ON6MU's

Allmode 5-band RF Power Amplifier

for the HF 80, 40, 30, 20 and 17 meterband

RE-PA30HF5B

By Guy, de ON6MU
rev1.1 okt/09
Prototype

About the 5-band HF amplifier RE-PA30HF5B

This project uses a widely available IRF510 MOSFET. This N-Channel enhancement mode silicon gate power field effect transistor is an advanced power MOSFET designed, tested, and guaranteed to withstand a specified level of energy in the breakdown avalanche mode of operation.
MOSFETs operate very differently from bipolar transistors. MOSFETs are voltage-controlled devices and exhibit a very high input impedance at dc, whereas bipolar transistors are current-controlled devices and have a relatively low input impedance. Biasing a MOSFET for linear operation only requires applying a fixed voltage to its gate via a resistor.
The built-in self-regulating actions prevent MOSFETs from being affected by thermal runaway. MOSFETs do not require negative feedback to suppress low-frequency gain as is often required with bipolar RF transistors.
I chose the IRF510 because lots of hams use 'em and they're cheap. But they perform a bit less when it comes to constant gain and/or power output across a wide range of frequency bands. I wasn't especially concerned with that, and the advantages outweigh the contra's, so I went with that MOSFET.

Rather then using a 1:4 toroid (which is excellent) to match Q1 impedance to 50 Ohms, I have applied the "old school" radio valve coupling; impedance matching circuitry between the output and the antenna using a L-filter...Why? FET devices are more closely related to vacuum tubes than are bipolar transistors (and because I do like to do things my way HI). Both vacuum tubes and the FET are controlled by the voltage level of the input rather then the input current. They have three basic terminals, the gate, the source and the drain. These are related and can be compared to the vacuum tube terminals. The ralationship between the two doesn't stop here...The two most important relationships are called the transconductance and output. An advantage of MOSFET devices is that they do not have gate leakage current and MOSFETs do not need input and reverse transconductance.

The amplifier is made to be driven by transmitters in the ½ to 2 watt range. Built-in to the power amplifier is a sensitive (Q2) T-R relay which will switch the unit in and out of the antenna line. When in receive, the amplifier is bypassed and the antenna feeds directly to the input jack, when you go to transmit, the T-R circuit detects the transmit RF power and automatically switches the power amplifier into the circuit and amplifies the applied RF power. If you decide to run "barefoot" turning off the AMP it will disable the amplifier and your QRP transmitter will feed directly through the amplifier without any amplification.
Power is supplied by any 14 to 25 volt (or 2 x 12v battery) DC source with a current draw of 1 to 3 amps depending upon RF power output.

The linear amplifier can be used with QRP SSB/CW/FM/AM/PSK transmitters on any of the amateur bands between 80m...17 meters.

The completed amplifier will reward the builder with a clean, more powerful output signal for a QRP rig when radio conditions become marginal.

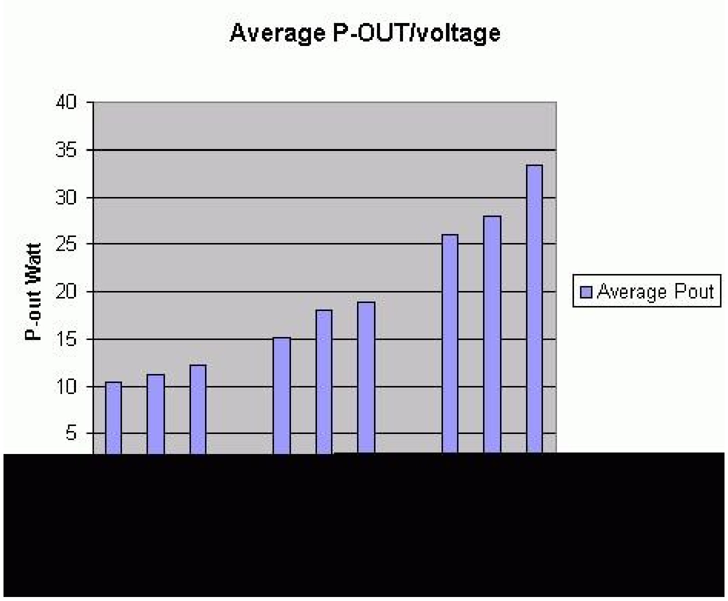
Band selection

Switching beween bands is done manually using a rotary switch.
You can build the amplifier for only one band or a combination of any other of the five available bands.

Drive

The input drive can be anything from 0.4watt to 2 watt max, which will be amplified to +/- 30 watt. The output varies on the drive power and the applied voltage.

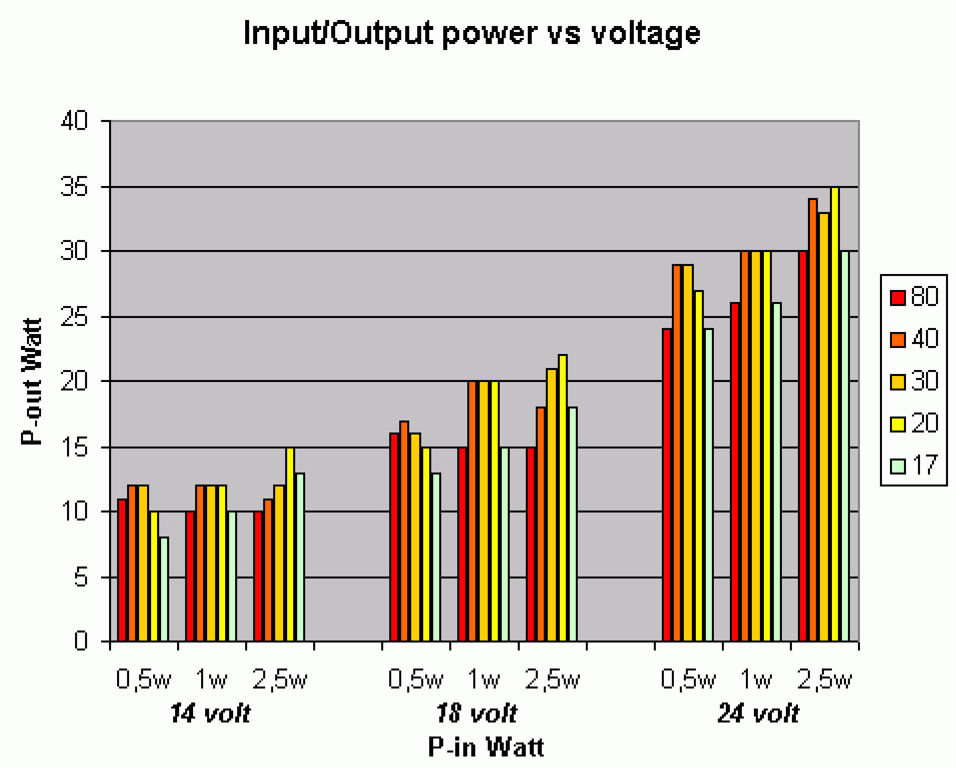
Graph 1: Average Output Power vs voltage



Power

The power output is not perfectly linear to the input frequency/band. The impedance 50 Ohms match could be solved by using a 1:4 toroid, or as I like to use, the "old school" radio valve coupling; impedance matching circuitry between the output and the antenna using a L-filter...And, the IRF510 isn't perfect. The N-channel mosfet has an input capacitance thats a bit on the high side and the output capacitance that varies with the cross over frequency. It can be a slight problem when it comes to constant gain and/or power output across a wide range of frequency bands. I wasn't especially concerned with that so I went with this MOSFET anyway. Of course the main issue was the simple design to be able to use five bands, which always has some compromise in this type of design. This means that there is some fluctuation of the output power par band. However, this is not a really an issue as I explained before.
When driven between the optimal range of +/- 1.5 watt the amplifier more then capable to deliver 30 watts +/- 10%. Output power for AM should be set to +/- 50% of max.
Although the design allows you to work in a varied range of voltages, the maximum output is only guarenteed @ 24volts.

Graph 2: Input/Output Power vs Voltage

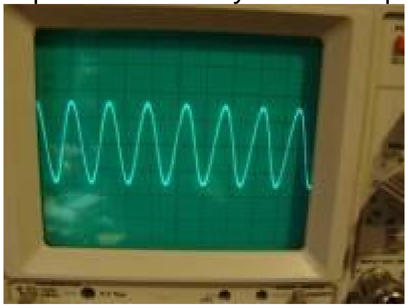


Higher power then 2 watts does not improve linearity as you can see in the above chart.

Bias
The power amplifier require biasing for proper RF performance. BIAS has be applied to Q1 to have clean proper and correct SSB modulation using this amplifier. Set P1 so that +/- 100 mA current flows through Q1.

Modulation modes
If proper BIAS to Q1 is applied, you can amplify any type of modulated wave.
Output power for AM should be set to +/- 50% of max.

Filter
RF purity and harmonic suppression is done here. Also allowing the FET to be coupled to the antenna system through antenna impedance matching circuitry (C16...C20, L2, C21...C25, C26, L4,C27). Care is taken at this stage so that no harmonic frequency is generated which will cause interference in adjacent band/harmonics on other bands. This 4-element L-type narrow band-pass filter circuit and a 3 element low-pass Butterworth PI filter for the desired frequency removes out any remaining harmonic signals very efficiently.
A picture from my oscilloscope:



RF-sensing
The basic principle of RF-sensing using a relay is clearly drawn in the schematic and pretty much self explaining.
Tip: I would like to recommend to add a mini-switch between C31 and GND if you plan to use it for CW. The on-time is to long for CW.

Input Attenuator

I made provisions to include an RF attenuator consisting out a Pi network of R2, R3/R4, R5 which gives a Forward Attenuation of 3.63 dB and a Input Return Loss of 23.23dB. There are numerous of reasons why I implemented it in this design. It improves overall linearity, achieves some "protection" and enhances stability of the drive input (being a transmitter, transceiver) and Q2 gate.

Cooling/heatsink

Q2 needs to be mounted isolated from the heat sink. Use proper thermal grease and isolator.
I used an old P3 heat sink, which work just fine.

I mounted a Pentium 3 heatsink on the back of the alu-casing. A square space is cut out of the back of the alu-box to allow Q2 to be screwed onto the heatsink. The heatsink is firmly mounted on the back of the chassis with thermal grease allowing the chassis as extra cooling surface.

Construction considerations

HAMs that are experienced in constructing RF projects will know a number of possibilities to create a good RF design.
Because I started from scratch and still was in experimental/design stages I have placed the capacitors/trimmers of each band directly around the switch, including the 80m coil L3. This works perfectly when short connections are used. You can however solder them directly to the PCB.

I mounted a Pentium 3 heatsink on the back of the alu-casing. A square space is cut out of the back of the alu-box to allow Q2 to be screwed onto the heatsink. The heatsink is firmly mounted on the back of the chassis with thermal grease allowing the chassis as extra cooling surface.

One thing I would like to bring to your attention...that are the trimmers that are used to tune each band (Ct1...Ct5). Do not use plastic trimmers, they will melt and perhaps burn through causing shortening and possible failure of Q2 and who knows what else. Please use air- or ceramic based trimmers.
If you do not have them, then the only way tweaking the amplifier by trial-and-error, hence adding C parallel to C16...C20 respectively.
These were my C's: C16=470, C17=340, C18=200, C19=80, C20=43pF

Use a choke (or a snap-on ferrite bead) at the point where the Vcc wires leave the alu-box.

Use small 50 Ohm coax between the in- and output of the PCB connections to the SO-239 connectors.

Enclosure Recommendations

To accomplish RF shielding the whole circuit needs to be mounted in an all-metal/aluminum case.

Grounding

To prevent ground loops, spurious oscillations etc. please take attention to:
- decouple the PCB in the chassis (housing)
- all connections and wire leads should be made as short as possible
- a proper PCB layout with enough ground surface ensuring normal ground paths
- the source of Q2 (IRF510) should also be grounded to the chassis as close as possible
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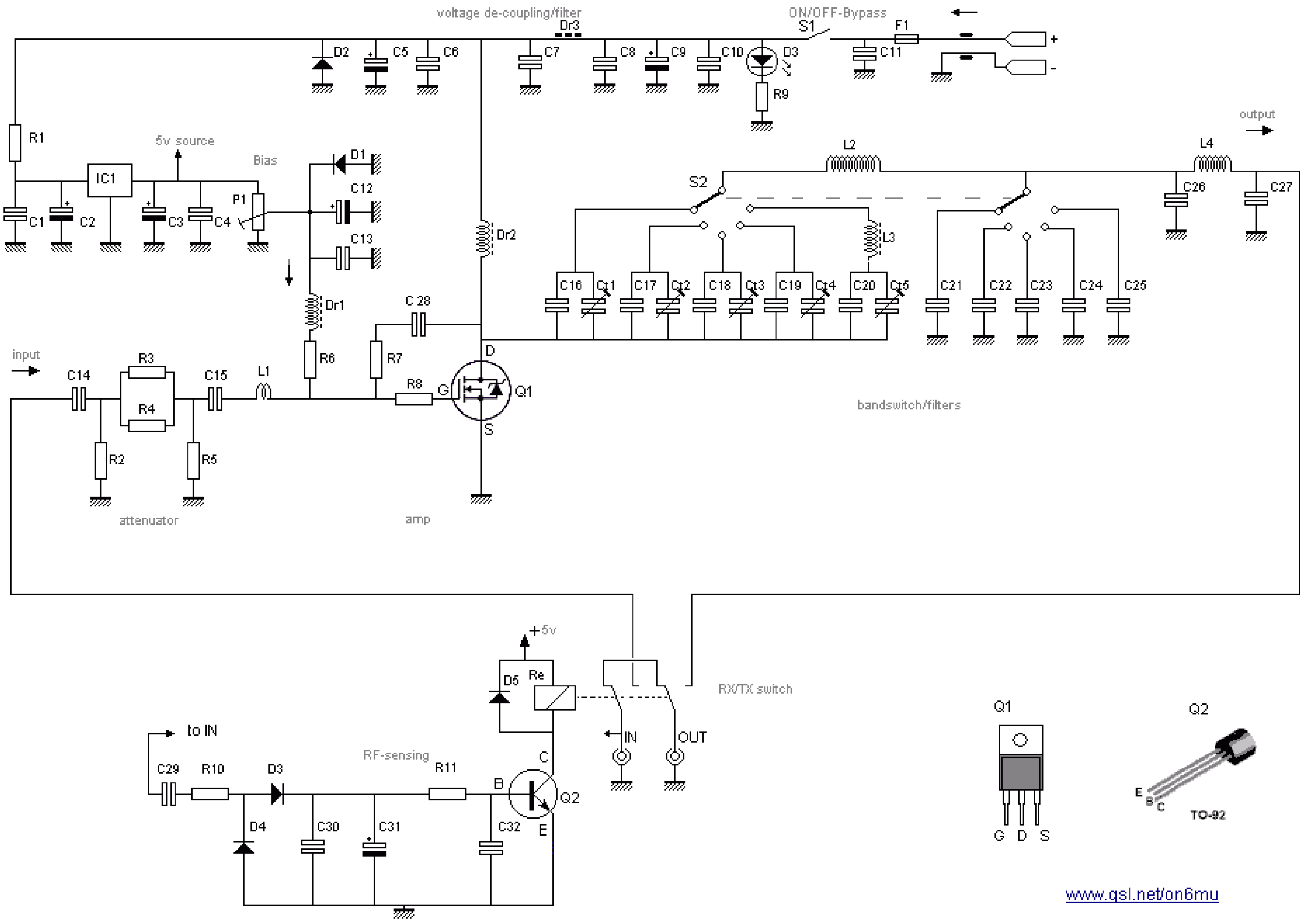
ON6MU 5-band HF Power Amplifier



Specifications RE-PA30HF5B

- Allmode: AM/FM/CW/SSB/FSK
- Bands: 80m, 40m, 30m, 20m, 17m
- Average output RF power: +/- 30W SSB @ 24v , 13 watt SSB @ 13.8v
- Works great with Yaesu FT-817, Ramsey QRP rigs or any other 1-2 watt transmitters
  Input power drive: 0.4...2.5watt max (ideal 1...2watt)
- All modulation modes
- Efficient band-pass type harmonic L-filter + lowpass Butterworth PI filter
- Usable voltages: Vcc 13.8 - 25 volts
- Average current I: +/- 2.5A @ 24 v at full load
- Built-in T/R relay automatically switches between receive and transmit
- VSWR overload resistant
- Multistage band pass and low pass filter for a clean signal
- Manual band switching


The 5-band HF power amplifier "insides"

The MOSfet 5-band HF Amplifier settings

Needlessly to say, but I will say it anyway, before testing anything please be sure to double check every connection. The project should be finished HIHI.
Connect a proper dummy load and a power meter to the output of the amp. Also put a Ampere meter in series with the Vcc, allowing monitoring of the current during the setup.
Set all trimmers (Ct1...Ct5) half way (in medium setting).
Set P1 to the ground (zero ohms).

Now gently increase the voltage to the amplifier while checking the current till you reach 18 volts. The only current you should see is a the liddle idle current of Q1 (a few milli amps and a a few mA of LED D3 if connected). We do not need the full 24 volts during the tuning/setting stages.

Now gently turn P1 till you get approx. 100 mA.

So far so good? Now we need to check if the (Q2) RF-sensing circuit is working properly (*Although I would like to recommend to test this before anything, rather then building the entire project and test it. Or at least before mounting the PCB in the alu-box, and without Q2 soldered. The RF-sensing ON-time can vary according to the relay used)*.
Connect your transceiver (or other drive) to the input, and set it to the lowest power rating of +/- 0.5watt and set your transceiver to 14.100Mc in CW/FM.
Be sure the dummy load is still at the output of the amp and the bandswitch is also set to 20m band.
Key your transceiver and if all goes well the relay (Re) should power up and you should see the current rise and your power meter should already show an amplification of the RF input power.

All working as planned? Excellent! Now we need to tune the filter-unit by setting the Ct's according to each band.
Set the drive power (your transceiver) to +/- 1...2.5 watts
Turn the band switch (S2) to 80m, as we start with the lowest band and work are way up from there. Also set your transceiver to the middle of the (each) band segment.
Carefully turn Ct5 till you get maximum output power (whilest checking the input SWR on your transceiver/SWR meter).
Current should be around 1.8...2 Amp +/- max (depending on the voltage and input power).
Next is to repeat the above for each band and setting the Ct capacitor trimmer(s) according to each band respectively.

After the filter is tuned in respect to each band you can increase the voltage to 24 volts. Then check everything again, band by band. Could be that you notice a slight difference in the peak output power, do to the capacity of the switch and the filter components. Just re-tune (if needed) each trimmer (Ct1...Ct5) for each band respectively.
The maximum current of the amplifier should never exceed 3 amps.

RF-sensing considerations

The basic principle of RF-sensing using a relay is clearly drawn in the schematic and pretty much self explaining.
Q2 (BC338, 2N2222) will conduct when RF energy is applied at the input of the amp (via R10, C29, D3, D4, C30 biasing the base of Q2) hence powering up a RF capable relay. This relay switches between RX and TX with amp.
When no Vcc is applied to our amplifier (and so Q2 too) no amplification is done bypassing the amplification. The input is simply re-directed directly to the output (as if your transceiver is connected without an amp). The RF sensing circuit is sensitive enough to react on .5 watt easily.
To allow the amplifier in SSB-modulation some extended PTT time-on the RF-sensing unit (Q2->relay) has to be

increased. C31 adds the needed "breathing" time. In FM/CW/AM/FSK modes a carrier is present and extended PTT time-on of the amplifier isn't needed, hence can be short.
Important: Everything will be within specs if you use RY5W relay, but timing (the "breathing time") can vary on the type of relay used (Ohms resistance value of the relay coil), hence experimentation of C31 is needed.

Although this example of RF-sensing isn't the Worlds most best sollution, it is pretty easy for beginners though. Better would be to drive Q2 from your transceiver (amp drive) as this will switch the amp at the very moment of PTT.
Tip: I would like to recommend to add a mini-switch between C31 and GND if you plan to use it for CW. The on-time is to long for CW.

Note:

Always use a dummy load for testing and adjusting the amplifier!!!
Remember that this is a prototype.

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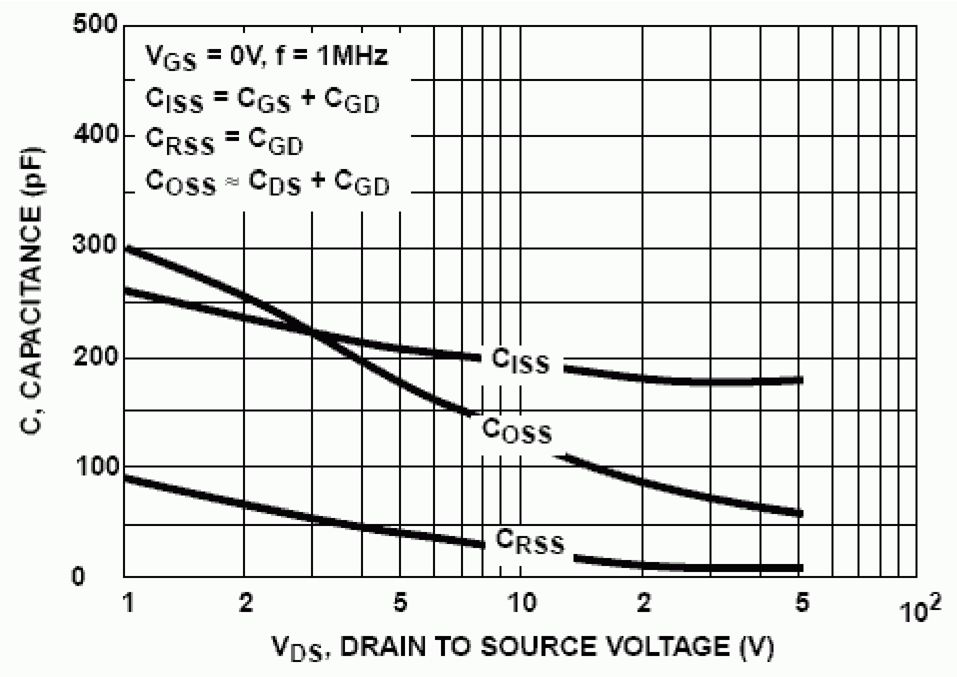
In the schematic D1 was shown in reversed state, hence could not set Bias correctly: fixed
Shunt Dr2 total turns was wrongly specified. Should be 20 turns instead of 35: fixed

MOSFET specs:



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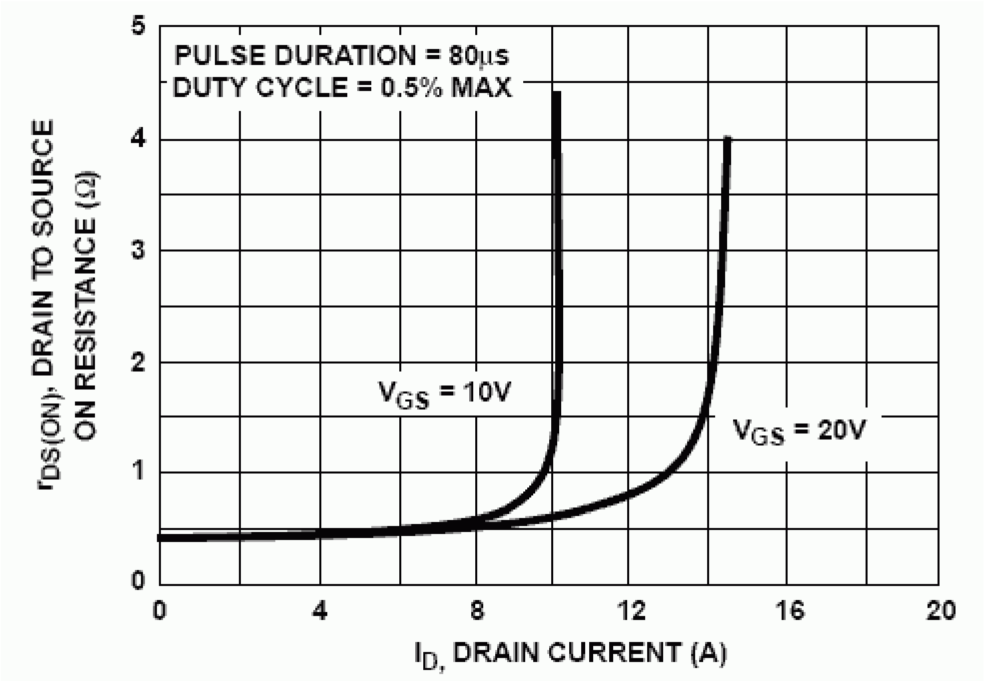

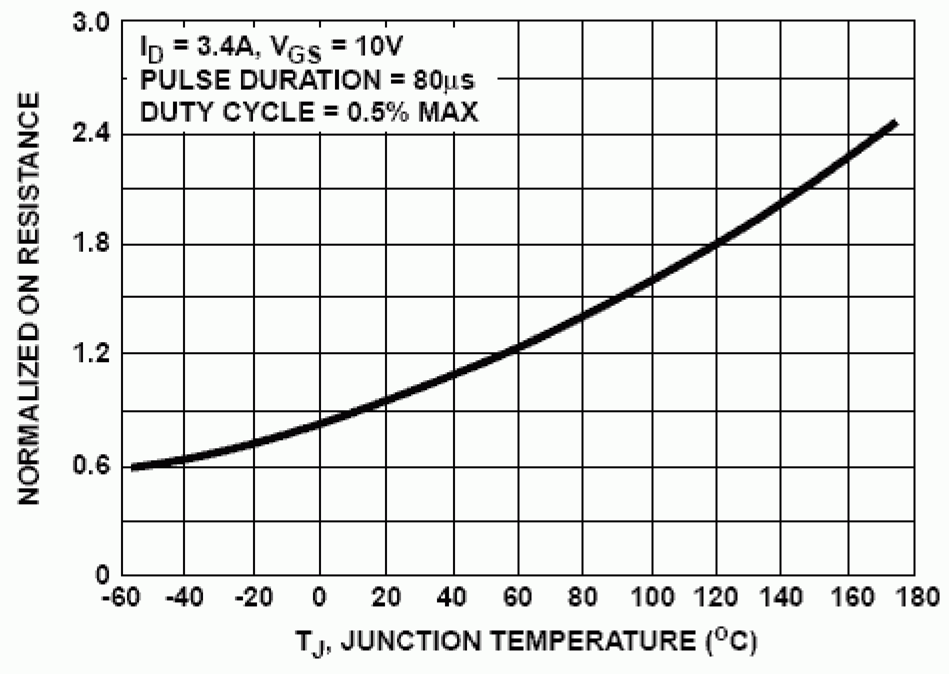

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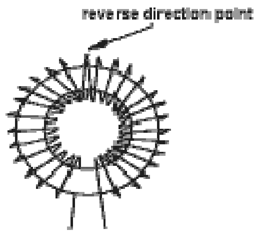
Coils

All we need to do now is make a few remaining coils that have to be handmade - for that "old-world craftsmanship" touch!
The wire used for the coils are enameled wire (stripped from any AC transformer).

Dr1: you need a ferrite core of 3mm diameter and about 5...8mm long. You wind 30 turns up and down the core, with no spacing. Wire used is 0.4mm enameled wire.



Dr2: Shunt made out of a small yellow/white toroid of +/- 13mm diamter (like those often found in PC switched power spupplies etc.). It has about 2 times 25 turns of 0.8mm enameled wire. Turn 25 turns closely together till you reach half way the toroid. Then reverse direction and make another 25 turns till you reach the end. This shunt is not too critical, so a few turns more or less will not cause any problem, but do not leave any space between the turns.

Dr3: a ferrite bead where you turn a few times a 0.6 mm wire through.

L1: 2 turns, no spacing, 5 mm inside diameter, 0.6mm gauge enameled wire

L2: 22 turns close together of 1.2mm enameled wire. Inside diameter is 9.5 mm and 26.5 mm long

L3: You need a ferrite core 14mm long (I broke a piece of a ferrite core like found in those old AM-radio's) and wind 11 turns close together of 1.2 mm enameled wire over the core. Inside diameter of the core is 9.5mm

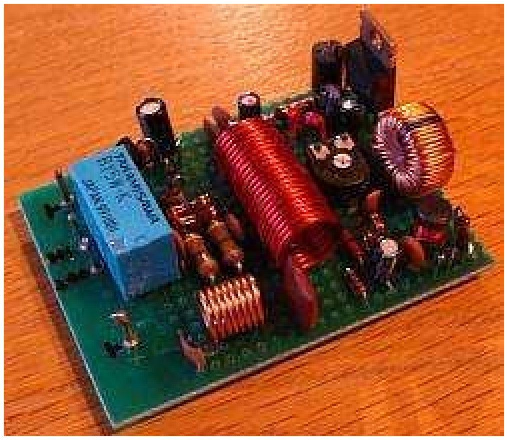
L4: 8 turns close together of 1.2 mm enameled wire. Inside diameter is 6.5mm and is 9.6mm long

Tip: remember to vernish or glue-fix the coils to prevent FM'ing do to vibrations

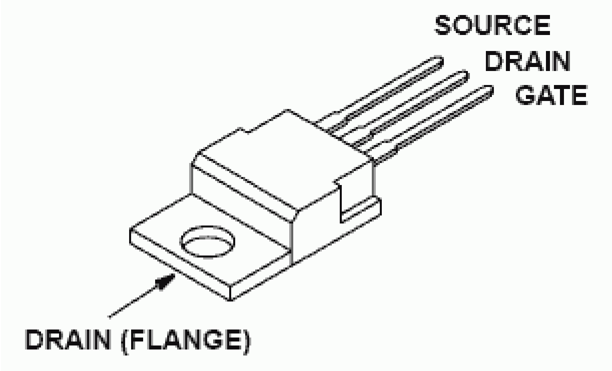
Parts list 5-band HF power amplifier

- Q1: N-Channel IRF510 MOSFET
  (with proper heatsink isolated from the mosfet)
- Q2: NPN BC338, 2N2222...
- C1: 100n
- C2: 1uF/50v
- C3: 1uF/16v
- C4: 100n
- C5: 2.2uF/50v
- C6: 100n
- C7: 4n7
- C8: 10n
- C9: 47uF
- C10: 100n
- C11: 47n
- C12: 1uF/16v
- C13: 68n
- C14: 100n
- C15: 100n
- C16: 39, ceramic 200v
- C17: 68, ceramic 200v
- C18: 180, ceramic 200v
- C19: 2 x 150pF parallel (or 330), ceramic 200v
- C20: 2 x 220pF parallel (or 470), ceramic 200v
- C21: 100, ceramic 200v
- C22: 220, ceramic 200v
- C23: 220, ceramic 200v
- C24: 470, ceramic 200v
- C25: 1200, ceramic 200v
- C26: 220, ceramic 200v
- C27: 100, ceramic 200v
- C28: 2n2
- C29: 470p
- C30: 47n

- C32: 150n
- R1: 47 1/2w
- R2: 390 1/2w
- R3: 47 1/2w
- R4: 47 1/2w
- R5: 390 1/2w
- R6: 1k
- R7: 1k
- R8: 10 1/2w
- R9: 18k
- R10: 1k
- R11: 1k
- P1: 5k potentiometer (BIAS setting Q2)
- D1, D3, D4: 1N4148
- D2, D5: 1N14001
- S1: Toggle switch (ON/OFF-Bypass)
- S2: 5-position quality switch (if possible silver plated)
- Ct1: 20pF ceramic or air-spaced trimmer
- Ct2: 30pF ceramic or air-spaced trimmer
- Ct3: 60pF ceramic or air-spaced trimmer
- Ct4: 60pF ceramic or air-spaced trimmer
- Ct5: 100pF ceramic or air-spaced trimmer
- 2 x SO239 connectors
- Re: RY5W-K relay
- F1 = 4 amp
- Alu-box
- Heatsink + thermal grease
- Dr1: ferrite core 3mm diameter, 5...8mm long. 30 turns, 0.4mm wire (+/- 4.7uH)
- Dr2: yellow/white toroid of +/- 13mm diamter, 2 x 20 turns of 0.8mm wire
- Dr3: a ferrite bead with 4 turns of 0.6 mm wire
- L1: 29nH; 2 turns, no spacing, 5 mm inside diameter, 0.6mm wire
- L2: 1.4uH; 22 turns close together, 1.2mm enameled wire. Inside diameter is 9.5 mm
- L3: 3.8uH; ferrite core 14mm long, 11 turns close together, 1.2 mm enameled wire. Inside diameter 9.5mm
- L4: 410nH; 8 turns close together of 1.2 mm enameled wire. Inside diameter is 6.5mm



IRF510 MOSFet specs:



Drain to Source Voltage	VDS: 100 V
Drain to Gate Voltage (RGS = 20kW)	VDGR: 100 V
Continuous Drain Current	ID: 5.6 A
TC = 100oC	ID: 4 A
Pulsed Drain Current	IDM: 20 A
Gate to Source Voltage	VGS: ±20 V
Maximum Power Dissipation	PD: 43 W
Linear Derating Factor	0.29 W/C°
Single Pulse Avalanche Energy Rating	EAS: 19 mJ
Operating and Storage Temperature Range	TJ, TSTG: -55 to 175 C°
Input Capacitance	f = 1.0MHz - 135 - pF
Output Capacitance	COSS - 80 - pF
Reverse-Transfer Capacitance	CRSS - 20 - pF
Internal Drain Inductance LD Measured From the Contact Screw On Tab To Center of Die	3.5nH
Pulse Source to Drain Current	ISDM - - 20 A
Source to Drain Diode Voltage VSD TJ = 25C°, ISD = 5.6A, VGS = 0V.	2.5 V

Little note on Antenna's

It's important to use a correct designed antenna according to band you would like to operate, or at least use a good antenna tuner to match the antenna (protecting your transmitter and proventing harmonics/interference...).

A resonant antenna is an absolute requirement for QRP operation, and an amplifier is not a "band-aid" for a poor antenna system!
We cannot expect good results from low levels of RF output if the power gets wasted in lousy coax, corroded connections, or poor antennas. Several examples can be found on my website and all across the Web. A dipole is always a good alternative (total length = 150 / freq - 5%).
Related

Remember that transmitting and/or using an power levels higher then your local license permit is illegal without a valid radioamateur license!