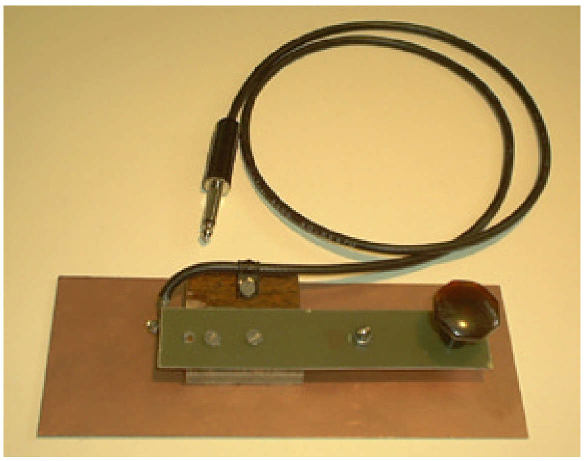
CRYSTAL SETS TO SIDEBAND

Chapter 9

ACCESSORIES

A MORSE CODE KEY

"Straight keys"



A simple telegraph key

A telegraph key for sending Morse code is an easy mechanical project. All that's needed is a reliable spring-loaded switch. The fingers contact a simple knob on a lever. The operator rests his wrist and forearm on the table and grips the knob with two fingers and a thumb. The operator pushes down on the knob, closing the switch contacts. A "straight" key like this is used to send both dots and dashes. The timing of the dots and dashes is totally dependent on the operator.

Commercial straight keys, especially the old ones, are made from elegant machined brass parts and springs on engraved Bakelite plates. The exact tension and gap width can be adjusted to each operator's preference. This sophistication is nice, but not essential for a beginner sending at low speeds. A straight key is good for code speed up to about 15 words per minute. Faster speeds are tiring and hard to send well.

The straight key shown above was made from two pieces of single-sided printed circuit board. The upper sender lever board serves as the spring and its underside is the conductive surface. The switch contact consists of a machine screw that touches the grounded lower board when the lever is pushed down. Two nuts on the screw adjust the contact distance. Most operators like to adjust the switch contacts so that the travel is about 1/32 inch. The spring action of the lever should be strong enough so that it breaks the contact sharply when the lever is released, but not so much force that it is tiring to use. The two pieces of circuit board are insulated from each other by a small block of plywood. The knob is a plastic pull handle from a drawer.

Several articles in QST have appeared in recent years describing how to make keys out of household junk. Most of these keys are really "paddles," rather than straight keys. Paddles are keys that they are pressed side-to-side instead of just downward. Paddles have two switch contacts and are used to control automatic "keyers" of the kind found in modern transceivers. When the paddle is pushed to the left, the keyer automatically generates perfect dots. When the paddle is pushed to the right, the keyer pauses the exact length of time and then automatically makes perfect dashes. It would not be hard to adapt the mechanisms described in those magazine articles to make a "straight," up-and-down key.

Mechanical bugs

No, we're not talking about a mechanical glitch, we're talking about a type of telegraph key. The next step up in sophistication from a straight key is a mechanical ***"bug."*** This telegraph key is activated with a paddle. When pushed left, it automatically makes dots, so long as the operator deflects the paddle. Mechanical bugs make the dots with a weighted beam that swings back and forth propelled by a weak spring. A dot occurs whenever the swinging lever closes the "dot switch." When the bug paddle is pushed to the right, it closes the "dash switch." The operator must make each dash manually. So unlike a modern keyer, the operator provides the timing for dashes. Mechanical bugs like this were standard among commercial radio-telegraph operators and hams for many years. Even railroad telegraph operators often used them.

You can still buy commercial mechanical bugs. At one time there were even complex versions that generated both dots and dashes automatically. A mechanical bug is a difficult basement project without a machine shop. It requires a great deal of patience to make a reliable mechanical bug, but it can be done.

Homebrew electronic keyers with automatic dots and dashes are a common homebrew project. Most hams just buy a keyer kit that has a tiny, pre-programmed "PIC" microcomputer chip that does all the difficult timing chores. Since a pre-programmed chip didn't fit my rules for "homebuilt," I built a homebuilt electronic bug that makes automatic dots but requires manual dashes.

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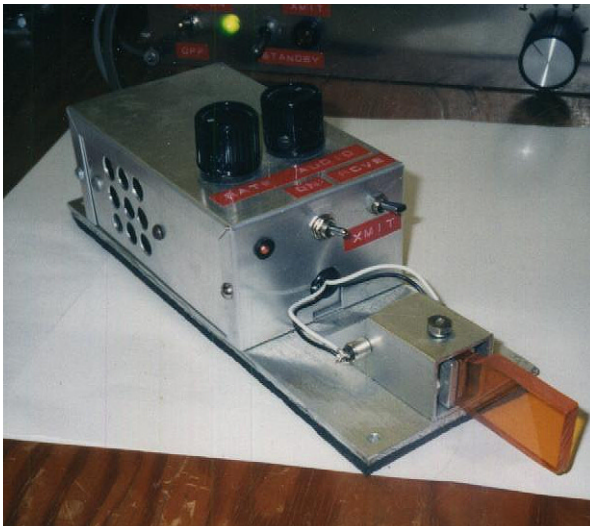
A HOMEBREW ELECTRONIC BUG

No matter how I adjusted the screws and cleaned the burned contacts on my 40 year old mechanical bug, the dots sounded more like static. Of course, if I had bought a quality bug in the first place, it would still be working. While I was trying to get the old bug working properly, it occurred to me that my key was the only part of my rig that wasn't homebrew. Ah ha! - a challenge!

I didn't see how I could build a decent mechanical bug with my limited tools. However, I figured that an all-electronic key that generated both dots and dashes automatically couldn't be too hard. I began prototyping a logic circuit based key on a large plug-in board. I quickly discovered that implementing automatic dashes wasn't so simple. The dashes had to be timed with respect to the dots and there could be no overlap. Moreover, the spaces between dots and dashes should be enforced regardless of how inept the operator might be. I soon had about 20 CMOS ICs wired in a complex mess of logic circuits that nearly worked. But no matter how many more gates I added, I always seemed to have glitches. This was becoming frustrating. Also, my new key was going to end up as a foot-long circuit board. I lowered my sights to building a simple electronic bug built with op-amp oscillators. The new key would have automatic dots, but manual dashes. In other words, it would be the electronic equivalent of a mechanical bug.

A homebrew electronic bug



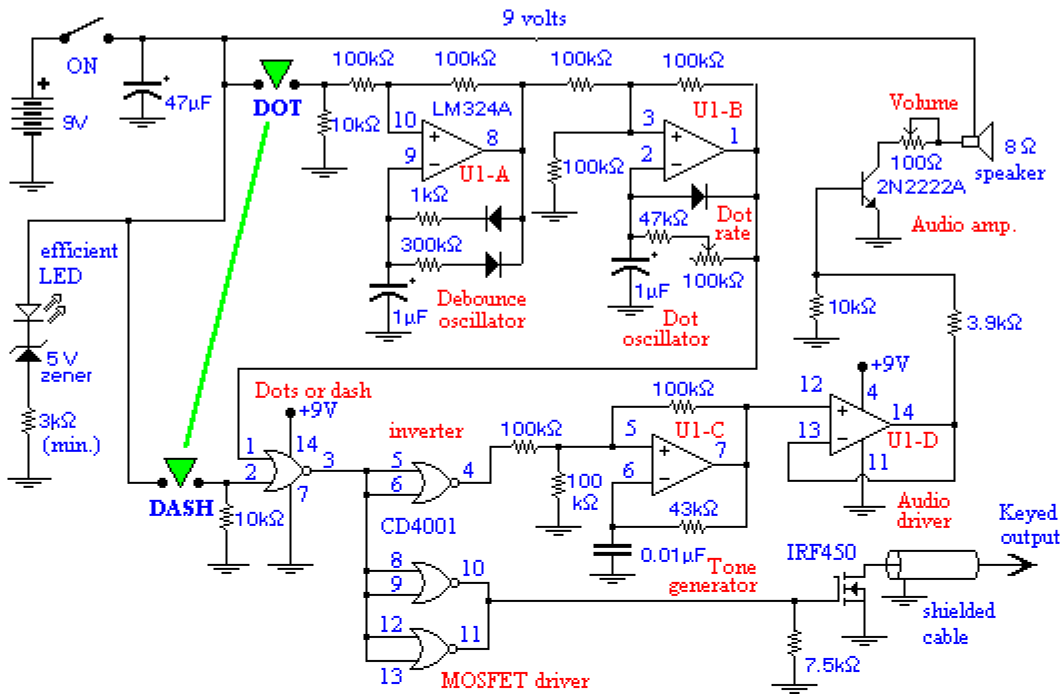
The mechanical parts

The mechanical requirement was to make two momentary-contact, spring-loaded switches controlled by a single paddle. I suppose I could have used printed circuit board switches like the straight key discussed earlier. However, my solution was to use two miniature, push-button momentary switches. The switches can provide both the switching and spring action. I mounted them on opposite sides of a piece of aluminum channel so that the buttons face each other. The back of the plastic paddle arm rests between the two buttons and pushes one or the other as needed. I cut out the paddle from a plastic sheet that I bought at a local plastics shop. By the way, scrap plastic is a great resource for material to make antenna insulators, stand-offs, boxes, etc. The bug is packaged in a commercial aluminum box and screwed onto a thick aluminum plate. I glued a piece of sticky rubber from an old mouse pad onto the bottom to prevent sliding from side to side.

After I got my bug working, I had trouble sending accurately. That is, I kept sending extra dots or half-formed dots. The biggest problem turned out to be insufficient return spring force. I supplemented the spring force of my button switches with coil springs that I stuffed into the aluminum channel on both sides of the plastic paddle. Afterwards I was surprised how much easier it was to send good code.

Another annoyance was that the key kept sliding on the table, so I screwed metal "railings" onto my tabletop to confine the key. The key continued to creep away from me so I finally just screwed it down to the table. Now I can bang away and the key stays put. Good sending is just plain hard. Any advantage you can give yourself is worth doing.

The electronic parts



Circuit Diagram for the Bug

My bug has two unusual features. It has a **built-in sounder** and it can **key any positive voltage to ground up to 400 volts.** The transistor that does the actual keying is a 400 volt N-channel MOSFET power transistor. I built the bug while I was still using a vacuum tube transmitter with a 6146 final. There was positive 300 volts cathode voltage on the key, so I needed high voltage capability. A keying relay would have worked, but after my experience with the old mechanical bug, I didn't want big currents flowing through mechanical contacts. The IRF450 N-channel MOSFET transistor handles any positive signal from 5 volt logic up to several amperes at high voltage. Of course you may use whatever size MOSFET is appropriate for your transmitter.

The built-in sounder consists of a small speaker and an audio oscillator. When I was on the air, I used to listen to my own signal in the receiver. Unfortunately the sound from my receiver was distorted from the transmitter being so close. The distortion led to poor sending. Too much coffee may have been another reason. Anyway, by listening to clean tones from the sounder, my “fist” is likely to be as good as it can be. The sounder can also be used as a stand-alone code practice sender.

My transmitter and receiver are more primitive than commercial transceivers. I still have to turn on the transmitter and mute the receiver manually. To do this more quickly, I installed a small toggle switch on the bug just to the right of the key paddle. The switch is just a contact to ground. Shielded leads connect the switch to both the transmitter and receiver. The ground lead triggers the Transmit-Receive relay in the transmitter and sets the receiver power supply to standby. It isn’t exactly “break-in keying,” but it’s OK for the time being.

Circuit Description

The bug runs on a 9 volt alkaline battery turned on by a small toggle switch. An efficient red LED that light on just one milliampere reminds me to turn it off. When it's time to change the battery, a 5 volt Zener diode in series with the LED makes the LED dim when the voltage gets down to about 6 volts. When not sending, the bug draws 1.2 milliamperes. This means the 550 milliampere-hour alkaline 9 volt battery will last over two weeks if I forget to turn it off.

All oscillators in the circuit are implemented with an LM324 quad op-amp. Op-amps were discussed in more detail in chapter 7. The LM324 is a great old component. It doesn't work at high frequencies like modern op-amps, but that can be a good thing because it doesn't oscillate unexpectedly. And unlike nearly all the old op-amps, such as LM458, LM741 or LM301, the LM324 almost always acts like an "ideal op-amp." It only needs one supply voltage and it rarely surprises you with "practical limitations."

The other component I haven't discussed before are the CMOS logic circuits, specifically the CD4001 NOR logic chip. Logic circuits consist of small arrays of transistors used for making simple binary decisions. For example, if you have two binary (high or low) inputs and you wish to know when either or both of the two inputs is high (a "one"), then these two input lines can be connected to the inputs of a two input "***OR gate***." When either or both lines go high, the output gate of an OR gate will switch from low to high. In this circuit we are using a "***NOR gate"*** which is also known as a "NOT OR gate." These work the same as an OR gate except that when either or both the inputs go high, the output will switch in the opposite way. That is, the output line will drop from high to low. "***AND gates"*** and "***NAND gates"*** are similar except that the output changes only when both inputs go high simultaneously.

The 4000 series CMOS logic gates are also old-tech and quite slow relative to modern CMOS logic chips. The "CD" part just identifies the particular brand of gate. The 4000 number identifies the particular construction technology of the logic gate. These 1970s era parts are immune to interference from RF and tolerate up to 18 volts peak. Modern CMOS is limited to lower voltages and is designed for performing logic at high speed. High speed isn't needed here and just makes the chips vulnerable to interference and self-oscillation.

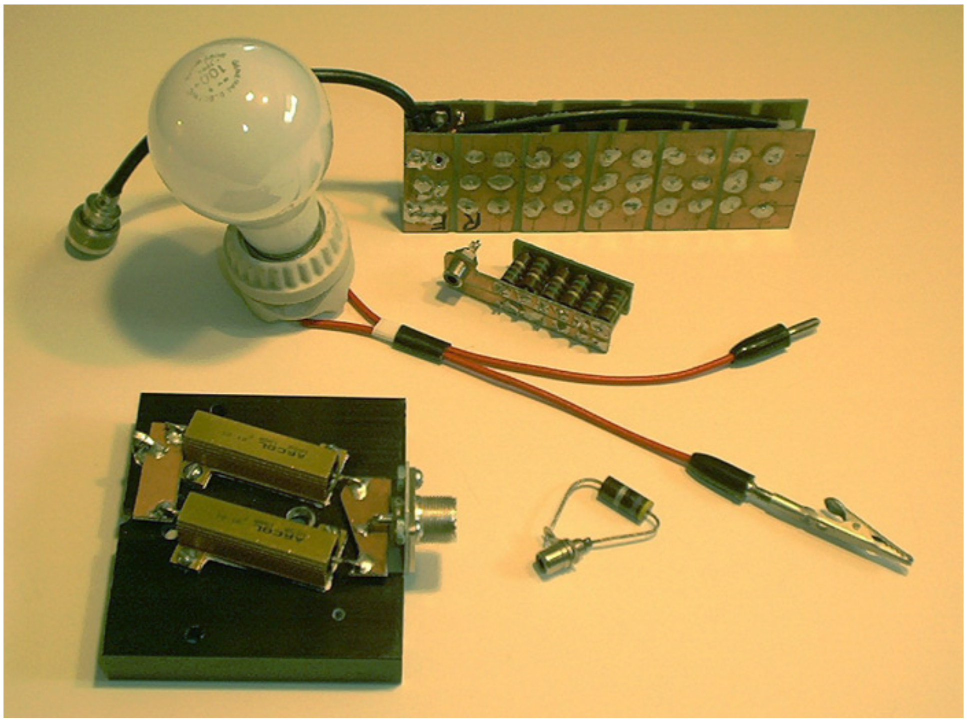
It's necessary to "debounce" the dot key. First I just tried turning on the dot-generating oscillator with the dot switch. Because my timing wasn't always matched to the oscillator speed, and because the contacts didn't always close solidly, the dots often sputtered like my old bug. Referring to the circuit diagram, the dot switch now keys a multivibrator (U1-A). This generates a narrow, repeating pulse that sets the maximum dot rate. The actual dots are formed by a second op-amp multivibrator, (U1-B). The pulses from (U1-A) start a new dot, provided that the second oscillator, (U1-B), is ready to start one. The dot rate is adjustable over a wide range using the 100K pot.

The dots and dashes are combined with a CMOS 4001 NOR gate to make a single keying signal. That is, the NOR gate puts out an output if either a "dot" or a "dash" is present. Two more NOR gates serve as a signal polarity inverter and driver for the keying transistor and for the audio oscillator. The NOR gate output turns on the audio oscillator (U1-C) by pulling up the hysteresis 100K feedback resistor. The audio oscillator in turn drives an op-amp voltage follower (U1-D) and the 2N2222 speaker driver. The audio volume control is simply a 100 ohm pot in series with the 8 ohm speaker.

I've used my bug for three years. I've had hundreds of QSOs with it and replaced the battery about twice a year. Once the paddle began to stick "on," so I had to oil the machine screw pivot on the paddle. Otherwise, the bug has given me good service and little trouble. This is an easy home project because it doesn't involve RF and is almost guaranteed to work.

DUMMY LOADS

A checkout of a homebrew transmitter begins with a low inductance dummy load. Once you are able to deliver a pure, stable sinewave into your dummy load, then you may graduate to an antenna.



Homebrew dummy loads ranging from 2 to 100 watts.

A dummy load is just a big resistor that can stand the power from your transmitter without smoking or catching fire. In order that it resembles a well-designed antenna, the dummy load should be a pure resistance with little accidental inductance or capacitance. Big, non-inductive resistors are pricey and must be specially ordered. That's why most hams buy commercial dummy loads rated for power equal to their transmitter's maximum power. Dummy loads are almost always designed for 50 ohms because that is the standard design impedance for most transmitter amplifiers and many antennas.

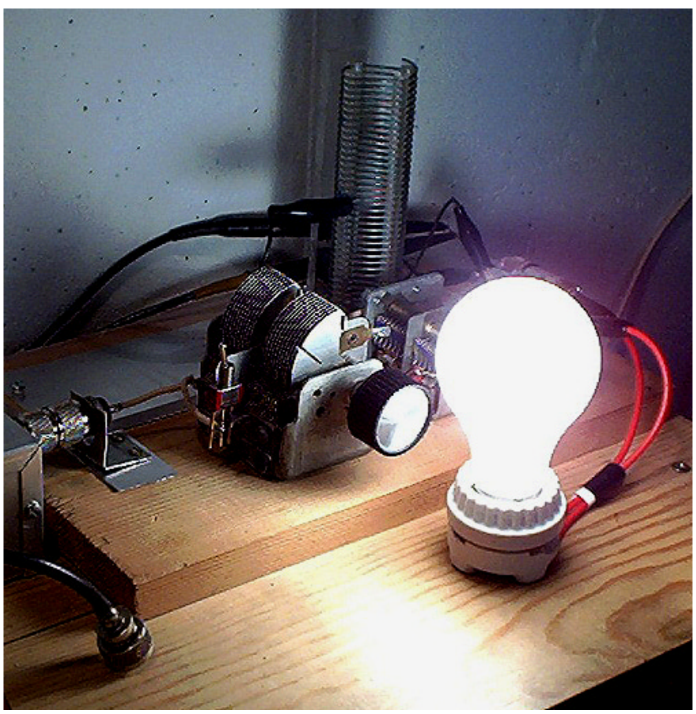
For a QRP, a dummy load can be as simple as a 47 or 51 ohm 2 watt carbon composition resistor. If you don't drive it continuously, five watts won't hurt it. Be careful, though. The heat may not damage the resistor, but it can melt oscilloscope probe tips clipped onto the metal resistor leads. For higher powers, you can build a good dummy load out of arrays of carbon composition or other low inductance resistors.

A dummy load is one of the few simple quality homebrew test instruments that a guy can make for himself in a few hours. A big dummy load resistor can be made from an array of low power, low inductance resistors. Metal film resistors and carbon composition resistors usually have low inductance and make good loads. For example, I happened to have a whole package of old 1 watt, 150 ohm carbon composition resistors. By placing them in the appropriate series/ parallel arrangement I made a 10 watt, 50 ohm dummy load. If you need a 50 watt dummy load, it can be made from an array of 25 two watt resistors. You will have to be clever selecting the resistance and arranging them so that the final resistance is 50 ohms.

For high frequencies, like the 10 meter band and above, it is important to use a low inductance connection with the resistance. Therefore, the leads into the dummy load should be coaxial cable. I used circuit boards with wide traces to connect the individual resistors in an array. In the large load it was also necessary to connect one end of the array to the other internally. I first used a simple wire for this and it had significant inductance. I replaced with wire with a grounded piece of coax and the inductance disappeared.

Beware of high power, "low inductance" resistors

I bought a pair of supposedly "low inductance" 100 ohm, 50 watt resistors. I put them in parallel and mounted them on an aluminum heat sink. They should have made a terrific high power dummy load. Alas, there was considerable inductance in these resistors and, even in parallel, at 14 MHz they had twice the impedance I expected. In summary, this big dummy load is useful, but it isn't 50 ohms.



Light bulbs as dummy loads

An ordinary filament light bulb can work as dummy load. They are far from ideal and should not be your only dummy load. However, they do have advantages: They are fun to use and great show-and-tell devices. However, at less than 100 watts, their impedances are much higher than 50 ohms and the impedance rises as they get hot. On the other hand, if you need a dummy load that simulates a high impedance antenna, then a light bulb is useful. Also, if you’re checking out a power meter, a light bulb gives an obvious indication of when the power output is maximum. Also, when a 40 watt bulb shines at full brilliance, obviously it is dissipating approximately 40 watts.

Similarly, Christmas tree light bulbs can be useful for checking out QRP transmitters.

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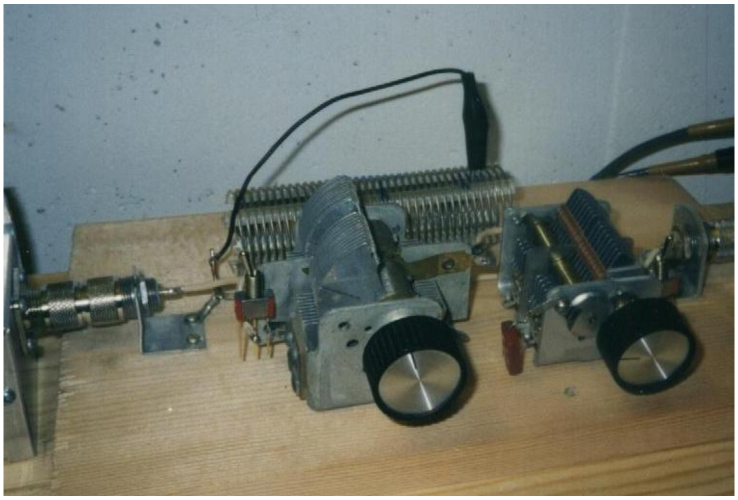
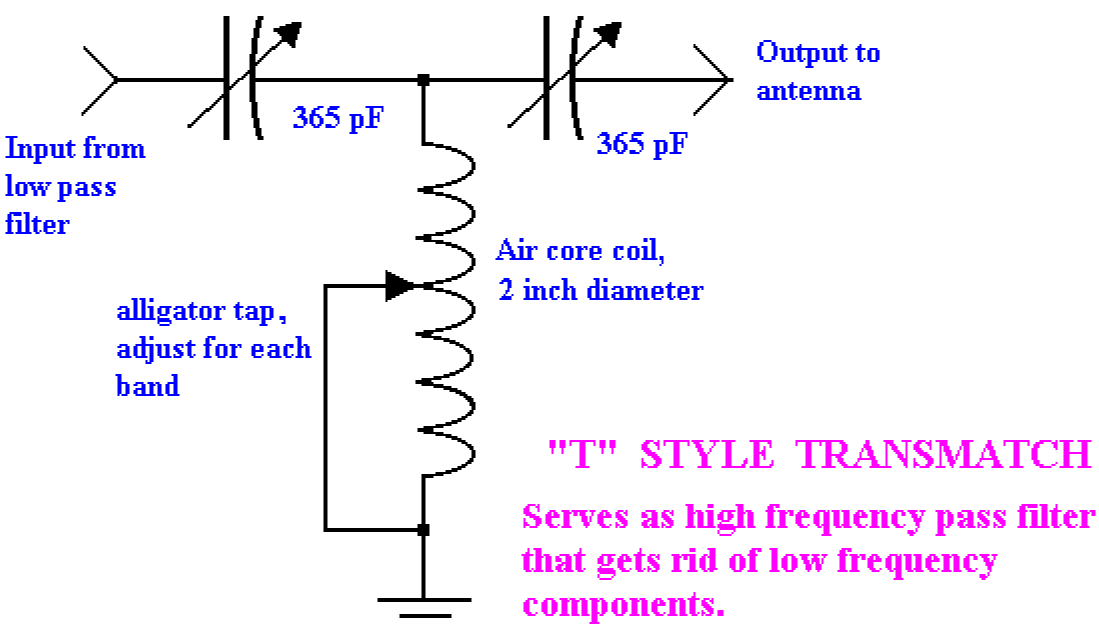
BUILDING A "T- MATCH" ANTENNA COUPLER

Modern transmitters are usually designed for 50 ohm antennas. The Chebyshev output filters found in modern transmitters only work at this design impedance. When you load them with a mismatch, you won't believe the scrambled waveform that comes out. In other words, they only filter properly at 50 ohms. Unfortunately, real antennas are usually higher or lower impedance and need some form of impedance transformer to make them appear as a 50 ohm load to the transmitter.



Old vacuum tube transmitters usually had built-in antenna couplers, but none of the transistorized designs in the ARRL annual handbooks have couplers. So after I built a transistorized transmitter, I needed an antenna coupler. The coupler designs in the handbooks were complicated with all-band capability and built-in power / SWR meters. They're nice, but I wanted to get on the air fast. I consulted Bob, NØRN, for advice. Bob had built several couplers and he thought a simple T-Match was best. It just consists of two variable capacitors and a variable inductor.

A Simple T-Match Antenna Coupler



How it works

The idea behind the T-Match is to resonate the variable capacitor on the left with the inductor to ground. When tuned to resonance the oscillation produces sinewave voltages across the L and C that can be much larger (or smaller) than the sinewave voltage that arrives on the input. Because the voltage across the inductor can be huge, the coupler can “match” the impedance of a high impedance antenna. The oscillating L and C work like a transformer, stepping the voltage up or down. For example, to drive a 300 ohm antenna, the impedance of a 50 ohm transmitter output will have to be made to "look like" it's six times higher in order deliver the same power. For this to be true, the voltage across the antenna will have to be 2.5 times higher.

The variable capacitor on the right is not nearly so critical. You will find that for most situations keeping the capacitor at full capacitance, 365 pF, produces the best signal. Sometimes I can get a little better sinewave output or slightly more amplitude by adjusting this capacitor. But usually, I just leave it alone. For the lower bands, 80 and 160 meters, you may need to add more capacitance in parallel with both capacitors using switches. My variable capacitors are dual section types from old broadcast radios. I use small toggle switches to add the capacitance from the second sections. In addition, the right hand capacitor has a fixed 1000 volt, 200 pF mica capacitor across the second section so I have plenty of coupling capacitance for 160 meters.

Packaging

My friend Bob showed me a T-Match he had built in a wood and plastic box.

“Why didn’t you use a metal box?” I asked.

“Oh, wood was easier and it doesn’t matter,” explained Bob. “Maybe I get more RF radiation here in the shack, but otherwise, there’s no need for a metal cabinet.”

I was anxious to get on the air, so I rummaged through my junk and came up with two dual section 365 pF broadcast radio variable capacitors. One of them was out of a 1935 radio. I thought using an ancient component had nostalgic charm. I also found a big piece of open “Air Dux” coil I could use for the inductor. I made the inductor “variable” by using an alligator clip to short out the unwanted length of coil. For RF connectors, I used SO-239 UHF connectors from Radio Shack. After an hour’s work I had screwed all the parts down onto a pine board and I had a T- match.

Improving performance on the higher bands

I originally used a simple 12 gauge wire connecting the grounds on the input and output connectors. This simple wire looks like a significant inductor on 17 meters and above. This small inductance can occasionally make loading difficult or impossible with some antennas. I replaced the wire with a low inductance, 3 inch wide sheet of metal and the difficulty largely disappeared. Try to maintain at least a half an inch of spacing between this ground sheet and your coil. Another modification that was helpful was mounting the coil vertically. This minimized the capacitive coupling between the coil and the sheet metal ground plane. I used clear plastic and epoxy to build brackets and insulate the bottom of the coil.

I tested the coupler by using a few ordinary light bulbs as dummy loads. Bulbs have a wide range of resistance, depending on the wattage and how hot the filament happens to be. The T-Match worked great and the bulbs burned brightly. It worked just as well on my real antennas, so I went on the air and began working folks right and left. So, if you just want a coupler that works, the story is over now. If you like, you may stop reading.

The T-Match as an aid for receiving on 80 and 160 meters

One surprise from this project was that my T-Match has become vital for receiving weak signals on 80 and 160 meter ham bands. These lower bands are quite close to the standard broadcast AM band, (550 – 1700 KHz). As you know, these stations are extremely powerful – as much as 50,000 watts. If you have such a station within 50 miles, or a less powerful station close to your house, there will be big RF voltages riding on your antenna at all times.

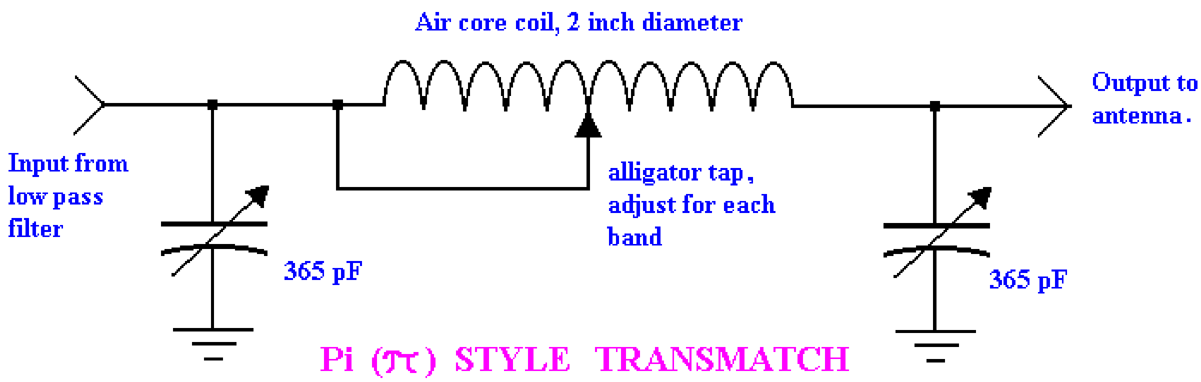
With these AM elephants bellowing in my neighborhood, my home-built receiver had trouble filtering them out and hearing the low power ham stations hundreds of miles away. The front end of a receiver can be easily overwhelmed and this problem may not be obvious. I couldn't hear the AM broadcasts in my headphones but the ham bands were mostly static and I didn't know there were any ham signals present. But when my receiver shared the antenna with the transmitter, the signal strength of the weak signals on the low bands peaked dramatically when the T-Match was properly tuned for the transmitter. The T-Match serves as a “high pass” filter that reduces the signal strength of the broadcast stations dramatically. Not only was I suddenly hearing dozens of CW stations on 80 meters, I found myself working QRP stations halfway across the country. I didn’t know that was even practical.

Using the T-Match on receive has another benefit. Since my receiver is designed for a 50 ohm input, when I peak the received signal strength using the T-Match, the 50 ohm transmitter is also (nearly) perfectly matched. So on any band, before I try to load the antenna with my transmitter, I peak the received signals with the T-Match.

Adding the whistles and bells

The interesting part of the T-Match story is what happens when you add the refinements - you know, the metal case, the power meter, and all that. After I had used my primitive coupler for a while, I wanted something more impressive. I already owned a metal enclosure that was about the right size. It took me considerably longer than an hour to build another coupler, but eventually I had a professional-looking T-Match in a metal box. I tried it out and ... it didn’t work worth a darn. It couldn’t match much of anything. It seemed to be a wonderful standing wave generator, but a poor antenna coupler.

I consulted Bob about my problem. He nodded knowingly. “Oh, yeah. It doesn’t work in metal cabinets. That’s why I used wood and plastic.” Now he tells me. “However,” he went on, “you could convert the coupler to a ‘π match.' That should work in a metal box since the capacitors go directly to ground and the accidental capacitance to the metal case will become part of the circuit. Also, you could use a powdered iron core inductor. The magnetic flux is confined to the core, so powdered iron cores work well in small metal enclosures.”



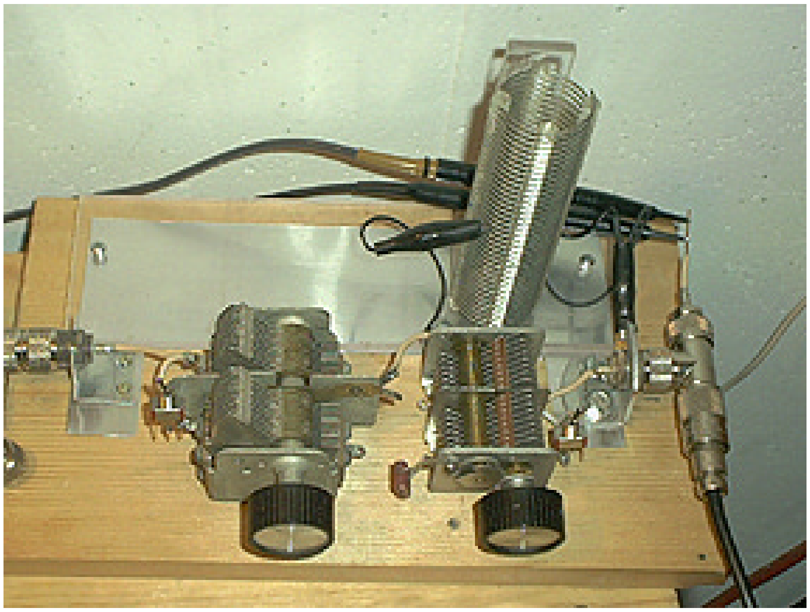
The π - Match

I tried out these ideas. Yes, I got the π to work, but I learned that the T-Match was better. If you examine the π-Match circuit, you'll see it is a low pass filter. That is, the high frequency noise gets shunted to ground through the capacitors, while low frequency components pass through the inductor. I was already using a low pass filter to suppress TVI, so the π-Match was redundant. When I used the π-Match I noticed the output waveform usually had low frequency, "roller coaster" distortion and sub-harmonic modulation on it that resembled AM modulation. In contrast, the T-Match serves as a high pass filter that removes these distortions. In fact, the low pass TVI filter and the T-Match work together as a band pass filter to maintain a pure sinewave.

I found a powdered iron core in my junk box large enough to handle 100 watts and I wound a multiple tap winding on it. Yes, the powdered iron core inductor worked, but it became hot and was clearly inferior to the air core. Since I didn't have any data on the core I was using, I ordered a big new core from CWS Bytemark with known properties. I bought a CWS (Amidon) T200-6. Sure enough, it heated up too. Long live air-core inductors!

My other experiment was built-in power meters. I installed dual meters for forward and reverse power. Cool, huh? Too bad they worked so poorly. The meters were voltage sensitive rather than power sensitive. For example, they read twice as much "power" into a 100 ohm load as into a 50 ohm load. I knew the meters weren't correct because all the other data I had from my oscilloscope, DC power input to the final, etc., all told me that the power into 50 ohms and 100 ohms should have been equal. I discovered I could compensate for this error by placing the power meters on the transmitter side, the 50 ohm side, of the antenna coupler. That way the voltage was constant for the same power level.

I soon retired the fancy coupler to the junk pile and I'm still using the piece of wood with the 1935 capacitor. (Now you know why I have so much junk.) In order to monitor my output power and frequency purity, I monitor the input to the antenna with scope probes going to a frequency counter and to an oscilloscope. The scope and the frequency counter readout are far more sensitive to the problems of a homebrew rig than an SWR meter will ever be.



The T-Match monitored by oscilloscope and counter probes. The low pass filter is on the left. The antenna coaxial cable exits on the right.

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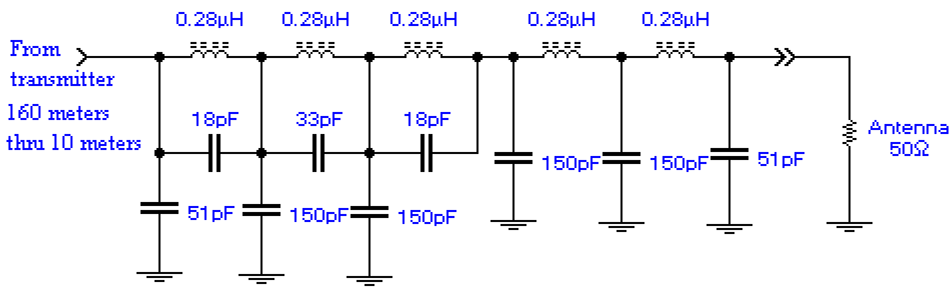
BUILDING A LOWPASS FILTER

Back in 1997 I carried my old vacuum tube HF transmitters down from the attic and looked at them critically. Hmmm ... Class C output stages. Class C equals harmonics. I hadn't been on the air in 30 years, but I knew from studying for my new license that spectral purity standards were higher than they used to be. At the very least, if I used my ancient transmitters, I would be risking TV interference (***TVI***) complaints from the neighbors. Consequently a transmitter lowpass filter became my first project.

I'm told that today hardly anyone with a modern transceiver needs or uses lowpass filters. However, if you do any homebrewing, especially with Class C or Class B output stages, a lowpass is a good idea. When placed directly on the transmitter output, I've found that the filter doesn't reduce power output and it doesn't make the antenna hard to tune, even when operating QRP. I think of my lowpass filter as "insurance" against angry neighbors and pink slips. So why not use one?

Your first question probably is," Do I need one for my little 5 watt QRP?" The answer is, "Probably not." However, as soon as you get complaints, your neighbors will eternally label you as the cause of every bit of snow on their TV screens or virtually any problem with their sets. Once the complaint syndrome begins, being "legal" and "meeting FCC requirements" aren't enough. It is much better to do everything you can to be sure the neighbors never realize that you might interfere with their TVs.

Electrical Design of the Filter

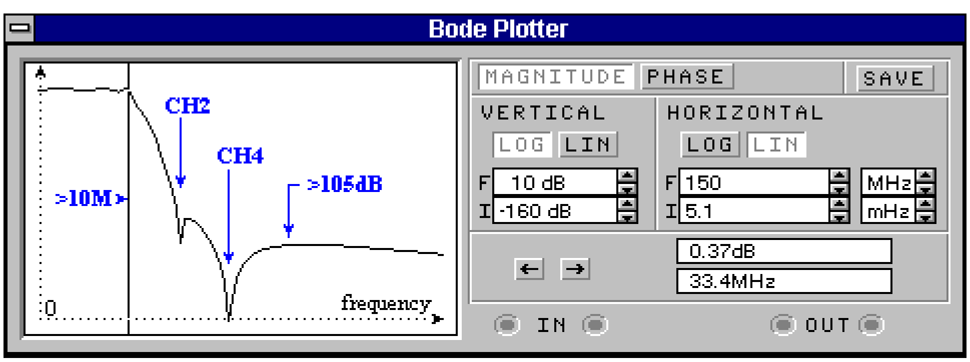


A five-stage lowpass filter

I started with a three stage elliptic lowpass filter from the good-ol' ARRL handbook. Later I acquired a "Spice" program for analyzing circuits, Electronics Workbench. I turned it loose on my lowpass and settled on the circuit shown above. The capacitors to ground tell us this is a lowpass filter. In other words, the capacitors shunt high frequencies to ground that might otherwise radiate in the TV bands, while lower HF frequencies will pass through the filter via the inductors. This filter is designed to pass all the ham HF bands from 10 meters (30 MHz) and below. As you will see shortly, it attenuates all frequencies above 10 meters.

Notice that there are 33 pF and 18 pF capacitors across three of the inductors. Each inductor is part of an LC resonant trap that appears as a high, series impedance to TV channels 2 and 4. However, the higher channels are also attenuated at least 105 dB. The main lesson I learned from Spice was that component values are surprisingly tolerant. I had used Chebyshev filter tables that have values to 4 decimal points and sophisticated "bell curves" for the different component values. That elegance made me think filters had to be precise. Wrong! Well, that's what Spice and my experience tells me. Notice that I made all the inductors identical and use only two values of capacitors to ground.

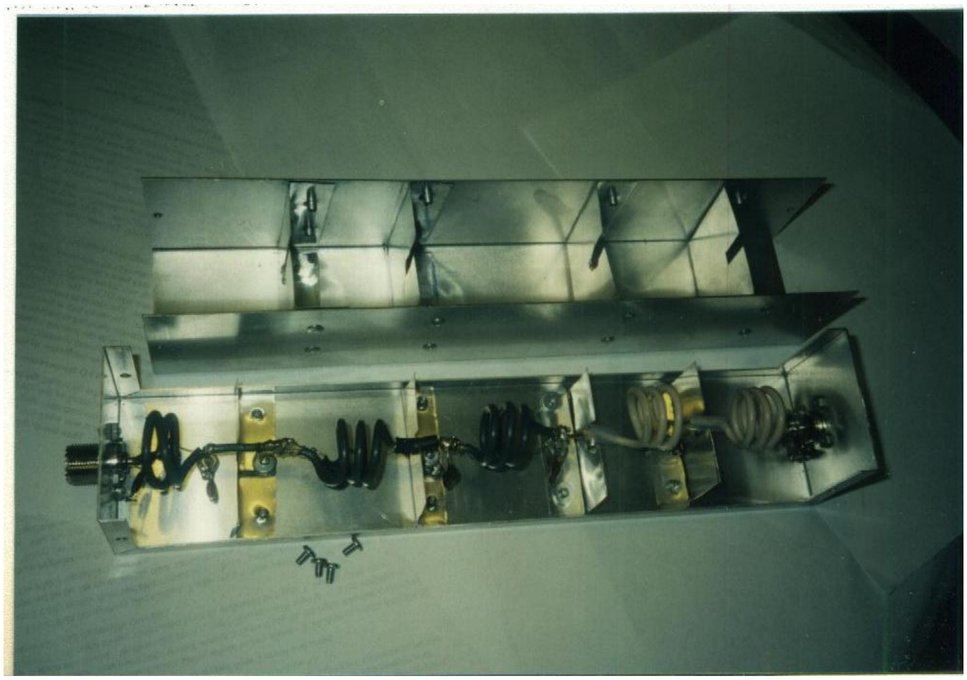
Like all complex reactive filters, this one is designed for specific impedances, in this case 50 ohms. That means that the filter only works correctly when the input and output impedances are 50 ohms. For that reason, it's inserted into the antenna line right after the transmitter and just before the power meter and antenna coupler. The antenna can have any impedance from near zero to hundreds of ohms, so the coupler serves as a transformer to match 50 ohms to whatever is needed.



Lowpass filter Bode plot

Construction Details

The filter is housed in a long, skinny aluminum box. Capacitance to ground is part of the design. Therefore, provided the leakage capacitance between the coils and the metal box isn't extreme, this stray capacitance won't degrade the performance. Just keep the coils at least 1/2 inch away from the grounded metal walls and the filter will work well. I used air core inductors, which meant that I had to rivet four pairs of overlapping metal partitions into my box to prevent coupling between the five coils. Without the metal shields, air core inductors would couple to each other like transformer windings. I prefer air core because simple coils don't dissipate significant energy. I'm also cheap.



Inside view of the filter. Each coil is isolated from its neighbors by notched partitions.

I wound my coils out of 12 gauge insulated copper wire stripped from Romex household three-conductor wiring cable. If you follow the dimensions in Table 1 exactly, you should get about the same resonant frequencies I did. Depending on the shape of your box, you may use either large coils with 2 turns or smaller diameter coils with 3 turns. The inductance will be about the same. The important issues are that the three LC traps should resonate well above the 10 meter band and there should be no significant attenuation below 30 MHz.

Table 1. **Air core inductor specifications**.

	turns	**diameter**	**length**	**inductance**
	2 turns	1.25 inches	0.5 inch	0.28 microhenries
or,	3 turns	1 inch	0.75 inch	0.28 microhenries.

How to measure air core inductance

How did I know when I had 0.28 microhenries? I calculated what the resonant frequency should be for 0.28 microhenries and a convenient fixed capacitor. I wound a coil, put the capacitor in parallel, and put the LC circuit across a frequency generator output. Using an oscilloscope to watch the voltage, I adjusted the frequency to find the resonant peak and then rewound the coil until it peaked at the calculated frequency.

The inductors could also be wound on powdered iron cores. An advantage of powdered iron is that the magnetic flux is confined in the cores and you can cram the filter into a smaller metal box without metal shields between filter sections. However, powdered iron core inductors will still have stray capacitance to ground.

All capacitors should be mica and capable of handling voltages consistent with your power level. If you're running more than 100 watts, it would be prudent to use capacitors with working voltages of 1000 volts or more. I used 500 volt caps with my 100 watts and so far haven't had any capacitor failures. Two identical 500 volt caps in series will give a working voltage approaching 1000 volts, but of course the effective capacitance will be half the value of each. Use real RF connectors on your filter, UHF SO-239 or equivalent.

Testing the filter

I tested my filter by terminating it with a 50 ohm load and then running an RF signal generator through it. There was no significant attenuation or distortion of the sinewave from 160 to 10 meters. Above 10 meters the output signal dropped to almost nothing. Similarly, when I loaded lightbulbs and 50 ohm dummy loads on all HF bands, 80 through 10 meters, I could see no differences with or without the filter.

So far, my only TVI complaints have been from my own family. On 15 meters, they see minor flickering on the picture. Not surprisingly, 17 Meters bothers channel 4 (4 x 18 MHz = 72 MHz) and 30 meters tears up channel 6 (8 x 10.1 MHz = 80.8 MHz.) I believe my biggest remaining TVI problem is my open-chassis transmitter with the PC boards exposed to the breezes. Obviously I need a cabinet.

When we bought a modern TV, all my interference problems vanished. Fortunately, modern TV designs and the increasing use of cable TV, Direct TV satellites, and 2.4 gigahertz digital cell phones, makes annoying the neighbors less and less likely. Considering that we are in "The Wireless Age," the future of our TVI problems looks surprisingly bright.

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STAYING LEGAL WITH HOMEBREW TRANSMITTERS

On Field Day I watched while up-to-date hams tuned up their rigs. I was amazed by how casually they assumed their signals were matched to the antennas and not suffering from rough CW tone, harmonics, or drifting frequency. They plugged beam antennas and dipoles directly into sophisticated transceivers and were instantly in business. I didn't see any antenna couplers, power meters, low pass filters, dummy loads, oscilloscopes, frequency counters, or any of the tools we homebuilders use to stay legal.

Investigate before you radiate

Many hams these days are building QRP transmitters. Before they go on the air with a homebrew transmitter, they should learn how to check it out. Out there on the bands are Official

Observers who send out little white SWL (Short Wave Listener) cards. Nine years ago when I got back on the air with my homebrew, vacuum tube antique, I quickly got an OO card from New Jersey. OO cards are *NOT* suitable for framing. The card informed me that my CW signal was drifting and had an obnoxious tone. Very embarrassing! Don't just go on the air and hope everything is OK. ***Investigate before you radiate!***

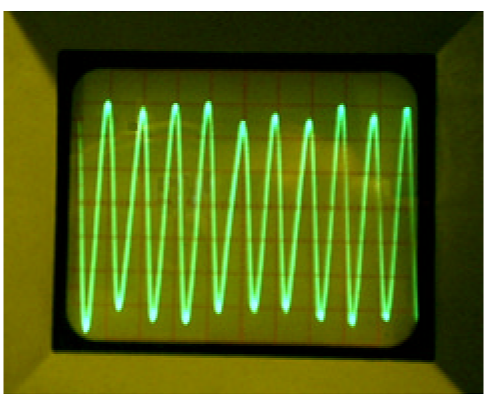
Listen to your own signal

A good way to find out how your signal would sound to another station is to load a dummy load then listen to it with your receiver. I routinely use an old Collins receiver for this purpose. The tricky part is desensitizing the receiver so that the signal strength simulates a signal on the air. I did this by shorting a coax connector and plugging it into the antenna jack on the back of the receiver. I also clamped ferrite blocks on the line cord and speaker wires to help keep RF out of the receiver cabinet. After I made these changes, the signal was sufficiently weak so I could hear any key-clicks, rough note, or "warble" instabilities. Now I could understand what my contacts were complaining about.

My 1967 homebrew transmitter was a mobile unit with a switching power supply. No matter how I filtered the supply, I couldn't get rid of the switching hash. The hash was extremely hard to see on the oscilloscope, but in the receiver, I could hear a distinctly rough note. No wonder I kept getting those 598 reports!

Oscilloscopes

In my opinion, an HF transmitter would be hard to build without a quality RF oscilloscope. Looking at the waveforms on a scope makes it easy to tune up a stage, or at least to get the tuning approximately right. When I operate, I keep a 10:1 scope probe right on the antenna feedline. That way, there's no question about what's being transmitted. A typical probe is rated for several hundred volts and has one megohm load resistance and five picofarads capacitance. This shouldn't bother your tuning and your transmatch can compensate for any slight mismatch.



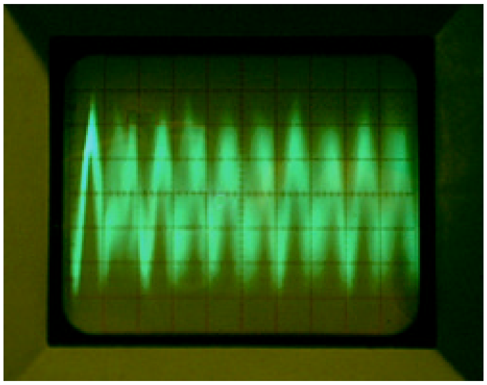
Usually on the lowest HF bands, like 80 and 40, you'll see a truly perfect sinewave on your antenna. But the higher the frequency, the less perfect the waveform will probably be. The 30 meter signal on the left is sharply focused, but it has a bit of low frequency modulation. This is quite all right.

A well-tuned 30 meter CW signal on the antenna lead

Beware of blurs

On the other hand, the 30 meter signal shown below is mistuned. Notice how only the first half sinewave is synchronized. After that, the waves are a blur of different, overlapping frequencies. Also, the reading on your frequency counter will usually be low and out of the desired band.

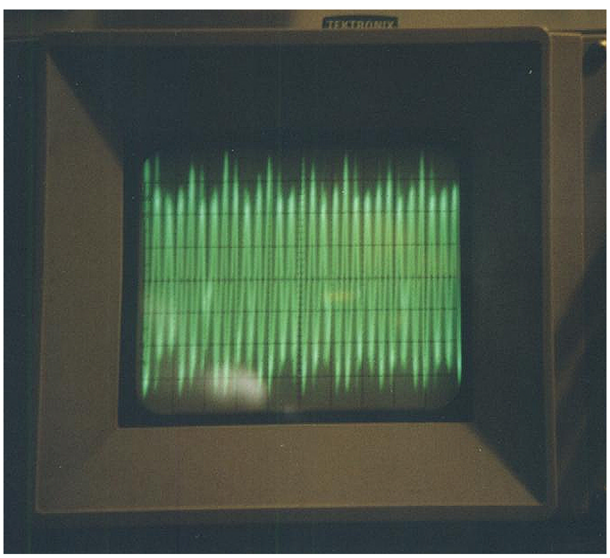
Usually tuning the transmatch instantly corrects this.



A poorly tuned 30 meter CW signal

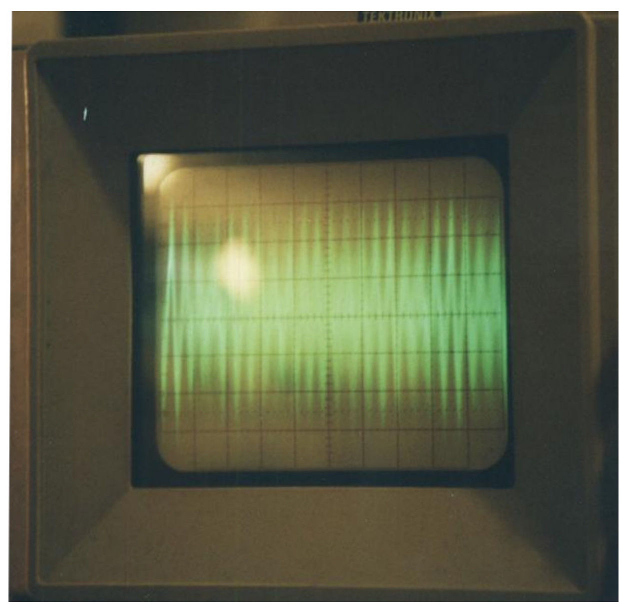
Look for the zero crossings

At even higher frequencies, like 15 and 10 meters, your sinewave may have more low frequency modulation and be slightly blurry as illustrated below. The higher the frequency, the more difficult purity becomes. Also, above 20 meters it becomes increasingly hard to know what's artifact from the oscilloscope and probe and what's actually going out the antenna. ***A reliable indication that all is well is when the picture focuses sharply enough to see the zero crossings clearly.***



An adequate signal on 10 meters

In contrast, the 10 meter signal shown below is too blurry. Tune your transmatch!



Tuning for maximum power out

I tune my transmatch for maximum amplitude of a sharply focused sinewave at my antenna lead. This gives me an approximate measurement of antenna impedance. For example, suppose I first I load my dummy load on 80 meters and get about 50 watts. Next I try to load my 40 meter dipole on 80 meters. Using the transmatch, it loads up and produces a sharp sinewave. Unfortunately, the 300 volts peak on the coax with a 50-watt signal suggests really high antenna impedance, about 900 ohms. If the antenna looked like 50 ohms, I would see about 70 volts peak. In my experience, with a match that poor, it may be safe for the transmitter, but nobody will hear me.

Measuring transmitter power with an oscilloscope

To measure the power output of your transmitter into an antenna or a dummy load, you can look at the RF voltage across the load with an oscilloscope. RMS power is the heating value of the electric current. That is, one watt RMS equals one joule of energy per second. Hams usually use RMS power instead of peak power or other possibilities. To find the power we first need to measure the RMS voltage of a sinewave. You can measure the peak voltage by counting the grid squares on the screen. Then, to get the RMS voltage, you divide the peak voltage by the square root of two. For example, suppose the RF sinewave on the screen is 100 volts peak:

$$100 \text{ volts Peak} / \sqrt{2} = 100 \text{ volts} / 1.414 = 100 \text{ volts} \times 0.707 = 70.7 \text{ volts RMS} .$$

Rather than calculating the square root of 2 or its inverse every time, you can proceed more quickly by remembering the factors 1.414 and 0.707. For example, suppose the RF voltage seen on the oscilloscope screen is 100 volts peak, then the RF power delivered to a 50 ohm antenna or dummy load resistor would be:

$$\text{Power} = I_{RMS} \times V_{RMS} = (V_{RMS} / \text{Resistance}) \times V_{RMS} = (V_{RMS})^2 / \text{Resistance.}$$

In this case, Power output = $(70.7 \text{ volts RMS})^2 / 50 \text{ ohms} = 100 \text{ watts}$.

Peak Envelope Power (PEP)

The U.S. government regulations for ham radio operates limit the power we can use to a specified amount of "***Peak Envelope Power***." This varies with different hambands and class of license. As examples, on 30 meters we are only allowed to use 200 watts PEP, but on 20 meters, 1,500 watts PEP is permitted.

PEP is defined as "the average power supplied to the antenna transmission line by a transmitter during one RF cycle at the crest of the modulation envelope taken under normal operating conditions." In other words, it is the peak RMS power for the highest part of a modulated waveform. So, if you were operating with single sideband phone, the measurement with an oscilloscope would measure the highest peak voltage seen on the scope multiplied by 0.707. Then, just as we did above, we would square this RMS voltage value and divide by the impedance of the antenna, e.g. 50 ohms. A CW transmitter output is measured the same way.

An oscilloscope for HF ham work should be rated for at least 50 MHz. A brand new oscilloscope like this will cost at least $2,000, but is not a good value. My Tektronics 5441 scope originally sold for $11,000 in 1976. Today that scope or equivalent ones can be found used in electronic surplus stores or mail-order catalogs for $400 or less.

An FM radio will detect serious frequency impurity

A serious splatter problem (noise mode) will make a roar of static in your FM radio. On the other hand, sometimes the FM radio just cuts out and goes silent. That may not be a transmitter problem. It could be that the radio's IF is just overwhelmed by your signal. Alternatively a harmonic of your transmitter frequency might happen to line up with your FM station and obliterate it. Again, the FM radio just goes silent.

DC power supply ampere meter

It is always nice to know how much current the transmitter is drawing. Linear amplifier stages run at roughly 50% efficiency, while the transmitter circuitry as a whole will be somewhat less than that, say 40%. DC current is another indication of the SWR (Standing Wave Ratio). That is, SWR describes how well your antenna is tuned. When operating correctly, 50 watts output should draw about 8 to 10 amperes at 12 volts. If it reads 15 or 20 amperes, it means you are way out of tune and the final amplifier is heating rapidly.

A typical HF frequency counter

Frequency counters

The most persistent problem a homebrewer faces is frequency drift. Commercial transceivers use frequency synthesizer chips slaved to unusually stable crystal oscillators. They also have built-in displays that read frequency to a fraction of a Hertz. This amount of precision is almost never justified by the specifications. But hey! The guy you're talking to hasn't read the specs on his transceiver and he believes his readout is gospel. Since we homebrewers just use simple, free-running oscillators, we drift and our contacts notice.

When I operate, I have two scope probes on the antenna line. One goes to the scope and the other goes to a frequency counter. A good counter is vital because most of the frequencies you must measure are too close to the edge of the ham band to simply count squares on the oscilloscope screen. When the transmitter is operating properly, the counter display is solid to within 10 Hz and doesn't dance around. The same conditions that cause blurry sinewaves on the scope cause the counter to read low and jump about. For example, if you are loading up on 15 meters and the counter reads something like "20.6XXXX" with the last few digits changing every second, you are mistuned. Don't be satisfied until the counter reads what it should and stays there. That is, you should see a relatively solid reading of a legal frequency, like "21.120XX." Counters can be a bargain if you buy them used. My used Hewlett-Packard counter originally sold for about $2000, but I paid $60 for it.

Lowpass filters

When operating homebrew equipment it's a safe bet you will occasionally generate out-of-band harmonics, especially while loading your antenna. A lowpass filter is simple insurance against generating interference above some design frequency. Another way I minimize the out-of-band noise problem is to keep a chart of the transmatch settings for each band tacked up on the wall. So when I switch bands, the transmatch is already fairly well adjusted before I key the transmitter.

Not so useful instruments

Power meters I have not found power meters particularly useful. I have a commercial one that gives readings that correspond well with the light produced by a light bulb dummy load. My homemade power meters aren't that good. The difficulty is that power meters only tell you the total power delivered to the antenna. I need to know more than that to avoid bad signal reports and OO cards.

Grid dip meters In the old days we used "grid dip meters" for frequency measurement. A grid dip meter measures the frequency of a resonating coil by placing a secondary coil next to the target coil. RF currents induced into the coil produce a drop or "dip" in the meter reading when the tuning knob on the meter is tuned to the resonating frequency. The approximate frequency is then read off the dial. Grid dip meters aren't at all accurate, but they got us onto the right ham band. Today's inductors are usually wound on powdered iron toroids. Grid dip meters don't work well on toroids because the magnetic field is trapped inside the closed loop. There is practically no leakage outside the toroid for the grid dip meter to tap into.

Spectrum analyzers A spectrum analyzer would be great for homebuilders. They measure the purity of transmitter signals by graphing all the frequency components. Pictures of analyzer displays are often shown in homebrew transmitter articles. Unfortunately, even a used spectrum analyzer with sufficient precision is pricey - many thousands. Since I can't afford one, they don't do me a bit of good. Without this tool, I have to "interpret" what I see on the oscilloscope and the frequency counter. Fortunately, that isn't hard.

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ANTENNA RELAYS

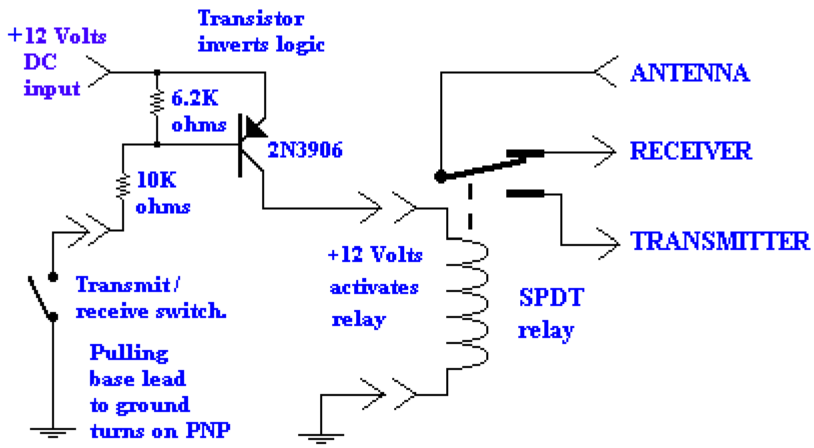
Switching from transmit to receive

If you simultaneously connect both your receiver and your transmitter to the antenna, you may burn up the front-end stages of your receiver when you transmit. When you first go on the air with your QRP transmitter, you will no doubt be irritated by the need to use a separate antenna for the receiver. A clumsy solution would be to rig up a manual switch to move the antenna back and forth from transmitter to receiver every time you stop sending. That's inefficient, to say the least. If you have to throw more than one switch to go between send and receive, you will be at a huge disadvantage when trying to work DX or in contests. Actually, even one switch is not up to modern standards.

Modern transceivers have "break-in keying." When they stop sending, the receiver instantly comes back on instantly and automatically. Non-homebuilders aren't even aware that switching antennas is a problem. I haven't yet mastered building break-in keying and still use one switch to go from send to receive. Even so, by the time my receiver comes back up after transmitting, I usually only hear the last three or four characters of my call sign from my contact, "…IYE". The other guy has already switched over and sent "KØ" before my receiver was back on the air. As you can see, one switch operation is the bare minimum.

Requirements for an antenna relay

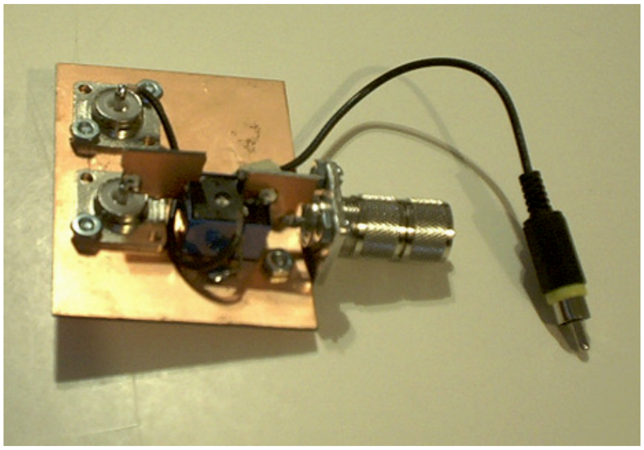
An antenna relay is usually a ***single-pole, double-throw*** switch, sometimes called ***SPDT***. The external antenna line is connected to the moving contact. This contact is normally resting against the receiver contact. When the relay is activated, the moving contact switches over to the transmitter contact.



Schematic of antenna relay The optional transistor inverter turns on the relay with a high impedance line switched to ground.

Unfortunately, ordinary relays have too much inductance on 10 meters. Inside the relay RF current must travel through a length of wire perhaps one or two inches long. This wire is not a coaxial transmission line or a wide, low inductance strip. The result is that ordinary relays often work poorly on 10, 12, and 15 meters. By "poor" I mean that no matter how you adjust the antenna coupler, you can't quite deliver a sharply focused sinewave to the antenna. (See the above article on checking out homebrew transmitters.) In fact, the final amplifier may remain in "noise mode" and not produce a sinewave at all. You can demonstrate that the problem is the relay by bypassing it and connecting the final amplifier directly to the lowpass or to the antenna coupler. Once the relay is out of the circuit, you will often find that the problem is cured and the antenna coupler will load the antenna just fine.

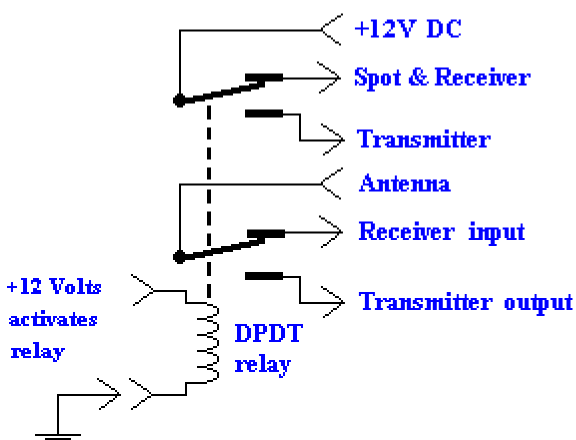
There are, of course, commercial coaxial cable relays to solve this problem. I built a usable antenna relay out of a *TINY* 10 amp relay rated at 120 volts AC (Radio Shack Part # 275-248A). The important specification is the "tiny" part. Since the relay is miniature, the wires inside the relay are very short. I kept the external transmitter RF leads as short as possible by implementing the "wires" with little, low-impedance rectangles of PC board. The connections only have to travel about 5/8 inch from the center conductors of the SO-239 RF connectors to the relay pins.



Homebuilt antenna relay

The receiver antenna connection is not nearly so critical. Therefore it was implemented with a three-inch length of RG-174 coaxial cable. The cable shield is only grounded at one end. These precautions reduced the inductance of the relay leads sufficiently. Now when I load my 10 meter vertical antenna, it works as well with or without the relay in the pathway. The relay coil was energized with another short length of RG-174 going to the phono plug on the right. I shielded the 12 volt signal wire because I was trying to keep RF out of my power supply. This goal was easier for me using the logic inverter to drive the relay coil. Don't bother building the inverter if you don't need it.

Turning on the transmitter power supply



In many homebuilt transmitter designs the antenna relay has another set of contacts to turn on the DC power supply for the transmitter. A VFO-controlled transmitter is much more complex than a crystal controlled QRP. There are usually one or more oscillators running during transmit that must be turned off during receive. Otherwise you will hear them as whistles in the receiver. The "double" relay above in older ham transmitters is usually a ***Double Pole, Double Throw***, a ***DPDT***. The DC supply line goes to a moving contact.

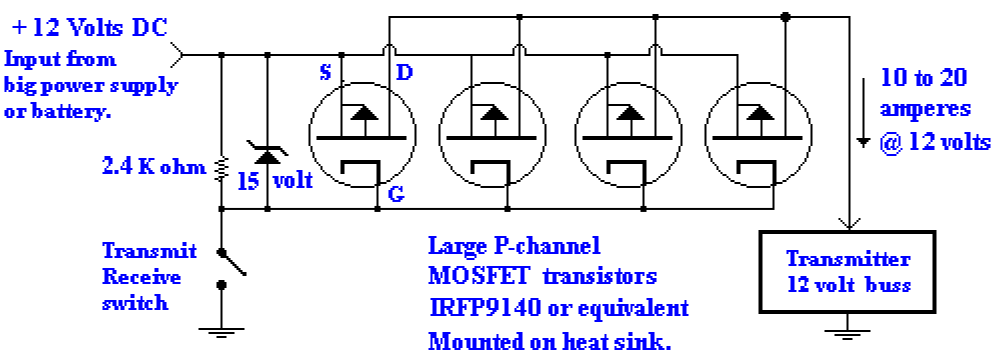
At rest this contact energizes the "spot" circuit and perhaps also the receiver. The "spot switch" allows you to turn on the transmitter crystal oscillator or VFO to figure out where your signal will be in relation to the fellow you're listening to.

Grounding one side of the relay coil activates both the antenna relay and the DC supply relay. In other words, this control line always has 12 volts on it. When the line is grounded by means of the send-receive switch, this line activates the transmitter. This same signal can also be used to "mute" or inactivate the receiver. Alternatively, the DC supply relay in the transmitter could turn the power to the receiver off and transfer it to the transmitter.

I have built three transmitters that used a DPDT relay to perform both the antenna switching and the DC power switching. Except for the 10 meter problem explained earlier, these big relays all worked well ... at first. But eventually, the DC power side always became intermittent. For this reason, if you are going to run a 50 or 100 watt transmitter, plan on switching at least 20 amperes. I recommend using a 30 ampere relay and maybe yours won't become intermittent. Of course, the bigger the relay, the more difficult it will be to use one section of the relay as an antenna relay. I finally gave up and used separate relays for the power and antenna. When I push the little send / receive toggle switch on my bug box, it activates the coils of both relays.

Avoid power relays

Yet another problem with relays is that, the larger the relay, the more DC current it takes to activate it. A big 20 or 30 ampere relay coil can draw 100 to 200 milliamperes of current just to turn it on. Better yet, don't use a DC power relay. Using the QRP keyer described in Chapter 6 as a model to follow, you may use P-channel MOSFET power transistors to turn on the transmitter and/ or receiver. A heavy duty P-channel MOSFET power switch is illustrated below



TRANSMITTER POWER SWITCH

The MOSFET power switch above uses four P-channel MOSFETs in parallel. When they are turned on, MOSFETs look like low resistances, 0.15 ohms or less. This means that little voltage is wasted across the switch. The larger the MOSFET, the lower the resistance. By putting several in parallel, the resistance can be lower still. Large TO-3 package MOSFETs can be bolted to a heat sink to keep the transistor temperature as low as possible. Otherwise, as the temperature rises, the internal resistance of the transistors will also rise.

P-channel MOSFETs are the easiest to use because you can turn them on by pulling their gates down to ground. In my first transmitter I used two big TO-3 case MOSFETs. Their heating was negligible when bolted to a large heat sink. In my second transmitter I used four smaller TO-220 case MOSFETS, type RFP30P05 p-channel MOSFETS. (Notice that you can decode the type number: 30 = 30 amperes, P = p-channel and 05 stands for 50 volts.)

Actually, for a given size and voltage rating of a transistor, N-channels are superior to P-channels. N-channels usually have about 1/3 of the on-resistance. Unfortunately, to turn on N-channel MOSFETs, you would need a 24 volt power supply to pull the gates ***up*** to about 12 volts above 12 volts. Every decision is a trade-off.

The 2.4 K ohm gate-to-source resistor insures that the transistors turn off when the switch opens. The 15 volt Zener diode on the gates is advisable because, in my transmitter, the gates of the transistor are in parallel with the antenna relay coil. When the transmit/ receive switch is opened, a big voltage can appear across the coil and may damage the transistor gates.

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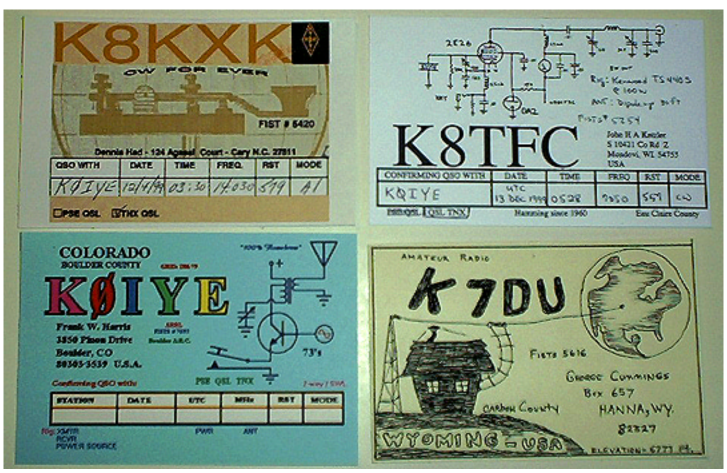
HOMEMADE QSL CARDS

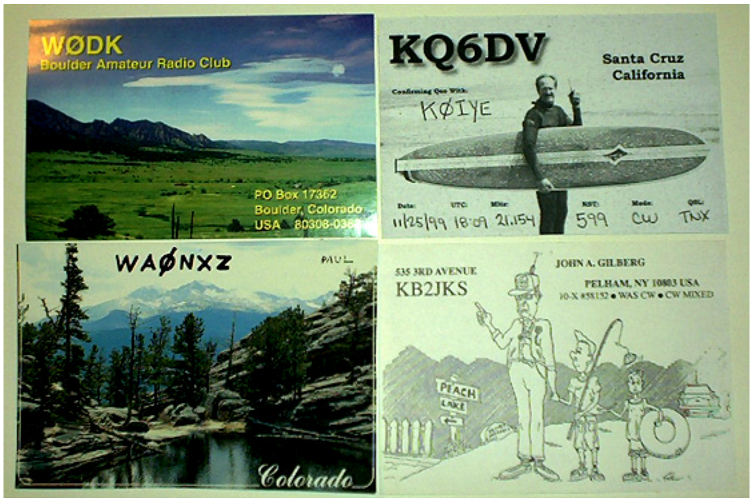
I do not miss the QSL cards from the old days. Fifty years ago the most common American QSL cards were bought from World Radio Labs. They had a map of the US with one's call letters printed in red. It seemed as though everyone who didn't send out World Radio cards was sending Allied Radio cards. Allied cards were just glossy white cards with big orange call letters and a couple of orange stripes. These designs were quite attractive, but since they were the vast majority of what you received, QSL cards were pretty monotonous. Back then, if you had bought QSL cards that would have been competitive with today's commercial cards, they would have cost a fortune. Hand-drawing my own cards was fun, but only for the first 2 or 3 cards. After that, it was far too time consuming to be practical. I managed to make a crude template and print some rough black and white cards that were barely acceptable, but they sure looked primitive.

Since the age of Xerox, computers, digital cameras, and the color printers, making your own color QSLs has become a breeze. Other than knowing how to run a computer, it is totally non-technical. I dare say that typical 12 year olds can make great cards, even if their parents can't. Considering how easy it is, I'm disappointed that so few guys make their own cards. These cards have much more "soul" than mass-produced commercial cards.



Here are a few examples of homebrew cards. The two on the left were made using Microsoft Paint, Mac Draw or a similar, standard drawing program. The ones on the right were made using hand drawings that were later Xeroxed. They were printed onto plain 5 by 8 inch index cards and then trimmed to postcard size. Not much to it, really!

My buddy Jack, KØHEH, used his digital camera to take a picture of a nearby mountain. Then he used a free QSL software program to overlay his call letters on the scenery and ended up with a beautiful card. The cards can be printed on a color printer using photo quality paper. The result is very classy.



Four more examples are shown above. The Boulder Amateur Radio Club card at the upper left, WØDK, could be made with a digital camera as was just described. Alternatively, one could begin with a regular color photo and a scanner. The photo card on the lower left, is from Paul, WAØNXZ. This card could have been done with a scanner or digital camera, but this particular card happens to be a commercial postcard with hand-lettered call sign at the top. It's a beautiful card but buying postcards is pretty expensive.

The guy with the surfboard holding the walkie-talkie at the upper right, is Tom, KQ6DV. He used his own photo but kept the cost down by not using color and photo quality paper. The card at the lower right, is from John, KB2JKS. He made a complex hand-drawing and then Xeroxed it onto cards.

There are loads of ways to make QSL cards today. And all of these cards are more interesting than commercial ones. Yes, printing cards a few at a time is expensive. But most of us don't send out zillions of cards anyway. Making them yourself lets you modify them as often as you like. You aren't stuck with some error on the card for the next two hundred copies. Even if it's just QSL cards, homebrew is more fun!