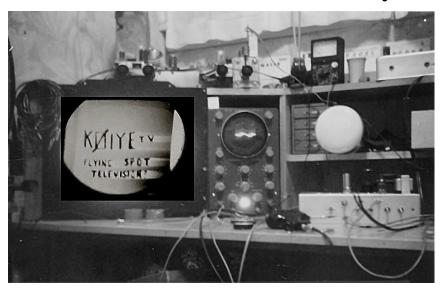
### MISCELLANEOUS RADIO PROJECTS

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### **Chapter 17B**

### **HAM TELEVISION - The Old Way**



### First, a glimpse of modern amateur TV

I was first inspired to write this article for my local ham club newsletter by Jim Andrews, WAØNHD. (Now KH6HTV) At our August 2003 ham club meeting he gave a wonderful hour-long presentation on modern Amateur TV. He showed us oscilloscope and spectrum analyzer images of audio, RF and video waveforms and block diagrams of all the required black boxes. At the end of his presentation he included a run-down on the available commercial ham TV equipment. It turned out that we could have put together a first-rate analog ATV station for under \$1,000. Less than that if we already owned a suitable camera, antenna, etc. If you plan to support your local emergency service and televise forest fires, floods and riots, then a station like Jim's is what you need. On the other hand, if you just like to play around with circuits like I do, then building something from scratch may be more satisfying.

**Update:** In 2015 Jim gave us another presentation. Today he uses full resolution digital HD TV. Aside from the perfect reception, I was fascinated to learn that hams are using the European digital standard rather than the American standard. The European coding method is optimized for extracting pictures from weak, noisy, distant TV stations. The American HD TV transmission standard is optimized for the maximum number of channels in the limited frequencyspectrum. To demonstrate his point, Jim showed us TV recorded from a test he ran in which he transmitted perfect 1,080 line HD TV from a small yagi antenna 6 feet off the ground in Cheyenne, Wyoming down to Boulder, Colorado, 100 miles away. He did this with only 6 watts! I still find this hard to believe. This compares to the 27,000 to 1,000,000 watts and the huge, mountaintop

antennas used by our numerous local commercial HD TV stations. Every engineering choice is a trade off!

### Homebuilt ham TV

Paradoxically, one of the best attributes of the old days was our relative poverty and the lower level of technology. Many services and gizmos that are routine today existed in the 1950s but were rare or unaffordable. Long distance telephony, walkietalkies, RTTY (radio teletype) and TV cameras are obvious examples. Ham radio allowed us high school kids to play with these toys decades before they were cheap or even available to ordinary adults. Since our toys were the latest technology, we were extremely excited about them. If you show a TV camera to modern kids, they fall asleep.

Television fascinated me as much as short wave radio. So after I had a working HF station, I wanted to get on TV. In the 1950s, the hard part of ham TV was the camera. The cheapest way to get one was to buy a WWII Navy surplus flying bomb camera. The Navy built radio-controlled flying bombs that could crash into enemy ships, Kamikaze-style. After much searching I was finally able to buy a camera with its huge iconoscope camera tube. Unfortunately, by the late 1950s finding an iconoscope that still worked was difficult and mine didn't. In contrast, TV monitors were easy to get. I toured the TV repair shops and for a few dollars I bought broken TV sets that their owners didn't want to pay to have repaired.

### A flying spot camera



Since TV camera tubes were out of reach, I resorted to using a TV set as a scanner. Large paper or grease-pencil transparencies were taped to the TV tube. A 914 photo-multiplier tube was mounted on the tilted aluminum box on the left. The photo tube "looked" at the light from a blank TV picture raster passing behind the slide. The flying spot of light scanned the slide, one line at time. It took five stages of amplification to boost the signal to the required few volts. I usually used the retrace

blanking pulses from the TV to make crude synchronization pulses. The pulses were combined with the varying light signal to make a complete TV signal. I wired a polarity switch on my combiner circuit so my slides could be either black on white or vice versa.

The TV light signal from the slide was roughly 6 MHz and was easily separated from the constant background lighting signal. Consequently it wasn't necessary to operate in the dark or enclose the scanner in a box. The crude blanking pulse sync worked, but it pulled the image to the left. The easy way to get real sync pulses was to receive channel 4 from Denver, 30 miles away, then remove the picture. My light signal was recombined with the channel 4 pulses then sent on to the monitor.

### Fun with flying spots

Obviously we couldn't televise forest fires with this scanner, but we played with it in other ways. When you're in high school, silliness can be great fun. Aside from televising test patterns, Iliked to do silhouette hand puppets and rude finger gestures. My friends and I used to draw up transparencies of signs like, "Help! I'm trapped in your TV set" or we would draw single frame cartoons and slides showing supposedly humorous TV ads.

Synchronizing the picture to channel 4 had a more nefarious advantage. I could broadcast images and superimpose them on top of real channel 4 broadcasts. For example, I had a tiny cutout of a vulture that I could place on David Brinkley's shoulder during the NBC Huntley- Brinkley evening news. Alternatively, a giant black silhouette of a hand might slide into the picture and tickle him under the chin.

Normally I just broadcast this entertainment around the house. However, the kids across the street were interested so I thought, "It's only a few milliwatts. I'll just broadcast it over there on channel 3, which happened to be vacant in our area. It's 200 feet instead of the legal 50 feet maximum, but beyond that, how far can it go?" My little slide and puppet show for the kids worked great. Nothing more came of "The Frank Show" until several years later when Jim Snyder, WØUR, was visiting my shack. I told him about my former flying spot project and he said, "So you were the culprit!"

He described how his brother was watching TV in their living room across town from myhouse, about 5 miles away. Suddenly he began hollering for Jim to come look at the TV. Jim sprinted into the room just in time to see the word "HELP!" written on top of channel 4. A few moments later the mysterious signal disappeared. I dug out my old slides for Jim and he thought he recognized the perpetrator. This was interesting because I never deliberately broadcast on topof channel 4 using an outside antenna. Even in high school, I wasn't that reckless. On that other hand, if my lower sideband was on channel 3, the upper sideband would have been on ... channel 4.

### **Broadcasting properly on 420 MHz UHF**

Unfortunately, being a poorly equipped kid, I was unable to generate and receive a signal on 70 CM over any distance. I scratch-built a little 420 MHz transmitter that appeared to work OK. That is, a 50 ohm ½ watt resistor on the output got hot and all the stages "dipped" when tuned. For all I could tell, it was working. At that time I had never even heard of filtering the output with a resonant cavity filter to get rid of the lower

sideband, so the vestigial sideband NBAM issue was blissfully ignored. That explains why Jim saw it across town. I also built an alleged 420 MHz converter that received my own signal over a distance of 12 inches or so. However, I had no real knowledge of what frequency I was actually sending and receiving. It might have been 30 or 50 MHz for all I knew. Another barrier for me was that none of my ham friends were interested in putting up UHF antennas, building converters and all that. They all were too busy with DX, building kilowatt finals, walkie-talkies, radio teletype and so on. We all had different interests and high school was a busy time.

As you can see, my ham TV project wasn't a complete success. It illustrates the difficulties with homebrew VHF and UHF. To be sure that you're producing a quality signal on the right frequency, you need expensive UHF test equipment. Moreover, you need a high level of craftsmanship to control the unwanted oscillations. If 10 meters is tricky, imagine getting 0.70 meters to work right! The only advantages are that you can use low QRP power levels and compensate by building small, high gain antennas. Most of the difficulty with the upper HF bands happens when you try to generate higher power over one watt. In contrast, with a small rooftop antenna a few milliwatts of VHF or UHF can get you around town.

In the final analysis, my TV project was loads of fun and I learned plenty. When you scratch-build, the rewards are usually quite different from store-bought ham radio and can be quite unexpected. For example, who would have thought QRP television could work so well?

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### **GETTING ON SIXTY METERS**

#### A ham band frontier?

Every generation or so, hams have been granted a new ham band. When 30 meters first opened up, Bob Hamilton, NØRN (former KØIYF), was ready with his homebrew CW transmitter. The bad news was that he was practically the only American on the band. The good news was that 30 meters had been open for years in Europe and suddenly *Bob was hot DX*. Everyone was calling him. This delightful situation lasted about a year, but as soon as the commercial equipment covered 30 meters, Bob's private DX band became history. After hearing this story I wanted to try out 60 meters when it opened on July 4, 2003.

#### What 60 meters is

Sixty Meters consists of five, 2.8 KHz wide channels with center frequencies on 5532, 5348, 5358.5, 5373 and 5405 KHz. They may be used by General Class and above. Thanks to new rules that took effect in March 2012, we are permitted to use USB SSB, CW and data modes and 100W effective radiated power. ARRL recommends that we set the carrier frequency to 1.5 KHz below the centers of each channel and restrict the audio to between 200 Hz and 2.6 KHz. Unfortunately these 5 frequencies are shared with several other services.

#### Modifying your present SSB rig

You may already own a 60 meter rig. Bob, NØRN, has a collection of transceivers and set out to put one of them onto 60M. His first try was an old Drake R4 that, with the proper crystal, supposedly "covers everything from 1.8 to 30 MHz." It turned out that the R4 could be used on any HF frequency *except 5.0 to 5.5 MHz*. The IF and VFO are in that range and spurious signals would result. Next he tried a Kenwood TS-180. His particular unit was missing a surface-mount, broadband filter that needed to have been assembled on a PC board at the factory. It's possible to kludge a filter, but it would be difficult because there is little room for it.

In modern rigs that use VHF IF frequencies, the only barrier preventing transmitting on 5 MHz is the firmware that vetoes illegal frequencies. Bob was able to put his Kenwood TS-50 on 60M by just clipping a diode to reprogram the microprocessor. The miniature Yaesu FT-817 can be modified by tearing the unit apart and soldering and unsoldering some tiny programming jumpers on a board. The Yaesu FT-1000MP was the easiest. He turned off the unit and then turned it back on while holding down two buttons. That brought up a menu that allowed him to select frequency ranges for different regions of the world. At the bottom of the list was "general coverage." This permits operation over the entire spectrum, even on standard broadcast.



### A homebrew 60 meter rig

My 60 meter transmitter and receiver converter are shown above. The copper box on the right is the receiver converter. The transmitter consists of 5 main modules: These are a 5 MHz VFO, a frequency converter for the VFO to make a 14 MHz VFO signal, a 9 MHz SSB generator, the mixer/ driver to combine 14 MHz with 9 MHz SSB to make 5 MHz SSB and, at the rear, a 50 watt linear amplifier. To get on 60, I added a crystal and 60 meter filters to two of my transmitter modules and I built the receiver converter box. The receiver converter has jumpers all over it because eventually I also planned to use it on 6 and 10 meters.

### **July 4<sup>th</sup> 2003**

I knew 60 meter SSB wouldn't be as much fun as 30 meters, but I naively hoped I might meet some eccentric homebrewers there. As midnight July 3<sup>rd</sup> approached I

tweaked my homebrew 60 meter rig on a dummy load. I could hear 4 strong RTTY stations between 5.3 and 5.4 MHz that ran continuously. One of them was parked pretty much on top of channel 2. At 11 p.m., just before the band opened, I found faint SSB stations on all five new channels way down in the noise. I couldn't copy any of them, but they were definitely there under the RTTY and static. They may have been those special-licensed experimental hams or perhaps they were the Coast Guard, far, far away. At 10 minutes after midnight, some relatively loud signals appeared on channel 4. One of them was Milo, NL7SA. These Alaskan hams were gushing about being the first to try out the new band. They said they were using Alaskan CB radios, but for me they were only about Q2-S2. For many years there have been 5 MHz SSB CB channels assigned just for Alaska. I had no graceful opportunity to call them and after a few minutes they faded.

The next night I heard two Alaskan fishermen trading shrimp stew recipes. One recipe featured shrimp, dried chipped beef and cabbage. Yuk! The other guy said he had just motored 35 miles back from his favorite fishing spot. They never gave call signs, so I believe I was hearing an Alaskan 5 MHz SSB CB channel. After a few days, more and more stateside hams appeared during the evening hours. Channels 1 and 5 had the least RTTY interference and were the most popular. Most guys were using FT1000MPs but I also heard a Kenwood TS-930 and an ICOM 746. Each channel turned into an impromptu "net" with the loudest guy serving as net control. For example, on July 10, Bob, K9CGD, in Longmont, Colorado served as moderator on channel 5 for several hours. As for me, apparently my signal was too puny to get more than a "Sorry old man, you're too weak." For one thing, my antenna is probably inadequate. However, my rig had been successful on four other SSB bands, so I was mystified about what was wrong.

#### In conclusion,

60 meters consists of 5 discrete frequencies inhabited by RTTY, buzzing data signals, crashing static and two or three channels of weak SSB signals. Basically, it's a whole continent of Yaesu owners trying to get their 60 meter WAS (Worked All States) sharing two or three "party line" channels. After just 7 days, some guys were already claiming as many as 28 states.

When you tune in, you will hear the two loudest guys talking about how neat 60 meters is and that they're going to sign off now so others will have a chance. And ten minutes later the same two guys will still be talking about shutting up, but not actually doing it. The other annoying category is the East Coast guys who are apparently talking to England. But of course, we can't hear England from Colorado and yet it seems impolite to interrupt, even though static is all that's on the channel.

So, what did I learn from getting on 60 meters? I learned that I better be prepared to be disappointed when I start a project. Also I should have done much more homework about what units might be the first on the air. I was naive to think I might be among the first. Oh, well, the Alaskan gourmet fishermen were interesting. Hmmmm ... I'm going back to 20 and 30 meter CW.

### BUILDING AN AVALANCHE PRACTICE BEACON

### Transmitters are easy, beacon receivers are much harder

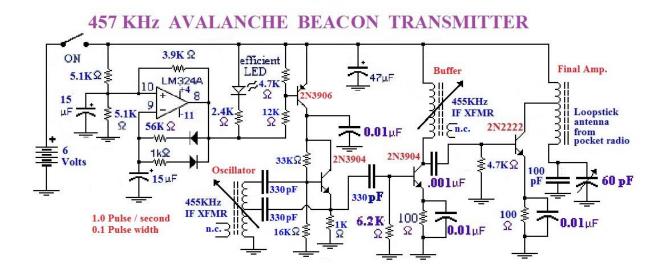
Avalanche beacons are indispensable for finding your buried friends. "Beacons" are actually transceivers. In beacon mode they send out 457 KHz pulses for days to help locate their owners. In receive mode a modern beacon has a range of about 50 yards and has an LED display showing direction and distance. Unfortunately, beacons are only useful if everyone in your ski party has a shovel, a beacon, turns on the beacon and knows how to use it. I'm fortunate to have two geriatric friends who drag me out every week to snowshoe around the peaks. Unfortunately beacons are pricey (\$200+) and I haven't been able to convince my friends to buy some. Also, now that we're OLD, we no longer glissade down avalanche chutes. Consequently our risk is less than it used to be. Still, we often find ourselves on steep snow slopes and I get nervous. When I was in the rescue group, I was required to have a beacon and bought a used one.



### An avalanche beacon and search receiver

The display indicates that the buried fellow is 14 meters away, directly ahead.

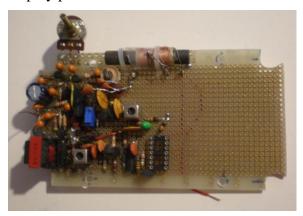
I had some search experience during rescue group practices, but I needed more. Close-in pin-pointing of a deeply buried beacon is a skill that needs more than a once-a-year rehearsal. To practice by yourself you obviously need a 2nd beacon. I wasn't going buy another one, but building a 457 KHz transmitter sounded easy and cheap. I looked up the specs on line: *Beacons transmit 0.1 second pulses of 457 KHz carrier repeated once per second.* The antennas are ferrite "loop sticks," exactly the kind found in pocket radios. The oscillator and RF amplifier(s) use 455 KHz IF transformers, also found in little radios. The transformers are tuned with threaded, powdered iron slugs inside the coil. After some trial and error my working beacon transmitter is shown below. It performs just like the real thing:



I packaged the transmitter in a Radio Shack plastic box



Once I had a working transmitter, I tried to build some fully functional transceivers for my carefree friends. Alas, receivers are difficult. My first simple direct-coupled receiver had a range of about 1 meter. Oops. My next approach was a TRF receiver with a BFO. It consists of a string of RF amplifiers ahead of the product detector and an earphone. Its sensitivity is barely adequate, but I never progressed to developing the display part.



Real beacon receivers have THREE orthogonal antennas, not just one. Also, they

have a microcomputer to display direction, distance and indicate multiple beacons. I estimated that, by the time I reached commercial quality performance, my homebuilt transmitter/receiver would need a separate backpack to carry it!

In conclusion, a practice transmitter is a relatively easy and satisfying project. I recently went on an avalanche practice with the local mountain rescue group. Because I had practiced the day before in my backyard, I did great. I localized multiple buried beacons and managed to dig one out that was buried 4 feet down. Fun! Well, *practices* are fun, but I can do without the real experience, thank you.

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### VERY VLF - BUILDING A WHISTLER RECEIVER

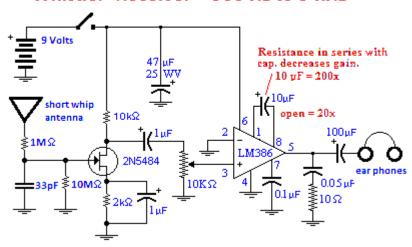
### An audio amplifier with a radio antenna

Very Low Frequency is defined as below 10,000 Hz. However, electromagnetic waves can exist at any frequency greater than zero. Consequently, there are radio waves around us at even the lowest imaginable frequencies. The only practical use I have heard of for them is a clumsy way to broadcast audio signals, such as music, into wireless headphones. The range of such system is very short and today Bluetooth microwave systems perform the same service much more gracefully.

For decades I had been hearing about "whistlers" but I never met anyone who had actually listened for them. Whistlers are audio frequency radio signals generated by lightning bolts. They are supposed to be aerie, other-world, sinking whistle tones generated by distant lightning bolts. The tones fall from roughly 5 KHz down to about 500 Hz. The descending frequency whistle supposedly results from propagation along different ionospheric paths to your receiver. The high audio frequencies arrive first, so the tone starts high and sinks rapidly over a few seconds. In theory, all we need to do is plug an antenna into the microphone/record cartridge input of a stereo amplifier. This allows us to hear audio frequency radio signals. They are already audio frequency, so no detector is needed. I tried this and it works! That's *the good news*.

The bad news is that if you are anywhere near 60 Hz power, your receiver will pick up lots of 60 Hz hum and nothing else. Obviously you can't power your receiver with AC and you have to take it outdoors. To hear whistlers we need a battery powered, audio frequency amplifier that can be operated far away from any AC power. One website says we should even get away from alleged electrostatic noises caused by tree leaves rustling!

### Whistler Receiver 500 Hz to 5 KHz



### How it works

I built a few versions of this receiver before I heard anything more than 60 Hz hum and a soft purring static. Even outdoors during visible lightning flashes, I was only hearing a soft, constant purr. My early versions all had bipolar transistor or bipolar opamp inputs, which may or may not be relevant. They all oscillated when I turned up the gain. The receiver that produced the most interesting VLF signals is diagrammed above. As you can see, it has a JFET transistor input. Most of the VLF receiver designs shown on-line have FET front ends. Several designs used TL082 FET op-amps for the input. I used the ubiquitous LM386 chip for the high gain audio amplifier. I wired it for maximum gain and, unlike the designs with bipolar inputs that I tried, I haven't been plagued with feedback. I originally assumed that I would need a gigantic antenna or perhaps a huge ferrite core with thousands of turns ... apparently not. All the on-line designs just use a simple whip antenna, a few feet long. With this receiver I can hear my old Heathkit audio frequency tone generator from several feet away. There was nothing attached to the generator but a short piece of shielded coax. Using this test I was able to confirm reception of audio RF up to about 6 KHz.



The receiver seems to work better with a bare metal enclosure. When it's hand-held, your body becomes a counterpoise and the sensitivity increases slightly. Unfortunately, real, classic whistlers seem to be rare. The sample recordings on-line were usually recorded on remote, desert mountain tops after days of patient listening. On-line sites also have recordings made in Alaska of exotic chirping noises caused by the aurora.

On the bright side there are strange sounds to be heard during local thunderstorms. When storms are within perhaps 25 miles, the most common noise is **a weak**, **continuous**, **erratic**, **stomping**, **rumble**. It doesn't relate to what my ears hear without the device nor does it correlate with the visible cloud flashes. When the lightning gets close, there are loud clicks and snaps in the headphones and many random background ticks and crackles. Sometimes I heard slow squeals that resemble the sound of corona hissing - That is probably exactly what it is! The closest I have heard to whistlers were short little squeaks associated with the corona sound.

Unfortunately I'm still waiting for my first big classic whistler. Spring is near, so surely the thunderstorms will soon return. For those of you interested in more practical things, your portable whistler detector makes a terrific AC power tracer. You can plug in an extra short antenna into the receiver and precisely locate live wires behind a wall or under a floor.

### HOMEBUILT METAL DETECTORS

### **Introduction to detector designs**

Metal detectors can be divided into three categories: Simple detectors demonstrate the basic principles for "show and tell" and are easy to build. These detectors will detect a tin can two inches away. When I was a teenager, there were 8 hams in my high school at the same time. One of my ham "friends" visited my shack. When I wasn't looking, he put a bit of solder into the coil form of the resonating inductor in my Heathkit VF-1 VFO. Not surprisingly, the VFO refused

to oscillate. When I opened the enclosure, I happened to notice the glint of metal inside the ceramic coil form. The VF-1 had no trouble detecting *that* tiny bit of metal.

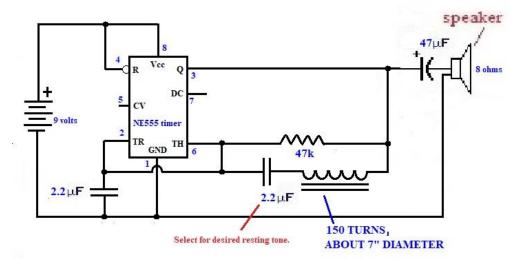
My detector is a more refined version of the simple detectors. My goal is to detect small coins within 6 inches reliably. Most detector designs produce a changing audio tone proportional to the frequency shift of an oscillator when the metal object comes close to the inductor in an LC oscillator. Building a metal detector that can detect a tiny gold coin under 6 inches of dirt is easy in theory, but *much* more difficult to develop and build.

The 3rd category of detectors, advanced commercial detectors, are complicated and some of them operate on exotic principles. Some use RF pulses like a radar and listen for echoes from the buried metal. There is another method in which one inductor is "balanced" against the seeker inductor. Slight deviations are detected and trigger a calibrated audible or visual indicator. Many of the commercial detectors can detect the difference between iron and non-magnetic metals. I assume they do this by reliably detecting the difference between rising inductance and falling inductance when approaching the metal object. Somehow these detectors must disregard subtle changes in the *distance* from the probe to the metal object.

#### An easy-to-build metal detector

I was intrigued by this simple schematic that I found on the "Circuit Digest" website:

### SUPER-SIMPLE METAL DETECTOR



This is the entire circuit. It's based on a NE555 timer IC that oscillates at an audio frequency and drives a loudspeaker. I started to gather parts from my junk collection when it dawned on me that, since the big coil is going to resonate at audio frequencies, the inductor will have to be huge, millihenries at least. The metal object it detects is going to have to alter the coil inductance dramatically to

make an obvious change in the audible tone. Surfing around, I found a U-tube movie clip of a fellow demonstrating his prototype of the same schematic shown above. To my ears, there was hardly any change in the tone frequency until he laid a pair of steel pliers directly on top of the coil! I had in mind detecting tiny things, like small, lost screws or coins. Clearly, this design is too insensitive for beach combing.

#### Sensitive coin hunting detectors

Now that you are an expert on building analog VFOs and direct coupled HF receivers, you know how to build a sensitive detector. I should say, you're ready to do man-months of R&D to make one that is as practical and polished as the simpler commercial detectors. The detector consists of a stable VFO oscillator with its frequency determined by the seeker inductor in parallel with a variable capacitor. The inductor is the sensor element. The capacitor sets the resting frequency of the seeker oscillator. When the inductor passes close to metal or other conductive object, such as your hand, the resonant frequency changes.

The change in frequency is detected by a direct coupled receiver controlled by a crystal oscillator. The crystal oscillator frequency is a few hundred hertz different than the resting frequency of the VFO. In ham radio terms, the crystal oscillator is the BFO and detects the frequency shift. The simplest metal detector indicator used by commercial metal detectors is an audio output that makes a continuous CW-like tone. The musical pitch changes whenever metal is sensed by the inductor.

#### **Commercial metal detectors**

I like to start my projects by guessing how they're designed, then building one using circuits I understand. Once I have built a working prototype, I like to see how the professionals did it: The website hobby-hours.com/electronics/metal-detectors website has several schematics for Heathkit detectors and some made by other brands. I was impressed by how complex most of them are! What they all had in common was that the frequencies were 200 KHz or less. I was expecting HF frequencies, like mine.

### Sensitivity versus stability and complexity, a trade-off

High Frequency RF provides the sensitivity we need. RF inductors are low inductance. Therefore, a nearby metal object can make a huge relative change in the inductance and resonant frequency. I used audible tone variation as the detection method. If we plunk a pair of steel pliers down on the sensor coil at RF frequencies, the resting frequency may shift by megahertz or it may kill the oscillation entirely. In contrast, subtle changes in the tone pitch can signify a penny 6 inches or more away from the sensor coil.

I wanted to hear the audible tone shifting *tens of Hz*, not megahertz. Obviously we need a truly stable VFO so that the resting frequency won't vary when there's no metal nearby. Similarly, the RF receiver listening to the RF seeker oscillator requires an equally stable Beat Frequency Oscillator (BFO). If both oscillators are stable, the musical tone we hear - the difference frequency - won't

drift and won't give a false indication.

### The seeker oscillator design

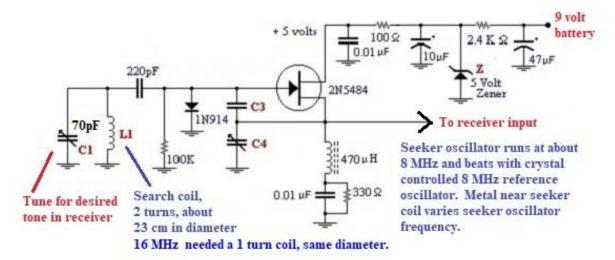
I first tried two really simple RF oscillators, like the examples shown in Chapter 6A. They weren't stable and didn't produce clean sinewaves. The tone in the radio receiver was rough and barely musical. Part of it was due to 60 Hz ripple from the lab power supply. When I ran them on a 9 volt battery, the tone improved but was still unpleasant. Next I tried a Colpitts VFO oscillator like those described in Chapter 10. This gave me clean, stable sinewaves that sounded pure, even when using the lab power supply.

I tried out the VFO circuit shown below for 8 MHz, 12 MHz and 16 MHz. Generating the right frequency for the VFO module is easy. However, the DC receiver module needs a crystal controlled reference oscillator, so you need a crystal for your BFO frequency. This may limit your frequency choices. Any HF frequency will work and 16 MHz is quite sensitive. Unfortunately, 16 MHz is also relatively unstable. The more frequency stability features you add (see Chapter 10), the more practical the higher frequencies will be. I found I couldn't even begin to test the complete unit until I had installed the VFO in a shielded box.

By the way, the VFO can't share its shielded box with the crystal controlled oscillator. If it does, the VFO will abruptly latch onto the frequency of the crystal oscillator whenever the two frequencies become close.

The tuning capacitor adjusts the frequency to become within audio frequency range of the receiver crystal oscillator frequency. I adjusted the frequency using a small, 5 to 13 pF, ceramic trimmer capacitor. I access the trimmer through a small hole in the lid of the VFO shield box. I later replaced the mechanical trimmer with a varactor capacitor which is tuned by a remote potentiometer.

### Seeker Oscillator and Search Coil



I also built 12 MHz and 16 MHz versions of this oscillator. As you would expect, the higher the frequency the more sensitive the detector. Unfortunately the higher frequencies were not as stable and harder keep in the receiver tuning range.

The sensor inductor is L1. C1 resonates with L1 and aligns the oscillator close to the receiver crystal frequency. This sensor oscillator puts out very little power without an amplifier. But since its only "audience" is the receiver located in the larger shielded enclosure, milliwatts may be all that are needed.

To test these oscillators as potential seekers for my project, I simply listened to the oscillator using a short wave receiver with a BFO. I was surprised how rough the signal sounded. The tone of the "whistle" tone improved greatly when I powered the detector with a 9 volt battery instead of my line-powered lab power supply.

### Would a crystal oscillator work as a VFO?

Although the above VFO circuit was adequate, it occurred to me that a crystal controlled "seeker" oscillator might also work and would definitely be more stable. In our ham transmitters, we have successfully "pulled" the frequency 3 or 4 KHz with series and parallel capacitors. Could a series or parallel inductor pull a crystal far enough to work as a sensitive metal detector?

I built an 8 MHz crystal controlled oscillator and added the inductor: When the seeker inductor was placed *in parallel* with the 8 MHz crystal, the crystal no longer controlled the frequency. The frequency dropped down to 5.3 MHz. When I waved my hand in front of the inductor I got a tiny change in frequency and audible pitch in my receiver. Aside from losing crystal control, the resulting oscillator/receiver combination was not stable enough.

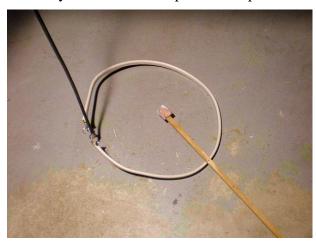
With the inductor *in series* with the 8 MHz crystal, the frequency dropped 3 KHz to 7.997 MHz. The good news was that it was super stable. But no matter

how much metal I waved in front of the inductor, the frequency counter and audio tone never wavered. Oh, well. It's refreshing to have a solid, indisputable result with no qualifications.

This result reminded me of when I was a test engineer in the Air Force. I was often given gadgets or techniques to try out with actual Air Force airplanes on a test range. The devices I tested nearly always worked ... "a little." I spent hours wondering if the slightly positive result was worth recommending for further development or deployment. One glaring exception was a small, cheap, plastic and steel gizmo that was designed to be scattered on enemy highways to puncture tires and slow convoys of trucks. First, the Soviet-built truck tires had a clever internal, spiral spring structure, so loss of air pressure wouldn't stop them. Also, tanks and personal carriers have steel tracks and were immune. Worst of all, the plastic wasn't sturdy enough. I was able to run one over with my Jeep and squash it flat. Total failure! Sometimes failure is good - no need to explore the idea farther.

### Seeker coil design

Over the range of 8 to 16 MHz, the seeker coil is simply one or two turns of wire in a 6 to 9 inch circle. Commercial seekers have a custom plastic disk containing the coil. I used a loop of Romex household wire cable. This is the 3 conductor wire that connects outlets in the walls and ceilings of our houses. Its 3 wires may be wired as an inductor with one, two or three turns. It is well insulated and sturdy enough to stand alone. I found that keeping the end of the probe assembly as metal-free as possible improved the sensitivity.



The seeker coil is connected to the electronics with 4 feet of RG-58U coax. The penny coin Scotch-taped to the end of the wooden stick is a test probe. A practical seeker coil assembly will need a wooden pole with a plastic mount for the Romex loop.

#### Metal probe parts worked poorly

The next photo, below, shows a metal-mounted seeker coil. Obviously, the coil mount is incomplete. I wanted to test if before I made a practical version. Metal parts are strong and easy to assemble. The purpose of the test was to find out if the metal pole ruined the sensitivity of the loop. I predicted that the metal

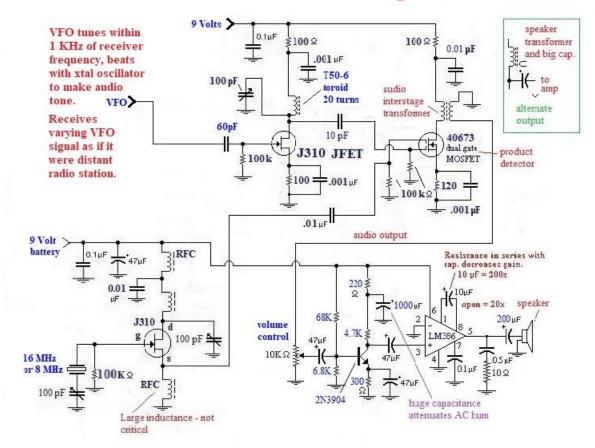
mounting tube "would be electrically the same" as the grounded outer conductor of the coax. It wasn't. *The only part of the loop that remained sensitive to the penny test probe was the end of the loop closest to the coax center conductor.* I also decided that a 6 inch (15 cm) diameter loop was better than 9 inch. You may disagree. (The black line behind the aluminum tube is its shadow and not a second black cable.)



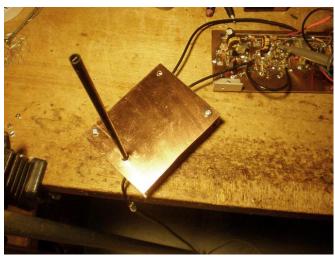
### The frequency shift receiver

As you might have expected, the detector receiver is a simplified version of the 40 meter D.C. receiver presented in Chapter 7A. The PC board was originally used as a prototype 10 meter DC receiver. This design could be used for any of the lower HF band frequencies. Lower frequencies, like 80 meters, will be less sensitive but more stable. As I learned, It's hard to make the system stable enough at frequencies above 20 meters. Maybe I should change my goal to 25 cent quarters at 6 inches!

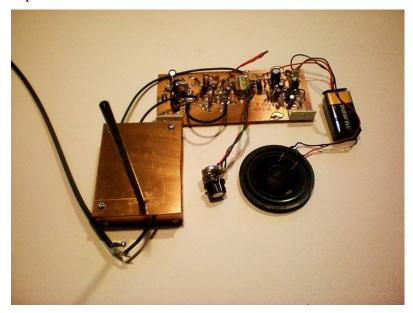
## Metal Detector Direct Coupled Receiver



Notice that the VFO has a buffer amplifier stage in the receiver. The reference frequency signal was large enough without an amplifier. If the signal is too large, you can decrease it by simply detuning the buffer amplifier LC circuit on the drain. I found it worked best designed like the mixer in a super-heterodyne receiver. One of the two input signals needs to dominate the mixer input.



The photo above shows the prototype VFO oscillator mounted in a shielded box. The DC receiver is on the right. Because of its crystal controlled BFO, an isolating shield for the DC receiver is desirable, but not as important. The tall, black plastic tube is a metal-free screwdriver for adjusting the frequency trimmer capacitor in the VFO.



Here are all the prototype electronic modules. I have not yet installed it in a rugged, beach-worthy chassis and probe. I'm still trying to make the detector reliable and stable enough for use at 16 MHz. At 16 MHz, it easily detects the penny at 6 inches, but it's "flaky" - hard to keep adjusted. I may have to retreat and settle for 8 MHz or lower. I shall complete this article if and when I have a practical, field-worthy instrument.

My main missing ingredient for this project is a reason for finishing it. There are no beaches with lost coins and jewelry around here. Nor do we have Australian-style gold fields where citizens can get a temporary license to search certain, lightly forested areas with a metal detector and a shovel. It looks like fun!

\*

### **ULTRA, ULTRA HIGH FREQUENCY**

### Talking on a sunbeam

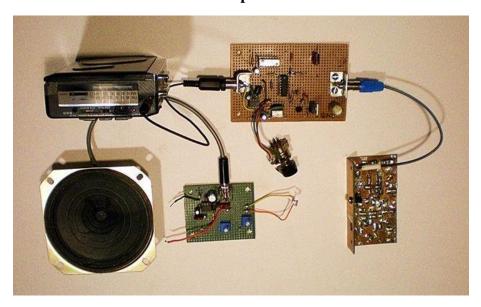
Alexander Graham Bell invented the telephone in 1876. In 1880 he demonstrated the "photophone." He considered it his greatest invention. Talking on an actual sunbeam was certainly a radical, improbable idea. The photophone wasn't practical so long as it relied on sunlight and had such a limited range. Bell was a romantic fellow. He didn't care that it was impractical, he was simply thrilled that he actually made it work. In his later years he reminisced about the magic of harnessing

sun light to communicate wirelessly, "farther than a man could yell and 'hearing' a passing cloud that blocked his sunbeam."

The photophone used lenses to direct a concentrated beam of bright sunlight onto a mirrored diaphragm that vibrated when a person spoke into a telephone-like mouthpiece. The light reflecting off the diaphragm was collimated with another set of lenses and directed toward apolished parabolic reflector as far as 200 yards away. The light beam was detected using a selenium crystal detector at the focal point of the reflector. Crystalline selenium can be used directly as a photocell to generate electricity. Bell's standard telephone earpiece converted the varying current into sound.

Thanks to diode lasers, fiber optic cables and photodiodes, today's optical communication offers higher bandwidth and data transfer rates better than radio, coaxial cable or any other transmission method.

### A homebrew demonstration of optical communication

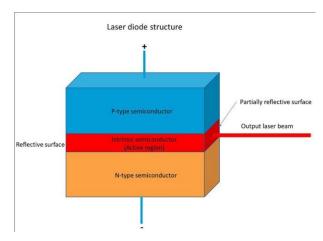


A Walkman radio on the upper left serves as a source of analog audio. The analog audio signal is sent to the Pulse Width Modulator (PWM) converter on the upper right. The converter sends the pulses to the laser diode on the circuit board on the lower right. A laser beam shines on a photodiode soldered onto the yellow and orange wires, bottom center. An analog audio amplifier raises the signal strength to drive the loudspeaker. Power supplies aren't shown.

### What's special about laser diodes?

If you measure the forward and backward resistance of my laser diode, it looks like an ordinary red LED. The forward break down voltage is the usual 1.6 volts and the reverse has infinite resistance. A laser diode is an LED constructed like a PIN diode. There is an Intrinsic layer of undoped semiconductor in the center that is the active light region. The intrinsic "I" layer is a kind of cavity resonator in which the light beam reflects back and forth, reinforcing the intensity and making the optical waves coherent - in phase with each other. Ordinary LEDs generate light which

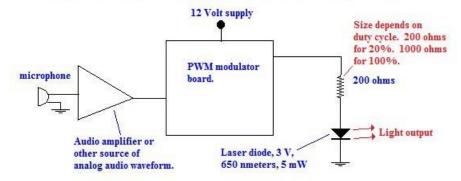
escapes in every direction with the light waves out of phase. Like other optical lasers, there is a reflective layer on one side of the crystal and a partially reflective layer on the opposite side. Some fraction of the light, the output, leaks out the partially reflective end. Laser diodes are packaged in a case that contains a lens to direct and help collimate the wave. Ordinary LEDs simply generate light which escapes in all directions with the light waves out of phase.



Diode laser/ photodiode optical links are a modern version of Mr. Bell's wireless optical telephone. The homebrew demonstrator shown earlier has the potential to be a terrific kid's toy. The circuits could be developed into a private telephone or a marksmanship game.

Then I realized that today all human beings over the age of six (except me) now own I-phones. The appeal of such primitive toys would be totally lost on them. I feel sorry for modern kids. If you show them a laser communicator or an anti-gravity machine, they will say, "Oh" and return to their I-phones. With such versatile marvels at their finger tips, they assume anything is possible and easy.

### OPTICAL TRANSMITTER



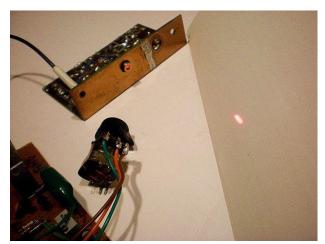
The pulse width modulated optical transmitter

The transmitter could be as simple as an analog audio amplifier driving the laser diode directly. In Chapter 17A I described the pulse width modulator which I used to experiment with PWM AM RF transmission. Here, the same modulator board drives the laser diode with full-power pulses. Unlike analog AM transmission, this optical signal is sent at 100% amplitude, like FM. The difference is that the duty cycle can be 10 to 20%. In other words, the transmitter is OFF 80% to 90% of the time. Aside from saving energy, the data is always transmitted at maximum power. This makes it far less vulnerable to noise.

### Pulses allow the laser to generate higher power than its rating

To prevent overheating laser diodes, they are limited to a certain average power. My diode is rated at just 5 milliwatts. But because of PWM, the 5 milliwatt *average* power limit can be maintained while driving the diode with 5 to 10 times as much current delivering 25 to 50 milliwatts peak power. This makes a huge difference in how far I can project a visible dot. Modern LED flashlights use the same trick to extend battery life. I measured my flashlight and, sure enough, it was generating 20% duty cycle pulses at a pulse rate too high for the eye to perceive.

For my demonstration I used a Jameco Valupro laser diode, PN# 2210204. The diode is packaged in a tiny brass cylinder about 0.5 centimeter diameter. One end of the cylinder has a glass lens. The opposite end has the (+) and (-) wires. The diode is rated at 10 mA average current at 3 V and delivers a 5 mW, 650 nanometer red spot. This diode is suggested for garage door safety cut-offs and similar short range application. It sells for \$3.49 and was the cheapest I could find. In contrast, if you want a serious laser diode that puts out big power that projects for miles, the price quickly soars to hundreds of dollars.



The laser diode projects a small, bright red dot that can be seen on the wall on far side of the room. It could probably viewed from miles away if someone looked directly toward the diode at night through a sufficiently large telescope. In the photo below, the light is projected onto a folded white sheet of paper. The bright red dot is greatly overexposed and looks white to the camera. (The diode was mounted on pieces of scrap PC board. The circuitry on the board is simply the diode and a current-limiting resistor.)

#### **Photodiodes**

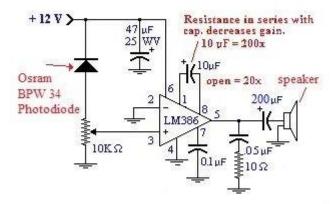
Photodiodes receive the pulsed digital or pulse modulated optical signals. For distant communication, the light is usually "piped" miles through pure silicon dioxide glass fibers. Consequently, telescopes and precise alignment of transmitter and receiver aren't needed. Like the laser diode, if you measure its forward and backward resistance, the pulse sensor appears to be an ordinary diode. The forward conduction voltage of mine is the usual 0.6 volts and the reverse polarity has infinite resistance.

Photodiodes can be used two ways. In *forward conduction mode* the light causes the diode to conduct and it produces a proportional current. In the *solar cell mode*, the diode generates a voltage proportional to the ambient light. I used an Osram type BPW-34 photodiode. It looks like a like a tiny, square, solar cell, about 2 mm across. It will switch ON or OFF in <20 nanoseconds. So in theory, the diode can handle pulse rates approaching 50 million bits/second. I'm using 8 KHz pulses. Obviously the same optical link could handle high resolution TV or other high data rate applications.

### The optical receiver

I searched on-line for "photodiode digital receivers" and the circuit below appeared. That was easy! This is the same LM386 audio amplifier that has appeared several times in earlier chapters. The photodiode drives the analog LM386 audio amplifier. I used the "photocell configuration." It is connected to the amplifier chip as though it were a microphone or other audio source. The 10K potentiometer is adjusted for optimum sound quality and volume.

### Optical Receiver



#### A moon shot

There is one challenge an ambitious lone experimenter could try: **moon bounce!** The Apollo astronauts left an array of precision, glass prism reflectors on the moon. Since the reflected pulse would need 2.5 seconds to make the round trip, it should be obvious if we are receiving a real reflection. **DX!** 

I measured the dispersion angle. It spread to 1 inch diameter at 30 feet. That's

plenty bright to be noise free. I calculated that my little laser beam would be 500 miles wide by the time it hit the moon. I think I'm going to need a better laser! At 30 feet distance the red spot diverges about 0.16 degrees. From what I read, a collimating lens could further narrow the beam and extend the range. Some lenses can focus a laser beam down to 3.4 arc minutes, about .0016 degrees divergence. Now the spot on the moon will "only" be 5 miles wide. Obviously the greater the distance the more precise the alignment must be. A telescope in front of the detector can increase the sensitivity of the receiver, but alignment won't be easy.

Searching on-line, I learned that since 1969, the reflectors on the moon have lost 90% of their reflectivity. Presumably they have become dusty and scratched by micrometeors. The reflector array is still useful, but a powerful laser is needed as well as a large, moon-tracking astronomical telescope. The 200 inch reflector scope on Mount Palomar should be adequate.

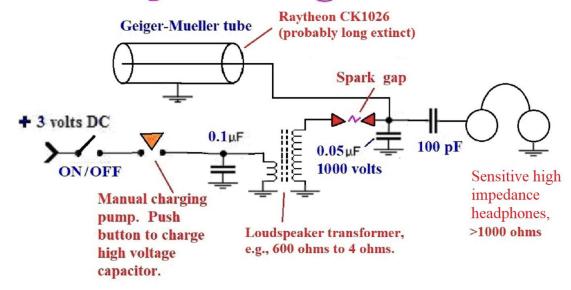
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### THE HIGHEST FREQUENCY

#### HOMEBREW GEIGER COUNTERS

The highest radio frequencies are called gamma rays. They are formed by violent collisions between atomic particles, decaying radioactive atoms, exploding stars and even occur in lightning bolts. The more violent the origin, the higher the frequency. Gamma rays were formerly defined as having wavelengths shorter than 10<sup>-11</sup> meters. X-rays are the same, but have longer wavelengths. Today X rays and Gamma rays are considered to be the same phenomenon. They ionize living tissue and can damage and kill it. Personally, I don't plan on trying out sideband on Gamma HF anytime soon. However, a receiver for Gamma rays can be amazingly simple:

# The Simplest Geiger Counter



Above is the schematic of my first Geiger counter. I *love* this circuit! It reminds me of a crystal set. A push-button connects the battery to the primary of a high ratio voltage step-up transformer. With each push of the button a spark jumps over to the isolated Geiger tube. With no resistive leakage, the high voltage charge remains on the tube for 4 or 5 minutes. When a Gamma ray zips through the tube, it ionizes the neon inside and causes a brief current to flow between the electrodes in the Geiger tube. A high impedance, old-fashioned headphone makes a "click" that the operator can hear. If you build one of these, an unusually sensitive Geiger tube is needed. Also, the sound level is quite weak and sensitive headphones are needed.

### The simplest Geiger Counter circuit

The high voltage generator circuit resembles an automobile ignition. The function of the breaker points is accomplished here with a manual push-button. The button pulses current into a voltage step-up transformer. A spark jumps across the gap and delivers over 400 volts to a storage capacitor. At the end of each pulse, the  $0.1~\mu F$  capacitor on the primary prevents most of the energy in the transformer from returning to the primary, thereby increasing the output voltage. The spark gap serves as a pseudo diode to keep the transformer secondary from discharging the high voltage capacitor. My spark gap was an old screw-adjusted mica trimmer capacitor with the mica removed. The gap was adjusted so that it was just barely open. You can't replace the spark gap in this circuit with a modern high voltage diode. Semiconductor diodes always have a slight amount of resistive leakage. This means you would have to push the button almost continually to keep the  $0.05~\mu F$  capacitor charged. When there is no spark, the spark gap has zero leakage and works better than a diode.

The .05  $\mu F$  storage capacitor has no conductive loads on it, just pure capacitance. As a result, the capacitor remains charged for many minutes ... until radiation penetrates the G-M tube and ionizes a path between the center wire and the grounded conductive outer shell. This produces a sudden, small drop in the high voltage which is detected by the headphones. When the G-M tube is placed close to a source of radiation, it will buzz continuously and you must recharge the capacitor more often.

I built the first version of this counter about 1957. Later I rebuilt it and added a vacuum tube audio amplifier and a small loudspeaker. That 2nd version is shown below. I also added a microammeter to display the average audio amplitude which corresponded to the average level of radiation. The colorful microampere meter came out of a thermometer device I salvaged. The labels "cold" and "hot" seemed appropriate. When I recently found the old counter in the attic, the vacuum tube circuitry was gone so I rebuilt it using transistors.

My GM tube is mounted in the detachable aluminum tube so it can be used as a probe. I sawed slits in the tube to expose the GM tube to radiation. The spring clips that allow the tube to ride on the enclosure originally held electrolytic capacitors in an old TV set. Aluminum belt loops on the back of the box allow me to carry it hands-free while hiking.





#### The Cold War

Why was a radiation detector one of my first electronic projects? Atomic energy was a big deal in the 1950s. Young folks may have heard about the early days of the cold war when the U.S. was in a nuclear stand-off with the Soviet Union. In grade school we were instructed to "duck and cover" if we ever saw a blindingly bright flash on the horizon. That meant dropping to the floor of our class room, crawling under our chairs and covering our heads with our arms. At the time I was living just 10 miles from New York City. I imagined that the flash of light would be followed a few seconds later by a shock wave, obliterating our school - and me with it.

The threat seemed real because the government televised atomic bomb tests at Yucca Flats, Nevada. Above ground A-bomb tests were big scary, fascinating events. In 1950 hardly anyone owned a TV so the neighbors invited us over to watch the explosions. They were complete with an ominous countdown - "4 - 3 - 2 - 1," then - FLASH! - there was no sound but the screen went white. After a few seconds the billowing cloud became visible, accompanied by the "Ooohs" and other exclamations from the announcer.

I worked for an Air Force pilot, Colonel Brooks Morris, who participated in one of these tests. His flight of F-84 fighters flew toward the bomb site, then abruptly turned away a few seconds before detonation. As the count approached zero, they closed their eyes and placed a gloved hand over their eyes. When the flash of light occurred, Brooks was shocked to see the bones of his hand illuminated like an X-ray.

Every city had Civil Defense signs directing people to the nearest bomb shelter. They were usually in a subway or other below-ground basement. Many people living in

the suburbs built their own underground backyard bomb shelters. One shelter I visited was simply a walled off portion of a basement. Another one was much more elaborate and was incorporated into the original house design. Every bomb shelter needed a Geiger Counter to test that water or food was safe and when it was safe to leave the shelter. It wasn't until after the Cuban missile crisis in 1963 that the fear of mutual annihilation noticeably decreased. Americans and Russians realized that nuclear war was **REALLY** not an option.



The photos above show a civil defense Geiger counter that I bought at a yard sale. Huge numbers of these were made. The Geiger-Mueller tube is the big round steel can. It only detects gamma rays, because alpha and beta rays can't penetrate the steel detection chamber. Gamma rays are the most penetrating and dangerous of the ionizing radiations. The counter has a vacuum tube amplifier powered by D-cells and an extinct type of 22.5 volt "B" battery. Does it still work? No, it doesn't. I eventually learned that *old Geiger counter tubes rarely still work*.

#### **Uranium prospectors**

Before World War II uranium was a rare, heavy metal with few uses. Suddenly it was in high demand. After World War II many guys saw uranium prospecting as a great adventure and a way to get rich. Uranium prospecting was much like the old gold rushes in California, Colorado, the Yukon and elsewhere. Instead of a donkey, gold pan and shovel, uranium prospectors typically had a World War II surplus Jeep and a Geiger counter.

The Canyon Lands wilderness in southern Utah was a major area searched by the prospectors. When I was a boy, I encountered a map of Utah drawn in the 1930s or earlier. I was fascinated by blank areas on the map showing what is today Canyon Lands National Park. The empty regions were marked "unexplored." In 1950 the area was still little known and it was entirely open for mining claims. It has little accessible water and sparse animal forage so there were no ranches, no homesteads and no previous mining claims. The prospectors managed to drive their Jeeps all over Canyon Lands and open it to prospecting. I doubt they found much uranium but they did blaze trails for recreational Jeep enthusiasts like me who have been enjoying it ever since. (I still own a 1952 CJ-3A Willys Jeep.)

So what did I do with my Geiger counters? My favorite adventure with a counter

happened near Jamestown, Colorado. By the 1960s the uranium prospecting boom was over but there were still fellows trying their luck with small claims that had never been profitable. We heard that there were two fellows working a small mine up on a steep mountain side. We drove up the Jeep road toward the mine. As we approached, there was a huge "BOOM!" A cloud



of dust and smoke emerged from the mouth of the mine. Two guys, who had been cowering behind trees near the entrance, emerged and asked us what we wanted. We explained that we had heard that the mine was active and we wanted to test our homemade Geiger counter on their tailings (waste) rock pile.

"You have a Geiger counter? Great!" they said. "We just blasted in the tunnel and we realized that we left our counter in town." They took us about 30 meters into the adit (tunnel) where there was a huge pile of loose rocks. The uranium vein they were following was a 2 mm wide layer of light green-colored, crystals. They held the counter probe against the newly exposed rock wall. Sure enough, there were more cracks in the wall packed with the pretty green crystals. The counter made a satisfying buzz. Big thrill!

### Geiger-Mueller tubes

Geiger-Mueller tubes are usually similar in construction to the old-fashioned, glass, voltage regulator tubes described in Chapter 14. They contain a partial vacuum with a bit of easily ionized gases, typically 98% neon with other additives. Like the regulator tubes, GM tubes have a conductive, cylindrical outer electrode in the tube with a metal wire inner electrode running down the center. In order for the tube to detect beta rays as well as gamma rays, the glass and outer electrode are sometimes thin and delicate. The thin glass enables the beta rays to penetrate the tube. Beta rays can be either high speed electrons or positrons. Some GM tubes have an extremely thin window at one end that will even detect alpha rays. Alpha rays are ionized helium atoms that have very low energy and can be stopped by a sheet of paper or a few inches of air.

Ionized gas ions in the tube produce ultraviolet light waves which are also ionizing. The UV light ionizes other atoms and multiplies the effect of a single ray or particle. Also, the higher the voltage across the tube, the more sensitive it becomes. This explains how a GM tube can often detect a single particle of radiation. Similarly, the coating on the outer electrode also becomes ionized and generates more UV light which also produces more ionization. Some GM tubes can also detect neutron rays. Neutron particles do not have a charge but they ionize atoms when they collide with the outer electrode coating.

### Quencher gas

The pressure in the tube is about 1/10 the atmosphere at sea level. One of the trace gases is a "quencher gas." When a conduction path forms, the ionized path tends to remain intact, making the tube insensitive to further rays. The quencher gas kills the remaining ionization, restoring the tube for more radiation. Formerly, quencher gases were organic molecules such as ethanol or butanol. After a few years the organic gases

broke down and the tubes became unusable. And that's why most old GM tubes don't work any more. Modern GM tubes use chlorine or bromine as the quencher gas. Halogen atoms don't degrade and modern tubes should last indefinitely.

GM tubes operate with a high DC voltage across them, typically 350 volts or higher. When radiation passes through the tube, it ionizes the gas and causes a small, brief current to flow between the electrodes. This produces a sudden drop in the capacitor voltage which can be heard in the earphones as a sharp "click" or popping noise. The "counter" is just you watching your wrist watch. Background radiation is typically less than 60 clicks per minute. However, that depends on the size, packaging, operating voltage and sensitivity of the GM tube.

### Where to buy GM tubes

I bought my new tube from Walmart, of all places. They offer J305 counter tubes made by 4 different manufacturers. All of them cost about \$25. E-bay offers loads of ancient tubes and Geiger counters for sale, even my old Raytheon CK1026 tube. I'll bet very few of the old tubes still work. A geologist told me he's had the same experience with old GM tubes - they're inert. The clear glass tube is the J305. The CK1026 is the black GM tube.



#### Modern photodiode radiation detectors

I considered using a modern photodiode as a Geiger counter sensor. Then I realized that these detectors are just 3 or 4 square millimeters in area. I'm sure they work well for detecting high radiation levels, but they're too small. The "Counts (clicks) Per Minute" depends on the size of the GM tube and its access to the radiation. "CPM" isn't an official measurement, but you'll immediately realize what's normal and what isn't. I read an article by a homebuilder who built a photodiode radiation monitor. It worked well at high levels of radiation but the background count was only about one click per minute - boring!

#### **Radioactive samples for testing**

If you're building a counter, you'll want a radioactive sample to test and adjust. Background radiation has too few counts per minute to easily demonstrate that your counter is working. I use a piece of uranium ore. Uranium 238 has a half life of 4.46

**Billion** years. Uranium 235 half life is "only" 704 **Million** years. U<sub>235</sub> is only 0.72% of naturally occurring Uranium. If it takes that many years for an atom to have chance of disintegrating, I'm surprised that an ore sample containing many other elements can be so radioactive. More to the point, I'm amazed a Geiger counter can make it seem so "hot." Smoke detectors contain a tiny bit of Americium 241. I opened my smoke detector to check it out. The little smoke-detection cage was clearly above background level, but it wasn't particularly active.

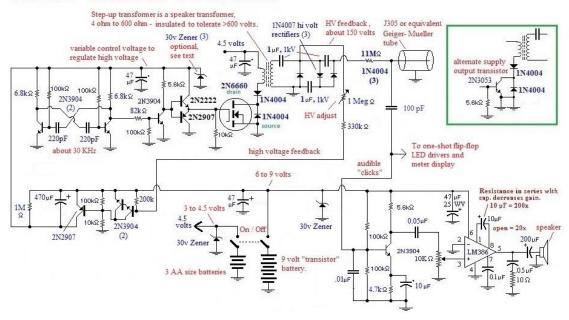
### A more modern Geiger counter

If you wish to build a counter, first look on-line for counter schematics. Virtually all the designs are simpler than mine. This is because some GM tubes are more sensitive than others and special components such as custom transformers and sound buzzers can reduce the complexity. Personally, I just kept adding available parts until I reached my goals.

I thought replacing the original push button charging system with a continuously operating 400 volt power would be easy ... it wasn't. My new GM tube seems to run at a higher voltage and the old manual push-button power supply didn't work. The new tube responds between 350 to 500 volts. Higher voltages sometimes "run away" and produce a continuous buzz. I used 3 AA cells in series for 4.5 volts just to power the final charge-pump transistor. These AA cells provide 30 to 40 mA and should run for over 100 hours. Also, I needed 6 or more volts, to run the 30 KHz oscillator and the audio amplifier. These >6 volt circuits together only draw 5 to 7 milliamps, so I was able to use a small 9 volt transistor battery for this voltage. By happy accident, when the AA cells are exhausted, the audio amplifier oscillates and tells me I need new AA batteries.

I found a Geiger counter schematic which described its step-up transformer. It had an unidentified ferrite core with a 500 turn (!) secondary winding and a 4 turn primary. I refuse to wind such a beast. It takes big currents at a low voltage to magnetize 4 turns. That's why the transformer driver needs large, low voltage batteries. I used an old vacuum tube era speaker transformer, roughly 600 ohms to 4 ohms. That's a ratio of 150 to one. A diode/capacitor AC voltage tripler following the transformer can reach >500 volts. To control the high voltage level, I used feedback from the first rectifier of the diode voltage tripler, about 150 volts. This lower voltage allows me to adjust the feedback and the maximum high voltage using a small 1 meg trim pot. I also tried a 6 volt center-tapped filament transformer - 3.15 volts to 120 volts DC. This also worked, but with a much smaller step-up ratio, it was harder to get enough voltage.

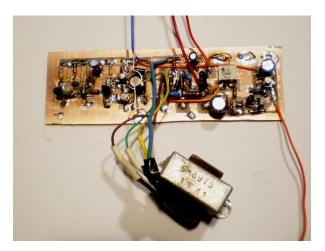
### BASIC GEIGER COUNTER



One design challenge was that **battery voltage declines with use**. I am always annoyed when I discover that my GPS, flashlight or other device goes "dead" when the alkaline cell voltage has only dropped to 1.3 or 1.2 volts. Alkaline cells aren't truly dead until they weaken to 1.0 volts. If we use a 4.5 volt alkaline battery, the voltage sinks to 3 volts when all the useful energy is gone. The Geiger tube stops responding to radiation below 350 volts DC so the high voltage should be adjusted so that 3 volts delivers at least 350 Volts. On the other hand, when the AA battery voltage is 4.5 volts, the high voltage shouldn't exceed 500 volts. The triple diode/capacitor voltage multiplier produces enough voltage even with a nearly dead battery. When setting up the power supply, adjust the 1 meg ohm pot so that it provides more than 350 volts with a 3 volt supply. With all new batteries the high voltage will approach 600 volts. It can generate even higher voltages, but the GM tube may run away - avalanche - when it detects radiation.

In a dark room using high voltage, radiation causes the neon to light up a gorgeous pinkish-orange. When you move your radiation sample along the glass tube, the flickering orange glow will follow the movement - Neat!

My final supply transistor is an expensive 2N6660 MOSFET - it works great, but it's fragile. The much cheaper 2N3053 bipolar transistor also works but isn't as efficient. You could also rewire the amplifier for an inexpensive P-channel MOSFET. For instance, the high voltage supply at the end of Chapter 8 uses a IRF9240. The power supply circuit board and transformer are shown below:



High voltage is dangerous to semiconductors

While I was bread-boarding, I managed to kill 3 transistors and one LM386 by momentarily touching the high voltage to these semi-conductors ... somehow. I wasn't aware of being clumsy, but suddenly the high voltage or sound level was weak or absent. After ruling out wiring errors or shorts, I eventually realized that the parts were dead. *IF* you are able to keep the HV away from the low voltage parts, this won't happen. Because I had some 30 volt Zeners, I put them on each power supply line. Lower voltage Zeners would have been better. Hopefully, I won't have any more accidents.

### The sound amplifier



A transistor amplifier and loudspeaker make the clicking noises audible without earphones. I used an LM386 amplifier because it was easy and has high gain. A difficulty with having the outer case of the GM tube grounded is that the clicking pulses start at zero volts and go negative. If the GM tube is raised above ground by a 200K resistor, the tiny pulses are positive and can be amplified directly with a high gain amplifier. I wanted to use the same grounded aluminum probe and coiled cable of my original counter. As a result, the pulses from the GM tube go negative, below zero volts.

The pulses first have to go to an inverter amplifier to change the polarity from negative to positive. The inverter transistor is biased full ON, so that the negative pulses will turn the transistor OFF. The rising collector voltage provides a big positive signal for the LM386 amplifier. The large emitter resistance, 4.7K  $\Omega$ , raises the input impedance and produces larger pulses for the LM386.

Another difficulty was that the radiation pulses were contaminated with a 30

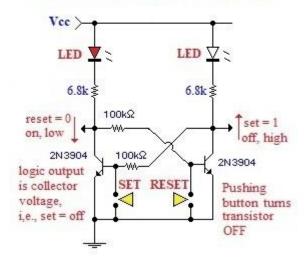
KHz sinewave from the high voltage supply. I can't hear 30 KHz of course, but it acts like the famous Dolby noise canceling system and eliminates the "noise" of the counter pulses. The input to the inverter is shorted to ground with a  $0.01~\mu F$  capacitor. This is a filter that helps eliminate the 30 KHz power supply noise and un-mask the Geiger pulses.

### LED display and meter drive

You would think that driving an LED with a >400 volt spike would be easy. Well, it *is* easy. Unfortunately the LED is only just barely visible with a high efficiency LED in a dark room. The sudden, brief drop in the GM tube voltage contains very little energy. In order to amplify it enough to drive an LED in daylight, the pulse needs to last longer and provide a much larger current. This looked to me like a job for a one-shot multivibrator or flip-flop:

The flip-flop I used was based on a Set /Reset multivibrator:

### SET - RESET BISTABLE FLIP-FLOP



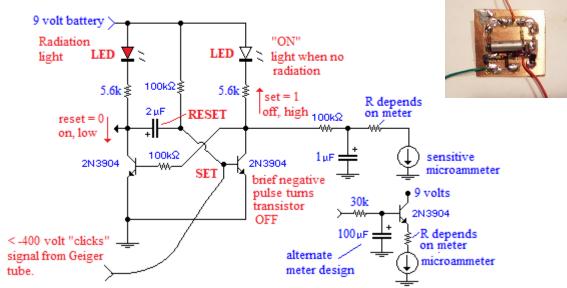
The R/S flip-flop is the most basic one-bit memory circuit. The goal of this circuit is to provide a way for transistors to preserve one bit of data. The output can either be the collector voltage on the left side or the right side. In the circuit shown above, the LEDs that light up are the opposite of the collector voltage. That is, when the collector voltage is a "one," the transistor is OFF. When the transistor is ON, the LED is lit and the collector voltage is low, a "zero." Of course, if you built it using PNP transistors, the reverse would be true. It's kinda confusing.

In a real computer circuit, this simple version needs to be protected from having two inputs happening at once or perhaps an input occurs early and ruins the calculation that the computer is trying to perform. This problem is fixed with additional logic circuits that only allow the output to change when the computer is ready to receive it and to ensure that the circuit doesn't receive conflicting inputs at once. A separate oscillator "clock pulse" coordinates the state changes. These more sophisticated flip-flops are the D type and JK flip-flops.

#### The one-shot flip-flop

This version of the flip-flop prolongs a pulse. It makes a new pulse wider than the pulse that triggered it. This is accomplished with a capacitor which resets the flip-flop after a time interval determined by the sizes of the capacitor and the 100K charging resistor.

### ONE-SHOT FLIP-FLOP DRIVER FOR LEDS AND RADIATION METER



The meter circuit displays the average radiation level. The pulses from the one-shot flip-flop charge a large capacitor. The meter displays the voltage on the capacitor. This works best with a very high impedance voltmeter. With selectable charging resistors, radiation levels could be integrated and calibrated. An ordinary micro-ammeter needle just moves in time with the "clicks" and the flashing "radiation" LED. The alternate meter design converts a micro-ammeter into a voltmeter. The transistor provides a continuous current proportional to the voltage which in turn drives the amperemeter. The picture below shows the response to a high level of radiation.



The picture below shows the "guts" of the completed Geiger counter.



**Units of radiation measurement** 

Measuring radiation is complicated with many different units and meanings. I can't keep them straight - Rutherfords, Curies, Sieverts, Rems, Roentgens, ergs/cubic cm and others. Personally, I like Rads. **Rads** express the radiation energy absorbed by tissue. It is a common unit used in medicine. **800 rads** of absorbed energy will kill any adult. **400 rads** will kill 50% of adults. Flying to Mars on a 3 year expedition is expected to cause about 80 rads *total* accumulation. If radiation exposure happens slowly, the body has time to repair the damage. If the 80 rads were applied to the whole body all at once, it might well cause a cancer or leukemia.

When radiation is used to diagnose and treat cancer, the total radiation exposure is often about the same as a trip to Mars. Fortunately, the cancer radiation treatment is tightly confined to the cancerous tumor. This means that while the tumor is killed, the rest of the body remains healthy and can "rescue" the damaged cells adjacent to the tumor. If you wish to sort out the units of radiation measurement, Google them and learn all about it.

#### Other uses for a Geiger Counter

Many areas of our country are plagued with radon gas creeping into our basements. Radon is a heavy, chemically inert, radioactive gas closely related to neon and argon in the periodic table. Because of its high atomic weight, it tends to gather in basements and not circulate. Personally, I have a hard time understanding the risk of radon gas in basements. Sure, if you work daily in an underground uranium mine and breathe huge volumes of radon, those levels of radon concentration are a proven health risk. Also, when we inhale radon atoms, they tend to remain in the lungs longer than lighter gases.

On the other hand, I'm suspicious of the industry built around measuring and reducing radon levels in basements. Every basement has a few atoms of radon floating around down there. The question is, at what level between uranium mines and typical cellars does the risk become worrisome? The U.S. Housing & Urban Development (HUD) website says, "Average outdoor level is 0.4 picocuries per liter of air (pCi/L). However, the average indoor level is 1.25 pCi/L and nearly one out of every 15 homes in the U.S. is estimated to have elevated radon levels at or above EPA's action level of 4 pCi/L." I checked my basement and found that the background count was lower than my backyard on a summer day. I decided the risk of working down there is trivial and I refuse to worry about it.

Like many old men, I was diagnosed with prostate cancer. I was tested for metastatic tumors using Technetium 99(meta). This is a radioactive isotope that gives off gamma rays but has an extremely short half life, 6 hours. It's injected into the blood stream and quickly spreads throughout the body. When I got home, I checked my radiation level and was startled how radioactive I was - my whole body buzzed. To protect my wife, I slept on the couch that night. The next morning, the radiation coming from me was almost undetectable.

In contrast, my prostate cancer was treated with radioactive seeds containing Iodine 125 which has a half life of 59.4 days. My crotch was obviously radioactive for most of a year. That was 15 years ago and I'm still disease free. My oncologist assured me that the risk from the  $I_{125}$  radiation is roughly one cancer per millions of patients. I have no reason to doubt her.

#### Plutonium fears

And then there was the nuclear meltdown at Chernobyl, in the Soviet Union: The cloud of fallout circled the Earth. I heard on the news that it would reach my state in the U.S.A. on a certain evening. That night it was raining lightly. I went out into the back yard and checked the radiation level in the wet grass. It was about twice the normal background radiation - about 120 counts/ minute. The next morning was bright and sunny and the grass was dry. I checked the radiation in the same location - all gone! It was back to the usual 50 counts per minute.

Rocky Flats is about 5 miles from my house. That's where American plutonium bomb cores were assembled during the cold war. In 1957 a fire in a waste storage area released significant amounts of plutonium 239 into the atmosphere. The plant was shut down in 1989 and completely disassembled. Decades were spent scraping and isolating the slight remaining contamination. In 2018 most of the several square miles of Rocky Flats acreage were opened to the public for hiking. Bob, NØRN, and I immediately went

to check it out with a Geiger counter. Random locations around the surface showed normal background radiation. There is a wide, shallow valley at the north end of the area that has a tiny brook feeding two old farm ponds. We dug up silt at the inlets of the ponds. We figured that any wind-blown plutonium dust would accumulate there ... nothing. Safe and boring!

Our local newspaper was bombarded with angry letters attacking the decision to let people hike on this rolling prairie. One letter said that if we inhale just one atom of Plutonium 239, it will lodge in our lungs, disintegrate and cause lung cancer. Yes, in theory ... but Pu<sub>239</sub> has a half life of 24,110 years. So if you live 96,000 years, there's an 87.5% probability that the atom will release its gamma rays. And there is a chance in a billion that that this particular atom will cause cancer. The vast majority of people have zero ability to analyze risks! Maybe a Geiger counter would help them, ... probably not. For me, I've found that a Geiger counter is a fun homebrew project and a useful tool to own.