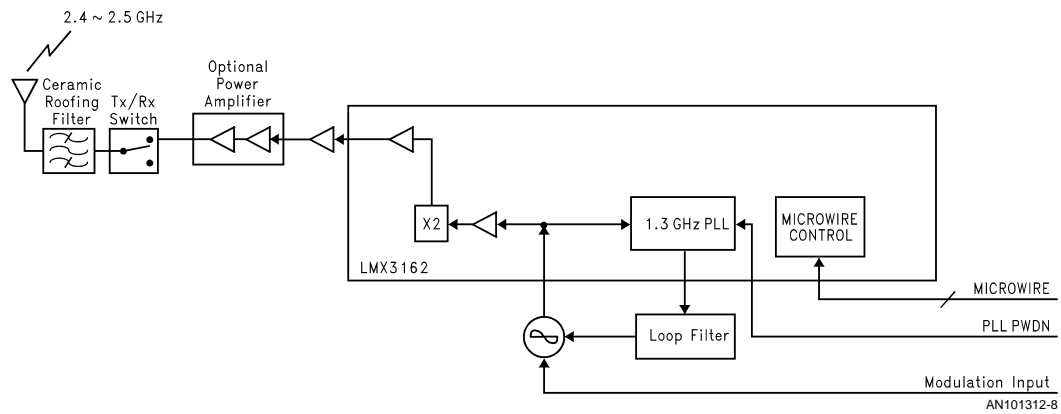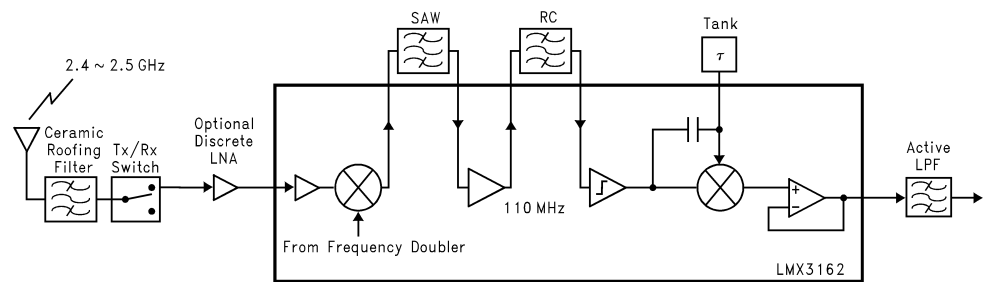

FIGURE 6. Bluetooth Modulated Signals

(a)

(b)

FIGURE 7. (a) Tx Block. (b) Rx Block

Removing all the harmonics and sub-harmonics of the carrier by filtering is also necessitated after amplification because the transmit spectrum is regulated by FCC. FCC also requires the radiated power at offsets of 500 kHz or more to be 20 dB below the peak power. *Figure 6* shows a PRBS15 modulated Bluetooth signal at the transmitter output (BT=0.5, GFSK and 320 kHz peak-to-peak frequency deviation) and a mask of transmit spectrum generated by a HP ESG4433 signal generator for comparison. (The top trace shown in *Figure 6* with larger side-lobe is created from the signal generator.) This indicates the requirement is met. The wideband unmodulated transmit spectrum is shown in *Figure 8*. The sub-harmonics is −36 dBm without any post-amplifier filtering, which meets the Bluetooth specification. The post-amplifier ceramic filter shown in *Figure 1* used for receive filtering can be shared by the transmit also.

The phase noise of LO has to satisfy certain requirements as mentioned in *Table 1* because the PLL is in the open loop operation either in transmit or receive mode. The unmodulated signal shows the phase noise for the transmit signal in *Figure 9*.
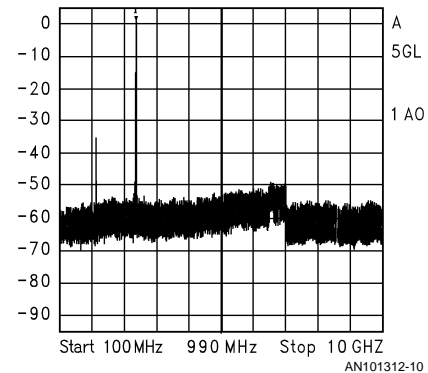

FIGURE 8. Harmonics of Transmitter Output

Moreover, the power supply of the VCO should be regulated. In our experiment, an external low noise voltage regulator, National Semiconductor LP2980, is used to isolate the supply of the VCO from any transient, especially for the power

amplifier. Typically, a 20-dBm power amplifier draws more than 150 mA. The IR voltage drop from the internal resistance of the battery and traces on the PCB may be in excess of the allowance without regulation. Given the VCO gain 10 MHz/V, the internal resistance of a Ni-MH battery used in handsets is about 0.25Ω and the series resistance is about 22 mΩ for 12 mil wide 35 micron thick copper traces, the total IR drop will be 40.8 mV. If the error budget allocates ±20 kHz, this means only ±2 mV is allowed due to the IR voltage drop.
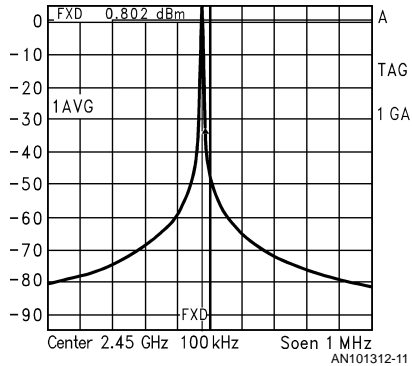

FIGURE 9. Phase Noise of Local Oscillator

4.3 Receiver

LMX3162 adopts the heterodyne receiver architecture as shown in *Figure 7*(b). The demodulated data can be obtained by two frequency conversions with some channel selection filtering along the receiver path.

The antenna will perceive many frequencies in the air. The ISM band signals will first be selected and the image, which is 220 MHz[9] below the signals, will be suppressed through a ceramic band-selection filter. Based on the sensitivity re-

quirements, the signals can feed to the LNA to enhance the performance of the receiver. LMX3162 meets the BER requirements of Bluetooth and HomeRF without the LNA.

[9]The image frequency is 2 IF (110 MHz).

An example is using a single bipolar transistor amplifier as shown in *Figure 10*. A gain of 10 dB and a noise figure of 3 dB can be achieved while consuming approximate 10 mA. The 2.7-V regulated supply can be run from the LMX3162 internally.
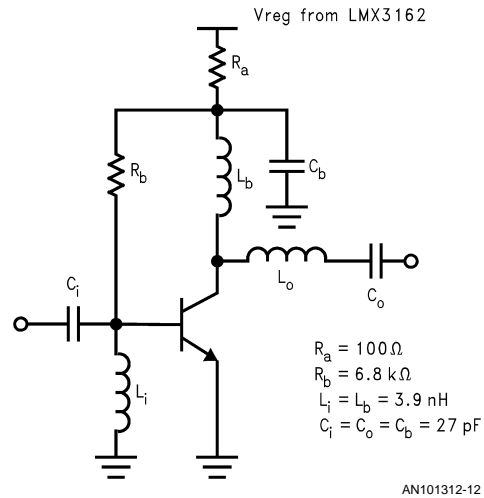

FIGURE 10. LNA/.PA in Low-Power Mode

Once the images are suppressed, the signals can connect to the RF input of the 2.5-GHz mixer inside LMX3162. The LO port of the mixer is connected to the frequency doubler internally. Since the IF is 110 MHz, the LO frequency should be 110 MHz below the RF carrier frequency. The mixer has 15-dB gain with 13-dB noise figure, and the OIP3 of this mixer is 7.5 dBm. The system noise figure from LNA to the RC filter is about 6 dB. The analysis of the receiver chain is shown in *Figure 11*.
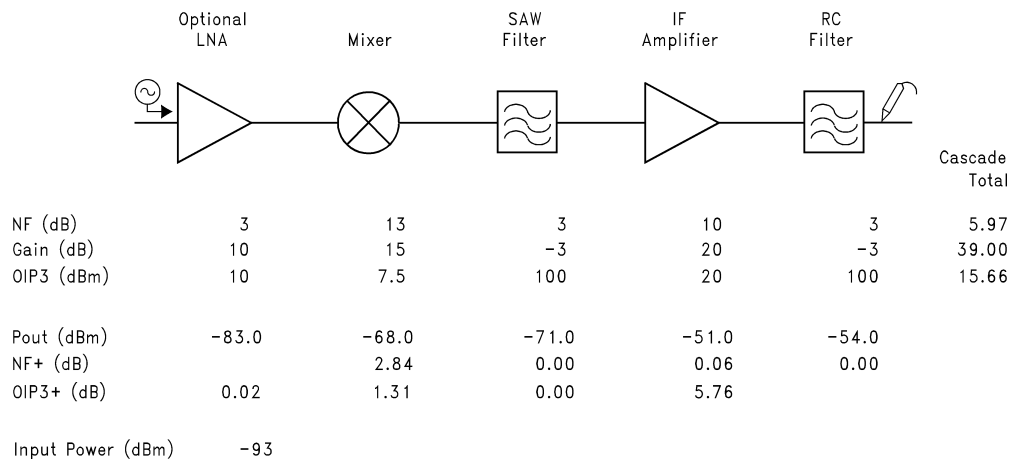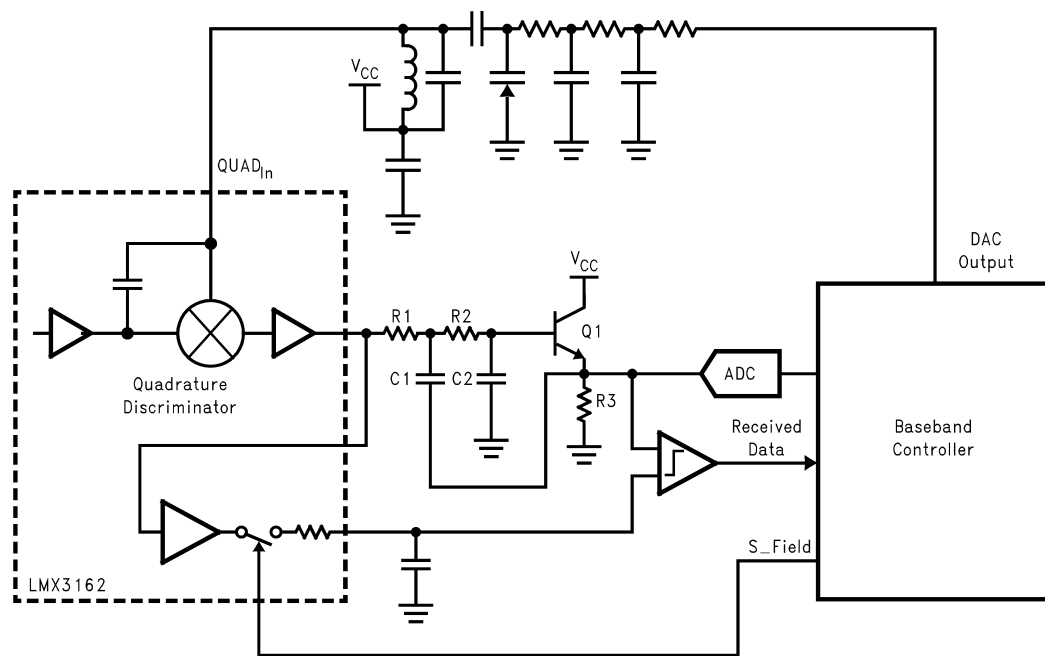

	Optional LNA	Mixer	SAW Filter	IF Amplifier	RC Filter	Cascade Total
NF (dB)	3	13	3	10	3	5.97
Gain (dB)	10	15	-3	20	-3	39.00
OIP3 (dBm)	10	7.5	100	20	100	15.66
Pout (dBm)	-83.0	-68.0	-71.0	-51.0	-54.0	
NF+ (dB)		2.84	0.00	0.06	0.00	
OIP3+ (dB)	0.02	1.31	0.00	5.76		
Input Power (dBm)	-93					

FIGURE 11. Receiver Chain Analysis

FIGURE 12. Quadrature Demodulation

The mixer has OIP3 of 7.5 dBm. With the OIP3 of 20 dBm[10] for the IF amplifier, the system OIP3 would be about 16 dBm. We assume SAW and RC filters are linear and negligible for the nonlinearity. This indicates the linearity of the latter stage (IF amplifier here) is more critical.

After the signal translated to IF, it is possible to do partially channel selection. The IF signals is band-limited by the SAW filter via the matching network. This SAW filter[11] is centered at 110 MHz, and has a 3-dB bandwidth of 1.5 MHz. The minimum insertion loss is about 3 dB. The SAW filter provides the selectivity and prevents spurious components to distort the signal in the following stages because of non-linearity.

Then, the IF signal is amplified and further suppressing the unwanted interference by an external RC filter before feeding to the limiter. This is because the limiter has a large DC gain and is inherently non-linear. Even small interference may possibly cause distortion. At the output of the limiter, the IF signal is strong enough for the discriminator to translate to the baseband. An internal 1-pF capacitor directs the IF signal to input ports of the discriminator and the external tank circuitry provides the correct phase shift between the two inputs to generate the baseband signal at optimum level. The post-detection filtering further limits the noise bandwidth and the configuration of quadrature demodulation as shown in *Figure 12*. An automatic the quadrature tank and the application of S_field on sampling the initial frequency offset between transmitter and receiver are operated with the baseband controller. The description of the automatic tuning tank and the Sample-And-Hold for data slicing comparison can be found in the evaluation notes.[12]

[10]The data sheet did not provide the OIP3 information. 20 dBm is a typical number for IF amplifier and is used for illustration purpose here.

[11]SAFU110.0MSA45T=>110.0 MHz center

SAFU110.6MSA40T=>110.592 MHz center

[12]Reader can find the description on p. 10 of evaluation notes.

4.3.1 Demodulation Parallel Tank

The quadrature tank circuit is shown in *Figure 13*. The resistor R_T is not physically presented in the circuit. Instead, R_T models the finite value of the quality factor of the tank. The principle of operation is that the internal coupling capacitor (C_l) and the resonant circuit provides instantaneous phase shifts that correspond to changes in modulation. The multiplication of these quadrature signals in the discriminator (mixer) then generates the output demodulated signal.

The transfer function of the quadrature tank can be derived[7],

$$H(j\omega) = \frac{-\omega^2 C_T L_T R_T}{R\left[1-\omega^2 L_T(C_T+C_l)\right]+j\,\omega L_T},$$
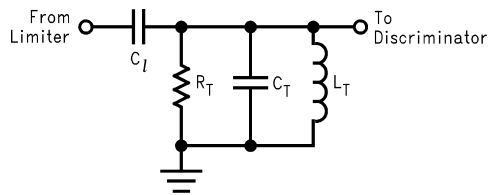
and its resultant phase characteristic of H(jω) is,

$$\phi = \mathrm{atan}\left[\frac{\omega/\omega_o}{((\omega/\omega_o)^2-1)Q}\right], \text{ where}$$

$$\omega_o^2 = \frac{1}{L_T(C_T+C_l)},$$

$$Q = \frac{R_T}{\omega_o L_T}.$$

In the LMX3162 evaluation board, C_l is an internal 1-pF capacitor. For tuning the quadrature tank at 110 MHz, C_T is a combination of a constant (18 pF) and a variable capacitor (2–6 pF).

FIGURE 13. Parallel Quadrature Tank

The choice of inductor entails a compromise among the tuning range, the quality factor (Q) and the bandwidth. Larger the inductor implies higher the Q. The Q of the quadrature tank as well as the filters along the receiver path determine the bandwidth. Therefore, higher the Q or larger the inductor means narrower the bandwidth. For instance, extensive filterings and moderate Q can lower the noise bandwidth. Then, the sensitivity and the inter-symbol interference both improve because the signal-to-noise ratio (SNR) increases. However, if the bandwidth is further reducing and it eventually chops out the signal bandwidth, the SNR, sensitivity and ISI obviously degraded. For this reason, 68 nH is used for L_T.
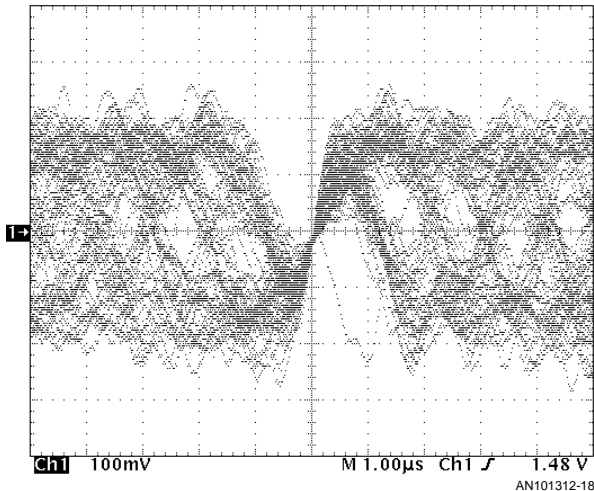

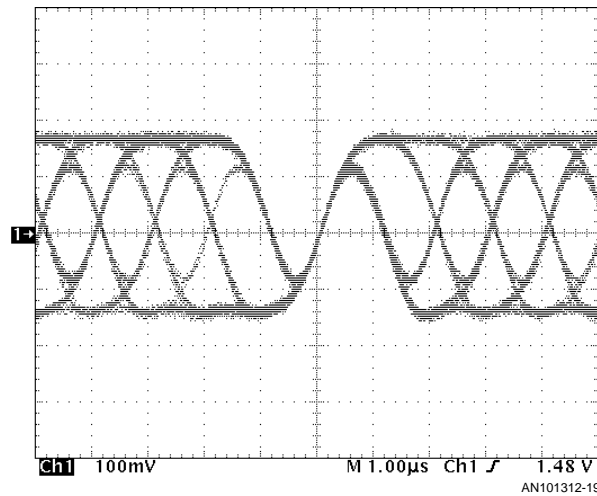**FIGURE 14. Eye Diagram, BER=1e-3, –83 dBm**

FIGURE 15. Eye Diagram, BER=0, –40 dBm

4.3.2 Performance

Without the LNA, the transceiver achieves the sensitivity of –83 dBm at the BER of 1e-3, with the received signal offset ±115 kHz by Bluetooth standards. This easily meets the Bluetooth minimum sensitivity requirement of –70 dBm. With the LNA and optimal SAW filter, sensitivity of –93 dBm can be obtained. The eye diagram of the received signal for BER of 1e-3 at an input power of –83 dBm and BER of 0 at –40 dBm are shown *Figures 14, 15* respectively.

TABLE 2. Interference Test for Bluetooth

Test Name	Conditions	Result
BER	PLL Locked, No LNA, BER=1E 3 dBm	–83 dBm
CCI	C = –60 dBm, C/I = 11 dB	Passed
ACI 1 MHz	C = –60 dBm, C/I = 4 dB	Passed
ACI 2 MHz	C = –60 dBm, C/I = 30 dB	Passed
ACI 3 MHz	C = –67 dBm, C/I = 40 dB	Passed
Image	C = –67 dBm, C/I = 9 dB	Passed
IMD	C = –64 dBm, I_1, I_2 = –39 dBm	Passed

A transceiver must operate with unwanted signals are either on the same or adjacent channels. Strong out of band signals can even desensitize the radio completely. *Table 2* lists the specifications to test the receiver in various conditions.
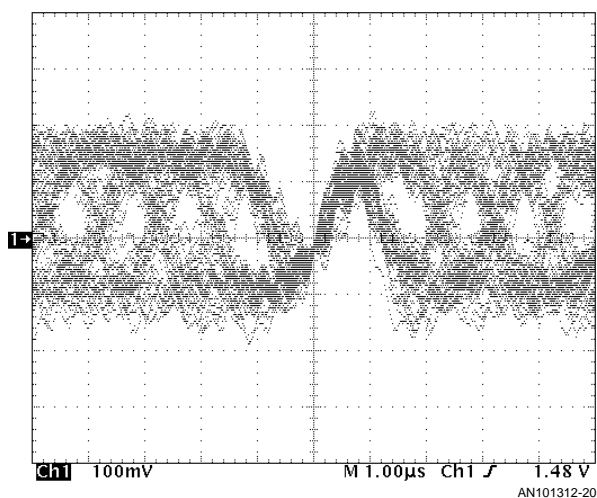
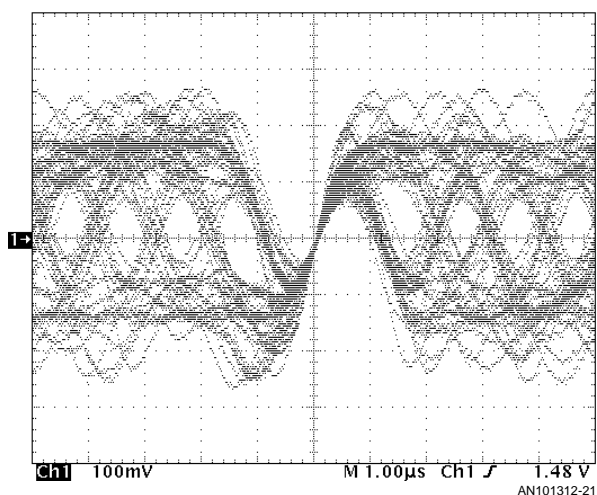**FIGURE 16. Eye Diagram for Bluetooth CCI Test**

FIGURE 17. Eye Diagram for Bluetooth ACI 1-MHz Test

The first one is Co-Channel Interference (CCI). The radio meets a BER of 1e-3 with CCI 11 dB below a desired input even at the power level –80 dBm. At the specified desired signal level of –60 dBm, the radio even meets the BER with CCI that is only 6 dB difference. For this CCI level, LMX3162 suffers no degradation in BER sensitivity. *Figure 16* shows the eye diagram for the Bluetooth CCI test.

The second category of interference test is Adjacent Channel Interference (ACI). A radio must achieve an individual BER test of 1e-3 with undesired Bluetooth signals from other users at 1-MHz, 2-MHz and 3-MHz offset. The input level of the interference is –4 dB[13], –30 dB and –40 dB respectively. LMX3162 meets the ACI tests. *Figures 17, 18, 19* show the eye diagram for the ACI test at different frequency offset.

The radio meets the relaxed specification for ACI 1-MHz off-set. In these experiment, the low cost SAW filter has a 3 dB bandwidth of 1.5 MHz and is wider than the Bluetooth signal bandwidth. The center frequency of the SAW filter used in these measurements is 110.6 MHz because a specific SAW

filter (see footnote 11) for these protocols was not available at the time the measurement was made. However, the specific SAW filter for bluetooth is available now and a narrower bandwidth filter will improve the performance of the LMX3162.

[13]The three year relaxed specification for the 1-MHz test is an ACI 4 dB below the desired signal.
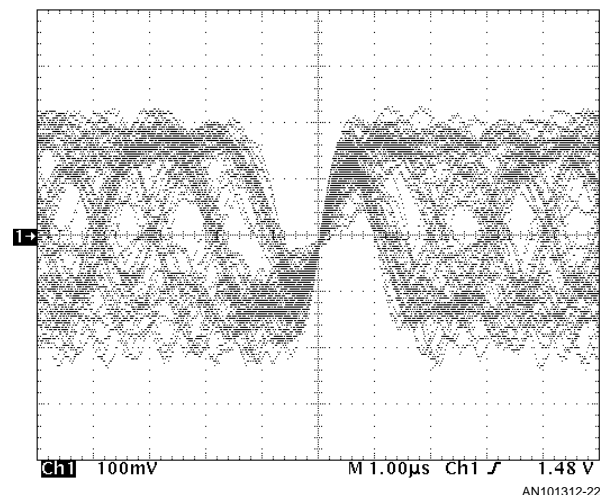

FIGURE 18. Eye Diagram for Bluetooth ACI 2-MHZ Test (–81 dBm)
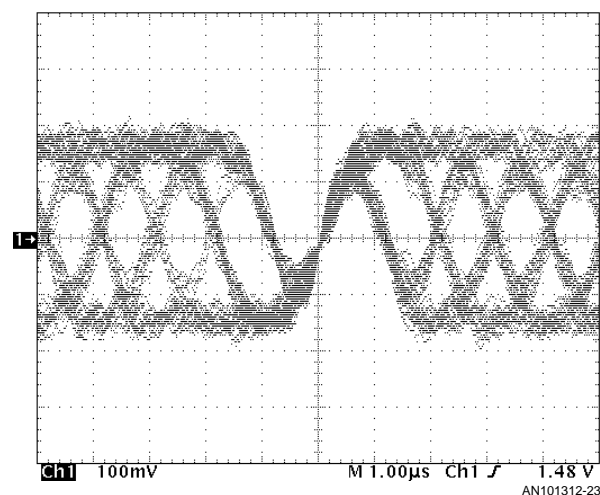
FIGURE 19. Eye Diagram for Bluetooth ACI 3-MHz Test (–72 dBm)

The last test shown in *Table 2* is measuring the intermodulation properties. The test measures the sensitivity of the receiver. (BER=1e-3) with the desired signal at –64 dBm, a –39 dBm static sine wave at 3-MHz offset and another Bluetooth signal at –39 dBm at 4-MHz offset. The intermodulation product creates an interference at 2-MHz offset. This frequency subsequently mixes with other input frequencies and generates an interference falling on the signal indirectly. This also degrades the sensitivity of the receiver. The result

shown in *Figure 20* captures the spectrum at the RF input with 3 signals when the BER is 1e-3 measured at the discriminator output.
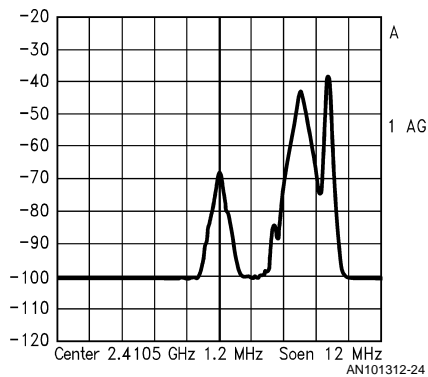
FIGURE 20. Bluetooth Intermodulation Test

5.0 CONCLUSION

LMX3162 is capable to support 2.4-GHz ISM applications. The difference in the implementations depend on the various standards. *Figure 21* summaries the optional devices for implementing for Bluetooth or HomeRF/Upbanded DECT. List of Materials and an optimized schematic are shown in *Table 3* and *Figure 22* respectively. For a complete MICROWIRE programming description, see LMX3162 data sheet and evaluation notes.[1][2]
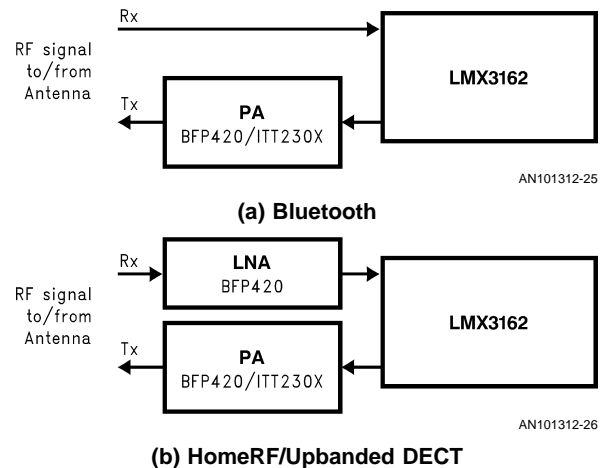
(a) Bluetooth

(b) HomeRF/Upbanded DECT

FIGURE 21. Optional LNA/PA for Bluetooth or HomeRF/Upbanded DECT

REFERENCE NOTES

[1] LMX3162 Datasheet.

[2] LMX3162 Evaluation Notes.

[3] Specification of the Bluetooth System, Version 0.9, May 1999.

[4] HomeRF SWAP Specification.

[5] Document CFR47, Part 15, Sections 15.205, 15.209, 15.247, Federal Communications Commission, USA.

[6] D.E. Fague, A. Dao and C. Karmel, "Techniques for Open Loop Modulation of a Wideband VCO for DECT", Proceedings of the RF Expo, March 1994.

[7] Wireless Communication, ″Demodulating with LMX2240 150 MHz IF Receiver″, National Semiconductor Application Note AN-1020.

| TABLE 3. Bill of Materials for LMX3162 |
|---|

Serial Number	# Used	Part Type	Designator	Vendor	Tolerance	Size
1	1	560 pF	C1*		+/−5%	603
2	1	15 pF	C10		+/−5%	603
3	3	0.01 µF	C13 C35 C68		+/−5%	603
4	1	0.015 µF	C2*		+/−5%	603
5	8	100 pF	C22 C41 C48 C5 C8 C11 C12 C14		+/−5%	603
6	2	not used	C23 C3		+/−5%	603
7	2	10 pF	C26 C16		+/−5%	603
8	1	2700 pF	C33		+/−5%	603
9	2	2.2 µF	C38 C39		+/−5%	603
10	1	1000 pF	C4		+/−5%	603
11	1	39 pF	C40		+/−5%	603
12	3	27 pF	C47 C9 C15		+/−5%	603
13	1	15 pF	C50		+/−5%	603
14	1	2 pF–6 pF	C51*	Murata TZBX4Z060BA110	+/−5%	603
15	1	18 pF	C52*		+/−5%	603
16	1	0.1 µF	C53		+/−5%	603
17	3	100 pF	C54 C55 C69		+/−5%	603
18	1	47 pF	C6		+/−5%	603
19	1	22 pF	C7		+/−5%	603
20	1	10 pF	C70		+/−5%	603
21	1	LMX3162	IC1			
22	1	Fin	J1	CDI 5763SF(SMA)		
23	1	RSSI	J10	CDI 5762SF(SMA)		
24	1	Disc Out	J11	CDI 5762SF(SMA)		
25	1	Thresh	J12	CDI 5762SF(SMA)		
26	1	V_{CC}	J15	CDI 5762SF(SMA)		
27	1	Tx OUT	J2	CDI 5762SF(SMA)		
28	1	Mod In	J3	CDI 5762SF(SMA)		
29	1	OSC In	J33	CDI 5762SF(SMA)		
30	1	DC Comp In	J4	CDI 5762SF(SMA)		
31	1	RF In	J5	CDI 5762SF(SMA)		
32	1	Vsw	J6	CDI 5762SF(SMA)		
33	1	10P_HEADER	JP1	Common Connectors CCU 255G HTSM 3203-40G2		
34	1	12P_Header	JP2	Common Connectors CCU 255G HTSM 3203-40G3		
35	2	2.5 nH	L1 L10	CoilCraft	+/−10%	603
36	2	3.9 nH	L15 L6	CoilCraft	+/−10%	603
37	1	68 nH	L16	CoilCraft	+/−10%	603
38	1	150 nH	L2	CoilCraft	+/−10%	603
39	1	220 nH	L3	CoilCraft	+/−10%	603
40	4	3.9 nH	L4 L7 L8 L9	CoilCraft	+/−10%	
41	1	120 nH	L5	CoilCraft	+/−10%	603
42	2	BFP420E-6327	Q1, Q3	Siemens		
43	1	mmBT3904	Q2	Fairchild		
44	2	3.3k	R1 R5		+/−10%	
45	1	3.9k	R10		+/−10%	
46	6	not used	R11 R13 R15 R16 R31 R6		+/−10%	

			TABLE 3. Bill of Materials for LMX3162 (Continued)			
Serial Number	# Used	Part Type	Designator	Vendor	Tolerance	Size
47	9	18	R14 R19 R23 R24 R25 R26 R27 R4 49		+/−10%	
48	2	100	R17 R7		+/−10%	
49	2	100	R18 R8		+/−10%	
50	1	1.2k	R2		+/−10%	
51	2	0	R21 R40		+/−10%	
52	1	51	R22		+/−10%	
53	2	6.8k	R28 R9		+/−10%	
54	1	1k	R29		+/−10%	
55	1	82k	R3		+/−10%	
56	1	3.9k	R36		+/−10%	
57	1	Out 2	TP3			
58	1	Out 1	TP4			
59	1	Out 0	TP5			
60	1	Trigger	TP6			
61	1	DFC22R44P084LHA, Murata	U2			
62	1	UCVE8X805A or URAE8X630B, ALPS	U3			
63	1	LP2980AIM5	U4	National Semiconductor		
64	1	SAFU110.0MSA45T, Murata	U5			

*All capacitors are X7R type. The Capacitor (with asterisk *) C1, C2, C51, C52 are recommended to use lower ESR to avoid leakage.
**URAE8X630B is soon replaced by modified version UCVE8X805A, ALPS.
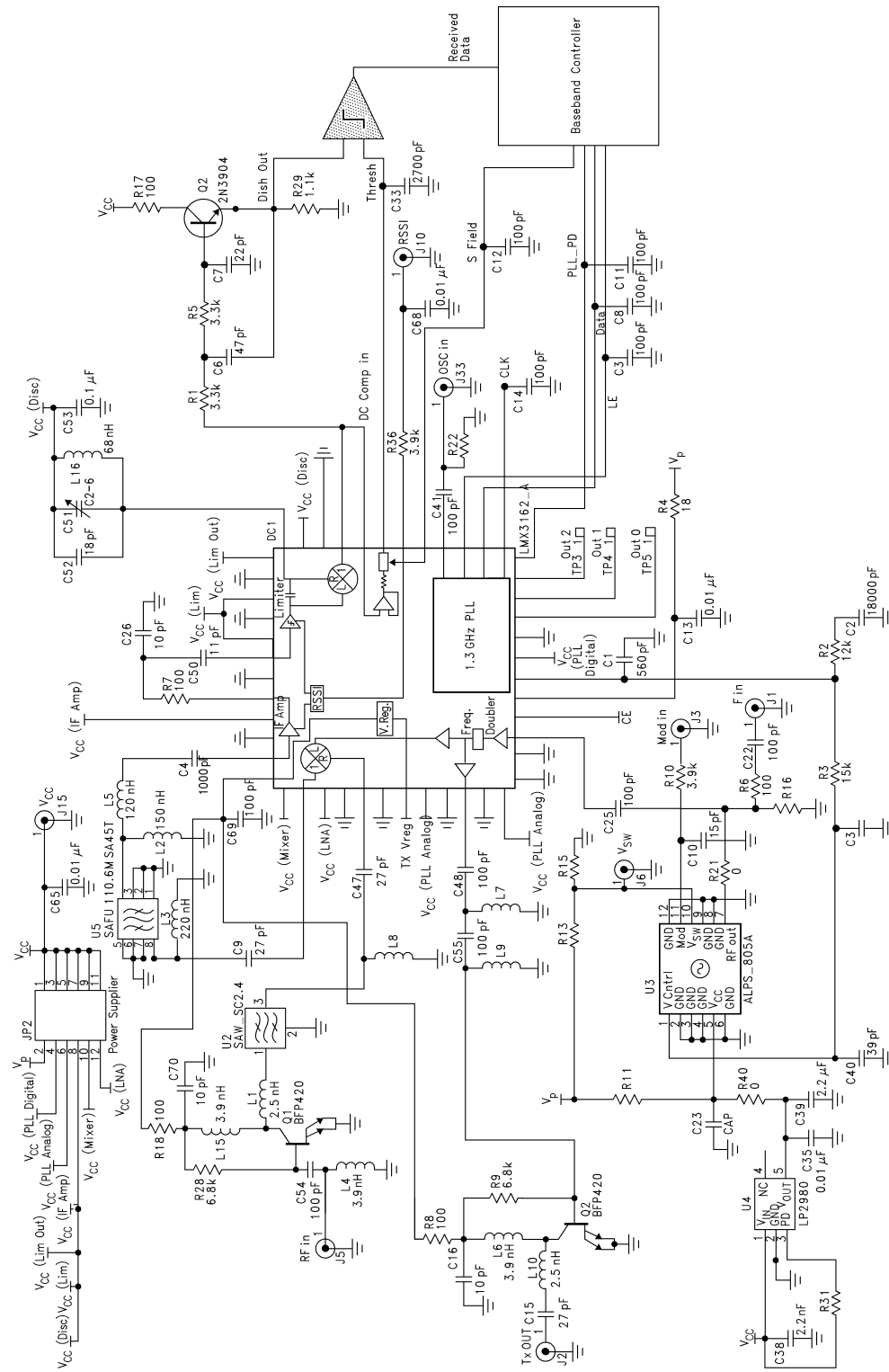
FIGURE 22. Optimized Schematics of LMX3162 Evaluation Board (include Tx buffer)

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Notes

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