IEEE:inspiring students towards greatness

Amateur radio workshop

By

Stephen Johnston

April 7, 2019

My research for the workshop

Over the summer and between my job, I was working on a radio workshop that I had promised during the election.

The radio provided is the Kaito KA009, an emergency radio that works through solar power, hand crank, dc power and battery input. In this work shop I'm going to describe not only how the radio works, but how to modify it in the event of an emergency to maintain contact with civilization.

Figure 1: The radio

Inside the radio

By utilizing Ampere's law, we can create small ripples inside the electromagnetic spectrum. These ripples travel for thousands of miles until they resonate inside an antenna. The antenna then generates a small amount of power that can be processed as a radio signal.

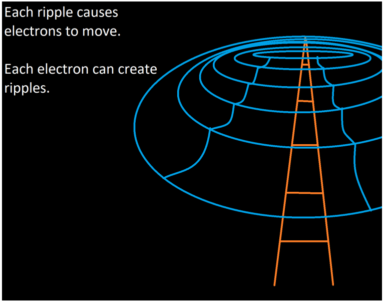


Figure 2 Electromagnetic plane wave ripples

The antenna

The first thing in a radio is it's antenna, which receives signals from the electromagnetic spectrum. As the spectrum waves ripple, electron's resist the change by moving in the opposite direction. This generates a voltage that we can measure. However, this voltage is not only comprised of the signal we want, but of every single signal in the universe. To solve this, we need to create a device that selectively filters out everything BUT the signal we desire.

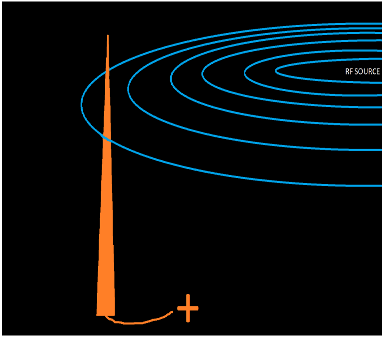


Figure 3: The signal reaching the antenna.

The Oscillator

We next need to have an equal frequency as an input to the mixer. The reasoning will be come clear in the next slides. We are able to generate a frequency by creating something called a *Local Oscillator*. There are three main types of local oscillators.

- Relaxation Oscillator
- LC (Or tank circuit) oscillator
- Crystal oscillator

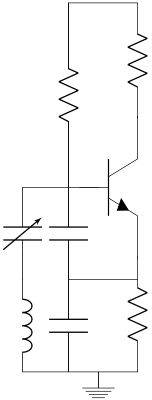


Figure 5: The Colpitts oscillator

Oscillators Continued

Oscillators are difficult to build. When building my own radio, I had great difficulty simply getting the oscillator to work. Oscillators follow two main conditions, called the Barkhausen Criterion.

1. The oscillator feedback circuit must have voltage gain and this gain when multiplied by the gain of the transistor must be greater than one.

2. The phase shift of the oscillator feedback circuit and the transistor must total to 0 deg.

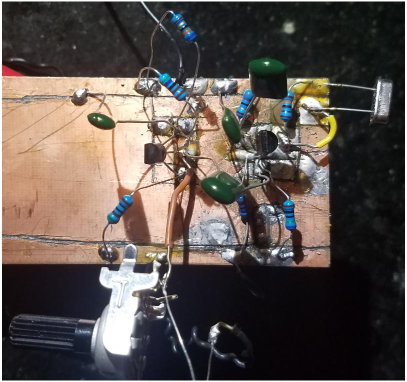


Figure 6: My local oscillator design.

The filter

Filters are complicated, and require calculus to fully understand. Without going into great detail, there are three primary filters. We use filters to selectively choose, both on the oscillator and on the antenna, what signal we want to listen to.

- Low Pass
- High Pass
- Band Pass

The *Band Pass* filter, in particular, is our region of interest.

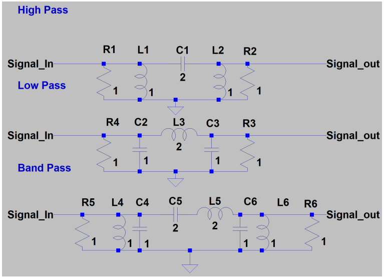


Figure 4 High Pass, Lowpass and Band Pass filters.

The bandpass filter

Filters are the most important concept for the quality of a signal, the more selective a filter, the more isolated your radio station will sound. If you've ever been driving and found yourself hearing two radio stations at once, that was because the filter was not able to totally remove the signal. We measure the quality of the filter with Q, which is measured by the equation

$$Q = \frac{f_c}{\Delta f} = \frac{f_c}{f_2 - f_1}$$

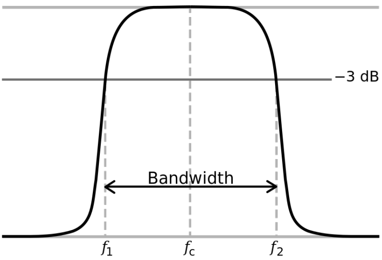


Figure 5: The ideal frequency band.

The mixer

When the frequency is filtered and we know what radio station we are tuned into, we need to have a way of translating this signal into sound. We first have to step down the frequency. We do this so that an amplifier can easily increase the power of the signal without interfering with other electronics. This is where the mixer comes into play.

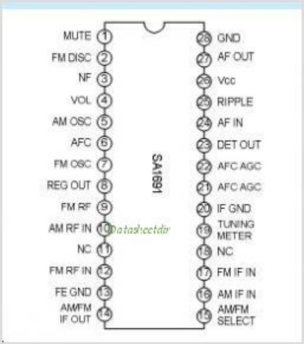


Figure 6: High level integrated circuit schematic

The mixer part 2

Product Overview	
Digi-Key Part Number	568-2087-5-ND
Quantity Available	**0** Factory Stock : 9,450
Manufacturer	NXP USA Inc.
Manufacturer Part Number	SA605DK/01,112
Description	IC MIXER FM IF SYSTEM LP 20-SSOP
Detailed Description	RF Mixer IC 0Hz ~ 500MHz 20-SSOP

Figure 7: Digikey product for RF mixing and amplification.

The mixer used in the radio provided is very similar to the one above. Mixers as of right now are fairly difficult to get ahold of, especially double balanced ones, and often cost up to $20 each. Modern mixers are used in the Ultra High Frequency band and are not designed for lower frequencies.

Mixer output

Most mixers are bought, and there's a real reason why. They rely on the intricate processes of transistor biasing. By changing the biasing levels of the transistor, the effective resistance of the transistor (G_m) changes too. This causes the signals to multiply. By utilizing trigonometry, the output of the mixer translates to

$$Cos(a) * cos(b) = \frac{1}{2} * (cos(a-b) + cos(a+b))$$

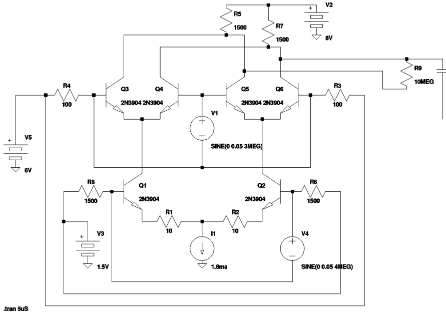


Figure 8: Gilbert Cell Mixer low level schematic

Mixer output

The output of the mixer for AM waves is effectively sound. A quick rectifying circuit will translate the wave from an AC signal into a differential DC wave, which can be played from a speaker.

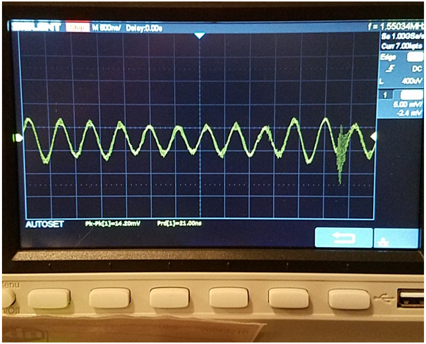


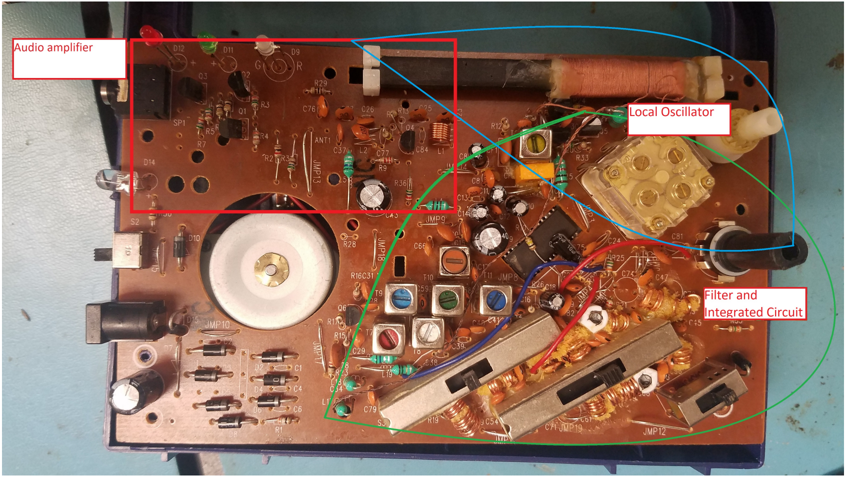
Figure 9: AM wave

So whats in the radio?

The radio provided to you has a variety of cool quirks and features. To start, every single component on the filter side of the radio is a variable component. This not only makes the radio instantly tune-able to nearly every exact frequency in the allocated bands, but it also makes the value of the radio in parts to be much greater than the entrance fee you paid.

Figure 11: The bottom of the radio

Up close


Audio amplifier
Local Oscillator
Filter and
Integrated Circuit

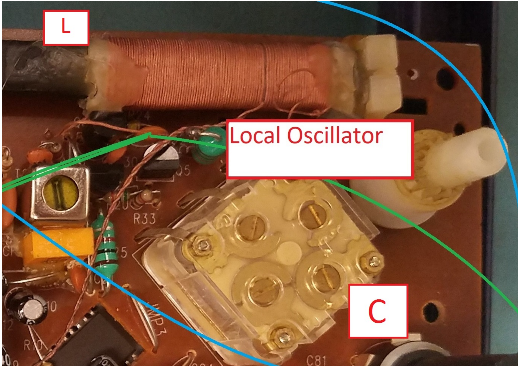
Up close part 2

A closer look shows that every single major component is connected with something called a "Jumper", meaning that alongside traces connecting every single component, there is also a jumper that preforms the same operation. This is used on prototypes for debugging purposes, but often is left on the board for testing. I mapped out each jumper and listed their purpose.

- Jumper 1: LO out
- Jumper 2:
- Jumper 3:
- Jumper 4:
- Jumper 5: Mixer in
- Jumper 6: Mixer out
- Jumper 7: PLL out
- Jumper 8: FM step down
- Jumper 9: PLL IN
- Jumper 10: Audio out

Changing the frequency of the radio

The FCC allocates a handful of distinct frequencies that citizens can use to communicate with each other for free. The closest frequency for an AM oscillator is at 3.525Mhz, which is a step up by 2Mhz. We can do this by returning back to the basics of the tank circuit and remembering that the resonant frequency for a tank circuit is $\omega = \frac{1}{\sqrt{LC}}$. In order to raise this, we simply have to decrease the size of L or C.



Changing the frequency of the radio part 2

I measured the value of the inductor to be 350μH and I measured the value of the capacitor to a range of 35pF to 300pF. Inductors have a property, much like resistors, that if another inductor is connected in parallel, it will decrease the inductance. To increase the frequency, we will use this fact. Remembering the equation previously, $2\pi \cdot 3.525 \cdot 10^6 = \frac{1}{\sqrt{LC}}$, we can reverse engineer the equation to give us the desired result.

$$\omega = (2\pi \cdot 3.525 \cdot 10^6)^{-2} = LC$$

$$\implies L_{new} = \overbrace{2.03 \cdot 10^{-15} \cdot C^{-1}}^{\omega}$$

$$\implies 2.03 \cdot 10^{-15} \cdot \left(35 \cdot 10^{-12}\right)^{-1} = 58\mu H$$

$$L_{new} = \overbrace{\left({L_1}^{-1} + {L_2}^{-1}\right)^{-1}}^{\text{Connecting } L_1 \text{ in parallel with } L_2} = 58\mu H$$

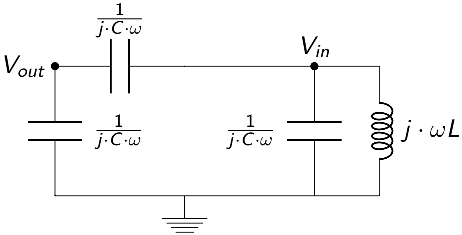
$$= \left({L_1}^{-1} + 350 \cdot 10^{-6}\right)^{-1}$$

$$\therefore L_1 = 69.5\mu H$$

Modifying the gain of the oscillator

So as you're probably noticing, the circuit doesn't work yet. I must have lied to you, just to take that sweet $20. Or perhaps, the feedback gain for the circuit was not as high as I had originally thought. In the feedback of the circuit, there are two capacitors that had been mentioned earlier. One is distinctly for feedback, but the other is ,mysteriously, for voltage gain.

Examine me a bit further



$$(V_{in} - V_{out}) \cdot j \cdot C_1 \cdot \omega + (V_{in} \cdot j \cdot C_{fb} \cdot \omega) + \frac{V_{in}}{j\omega L} = 0$$

$$(V_{out} - V_{in}) \cdot j \cdot C_1 \cdot \omega + (V_{out})\, j \cdot C_2 \cdot \omega = 0$$

Modifying the gain of the oscillator ctd

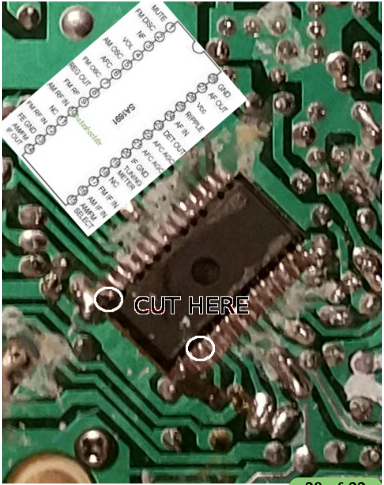
The feedback capacitors in this circuit were measured to be —-. Remembering from the slides in the beginning, the Barkhousen criterion requires that the voltage on the input to be much higher than the voltage on the output. When the conditions are plugged into the extended equation on the right, it makes complete sense as to why our circuit isn't working.

$$V_{out} = V_{in} \cdot \left(\frac{j \cdot C_1 \cdot \omega + j \cdot C_2 \cdot \omega + \frac{1}{j\omega L}}{j \cdot C_1 \cdot \omega} \right)$$

$$V_{out} = V_{in} \cdot \left(1 + \frac{C_2}{C_1} - \frac{1}{\omega^2 \cdot C_1 \cdot L} \right)$$

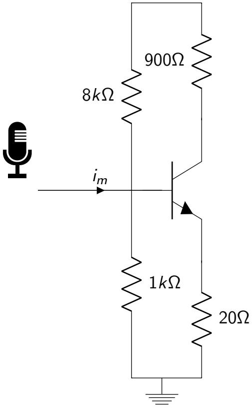
Conversion into a transmitter

Now that we've modified the LO for 3.5MHz, we need to think about how we can communicate with the outside world. There's a variety of ways to do this for amplitude modulation. For this workshop, we're going to cut the trace leading from mixer in (usually the place where radio waves go in) and replace it with a switch. This switch will change between receiving and transmitting.



Conversion into a transmitter

Next we grab our breadboards and build the circuit used for transmitting our voice over the air. A microphone translates changes in the air pressure into a small voltage signal. Next we amplify this signal and feed it into the mixer.



Conversion into a transmitter

The microphone input goes into the mixer and multiplies with the carrier signal. This carrier signal then is transmitted through the dipole antenna.