Does Your Receiver have an IQ?

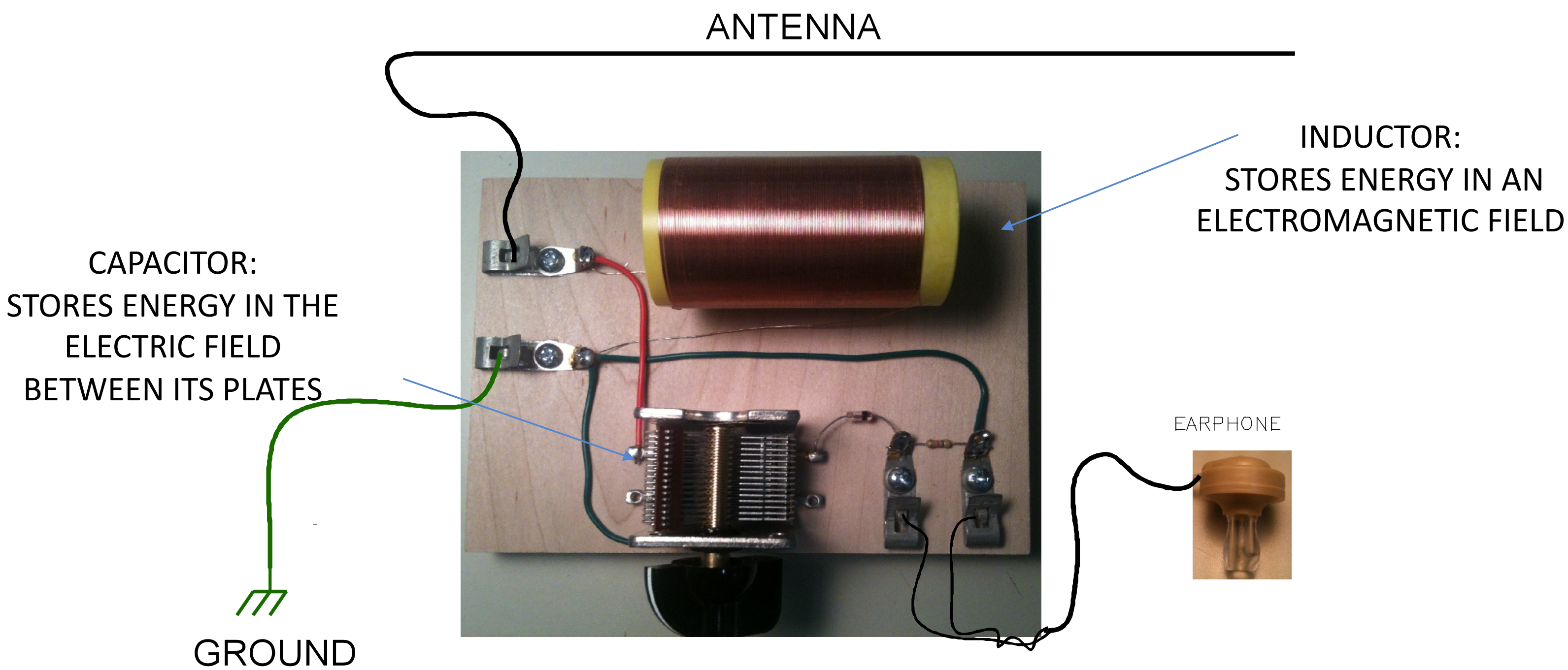
A Brief Presentation of how Radio Receivers have Evolved over the Decades of Radio, and Describing how some Modern SDR Receivers work using the Quadrature Sampling Detector, also known as the Tayloe Detector.

Recent Rigs I've Built from Kits:

- **BitX40** by Ashar Farhan. Based upon enthusiastic reports from Doug Miller, W4DML I have bought and built three of these SSB rigs. But I never looked deeply into how it worked, just had fun with it!
  Today I will show how it works when receiving signals.

- **QCX** by Hans Summers, QRP-Labs. I attended the QRP seminar in Xenia(4 Days in May) and was very impressed with Hans Summers' presentation describing his new radio design. Hans lectured about implementing a Quadrature Sampling Detector with a commonly used Digital Synthesis IC, he spoke about I and Q signals. I was completely unfamiliar with QSD, I & Q, and decided to find out about that.

BEFORE SOFTWARE DEFINED RADIOS, RADIO RECEIVERS RELIED ON THE ‘MAGIC’ OF ELECTRIC AND ELECTROMAGNETIC FIELDS TO TUNE IN STATIONS



RESONANCE CONCEPTS

Putting inductors and capacitors together creates an electronic "bell" that rings or resonates.

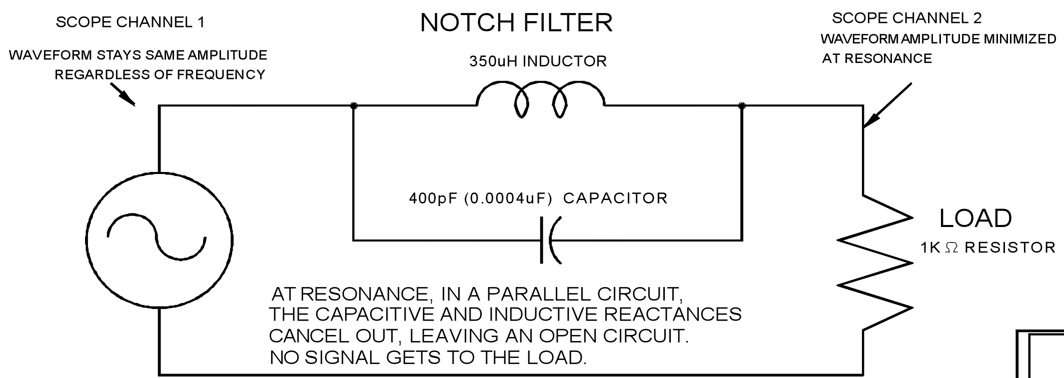
Inductor feeds capacitor; capacitor feeds inductor in a back and forth, reciprocal way.

Resonance occurs when capacitive and inductive reactance values are equal:

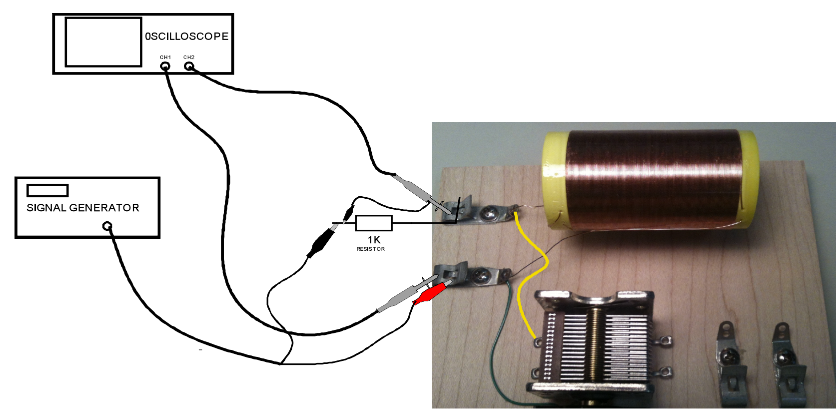
$$2\pi f\ L = \frac{1}{2\pi f\ C}$$

An LC circuit can store electrical energy oscillating at its resonant frequency. A capacitor stores energy in the electric field between its plates, depending on the voltage across it, and an inductor stores energy in its magnetic field, depending on the current through it.

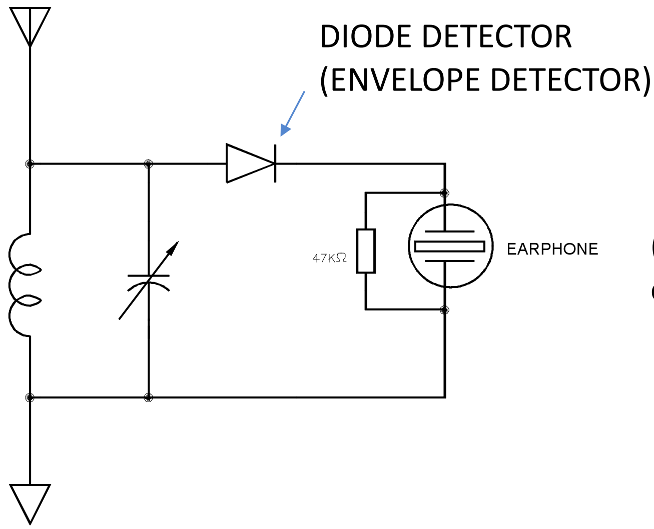
IN A PARALLEL CIRCUIT OF BOTH CAPACITIVE AND INDUCTIVE REACTANCES, AT RESONANCE THE CIRCUIT HAS INFINITE IMPEDANCE WHICH PREVENTS CURRENT FLOW TO THE LOAD



Experiment #5 Schematic



$$f = \frac{1}{2\pi\sqrt{LC}}$$



(The earphone in this example has capacitance)

With one side of the LC circuit tied to an antenna, and the other side to ground, signals captured by the antenna that are not at the resonate frequency of the circuit are passed through the circuit to ground. Signals that are at the resonate frequency do not get shunted to ground and are available for ‘detection’ by a Germanium diode rectifier.

THE ‘TUNED RADIO FREQUENCY ‘ RECEIVER (TRF) CONTAINS TWO OR THREE TUNED RF AMPLIFICATION STAGES BEFORE THE DETECTOR

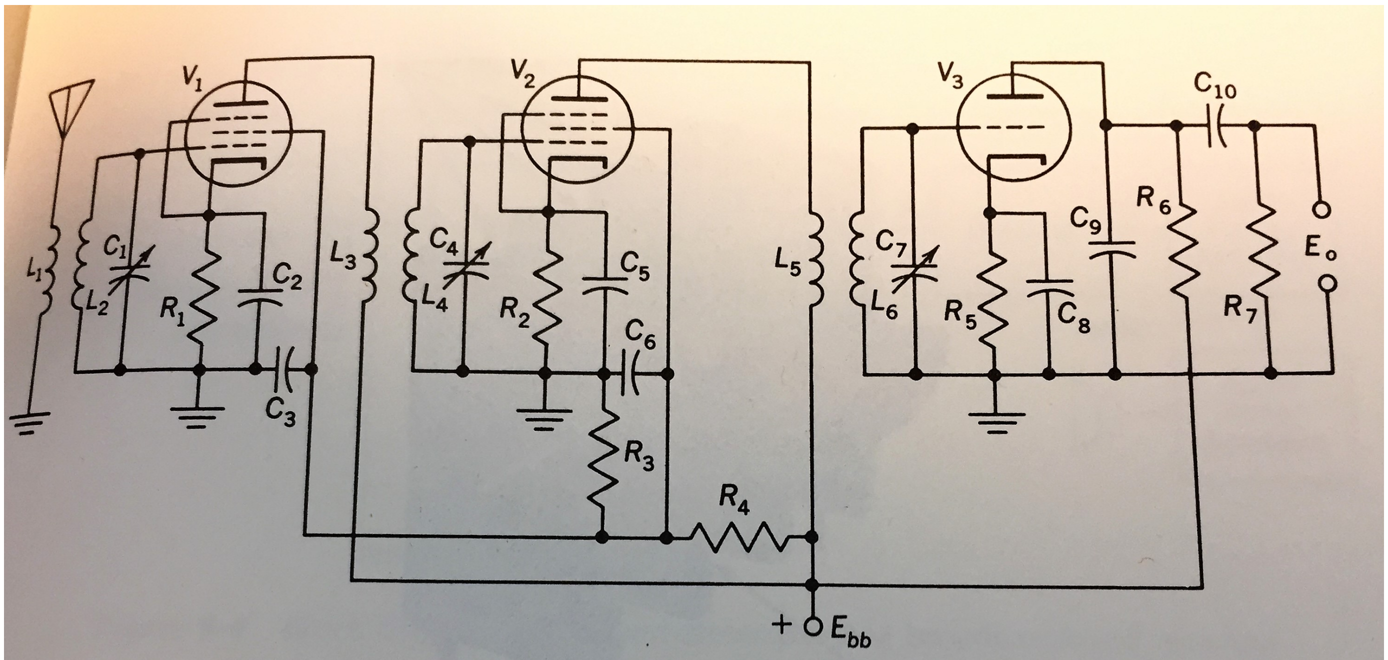
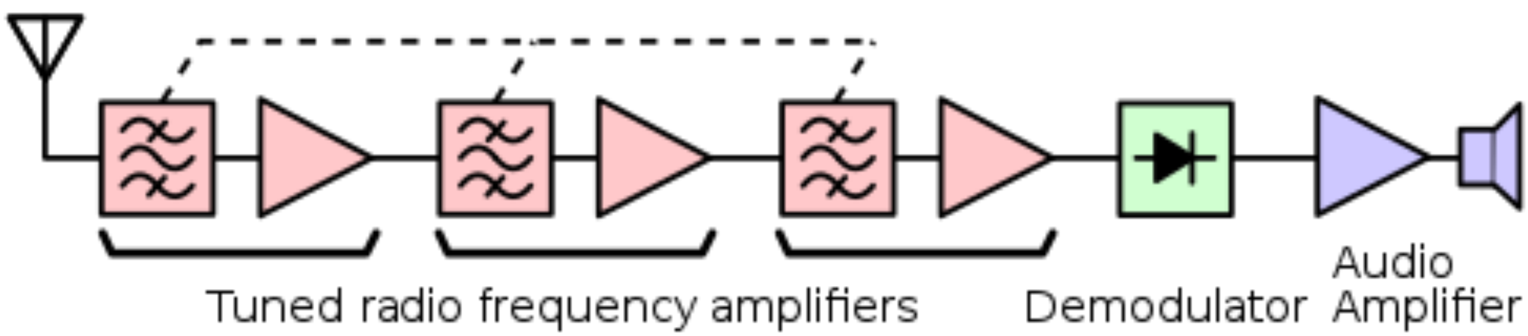
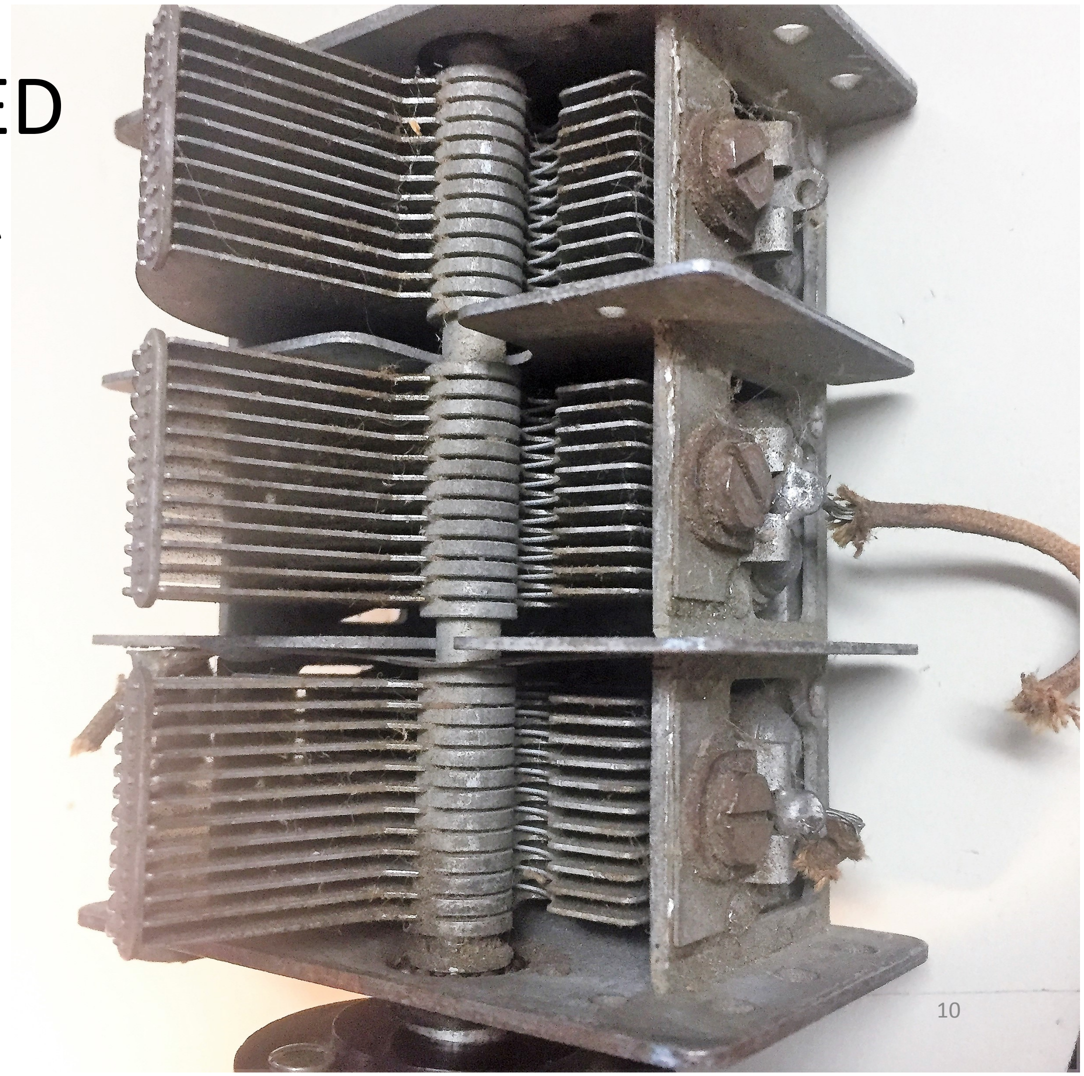


Figure 8-2 Front end of a TRF receiver.

Each RF stage of a TRF receiver had to be tuned to the same frequency, so the capacitors had to be tuned in tandem when bringing in a new station. In some later sets the capacitors were "ganged", mounted on the same shaft or otherwise linked mechanically so that the radio could be tuned with a single knob, but in most sets the resonant frequencies of the tuned circuits could not be made to "track" well enough to allow this, and each stage had its own tuning knob



TRF RECEIVER GANGED VARIABLE CAPACITOR



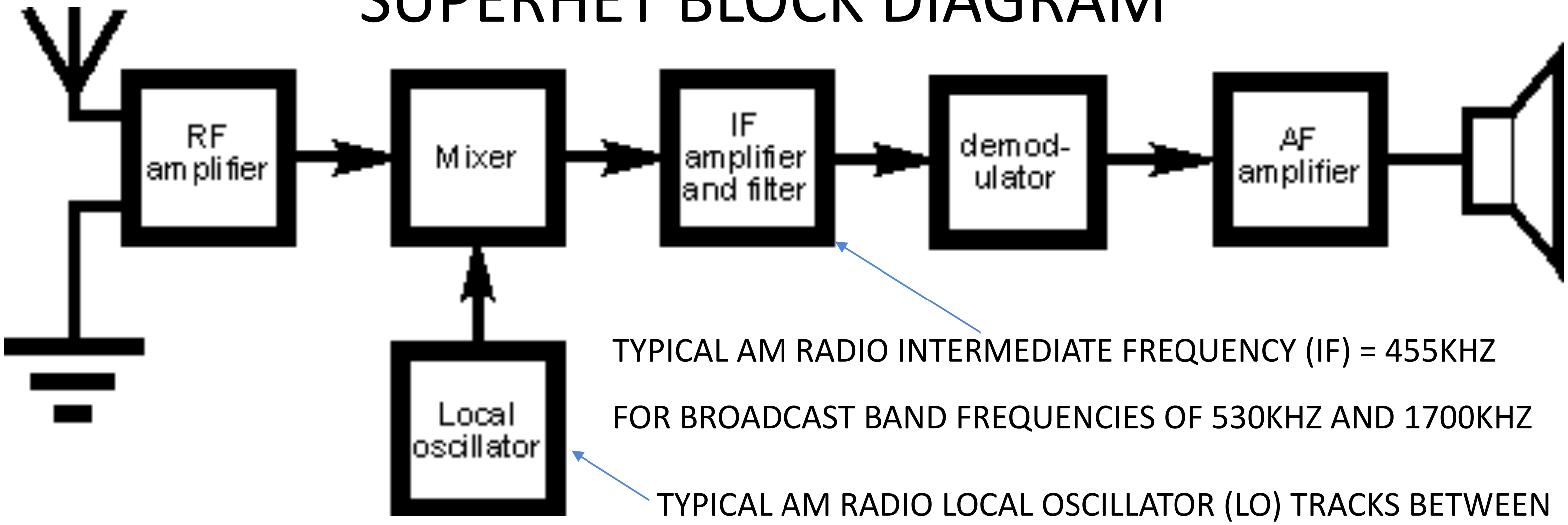
The major problem with the TRF receiver, particularly as a consumer product, was its complicated tuning

Note that this is a simple and straight forward design, and most of the circuits disadvantages would not apply if the receiver was used for one frequency only. Cascading RF gain stages works well for a single frequency. This is the basic principle of the superheterodyne receiver.

THE SUPERHETERODYNE RECEIVER (Superhet)
INVENTED BY EDWIN ARMSTRONG IN 1918, REPLACED THE TRF RECEIVERS BY THE MID 30'S.

Armstrong built a cascade of fix-tuned amplifiers at a low frequency where a large amount of stable gain was easy to obtain and. Then he preceded this amplifier cascade with a frequency translator or mixer stage in order to convert or "heterodyne" the desired signal to the new "intermediate frequency" or IF. Armstrong called this new receiver (which used heterodyning to translate signals to a fixed, lower intermediate frequency for reception) the "superheterodyne" receiver.

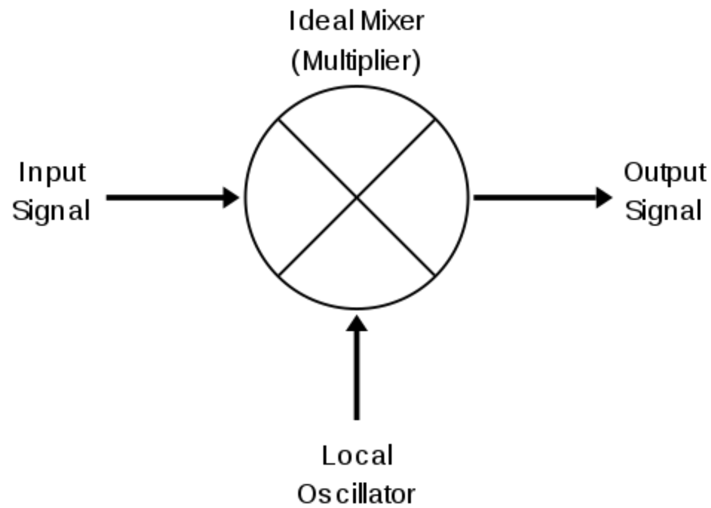
SUPERHET BLOCK DIAGRAM



TYPICAL AM RADIO INTERMEDIATE FREQUENCY (IF) = 455KHZ

FOR BROADCAST BAND FREQUENCIES OF 530KHZ AND 1700KHZ

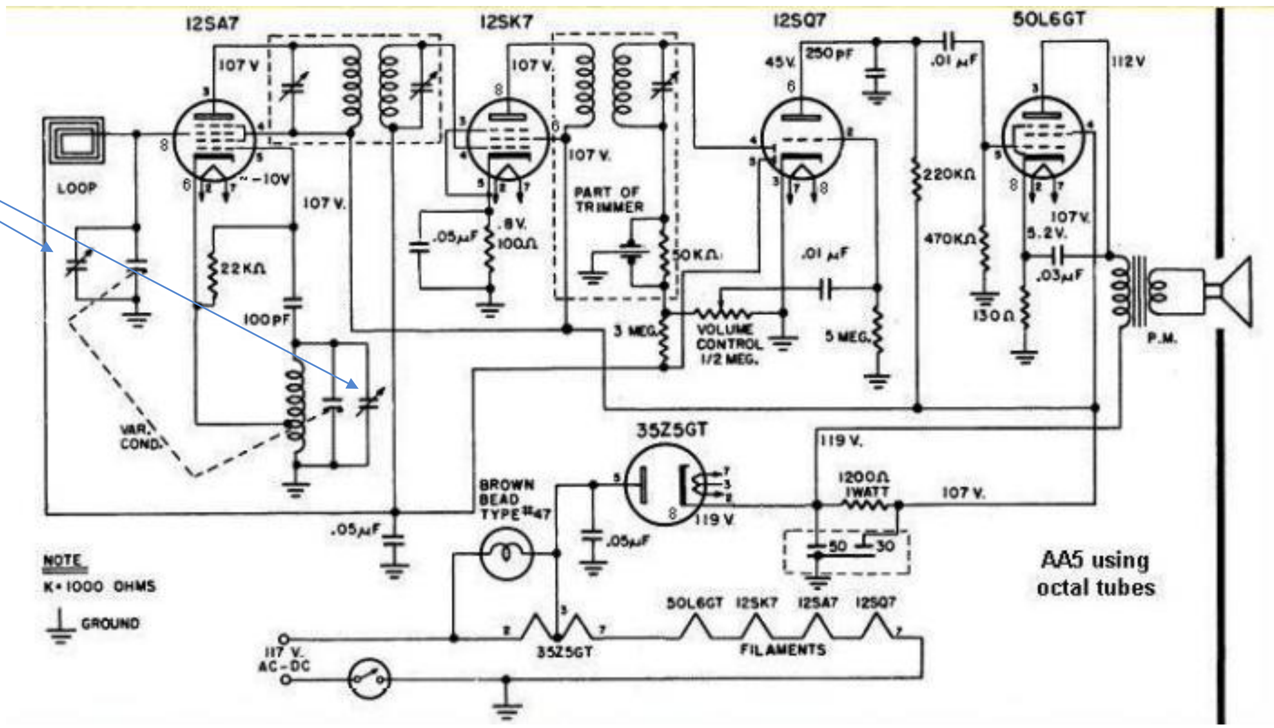
TYPICAL AM RADIO LOCAL OSCILLATOR (LO) TRACKS BETWEEN 985KHZ AND 2155KHZ



SUM AND DIFFERENCE PRODUCTS OF THE INPUT SIGNAL AND THE LOCAL OSCILLATOR ARE PRODUCED.

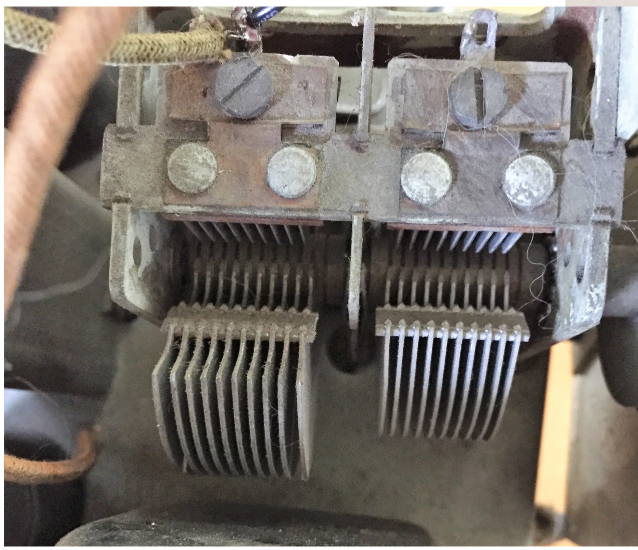
The essential characteristic of a mixer is that it produces a component in its output which is the product of the two input signals. A device that has a non-linear (e.g. exponential) characteristic can act as a mixer. Passive mixers use one or more diodes and rely on their non-linear relation between voltage and current to provide the multiplying element. In a passive mixer, the desired output signal is always of lower power than the input signals.

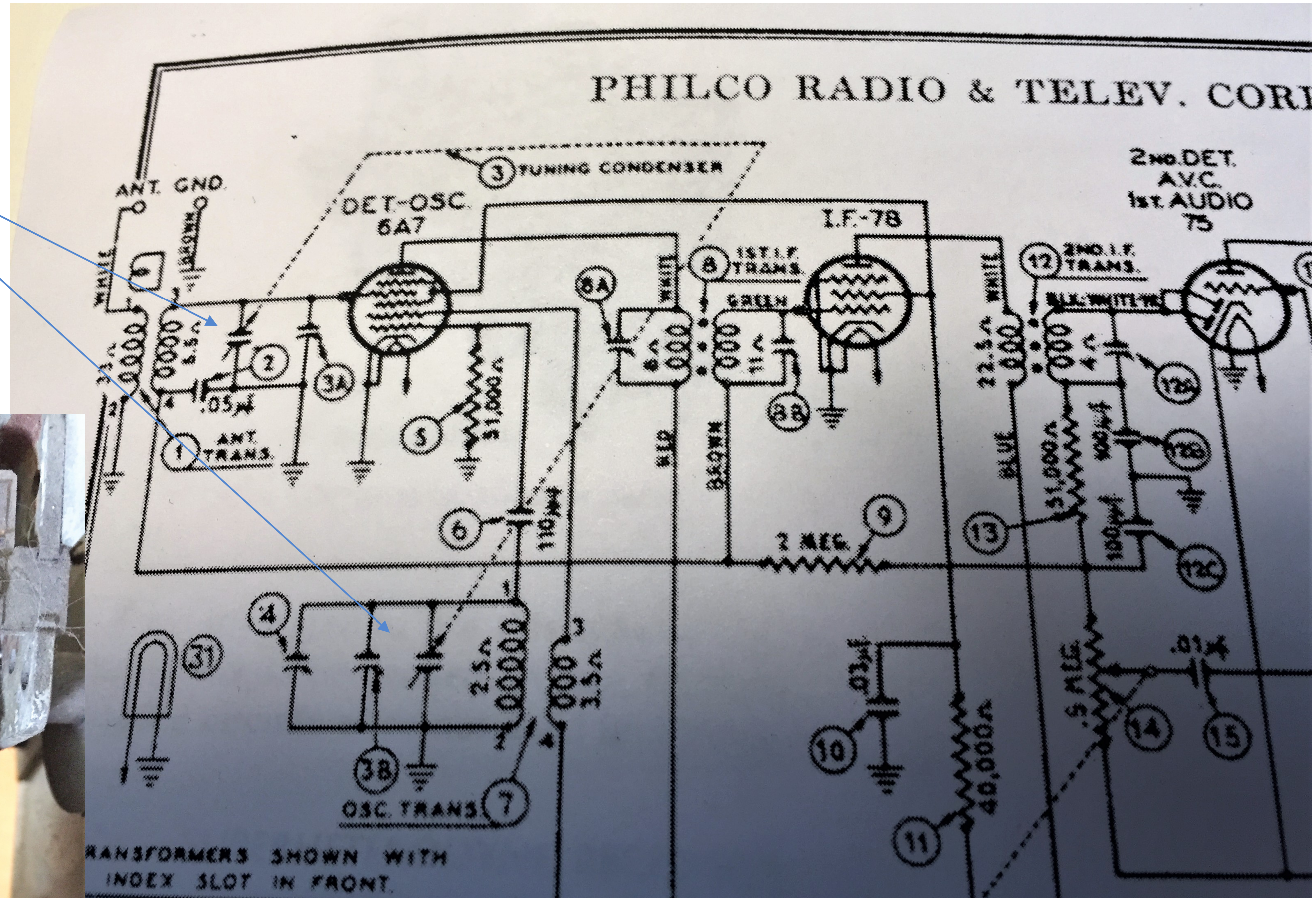
The local oscillator frequency is determined by a variable capacitor that is ganged to the main receiver tuning variable capacitor



GANGED CAPACITORS

THE CAPACITOR FOR THIS RADIO





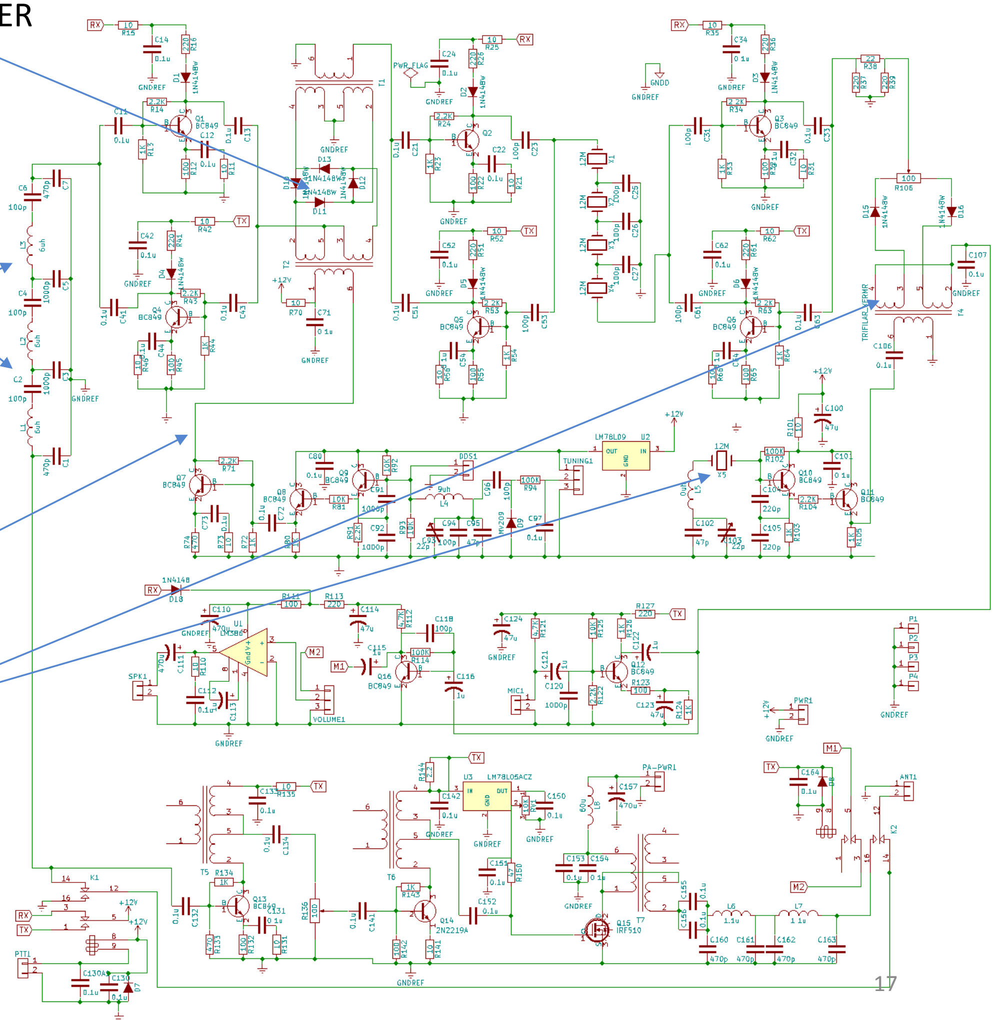
THE BITX40 HAS A SUPERHETERODYNE RECEIVER

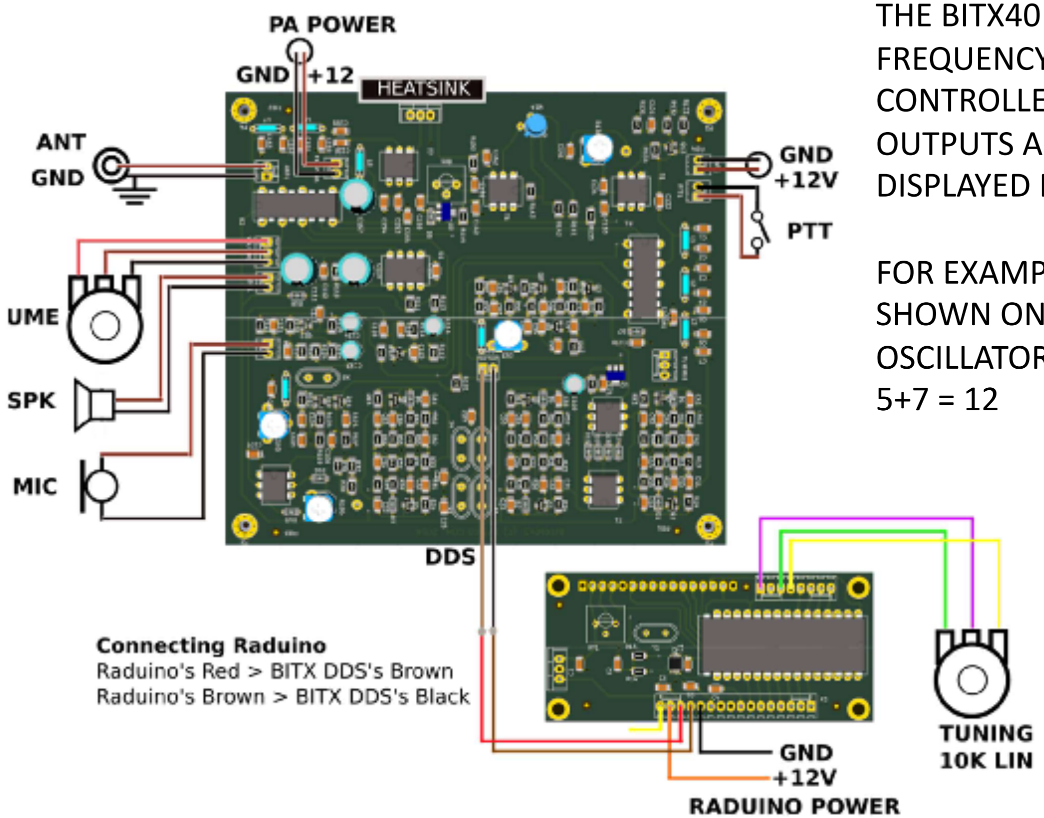
DIODE MIXER

3 POLE BANDPASS FILTER REQUIRES NO TUNING

LOCAL OSCILLATOR (LO) FROM Si5351 SYNTH

PRODUCT DETECTOR DEMODULATOR





THE BITX40 USES A 12MHZ INTERMEDIATE FREQUENCY. THE LOCAL OSCILLATOR IS AN ARDUINO CONTROLLED FREQUENCY SYNTHESIZER THAT OUTPUTS A SIGNAL THAT WILL ADD TO THE DIAL OR DISPLAYED FREQUENCY TO EQUAL 12 MHZ.

FOR EXAMPLE, IT THE BITX40 IS TUNED FOR 7MHZ SHOWN ON THE LCD DISPLAY, THE LOCAL OSCILLATOR WILL BE RUNNING AT 5MHZ.
5+7 = 12

AN INTRODUCTION TO A QUADRATURE SAMPLING DETECTOR
THE TAYLOE DETECTOR

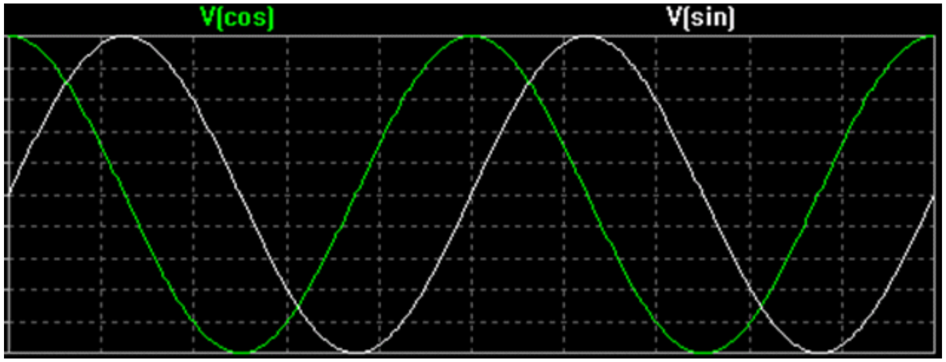
- I and Q stand for In Phase and Quadrature Phase. The quadrature Phase is merely the signal shifted by 90 degrees from the In Phase Signal. QSD means Quadrature Sampling Detector.
- **'Give Me *I* and *Q* and I Can Demodulate Anything'**

  Gerald Youngblood, AC5OG, Flex Radio CEO
- If you have both the I and the Q data, you can demodulate any kind of modulation
- Invented by Dan Tayloe N7VE in 2001, it is a **'famous high performance Quadrature Sampling Detector'**

  Hans Summers, G0UPL, QRP-Labs

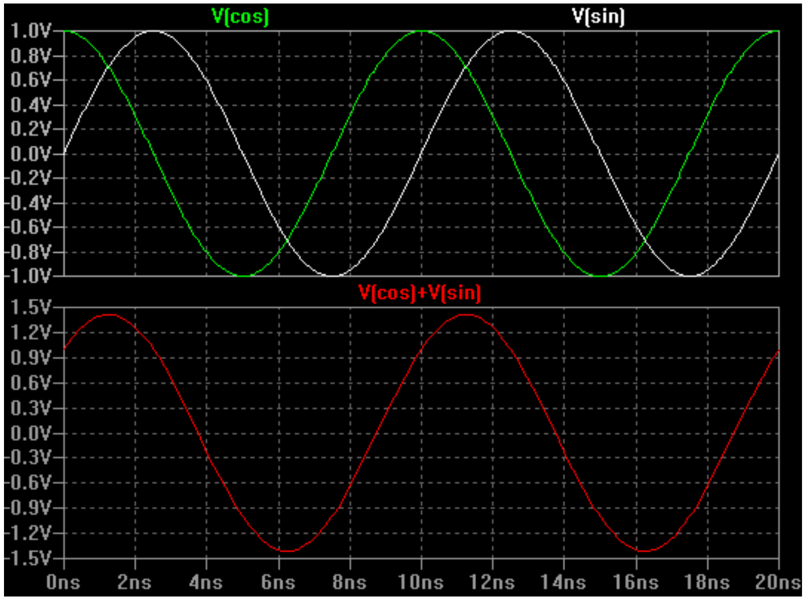
Quadrature Signal Concepts

If the phase Φ difference between two sinusoids is 90 degrees (or π /2 radians), then these two signals are said to be in quadrature. An example of this is the sine wave and the cosine wave.



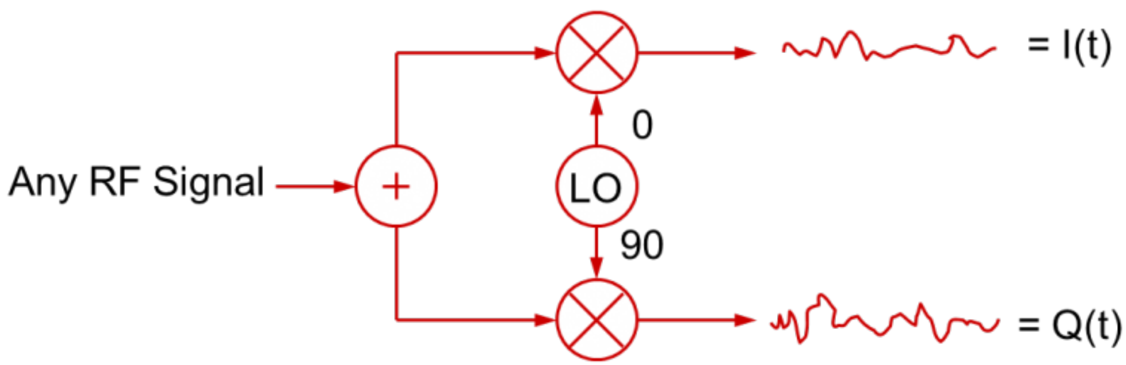
By convention, the cosine wave is in-phase component and the sine wave is the quadrature component. The capital letter I represents the amplitude of the in-phase signal, and the capital letter Q represents the amplitude of the quadrature signal.

If both I and Q were equal to 1, then the sum will be a new signal that is shown graphically below



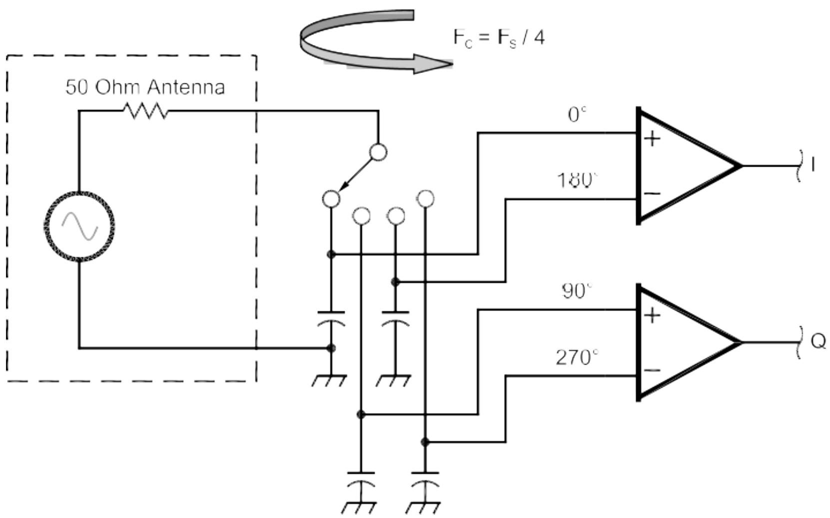
By now you can see that the amplitude and the phase of the sum of the quadrature signals is a function of the value of I and Q.

By mixing an RF signal with LO (local oscillator) signals in quadrature, I(t) and Q(t) baseband signals can be created.



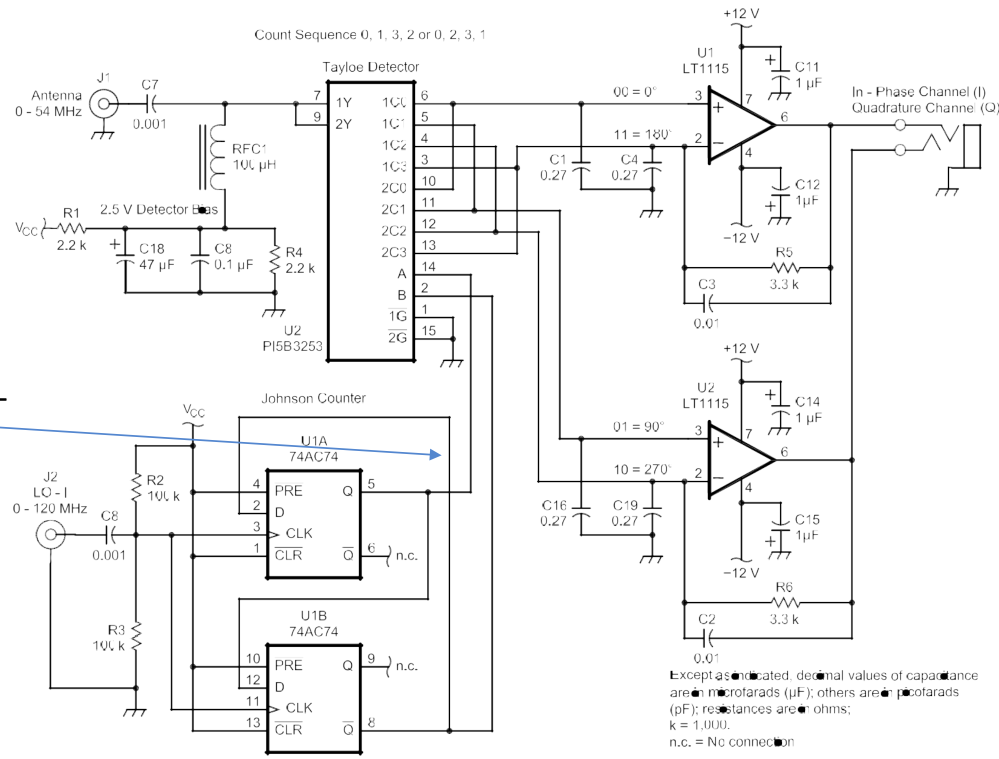
This is the fundamental basis for most modern RF signal demodulation.

Tayloe detector: The switch rotates at the carrier frequency so that each capacitor samples the signal once each revolution. The 0° and 180° capacitors differentially sum to provide the in-phase (*I*) signal and the 90° and 270° capacitors sum to provide the quadrature (*Q*) signal.



The capacitors act as 'sample and hold' and contain the voltage corresponding to each switched value for summing in the amplifiers. This works like an envelope detector formed by the capacitor following the diode in an am radio.

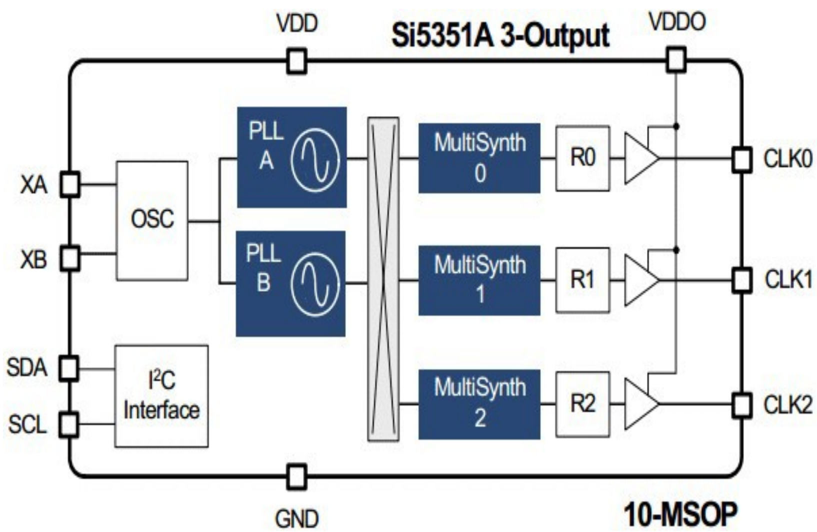
TWO BIT
COUNTER OUTPUT
00
01
10
11

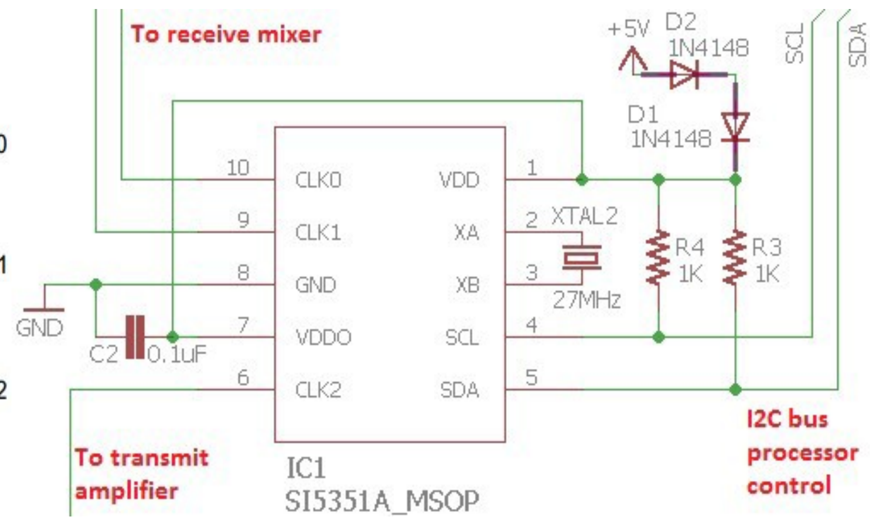


Often a divide-by-4 circuit is used, to produce quadrature oscillator outputs from an oscillator input at 4x the reception frequency. This also creates challenges particularly as you try to increase the reception frequency to cover higher bands. For example, on 10m e.g. 30MHz, a local oscillator at 120MHz is required and the divide-by-4 circuit must be able to operate at such a high frequency. Devices such as the 74AC74 can do so, but pushing it higher into the 6m band cannot be done with the 74AC74.

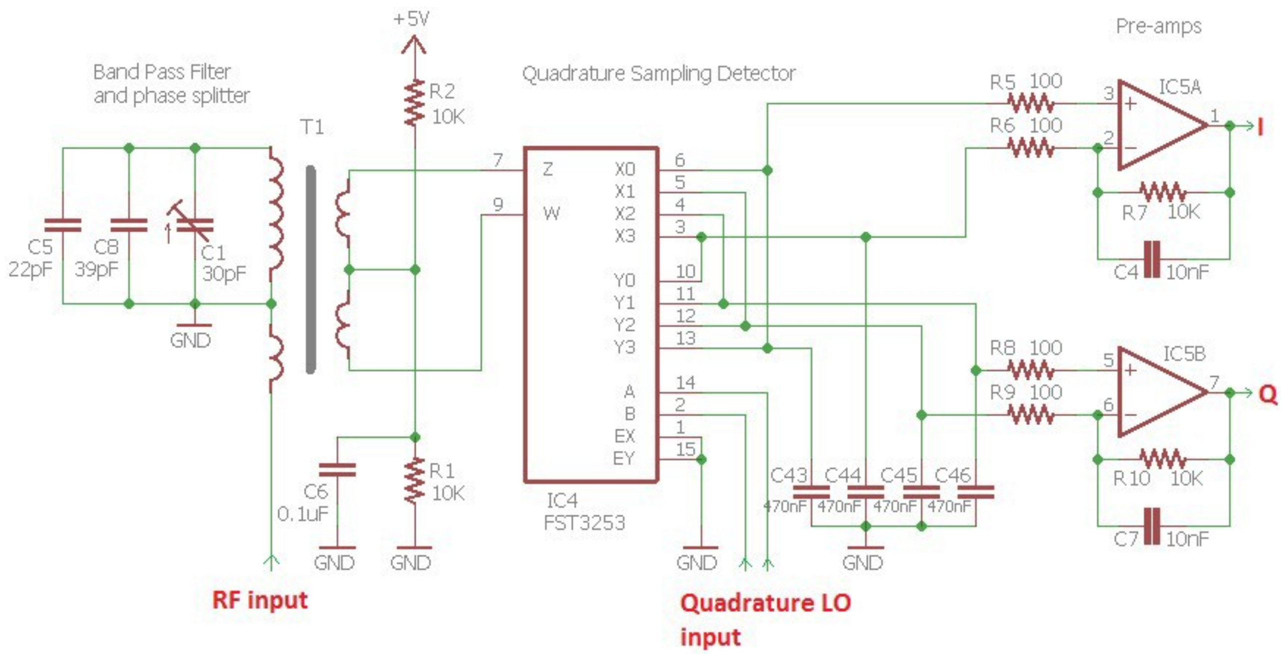
The Si5351A has a phase offset feature, which is not really very clearly described in the SiLabs documentation. However, QRP Labs has perfected the technique to put two of the Si5351A outputs into precise 90-degree quadrature, which is maintained without tuning glitches as the frequency is altered. It's a nice development because it eliminates one more circuit block.

"To the best of my knowledge this the first time the Si5351A has been implemented in a product directly driving a QSD with two outputs in quadrature (no divide-by-4 circuit)." *Hans Summers*

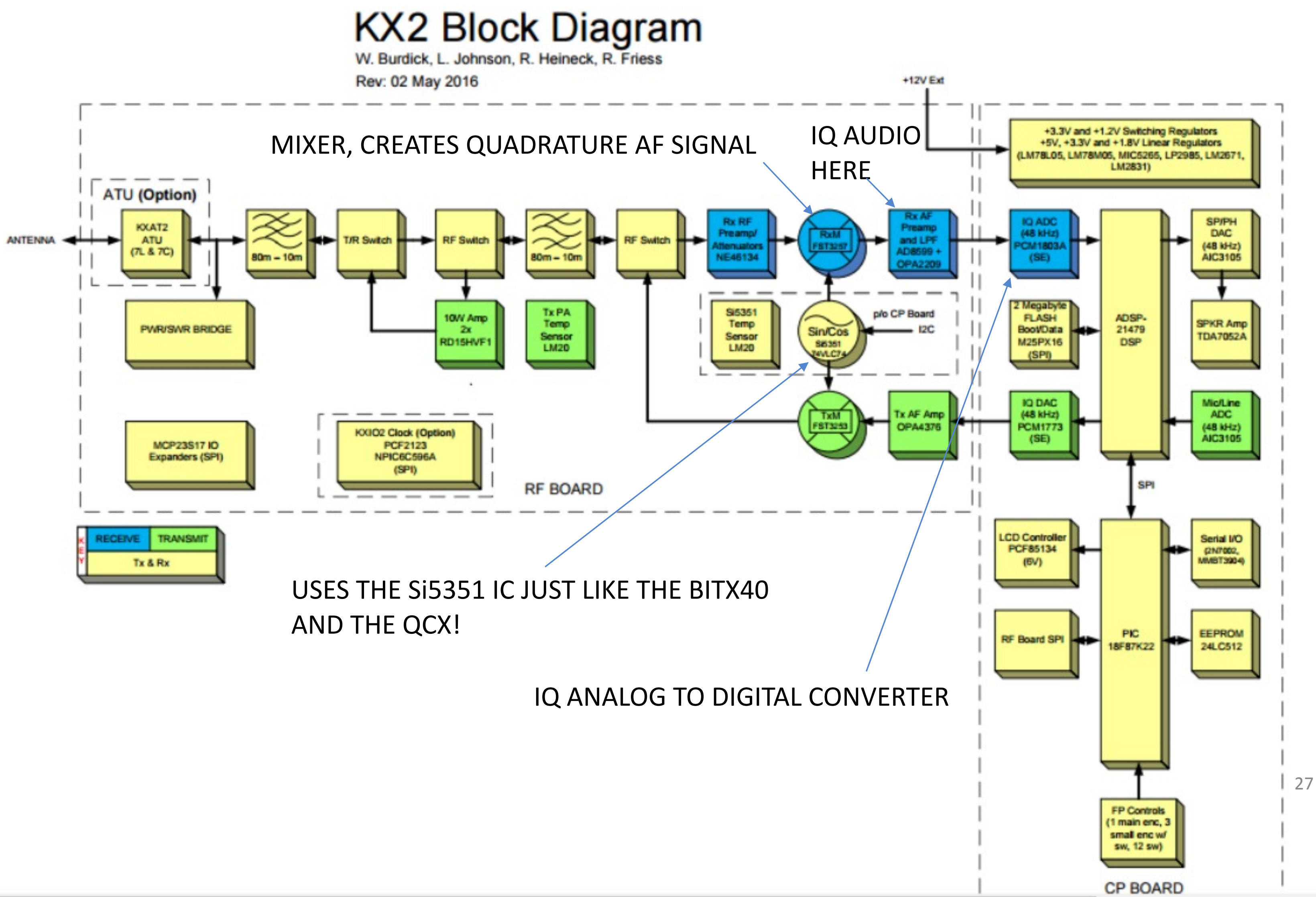




THE QRP-LABS QCX RECEIVER FRONT END



A DIRECT CONVERSION RECEIVER



MIXER, CREATES QUADRATURE AF SIGNAL

IQ AUDIO HERE

USES THE Si5351 IC JUST LIKE THE BITX40 AND THE QCX!

IQ ANALOG TO DIGITAL CONVERTER

A Software-Defined Radio for the Masses, Part 1
By: Gerald Youngblood AC5OG
QEX Jul/Aug 2002

Tektronix Blog
What's Your IQ – About Quadrature Signals…
2015-06-22 by: Alan Wolke

Software Defined Radio for amateur radio operators and shortwave listeners
2016 and 2018 (Kindle Revision)
by: Andrew Barron ZL3DW

QCX: 5W CW Transceiver kit assembly instructions
Designed and produced by QRP Labs, 2017
by: Hans Summers

Communications Electronics 2nd Edition
1972
By: J.J. DeFrance

Quadrature Mixers, IQ Demodulation, and the Tayloe Detector
Aug 10, 2015 - Uploaded by devttys0
https://www.youtube.com/watch?v=JuuKF1RFvBM