

# Getting started with High Efficiency AM on HF

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**T**here 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), or 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 (where and for how long possible) are 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 or 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 (in the UK) 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 (class E) 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 ..... A brief explanation

Taken from the FAT5 manual on Dave's site.... [www.s9plus.com](http://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 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 sine or squarewave output at the transmit carrier frequency. MultiRock II is much more versatile than a simple VFO as it has many other facilities.



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

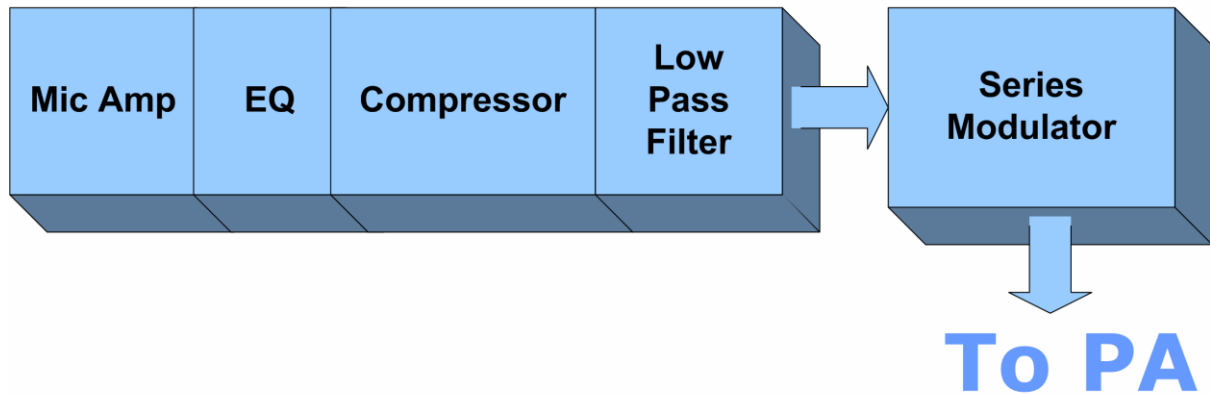
Two pre-settable independant control outputs  
for external switching e.g. antenna / pre-amp etc

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.

#### **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...

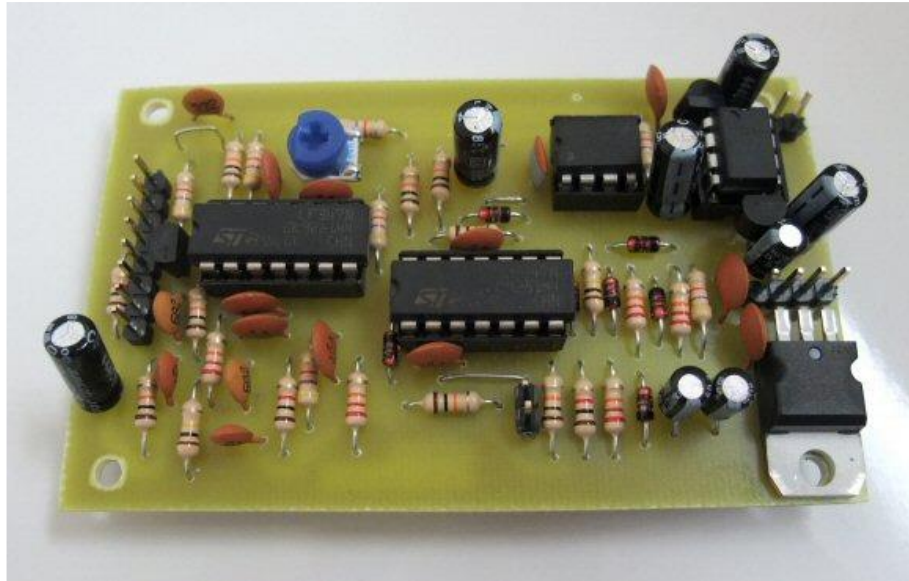
# FAT 5 Modulator



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 roll 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.

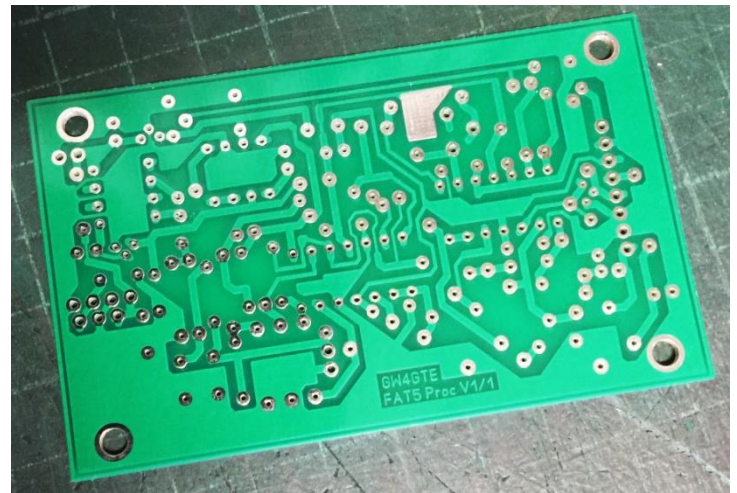
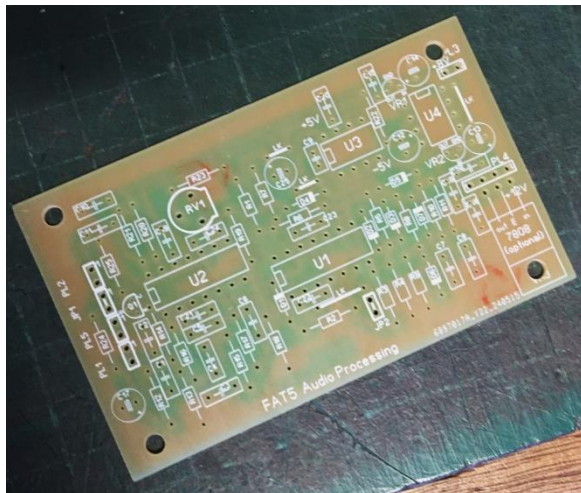
The AM HF bands allows a bandwidth of about +/- 4kHz but the 60m bandlet must have a narrower bandwidth of max +/- 3kHz. This is easily achieved with FAT-MAX simply by changing one capacitor. This processor is sent out with 4kHz (approx) HF cut-off but by changing the capacitor value in the HF filter circuitry it can be tailored to 3kHz or lower. 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. This information will be sent along with the FAT-MAX kit.

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.



Since this photo was taken a new PCB has been made, as have all the kit PCBs, professionally at no extra cost.

Here is the new PCB... Top and Bottom.



All the kit PCBs have silk screening (component marked on the top), plated through tinned holes and solder resist.

## The Modulators

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

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.

Here, taken from the manual, is shown a typical set up using the TDA2050. The LM3886 set up is also shown in the manual on the S9Plus site.

The schematic is divided into two main sections: **PCB** and **External to PCB**.

**PCB Section:**

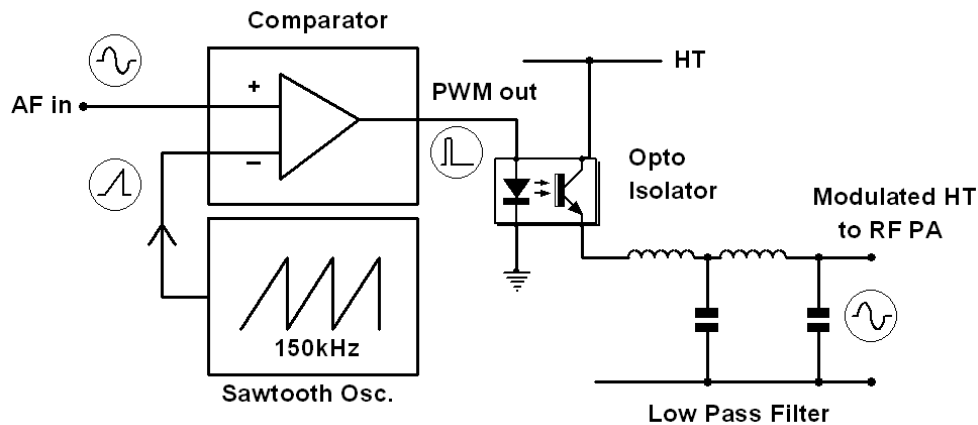
- Power and Grounding:**
  - PL1/4 V (supply):** Connected to the positive supply rail.
  - PL1/6,7,8 Main E:** Connected to the common ground.
- Input Stage:**
  - AF IN PL1/2:** The audio input signal.
  - RV1 10k:** A variable resistor (pot) in series with the input.
  - C1 0.47u:** A coupling capacitor following the input.
  - R2 10k:** A resistor connected from the input line to ground.
- Feedback and Biasing:**
  - RV2 10k:** A variable resistor (pot) used for setting the carrier level.
  - R1 10k:** A resistor connected from the supply rail to the non-inverting input (pin 1).
  - R3 22k:** A resistor connected from the output (pin 4) back to the non-inverting input (pin 1).
  - C2 4u7:** A capacitor connected from the non-inverting input (pin 1) to ground.
- Output Stage:**
  - U1 TDA2050:** The central integrated circuit.
  - R4 1k:** A resistor connected from the inverting input (pin 2) to ground.
  - C3 4u7:** A capacitor connected from the inverting input (pin 2) to ground.
  - R5 22k:** A resistor connected from the output (pin 4) to the inverting input (pin 2).
  - R6 2.2R:** A resistor connected from the output (pin 4) to the common ground.
  - C6 0.47u:** A capacitor connected from the output (pin 4) to ground.
- Other Components:**
  - C4 100n:** A capacitor connected from the supply rail to ground.
  - C5 470uF:** A large electrolytic capacitor connected from the supply rail to ground.

**External to PCB Section:**

- Output Stage:**
  - The output of the TDA2050 (pin 4) is connected to the base of a **2N3055** NPN power transistor.
  - The emitter of the 2N3055 is connected to ground.
  - The collector of the 2N3055 is connected to the positive supply rail.
- RF Output:**
  - A **0.5R** resistor is connected between the collector of the 2N3055 and the **RFC** (Radio Frequency Choke).
  - The **RFC** is connected to the **To RF PA** (To Radio Frequency Power Amplifier) output.

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).

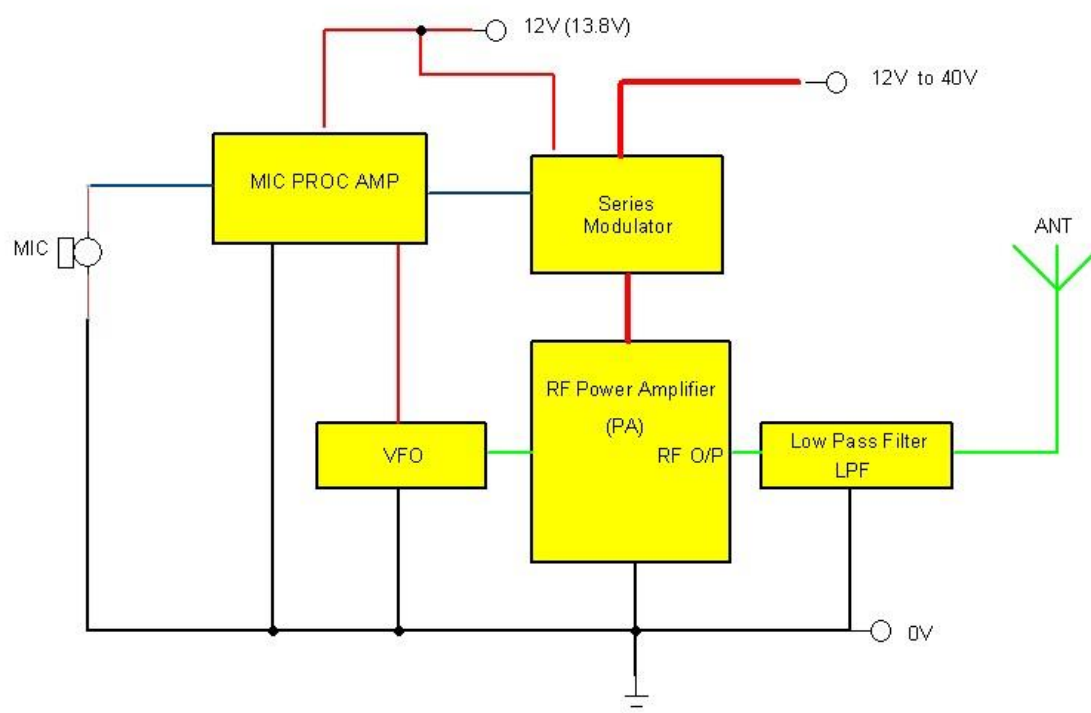
The filter components are contained on a separate PCB or chassis mounted. Because the filter is vital to ensuring a spectrally pure signal we have decided to only supply components with the LPF parts included. The LPF PCB need not be purchased if direct chassis mounting is planned. See the purchasing 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.

A new PCB 'commercial' is sent with the kit. The photo shows the original 'shack-made' PCB.



### A block diagram of the updated FAT5 PA manual on the web site



A complete explanation of the PA is given in the new FAT5 PA on the S9Plus web site [www.s9plus.com](http://www.s9plus.com) or from me at [ericgw8lj@outlook.com](mailto:ericgw8lj@outlook.com). The unique fact about the new PA is that only one sine or squarewave at the transmit frequency is needed. The power is decided by the PA power supply used and not the output from the VFO/exciter. The VFO drive (Xtal or VFO) remains the same for QRP use or a 400W pep transmitter.

### 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  $R_{DS\ on}$  (Drain to Source Resistance when saturated) and the lower this resistance, typically  $0.15\Omega$ , 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  $0.83 \times 100 = 83\%$ . 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  $360^\circ$  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  $180^\circ$ , 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  $180^\circ$  and  $360^\circ$  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  $180^\circ$ . 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 than the ones as shown above.

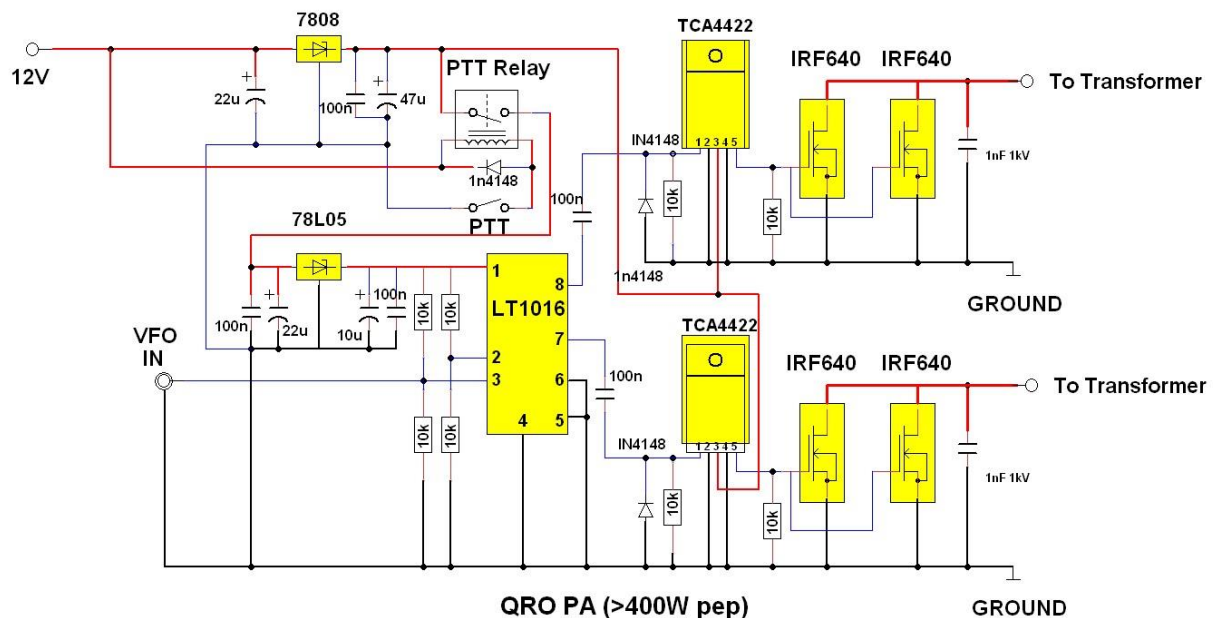
**Now we come to Class E:** *This is effectively a switch. When in conduction, ie current flows from Drain to Source of an FET, the voltage is zero across the device as is the case with a mechanical switch. Also, with no drive to the gate of the FET the full applied voltage is across the FET the device 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.

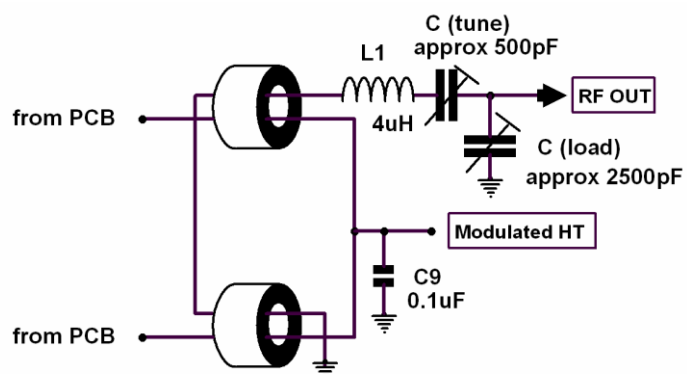
This is a simple explanation but should give the idea of the workings of the Class E amplifier and 90% and higher is easily achievable with this type of PA which means very little heat, less than 10% is dissipated in the PA. A high power PA (400W pep) can be built with just a few of these cheap FETs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

Below is shown the universal FAT5 PA used for 160m, 80m and 60m and 40m. Any stable VFO at the transmitted frequency can be used which 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 is at the same output level for all PA (RF) levels. The power output is dependent upon the applied PA voltage (absolute max 50V) and the VFO drives remain unchanged. The VFO is used at the transmit frequency and not twice the frequency found in other Class E designs.

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, at the time of writing, with the suffix 'N', the device being labelled as IRF640N and are the 5<sup>th</sup> generation devices. The outputs of these FETs are connected to a transformer.



## The 'conventional' PA tuning

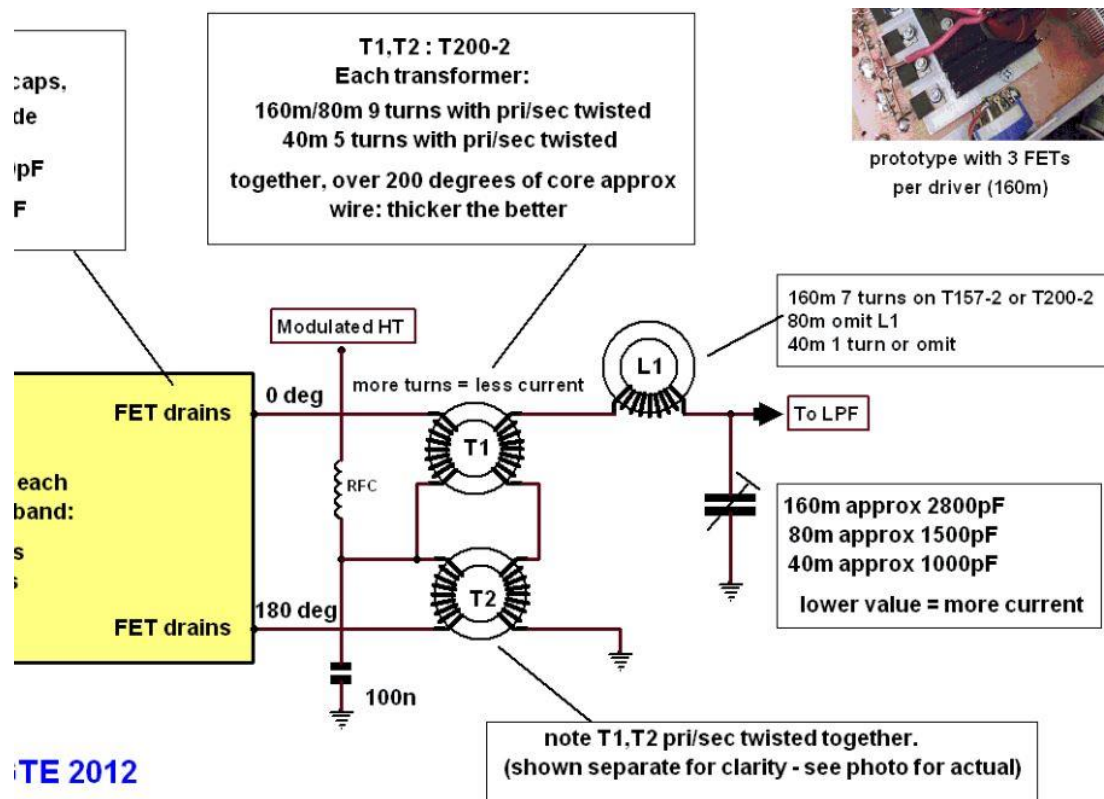


This type use ferrite cores, a tuning coil, tuning variable capacitor (isolated from chassis) and a loading variable capacitor. These parts are not available in the kits but we can supply the ferrite cores if needed or they can be obtained from Farnell with their part number: 1463420, and are Fair-ite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



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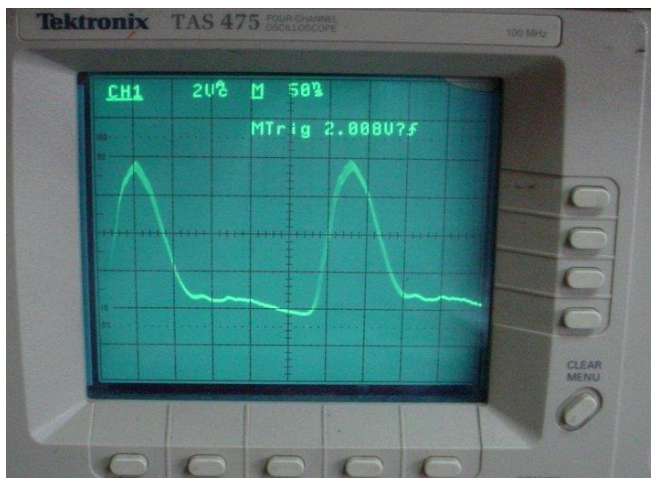
The 'commando' PA tuning use less components and a different type of transformer, and these are Iron dust types T200-2. They are 2" diameter (T200) and are coloured RED with a grey base. The '2' signifies the frequency uses. Although not normally supplied as kits, we can also supply these at cost. It 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  $\Omega$  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.

## 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.....



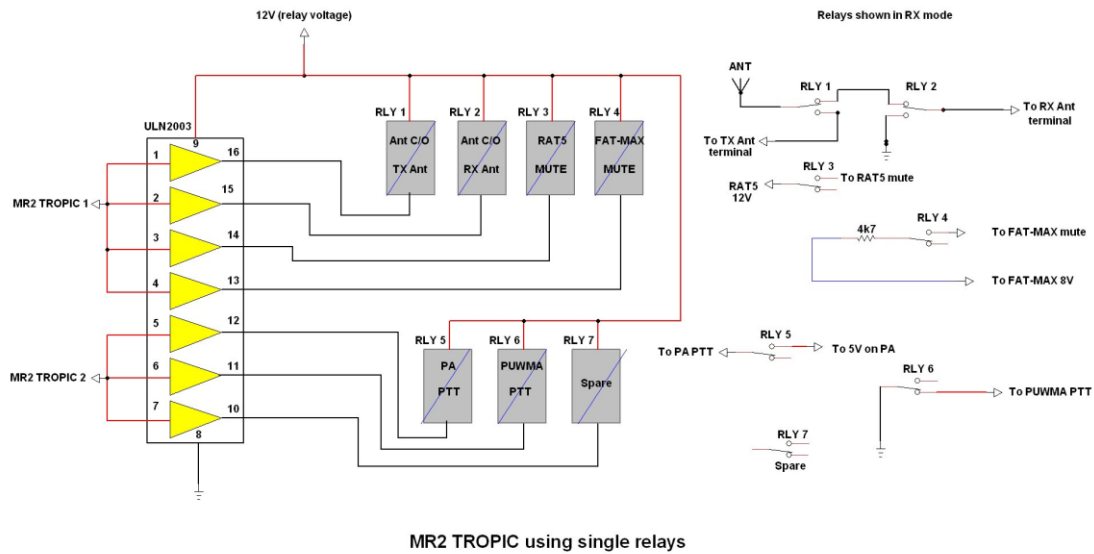
The picture shown of the waveform above is taken on a 100MHz scope with the 'Y' bandwidth set to 20MHz.

## 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.





## 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.

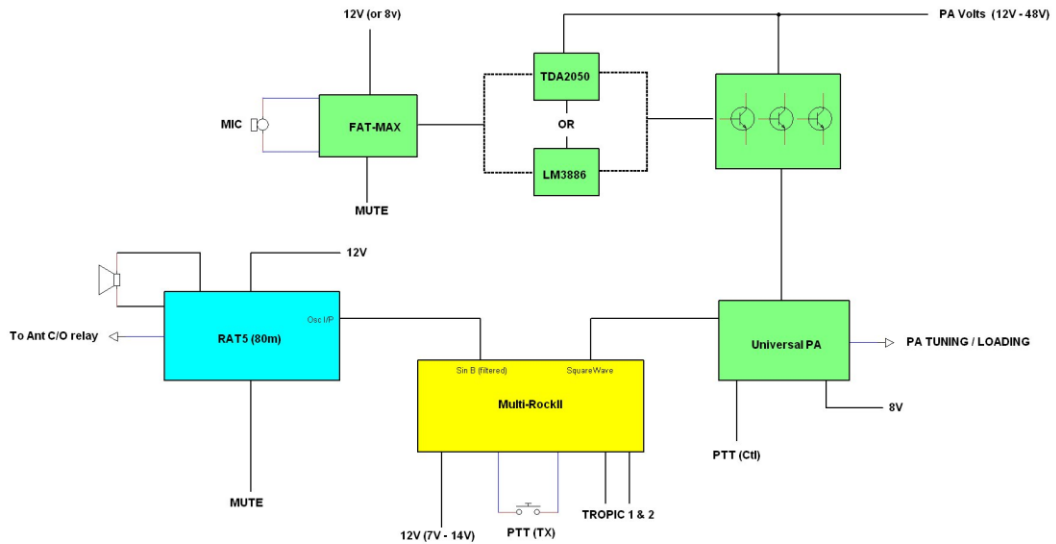
## How it's all put together

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. The VFO is shown is the MR11 as it has other facilities such as supplying the tuning frequencies for an AM receiver (RAT5 shown) and TROPIC which is a 'Transmit-Receiver' changeover switching system but any stable VFO can be used.



# 80m (160m) Transceive Block Diagram

## With Analogue Modulator



Title		
Author		
File	Document	
signs00m Transceiver Block (analogue mod).dsn		
Revision	Date	Sheet
1.0		1 of 1

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](http://www.s9plus.com) or [ericgw8ljj@outlook.com](mailto:ericgw8ljj@outlook.com)

I hope this information is useful.  
Thanks,  
Eric GW8LJJ.