WORLD’S ONLY ALL FETRON RADIO & the OMEGA DEVICE.

Dr. H. Holden. Dec 2011.

INTRODUCTION:

The Fetron was a product of research and development in the Aerospace and Avionics industry by the Teledyne Company in the USA in the early 1970’s. The Fetron is a unique combination of N channel Junction Field Effect transistors. The electrical configuration is a form of the Cascode connection. They were built primarily as a plug in tube or solid state pentode replacement, although triode equivalents were also made. The basic idea behind the Fetron is that it would have the electrical properties of a pentode, but no microphony and no heater power consumption and the advantages of semiconductor efficiency and reliability with lower noise and a higher gain. Fetrons usually had a much higher amplification factor than the tube they replaced. Teledyne also produced a range of semiconductor devices such as high voltage junction Fets and they still produce beyond excellent quality miniature RF relays. Every Teledyne product I have inspected and used over a lifetime has always impressed me with the innovative nature of it, the outstanding manufacturing quality, excellent physical appearance and electrical performance. In view of this I decided to engineer a multi-band radio composed of entirely Fetrons to be powered by a single 90V battery and to incorporate some of my other favourite Teledyne devices.

REPLACING TUBES WITH SEMICONDUCTORS:

The idea of replacing a tube with a plug in transistor substitute has occurred to many people since the transistor was invented. Although there are mathematical models for transistors as voltage to current control devices, fundamentally they are current to current control devices. In most instances the input (base-emitter) current controls the output (collector-emitter) current. Tubes on the other hand are voltage to current control devices or transconductance amplifiers where usually the grid to cathode voltage controls the anode to cathode current. Transistors have a much lower input resistance than a tube in the grounded emitter or grounded cathode configuration respectively.

By the time junction Field Effect transistors had arrived on the scene, high voltage versions were possible substitutes for the Triode tube. They had a similar transfer function of gate voltage versus drain current to grid voltage versus anode current for the triode tube. Also junction Fets have a similar high input impedance to the tube.

In the grounded source or grounded cathode circuit both the single Fet and the triode are affected by the Miller effect, or the effective amplification of the drain to gate (or the anode to grid) capacitance. This capacitance value which is intrinsic to the device is multiplied by the amplification factor of the device. This problem limits the high frequency response and results in significant input to output feedback as the frequency of operation increases. In tube circuits, if a tuned circuit of similar resonant frequency is placed both in the grid and in the anode circuit of a triode stage, oscillations occur due to the feedback capacitance and the two resonant circuits exchange energy with each other.

Historically the Miller capacitance problem was solved with an added neutralisation capacitor feeding back an out of phase signal from a coil extension on the anode resonant circuit to the grid (or to the base in a transistor circuit) via a small adjustable capacitor. In early transistor radio intermediate frequency amplifiers, with devices such as OC45's with a large internal feedback capacitance, they required neutralisation. Later, better transistors such as the OC169, AF117 or AF127 had a much lower feedback capacitance and didn't require neutralising in 455KHz IF stages.

In vintage TRF radios based on triode tubes the added neutralising capacitor was called a Neutrodon and the radios sometimes called Neutrodynes. Neutralisation is not necessary in grounded drain (collector or anode) or "follower" circuits because the effect of the Miller feedback capacitance is eliminated. The grounded base (gate or grid) circuit also eliminates the Miller effect.

The *Pentode* however has the unique property of high isolation between its input (grid) and its output (anode) by virtue of the screen grid. Pentode tubes for example are excellent in radio frequency (RF) stages or intermediate frequency (IF) amplifiers as they are stable with a tuned circuit in both the grid and the anode circuit. The Figure 1 below shows amplifying stages with an input circuit (I/P) and an output circuit (O/P). No resistors or bias components are shown. In the pentode the screen grid voltage is held at a constant voltage K. (this is usually done by connecting it to a resistive divider with a bypass capacitor or connecting it to the HT supply).Two triodes arranged in Cascode work by clamping the upper triode's grid to a fixed voltage K which sets the upper triode's cathode to another fixed potential (k). This stabilises the anode potential of the lower triode and as a result the Miller effect is eliminated. The J-Fet equivalent of Cascode is shown.

It can be seen that the J-Fet equivalent of Cascode would be a "4 legged device" and the equivalent screen connection could be problematic with biasing in different circuits if a "J-Fet equivalent of a tube" was plugged in to include the "screen grid" connection. The Fetron solves this problem by connecting the gate of the upper Fet to another voltage source, ingeniously the source of the lower Fet. This voltage is usually constant from the perspective of AC in most tube circuits as the cathode is bypassed. If it is not, it still does not matter, as any AC component coupled via the gate of the upper Fet to its source and the drain of the lower fet is in phase with the input voltage on the gate of the lower Fet, so the alternating potential on either side of the Miller capacitance (from the gate to the drain) of the lower Fet is the same, so the Miller effect is still eliminated. Obviously the drain current properties of the two Fets within the Fetron have to be especially matched for the task for this configuration to work.

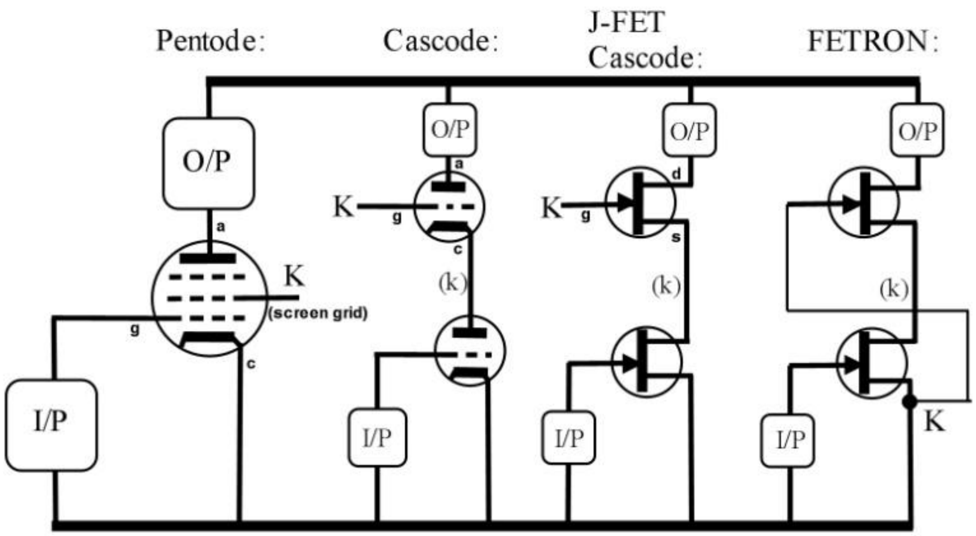


FIGURE 1.

The scans below are historical documents on the Fetron TS6AK5, which is the equivalent of a 6AK5 tube:

FETRONS

THE field effect transistor (FET) is currently being used in the front end of a.f. and r.f. circuits, as well as being developed into simplified forms of logic circuitry for micro-miniature applications such as wrist watches and pocket calculators. Aside from the manufacturers of such luxury items, our attention is turned here to more domestic matters such as television receivers, radio transmitters and receivers. Where thermionic valves are still being used, there is some reluctance to effect a total conversion to semiconductor techniques. We can have the best of both worlds because we can now replace valves in some circumstances with direct equivalent improved performance transistors. Particular areas of application also include unattended relay stations, and telecommunications terminals, as well as domestic receivers.

TRIODE EQUIVALENT

These transistors, called "fetrons," have emerged from the military applications stable and are being made available for other applications, although very little is generally known about the performance so far. The fetron is basically an arrangement of two n-channel field effect transistors (Fig. 1) connected to provide the equivalent working characteristics of a triode valve but with a much better frequency response at both ends of the spectrum. This is because the fetron has an extremely low channel resistance and inter-electrode capacitance. Furthermore, since there are no heaters, operation is immediate on switch-on.

OTHER FEATURES

The life of the fetron is likely to be much greater than the thermionic valve under normal working conditions and the degradation of operational characteristics is minimal. Other important features include a higher amplification factor (almost ten times that of a valve) and a lower noise figure. Since no heaters are used, power requirements are simplified to just one high tension supply.

PENTODE CHARACTERISTIC

Both the thermionic valve and the FET are voltage controlled devices, hence design equations are virtually the same. Although the pentode anode voltage-current characteristics are similar to the drain characteristics of the fetron, the latter are more clearly defined at the cut-off region or "knee" and exhibit stable current drain for various drive conditions (Fig. 2).

Since the main purpose of the fetron is to act as a direct replacement for the triode valve, it is essential that it should withstand high voltages and have a matched gm. The single junction FET cannot do this, but when two specially selected FETs are cascaded the problem is overcome. It is also possible to reduce the Miller (gate to source capacitance) effect by using a low capacitance, small signal, high gm FET at the input circuit, coupled with a high voltage output FET.

With the arrangement shown in Fig. 1, the output FET acts as a voltage dropper for the input FET and the Miller effect capacitance of each is in series. The output impedance is also greater than in a valve pentode, resulting in the excellent characteristics shown in Fig. 2. Since the input gate circuit is effectively a reversed bias junction, it presents a very high resistance load to the signal source.

Fig. 3 shows the transfer characteristic of a fetron which has been made

Fig. 1: Basic arrangement of two field effect transistors in one package to form a fetron, and the symbol of the 6AK5 valve.

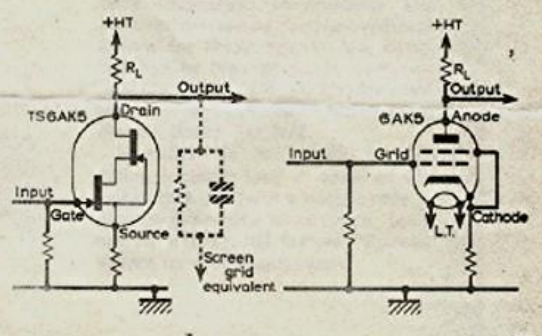
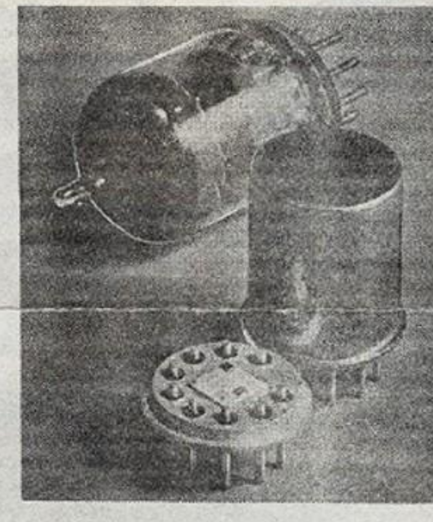


TABLE 1:

TYPICAL PENTODE DEVICE CHARACTERISTICS— Rk—200 Ω, Eb—120V		
PARAMETER	6AK5	TS6AK5
Plate voltage breakdown	350V	350V
Plate resistance	0·5MΩ	5·0MΩ
Transconductance	5,000μmhos	4,500μmhos
Plate current (Rk=200Ω)	7·5mA	7·0mA
Grid voltage for Ib—10μA	−8·5V	−5·0V
Amplification factor	2,500	22,500
Input capacitance	4·0pF	6·5pF
Output capacitance	0·02pF	0·02pF
Useful frequency limit	400MHz	600MHz

TABLE 2:

TYPICAL TRIODE DEVICE CHARACTERISTICS (EACH SIDE)—Rk—2—70 Ω, Eb—130V		
PARAMETER	12AT7	TS12AT7
Plate voltage breakdown	400+V	350V
Plate resistance	15kΩ	250kΩ
Transconductance	4,000μmhos	3,000μmhos
Plate current (Rk=240Ω)	5·0mA	9·0mA
Grid voltage for Ib=I10μA	−7·0V	−7·0V
Amplification factor	60	750
Input capacitance	2·2pF	25pF
Output capacitance	1·5pF	3·5pF



up from selected FETs to approximate closely that of a particular valve (shown dotted) operating within the same limits. If special requirements include partial operation beyond this FET cut-off then clearly a more appropriate FET device must be selected for this, perhaps providing a higher current for the same control voltage. The gm or transconductance ratio of the fetron gives a true square law property with consequent harmonic distortion figures of an extremely low order. In fact, harmonics beyond second order are claimed to be negligible.

Although the simulation of the "screen grid" principle can be effected within the fetron package, the similarity of the transfer curves to those of a pentode must not be taken as an assumption that the fetron is an ideal replacement for the pentode, even though the noise figure may be lower. The fetron has a markedly improved performance over the triode due to square law operation.

POWER REQUIREMENTS

Power supplies can be greatly simplified: first by the elimination of low voltage lines; secondly by the use of less stringent h.t. regulation. Current requirements are similar to or slightly higher than for a triode, but surge currents of up to about 1,000 times can be tolerated. Due to the lack of heating requirements the fetron will operate at more confortable temperatures around 65°C. The case is ruggedised by using a deep-drawn steel cap welded to a large diameter header, using the same pin arrangement for connections.

Fetrons that have been made so far include replacements for the 6EW6, 6JC6, 6AK5 and 12AT7 but with ready made FET junctions currently available it is expected that the majority of common types can be simulated. More familiar types such as 6V6 and 6AQ5 are next on the list. The type number given to fetrons consists of the equivalent valve number but prefixed TS. Hence the

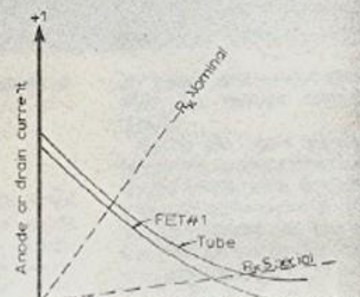


Fig. 3: Transfer characteristic of a fetron compared with a valve.

fetron for replacing the 12AT7 is TS12AT7.

The manufacturer who has announced these activities in fetrons is the American company Teledyne Semiconductors, who are selling in the U.K. via the distributors GDS Sales Ltd. of Slough. Prices are higher than for valves but this is offset by the long term performance advantages described. GDS Sales quotes £8 for the TS12AT7 and £6·50 for the TS6AK5 for orders of 1 to 99, these being the first available in the U.K. Although this price is high the long term advantages of reliability and performance are compensatory. Small orders for these devices are being handled by the subsidiary company *Best Electronics (Slough) Ltd, Michaelmas House, Salt Hill, Bath Road, Slough, Bucks, SL1 3UZ.*

Elsewhere in this issue we are taking a closer look at some of the valves that still have a unique role to play in radio and electronics. Look out for our special feature "Special Valves for Communications".

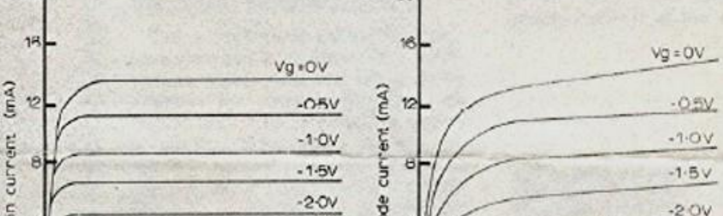


Fig. 2: Comparison of output drain characteristics with those of the 6AK5 anode.

As can be seen from the data above there is also a Fetron equivalent of a triode the 12AT7. Notice the very high amplification factor of the TS6AK5 Fetron of 22,500 compared to the 2,500 of the 6AK5 even though most of the other parameters are nearly identical.The Drain resistance is very large at 5 MΩ as the Fet is an excellent constant current source. The transconductance *gm* or ratio of change in plate(drain) current to change in grid(gate) voltage is also the ratio of the amplification factor to the plate(drain) resistance: 22,500/5000,000 = 4500 μmhos, which is about the same as the 6AK5 tube.

There are 3 features of the Fetron not alluded to in the data:

The first is that it is essential that the metal can is earthed if they are being used in a radio-frequency application.

The second is that if the input terminal (gate of the lower fet) is taken positive with respect to the source (cathode connection) the gate suddenly draws current. In the 6AK5 tube this is a very gentle process, but sudden conduction in the TS6AK5. In most circuits such as amplifiers, the grid(gate) runs in the negative region so this is not a problem. However in oscillator circuits that use grid current self bias, if the Fetron is plugged in place of the 6AK5, the gate draws current and the oscillator malfunctions producing a distorted output with multiple harmonics. This can be solved with a diode in the gate circuit to povide the self bias function.

Thirdly, practical experiments with the Fetron indicate that the input to output isolation is not quite as good as the 6AK5, in that when they are used in IF stages, with identical tuned circuits in the input and output, they are a little more prone to instability. The higher amplification factor might be the reason, as this tendency can be eliminated with a small amount of degeneration to lower the stage gain.

So despite the Fetrons being marketed as plug in tube substitutes, they could not always make a direct plug in replacement depending on the specific circuit.

Constructing an all fetron radio:

The radio in the following photos was constructed and has some unusual features. The radio is powered by a single 90V battery (or the Omega Device see below). The power lamp is a 70V striking voltage neon lamp.

Circuit description:

The radio is a dual band single conversion Superhet with a tuned RF stage. The frequency coverage is 550 KHz to 1650 KHz (MW) and 5.7MHz to 18.2 MHz (SW). The antenna is a 6 inch long ½ inch diameter ferrite rod which also works well on SW up to about 10MHz. The MW coils are wound with 60 strand Litz wire. Above 10Mhz an external antenna is useful for the short wave band.

The Fetron lineup is:

RF amplifier: TS6AK5, Mixer: TS6AK5, IF amplifier: two TS6AK5, Local Oscillator: TS6AK5, Local Ocillator buffer: TS6AK5, Audio pre-Amplifier: TS6AK5 and audio output stage 4 TS6AK5's wired in parallel for class A 1Watt undistorted output into a Philips 3.2 Ohm 4" speaker. The buffer provides an external output for a frequency counter.

In addition two Teledyne 2N4886 high voltage N Channel Junction fets are used in a bridge circuit for an S meter. The band change is executed using three miniature Teledyne latching RF relays. These relays are controlled by a band change switch on the front panel which is an industrial grade mechanically robust motor switching swtich from Telemechanique, so it will not wear out in a hurry and it has a good feel to it.

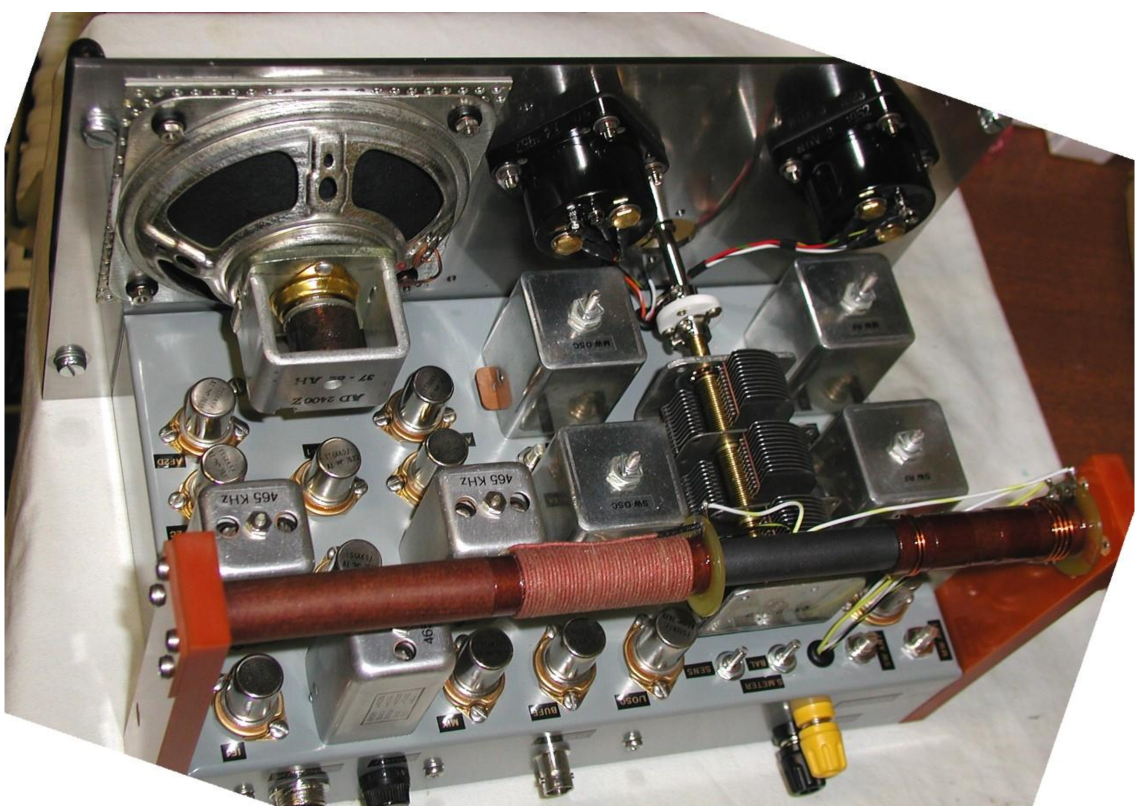
The detector and AGC and oscillator self bias diode are 1N663A silicon diodes (which were one of AMD's first products).The main 3 gang tuning capacitor is driven by an Eddystone ball-epicyclic reduction drive knob and dial assembly. Incandescent lamps were placed inside the dial assembly to illuminate the dial. Also lamps were placed inside the battery volt meter and the S meter. These meters are moving coil types which are ex avionics hellicopter parts. The faces were repainted and labelled for S units and voltage.

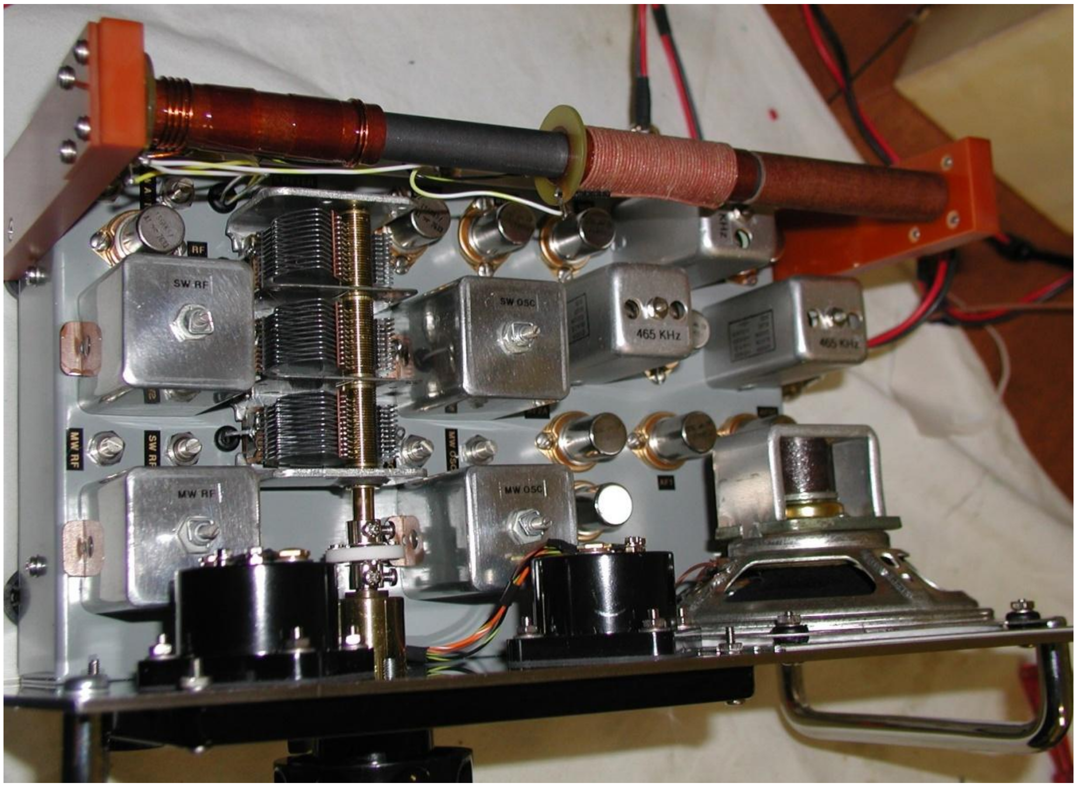
The radiofrequency trimming capacitors are metal vane ceramic variable and chassis mounted. The RF coils were wound on to formers and inside military spec shielding cans with high permeabilty adjustable powdered iron cores. The IF transformers are 465KHz Americam made Miller units. The audio output transformer is made by Hammond in the USA and supplied by AES.

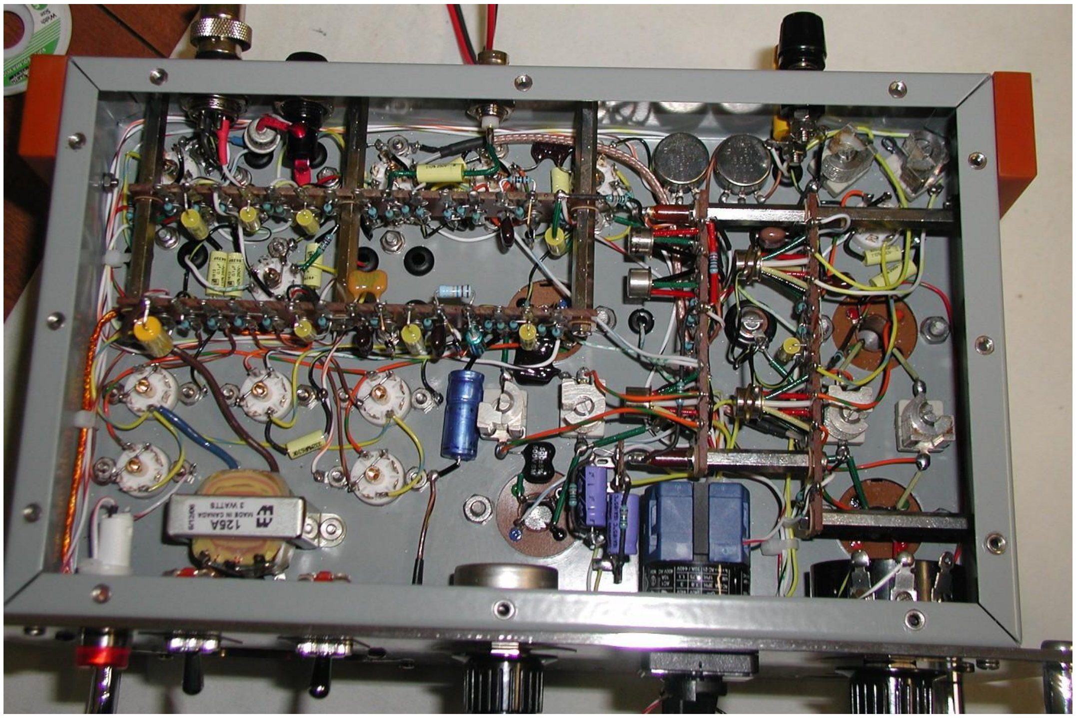
Mechanical construction:

The chassis is steel and grey coated. It was supplied by AES(Antique Electronic Supply USA). After all the holes where created, the bare edges were painted.To prevent any surface damage the chassis and panel were heavily coated in plastic tape while cutting the holes, so that they remain scratch free.The front panel was crafted from 3mm thick stainless steel. The surface treated to create an Engine Turning finish. All the hardware used in the radio, typically 6-32 and 4-40 UNC machine screws are stainless stell. These were supplied by PSME (Prescision Scale model Engineering) in the USA.The Fetron sockets are ceramic with gold plated pins, these are popular in the Audiophile industry for tube work. The wiring in the unit is with high quality teflon multi coloured hookup wire from a submarine parts supplier. The front panel handles are chrome plated brass. The switch lables for the most part are pre made items which came from the electronic markets in Akihabara in Japan.The tag boards used on the radio underside also came from that location.

Photos of the radio are shown below. The red power lamp is the 70V striking Neon:



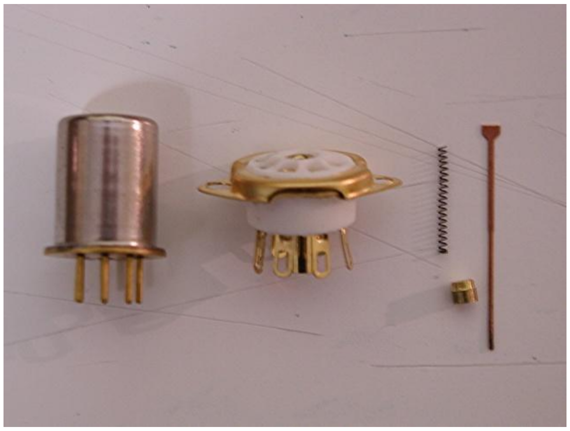




The Speaker mesh is perforated aluminium and lacquered clear. Captive pressed stainless steel 4-40 nuts were fitted to the chassis base to allow repeated removal of the base plate. The three Teledyne RF relays (in TO-5 cases) have earth spring clips to earth their metal bodies. To save battery power latching relays were used and driven by a simple RC network to provide a current pulse to execute band changing. The two TO-5 cased J-Fets for the S meter can be seen upper middle right with the red, green and black sleeving on their lead wires. Notice the blue industrial motor switch used for the band change. The orange wire on the left chassis edge is twin shielded Teflon coated coax. The 3 gang variable capacitor, as usual, is mounted with posts within rubber grommets to prevent acoustic feedback to the capacitor's plates.

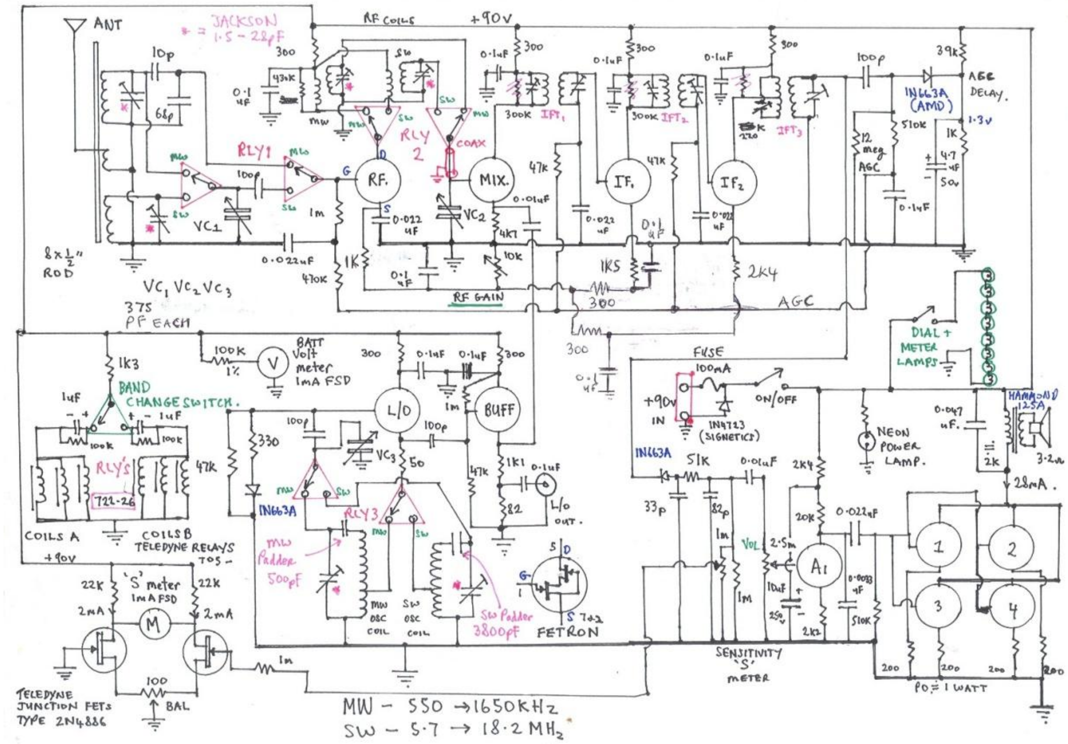
Due to the fact that all of the trimmer capacitors are chassis mounted and the adjustment potentiometers for the S meter are too (seen just above the 2N4886 Fets), the entire electrical adjustment can be done from the chassis top. The dial was created in a photo editor and manufactured as a transparent sticker and applied to the metal Eddystone dial plate. The dial plate and the front panel had the kidney shaped meter holes very carefully cut by hand.

In order to earth the Fetron bodies the ceramic tube sockets were modified. This was done by removing the phosphor bronze and spring assembly from some standard miniature test laboratory clips and fitting them into the centre metal ring of the tube socket by using a small machined bush:



The phosphor bronze wire is slipped through the spring and then through the centre of the socket from the top. The bush is soldered into the tube section on the socket base and the bronze wire is folded over and cut off after it passes through the clearance hole in the bush. This results in the flat top section of the phosphor bronze wire projecting a little above the height of the plane of the top of the socket and spring loaded. When the Fetron is plugged into the socket the bronze wire springs against the Fetron's base securing the earth connection to the Fetron body without having to solder to the Fetron.

The following is the Radio's schematic. Two of the 12v lamps are in the meters the remaining 6 are on a strip-line pcb added into the base of the Eddystone dial. Note the 1N663A diode in the gate circuit of the L/O for self bias to prevent the FETRON forward gate conduction problem described above. The input is fuse and diode protected. It is likely, that unlike a tube, a Fetron would be damaged by the application of reverse polarity.



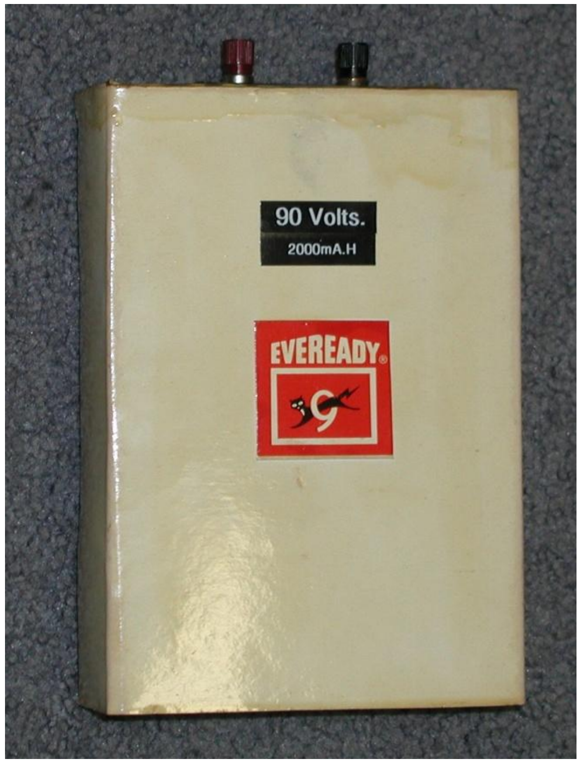
FETRON RADIO H.HOLDEN.

Powering the Radio from 12V - THE OMEGA DEVICE:

The current consumption @ 90V is about 0.047A making the power consumption around 4 watts, which is significantly less than a tube radio employing 6AK5 tubes, because there is no heater demand. The current consumption with the dial lamp string running is 0.075A.

About 2.5 watts of this power is consumed by the class A audio output stage which has a current drain of 0.028A. One option could be a class AB output stage, however calculations showed that it would have been more difficult to attain the 1 watt power output with two paralleled Fetrons per side in the output stage (still using a total of 4 Fetrons) and it would have required a phase inverter circuit or a transformer to drive them. The class A output stage, although a little more power hungry than class AB does give very good results with pleasant sounding audio reminiscent of a typical tube radio with a class A output stage.

A special battery 90V 2000mAH was constructed from a number of AA sized NiCad cells and an Eveready logo put on it for a bit of fun, shown in the photo below:



The 90V battery above is completely electrically quiet. Ideally the radio would be powered by a rechargeable 12V battery. This would require a 12V to 90V switch-mode converter. This sort of converter has been attempted by many enthusiasts of tube radios from the battery area to power "battery valve radios". However a problem inevitably crops up: Converters which operate in switch-mode generate RFI or radio frequency interference, affectionately referred to as "Hash". This results in buzzing signals being detected by the radio.

A medium wave or shortwave radio makes a *very sensitive detector of radiated electromagnetic fields*. For example a typical AM radio with a ferrite rod will produce a loud buzz swamping out all received stations when held within a few feet of a computer monitor or a flat screen TV which contain switch-mode power supply units. Some Amateur radio enthusiasts will not allow a single switch-mode power supply in their shed and insist on a linear (transformer) power supply because of this RFI problem.

Most people would be surprised about the large levels of RFI emitted by appliances like computers and flat panel TV sets. I do not believe these are hazardous to your health, however it is still a form of "radio frequency pollution". These signals can not only cause interference on shortwave reception especially but they can desensitise RF receivers in home automation systems. Some folks have had solar control systems with switch mode power supplies in them installed, only to find that their garage door controllers stop working due to de-sensing of the super-regenerative receivers in the door controllers from RFI as one example.

Similar RFI signals are emitted from the electronics within the supposedly "green" compact fluorescent lamps, but not by the conventional Edison lamps. These HF signals are generated by the rapid switching times as the switching devices, typically transistors or mosfets go into and out of conduction. The rectangular waves have Fourier frequency components which are in the radio frequency spectrum. Having said that, saturated switching remains the most efficient way to transform voltages and this is why this system persists in the power supply units of practically every home appliance these days. In short it is not a good proposition to have a switch-mode converter close to a sensitive radio receiver. A pure sine wave converter could be an option but this would be much more complicated to execute.

The question is, how to make a completely RF silent switch-mode converter?

Enter the OMEGA DEVICE, named so because this supply is the last word in low RFI supplies. This converter has the following properties:

1) Input voltage 12.6 V @ 0.55A.

2) Output voltage 90V @ 50mA.

3) 65% efficiency.

4) Zero detectable RFI > 150KHz.

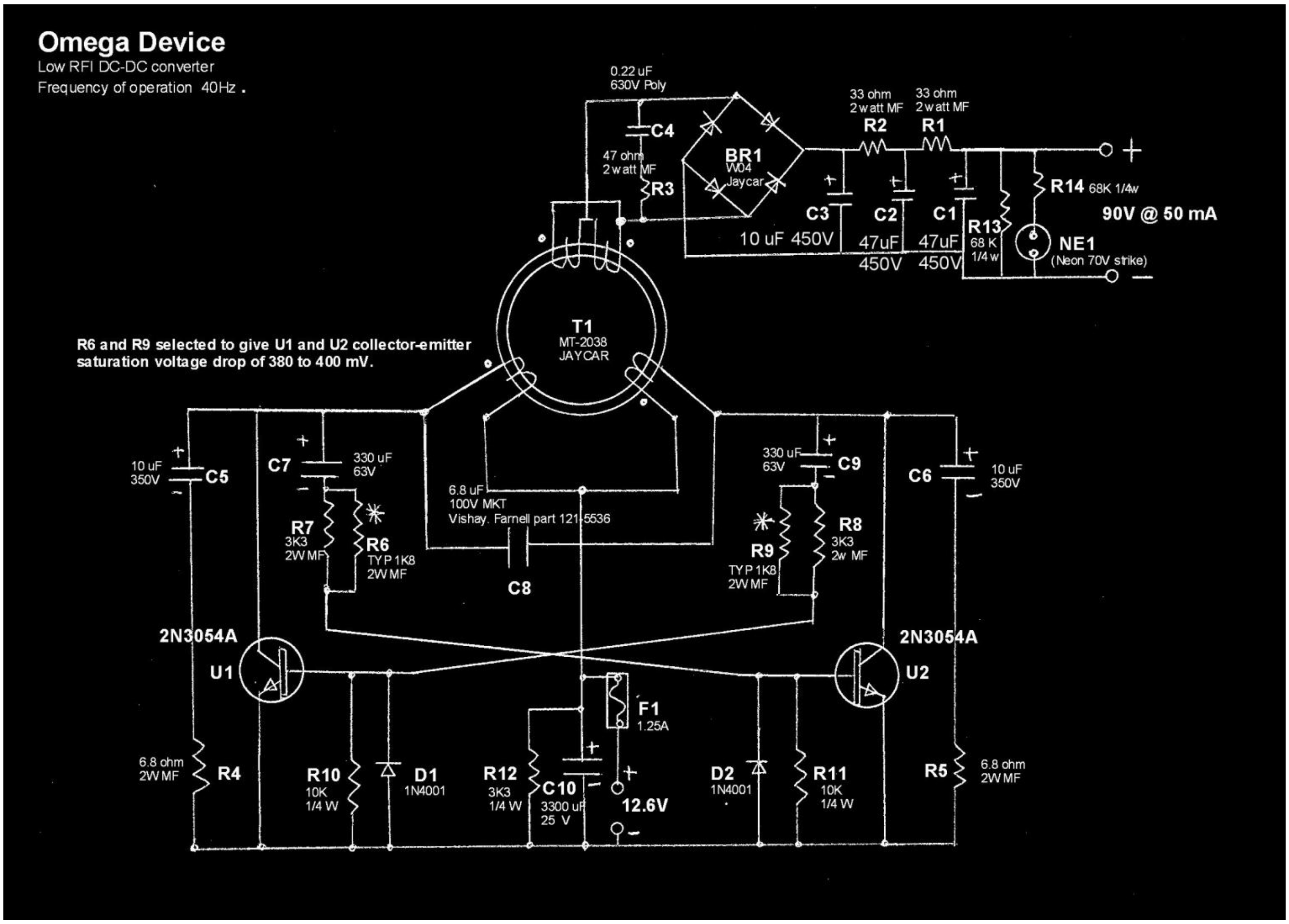
5) Operating frequency 40Hz

6) Off the shelf Jaycar PCB mount toroidal transformer.

The low RFI system was achieved with a simple circuit with attention to a few special details:

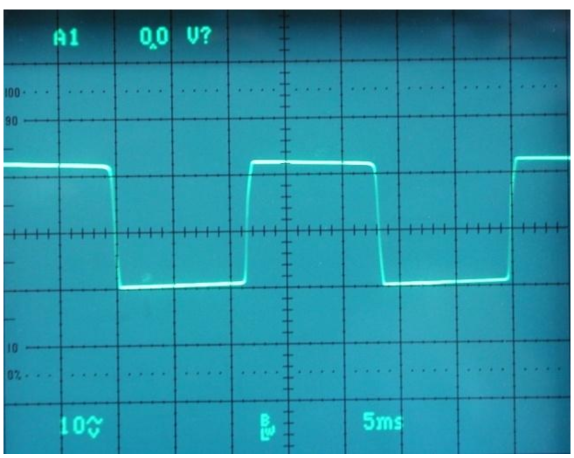
Low operating frequency with an iron cored transformer. This reduces the switching events per unit time and this helps compensate for the deliberately slower switching transitions than used in the typical switch-mode PSU. The slower transition time contains lower HF spectrum Fourier components. The switching time and transition shape was controlled by tuning the primary of the transformer with a large capacitor and RC snubber networks on the transistor's collectors. Also the drive to the switching transistors is adjusted to be enough to gain saturation of the collector-emitter voltage to 380mv to 400mv and no lower. Experimentation shows that all other things being equal, the RFI increases significantly the more heavily the transistor is saturated. RFI is produced when the transistor suddenly comes out of heavy saturation.

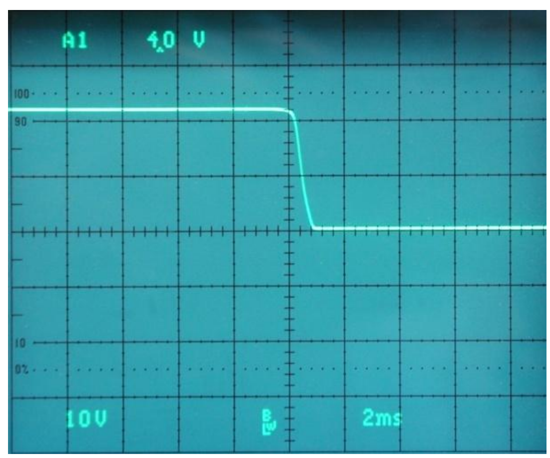
The power inverter shown below (Omega Device) has no detectable RFI when the running exposed PCB placed directly on top of a transistor receiver at maximum gain with a LW band that extends down to 150 KHz. This means that the Omega Device PCB requires no shielding and it was conveniently mounted in a grey polycarbonate case.



The photos below show the Omega Device hand made PCB:

The collector waveform from one of the 2N3054A transistors is shown below:





As can be seen from the trace on the right above the switching time of the transistor’s collector waveform is slow and is part of a sine wave from the tuning of the transformer’s primary and takes about 0.8 ms. While this slower switching time reduces the efficiency a little, this is offset by the slow switching speed, about 40 Hz, so the number of switching events per unit time is relatively low compared to most switch-mode PSU’s.

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