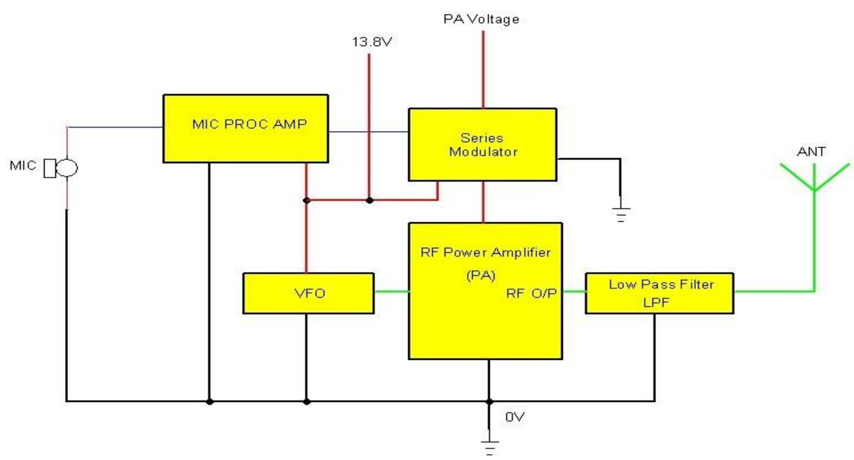
A High Efficient, Low Cost, AM Power Amplifier for 160m, 80m, 60m or 40m Band

Introduction

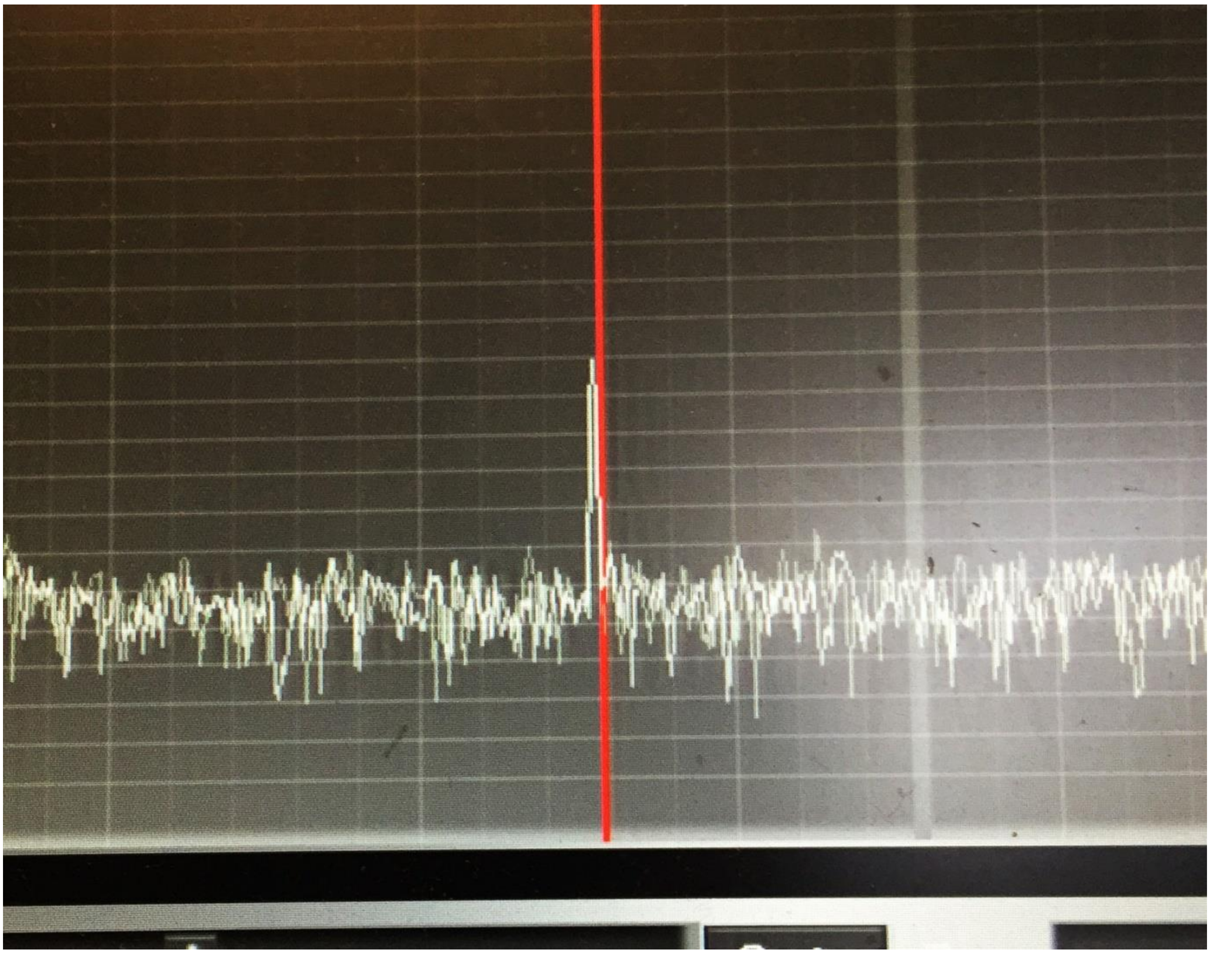
There are several ways to get on the air using AM (Amplitude Modulation) as the mode of operation and this can be with the use of all-mode 'ham' transceivers, vintage transmitters and ex-military equipment. The way described in these pages is by the home-brewing (home-made) method. The receiver can be part of the existing equipment, a separate communications receiver with AM facilities, local SDR (in the shack) or remote (WEB SDR).It is very rewarding building your own station and is made easy by using AM as the mode and the method shown will ensure parts are readily available, either by sourcing the parts yourself or by using a kit of parts for the various stages. There is nothing more frustrating than taking a design from a magazine or on-line to build a transmitter, receiver or any other electronic equipment, to find that the parts needed are no longer available. Obviously I cannot guarantee the continued supply of parts of the kits as on the S9Plus site but where there is a probability of parts running out, I will endeavour to source replacements or change the designs to accept replacement components. I do however, have plenty of the parts needed in stock. The different parts (modules) of the transmitter can be built up gradually and tested or can be built complete. A complete transmitter is shown here as a block diagram. This uses a modified PA module of the FAT5 PA originally designed by Dave GW4GTE.



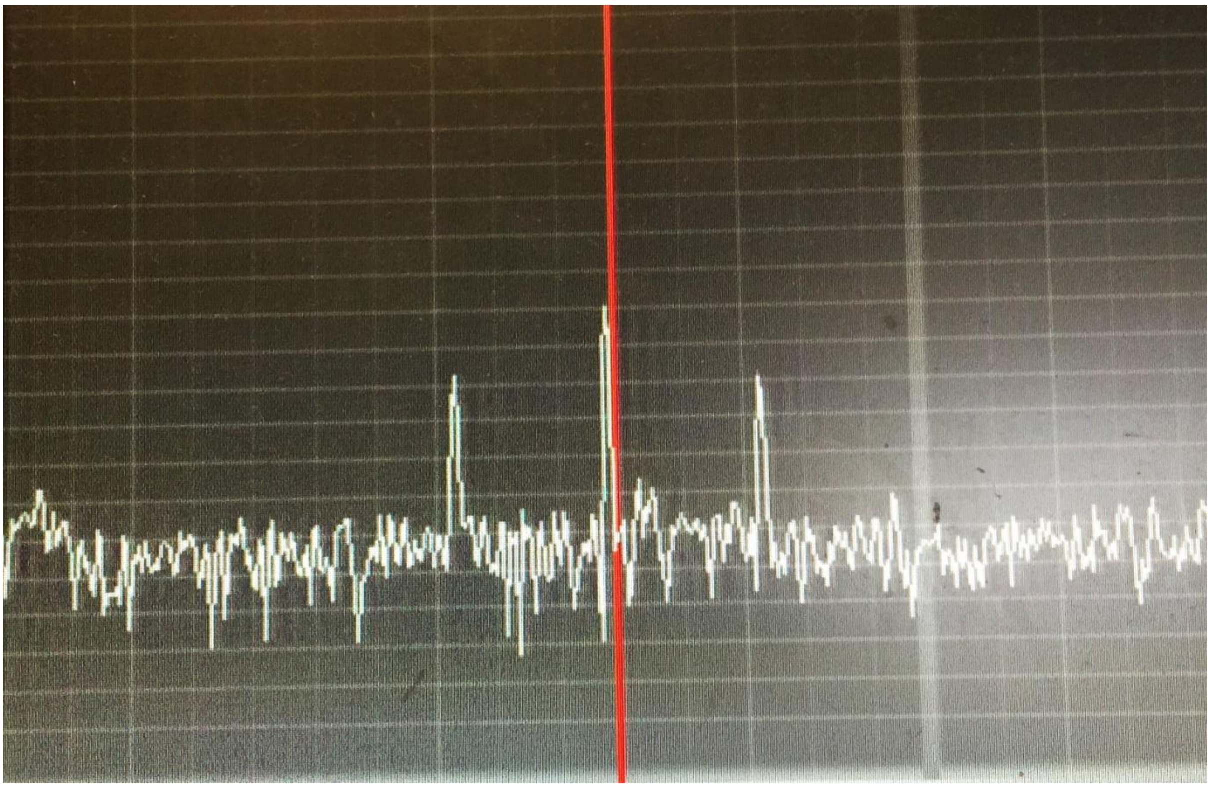
The project described in these pages is for the PA part of the transmitter and the other parts to complete the transmitter can be your own units or from kits or part kits from the web site www.s9plus.com These are designed to accompany this type of PA and all are available on a non-profit, cost recovery basis to keep costs as low as possible. Here is a short description of amplitude modulation of a PA...

Amplitude Modulated PA

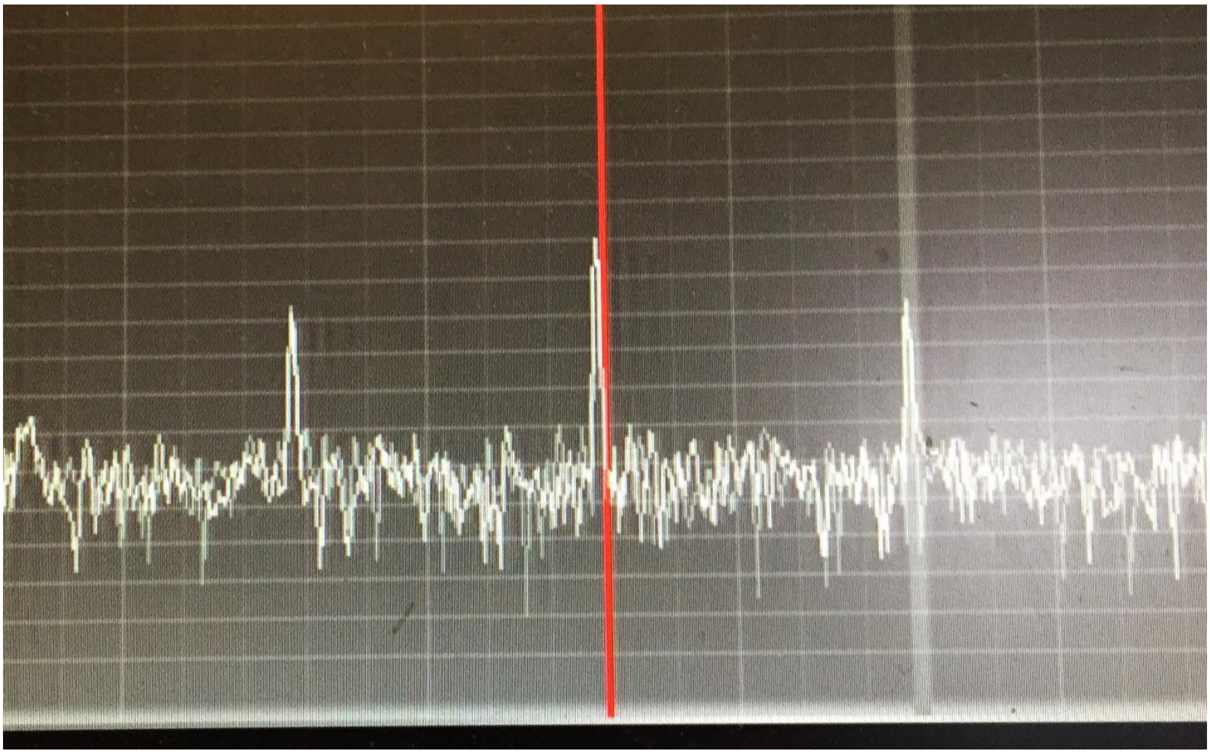
Amplitude modulation in an AM transmitter is when an RF carrier is modulated with another signal. This project uses an audio signal (speech) to modulate (mix with) the RF signal (carrier). The modulation process creates another two signals. One lower than the original carrier frequency and the other is above the carrier frequency. This is similar to a superhet receiver where the input received signal is mixed with a local oscillator to produce sum and difference frequencies (two side frequencies or bands of frequencies) and one is selected as the IF (intermediate frequency). The transmitted (un-modulated) signal referred to as the carrier is the frequency and its power level reference. When the carrier is modulated it produces two other frequencies that use the same PA voltage so the main signal (carrier) voltage has to be set to allow for the extra two signals to be able to use the same voltage (and current) as the carrier on its own. The carrier voltage is normally set at 50% of the full supply. The sidebands produced by modulation is when at peak modulation (loudest audio signal) half the amplitude of the carrier voltage. When added together the carrier and the two sidebands (2 X 50% of the carrier voltage) produces double the carrier voltage. The doubling of PA voltage also causes the current to double (square law) hence the power is four times that of the carrier alone. As an example transmitting a carrier at 100W, when fully modulated (PEP) the power indicated on an in line antenna 'peak setting' power meter will indicate 400W. The meter is not fast enough to show the full output power without a delay circuit within the meter so a peak reading meter will be required.
In this photo an un-modulated carrier is shown received on an SDR receiver so that the signal can be seen and examined as well as being heard.



This one shows the carrier modulated with a 1kHz signal...



And another off air photo of the carrier modulated with a 2kHz signal...



It can be seen that the carrier does not change in amplitude when modulation is applied. It is the sidebands (audio modulation) that changes in amplitude during different levels of audio. The receive station receiving a steady 'S9' on the signal meter with an un-modulated transmitted carrier will receive the same signal strength shown on the meter when the carrier is fully modulated as the meter will not be fast enough to show any signal level changes during audio modulation. The actual power received is the carrier power and the intelligence (speech) is sent as two sidebands, one lower and the other above the carrier frequency and the combination of these sidebands 'beating' with the carrier produces the audio in the receiver. The stronger the audio signal (depth of modulation) the louder it will sound on the receiver's loudspeaker. The power as seen on the 'S' meter will be the same at all levels of audio. The PA wattmeter measuring the RF power output to the antenna will read higher when the carrier is modulated because the transmitter is sending out a carrier and two peak modulated sidebands when a sinewave is used for modulation. These two sidebands are very close to the carrier so the power meter is measuring the power (current) of all three signals. When audio is used as the modulation, the two sidebands will vary in amplitude and so will the reading show some variations on the antenna power meter if a peak reading meter is used. The meter measuring the signal volts and displaying in dBs is not fast enough to show the varying voltage when modulation is applied. Connecting a scope to display the voltage with a steady sinewave along with modulation the increase can be seen easily and it can be observed that when fully modulated the voltage amplitude of the carrier can be seen. This is the combination of the carrier and sidebands and they move in and out of phase to each other. When all three signals are in phase the combination is showing twice the voltage amplitude of the carrier alone. Twice the voltage is also twice the current so the power increase is four times. When the three signals are out of phase the waveforms shown on the scope is much lower than the carrier alone. The waveform is shown as rise and fall in amplitude and consequently in power so the output power is an average of the total. The carrier remains constant in amplitude during the RF period but changes in amplitude during audio peaks and troughs. The changes are too fast for the 'S' meter to show these, so it shows the carrier signal voltage level.

What is required?

AM is found on several of the HF bands and are usually operated using Class 'C' PAs or as a function of a multimode transceiver. The project set out here is of a high efficiency transmitter PA (Class 'E') and the bands that can be used are 160m, 80m, 60m and 40m. It is not possible, at the moment of writing, to use this mode of PA on bands higher than 40m. This is because of the limitation of the FETS and Drivers used at power for these frequencies. The PA to be described is Class E and has the ability to run at the full maximum power for the bands used. The maximum power for, in the UK, (recently some bands are allowed 1kW), 160m, 80m and 40m is 400W pep (100W carrier) whereas the power is limited to 100W pep (25W carrier) for the 60m bandlet.

Class E brief explanation

Taken from the FAT5 manual on Dave's site.... www.s9plus.com

"A Class E amplifier achieves high efficiency due to the fact that when ideally tuned there is no appreciable time overlap between the above-zero voltage applied to the FET drain and the above-zero current flowing through it. Obviously there must be volts for current to flow – the flywheel effect of the PA tuning produces this. The point is that when the FET changes state from on to off or vice versa, the source-drain voltage is almost zero, so no appreciable power is lost as heat as the FET switches. To achieve this, the PA is tuned for the required phase relationship between Volts and current. There must be a reactive element present to achieve this, so conventional resonance tuning resulting in a purely resistive impedance transformation won't work".

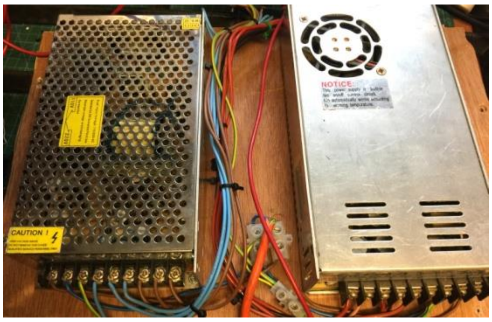
What that all means in simple terms is: The PA is a switch, and when the FET is ‘turned’ hard on (saturated) maximum current flows but with no voltage as the drain is now at source potential. Obviously nothing is perfect and because of device resistance, a little voltage will be at the drain with respect to the source; however this will be small and decided by the tuning. The voltage and current is not appearing together so very little heat dissipation is given off by the FET. For this to work, and provide power at the antenna, a pair of FET circuits is used in push-pull. The outputs are connected to a transformer and the voltage along with the current is supplied at the antenna to produce the required power.

PA Power levels

The power output of the PA is dependent on the PA voltage. The drive to the PA is from the VFO connected to the comparator and is the same output (drive) level for all power output levels of the PA. The PA can be used with a power level <10W pep or as high as 400W pep using the same VFO. The highest power, and hence the PA voltage is determined by the FETs used and is recommended to be no higher than 40V. Normally 36V provides 400W pep. Test made during the preparation of this publication, with 13.8V volts as the PA power supply the power output at a 50Ω load connected via dummy load was 50W as shown on the power meter

Increasing the PA supply to 23.5V the power output increased to 160W.

With the supply connected to two 'Chinese' filtered SMPSU to provide 39V the power increased to 410W.



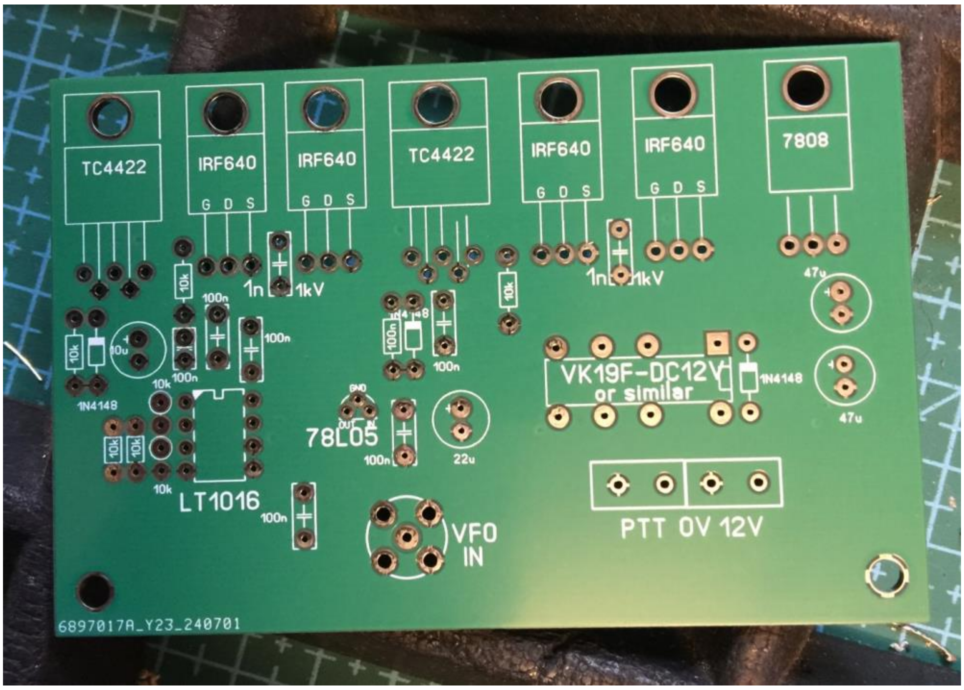
The PA efficiency at all the different power levels was 97% on my test setup. The only changes to provide the different RF power levels to the dummy load, was the PA voltage. The current increases in a linear mode along with the voltage so that if the voltage doubled the current also doubled and is referred to as 'square law'. Doubling of the voltage therefore provides a four times power increase. The 'S' meter (calibrated) on a receiver shows increases in 6dB. Each change of the 'S' point shows an increase (or decrease) in twice (or half) the voltage but due to the square law it represents four times increase 25% (¼) power decrease.

PA Driver

Any stable VFO at the transmitted frequency can be used at the transmitter frequency and it can be a sine wave at 1V or a squarewave at the standard logic level (3V to 5V). The output of the VFO is connected to the precision comparator on the PA board. The VFO need the same output level at all PA (RF) levels as the power output from the PA is governed by the PA voltage and the current drawn. The VFO is used at the transmit frequency and not twice the frequency found in other Class E designs.

The PA

This is built on a PCB of commercial quality so all parts are shown on the top side of a double-sided board commonly called silk screening. This is a modified PA module of the FAT5 PA designed by Dave GW4GTE.



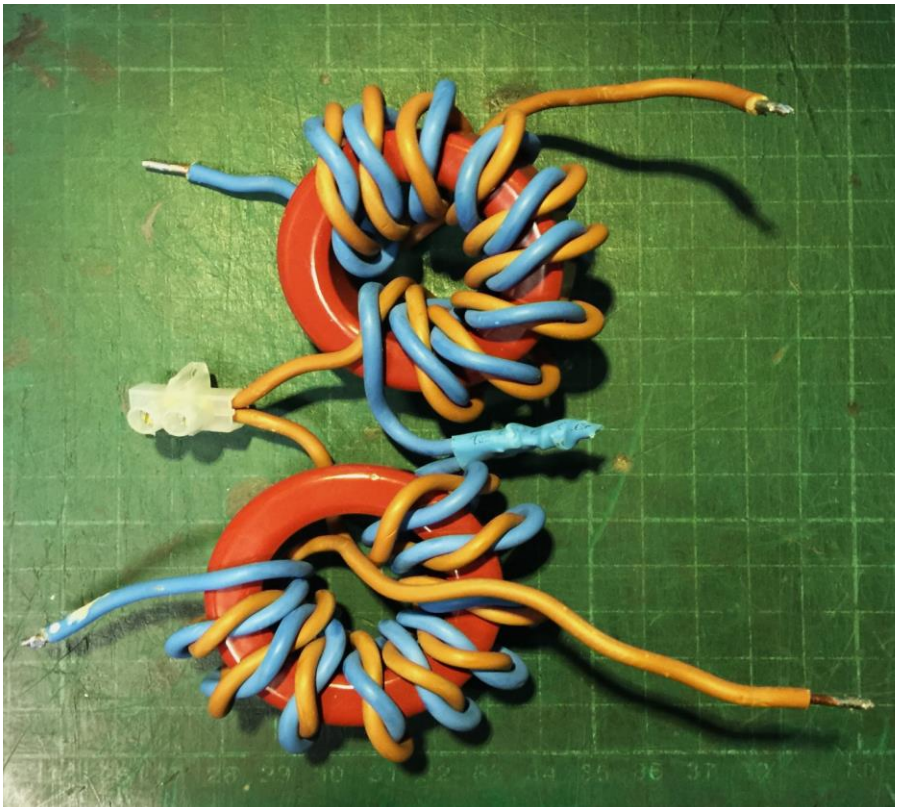
PA TUNING

This uses two T200-2 toroids and bifilar windings to perform an RF transformer. The RF transformer is actually two separate transformers. Each transformer primary is driven by one pair of FETs. As the FET-pairs are driven in anti-phase the primary windings are in anti-phase. The transformer secondaries are connected in series with one winding reversed so that the outputs combine in-phase. The PA tuned circuit is a conventional impedance matching arrangement. It has to work hard converting the low impedance output of the FETs up to 50 ohms. Additionally it is responsible for establishing the correct phase relationship between voltage and current around the PA tank. Class E achieves high efficiency by minimising FET switching loss. This is done by adjusting the tuning such that when the FETs switch, the voltage across them is close to zero. Because of this requirement a different tuning method must be adopted and monitoring the FET drain waveform shape is essential when initially setting up.

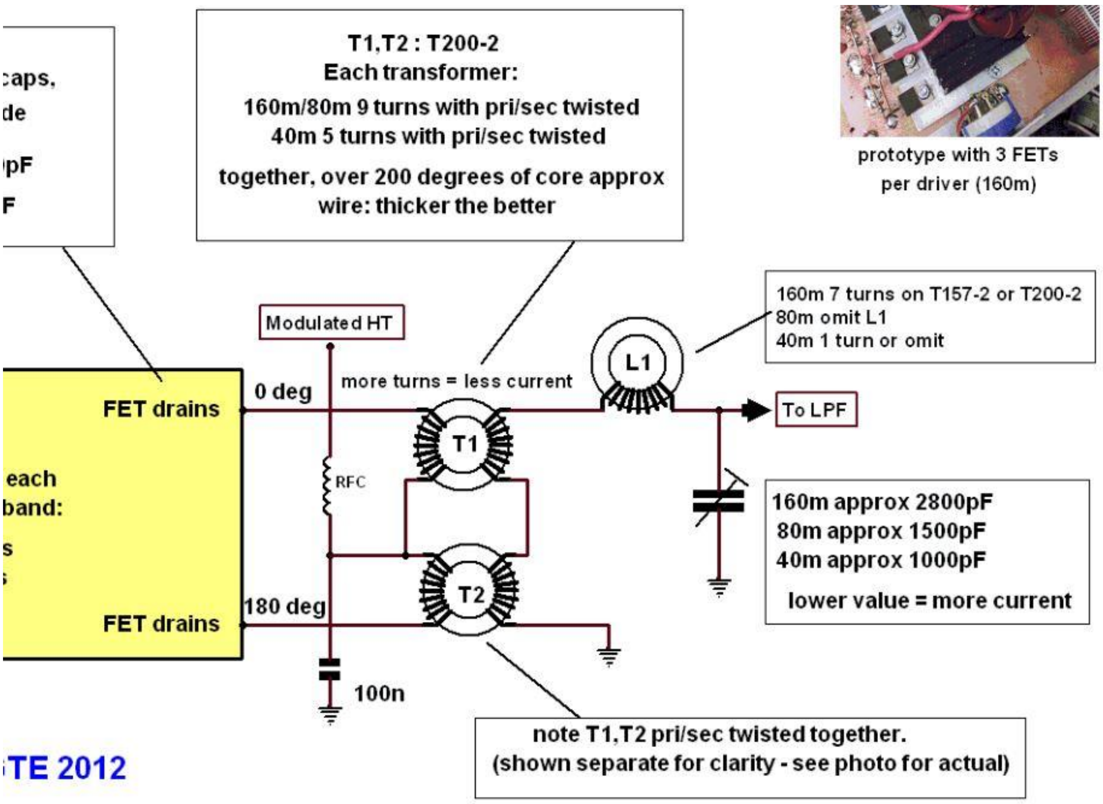
Constructing the PA Tuning Unit.

This uses a pair of T200-2 toroids with heavy (2.5 mm^2) mains type cable stripped from the outer PVC sheath and the bare copper earth wire removed. Smaller cable such as 1.2mm^2 can be used for lower power such as 200W pep. Leave the brown and blue insulation on the wires. Take a 1 metre length of the brown and blue cable and twist together using a pliers and an electric drill. Place one end of the pair of wires in the chuck of an electric drill gun and hold the other ends of the wire in the jaws of bull-nose pliers. Slowly rotate the drill chuck so that the two lengths of wire are twisted to provide an even twist throughout the length. It does not have to be very tight, so just enough to keep the two twisted together.

Showing the PA 'transformer'… (with heavier cable)



The Circuit of the transformer



To summarise

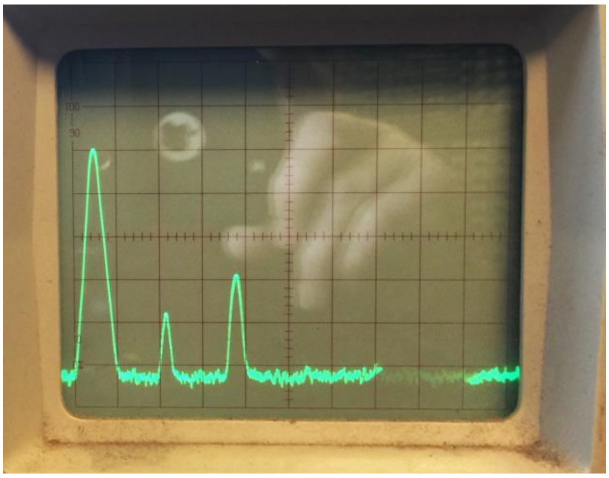
A Class E amplifier achieves high efficiency due to the fact that when ideally tuned there is no appreciable time overlap between the above-zero voltage applied to the FET drain and the above-zero current flowing through it. Obviously there must be volts for current to flow – the flywheel effect of the PA tuning produces this. The point is that when the FET changes state from on to off or vice versa, the source-drain voltage is almost zero, so no appreciable power is lost as heat as the FET switches. To achieve this, the PA is tuned for the required phase relationship between Volts and current. There must be a reactive element present to achieve this, so conventional resonance tuning resulting in a purely resistive impedance transformation won't work. The question then is how to establish the correct tuning-point. The correct tuning point is reached when the circuit is working at its maximum efficiency for a given power level.

Testing It (80m version)

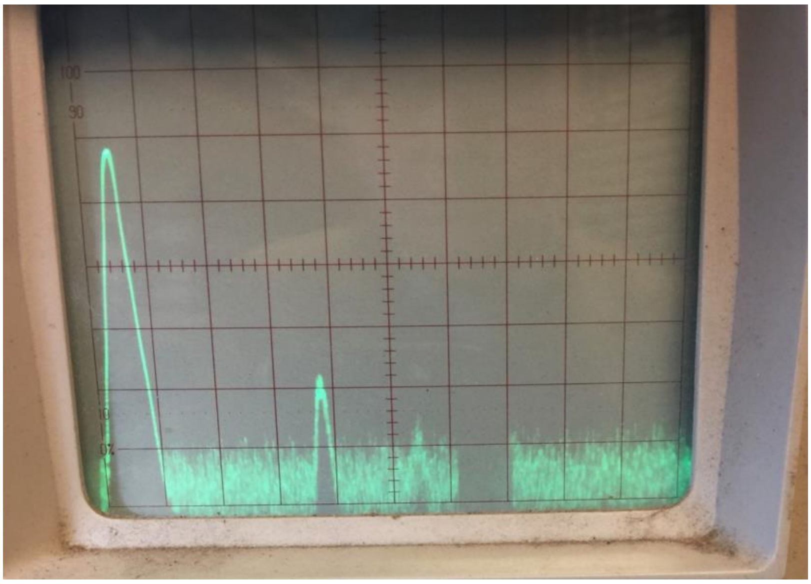
A scope (oscilloscope) is needed for the following test.
A single or dual beam scope with at least 20 MHz 'Y' resolution should be used to be able to see two sets of waveforms for ease of setting up. Set the scope 'Y' amplitude input to 2V per division and the 'X' timebase to 50nS.
Connect a single pole single throw (SPST) switch on the PTT pins.
With 12V (13.8V) applied to the pins on the PA PCB, the VFO connected and the PTT pins operated so that the pins are grounded, the pulse amplitude (pins 7 and 8) of the comparator should be 4V (or very near) squarewaves at the VFO frequency. Pin 8 will be the complimentary (180 deg opposite) phase of pin7. These squarewaves should also be seen at pin 1 of the FET Drivers (TC4422). The outputs of the TC4422 drivers are connected to the gates of the IRF640 FETS. Placing the scope probes on the gates of the FETs (There are two in parallel on both sides) a larger squarewave (8V) will be seen in a working circuit. There will not be any waveform, other than a small leakage, on the drains because there is no voltage connected to them yet.

Filter It

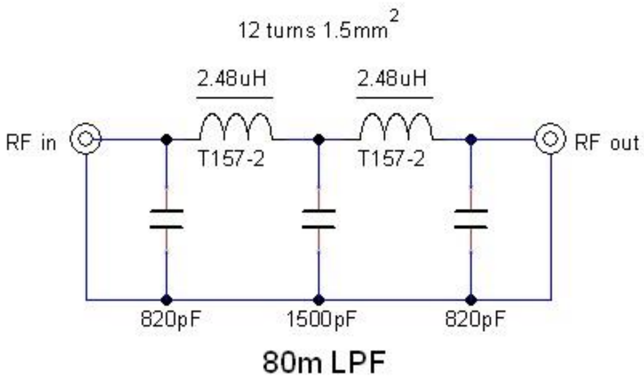
Although the RF sinewave, which is the power output seen at the antenna, shown on the scope in the tests looks clean, and indeed it is at the band it is tuned to. For this test it is 80m with the VFO set at 3.615 Mhz. It will not be the case at frequencies above the tuned band. The PA is using push pull outputs which greatly reduces or attenuates the even harmonics but odd harmonics are still possible to be created as seen here...



Using single ended PAs there are even as well as odd harmonics emitted and is the reason why push pull is used in this project along with providing more output from the same applied PA voltage.
A Low Pass Filter (LPF) is fitted between the output of the PA and a resonant antenna for the band or the antenna via an ATU. The filter is constructed to cut off or greatly attenuate before the third harmonic as the second harmonic is normally very much attenuated with a push pull output



It could be argued that an LPF is not needed with a resonant antenna for the band but it should be fitted as ‘belts and braces’.
Fitting a LPF type with a capacitor input to ground as in the circuit



The parts (picking) list shown below is for a QRO PA but for a QRP (up to 100W pep) only one IRF640 is used on each side.

Picking List QRO Class E PA

Please DO NOT use UNleaded solder

Component	Value	Ident / Info	Quantity
Resistors	10k		8
Capacitors	100nF		7
Capacitors	10uF	Electrolytic	1
Capacitors	22uF	Electrolytic	1
Capacitors	47uF	Electrolytic	2
Capacitor	1nF 1kV	Ceramic	2
TC4422		FET Driver	2
IRF640		FET	4
LT1016		Precision Comparator	1
7808	8V	Regulator	1
78L05	5V	Regulator	1
Relay	12V	VK19-DC12V or MCB-S-212-C-M	1
Connector		SMA	1
Connector		DIL pins	2 X 2
SMA socket		VFO IN	1
PCB	GW8LJJ		1
Screws, plane and spring			7
Solder Tags		For IRF640 Drains	2
Mica insulator kit		(Not needed for 7808)	6
IC socket 8Way DIL		For LT1016	1
DIODES	1N4148		3