MOTOROLA
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MC13190

Package Information
Plastic Package
Case 1311
(QFN-32, 5x5 mm)

Ordering Information

Device	Device Marking	Package
MC13190FC	13190	QFN-32

The MC13190 is a Short-Range, Low-Power 2.4 GHz ISM band single chip radio. Together with an appropriate microprocessor or DSP for a Baseband Controller, it provides cost effective solutions for short-range (up to 10 meters), battery-powered data links. Applications include remote control, wire replacement, wireless streaming audio, and wireless game control. The receiver includes a low noise amplifier (LNA), AM demodulator, band pass filter and limiting IF. The transmitter includes modulation control, baseband filtering and AM modulator. An on-chip PLL/VCO derives the RF frequency from a fixed 256 multiplication of the reference frequency. The device is fabricated using Motorola's RF BiCMOS process and is housed in a 32 lead QFN package with backside ground.

- Typical Receiver Sensitivity: -71 dBm for 2×10^{-4} Bit Error Rate (BER)
- Typical Output Power = 4.8 dBm
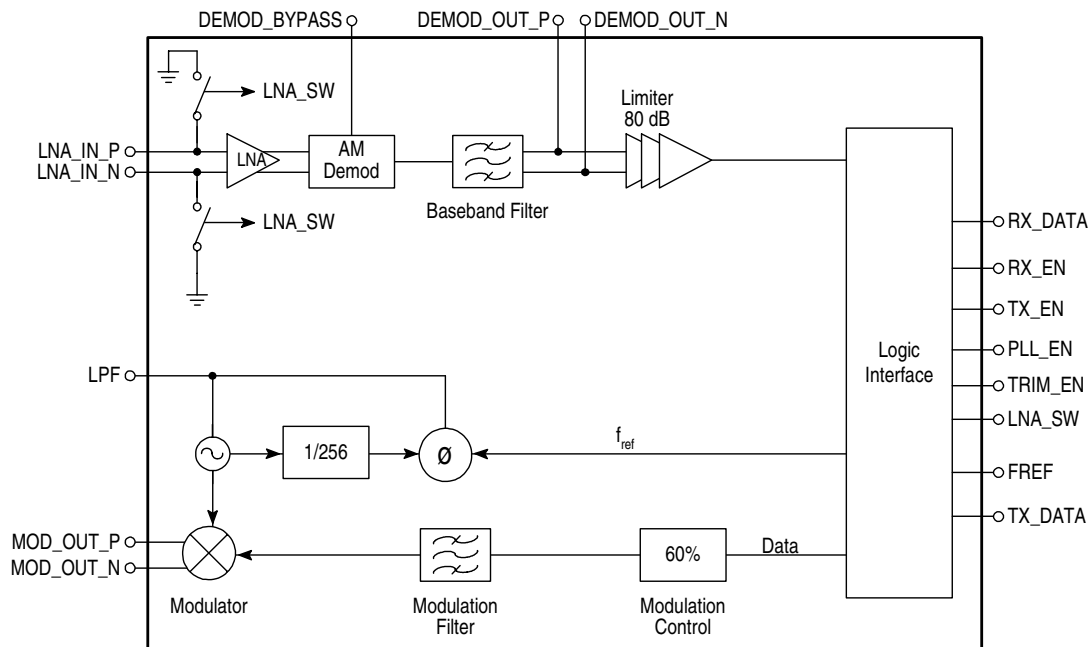- Fully Differential RF Input and Output

Electrical Specifications

Figure 1. Simplified Block Diagram

1 Electrical Specifications

Table 1. Maximum Ratings

Rating	Symbol	Value	Unit
Supply Voltage	V_{CC}, V_{DD}	3.2	V
Signal and Control IC Contacts		3.2	V
Demodulator Supply Voltage	Demod_VCC	3.9	V
CW Input Power		7.0	dBm
Gnd IC Contacts Voltage		0.3	V
Capacitance Load at RX_DATA		10	pF
Storage Temperature	T_{stg}	-65 to 150	°C
Operating Temperature	T_A	0 to 50	°C

NOTES: 1. Maximum Ratings are those values beyond which damage to the device may occur. Functional operation should be restricted to the limits in the Electrical Characteristics or Recommended Operating Conditions tables.
2. Meets Human Body Model (HBM)) ≤2.0 kV and Machine Model (MM) ≤200 V except RFand Limiter circuit contacts. Limiter circuit contacts (contacts 19 and 17) = 900 V HBM, 125 V MM. RF Contacts = 80 V HBM, 50V MM. RF contacts have no ESD protection. Additional ESD data available upon request.

Table 2. Recommended Operating Conditions

Characteristic	Symbol	Min	Typ	Max	Unit
Supply Voltage	V_{CC}	2.5	2.75	3.0	V
Digital Supply	V_{DD}	2.0	2.75	3.0	V
Signal and Control Pins		80% V_{DD}	-	V_{DD}	V
Demodulator Supply Voltage (no LNA input signal)		2.7	3.1	3.3	V
Input Operating Frequency		2.411	-	2.473	GHz
Maximum Input Power into LNA_IN		-	-	0	dBm
Differential Load Impedance for Transmitter (MOD_OUT)		-	50	-	Ω
Differential Source Impendance for Receiver (LNA_IN)		-	25	-	Ω
Transmit Data Rate (Manchester Encoded)		4	5	6	Mbits/s
Transmit Data Encoding		Manchester, 50% Duty Cycle			

Table 3. System Characteristics

(V_{CC} = 2.75 V, T_A = 25°C, RF Receiver Frequency = 2.442 GHz, 60% AM, Bit Rate = 5.0 Mbps Manchester coded, unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Receiver Sensitivity for 2×10^{-4} Bit Error Rate		-65	-71	-	dBm
Baseband Filter Lower Corner Frequency		-	0.35	-	MHz
Baseband Filter Upper Corner Frequency		-	6.0	-	MHz
Receiver Recovery Time from a 7.0 dBm Burst		-	-	15	µs
AM Modulation Depth		50	60	88	%
Transmit Power (modulated)		1.9	4.8	-	dBm
Receive Supply Current (P_{in} = -50 dBm)	I_{CC}	-	11	-	mA

Transmit Supply Current
    Logic 1
    Logic 0
    50% Duty Cycle
	I_{CC}	-
		-
			54
			27
			40.5
				-
				-
					mA

Standby Supply Current		-	51	-	µA

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Electrical Specifications

Table 4. Receiver Section
(V$_{CC}$ = 2.75 V, T$_A$ = 25°C, RF Receiver Frequency = 2.442 GHz, 60% AM, Bit Rate = 5.0 Mbps Manchester coded, unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Low Noise Amplifier and Am Demodulator					

Current Consumption
  Active
  Disabled
		-
		-
			11
			7.0
				-
				-
					mA
					µA

Recovered Signal Level at -65 dBm		-	5.0	-	mVpp
Limiter and Level Shifter					

Current Consumption
  Active
  Disabled
		-
		-
			240
			3.0
				-
				-
					µA

RX_DATA Drive Capability (5.0 MHz)		-	-	10	pF
Output High with respect to VDD_RX_DATA @ -100 µA		80% V$_{DD}$			V
Output Low with respect to GND @ -100 µA				0.2	V

Table 5.   Transmit Section
(V$_{CC}$ = 2.75 V, T$_A$ = 25°C, RF Transmit Frequency = 2.442 GHz, 60% AM, Bit Rate = 5.0 Mbps Manchester coded, unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Frequency Synthesizer (V$_{CC}$ = 2.75 V, T$_A$ = 25°C, unless otherwise noted.)					

Total Current Consumption when active
  Active
  Disabled
		-
		-
			10.2
			1.1
				-
				-
					mA
					µA

Frequency Range (FREF x 256)		2.4	-	2.484	GHz
Reference Input Frequency	f$_{ref}$	9.375	-	9.704	MHz
RF Frequency Divide Ratio	N	-	256	-	
Trim Time (using fixed clock derived from reference)		-	-	100	µs
Time required to turn on and lock after trim (250 kHz Loop Bandwidth)		-	25	-	µs

Reference Input Level
  Ref Low
  Ref High
		-
		V$_{DD}$ x 80%
			-
			-
				V$_{DD}$ x 20%
				-
					V

Table 5.   Transmit Section (Continued)

(V_{CC} = 2.75 V, T_A = 25°C, RF Transmit Frequency = 2.442 GHz, 60% AM, Bit Rate = 5.0 Mbps Manchester coded, unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
AM Modulator					

Current Consumption
    Active
    Disabled
		-
		-
			16.4
			3.0
				-
				-
					mA
					µA

AM Modulation Depth Range		50	60	88	%
Output Power		2.0	4.8	-	dBm
Occupied Bandwidth (99% Signal Energy)		-	22	-	MHz

Out of Band Spurious at Antenna Port
    30 MHz to 1.0 GHz
    1.0 to 1.275 GHz
    1.8 to 1.9 GHz
    5.15 to 5.3 GHz
		
		-
		-
		-
		-
			
			-45
			-40
			-45
			-50
				dBm
				-
				-
				-
				-	

Acceptable Duty Cycle for TX_DATA Signal (Manchester Encoded)		48	-	52	%

Table 6.   Enable Logic Levels
(V_{CC} = 2.75 V, T_A = 25°C)

Symbol	Characteristic	Min	Max
V_{IH}	High Level Input Voltage	80% V_{DD}	-
V_{IL}	Low Level Input Voltage	-	20% V_{DD}
I_{IH}	High Level Input Current	-	1.0 µA
I_{IL}	Low Level Input Current	-	1.0 µA

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2 Contact Connections

Table 7.   Control Contact Definitions

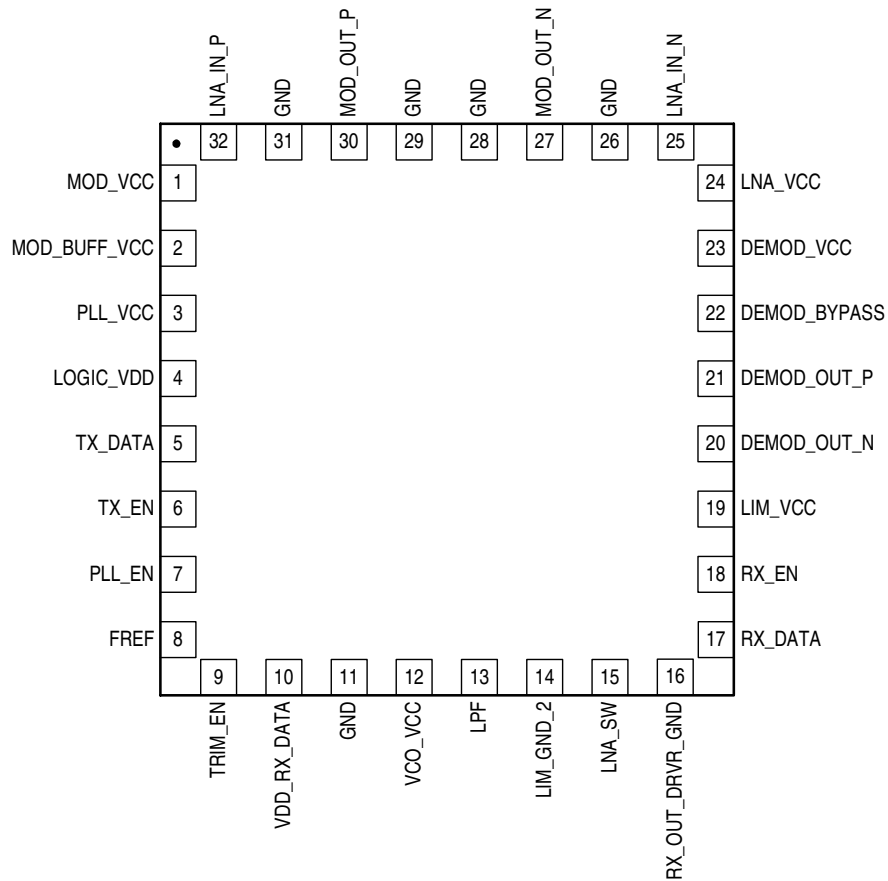| Contact	Description
RX_EN	Enables LNA, Demod and Limiter
TX_EN	Enables TX Filter, Modulation Control, PA/Modulator
PLL_EN	Enables Frequency Synthesizer and VCO
TRIM_EN	Enables VCO Trimming
LNA_SW	Switches LNA Inputs to Ground in TX Mode

Figure 2.   Contact Connections

3 Application Information

3.1 Introduction

The MC13190 is a 2.4 GHz transceiver that takes advantage of AM modulation to provide wide-band data capability with simple, low-cost circuitry. The transmit and receive baseband filters are designed for 5 Mbps Manchester encoded data. This high data rate capability is intended to provide low latency, avoid interference through short-burst protocol and allow for multiple retransmissions. The baseband interface is simple to allow maximum flexibility in applications. Depending on protocol choices and bit error rate requirements, the MC13190 is capable of supporting up to 1 Mbps data throughput.

3.2 Modes of Operation

The MC13190 has three modes of operation; Standby, Transmit and Receive. Refer to Figure 1, Simplified Block Diagram, for circuit functions.

3.2.1 Standby Mode

Standby mode is automatically initiated when all enable (_EN) IC Contacts are kept low. The current consumption during standby mode is typically 51 µA.

3.2.2 Transmit Mode

In the Transmit mode, the VCO frequency is set based on the reference by the PLL, the transmit chain is enabled, the transmit data is filtered and AM-modulates the transmit carrier. This sequence is shown in Figure 3. The switches to ground at the input of the LNA as well as the PLL are enabled ahead of the TX chain. Optionally, an external Transmit/Receive switch can be used and LNA_SW can be left low. This delay allows the PLL to settle prior to application of data. During power-up of the TX chain, TX_DATA should be kept low. This guarantees the modulator powers up at minimum output power which will prevent splatter.
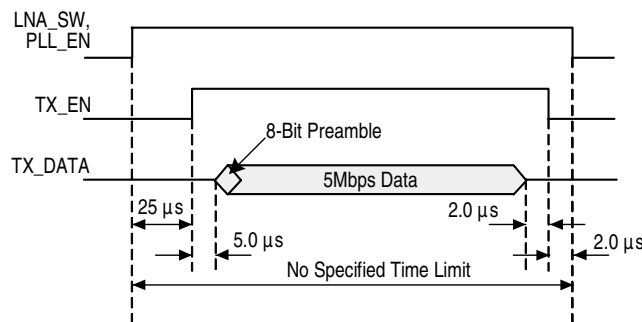

Figure 3. Recommended Timing During Transmit Mode

It should be noted that the transmit baseband filter is optimized for 5 Mbps Manchester encoded data. The MC13190 does not provide this encoding. See Section 3.6.1 for discussion of Manchester encoding.

The internal 2.4 GHz VCO includes circuitry to perform an automated trimming cycle. In the TRIM cycle, the VCO will trim itself to the required frequency keeping the control voltage within the specified range. After initial trimming, the VCO does not require trimming again until the supply voltage and/or the temperature changes. Trimming every one to 10 seconds is, however, recommended. The TRIM cycle timing is shown in Figure 4.
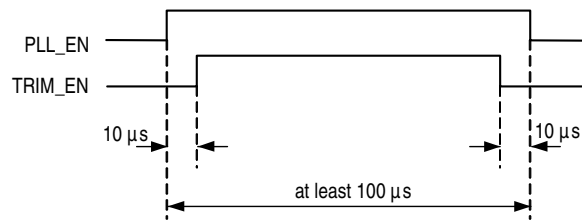

Figure 4. Recommended Timing During Trim Mode

The PLL is enabled, a delay of 10 μs is observed for the VCO and the PLL to settle, and then trimming is begun. Trimming continues until TRIM_EN is taken low and should continue for a minimum of 100 μs. After the TRIM_EN is taken low, the trim information is stored internally, a process that takes about 10 μs. PLL_EN must remain high while the trim information is stored.

The frequency synthesizer uses a fixed 256 divider and must be enabled in both TRIM and TX mode. The frequency synthesizer is not required in the receive mode and may be disabled. The frequency synthesizer requires an external reference signal (IC Contact 8), FREF, and an external loop filter connected to IC Contact 13.

3.2.3 Receive Mode

In Receive mode, the 2.4 GHz signals from the antenna are amplified by the LNA, peak detected in the demodulator and filtered and amplified to produce the RX_DATA output. The response time after the first time RX_EN is pulled high is set by the charging time of the demodulator bypass capacitor and is about 700 μs. Once the capacitor is charged, internal circuitry maintains the charge for at least one second and the response time is reduced to around 7 μs. An 8-bit preamble allows for receive circuitry setting. The receiver baseband filter is optimized for Manchester encoded 5 Mbps data. The Receive sequence is shown in Figure 5.
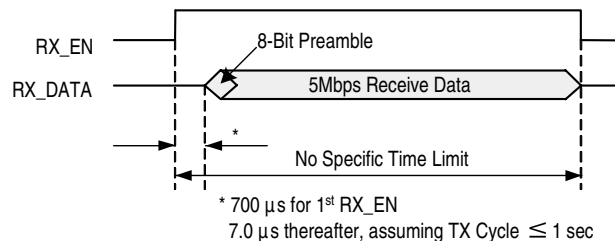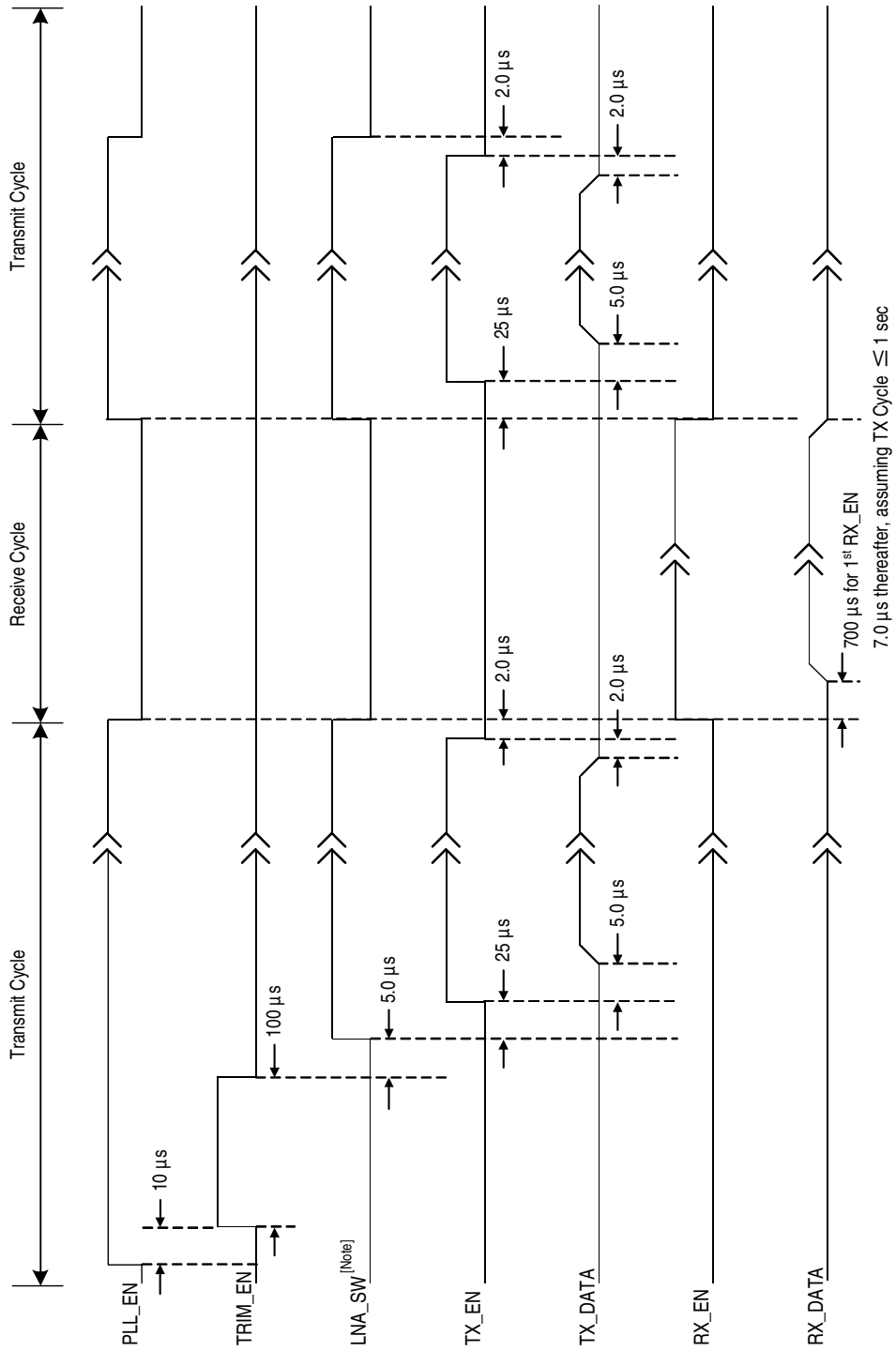

Figure 5. Recommended Timing During Receive Mode

3.3 Transmit and Receive Sequencing

Figure 6 shows the sequencing and timing for a typical Trim, Transmit, Receive and Re-transmit cycle. Note that the PLL and VCO (PLL_EN) are off during the Receive cycle. This sequence can be repeated as often as needed and is controlled by the applications software. The TRIM cycle should be repeated at regular intervals of 1 to 10 seconds or when the temperature and/or voltage have changed.

Figure 6.   Transmit/Receive Timing Sequence

3.4   Basic Transceiver Circuit

Figure 7 shows the basic transceiver evaluation board circuit schematic with reference oscillator and Figure 8 shows the optional external LNAs. Figures 9 and 10 show the evaluation board printed circuit board layout details.

This realization is intended for device evaluation and has been designed with a 50 Ω interface. C19, C20, L10 and L12 form a lumped-element balun. In equipment applications a differential antenna can be interfaced through matching elements directly to the LNA and Modulator contacts. A PCB dipole antenna with balun and SMA connector is available for link evaluations. The RF circuit layout is critical and should be duplicated exactly. In normal applications, the entire transceiver should be shielded and control lines from the baseband should be as short as possible.

The optional external LNA circuits require an external differential switch that is implemented with PIN diodes D1, D2, D3 and D4. T1 and T2 are quarter wave lines for isolation. IC Contact 15, LNA_SW, is grounded since the internal switch is not used. If the LNA are used, C25 and C30 are not placed and "zero Ohm" resistors R5, R9, R13 and R14 insert the LNAs into the receive path.

Voltage supply Contacts 1, 2, 3, 12, 19, 23 and 24 require bypass capacitors as close as possible to the device. Logic supply Contact 4 can directly interface to the baseband supply in equipment applications. The DEMOD_BYPASS (Contact 22) bypasses the demodulator bias circuitry for both RF signals and low frequency signals. The differential demodulator output from contacts 20 and 21 is available at TP1 and TP2. The PLL loop filter is the standard R+C // C network and connects between contacts 12 and 13.
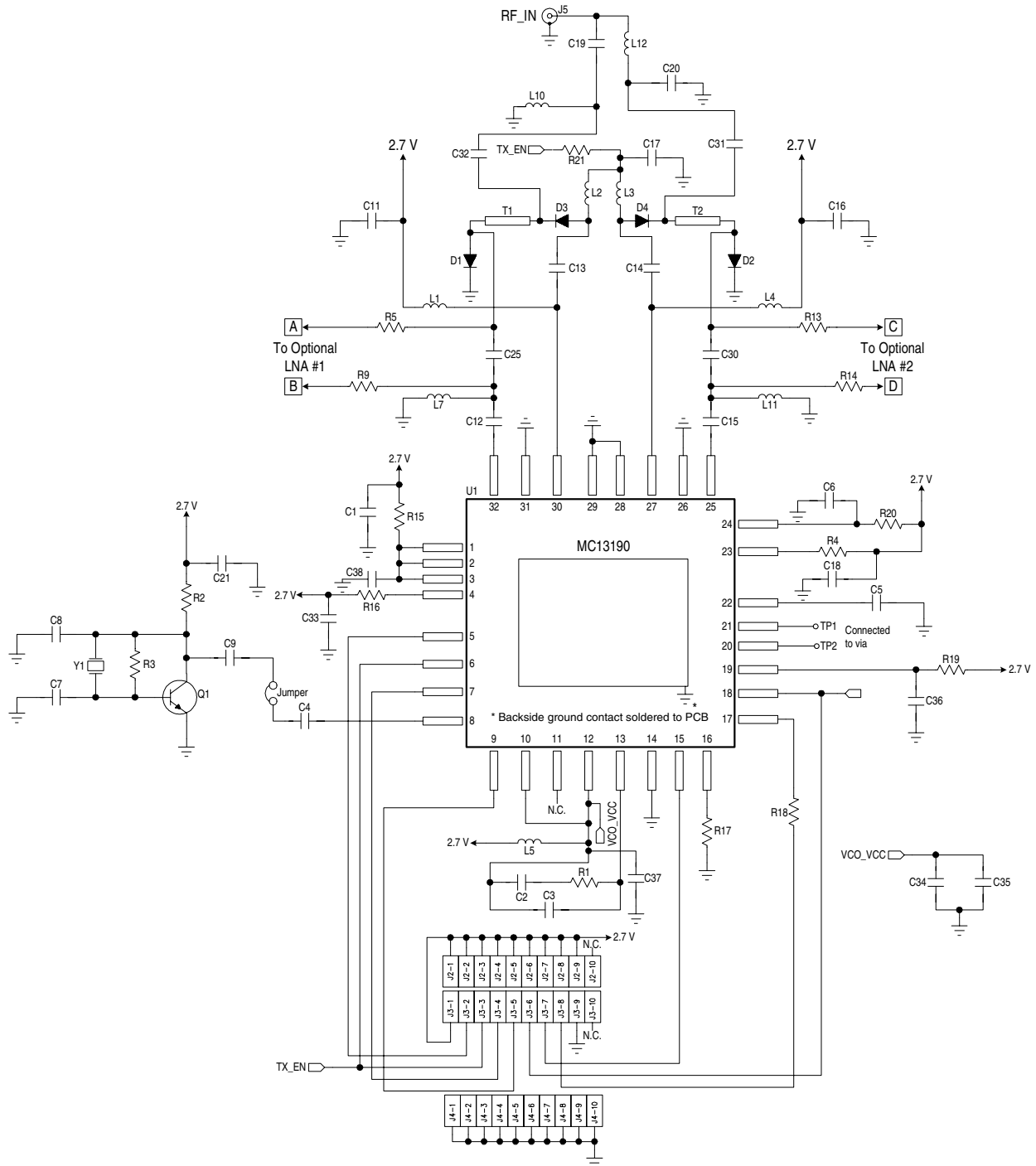
Figure 7.   Transceiver Application Circuit Schematic
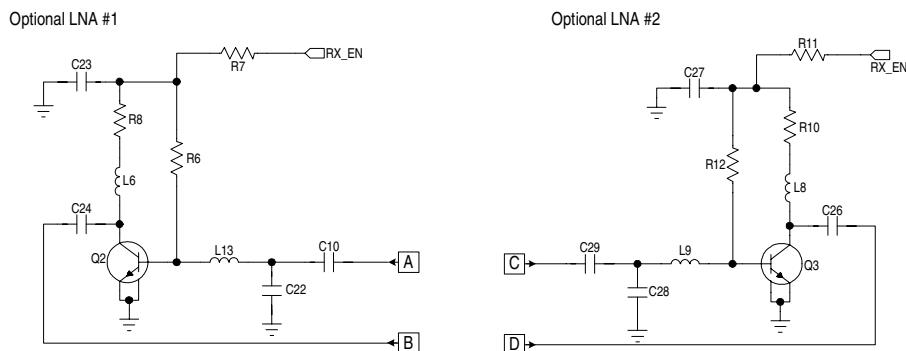
Application Information

Figure 8. Optional LNA Circuits

Table 8. Bill of Materials

Reference	Value	Description
C1, C6, C11, C16, C18, C21, C33, C35, C36, C37	0.1 µF	0402 Ceramic, Murata
C2	82 pF	0402 NPO Ceramic, Murata
C3	12 pF	0402 NPO Ceramic, Murata
C4, C23, C27	1000 pF	0402 Ceramic, Murata
C5	1.0 µF	0603 Ceramic, Murata
C7, C8	27 pF	0402 NPO Ceramic, Murata
C9, C34	100 pF	0402 NPO Ceramic, Murata
C10, C13, C14, C29	6.0 pF	0402 NPO Ceramic, Murata
C12, C15	3.0 pF	0402 NPO Ceramic, Murata
C17	10 pF	0402 NPO Ceramic, Murata
C19, C20	1.5 pF	0402 NPO Ceramic, Murata
C22, C28	0.5 pF	0402 NPO Ceramic, Murata
C24, C26	2.0 pF	0402 NPO Ceramic, Murata
C25, C30, C31, C32, C38	33 pF	0402 NPO Ceramic, Murata
D1, D2, D3, D4	BAR63-03W	Pin Diode, Siemans
J2, J3, J4		1 x 10 Header Strip
J5		SMA Right Angle
L1, L4	2.2 nH	0402 Toko
L2, L3	15 nH	0402 Toko
L5	2.7 nH	0603 Toko
L6, L7, L8, L11	3.0 nH	0402 Toko
L9, L13	0.5 nH	0402 Toko

Table 8.   Bill of Materials (Continued)

Reference	Value	Description
L10, L12	1.8 nH	0402 Toko
Q1		MMBT3904
Q2, Q3		MBC13900
R1	12 kΩ	0402 5%
R2	560 Ω	0402 5%
R3	68 kΩ	0402 5%
R4	51Ω	0402 5%
R5, R9, R13, R14	0 Ω	0402
R6, R12	49 kΩ	0402 5%
R7, R11	130 Ω	0402 5%
R16, R17, R18	180 Ω	0402 5%
R8, R10, R15, R19, R20	10 Ω	0402 5%
R21	270 Ω	0402 5%
T1, T2	$Z_0 = 25\ \Omega, \ell = 0.72$	Microstrip Transmission line, ε_r = 4.5 mils, t = 10 mils
U1		MC13190
Y1	9.357 MHz	Temex
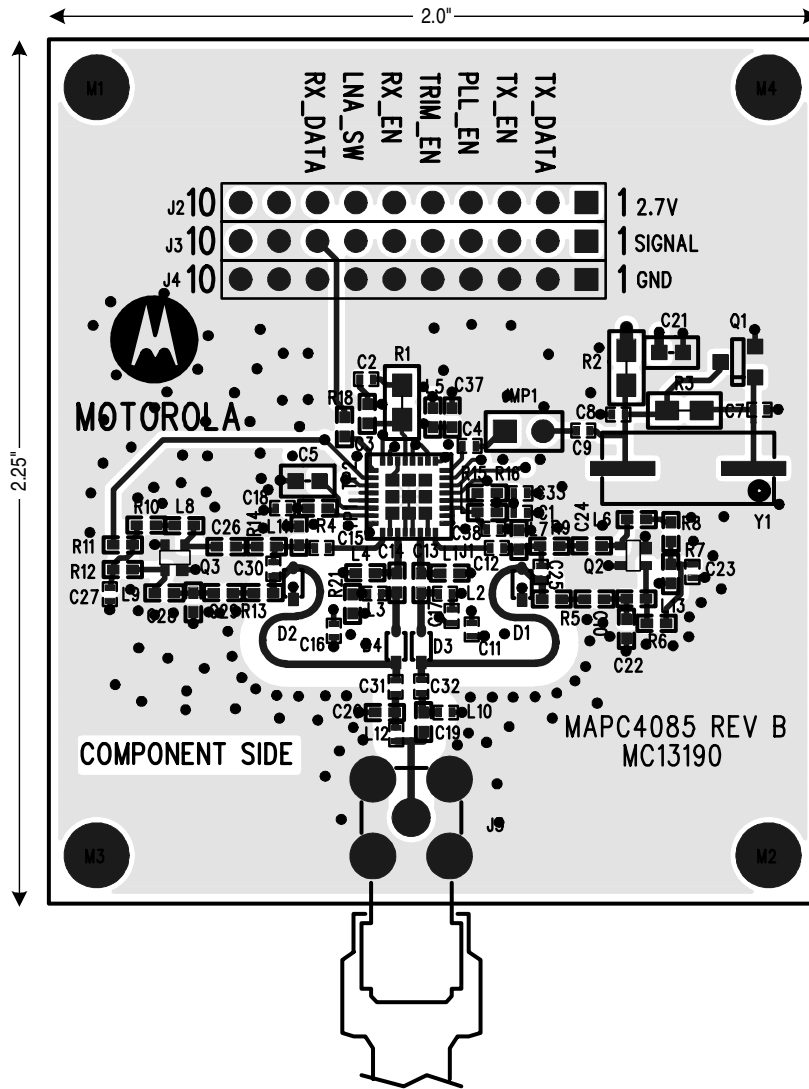
Figure 9.   Transceiver Circuit PCB Topside
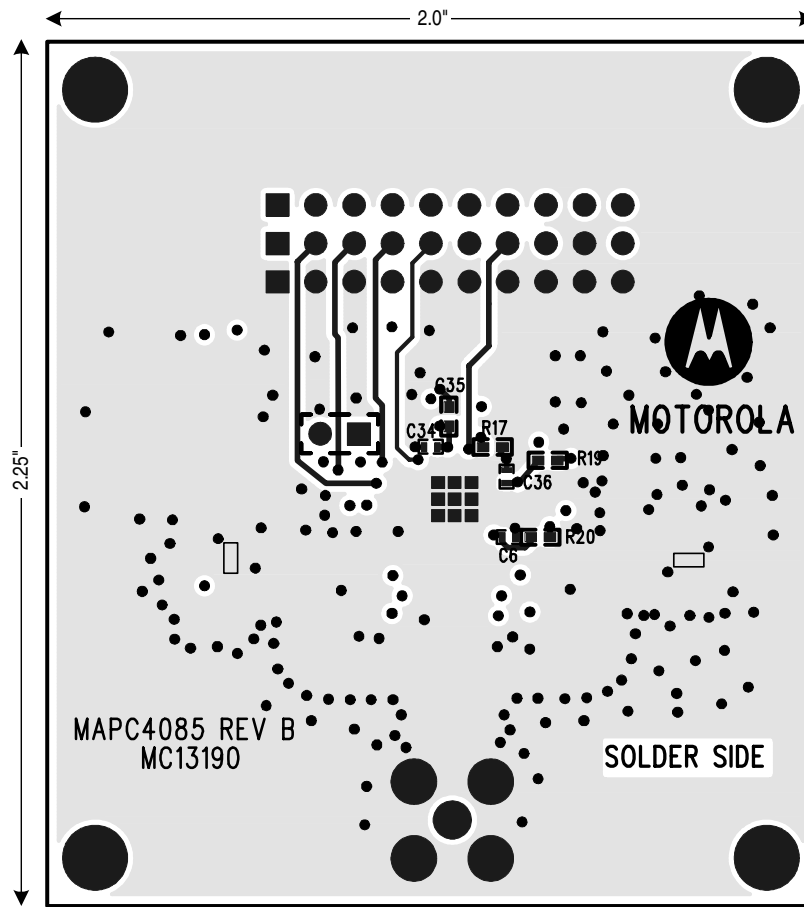(Active Dielectric = 10 mil FR4, Total Board Thickness = 0.062")

Figure 10.   Transceiver Circuit PCB Bottom Side
(Active Dielectric = 10 mil FR4, Total Board Thickness = 0.062")

3.5   Baseband Interface

Referring again to Figure 1, the Simplified Block Diagram, the baseband interface is accomplished through the Logic Interface block. TX_DATA and RX_DATA provide the data interface. The MC13190 is designed to transmit and receive 5 Mbps Manchester encoded data. Data rates of between 4 and 6 Mbps are acceptable. The data pulses should be between 100 and 200 ns duration. The MC13190 does not provide encoding or decoding. The baseband device chosen must be capable of encoding and decoding a 5 Mbps data stream. FREF can be supplied by the baseband and can be "warped" or "dithered" to provide frequency variation.

The remaining five control lines are controlled through GPIO lines.

3.5.1   Low Data Rate Applications

For low data rate applications, an alternate approach can be used to employ a low-cost microcontroller. Figure 11 shows the basic principals. A Motorola MC68HC908GR8 is shown but the same approach can be used with any MCU that is capable of performing the required task. The system reference frequency is chosen to be the 9.537 MHz required for the MC13190's transmit synthesizer. The reference is also fed to a programmable divider which becomes an FSK generator controlled by the transmit data from the MCU. F1 will be 4.769 MHz while F2 will be 2.384 MHz. These frequencies AM modulate the 2.44 GHz carrier as though they were data. On the receive side, RX_DATA drives a peak detector tuned for F1. F1 therefore

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produces a high output and F2 produces a low output. This recovered data stream is feed to the receive data input of the MCU. FSK, rather than ASK, was chosen to keep the baseband limiter compressed and reduce baseband noise. This technique has been shown to work up to 100 kb/s data rate. Details are given in Motorola Application Note AN1946/D.
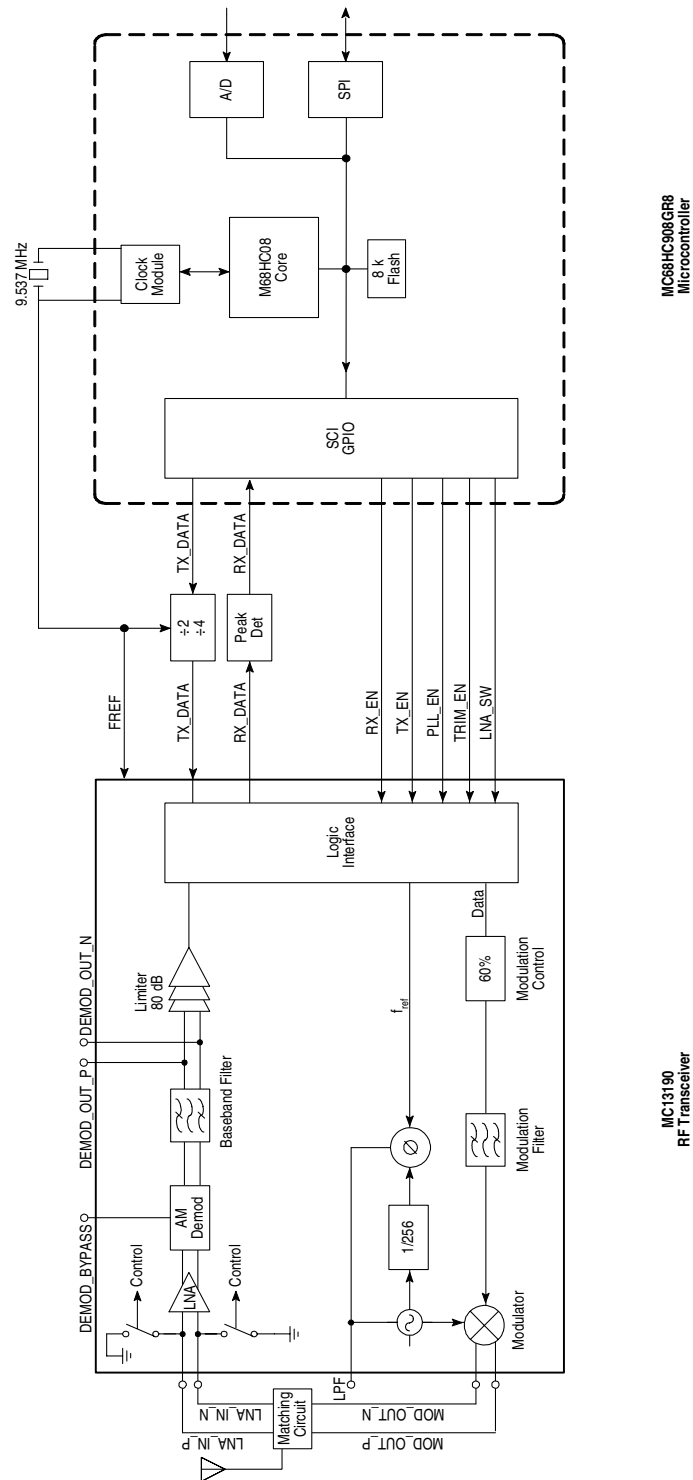
Figure 11.   MC13190 Interface with HC08 Microcontroller for Low Data Rate Applications

3.6   Protocol Considerations

3.6.1   Manchester Encoding

As mentioned earlier, the MC13190 has been designed for use with protocols that employ Manchester encoding. The basic principle of this coding technique is that each data bit is encoded as a transition as opposed to a level. This results in two half-bits as shown in Figure 12. A data 1 bit is encoded as a high-low transition while a data 0 bit is encoded as a low-high transition. Each data bit then has a transition which facilitates data clock recovery. The half-bits are the transmitted and received symbols so each data bit results in two channel symbols.
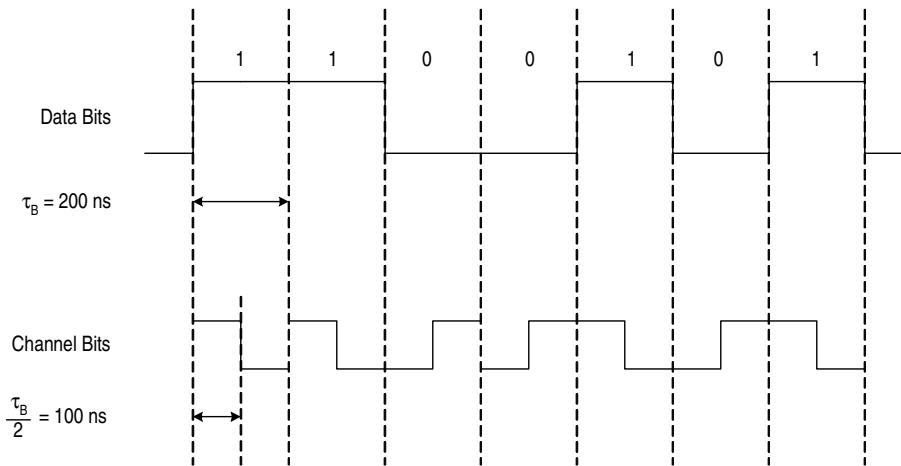
Figure 12.   Manchester Encoding of 5 Mbit Data

At 5 Mbps a data bit is 200 ns long. The channel bits are then 100 ns each but because of the encoding algorithm there can be two half-bits in sequence when a data bit transition occurs. This is also the maximum number of half bits that can occur in sequence.

Although the active filters in the MC13190 transmitter are designed for a specific data rate and Manchester encoding, there is nothing to prevent the application from using other rates or encoding in just the transmitter.

The transmitter uses slope control and low-pass filtering to control the bandwidth of the baseband signal. These filters assume a 100 ns Manchester encoded half-bit with a tightly controlled duty cycle. TX_DATA is dc-coupled so there is no limit on the length of the data bit. A data 1 or 0 can be maintained indefinitely. If the pulse length at TX_DATA is much shorter than 100 ns, the slope control will not allow the modulator to peak and the modulation index will decrease.

The receive filters are hard-wired for 5 Mbps Manchester encoded data as shown in Figure 12 and cannot be changed by the user. These filters have bandpass response to maximize the performance of the receiver. The receiver is ac-coupled. Using Manchester encoded data rates outside the range of 4 to 6 Mbps will result in less than optimum performance. If the rate is too high or low, the data will fall out of the receiver passband and performance will degrade quickly.

3.6.2   Channel Considerations

The 2.4 GHz band is a noisy environment prone to multipath fading. Noise takes many forms but, at 2.4 GHz, microwave ovens and other users predominate. Multipath fading occurs when the same signal arrives at the receiver at different times. Not only can multipath impact the absolute signal level but it can also result in frequency selective fading and intersymbol interference. The AM modulation scheme used in the

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MC13190 makes it susceptible to frequency selective fading through the "notching" of the carrier causing performance degradation in the envelope detector. These effects cannot be avoided so must be dealt with in protocol design. Sufficient margin must be built into the link and redundancy into the protocol to reduce bit error rate to an acceptable level.

3.6.3 Packet Structure

The 5 Mbps data rate that the MC13190 supports is high enough to allow multiple users to occupy the same frequency channel using time division multiple access (TDMA) techniques. The protocol for implementing the TDMA is left up to the system integrator and is heavily dependent on the number of users per unit area, the amount of data to be transmitted per user per unit time and the method used to detect the symbols.

The high level frame structure should allow for the total number of users required as well as the number of retransmissions allocated to each user with a guard band between each packet to allow for the timing uncertainty associated with each of the users clocks. The upper bound of the frame structure is determined by the desired data throughput for each user and the latency of the data. If low latency is the primary design goal, a short frame should be used.

The packets should be structured to provide for a robust synchronization between the transmitter and the receiver as well as a means to deliver the payload reliably with some level of error detection or correction. The packet should be designed with a preamble of at least 8 bits to allow for transceiver settling, a synchronization code, a header, the payload, and the error detection overhead. A suitable form of error detection could be an N-length CRC calculated and appended to the packet.

A common method of synchronization used in the industry is to transmit a length of a code that has been designed to provide for fast acquisition of the codeword yet low probability of false detection. The ideal code word has a very low autocorrelation side lobe. That is to say, when the codeword is shifted the correlation value is very low. A Barker or Neuman-Hofman code could be used and are well documented in most digital communication texts.

The MC13190 receiver outputs a waveform that has no timing associated with it. In other words, the baseband symbol detector will need to determine the waveform timing in order to make the correct bit decisions on the sampled waveform. Since the transmitted date is Manchester encoded, it is recommended that the input waveform be at least 8X oversampled so that there are at least 4 samples per half of the waveform. The correlation with the synchronization word should be performed on all samples of the waveform, but it is recommended that the bit decisions be based only on the second half of the Manchester encoded waveform since a transition is guaranteed at the middle of each transmitted bit. It should be noted that an artifact of the MC13190 baseband filtering is some corruption of the first half of the Manchester encode bit cycle as well. 8X oversampling should provide for adequate timing resolution of the bit edge transitions to insure correct bit decisions if the packet length is not too long. The packet length will be limited primarily by the accuracy of the reference clocks in the system. If the reference source has a guaranteed stability of 50 ppm, then a worst case timing shift will be 100 ppm or up to 20 ps per 200 ns bit. This would limit the packet length to 250 µs before the accumulated timing drift will begin to affect the symbol detection. A method of coherent detection could be employed where a tracking loop is implemented if longer packers are desired.

3.7 Device Characterization Information

Table 9. Broadband Differential Scattering Parameters

f (GHz)	LNA RX Mode		LNA TX Mode	
	Mag	$\angle\ \phi$	**Mag**	$\angle\ \phi$
0.5	0.866	-17	0.946	-51.5
1.0	0.830	-40.2	0.807	-115.7
1.5	0.655	-69.3	0.736	173.4
2.0	0.440	-110.3	0.784	121.1
2.5	0.340	-176.5	0.845	89.7
3.0	0.478	120	0.889	69.8
3.5	0.640	86.6	0.917	56.1
4.0	0.756	66.4	0.936	46
4.5	0.831	52.5	0.950	38.2
5.0	0.879	42.3	0.959	31.8
5.5	0.910	34.4	0.966	26.5

4 Packaging

NOTES:
1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
3. THE COMPLETE JEDEC DESIGNATOR FOR THIS PACKAGE IS: HF-PQFP-N.
4. CORNER CHAMFER MAY NOT BE PRESENT. DIMENSIONS OF OPTIONAL FEATURES ARE FOR REFERENCE ONLY.
5. COPLANARITY APPLIES TO LEADS, CORNER LEADS, AND DIE ATTACH PAD.
6. FOR ANVIL SINGULATED QFN PACKAGES, MAXIMUM DRAFT ANGLE IS 12°.

Figure 13. Outline Dimensions for QFN-32, 5x5 mm
(Case 1311-02, Issue D)

NOTES

HOW TO REACH US:

USA/EUROPE/LOCATIONS NOT LISTED:

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P.O. Box 5405, Denver, Colorado 80217
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