Quadrature Modulator/Demodulator IC Covers Baseband to 250MHz

Introduction

Most modern wired and wireless communication systems require sophisticated frequency conversion to and from baseband. Quadrature, or I/Q, modulation is frequently used by system designers to up-convert data to an intermediate frequency (IF) of anywhere from 1MHz up to several hundred MHz. Simultaneously, the receiver must down-convert the information contained at the IF and output the data in its original I/Q format. RF Micro Devices has developed an advanced integrated circuit (IC) that can perform both of these important functions. The RF2703 Quadrature Modulator/Demodulator is a monolithic IC that operates from a single 2.7V to 6V power supply. This low cost, high performance IC packs an LO limiting stage, a digital divider, and two double-balanced mixers within a small SO-14 plastic package (see Figure 1).

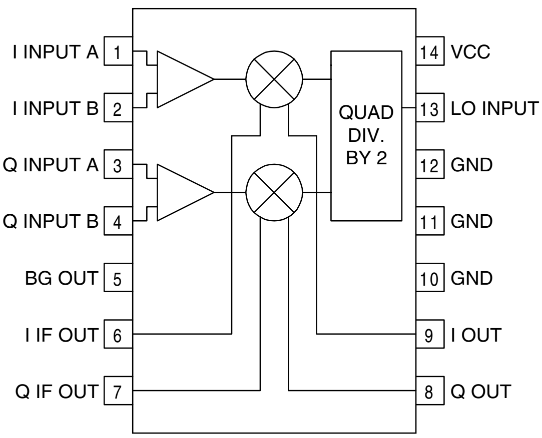

Figure 1. The functional block diagram.

Demodulator

The RF2703 can be configured easily within a receiver to perform as a quadrature demodulator, as illustrated in Figure 2. The RF2703 outputs I and Q signals with typically 2° or better phase error and 0.1dB or better amplitude imbalance. The baseband (I/Q) outputs of the device can handle data rates from DC to 50MHz and can drive greater than 1Vp-p into a high impedance analog-to-digital converter (ADC) or operational amplifier. DC offset between the I and Q outputs is typically smaller than 10mV.

Operation of the RF2703 is simple and easy to understand. When used as a demodulator in a receiver, the system IF carrier is fed from an IF amplifier or filter into the I INPUT and Q INPUT ports of the RF2703 (pins 1 through 4 in Figure 1). These input pins are tied together in demodulation mode so that the IF signal is fed into the Gilbert cell mixers (see Figure 3) in parallel. The input impedance of each of the four input pins is 1200Ω, but when these pins are driven in a single-ended configuration the total impedance is half that, or 600Ω (refer to Figure 2). The IC can also be driven differentially where pins 1 and 2 are complementary and pins 3 and 4 are complementary.

The IF signal drives the lower differential pair of each of the two Gilbert cell mixers. The upper transistors, or switching transistors, are driven by the local oscillator (LO) signal. The LO signal is provided by an external VCO or other frequency synthesizer and is connected to the RF2703 at the LO pin. Since the LO circuitry is driven by voltage and there is no concern for noise figure or maximum power transfer, there is generally no need to match this port. A shunt 50Ω resistor can be placed externally to the port to interface with test equipment, but otherwise power is not a concern. If a VCO or other LO source cannot supply enough voltage, a reactive match (voltage transformation) can be implemented. The LO signal frequency must be twice the frequency of the IF signal, because the digital divider (flip-flop) which splits the LO signal into two quadrature waveforms also divides the frequency of the LO signal by two. The highest frequency of recommended operation is 250MHz for the IF signal, which translates to 500MHz for the LO input. The IC will operate above this frequency range but phase accuracy and amplitude balance may degrade.

From the system designer's point of view, using twice the LO frequency is beneficial in that LO leakage into other components of the system does not appear as co-channel interference. In a typical receiver, the received signal may be very weak (≅ -110dBm) at the antenna. As the signal passes through an LNA/mixer stage it is down-converted to IF. Assuming the LNA/mixer stage has 20dB of gain, the IF signal is now at -90dBm. Any kind of jammer at the IF frequency (co-channel interference) greater than around -100dBm will wreak havoc once the IF signal reaches the IF amplifier. The jammer will be amplified and reduce dynamic range, effectively increasing bit error rate. An IF VCO commonly outputs levels around -5dBm. Since

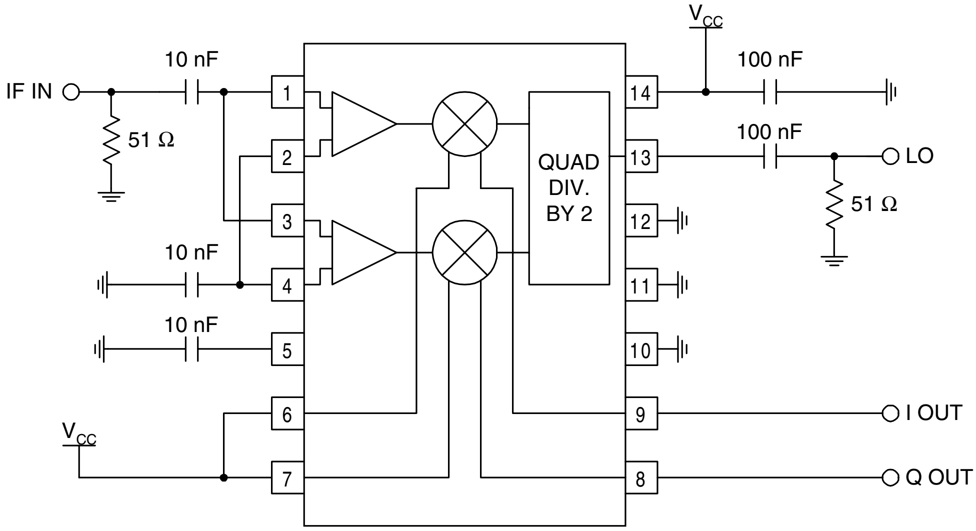

Figure 2. The demodulator configuration.

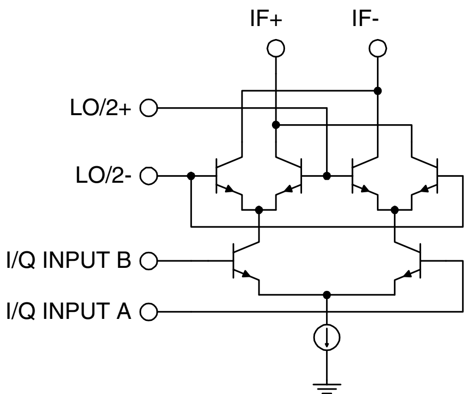

Figure 3. The Gilbert cell Mixer equivalent circuit.

it is virtually impossible to get 95dB of isolation inside a portable device, such as a cordless or cellular phone, the VCO output will leak into the IF signal path and act as co-channel interference. With a 2X frequency LO source, this problem is eliminated because any leakage into the IF path will be bandpass filtered, a huge advantage. In some systems, CDMA cellular for example, the transmission chain uses gain control to precisely regulate the output level of the radio frequency (RF) carrier. The gain control is generally done at IF by an automatic gain control (AGC) amplifier before the data is up-converted to RF. Under conditions where the AGC amplifier is attenuating, the output of the amplifier can be down around -90dBm. As in the receive case, the VCO output can leak into the IF path at the AGC amplifier output or into the upconverter input. This co-channel interference will not be filtered and will pass out the antenna as a jammer. Once again, a 2X frequency LO source will not cause this problem as its leakage will be filtered out before it ever reaches the antenna.

As the 2X frequency LO signal enters the RF2703, the LO signal immediately passes through several limiting amplifier stages to ensure that it will have a large enough signal swing to drive the flip-flop circuitry. This feature allows the system designer to have great flexibility with LO signal level. The IC will accurately perform the dividing function over all but the highest frequencies with as little as 60 mVp-p drive level at the LO input. Since performance of the LO circuitry is frequency-dependent, especially at the higher end of the frequency range, phase and amplitude accuracy can be optimized by increasing the LO signal level from 60 mVp-p until sideband suppression is maximized.

The LO signal continues straight from the limiting stages to the flip-flop. The LO actually acts as the clock signal for the flip-flop, which divides the clock frequency by two and outputs two signals which are 90° out of phase. One of these signals drives the switching transistors of the I Gilbert cell and one of them drives the switching transistors of the Q Gilbert cell. The Gilbert cells mix the IF and LO/2 signals together to extract the baseband data; 20dB of conversion gain is also provided in the mixers to boost a weak IF signal. The baseband data proceeds through output buffers and exits the part at pins 8 and 9 (IOUT and QOUT). The output ports have a 50Ω AC output impedance but are designed to drive high impedance loads (>10kΩ). Each output also contains an internal 2 kΩ resistor that sinks current for the output emitter follower transistor. Since the outputs are DC coupled, using lower impedance output loads will cause more current to be drawn from the IC. The RF2703 can drive down to a 50Ω DC coupled load, but the output voltage swing will decrease by more than 6dB. Typically an ADC, op-amp, or digital filter will follow the RF2703, all of which have high input impedances.

Having described the circuitry involved in demodulation, it is helpful to understand how a demodulator works mathematically. The following example is a simple but effective way to communicate the theory of operation of a quadrature demodulator. In the example, single sideband (SSB) modulation will be used, where the data signals are two sinusoids, i(t) and q(t), that are in quadrature. When the IF carrier with data reaches the demodulator, it can be expressed as follows:

$$V(t) = A\cos[(\omega_{IF} + \omega_m)t] \quad (1)$$

where:

A = signal amplitude,

ω_{IF} = the IF carrier frequency, and

ω_m = the data frequency.

As shown in Figure 4, an LO signal at the IF frequency is split into an in-phase signal and a quadrature signal. These two signals are then multiplied with V(t):

$$Vi(t) = A\cos[(\omega_{IF} + \omega_m)t]\cos(\omega_{IF}t) \quad (2)$$

and

$$Vq(t) = A\cos[(\omega_{IF} + \omega_m)t]\sin(\omega_{IF}t) \quad (3)$$

where:

Vi(t) = the in-phase product and

Vq(t) = the quadrature product.

Using trigonometric identities:

$$Vi(t) = A/2\cos(\omega_m t) + A/2\cos[(2\omega_{IF} + \omega_m)t] \quad (4)$$

and

$$Vq(t) = A/2\sin(\omega_m t) + A/2\sin[(2\omega_{IF} + \omega_m)t]. \quad (5)$$

After low-pass filtering at baseband:

$$Vi(t) = A/2\cos(\omega_m t) = A/2\ i(t) \quad (6)$$

and

$$Vq(t) = A/2\sin(\omega_m t) = A/2\ q(t). \quad (7)$$

Thus the demodulator has retrieved the data. The above math can be worked in reverse to illustrate SSB modulation.

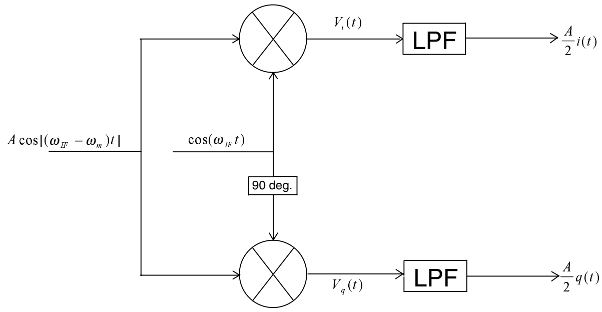

Figure 4. Quadrature Demodulation Operation.

Modulator

The RF2703 can be configured as a quadrature modulator for use in a transmit chain, as in Figure 5. Generally, quadrature modulators are described by their single sideband (SSB) output spectrum. Typical carrier suppression for the RF2703 is 25dBc, although this number can be increased by adjusting the DC voltages at the I and Q baseband inputs (pins 1 through 4) to obtain a null in the carrier. Suppression of the unwanted sideband is typically 35dBc or better, which corresponds to less than 2° phase error and less than 0.1dB amplitude imbalance. The RF2703 is capable of driving several hundred millivolts peak-to-peak into a 1200Ω load (see Figure 6) while providing up to 15dB of conversion gain (see Figure 7).

Operation of the RF2703 in modulation mode is similar to that in demodulation mode, except in reverse. In this case, baseband data is fed into the I INPUT and Q INPUT ports (pins 1 through 4). Figure 5 shows how to connect the baseband single-endedly, but the data can still be connected differentially just as in demodulation mode. The data drives the lower differential pair of each of the Gilbert cell mixers; the I data drives one mixer and the Q data drives the other.

The LO signal is applied to the IC as described earlier with the frequency at twice what the desired IF output frequency is. The same levels and frequency range used in demodulation mode apply in modulation mode. The LO signal proceeds through the limiting stages and through the flip-flop to drive the switching transistors of each of the Gilbert cell mixers. The outputs of the two mixers are summed together by tying pins 6

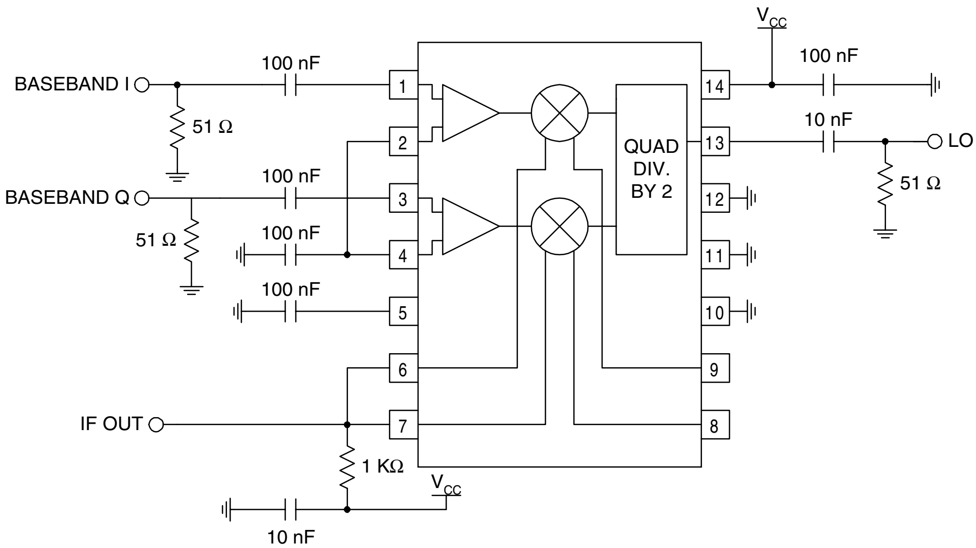

Figure 5. The modulator configuration.

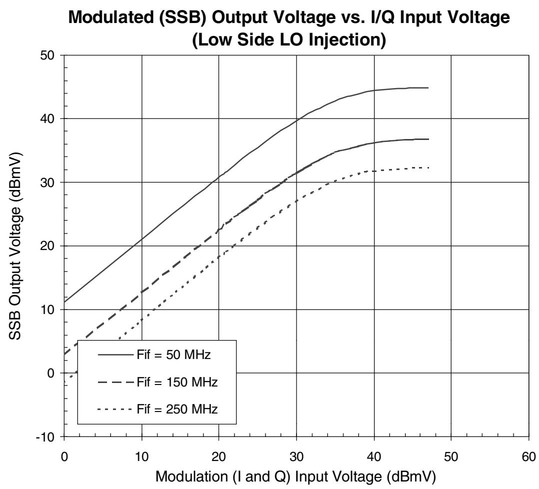

Figure 6. IF Output vs. I/Q Modulation Level

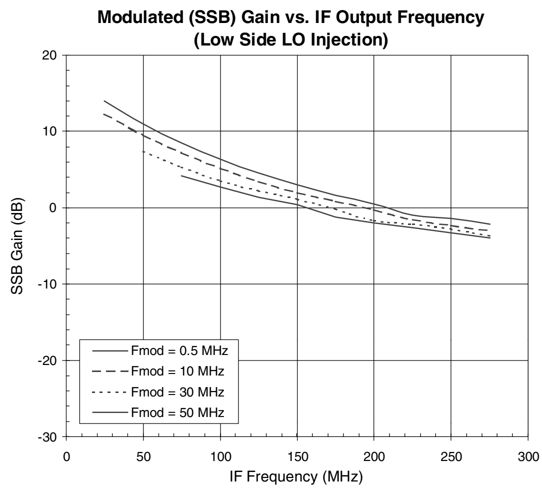

Figure 7. SSB Modulator Gain vs. IF Frequency

and 7 together external to the part.

Pins 6 and 7 are direct connections to the collectors of the switching transistors of the Gilbert cells. For this reason, the power supply (Vcc) must be connected to these pins in both operation modes. During modulation, Vcc is provided through a load resistor or through an inductor. In modulation mode the load resistor not only provides DC biasing, it also determines the conversion gain of the Gilbert cells. Since connecting through a resistor will cause a voltage drop which can saturate the Gilbert cell switching transistors, it is recommended to use no more than 1200Ω. If a choke or matching inductor is used in parallel with the resistor, then this value can be increased somewhat. It may be necessary in a system to match the output to a lower impedance, and this can be achieved by a simple L-C network tuned for the frequency desired.

Conclusion

The RF2703 provides two critical building blocks in RF system design. This low-cost, high-performance IC fills the need for extremely accurate modulation and demodulation for any number of wired and wireless communication systems. With outstanding performance, low cost, and small size, the RF2703 is helping to simplify many RF system designers' work.