Medium Power 137kHz Linear Power Amplifier

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This project was conceived on the back of an envelope after running a WSPR beacon thorough my 600 Watt switch mode Power Amplifier, and setting light to the plastic shed containing the loading coil [1]. I realised I needed a lower power transmitter that would be safe to leave for continuous unattended operation. Previous tests on air had shown that a QRP Tx supplying around 6 watts was inadequate – no one heard me – and the big one was, well, too dangerous to feel comfortable about running unattended. So a 137kHz PA in the region of 30 – 50 Watts was going to be needed. Initially I thought of building a class E design, and while looking for suitable devices for that, realised I had quite a large stock of a rather old, indifferent RF FETs salvaged from a scrap industrial plasma welder. These were RFPP53 devices, no data could be found but it was clear they were 50 volt devices, used eight to a board at 13.56MHz for 1kW output. They would make a quite nice linear transmitter for LF, and a linear design would be useful to have on the shelf for any future data-mode tests for waveforms with an varying amplitude component. Not too many linear designs for 137kHz exist, G0MRF has a design for a 250 Watt linear PA [2]

Overall Design

I wanted to run from a 24 – 26 Volt supply so the devices would not be ideal, but so what – I had plenty! It might be possible to get the 40 – 50 Watts from a single device but the harmonics would be awful and efficiency poor, so a traditional push-pull design was the obvious route. Design for more power than is needed to start with; with a 28V supply, 60 Watts output requires a push-pull load resistance (between the drains) of $24^2/60 * 2 = 19\Omega$. My LF system on 137kHz has 100Ω load resistance so a transformer of around 1:2 to 1:3 impedance transformation would do the job.

Figure 1 Shows the circuit diagram of the final amplifier, and two photographs of the finished breadboard construction can be seen at the end.

Output Transformer

Looking through the junk box revealed several cores obtained over the years for SMPSU use. A 35mm diameter pot core made from 3C85 material was found which I knew this was good for SMPSUs; it had been in a homebrew one many years ago supplying 80 Watts or so. The all important core cross sectional area (A) was measured as $180mm^2$ and using the low value of B_{max} of 0.08 Tesla as a limit to avoid losses, the minimum number of volts per turn determined from :

$V_{RMS} = 4.44. F . N . A . B_{MAX}$

$V/N = 4.44 * 135000Hz * 180*10^{-6} * 0.08 =$ 8.6 Volts / turn maximum (RMS volts)

With a 26V supply, Vpk-pk across the two FET drains would be 52V, or 18V RMS, so a minimum of three turns is needed. Since the winding must be centre tapped, this has to become 4 primary turns. So for a 1:2 to 1:3 transformation 8 to 12 turns would be needed on the secondary.

The bobbin could just be filled with 13 turns of single strand 0.8mm enamelled wire, so this was chosen as the maximum number to be used, with taps at 8 and 11 turns made by twisting the wire on itself at the appropriate position / turn, and passing the double-strand across the winding to the outside world for connection. This prevents any need for soldered joints inside the transformer bobbin. The toggle switch visible in the photographs selects either the 8 or 11 turn tap positions. The primary was wound on top of the secondary, and consisted of 2 + 2 turns of bifilar twisted 1mm diameter wire. The whole lot just fitted within the pot core, although it was a bit tight with all the tap positions all having to be brought to the outside world.

Driver Stage

The PA stage was built first, and to test it RF from a signal generator applied to the gates via a 1:1 RF transformer to see what sort of drive would be needed - no data sheet was available for the devices, everything had to be determined by measurement. To keep things simple, the gates are damped with 51Ω resistors, which also serve as the bias inject – bias being set separately by individual presets for each device supplied from a stabilised 12V source. Differential impedance is therefore 100Ω, and with Miller feedback from drain to gate, we're probably looking at around a total R_{in} of 50 to 100Ω at this low frequency.

Each device was set to run with 250 - 300mA bias – this seems to be a standard for high power MOSFETs.

It turned out that the devices could be driven to saturation with 250mW from a 50 ohm source applied differentially to the gates. 150mW was sufficient for just-noticeable non-linearity in the output waveform. Also, and this was the good bit – I couldn't get the things to go unstable. Probably due mainly to the low value of gate damping resistors, but also to the FETs being of ancient heritage and not terribly high frequency devices.

At 200mW maximum, a BFY50 in class A is just asking to be used. Running from the 12V stabilised rail, a load resistance of 200 ohms will allow 360mW maximum with a quiescent current of 50mA. All comfortably within a BFY50's ratings. So an intermediate transformer of 2:1 is now needed to transform this 200Ω optimum to the 50Ω or so of the device inputs. A small 15mm toroid, of 3C85 type material (recovered from the current sensing transformer of a defunct SMPSU) was wound with 8 quadrifilar turns. Two of the four strands were series connected for the primary with the remaining two paralleled for a thicker secondary, giving a 2:1 isolated transformer.

I needed to obtain full power with less than +3dBm drive, so the driver had to have about 24dB gain (16 times voltage). With R_{load} for the BFY50 of 200Ω an emitter degeneration resistor of about 200/16 = 12.5Ω was required. This was made up of a 20Ω unit setting the DC bias, and another 33Ω in parallel, decoupled at AC. Base bias resistors were chosen to give the 50mA quiescent, and present a load to the input of about 100 ohms. A 200 Ω preset used as an input attenuator gives an input close to 50Ω when set near to maximum. The IN4001 compensates bias with temperature.

Control and Switching

For beacon use the PA has to be capable of being enabled and disabled from a ground-to-Tx line. A P-Channel Mosfet controls the input to the 12V regulator, so all bias and driver supplies are removed in standby, resulting in zero power consumption. A small 12V fan was also wired into circuit to allow a smaller heatsink to be used than might otherwise be reasonable – remembering that for WSPR operation up to four minutes continuous transmission could occur.

Results

Maximum power output before device saturation set in was a bit lower than expected. 40 Watts could be obtained with ease from a 26V supply (using the 8 turn secondary tap into 50Ω for a device R_{load} of 12.5Ω). But much above this the waveform began to flatten which is considerably below the 100 Watts that should be achieved at this load resistance. The devices saturated with about 3 - 4V across them, but as they were designed for 50V operation this perhaps may not be too unreasonable. So efficiency wouldn't be very good, but the power out was at the level I was after, and it was very linear and stable, so call it 80 – 90% successful!. At 40W into a resistive load, the output sinewave looked perfect on a scope, and on a spectrum analyser showed to be in the -30dB region. Given the Q of the antenna system – no Low Pass filter was going to be needed provided the amplifier wasn't driven into saturation.

Connecting to the antenna (with the transformer tap adjusted for 100Ω load), again resulted in around 40 watts output. The unit has been running at this level continuously, with a WSPR duty cycle of 33% for a couple of days now.

Replication

You almost certainly won't get the RFPP53 devices I used, and I wouldn't recommend them anyway. Better to use proper 28V design devices with their lower $R_{DSS(on)}$ and lower saturation voltage drop. Audio devices like the 2SK414 will probably do – they were more than adequate at 73kHz in the good old days – and have a similar transconductance. They might not have as good a frequency response though.

I have an inherent dislike of using switching type power MOSFETS for linear operation ; it just doesn't ***seem*** right, but others have done so successfully [2]. Setting the bias is a bit critical as they have a much higher transconductance, which results in potentially lots more gain and, lower input impedance. It will be worth trying devices from the IRF620 / 30/ 40 family which being rated at 200V gives plenty of safety margin. If gain proves too high, and instability sets in, connect a simple feedback resistor (with a DC blocking C) from Drain to Gate of each device. Start with 330 ohms and alter the value until you end up with a gain / stability that is acceptable.

All the ferrite cores I used are a bit old-hat now as all my experimentation in SMPSUs was done in the last century - but the basic rule applies : $V_{RMS} = 4.44 . F . N . A . B_{MAX}$

Any ferrites and cores designed for modern SMPSU use will work at 137kHz; almost certainly they will at 500kHz, and perhaps even on topband provided that equation is met. Beware core shapes though. Use UNGAPPED cores for transformers. Use gapped cores for inductors and for carrying DC – but that's another story. If you have obscure ferrite cores that are clearly not part of SMPSUs, treat with caution. Those designed for EMC uses are appalling as transformer cores. Use an LC meter to check Al value, and if it is less than 1uH / turn^2 then the ferrite is probably not suitable for LF use. But with the plethora of SMPSU stuff in the catalogues, there is little point in trying to make use of dubious surplus cores of uncertain type

Frequency Extension

At 500kHz it was clear the output stage would still function perfectly, but the reduced FET input impedance at this frequency loaded the driver more, so it was not possible to actually get full power output as the driver went into saturation. It is quite possible, though, that with an uprated driver of something like 2 Watts capability and some resistive feedback around the output FETs to flatten the frequency response, broadband LF operation from 100kHz to 3.5MHz may be achievable. As I already have a perfectly good broadband PA for 500kHz to 40MHz I'll leave it for others to follow-up.

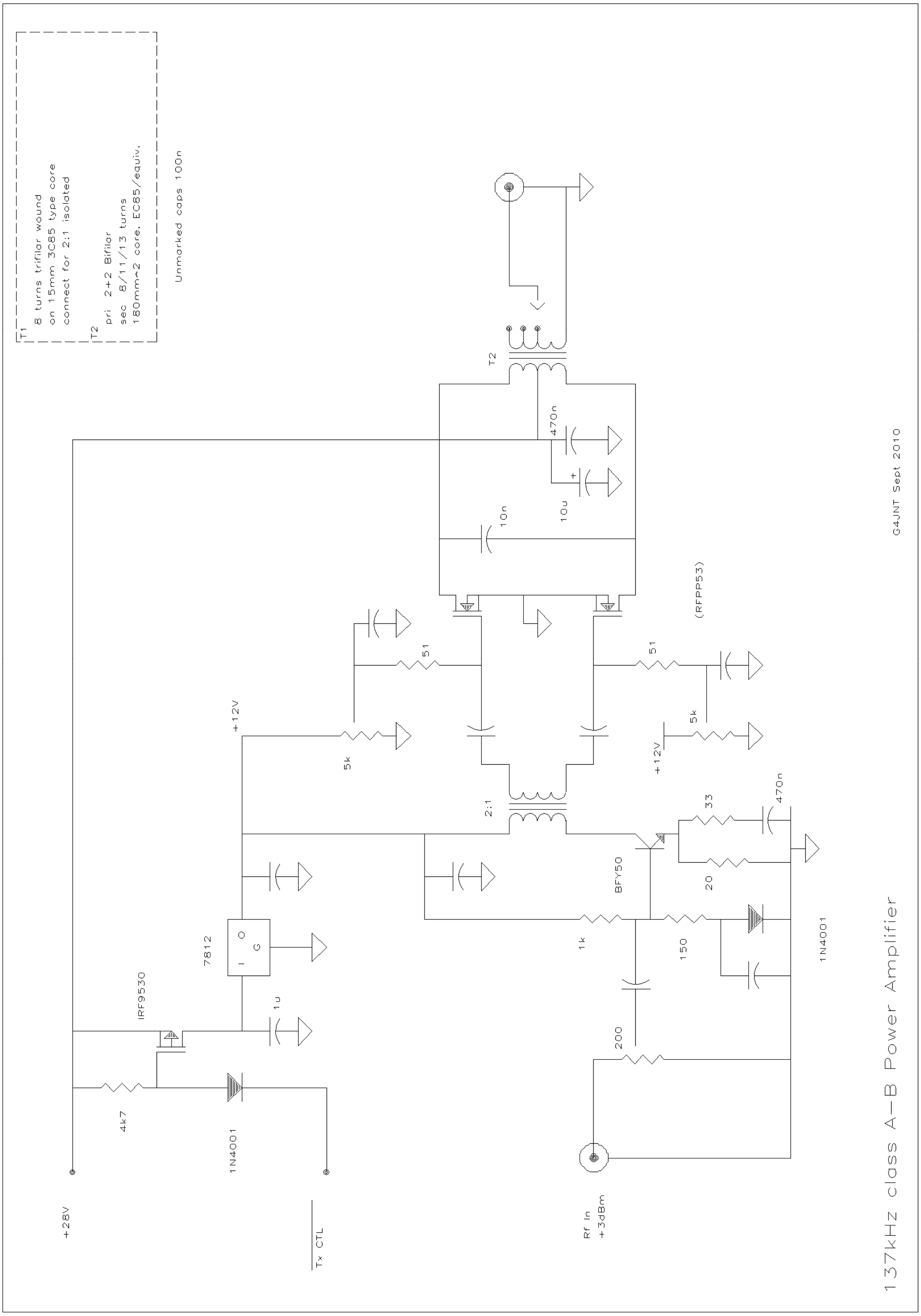
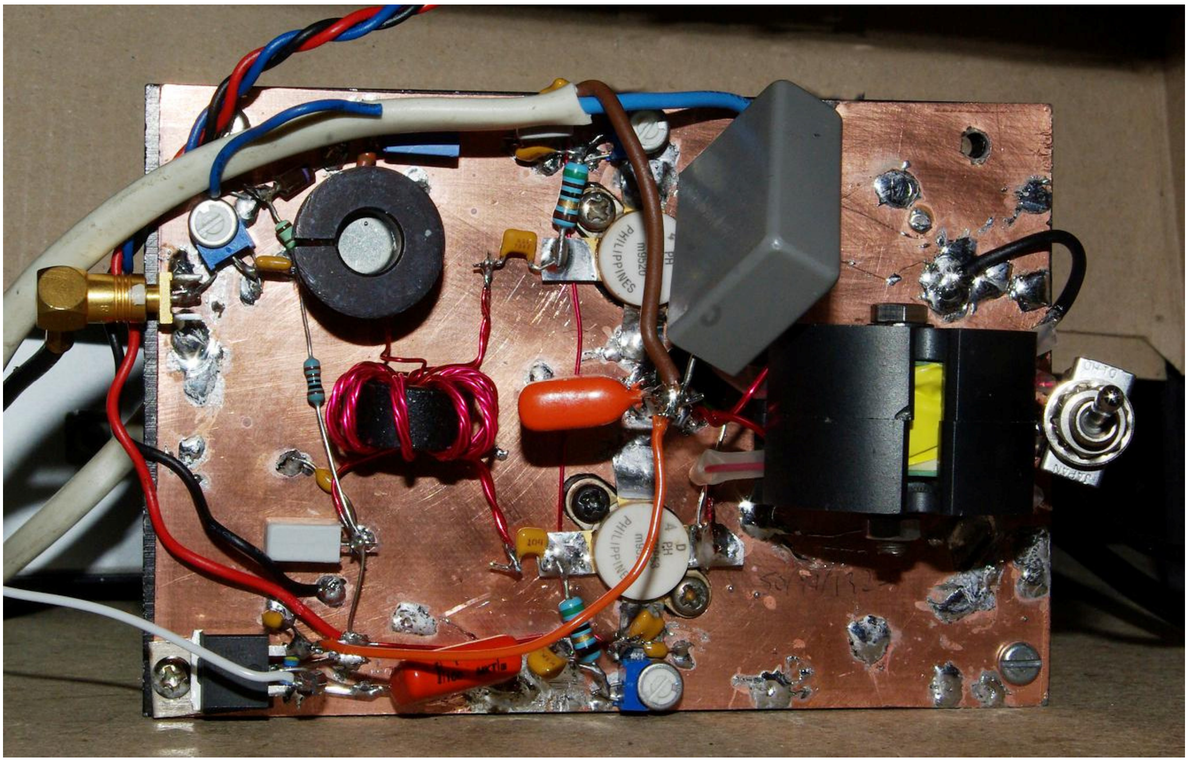
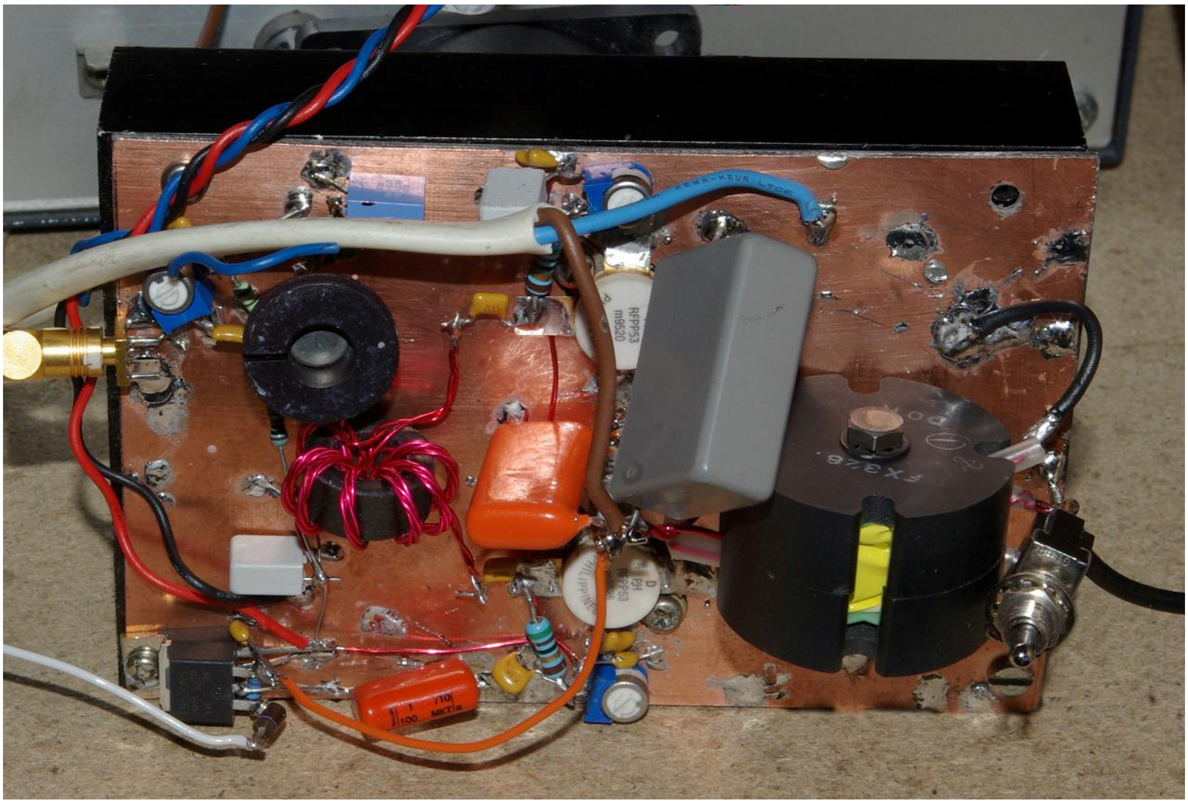


Figure 1 Circuit Diagram





References

[1] http://www.g4jnt.com/QRO_LF_DoesThis.JPG and http://www.g4jnt.com/Melted_ATU_Cabin.JPG

[2] http://www.g0mrf.com/lf.htm