The quadrature FM detector – analysis and design

Introduction: A number of FM detectors are in use today. FM detection can be done using PLLs, or slope detection or quadrature detection. This brief paper addresses the techniques of quadrature detection.

The functional schematic of a quad detector is shown below in figure 1.0

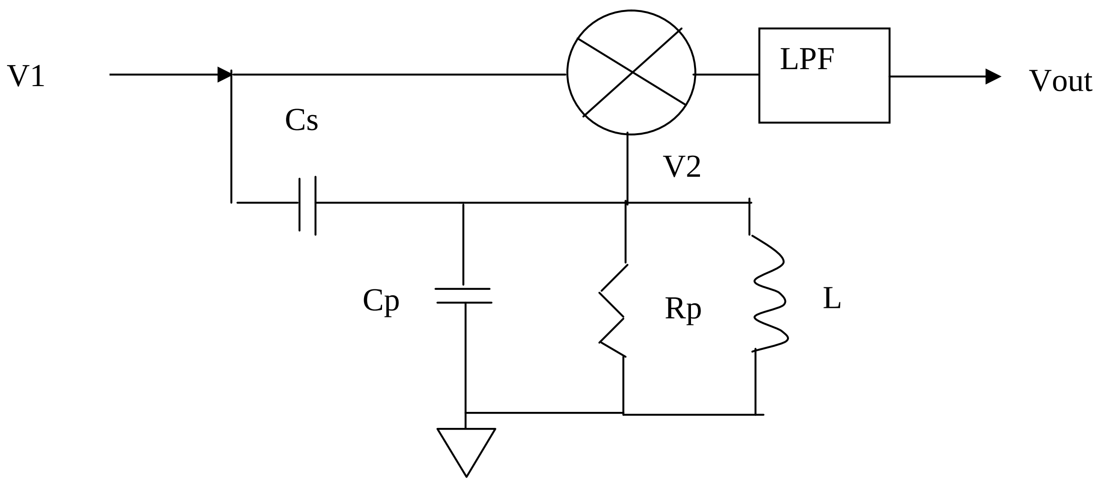


Figure 1.0

A phase shift network consisting of Cs and a coil with components Cp, Rp, L takes an input signal V1 and changes its phase. The phase shifted signal is V2. V1 and V2 are both applied to two inputs of a mixer. The output of the mixer is low pass filtered to yield the detected signal from a FM wave. The following analysis shows how.

The following equation represents the signal V2 in terms of V1

$$v_2 = v_1 \cdot Q \cdot \frac{C_s}{C_s + C_p} \frac{1}{\sqrt{1+a^2}} \angle(90^\circ + \tan^{-1} a) \qquad 1.0$$

Here the parameter a is given by:

Signal Processing Group Inc., technical memorandum. Website:http://www.signalpro.biz. Signal Processing Group Inc., designs, develops and manufactures analog and wireless ASICs and modules using state of the art semiconductor, PCB and packaging technologies. For a free no obligation quotation please send us your requirements by email at spg@signalpro.biz

$$a = 2Q\frac{\Delta\omega}{\omega_n}, \qquad 2.0$$

In this equation,

$\Delta\omega$	=	the deviation from the carrier frequency.
Q	=	is the quality factor of the phase shift network, $Rp/\omega_n L$
ω_n	=	resonant frequency of the network, given by,

$$\omega_n = \frac{1}{\sqrt{L(C_s + C_p)}}.$$

The input signal V1 applied to one mixer input is a amplitude limited signal, while the signal V2 is a linear signal. If the output of the mixer is integrated over a half time period, then the average value of the mixer output current is obtained.

Using some simple mathematics and assuming that the mixer is designed using bipolar transistors, the following expression is obtained for the transfer function of the quadrature modulator.

$$\frac{\bar{i}_o}{2I_o} = \frac{2}{\pi}Q\frac{C_s}{C_s + C_p}\frac{V_1}{2V_T}\frac{1}{\sqrt{1+a^2}}\frac{a}{\sqrt{1+a^2}}. \qquad 3.0$$

Here,

V_T	=	The thermal equivalent voltage, KT/q ~ 26mV at 300K
q	=	electronic charge
K	=	Boltzman's constant
T	=	temperature in Kelvin.
Io	=	0.5 *Mixer tail current

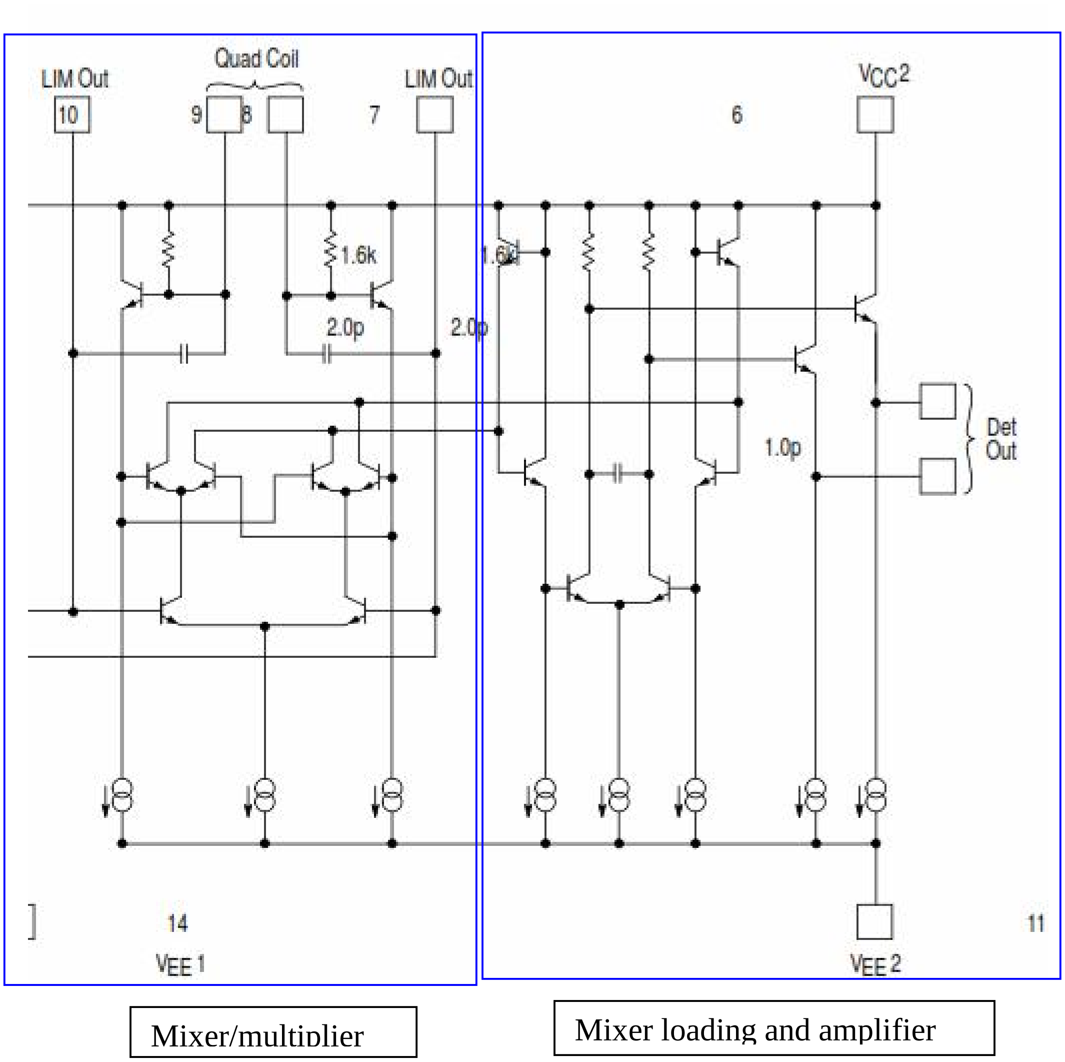
And,

$\overline{io}$, is the average mixer current output.

Signal Processing Group Inc., technical memorandum. Website:http://www.signalpro.biz. Signal Processing Group Inc., designs, develops and manufactures analog and wireless ASICs and modules using state of the art semiconductor, PCB and packaging technologies. For a free no obligation quotation please send us your requirements by email at spg@signalpro.biz

The rest of the quantities have been defined above. A partial view of the MC13155 device is shown for the quadrature detector section of the device. This will now be analyzed.

Limited inputs to the detector.



Description:

The limited outputs from the previous stage are input to the mixer stage. The mixer is a variant of the Gilbert cell with diode connected npn loads to compress the signal and keep it within a linear range. The outputs of the mixer are buffered using two emitter followers. These emitter followers also act as level shifting elements so that the input signal to the amplifier is correctly biased. The output of the amplifier is buffered and connected to the output pads.

Signal Processing Group Inc., technical memorandum. Website:http://www.signalpro.biz. Signal Processing Group Inc., designs, develops and manufactures analog and wireless ASICs and modules using state of the art semiconductor, PCB and packaging technologies. For a free no obligation quotation please send us your requirements by email at spg@signalpro.biz

The limited inputs to the mixer are also connected to the quad coil differentially through the 2pF internal capacitors (Cs in the equations above). The quadrature coil is itself external to the IC. The equations developed above can be used with a few modifications to calculate the components for various operating conditions as follows.

The operating Q of the circuit is given by:

$$Q = RT/XL,$$

Here RT is the equivalent resistance across the quad coil. XL is the reactance of the inductor ($2\pi fL$, f = desired frequency).

The resonant frequency expression is the same as considered above, with the exception that the capacitance Cp should also include the parasitic capacitance encountered across the pins of the device and PCB parasitics etc. (Implies that some trail and error would be required in reality).

The following is a design example for a wideband detector at 70 MHz IF frequency, and a loaded Q of 5. The loaded Q of the quadrature detector is chosen somewhat less than the Q of the IF bandpass. For an IF frequency of 70 MHz and an IF bandpass of 10.9 MHz, the IF bandpass Q is approximately 6.4.(f/bandpass).

Let the external Cext = 20 pF. (The minimum value here should be greater than 15 pF making it greater than the internal device and PCB parasitic capacitance, Cint ˜ 3.0 pF).
Cp = Cint + Cext = 23 pF.

Solve for L: then,

$L = (0.159)^2/(Cpfc^2)$

L = 198 nH, thus, a standard value is chosen.
<u>L = 0.22 µH</u> (tunable shielded inductor).

The value of the total damping resistor to obtain the required loaded Q of 5 can be calculated by rearranging:
RT = Q(2pfL)
RT = 5 (2p)(70)(0.22) = 483.8 Ω.
The internal resistance, Rint between the quadrature tank Pins 8 and 9 is approximately 3200 Ω and is considered in determining the external resistance, Rext which is calculated from: Rext = ((RT)(Rint))/ (Rint – RT)
Rext = 570, thus, choose the standard value.
<u>Rext = 560 Ω.</u>

Signal Processing Group Inc., technical memorandum. Website:http://www.signalpro.biz.
Signal Processing Group Inc., designs, develops and manufactures analog and wireless ASICs and modules using state of the art semiconductor, PCB and packaging technologies. For a free no obligation quotation please send us your requirements by email at spg@signalpro.biz

References

1.0 A Quadrature Demodulator Tutorial Danielle Coffing and Eric Main EETimes Design

2.0 MC13155 Datasheet.

Signal Processing Group Inc., technical memorandum. Website:http://www.signalpro.biz. Signal Processing Group Inc., designs, develops and manufactures analog and wireless ASICs and modules using state of the art semiconductor, PCB and packaging technologies. For a free no obligation quotation please send us your requirements by email at spg@signalpro.biz