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Chapter 16B

HOMEBREWING VHF HAM RADIOS

2 Meter VHF Transmitter Circuits

Until I learned the techniques derived at the end of Chapter 16A, the best 2 meter amplifier stage I could build was a grounded emitter, 2N3866 transistor amplifier with a gain of 1.44. If I put three of these in series, I can produce a voltage gain of about 3. Pretty feeble, but it was the best I had at the time. Below is an amplifier with 3 of these in series.



These 2N3866As run hot. Even though they are well below maximum current rating, I put little top-hat heat sinks on them to keep them cooler. When I used the amplifier to drive the "1 watt to 3 watt amplifier," it appeared to produce an entire 14 milliwatts using my original erroneous power measurement method.

14 milliwatts was pathetic, but then it occurred to me that cell phones routinely connect to cell towers with milliwatts. Using my roof-top antenna, the repeater might be able to hear me. It is about 5 miles away, but pretty much line-of-sight. However, before I could activate a repeater, I needed to generate the correct low frequency code. I would also need an audio amplifier to drive the FM modulator. First the repeater code:

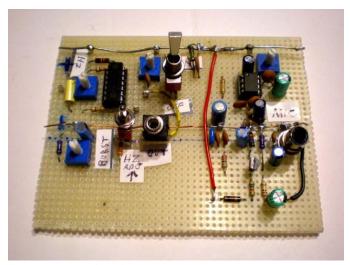
A repeater-activating 100 Hz oscillator

Most hams in my area use 2 Meter and 70 Centimeter repeaters. The usual mode is wide band FM voice modulation. So far as I know, all of our repeaters are still analog and not digital. Without repeaters the average VHF and UHF handheld radio is pretty much limited to line-of-sight operation. The repeaters are usually located on mountain tops or other high elevation. Repeaters are assigned ham call letters and are given specific frequencies which are reserved for these specialized transmitters. In accordance with FCC rules, the repeaters periodically identify themselves in Morse code when you release your push-to-talk button. In my area the repeaters, WØIA and WØDK, use the call letters of old time hams I knew when I was a teenager. Gene Link, WØIA, in particular was one of my mentors. It's nostalgic to hear their call letters on the air again.

When the user dials in the broadcast frequency on his transceiver, the transceiver's microcomputer knows from the frequency that the user is calling a repeater. For every assigned repeater frequency there is an associated calling frequency. On 2 meters they are located 600

KHz above or 600 KHz below the broadcasting frequency. The user dials in the listening frequency but his transceiver automatically transmits on the calling frequency. If your calling signal has the correct low frequency tone code, the repeater rebroadcasts your signal on its broadcast frequency.

I built my first code generator on the same board with the microphone amplifier shown below:



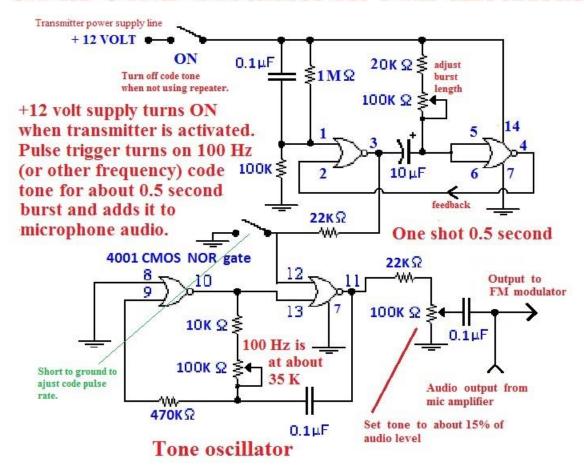
Repeater activating code generator

My local VHF repeater is described as "146.7 MHz (-) 100 Hz." This means that the calling frequency is 600 KHz below (-) at 146.1 MHz. Some repeaters are described as (+)" which means that the calling frequency is 600 KHz above the VHF broadcast frequency. A 100 Hz low level tone is needed on the calling transmitter to activate the repeater. The tone is a low level audio frequency burst of sound that typically lasts 0.5 seconds. Some repeaters use other code frequencies, such as 88 Hz, so the code generator needs a way to adjust the code frequency.

As you know, Frequency Modulation means that the nominal frequency shifts up and down in time with the speech audio amplitude and frequencies. The louder the speech signal, the farther the frequency shifts from the nominal frequency. The bandwidth of the signal can be quite wide, as much as 15 KHz. The activation tone deviation is set to about 15% of the total shift range. Because of the low amplitude and because the audio amplifiers in modern receivers limit the low frequency response below a couple hundred Hz, the user usually can't hear the activation code.

A difficulty for a homebrewer is that, in order to talk to most folks, the users need to generate the activation code and receive on a different frequency than the one where they are transmitting. If you're like me, you are probably only interested in using one or two repeaters from your home station. Only the calling frequency needs to be precise and stable. The receiving frequencies can be covered with a relatively primitive but versatile analog tuned receiver such as the VHF to HF converter described in Chapter 16C.

100 Hz TONE OSCILLATOR FOR REPEATER



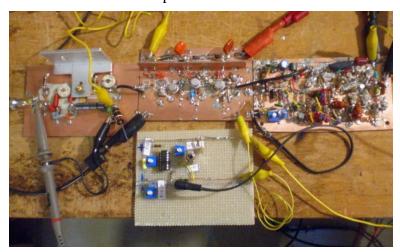
I made my code generator out of my usual 4001 NOR gate MOSFET logic circuit. (I own lots of them.) The same circuit can also be fashioned from a 4011 NAND gate, but the polarities would reverse and you would have to use different output pins to achieve the same result. Most other integrated circuit logic series should also work. You could also build this using op-amps like the oscillator and one-shot circuits in the electronic bug key presented in Chapter 9. If you're a purist, you could build it from discrete transistors like the multivibrator, flip-flop circuit presented in Chapter 10.

The 4001 CMOS "NOR" logic circuit has two input pins. When either **OR** both pins are pulled high, the output pin will go low. The "N" in NOR refers to the output being inverted, as in "NOT," high, that is, zero volts. If both input pins are tied together, the output pin simply inverts the input polarity. These individual NOR gates can be directly wired together to create any combination of logic you wish. Here they are used with resistors and capacitors to produce oscillators. When the capacitor charges up to, (or down to), the switching threshold, the output pin instantly flips to the opposite polarity.

The circuit is powered and triggered by the power supply line to the transmitter. When the transmitter turns on, the tone generator is powered and also activated by a "one-shot" pulse generator. The tone oscillator generates its 100 Hz tone until the one-shot pulse ends after about 1/2 second. As you can see, the tone is adjusted to a low amplitude compared to the microphone audio. To adjust the 100 Hz frequency, pin 12 of the tone oscillator is grounded with a switch. This turns on the tone continuously so that you can adjust the 100K ohm frequency pot using a

Milliwatts may be all you need

Once I had my "14 milliwatt" transmitter and a working tone generator, I cautiously tuned it up on my roof-top vertical antenna on the repeater calling frequency, 146.100 MHz. I monitored the antenna terminal with my scope using the 3 pF probe. It tuned up easily and behaved about the same as the 51 ohm resistor. Next I switched on the repeater activating code generator. I tuned the receiver to the repeater broadcast frequency, 146.700 MHz, and keyed the transmitter. The atmospheric static disappeared and a carrier appeared! When I turned off my transmitter, the repeater broadcast frequency carrier stayed on for about a second longer than my transmitter. Then the repeater sent its call letters in Morse code, WØDK. IT WORKED!



With a clear path to the repeater and a decent antenna, milliwatts were apparently enough. I learned later that I was actually transmitting about 3/4 watt. The next week I tried to check into the club informal "round table" net with 100% homebrew gear. I thought it would be great fun if nobody noticed I wasn't using my usual Icom commercial transceiver. I wired in an LM386 audio amplifier board I had used on other projects and tried it out. Evidently my test procedure was much too casual. The fellows on the roundtable couldn't understand a word I said. Since it was not a private QSO, I quickly switched to the commercial Icom transceiver. My next project was to explore why my audio was so awful when produced by a microphone instead of the Walkman radio.

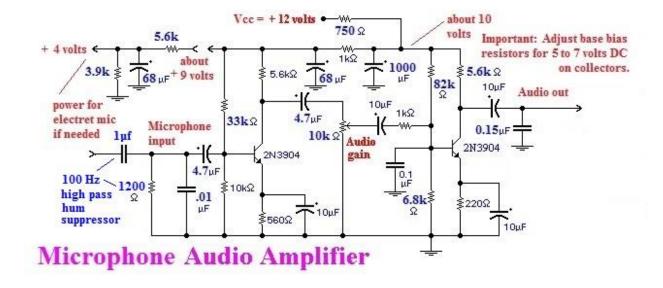
A microphone amplifier

My first step was to measure the peak audio voltage when using the Walkman earphone output for an audio source. When plugged into the FM modulator, I set it up so that the audio sounded quite natural in my handheld Icom transceiver. The audio input to the FM modulator averaged about one volt peak with occasional 2 volt peaks. Next I set up the microphone placed up against a radio speaker. I adjusted the audio output from the microphone amplifier to 1 volt peaks. Obviously I needed a way to know whether I was speaking loudly enough or whether the microphone gain was too high or low. I did notice that the waveform on the scope had more high frequency sinewaves than the audio waveform from the Walkman. I listened to the audio using headphones plugged into my commercial handheld. The fellows on the net were right. The voice was distorted, either too faint to understand or too loud with sharp, scratchy sounds. Either way, it was usually impossible to understand.

I built another LM386 audio amplifier on the same board as the tone generator. As explained in Chapter 7B, the input source must have an output impedance of at least 470 ohms to keep the LM386 from oscillating. I used the "bullet proof" version of the LM386 circuit including the 15K ohm shunt from output to pin 1. The resistor is supposed to suppress excess treble response. Notice that all the circuit variations of the LM386 already have an R-C filter on the output to blunt the screechy high frequencies. It was nice to see that I'm not the only person who noticed that these amplifiers have way too much treble and not enough bass response. I tried a really heavy duty R-C on the output, a 27 ohm resistor in series with a one microfarad capacitor. This clobbered the high frequencies but also attenuated everything else. This necessitated a single stage transistor pre-amp. I still wasn't happy with the result. Low audio volume sounded OK but higher audio levels were still too scratchy.

A two transistor audio amplifier

I built three iterations of transistor microphone amplifiers before settling on the circuit shown below:



Not all 2N3904s have the same gain

I modified this circuit from a 3 stage amplifier board I had used in a receiver. Three stages produced too much gain for this application and caused noise and distortion. Consequently I bypassed the last amplifier stage. I first built it using my usual 2N3904 biasing resistors, but the transistors were either fully saturated (about 0.5 volts) - turned full ON - or they were completely turned OFF - (Collector voltage = Vcc supply voltage). I had to change the Vcc-to-base resistors and sometimes the base-to-ground resistors to turn the transistors half ON. The resting DC collector voltages with microphone disconnected should be between 4 and 7 volts DC. This ensures that the audio signal will not be clipped and distorted when it is amplified.

Another difficulty was that the amplifier had way too much treble. To get rid of it, I put $0.1\mu F$ capacitors to ground on each transistor base. The $0.01\mu F$ capacitor on the microphone input also eliminates "crystal set" interference from my nemesis, the local 1190 KHz AM radio station. A further difficulty is the 60 Hz hum from my AC power supply. The 1 $\mu F/1200$ ohm input high pass filter helps, but it NEVER goes away completely.

60 Hz hum is harder to eliminate with FM

Many months later, after I had a working VHF final amplifier, I could hear a slight 60 Hz hum on my signal. Hum is a difficult problem in a line-powered, 18 MHz crystal-controlled, VHF FM transmitter. As you know, FM frequency deviation controls volume = loudness of the received signal. In my transmitter, the audio amplifier must supply about 1 volt peak audio signal - (1,000 mV peak). The raw output from a microphone is usually less than 100 mV peak.

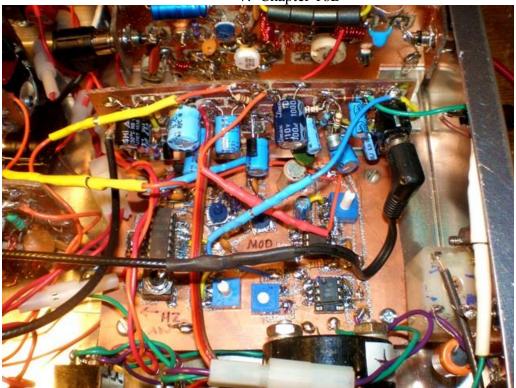
Now suppose there are 10 millivolts of 60 Hz hum added to the microphone input: The FM modulation is applied to the 18 MHz crystal oscillator. Therefore, there will be 10 mV of 60 Hz frequency deviation *added to the 18 MHz modulation*. To move the RF to 2 meters, the frequency is *multiplied 8 times to 144 MHz*. This will produce 80 milliVolts equivalent of 60 Hz hum on the signal. Compared to 1,000 mVp, 80 mVp is not a big deal, but your contacts will notice. In contrast, with SSB or AM voice modulators, if there is 10 mVp 60 Hz in the audio signal, 10 mV 60 Hz will remain insignificant compared to a 1,000 mVp speech signal.

I eliminated most of the 60 Hz hum by using multiple L-C and R-C high pass filters in series. The circuit above has two R-C filters in the supply current to the input amplifier stage and one more in the electret power supply. Starting from the 12 volt supply, the current passes through 4 filters which reduce the 60 Hz component to less than 2 millivolts peak. The random noise level is 2 mV peak, so I can no longer see the 60 Hz component on the scope. The audio output level from the microphone has 100 mV peaks. If there is 8 times 2 mV noise, that will result in 16 mV of noise and 60 Hz modulation added to the speech signal. This *should be* nearly inaudible in the speech signal.

Another factor that makes hum worse is that transistors amplify tiny signals more than large signals. This property is useful in SSB amplifiers in which it's desirable to amplify tiny whispers more than loud voices. I also used this principle in the Chapter 7C receiver to even out the VFO signal amplitude over a wide range of frequency. Unfortunately, in this application it exaggerates the hum problem.



I also rebuilt the 100 Hz burst generator on a PC board that was more compact. All the various wire connections between the boards are Molex pins insulated and color-coded with colored shrink tubing. To fit the modules inside the enclosure, the audio amplifier had to be mounted vertically:

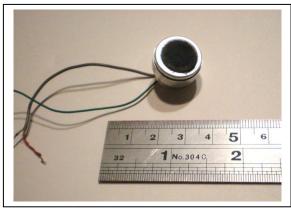


Try a different microphone

I switched to an electret-type microphone, the same type used on the SSB transmitter in Chapter 15. Electrets are based on a vibrating metal diaphragm that is half of a capacitor. They have a built-in little amplifier so they need a 4 Volt DC supply voltage. I made a 4 volt supply by stepping down 12 volts with a 7.5K ohm resistor in series with a 3.9K ohm to ground. I added an additional wire from the microphone down to the microphone amplifier. To connect the 4 volts I made a simple one-wire connector out of Molex connector pins.

Huge improvement! The electret is more sensitive than the old crystal microphone cartridge and has much better bass response. The electret I'm using is a Radio Shack part. Sadly, Radio Shack has gone out of business. There are lots of electret microphone cartridges on the market, but during the SSB project, I found that most of the ones I tried weren't any better than the old crystal microphone. Compared to most electret microphone cartridges, this one is unusually large, about 1.5 cm in diameter. That may be a good indicator for sensitivity and bass response. I packaged the microphone in a length of 3/4" copper water pipe. The push button on the side activates the transmitter for "push-to-talk."





How to test it on the air when there is nobody to listen



We hams are not supposed to rebroadcast anything, let alone our favorite rock music stations. My solution was to tape-record a few minutes of me counting to 50, then giving my call letters and repeating. I scotch-taped the electret microphone to the loudspeaker as shown. Using the oscilloscope I adjusted the volume to match the audio waveform amplitude to be the same as if I were talking into the microphone live. I switched to a different 18 MHZ crystal to avoid interfering with the repeater. To keep the test fairly local, I just used the roughly 1/2 watt amplifier strip and didn't connect the final amplifier board or an external antenna. While the transmitter was on, I ran outside with my hand-held and listened to the audio from 100 meters away. As I hoped, the audio was MUCH better with the electret microphone and without the LM386.

Another way to hear yourself is to transmit on the repeater calling frequency when the repeater is not being used. Wear headphones so there will be no feedback. While you are giving your callsign and explaining that you're just testing a transmitter, listen to the repeater broadcast signal, 600 KHz away. You will hear your voice as others are hearing it.

Once again I prepared to attempt the weekly 2 meter roundtable. I switched over to the repeater frequency crystal. Then I tuned the antenna while listening with headphones. Lad, KEØTZB, heard me and gave me a signal report. "Weak audio and 60 Hz hum on the signal." He understood my speech! Apparently my old Heathkit lab DC power supply is not very well filtered for 60 Hz. I had noticed the hum before, but I didn't think it was significant. Guys spoiled by commercial equipment have *very* high standards. Lad and I had an actual conversation - communication! **My first homebrew 2 meter contact!** I switched to the Icom hand-held for the roundtable. No need to torture the guys with 2nd rate audio.

Oh, and by the way, I later switched the power supply to the precision 12 volt supply described in Chapter 8. According to my ears, the 60 Hz hum was virtually eliminated, but the commercial gear hams disagreed. Also, I later discovered that most of the 60 Hz difficulty with my lab power supply was because I had not grounded the negative side of the 12 volt supply to the power supply enclosure.

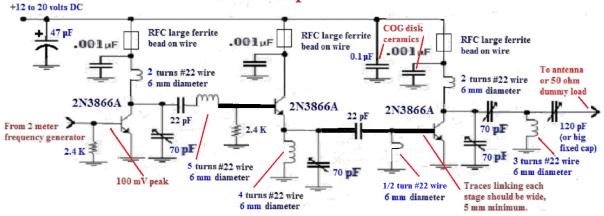
A lab bench DC power supply like mine consists of 3 separate, isolated supplies in the same box. It contains one 5 volt supply and two adjustable 0 to 20 volt supplies. They are isolated from each other because each one is powered by a separate line-isolation transformer

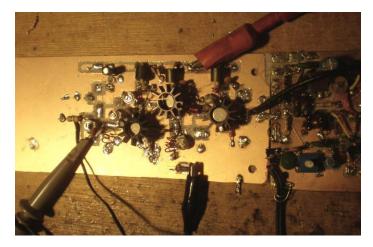
winding. The 3 supplies can be wired together like loose batteries. They can be wired in series in any order or voltage. I can have 5 volts, 25 volts, 45 volts, minus 20 volts or any combination. Because each supply is isolated, its wiring resembles an antenna picking up 60 Hz noise from the power line. When I made the effort to deliberately connect the negative side of the 20 volt supply to ground, the 60 Hz hum was greatly reduced.

ONE WATT AMPLIFIER AND ANTENNA COUPLER

Using what I had learned in Chapter 16A, I finally managed to reach one watt output into 50 ohms with a design that is comparable in complexity to most on-line homebuilt schematics. The "one watt to 3 watt" MRF652 final amplifier stage was *not* needed. The new design has three 2N3866A transistors. Judging from the power curves in the specifications shown earlier, it is now working as well as can be expected with 12 or 20 volt DC supplies. Peak voltages shown below are my oscilloscope observations and are much lower than the actual voltages which I can't measure.

145 MHz one watt amplifier and antenna coupler





When powered by 12 volts DC, this amplifier puts out about 3/4 watt. The amplifier board draws 350 mA DC. When powered by 20 volts, it delivers significantly over 1 watt. Using my crude power measurement technique, I observed 25° C rise on the load resistor during one minute. Supposedly, the 2N3866s can tolerate 28 volts, but I don't wish to try this.

I recommend using transistor heat sink hats like the little star-shaped ones shown in the picture. The transistors run hot to the touch, 85° C, but are well below 200° C, their rated maximum temperature. However, there's no need for unnecessary stress. When the amplifier runs for a minute, the current drawn by the amplifier and the output power drop about 10%. It recovers its original current and power when cooled to room temperature.

I used this 1 watt driver successfully for several months. But one day, over a period of a few minutes, the output transistor faded into the sunset. Specifically, the output slowly sank to about 50 mV peak. When removed from the circuit, the transistor base-to-collector P-N junction voltage measured infinite, "OL," and the base-to-emitter measured 0.35 volts. Both voltages should have been about 0.75 volt. The replacement transistor worked well and I concluded that running 20 volts on the transistor day after day with the heat sink shown in the photo was not adequate. I need a better heat sink, a circulating air fan or operation at a lower supply voltage. The simplest solution was to lower the supply voltage to 14 volts DC.

Looking at the schematic, the first and last stages are the common emitter amplifier scheme I used earlier. The first stage is perhaps unnecessary and I wouldn't be surprised if the same output power can be obtained without it. I tried this, but it wasn't quite as powerful. The first stage output has a coil in series with the base drive which was derived from the "academic" paper design. All these little changes helped "a little." If you experiment, I'll bet you can find other combinations of circuits that work as well or better.

Emitter follower voltage to current "transformer"

The center amplifier stage is an emitter follower circuit. These have very high input impedance, but low output impedance. The voltage gain is always less than one, but the current gain can be huge. The input drive to an emitter follower may be a relatively high peak voltage, but have high source impedance. As a result there is very little current available to drive the base of the next stage. An emitter follower stage is ideal for stuffing base current into a grounded emitter amplifier. The usual grounded emitter amplifier needs more drive current than a nearly open circuit resonating coil can provide. In other words, the follower acts like a transformer with many turns on the primary and only a few on the secondary. A transformer would work here, but they are usually hard to build and match impedances at VHF and above.

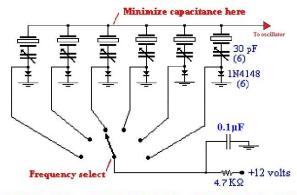
Notice that the emitter follower stage in the center should be fairly well matched to drive a low, 50 ohm load directly. Unfortunately, it worked poorly when driving directly or through the antenna coupler. The grounded emitter 3rd stage has a one volt peak (oscilloscope measured) output when operated open circuit. In other words, it was really 10 volts peak or more and high impedance. However, when loaded with the antenna coupler and dummy load resistor, the 3rd stage delivered significantly more power to 50 ohms through the "T" coupler. In summary, three stages may not be strictly necessary, but this is a conservative design that is more likely to produce at least 3/4 watt.

Antenna coupler

If you have built a "T" type coupler for HF, you probably observed as I did that power to the antenna was nearly always maximum with the output variable capacitor set to maximum. In other words, normally a 2 element "L" network was adequate and a full "T" was not really necessary. There were rare occasions with HF when the output capacitor had to be tuned for the highest output power. I assumed VHF is similar so eventually the 120 pF trimmer might be helpful. (It was helpful. Primarily it helped to stabilize the sinewave.)

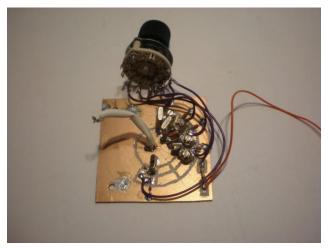
Rotary Crystal Switch

I started out with two crystals for the transmitter. During experimentation I changed them by soldering them in and out - very inconvenient. If I were to use a rotary switch with several crystals, the long wires between the crystals and oscillator would change the resonant frequency and might even prevent oscillation. A solution is diode switching. A diode can be used to ground one end of the crystal thereby activating it. I used this trick before with my 10 meter SSB QRP module. The crystals are turned on one at a time by a remote rotary switch which forward-biases each diode with DC current. If I select a switch position without a crystal, the transmitter puts out a normal-appearing sinewave at a frequency between 138 MHz and 141 MHz - not desirable.



MULTI - CRYSTAL OSCILLATOR

The 2 meter band extends from 144.000 MHz to 148.000 MHz. The bottom 100KHz is reserved for CW. 18.000 MHz, 18.356 MHz and 18.432 MHz microprocessor crystals are available for less than \$1 each. By putting the 18.000 MHz crystal in series with a small capacitor, the frequency can be raised giving you a legal CW frequency such as 144.032 MHz. The 18.356 MHz crystal produces 146.848 MHz. The 18.432 MHz crystal produces 147.456 MHz which is at the high end of the 2 meter phone band. Some frequencies in the band are designated as "official simplex frequencies." "Simplex" is just 2 guys chatting directly without a repeater. 147.495 MHz is a simplex frequency which I was able to reach with a series trimmer cap in series with the 18.432/147.456 MHz crystal. These 3 super-cheap crystals allow you to develop your transmitter without ordering custom crystals. The last custom crystal I bought cost \$65! In the picture below the crystal that is isolated from the others is the 18.000 MHz crystal.



Power Supply

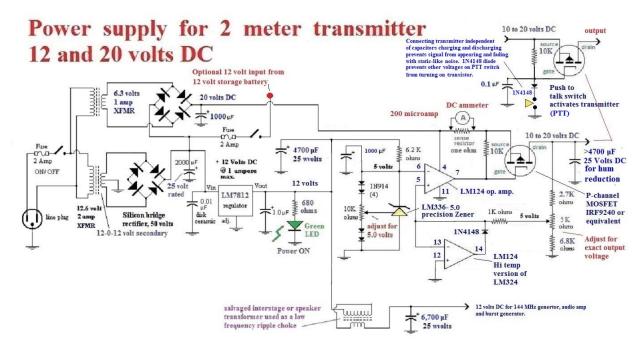
The power supply for the transmitter delivers 12 volts and (adjustable) 20 volts. The two supplies are regulated separately. The usual, medium size LM7812 regulator supplies the 12

volts. When I put the oscilloscope on the 12 volt supply line, I found ripple that caused the 18 MHz oscillator frequency to shift back and forth at 60 Hz. The FM modulator is particularly sensitive to AC ripple. 60 millivolts peak ripple on the 12 volts supply buss made an unacceptable hum which became much worse after the 2 meter signal passed through the final amplifier board. The manufacturer's data sheet implies that a 1.0 μ F output capacitor is enough to suppress any noise not clipped by the transistors inside the regulator. Not true!

Eliminating power line hum

I tried a 470 μ F capacitor but that made little difference. I replaced it with a 4,700 μ F which improved the ripple but didn't eliminate it. I finally seemed to have fixed it by adding an additional inductor/ capacitor filter with a huge 6,700 μ F capacitor. The inductor choke was made from a small transformer from my junk box. It could be an output-to-speaker transformer or it might be an interstage transformer. It is roughly one inch on all sides and has relatively low DC resistance windings, about 10 ohm. Similar sized transformers in the junk box had too much resistance and reduced the 12 volt line to 9 or 10 volts. I put the two windings in series which had enough inductance to reduce the 60 Hz ripple to less than a few millivolts AC peak. The choke series resistance reduced the 12 volt supply voltage by less than 0.1 volt DC.

The precision regulator design for the 20 volt output was an attempt to be sure that there would be no power line hum. After my experience with the 12 volt supply, I guessed I would need to add another big L-C filter to the 20 volt line, but that wasn't necessary. I changed the original 1.0 μ F capacitor to 2,200 μ F and the remaining ripple *seemed* to vanish. When I listened to the signal echoed back to me through the local 2 meter repeater I could not hear any 60 Hz hum. The one watt signal is a bit weak with slight background noise, but my speech was quite clear. Amazing! For the moment, I seemed to have a working VHF transmitter enclosed in a sturdy aluminum box!



Originally the supply just used the single, double 12 volt, center-tapped transformer. It was rectified with a bridge to produce 24 volts DC. An intermittent short circuit on the 20 volt output killed two type 7812 regulators and several other parts. The short turned out to be a hole in the mica insulator on the output transistor. I'd never seen *that* happen before. I redesigned the supply to separate the 12 volts from the 20 volts by using a separate 6.3 volt filament transformer added on top of the 12.6 volt transformer.

Notice that the bridge rectifier on the 12 volt supply is not using the two diodes on the left. When I converted the output from 24 volts to 12 volts, I started to replace the bridge with 2 separate rectifier diodes. Then I realized that all I had to do was disconnect the green ground lead and move it to the center tap on the 24 volt transformer secondary, visible on the lower left. Oh, and don't forget to heat sink the 7812 and MOSFET transistor as shown below.

The 1,000 μ F bypass capacitor on pin 6 of the LM324 is a redundant attempt to reduce 60 Hz hum on the FM audio signal - one of the many annoying glitches you'll discover.

Static-like noise when releasing PTT button

To reduce 60 Hz hum on the signal, I kept adding larger capacitors onto the outputs of the 12 and 12 - 20 volt supplies. This helped the hum, but when the microphone push-to-talk switch was released, the big capacitors retained enough charge to power the transmitter for a couple seconds. As the signal faded away, an unpleasant static-like noise was transmitted. Rather than key the entire supply on and off, I used another P-MOSFET as an ON/OFF disconnect between the capacitors and the output stages. Any of the P-channel MOSFETs used to key QRPs in other chapters will work. Now the supplies are active continuously, but only connected to the output stages during transmission. An early view of the working supply is shown below. Later several large electrolytic capacitors were added to reduce 60 Hz hum.

The red LED transmit light is turned on by the push-to-talk switch. LEDs are only rated for a few volts reverse voltage, so I added an ordinary 1N914 diode in series with the LED to prevent damage to the LED.



"Volume Units" meter

Adjusting the microphone audio volume on an FM transmitter is different than with SSB and AM modes. The FM carrier level is constant so we can't use output stage power supply DC current variation to indicate whether we're talking loudly enough. To monitor the audio input to

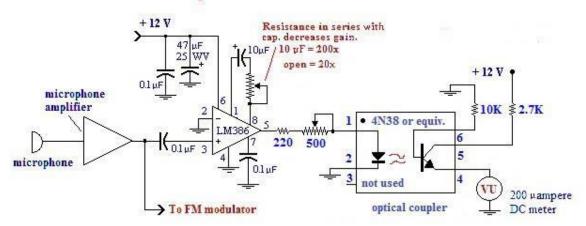
the modulator I needed a "VU" meter. "VU" stands for "Volume Units." They were defined in decibels for audio equipment way back in 1942. I used a 200 microampere DC ampere meter that was designed for this purpose. The highest 20% of the scale is colored red to indicate overmodulation.



I also installed a DPDT switch on the meter wires which allows it to display the audio volume or the voltage across a one ohm sense resistor indicating the power supply DC current for the MOSFET output stage. The output stage current responds to antenna tuning and power supply voltage rather than audio volume.

My first attempt to install the VU meter was to tap the AC voltage from the microphone audio amplifier output, rectify it and pass it on to the meter. This approach gave a good visual reference but the rectifier on the audio line badly distorted the speech. To fix this I added an "isolation amplifier" to generate the meter drive separately from the audio amplifier that feeds the FM modulator. I first tried an R-C coupled transistor amplifier stage similar to the microphone amplifier. It also loaded down the modulator input and distorted the speech. When observed on the oscilloscope, the audio waveform became asymmetrical with negative spikes and clipping. Speech was distorted even with a $0.1~\mu F$ coupling capacitor.

VU Meter Audio Amplifier



A difficulty with the LM386 was that the output capacitor must be large, $100~\mu F$, in order to drive the VU ammeter. This big capacitor has a large charging current when first turned on. This current surge slammed the meter to full scale making an audible snap that sounded like the meter was being destroyed. I managed this problem with big capacitors on the meter, but I didn't like the slow response and insensitivity.

Optical couplers

My eventual Rube Goldberg* solution connected the LM386 to the meter with an optical coupler. If you aren't familiar with optical couplers, they are invaluable when you want to connect two circuits that must have zero electrical coupling between them - no capacitance, infinite resistance, high voltage difference, etc.. They are packaged as little ICs, 4 pin or 6 pin. There are two types: The 4 pin couplers just have an LED that shines on a photo diode inside the plastic case. This type is good for binary ON/OFF applications. The 6 pin variety has an internal NPN photo sensitive transistor and can transmit varying voltage levels such as an audio signal.

I had two different, unlabeled 6-pin couplers in my junk collection, but both worked interchangeably. They have a dot pressed into the plastic to indicate pin 1. My impression after searching on-line was that optical couplers are all similar and have numbers like 4N25 or 4N38. It's probably overly complicated, but this system worked the way it was supposed to - sensitive, fast and no slamming the meter needle during turn on.

(*Rube Goldberg was a cartoonist in the 1940s. He drew cartoons that diagrammed ridiculously complicated machines.)

Harsh noise on the modulation

As explained earlier, I had a brief conversation using the repeater with Lad, KEØTZB. He commented that my signal was weak and had obvious power line hum. After that experience, the repeater worked poorly for several weeks. There was loud coarse noise on my modulation that made my speech impossible to understand. One empirical solution was to tune up the transmitter on the calling frequency using a dummy load. Earlier, I was tuning the transmitter and antenna coupler on my test frequency crystal, 145.7 MHz. It always passed my "tape recorder test" with the microphone taped to the recorder loudspeaker. But when I switched over to the repeater calling frequency at 146.1 MHz, the voice modulation returning from the repeater at 146.7 MHz was replaced with a coarse, static-like sound.

This annoying static came and went unpredictably. I had less noise when I kept my mouth farther away from the microphone and didn't talk directly into it. Another partial "cure" for the noise was simply to put the lid on the transmitter so that it was fully enclosed in aluminum. Unfortunately, when I did that, the elimination of loud static-like noises allowed me to hear the 60 Hz hum *AGAIN*, loud and clear. *PERMANENT* cures for these difficulties are really elusive. One consistent observation is that the higher the output power, the more likely there will be noise and hum.

I was pleased to notice that commercial transceivers sometimes make static-like noises too. Listening to stations on the repeater, they often have moments when their voices are covered by static as loud as the voice. It *seems* to be related to low signal strength. For example, when a fellow with a handheld with a little whip antenna is moving, his signal loses access to the repeater and the same static appears.

A dream come true

Using the one watt transmitter just described, together with the Chapter 7C receiver and the 2 meter converter (Chapter 16C), I finally succeeded in checking into our local, weekly 2 meter net. My signal strength and voice quality were good enough that nobody noticed or at least didn't say anything. 15 minutes before the net started, I tuned the transmitter output using the roof top antenna and spoke live into the microphone - there were no harsh noises coming back from the repeater. Lad, KEØTZB, heard me experimenting and commented that my voice was a

bit scratchy and my signal was weak with background static. Turning down the microphone gain fixed the modulation quality. I turned the power supply voltage up to 20 volts which gave me a full one watt output and eliminated the background static. I checked into the net and chatted with the guys for an hour. Using the homebrew receiver was a bit awkward because I had to turn down the speaker volume while transmitting. (I had not yet installed the push-to-talk circuitry.) No one noticed that I was not using my usual Icom handheld until Lad eventually told them I was 100% homebrew. Very cool.

The quest for a 5 watt amplifier

Whenever I ran the one watt driver at 20 volts DC, the transistors became quite hot. Eventually the third 2N3866 stage died and the transistor had to be replaced. It probably simply overheated. I would like to have an additional final amplifier stage that would produce about 5 watts when the entire transmitter is operated on 12 volts DC. As you'll soon see, this goal has become another Thomas Edison-style, try-everything project.

My one watt triple amplifier wasn't necessary

Over many months I built several higher power amplifier stages to follow the 1-watt triple 2N3866 amplifier. They were all based on VHF MOSFET transistors. These transistors are all expensive but usually rated for large power outputs - like 15 to 30 watts. On a whim I tried connecting one of my more successful MOSFET amplifiers directly to the 145 MHz frequency generator. **It worked!**

Apparently the 1 watt amplifier was overdriving the final amplifier and there was not enough supply voltage on the final amplifier to deliver more power. Without the 1 watt driver, the final amplifier not only put out as much as 6 watts, it could be operated with a 24 volt DC supply. Since I wasn't using the 1 watt driver and the MOSFET voltage ratings are quite high, 28 volts or higher, I could turn the variable supply as high as I liked. Oh, well. As always, my adventure with 2N3866s was extremely educational. I already own a working commercial 2 meter handheld. I didn't start this project just to get onto 2 meters. The R&D done on the higher power amplifiers is described below.

The VHF final amplifier project:

I began by trying to use the 1 watt transmitter described above to drive the "1 watt to 3 watt amplifier" described in Chapter 16A. In spite of the 1 watt driver strip having an antenna coupler output and the final amplifier having a load matching input capacitor and inductor, I was unable to generate a significant output from the "3 watt amplifier." I powered the amplifier with the variable lab power supply and was only applying about 4 volts DC. There was a 50 mVolt peak sinewave output visible on the oscilloscope. I was tuning the trimmer capacitors when the sinewave suddenly vanished. The DC supply current soared and I had another totally dead, shorted, MRF652 transistor. So much for \$38, obsolete MRF652 bipolar transistors.

MOSFET VHF Amplifiers

It would be nice to have VHF power MOSFETs controlled solely by open circuit, high impedance voltage instead of current. I used to be under the impression that VHF MOSFET power transistors were impractical because the input capacitance would be a huge capacitive load

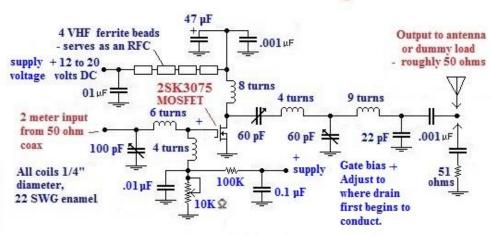
at VHF frequencies. If the input driver power (volt-amps) must be equal or higher than the output power, why bother?

The smaller VHF power MOSFETs have 20 pF input capacitances or more. In contrast, the older, low frequency, low power MOSFET power transistors, such as the IRF530, have 2,000 pF or more. Yes, the new VHF MOSFETs are greatly improved, but it will still take power, or more accurately, *volt-amps* to drive them. If you must charge and discharge a 20 pF capacitor 146 million times a second, that takes as much RF current as a 55 ohm resistor at that frequency. As we learned in Chapter 16A, a capacitance like this can be canceled by placing a resonant inductor in parallel with the gate. See? Learning how to build bipolar VHF amplifiers wasn't a waste of time, after all.

The 2SK3075 MOSFET VHF power transistor

The 2SK3075 transistor appeared to be exactly what I needed. I bought some for \$6 each. I predicted that I might burn up a few during the R&D - that was correct. The Toshiba datasheet brags about the wonderful performance of the 2SK3075 but does not explain how to use it in a circuit. Their numerous application notes didn't apply to this transistor at all. Toshiba does provide a "test circuit" that was quite similar to the MRF652 amplifier which I had already built. It was easy to modify the "One watt to 3 watt amplifier" to the suggested 2SK3075 "test circuit" MOSFET amplifier. Below is my version of the 2SK3075 amplifier:

2 meter 5 watt amplifier

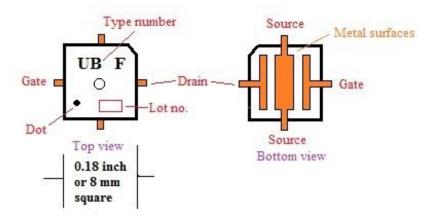


This MOSFET is an *enhancement transistor*, meaning that zero volts on the gate turns the drain current OFF. It has an adjustable + bias which is supposed to be adjusted to the turn-ON threshold, about 1 volt. In practice, this did almost nothing to increase output or reduce drain supply voltage.

A big challenge - a heat sink for the microscopic 2SK3075

These surface mount transistors are just tiny black squares, 0.18 inch - 8 mm - on a side. The drain, gate and source contact pins are connected to metal strips that extend across the bottom of the chip. Evidently these transistors are designed to be placed on a custom heat sinkthat is somehow built into the circuit board. During operation these tiny transistors must dissipate 3 or even 4 watts of heat! How could I build such a thing?

2SK3075 MOSFET CHIP



I had the perfect solution - the dead MRF652 transistor. The MRF652 transistor body is a tiny ceramic cylinder that extends through the board. The ceramic is an excellent heat conductor but doesn't conduct electricity - just what I needed. I unsoldered the MRF652 transistor, cut off the base and collector tabs, turned it upside down and soldered the emitter tabs back down to the circuit board. The tiny square terminals were connected with tiny straps of flat, wide, used solder wick. Notice the piece of toothpick placed to keep the solder wick from shorting to the old MRF642 base tab. I applied a tiny amount of silicone grease to the chip/ceramic contact surface. I fastened the threaded stud to a thick strip of aluminum on the back of the circuit board. Voila!





This former-MRF652-heat sink dissipated heat well. The big strip of aluminum became impressively warm. Unfortunately the aluminum strip flexed the tiny solder connections to the chip and the amplifier became intermittent and unusable. I should have bolted the ends of the large aluminum strip to the board. That might have made it reliable.



I rebuilt the entire circuit on a new board shown above. The new heat sink is a heavy aluminum, square post that presses down on the chip from the top. The aluminum parts are screwed together with tapped, threaded holes. Silicon grease was smeared on the chip and between the aluminum pieces. The tiny 2SK3075 pins are hard soldered to the circuit board traces and have no opportunity to bend. The vertical 1/4" square post is aligned and pulled straight down onto the top of the chip by the steel wire that is attached to the opposite side of the board. *Assuming* the contact with the chip is tight enough, this second heatsink can handle more than enough heat.

Other than the positive gate bias, this circuit is almost the same as the old MRF652 amplifier. The 8 turn drain coil and 4 turn gate coils were smaller than the sizes given in the Toshiba test circuit for 520 MHz. This circuit works great at 145 MHz, so the values can't be very critical. These transistors are radically different than bipolar transistors. It doesn't seem necessary match impedances. With bipolar transistors, the 4 turn base coil would have to be resonated with the effective base capacitance to ground for *each frequency* in order to make the base capacitance seem to disappear. The original collector coil was 5 turns and was acting pretty much like a Radio Frequency Choke (RFC). Clearly at 520 MHz or 145 MHz the 8 turn coil is even more obviously a non-resonant inductor. I'm astonished how un-critical these values are! Now I know why bipolar VHF transistors are considered obsolete and why Toshiba doesn't offer guidance on how to design with their MOSFETs. *Apparently you can use pretty much any component values you like and it will probably work acceptably between 100 and 500 MHz!*

Unfortunately, the 2SK3075 is EXTREMELY heat sensitive

The bad news about this transistor is that it is almost impossible to solder without damaging it. It's like trying to solder wires onto a snowflake. The Toshiba data sheet shows it producing 7.5 watts at 520 MHz with only 9.6 volts DC supply. When I first got mine working, it needed 20 volts to produce 5 watts at 146 MHz. It should have produced 5 watts with less than 10 volts. Still, that was a new record for me - 5 watts! It died a few days later. I now believe that I damaged the chip when soldering the little straps of solder wick onto the microscopic pin connections. When I made the second circuit board and heat sink, I didn't use solder wick straps and the transistor was even more damaged during soldering. It drew current at much lower voltages and after a few minutes it drew more and more supply current until the chip

shorted and died. Another transistor probably died from static electricity on the gate. The gate suddenly became shorted to the source. Be careful to keep the gate connected with a conductive path to the source (ground) at all times. Probably a 10K resistor is enough. After destroying all 5 chips, I gave up on this transistor.

Solder paste

What I should have done was use solder paste and a heat gun or an exotic, temperature controlled oven. The chip is only rated for 150° C. Tin/silver paste melts above 150° C. The tin/lead solder paste melts at 136° C. In theory, there is a 14° C zone in which tin/lead solder can be applied safely. The little tubes of paste must be stored in a refrigerator, but not frozen. In any case, the paste is only good for a year and costs over \$20 a tube.

Several of my ham friends are using Baofeng 2 meter, handheld, 4 watt transceivers that cost \$38 each. Ha! Well, that certainly puts my homebuilding project in a different light! The world economy is weird.

Initial Check out of the circuit board

In spite of all my 2SK3075 transistors eventually dying, three of them seemed to perform well, for a while. The following advice also applies to other MOSFET transistors:

When you first solder the chip onto the circuit board, be extremely careful you don't ground the gate or drain pins to the emitter strip which crosses the center of the chip. If the gate pin is grounded, obviously it won't work. To be sure it isn't grounded, unsolder the 4 turn coil that connects it to ground. Measure the gate to ground resistance with your multimeter. If it reads a measurable resistance, the gate is grounded and the chip needs to be moved and resoldered. If you measure the drain resistance to ground with the gate not grounded, you may discover that the drain resistance to ground is very low. This probably means the transistor is working and has been latched ON by static electricity. Temporarily connect the gate to the source and the drain resistance should return to infinite, open circuit. If it stays low, the transistor is dead.

In summary, the 2SK3075 transistor can be a terrific, compact, efficient amplifier. But it will only work if you can solve the solder temperature, heat sink and circuit board problems. I have read that circuit boards in amplifiers like this use a custom super-thick, delicately etched, copper printed circuit under the transistor to dissipate the heat - Not really a basement homebrew project.

Applying power to a final amplifier

When I first applied DC supply voltage to a MOSFET amplifier, there was zero DC current flow. I thought perhaps the drain pin was not actually contacting the circuit board, but no! I applied the 145 MHz driver signal and the output surged to life with big sinewaves across the dummy load. Begin with very low DC voltage on the drain, perhaps 4 volts. After you have tuned all 3 capacitor trimmers for maximum output RF voltage across a 50 ohm dummy load, cautiously raise the DC supply voltage to 12 or even 20 volts. If you are using DC bias, you will have to tweak all the capacitors and DC bias pot back and forth to find the optimum combination of all the settings.

Trimmer capacitors and "loss tangent"

When I rebuilt the board, I replaced a damaged plastic trimmer capacitor. It had appeared to have turned into a 30 ohm resistor. **Don't use plastic trimmers!** Use ceramic trimmers that

are at least 1 cm in length. The microscopic surface mount ceramic trimmers are too difficult to solder and adjust.

Every capacitor has an insulator in between two parallel plates. If the insulator is just an air gap or vacuum, then the capacitance is solely dependant on the area of the plates and the distance of separation. If the insulator is any other non-conductor, it will have a "dielectric constant." The dielectric constant of vacuum, 1.0, multiplies the capacitance by a factor of one no change. Most plastics multiply capacitance in the realm of 3 to 5 times. Ceramics are usually relatively low, 1.5 or 2. To use an extreme example, water has a dielectric constant of about 80. The downside of water is that it has so much power loss - effective parallel conductance - that no one uses water as a dielectric to make capacitors. The power loss coefficient is called the "loss tangent." The higher the frequency, the more important the loss tangent becomes.

At VHF frequencies, loss tangents are critical. That's why all the tuned circuits use capacitors with mica or ceramic dielectric. I was tuning one of my attempts at a 5 watt final amplifier and happened to touch the ceramic trimmer in the drain LC circuit with my finger. It tuned up properly but the capacitor was as hot as the load resistor! Capacitors are supposed to be pure capacitance, not a capacitor in parallel with a smoking hot resistor. I put in another type of ceramic trimmer and the new one runs cool.

Even ceramics aren't always free of significant loss at VHF. As an aside, I discovered that ceramic coffee cups in our 2.45 GHz microwave oven vary in how much heat they absorb. My worst cup becomes hotter than the coffee. Does it have a loss tangent higher than coffee?

The MRF148A and a novel balun-style transformer



After my last 2SK3075 died, I looked for less heat sensitive transistors. The Macom MRF136 (\$25 each), the MRF137 (about \$30 each) or the MRF148A transistors (\$38 each) sold by Mouser.com fit that description. I reasoned that that burning up five \$6 transistors was less economical than buying one \$30 transistor that could stand 200° C. These three MOSFET transistors made by Macom have large housings, similar to the MRF652. They have the same big, gold-plated lead tabs. The housing is designed to be screwed down to a large heat sink. I

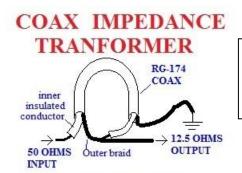
used a flat, 1/8" thick aluminum plate with the same dimensions as the circuit board. Both transistors are rated to handle 30 watts heat dissipation.

After the 2SK3075 attempt I built a similar circuit based on the MRF137. It worked for a day, but only produced about 1.5 watts with a 14 volt supply. The next day the transistor died. It seemed to be disconnected from the world - open circuit on the gate and drain. And as usual, I had no idea why. I started over with the MRF148A.

The MRF148A is very similar to the MRF137 MOSFET, but is supposed to be more rugged. It's rated for 30 watts and a **50 volts** (!) DC supply. My next attempt used the same board, but a different gate drive suggested by the MRF148A datasheet test circuit. It performs about the same as the MRF137 did before it died. Supposedly the gate bias voltage is essential for best performance. At first I didn't observe this. Since the amplifier had a disappointingly low output, 1.5 watts, I won't label the recommended drive circuit as a "success." At that time, I was running the 1 watt driver and final amplifier on 14 volts so I didn't risk damaging the 2N3866 driver board. However, I used it to join the local 2 meter round table. Unfortunately, a bit of 60 Hz hum returned to my audio and, of course, the guys told me all about it.

Coax balun transformers - another trick for our tool kit

The recommended "test circuit" supplied by Macom had a creative input transformer made out of thin coax. That's the most novel feature of their circuit. The coax transformer was equal to several other gate drive circuits that I tried on this transistor but their recommended circuit was much more stable. The 4:1 impedance matching transformer design was totally new to me. Not only does it claim to solve the problem of severe impedance matching - 50 ohms to 12.5 ohms - it's easy to build. Unlike the balun transformers used in Chapter 12 for HF high power final amplifiers, this one is simply made from a loop of thin coax. No molded ferrite is required. I have no way to know whether it really works as a transformer and is not just a couple of capacitors. When I wired it wrong the first time, it worked 2/3 as well. Interesting!



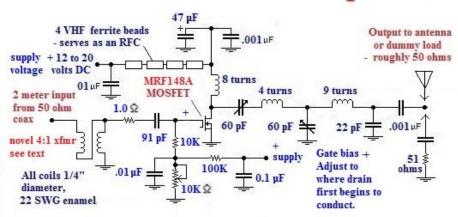
Intact portion of the coax is 1.75" long.

Make outer braid sections as short as practical.

The MRF148A test circuit plans call for "25 ohm line, Subminiature coaxial line." RG-174 coax is 50 ohms about 1/8" in diameter. Hopefully this is adequate.

This transformer reminds me of the air inlet and counter-current exhaust system in my home's natural gas boiler. The hot exhaust gas flows out through the inner pipe of a pair of concentric pipes. The cool air from outside enters the furnace through the outer pipe and cools the hot exhaust gas. Simultaneously the incoming air is heated by the exhaust gas before burning.

2 meter MRF148A amplifier



My first drive circuit used calculated inductors like the drive circuit I developed for the 2N3866 bipolar transistor. The MRF148A data sheet said the input capacitance was 62 pF so I resonated that with a parallel, 1.8 turn, 6 mm diameter coil. When used with the above impedance transformer, this worked as well as the 91 pF plus 1.0 ohm resistor recommended by Macom. However, my circuit was quite unstable. Every change in supply voltage threatened to put the output in chaos, "noise mode." The simple 91 pF with 10K resistor connection to the bias supply was stable no matter what supply voltage was applied.

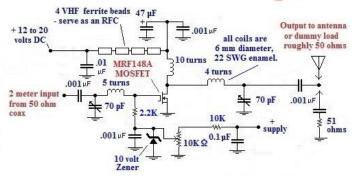
This brings up a question: What was Macom's recommended 1.0 ohm resistor for? I didn't know, so I put it in for good luck. When I removed it, there was no noticeable difference. Also, I originally had two more variable capacitors in the output coupler, but one of them peaked at maximum capacitance and the other at minimum. I took them out and power increased slightly. At first, I saw no increase in power with the DC voltage bias. Later when I tried the bias voltage again using higher supply voltages, I did see a 25% increase.

The MRF148A is recommended for up to 175 MHz as apposed to only 150 MHz for the MRF137. That might explain some of the improvement. Using an independent power supply, I was able to increase the voltage on the MRF148A to about 23 volts at 450 mA. Above that voltage there was no increase in output power. The slight 60 Hz hum problem was improved by big 1,200 μ F capacitors on the supply line. I found some small 25 volt, 4700 μ F caps and they are a bit better. It's frustrating that hum is so difficult to suppress.

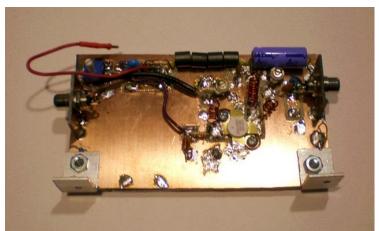
Fewer parts are often better

After lots of trial and error, I settled on the MRF148A circuit shown below:

2 meter MRF148A amplifier



I first used this same circuit with no positive gate bias. The gate was grounded with a 3 mm high loop of thick wire. After I eliminated the 1 watt driver, I tried again to add positive bias. Using 20 volts and tuning the DC bias I was able to increase the power to 8 watts into a dummy load! Unfortunately there were harsh noises and some kind of feedback at that level. I probably need to totally shield isolate the final amplifier. I was able to produce hum-free audio and clear speech when I reduced the supply voltage to about 15 volts - 2 watts. Sigh. Oh, well. The audio is clear and virtually hum free echoing back from the repeater. That was the goal.

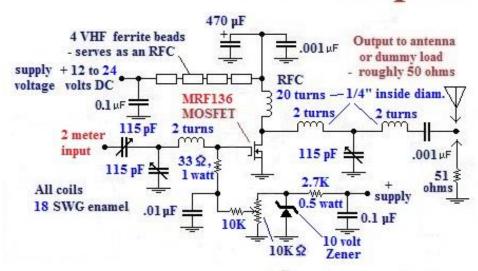


A 2 meter amplifier based on the MRF136



I built another prototype board for the MRF136. *Notice that all the control trimmers are located at the top of the board.* That way the controls are easily adjusted when installed vertically in the transmitter. The supply voltage comes in on the bottom. The circuit below is quite close to the Macom suggested MRF136 test circuit for 150 MHz. The heat sink is a 1/8 inch thick aluminum sheet on the far side of the circuit board. The circuit is very similar to the one for the 2SK3075. The process of building the board and heat sink required a lot of manual fitting and mounting the bare transistor. To protect the gate from static electricity, before soldering it in place, I wrapped fine, bare wire around the gate tab and shorted it to the source tab. I predicted that it should be almost impossible to overheat the MRF136 or damage it while soldering. So far, that seems to be true. Happily, the circuit worked right away.

2 meter MRF136 amplifier



The Macom MRF136 MOSFET is similar physically and electrically to the MRF148A. The differences are that it is only rated at half the power but it can operate up to 400 MHz. It is rated for 28 volts drain to source and 15 watts dissipation - more than I need. The only downside I have encountered is that the MRF136 is much more prone to self-oscillate. When self-oscillating at about 110 MHz it puts out over 4 times more power than at the desired frequency. The datasheet warns about oscillation and they suggest loading the input and output to keep it on frequency. The one watt 33 ohm bias resistor serves that purpose. The forward voltage bias, +3 to 6 volts DC can increase output power significantly. The tricky issue is that the DC bias, input tuning and output tuning controls must all be adjusted together for optimal settings. Raising bias voltage can make the output power go up or down, depending on the supply voltage and variable capacitor settings.

Two MOSFET amplifiers in series

In case you're wondering, when I put two MOSFET amplifiers in series with a 20 volt supply, there was little or no improvement. Presumably the second amplifier was being overdriven and more drive voltage didn't increase output. If the supply voltage on the second MRF148A amplifier were doubled, perhaps the output would probably increase to as much as ... 20 watts?

AC hum, harsh noise or scratchy sounds when operating on FM phone

At present, I'm operating with 2.5 watts output using the MRF148A final. As mentioned earlier, the MOSFET output can be driven directly with the frequency generator. This means that I can use the full 20 volts and am not limited to the 14 volts for the 2N3866s.

Danny, ON1MWS, told me that he has managed to make his first all-homebrew SSB contacts! As explained in Chapter 15, that is a rare achievement. He complained that all his contacts wanted to talk about was his less-than-perfect audio quality. Sounds familiar. I told Danny that I have realized that we are giving our commercial transceiver friends a way to feel "useful." If we are really lucky, they may recommend different brands of commercial microphones and using gold plated connectors. It is fun to be a homebrew snob, but we have to be careful to conceal our pride and prejudice.

Fully enclose the transmitter with metal

When operating at 2 watts, the scratchy noises were happening at any usable audio gain level. Also, I sometimes had loud, harsh roaring noises coming back from the repeater. There was a simple cure - **put the lid on the transmitter enclosure so that the circuitry is fully shielded**. Not only did the scratchy noises go away, I could now turn up the microphone gain and produce louder audio on the signal returning from the repeater. In practice, higher FM frequency deviation is often as good as doubling the output power.

60 Hz hum is a tough challenge

Unfortunately, when I doubled the power, the hum returned. In my opinion, it's quite mild. But naturally the fellows with the commercial transceivers consider it an inexcusable defect. Because the repeater doesn't transmit on its calling frequency, repeaters are a wonderful way to hear your own signal as others will experience it. I added MORE big capacitors and series inductors on the 12 volt and 20 volts power busses to try to reduce the millivolts of 60 Hz ripple. I reduced the hum by small increments but it was always still audible.

"Hum eliminators"

Hum is a common problem in line-powered audio equipment. Each audio amplifier, guitar, etc, - usually has a green, safety ground wire in its power cord. Inside the unit's circuitry there are subtle 60 Hz voltages which are capacitively and magnetically coupled here and there. When these currents flow to ground, the green ground wire provides a way for the current to leave the circuit. Supposedly, if you can stop small 60 Hz currents from flowing through the green safety wire, hum will be eliminated. As a test, you might try using one of those adapters that connects a 3 pin 120 volt plug to a 2 hole socket. These adapters open the safety ground wire, stopping those tiny currents. However the green safety wire also protects against emergency short circuit currents.

If your hum disappears, then a formal "hum eliminator" may fix your problem. *Hum eliminators are basically a pair of reversed diodes* in series with the green safety wire. Some of them have extra capacitors and resistors. The diodes allow big emergency, short circuit AC currents to flow, but ignore 60 Hz voltages less than 0.7 volts. The diodes are used like low voltage Zeners to prevent the tiny 60 Hz currents. I tried an 2 pin adapter but there was no change in the hum on my signal audio. A "hum eliminator" would not help me. Try everything!

A crude hum solution

A temporary solution to the hum problem is to run the transmitter on the 12 volt deep discharge battery. You may remember that all my HF equipment is designed to run on a 12 volt buss. When I began to use the line-powered, 200 watt, 12 volt DC power supply (Chapter 8), I did not have a hum problem on SSB phone. FM modulation seems **much** more sensitive to hum than SSB modulation.

To run the 2 meter transmitter on batteries, I added a DC connector on the back panel and put a 3 amp fuse on the input line. The transmitter draws roughly one ampere at 12 volts or less. At first I just connected the 12 volt battery line to the internal 12 volt power power buss. Then I realized that if it shorts to ground, the battery could send hundreds of amperes into my little transmitter. Since 12 volts is less than 14 volts, I lost some output power, but the extra audio modulation makes up the difference. All the hum is gone and, to my ears, the audio coming back from the repeater sounds as good as the commercial transceivers. The struggle goes on.

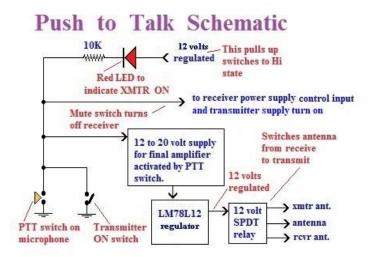
Once I was "acceptable" on the weekly round table using battery power, I volunteered to be net control. Unfortunately I was not as loud as the other stations. I was driving them nuts having to turn their volume controls up every time I talked and down when I stopped. I had to switch over to the handheld Icom to finish the net. Sigh.

Months later, the weather forecast said we would have a huge snow storm, "2 to 3 feet." One of my preparations was to rush out and buy a second deep-discharge 12 volt battery in case the power went out. We had our snowstorm. Fortunately it was "only" 2 feet deep and the AC power stayed on. After the storm I put the batteries in series giving me 24 volts DC, hum free power. I wired the second battery to supply the final amplifier stage with 24 volts. Since 24 volts is more than 20 volts, I got slightly more power with no hum. Unfortunately, the extra power increased the sensitivity to RF feedback. If you connect DC batteries to your transmitter like this, don't forget to put in a fuse in series with each positive battery connection.

Push to talk - "PTT"

Making these VHF circuits work was so difficult, I forgot to plan for success. As you would expect, trying to operate the transmitter and receiver as a station with two separate units and one antenna is impractical. On the roundtable, when I wasn't the net control guy, I could participate because I knew when it was my turn to talk and I had time to turn off the receiver and turn on the transmitter. The transmitter remained connected to the 2 meter antenna on the roof. I used an 18" piece of wire plugged into the receiver and could hear the 100 watt repeater OK. I soon learned that push-to-talk is essential for general use.

Our local ham club had a little contest to see who could contact the most members on 2 meters on the same frequency without using a repeater. It was "simplex" communication, just as we have been doing on HF bands. To hear weak stations, I had to switch the roof antenna back and forth, as well as turn the receiver and transmitter ON and OFF - without getting confused. With everyone calling each other, requiring 5 seconds to go from receive to transmit was chaos. Several guys heard me, but I didn't really contact anyone. The winner contacted 16 members. I believe we may assume he had a PTT switch. PTT is not a luxury.



Receiver muting and transmitter activation

Muting for the Chapter 7C receiver is explained in that chapter. In that receiver, an LM317 regulated supply is turned off with a contact pulled to ground. A fairly universal way to

key a phone transmitter is a push button on the microphone that shorts a wire to ground. I copied this method from my ancient Hallicrafters microphone. The transmitter activation logic is shown in the power supply schematic show earlier. When the push button on the microphone is pressed, a logic circuit turns on the red "On-the-Air" LED, the 12-to-20 volt supply and sends a remote mute signal to the receiver. I also added a manual switch so that the transmitter can be keyed without holding the microphone button down.

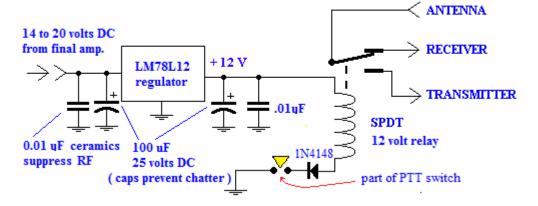
Antenna switching - the same old way

I'm still using an old fashioned T-R electromechanical relay, just like I used in the HF rigs. The 12 volt relay was powered by the 14 to 20 volts supplied to the transmitter final amplifier. I was afraid the 12 volt relay might be damaged with higher voltages. A simple series resistor would work, but I wasn't sure what voltage I might eventually use on the final amplifier. I used an LM78L12 voltage regulator to limit the relay voltage to its design level.

The best attribute of relay switching is that it works. I used a tiny relay, less than one inch on a side to minimize the internal inductance. To my surprise, the relay doesn't noticeably attenuate the VHF output. I don't know why, but without the big 100 µF capacitors, the VHF signal made the relay chatter - rapidly switch on and off. Without the VHF there was no chatter. The chattering seems to work like an electro-mechanical door bell or buzzer from the year 1920. It appears to be a low frequency relaxation oscillation. Little ceramic caps also help suppress the chatter. The higher the output power, the more caps and effort I needed to suppress the interference. Both large electrolytics and ceramic caps were needed. *Obviously the output stage needs to be totally confined to a shielded box*.

The PTT switching wire is isolated from the other PTT voltages by the 1N4148 diode. Otherwise the 12 volts on the coil might affect the supply transistor, the receiver mute, etc.

Antenna Switching Relay



Clearly modern commercial 2 meter transceivers don't contain big clanking relays. It is surprisingly hard to find schematics for commercial gear but I have heard that this is accomplished with "pin diodes." The diodes are biased on and off with a small DC signal - another project!

Pin diodes to switch the antenna

PIN diodes consist of 3 layers of semiconductor; **P-**type, pure, un-doped "**I**ntrinsic" semiconductor and **N**-type. Researching on-line, I discovered that to turn them off, the diodes

must be reverse-biased with high voltages, many times higher than Vcc. The high voltage minimizes the capacitance of the diodes - just like a varactor diode. I found a homebrew T-R switch design for a 100 watt amplifier. It has a separate 100 volt DC power supply just to shut off the diodes! Excluding the 100 volt power supply, the whole "switch" was a circuit board larger than my MRF final amplifier stage. Obviously the little 2 meter commercial hand-held transceivers must be quite different.

Status of the VHF project

My 2 meter R&D still isn't complete. I had hoped to at least equal the 5 watts output of the little Icom hand-held. Surprisingly, I continue to enjoy working on a project that only produces tiny little forward steps on a long, long journey. Below is the transmitter in its present, 2 watt state. The button on the homemade microphone is for push-to-talk. At present, the transmitter, Chapter 7C receiver and 2 meter converter now work together as a successful, but less than perfect, 2 meter FM phone station.





If you only wish to communicate on 2 meters, clearly homebuilding is *NOT* the way to do it. By the time you've invested months of time and bought all the parts, homebuilding is way, way more expensive than buying a handheld. Temporary, intermittent performance seems to be normal for VHF homebrewing. However, it is extremely educational and left me in awe of my marvelous little 5 watt store-bought hand-hand. If nothing else, homebuilding a VHF station will keep you out of saloons and away from those hussies and floozies.