Getting started with High Efficiency AM on HF

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) and, as will be described, Home Brewed.

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 radio magazine to build a transmitter, receiver or any other electronic equipment, to find that the parts needed are no longer available. Our kits are of proven design and sufficient stock is held by us to ensure a quantity of kits can be supplied into the future. Obviously we cannot guarantee the continued supply of parts and where there is a probability of parts running out, we will endeavour to source replacements or change the designs to accept replacement components.

The parts of the receiver and / or transmitter can be built up gradually and tested or can be built as one self-contained transceiver. A separate receiver can still be used even with the transceiver version.

What is required?

This will be determined in the first instance by knowing what the final project is to be; a transmitter of transceiver, and for what band. AM is found on several of the HF bands but, as the projects set out here is of a high efficiency transmitter (Class E), 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 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 ..... A 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.

The full manual is available on Dave's site and although written for the original FAT5 PA, the method of tuning and technical explanation is relevant to the new 'universal' FAT5 PA.

The receiver

Any HF receiver that has AM mode and covers the relevant band of frequencies can, of course, be used. We have produced a design that is relatively simple to build with the supplied PCB in a kit, and is a superhet with very good performance. This kit is called **RAT5** and details can be found from the web site shown at the bottom of this article. This is a stand-alone receiver and works from a 12V (or 13.8V) battery or mains power supply. RAT5 as it stands, has varicap tuning and no readout display but can cover, by capacitor changes (supplied), MW, 160m or 80m. Another change of capacitors and a retune will allow it to work on the 60m band and details and parts are available to order. There is a variation of this receiver that has been designed to be tuned with our **MultiRock II** signal source which provides an LCD (Liquid Crystal Display) frequency display.

The transmitter

The transmitter comprises of the following:

Frequency source (VFO).

Speech amplifier.

Modulator.

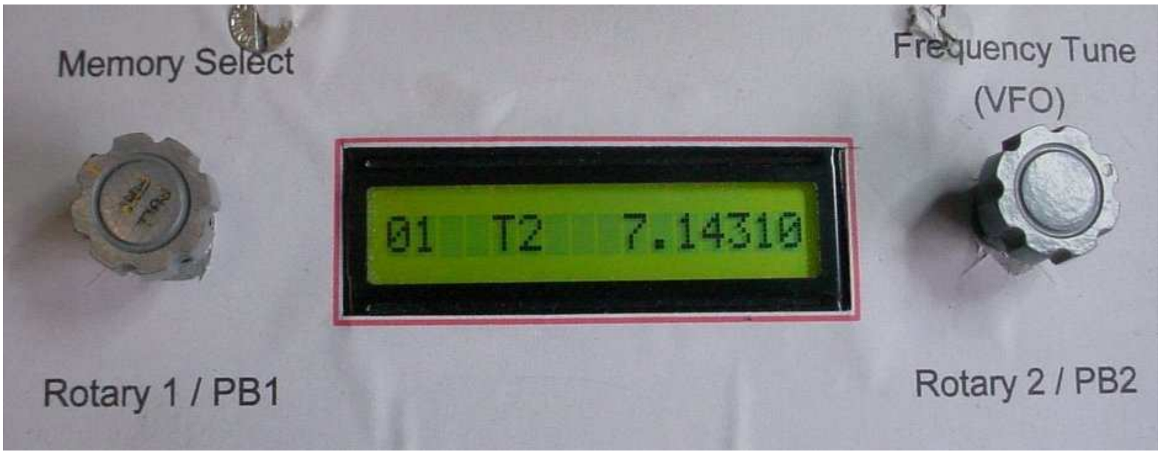
Power Amplifier (PA).

Antenna change-over and transmit / receive (TX/RX) control.

Let's take these in order.....

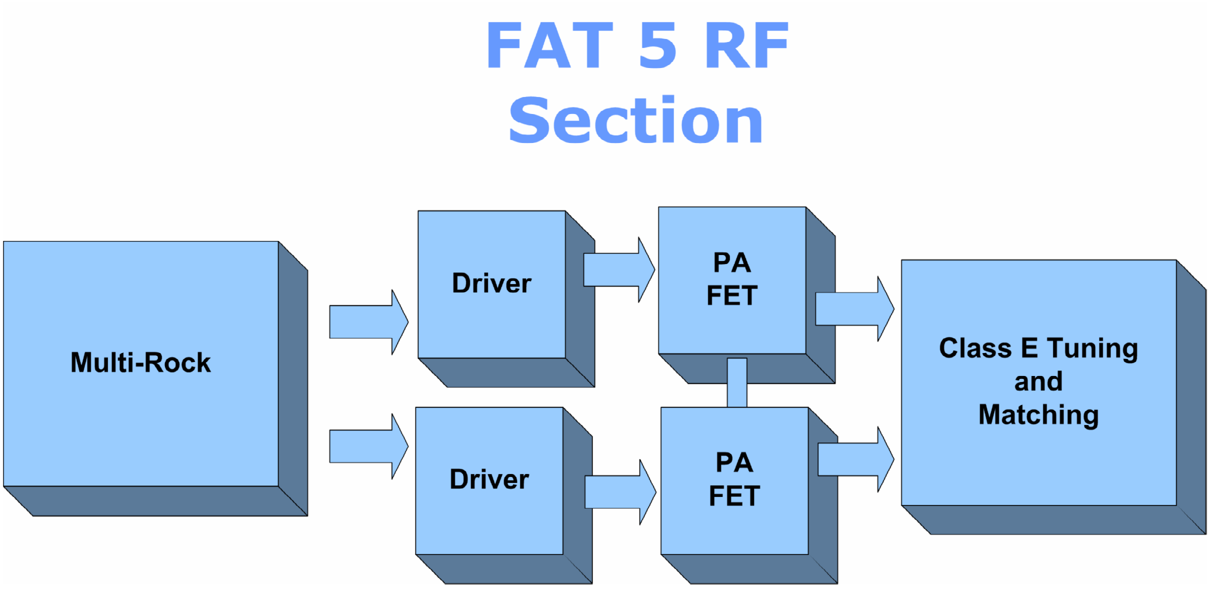
Frequency source.

This can be any VFO that has a stable squarewave output at twice the carrier frequency. This is because the PA needs bi-phase squarewave pulse for Class E operation. The earlier MultiRock we supplied as a kit had this bi-phase on board that was connected to the FET drivers on the PA board. This MultiRock has now been superseded by **MultiRock II** and is much more versatile. Although it has bi-phase outputs not only squarewave but also sinewaves, only one squarewave is required as the divider that produces the bi-phase along with the correct frequency (half of the VFO frequency) for the PA is now on board the **Universal FAT5 PA.** Although twice the carrier frequency is selected by MultiRock II (MRII) the display reads the carrier frequency. The times two is selected in the menu of MRII and is shown as 'T2' on the display along with the actual transmitted carrier. This can be set to X1, X2 and X4 and it can also be set for RX, perhaps when using the MRII with an SDR module where X2 or X4 is required as the 'XTAL' or external oscillator.



MRII is designed to replace the original MuliRock and here are just some of the features....:

Basic Features (tbc)	
Frequency range :	10kHz - 60MHz
Outputs :	bi-phase 600mV p-p sine wave and 5V p-p square wave
Memories :	48
Tuning rate :	10Hz, 100Hz, 1KHz, 10kHz or 100kHz selectable
Receive Features	
Osc :	Settable IF offset x2 and x4 multiplier (SDR)
Display :	Settable Display offset
Transmit Features	
Osc :	x2 and x4 multiplier
PTT Control :	Two pre-tx sequenced outputs with settable delay 0-150ms
Per Channel	
Two pre-settable independant control outputs for external switching e.g. antenna / pre-amp etc	
Other features include setting of number of memories available, set start memory, set start tuning rate and frequency calibration. Most parameters can be set globally then modified per channel as required.	

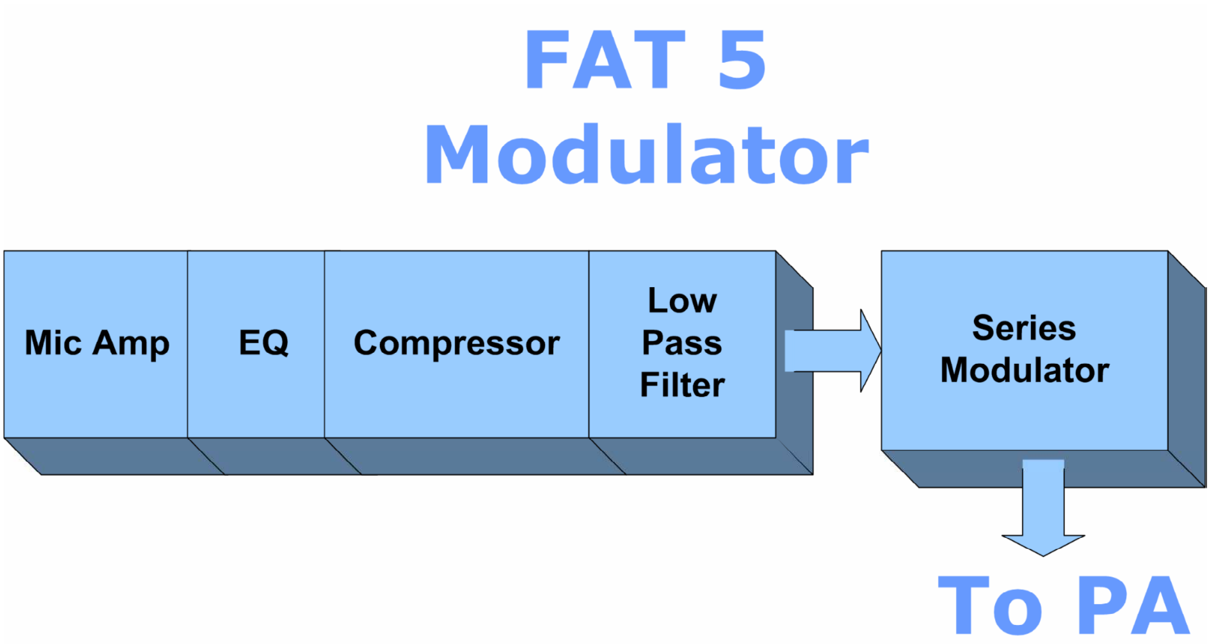


A block diagram taken from the FAT5 PA manual on the web site

It can be seen there is no more circuitry required for a CW transmitter and the power is decided by the PA power supply used and not the output from the VFO/exciter. The VFO drive (Original MultiRock shown) remains the same for QRP use or a 400W pep transmitter. For AM of course, a modulator will be needed.

Modulator

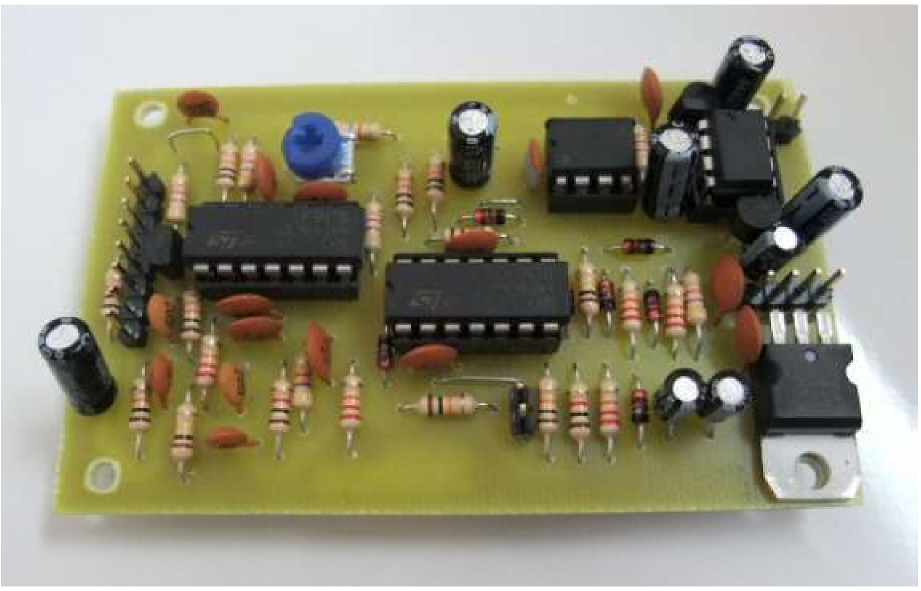
Here is where there are several choices. Whichever modulator is used, it will be of the series type. The modulator is in series with the PA power supply and the PA. Two of the modulators, which are governed by the power output required, are linear types and the third modulator type is Pulse Width. The modulator block diagram taken from the Modulator manual on the web site...



The first block in the modulator block diagram is the speech processor and is our **FAT-MAX.** This provides two types of processing. It has an AGC system that ensures the carrier is fully modulated (as near as possible) even when the voice level drops. This is ideal for noisy bands (QRN). It does not have the usual pops and thumps as is obvious on some speech processors. It also has an excellent cut-off both LF (low frequency) and HF (high frequency). The LF cuts off at about 300Hz and the HF is tailored to about 4kHz. The HF has a sharp (elbow) cut off and can be adjusted over a very large range.

The AM HF bands allows a bandwidth of about +- 4kHz but the 60m bandlet must have a narrower bandwidth of max +- 3kHz. This is easily achieved with FAT-MAX simply by changing one capacitor. This processor is sent out with 4kHz (approx) HF cut-off but by changing the capacitor value in the HF filter circuitry it can be tailored to 3kHz. We have made several tests and have come up with a capacitor value that can be simply placed across the existing capacitor to reduce this HF to 2.7kHz.

The speech quality is certainly not impaired as will be evident by listening to stations using this processor on 60m. Here is the speech processor assembled from our kit of parts...... It can be used with any transmitter that has a line input connection to the modulator and is a perfect match for any of our modulators. The FAT-MAX manual on the site will give full information.



The Modulators

There are two types, linear and PWM (Pulse Width Modulation). Also there are two linear modulators available....

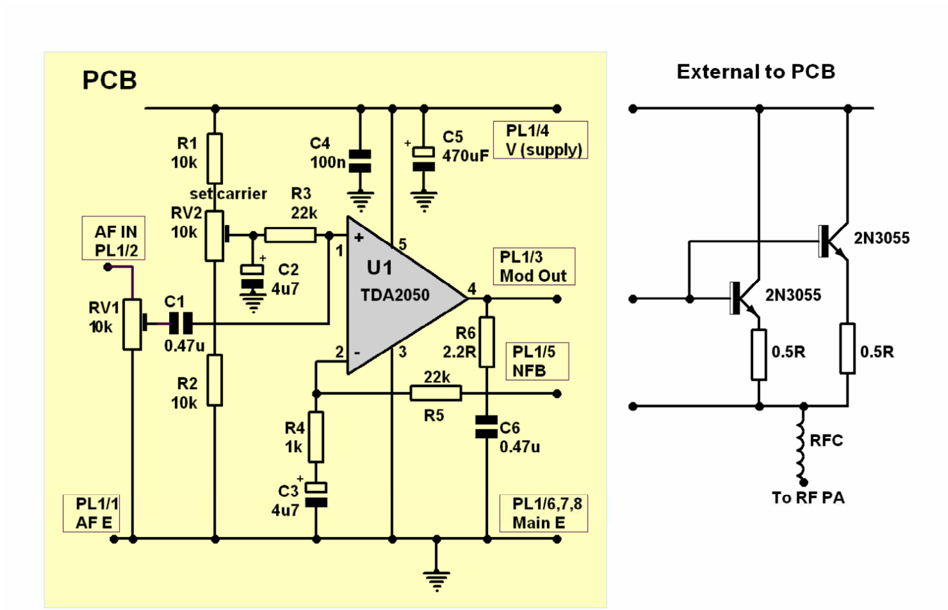
The TDA2050 modulator is a good solution for low/medium power transmitters. The limitation for higher power is the maximum TDA2050 operating voltage of 50V. When used in conjunction with the FAT5 RF-PA module with all FETs installed it is unlikely this voltage will be exceeded. Unlike the LM3886, the TDA2050 does not have internal mute circuitry for low voltage cut-out thus allowing a QRP transmitter to run off say 13.8V (10W carrier can still be expected at this voltage however).

The circuit is essentially a single IC power op-amp with supporting circuitry, biased to operate from a single rail. The output is set for a standing voltage of around half-rail. C3 isolates R4 making the gain at DC unity. Under AC conditions R5 and R4 define the gain as 22. R6 and C6 are added as per the device data sheet to form a pole to prevent high frequency oscillations. The amplifier is non-inverting as the audio input is fed to the positive input of the IC.

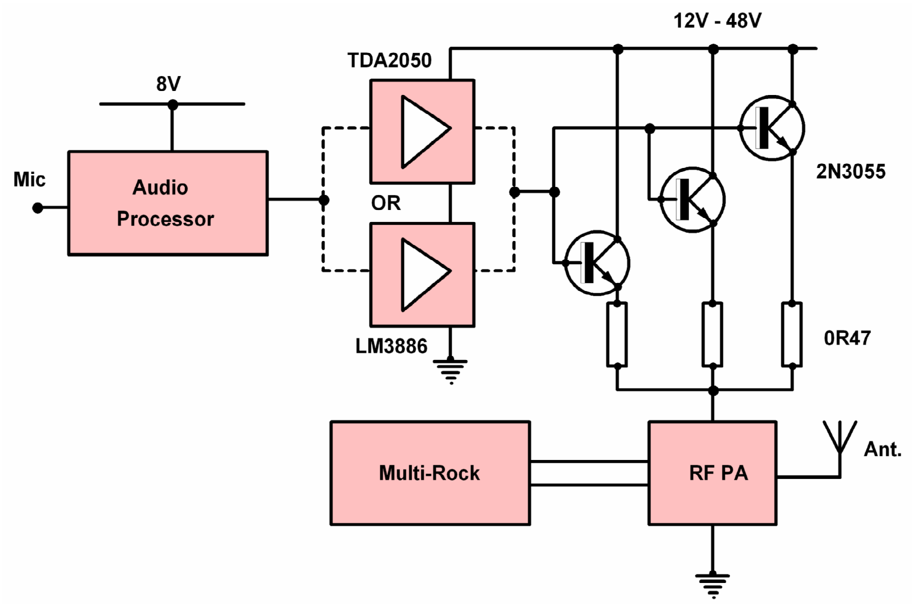
See the modulator manual on the site for circuit component references and all information.

Here, taken from the manual, is shown a typical set up using the TDA2050, the LM3886 is also shown in the manual.

The 2N3055s (or similar) and RF choke is not supplied with the kit as these normally easy to obtain if not already in the 'junk' box. The resistors can however, be sent on request.

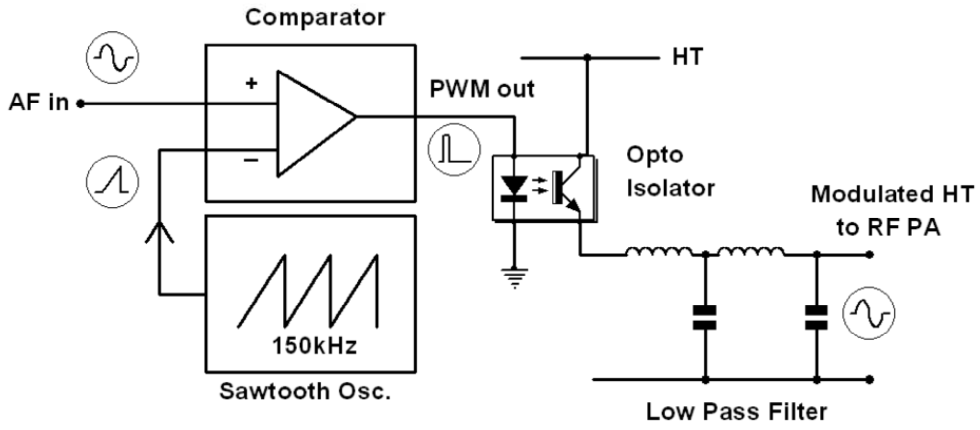


Also taken from the modulator manual a typical set-up.....



PWM

The 'PUWMA' pulse width modulator is the latest addition to the FAT5 range of modules. It is a more complex modulator than the analogue designs, but the high efficiency of pulse width modulation gives a considerable reduction in heat generation and power consumption making this method of modulation tempting for higher power transmitters, for battery powered builds, or compact designs where heat dissipation can be a problem.



This is a simplified version of the PWM and is taken from the PUWMA manual on the site where there is a full explanation of the system.

The kit is supplied in two parts, the PWM and the Low Pass Filter. This filter is a must otherwise you will be transmitting squarewaves all over the band!

The filter comprises of two Iron dust toroids type T200-26. These are colour-coded Yellow with a white base. As with the RED toroids used in the RFPA section, the T200 refers to the diameter (2") and the '26' is the operating frequency (in simple terms).

The filter components are contained on a separate PCB or chassis mounted. Because the filter is vital to ensuring a spectrally pure signal we have decided to only supply components with the LPF parts included. The LPF PCB need not be purchased if direct chassis mounting is planned. See the purchasing options on the kits page at s9plus.com. L1, L2 and C18-C23 form a 4-pole low pass filter with a -3dB point around 15kHz and an attenuation at 150 kHz of some 80dB. This level of attenuation is more than sufficient to ensure no unwanted sidebands appear on the carrier every 150 kHz.

Here is a prototype of the filter....It is not shown as the actual PCB used in the kit. The actual PCB has connectors fitted so that 1mm wire, or larger (same as used for the windings) can be placed in the screw connectors as fitted on the filter and PWM boards.

The CLASS E FAT5 PA

To explain this type of PA, we will look at the types commonly used and then it can be seen why we have chosen this method.

Firstly, here are some, of several parameters for RF Power Amplifiers:

Output Power.

Linearity,

And most importantly, as far as we are concerned, Efficiency.

The power ‘class’ of the amplification determine the level of performance. And this in turn is determined by the applied bias to the PA stage.

The efficiency can be represented by the equation: Power output to the antenna divided by the DC power supplied to the amplifier (or power input) or more correctly, the Drain of the FETs as these are used because of their fast switching action and high impedance inputs. The type used however, need to have a low RDS on (Drain to Source Resistance when saturated) and the lower this resistance, typically 0.15Ω, the better, or more efficient. *There are also other factors to be considered but not explained here to avoid complications.* If an amplifier has a DC of 24V applied and the current drawn is 10A as an example, when correctly tuned into a suitable load, the power supplied will be 240W. If the output is measured at the load as 200W then, with the above equation, 200/240 = 0.83. To obtain the percentage it is multiplied by 100, so 0.83 X 100 = 83%. This is the efficiency of the PA amplifier.

In the above example, 83% is the power output and the rest, 17% is dissipated as heat. There are other factors that determine percentage loss but for this explanation there is no need for further discussion. This efficiency of 83% is quite good and even better, 90% is easily achieved with Class E.

Let’s look at Class A, the typical PA class of emission for amateur transmitters. This type is the most linear, in that the output signal is as near as it can possibly get to the input signal, albeit at a much larger output. In a class A amplifier, the amplifying transistor (or valve) is biased so that it is conducting (current flows) at all times. Another way of saying this is that the conduction angle of the stage is 360^{o} or conducting for the full cycle of the input signal. The efficiency of this PA is up to 50%

(at best). So for the same applied 24 volts and assuming the same current is drawn, 10A, the power output is (50% of 240W = 120W. That means 120W is dissipated as heat!

Looking at Class B, the conduction angle is 180^{o}, ie it is in conduction only half the time either on the positive or negative half of the input signal. This class of emission is more efficient than Class A and an ideal Class B amplifier (bias set to determine the class of emission) is about 75%, which is better than class A of course but means there is still a power loss of 25% converted to heat.

There is a combination, and indeed, combinations, of Class A and class B amplifiers and their conduction angle is between 180^{o} and 360^{o} and efficiency is between 50% and 75% (which is expected).

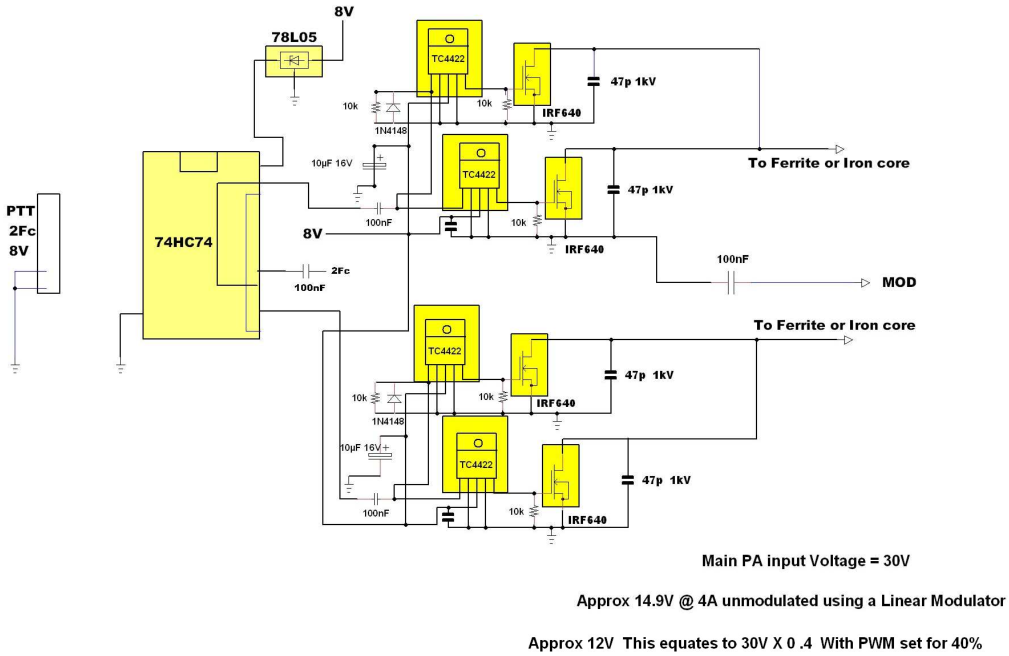
Class C, this is where the bias is set so that the amplifier has a conduction angle, under steady-state conditions, of considerably less than 180^{o}. Under these steady conditions, no current flows. The linearity is the poorest compared to the ones mentioned above but the efficiency can reach over 80% which is much better that the ones as shown above.

Now we come to Class E: *This is effectively a switch. When in conduction, ie current flows from Drain to Source of an FET, the voltage is zero across the device as is the case with a mechanical switch. Also, with no drive to the gate of the FET the full applied voltage is across the FET the device is off and there is no current flow. This is termed as having zero overlap of voltage and current (either on or off) and in theory this is 100% efficiency, as there is no loss and no biasing. However, there is no perfect electronic switch and there is a slight overlap. Although the 'on-off' produces square-waves, there is 'flywheel' action (like the back EMF in a relay coil) that is created because across the FET is a capacitor (shunt capacitor) and a coil (transformer in our push-pull design) and the current charges this capacitor when the switch (FET) is closed. This inductance / capacitance resonator (LC), the reactive element, ensures only the fundamental frequency current can flow in this output network to the load. The 'flywheel' effect of the LC network drives the current through either the switch (FET) or the shunt capacitor. This fundamental frequency has no harmonics (ideally) and so, is a sinewave.*

This is a simple explanation but should give the idea of the workings of the Class E amplifier and 90% and higher is easily achievable with this type of PA which means very little heat, less that 10% is dissipated in the PA. A high power PA (400W pep) can be built with just a few of these cheap FETs onto a moderate heatsink with no forced air cooling.

Below is shown the universal FAT5 PA and although it is labelled 40m it is also used for 160m, 80m and 60m with some small component changes (supplied with the kit).

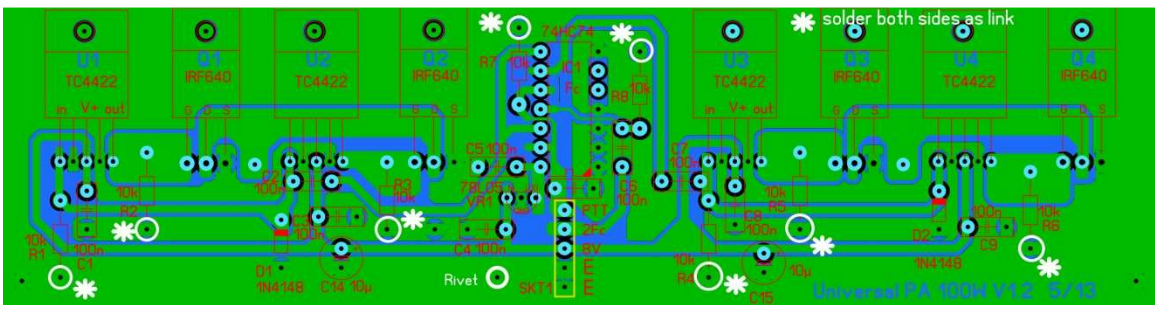
MRII supplies the twice frequency squarewave and is connected to the PA on-board 74HC74. This provides accurate bi-phase signals to the FET drivers, TC4422. As stated previously, the power output is dependent upon the applied PA voltage (absolute max 50V) and the VFO drives remain unchanged.



40m 100W PA

The FETs used are IRF640. It is imperative to use good quality branded devices as cheap ‘Chinese’ imports will not always be a good choice. We supply in the kits, branded types and are marked with the suffix ‘N’, the device being labelled as IRF640N and are the 5th generation devices. The outputs of these FETs are connected to a transformer.

Here is the PCB layout of the universal PA...



Use for 40m

The kit contains two sets of C10, C11, C12 and C13 and for the 40m version these are 47pF and rated at 1kW. All the other components are used to make up the kit.

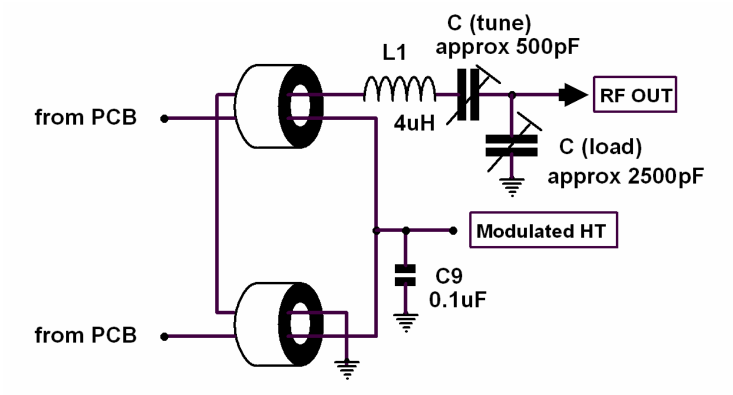
Use for 160m / 80m

To use on any of these two bands, the capacitors C10 to C13 (yellow highlight on picking list) are the ones to use and are 470pF, 1kW. All other components can be left as for the 40m version ***OR*** two of the TC4422s (U1 and U3) can be removed along with R1, R5, C1 and C8. ***ALSO***, links have to be placed on the GATE of Q1 and Q2, the left hand side of the board along with a similar link joining the GATES of Q3 and Q4. This is done so that one driver (TC4422) on each side drives two FETs.

For the 160m / 80m kit there are only two TC4422s supplied and R1, R5, C1 and C8 have been removed.

There are two types of PA tuning (conventional and commando) so two types of transformers are used....

The 'conventional' PA tuning

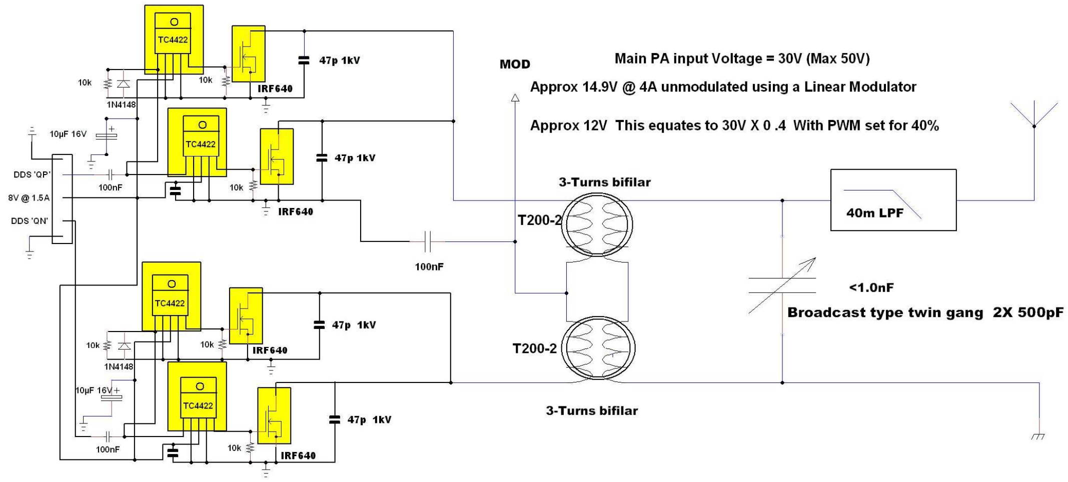


This type use ferrite cores, a tuning coil, tuning variable capacitor (isolated from chassis) and a loading variable capacitor. These parts are not available in the kits but we can supply the ferrite cores if needed or they can be obtained from Farnell with their part number: 1463420, and are Fair-ite type 2643167851.

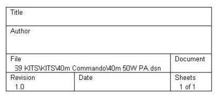
The variable tuning capacitor handles the high voltage (at RF) and consequently is the component, along with the tuning coil, under stress. These components must be isolated from ground. The loading variable capacitor can be a broadcast 'gang' type and can be padded with suitable (Silver Mica) capacitors to bring it to the required capacitance. The FAT5 PA manual on the site will give all the information needed.

Commando Tuning FAT5 PA

This is a variation on the conventional PA tuning as shown above and use less parts.



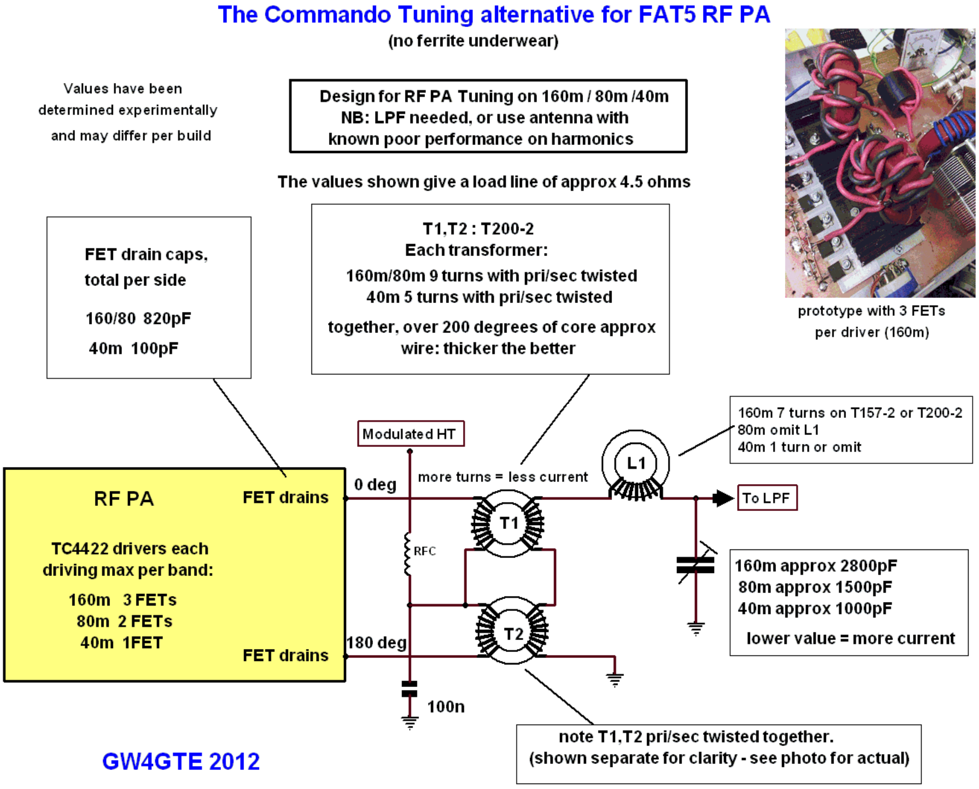
40m 100W PA Commando series



The 'commando' PA tuning use less components and a different type of transformer, and these are Iron dust types T200-2. They are 2" diameter (T200) and are coloured RED with a grey base. The '2' signifies the frequency uses. Although not normally supplied as kits, we can also supply these at cost. It can be seen in this new PA that the output of the transformer is connected directly to the antenna (socket) and the loading variable, as before is connected across this. It will be prudent to use an LP (low pass) filter to cut off well before the third harmonic. The second harmonic and other even harmonics in this push pull arrangement should be well suppressed but it is well to check rather than assume. The details are available from us for suitable filters for all the bands used. Of course, all responsible hams use LP filters anyway! It is imperative whichever PA tuning is used, that an antenna with 50 Ω impedance at the transmitted frequency is used. This being said and correctly tuned (as per manual) the frequency can be varied over a fair range without a retune.

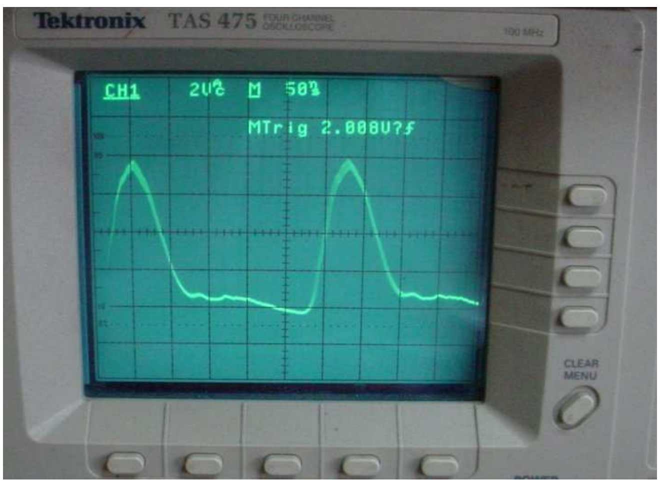
The above shows the PA values for 40m but is also applied for other bands with different number of turns.

Here is another diagram of the 'commando' tuning and with an 'L' match. This allows correct matching impedances to the antenna if the impedance is not suitable when using PWM (explained in the manual).



Waveform at the FET Drains

Shown here is typical of the waveform seen at the FET drains. A scope with a ‘Y’ bandwidth of 20MHz will be ideal for this display with a X 10 probe. If a higher bandwidth scope is used, the frequency range should be limited otherwise a distorted trace (waveform) will be seen. Also it would be prudent to keep the earth contact of the scope lead as short as possible and as near the probe when taking these measurements.....

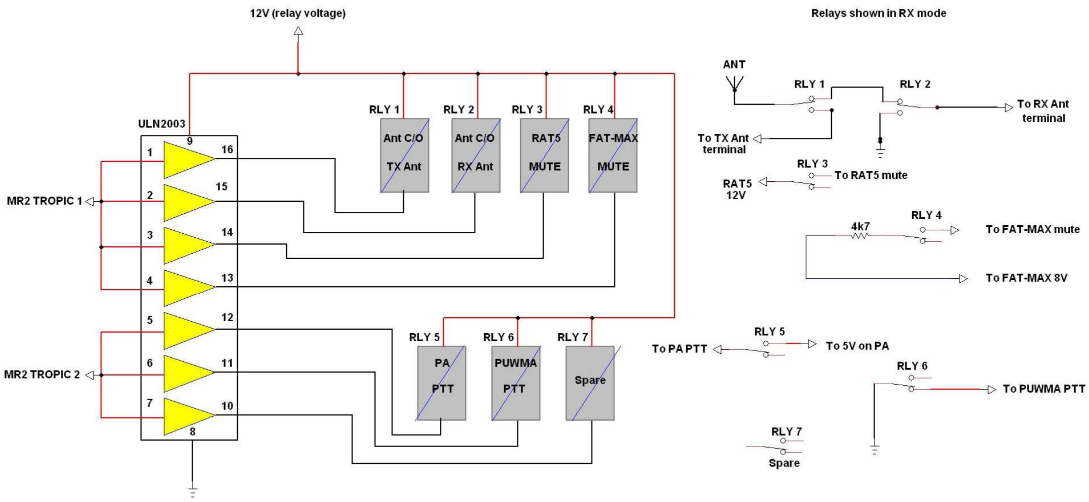


The picture shown of the waveform above is taken on a 100MHz scope with the 'Y' bandwidth set to 20MHz.

The Change-over

Whatever type of transmitter or transceiver is used, some reliable means of antenna change from TX to RX is used along with muting of the RX on transmit and the speech processor / modulator on receive. The PA voltage is normally left on during receive or stand-by mode.

MRII has a PTT (Push To Transmit) switch that can be operated from its built-in TROPIC (Transmit Receive Pic Controlled Change-Over) so that reliable change-over switching can be applied using common type relays. The diagram shows single relays ie with single change-over contacts to illustrate the order of switching.



MR2 TROPIC using single relays

The Power Supply

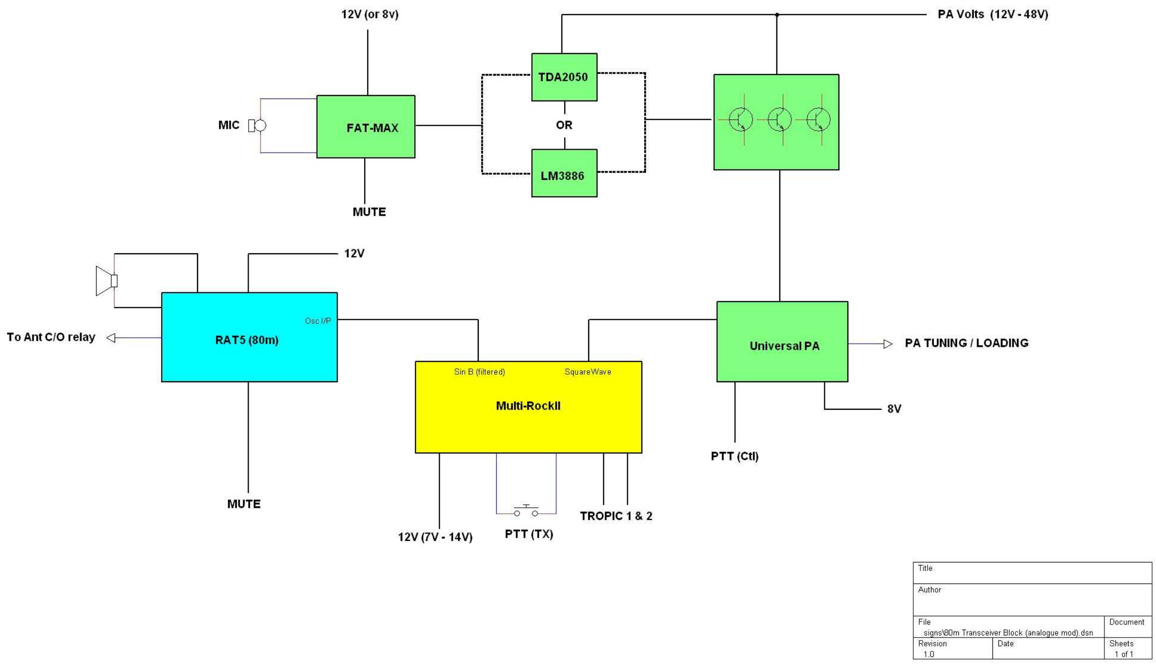
This can be the usual shack 13.8V supply or it can be run from batteries. The power supply choice will be determined by the power output. The popular power supplies used are switched mode types BUT they must be EMI filtered! These are available from the web (Ebay sources China and Hong Kong) and the ones to look for are 12V. 24V, etc with current rating of 10A, 15A or 20A, depending on the power output required from the TX. The suitable power supplies are advertised as 'for CTV' etc and EMI filtered. A power supply with 24V with 10A capability will supply over 200W power output at about 90% efficiency of the PA. The PA tuning can be selected by varying the PA transformer and capacitor relationship to produce an RF output using a high voltage and low current and vice-versa. The FAT5PA manual will give more details. These power supplies can be placed in series to provide a higher voltage but do not increase above 48V to be on the safe side.

How it's all put together

This is an idea of how a transceiver can be built with our kits. Although shown with the analogue modulator, the PWM modulator can be used. The bands shown are 160m and 80m but it is also the same set-up for 60m and 40m.

80m (160m) Transceive Block Diagram

With Analogue Modulator



For further information on all the available kits and comprehensive manuals complete with the schematic diagrams and PCB layouts are available from the Web site of Dave GW4GTE, the kit designer, at www.s9plus.com