Medium Power Linear Power Amplifier For LF/MF

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This is an updated version of the LF Linear amplifier described in [1] After giving that amplifier to G0API to use on PSK31, I decided I did actually need one (to work him with) so this updated version was built.

Overall Design

Although switching MOSFETS really aren't designed for linear operation, enough people have now used them with varying degrees of success to make them worth looking at. Some designs can be seen at [2]. I had a lot of spare IRF520 devices, these are 100V rated and have a quoted $R_{DS(ON)}$ of 0.2 ohms. IRF540 devices with their lower on resistance would no-doubt be more suitable but as I had so many of the former, they were just used and with a 26 – 28V Volt supply, would be well within their voltage limitation. These FETs are lower power than the RFP devices used previously, so the target power output was reduced to somewhere in the 40 - 50 Watt region

Figure 1 Shows the circuit diagram of the final amplifier, and a photograph of the finished design using surface mount components can be seen at the end.

Output Transformer

Designing for maximum power and a saturation voltage of 3V; based on a 26V supply, 50 Watts output requires a push-pull load resistance (between the drains) of $23^2/50 * 2 = 21\Omega$. The design was for a nominal 50 ohms out so a turns ratio of $\sqrt{(50/21)} = 1.54$ would be needed

Looking through the junk box revealed an RM10 sized core made of F44 material, marked with an RS part number, 231-8757. (RS Components still supply this item). The data sheet suggests typical operation up to 300kHz in SMPSU use, so when used with a sinusoidal waveform and lower B_{MAX} will quite OK to 500kHz or more.

The all important core cross sectional area (A) was 95mm^2 and using the lowish value for B_{max} of 0.06 Tesla as a limit to avoid core losses, designing for the worst case at 135kHz the minimum number of volts per turn determined from : $V_{RMS} = 4.44. F . N . A . B_{MAX}$

$V/N = 4.44 * 135000Hz * 90*10^{-6} * 0.06 =$ 3.2 Volts / turn maximum (RMS volts)

With a 26V supply, Vpk-pk across the two FET drains would be 52V, so 18V RMS, and a minimum of six turns is needed. 8 turns centre tapped were actually used, made from 4+4 parallel turns of 0.8mm wire. So for the ratio needed, a 12 turn secondary is suited. The secondary was actually made with a tapped winding of 10, 12 and 15 turns, with the taps 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 whole lot just fitted within the pot core, although it was a bit tight with all the tap positions being brought directly to the outside world.

Driver Stage

To keep things simple, the MOSFET gates are damped with 62Ω resistors, which also serve as the bias inject – bias voltage being set separately by individual presets for each device supplied from a stabilised 12V source. Differential impedance is therefore a maximum of 120Ω resistive, and with Miller feedback from drain to gate, we're probably looking at appreciably lower value of R_{in}

Each device was set to run with around 100mA bias. The devices can 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. To compensate the higher Gm , and the fact the FETs were non-optimal, switching devices compared with the proper RF ones used previously, a simple feedback network consisting of 430 ohm 0.5Watt resistor and DC blocking capacitor was added between Drain and gate of each device. This modest negative feedback lowered the gain such that around 300mW was now needed for full drive, and the total input resistance reduced to around 40 ohms

The original amp used a BFY50 as a driver, but I was running out of junk-box stocks of this ancient wire ended component and wanted to use an SMT device with a PCB pad as its heatsink. The BFQ19S has a ridiculously high Ft for use at this frequency (over 5GHz) , but was to hand, is readily available cheap, and has the right sort of power rating, Pmax = 1 Watt Running from the 12V stabilised rail, a load resistance of 160 ohms will allow 300mW output maximum with a quiescent current of 60mA. All comfortably within its ratings. So an intermediate transformer of 2:1 is now needed to transform this to the 40Ω or so of the device inputs. A small 12mm torroid, of (probably) 3C85 or F44 type material was as wound with 5 quadrifilar turns of 0.2mm wire. 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 transmission line 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 BFQ19S of 160Ω an emitter degeneration resistor of about 160/16 = 10Ω was required. This was made up of a 20Ω unit setting the DC bias, and another 20Ω in parallel, decoupled at AC. The second one can be varied to adjust the overall gain. Base bias resistors were chosen to give the 60mA quiescent, and present a load to the input of about 50 ohms. The IN4001 compensates bias with temperature.

Control and Switching

The PA is 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 24V fan was also wired into circuit to allow a smaller heatsink to be used than might otherwise be reasonable.

A double pole relay was used for antenna changeover. One set of contacts are used conventionally, and the other set used to switch a 47Ω resistor across the Rx port when transmitting. This lowers RF leakage and ensured the receiver input is correctly terminated. An isolation of 70dB was measured at 475kHz.

Results

Maximum power output before device saturation sets in is around 40 - 50 Watts with a 26V supply (using the 15 turn secondary tap into 50Ω for a device R_{load} of 14Ω). Lower output at 35 – 40 Watts at slightly reduced current (higher efficiency) was possible with the 12 turn tap position. Much above this the waveform began to flatten. The devices saturate with about 3 - 4V across them, so efficiency is lower than could be possible. Using IRF540 devices would give lower V_{DS} For saturation and increased efficiency 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.

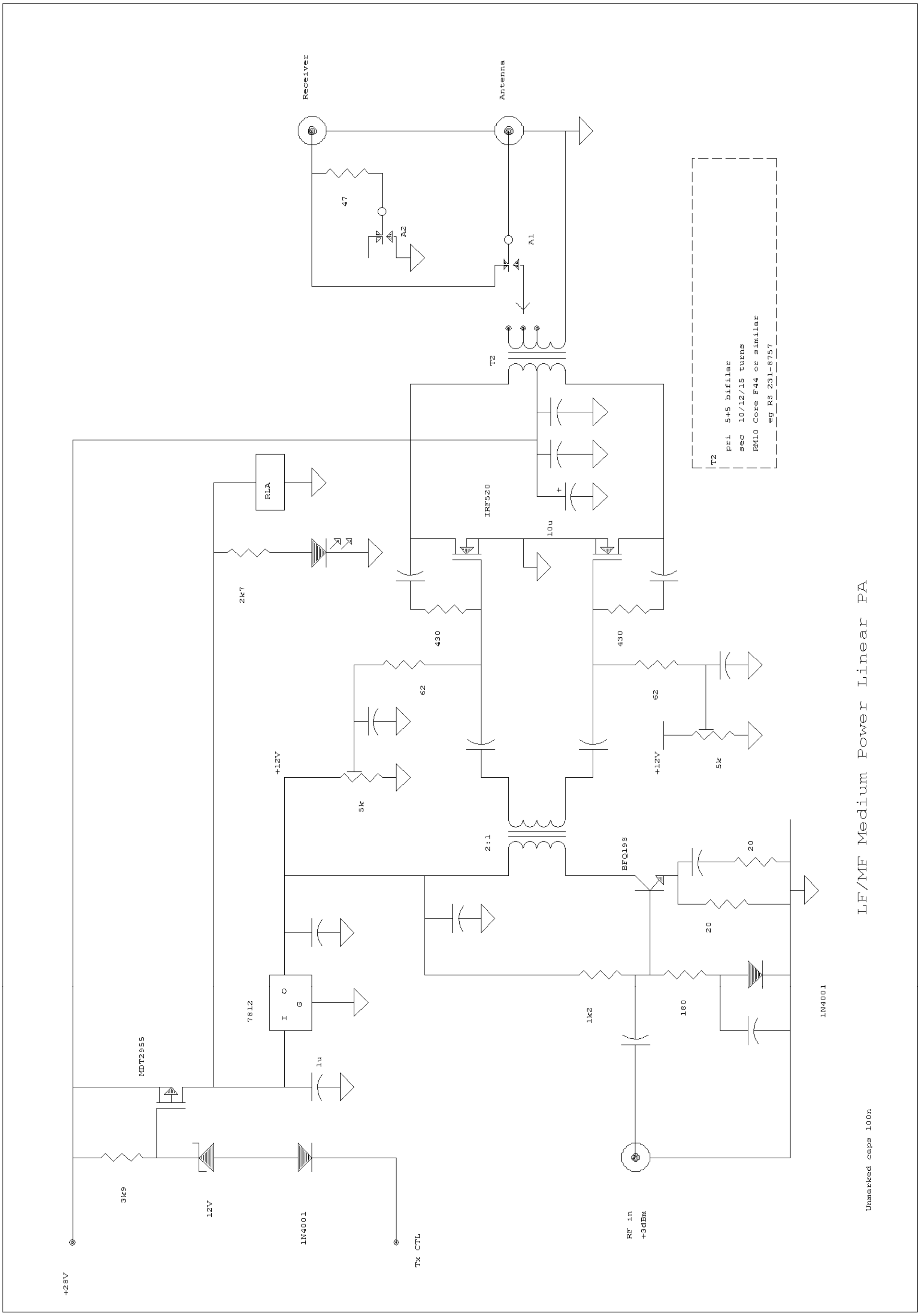
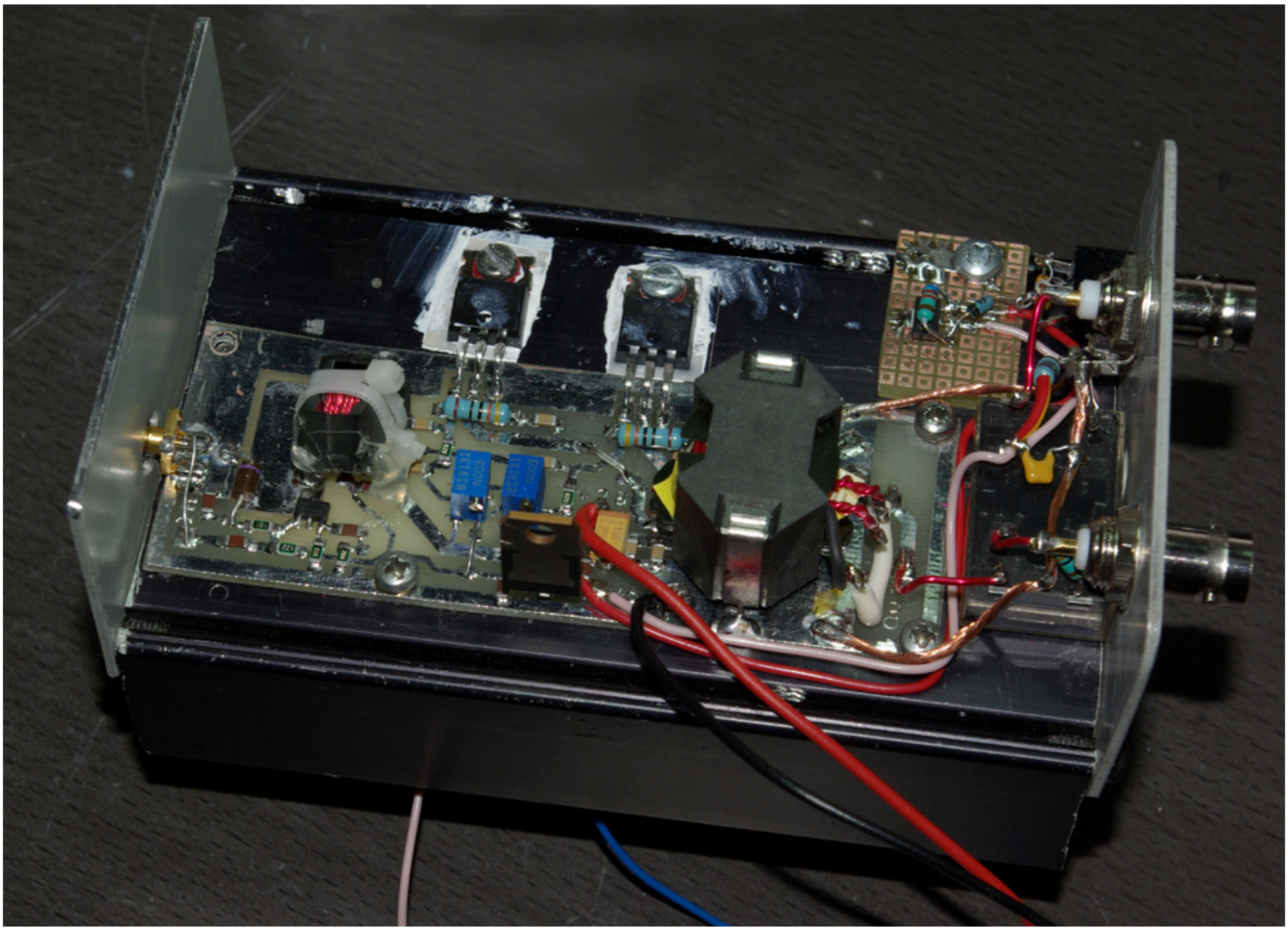


Figure 1 Circuit Diagram



References

[1] http://www.g4jnt.com/Linear_LF_PA.pdf

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