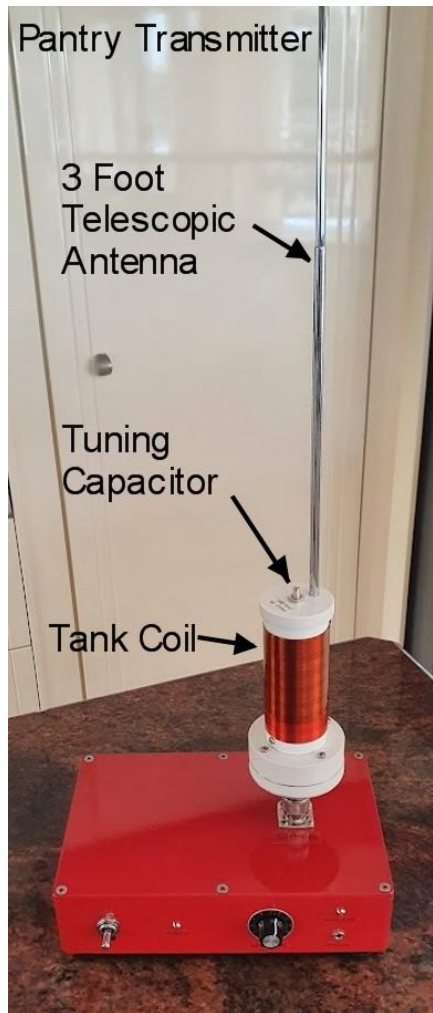


THE LOW POWER SHORT RANGE “ULTRA – LINEAR” PANTRY TRANSMITTER WITH VOLUME LEVELLING, TO SUPPORT WITHIN THE HOUSE USE OF VINTAGE MW BAND AM RADIOS.

Dr. H. Holden. 2025.



Transmitter Unit with 50 Ohm Output, 90mW.

< 1uW radiated EM wave power.



Background:

Collectors of vintage MW band AM radios would like to have their own low power AM radio station to tune into, which played their favourite music. Especially in the light that many AM radio stations have been shut down now and for those people living in peripheral or fringe areas, the remaining signals may also be too weak to receive.

There is nothing like the joy of tuning into an actual station on a MW band radio, especially if you grew up from childhood with these radios in the 1950's to 1980's era. Those of us, now getting older, that did just this and many of us have a kind of sentimental attachment to AM radio and the radios themselves.

Transistor radios have even been mentioned in the songs of that era themselves. For example the Van Morrison song Brown Eyed Girl (1967), the lyric fragment; "going down the old mine with a transistor radio" It was pointed out later by an Engineer that a transistor radio stops working if you take it underground. However, the song was saved, because it could have been an open cast mine.

Therefore, a low power radio transmitter, which just has enough output energy to transmit about the house and no further, is very appealing to the vintage MW band AM radio collector.

A popular name for these low power transmitters in the UK is a "Pantry Transmitter" You might keep it in the pantry and transmit to a few rooms in the house. In the USA they get referred to as Part-15 transmitters, because a specific set of FCC regulations: Part 15.219 applies to them.

Many designs of Pantry Transmitters have appeared over the years as hobby projects in magazines and also available as kits on eBay and Ali-express. Some are of dubious quality or poor design. Early designs used Tubes and would accomplish things such as sending a playing Gramophone Record to a MW band radio nearby, so that the user could hear their record playing on the radio.

Although these regulations don't apply in all countries, the USA's FCC's Part 15.219 Regulation Transmitter Specifications do provide a useful "metric" to avoid interference to others.

Obviously any MW band AM transmitter circuits, regardless of their RF amplifier design, combined with some design of Antenna structure, must never be allowed to transmit a higher actual electromagnetic (EM) wave power than the "FCC's regulation transmitter-antenna arrangement"

In this article, the maximum EM wave power (units Watts) that the Part 15.219 compliant Transmitter-Antenna arrangement can emit and also the Electric Field intensity E (units Volts per meter) generated away from the antenna are calculated.

The FCC's Part 15.219 rules specified that the Antenna wire and Earthing combination wire length should be no longer than 10 feet (3 meters) and that the DC power consumption of the RF output stage should be no more than 100mW.

Most Pantry transmitter designs use Class C output stages and Class-C, or a switching style class E radio frequency output amplifiers are such that their DC power consumption is closely correlated with their RF output power. Typically, if the Class-C or E output stage consumes 100mW DC power, the RF power output is in the order of 90mW (This was also the value used

in the NEC4.2 analysis of the Part 15.219 arrangement, see below) Of note though, this is not the actual radiated EM wave power which is only a tiny fraction of the 90mW figure.

However, a Class-A RF amplifier is not this way at all and it consumes the same power from the power supply regardless whether its output RF level is 1mW or 100mW. Therefore the metric of “100mW DC power consumption” used in the Part 15.219 specifications is inapplicable to the Class-A RF output stage.

From the design perspective, for low modulation distortion, it is much better to have a linear modulator and linear output stage and modulating the carrier wave, prior to a Class-A RF output stage. This is much less efficient, wasting power as heat, but it is better for linearity than a Class-C stage with the modulation applied to its power supply which in most cases results in more modulation distortion.

In any case, regardless of the efficiency merits, it is very easy to ensure that a Class-A output stage's RF power output is exactly 90mW on testing the RF output voltage it into a dummy load instead. In essence this makes the Class-A stage just as technically and ethically compliant and practically equivalent to a Class C stage consuming 100mW from its power supply.

As will be shown here, any small differences in the power levels at the RF output stage are shrunk into relative insignificance, because even for the perfectly implemented Part 15.219 setup only about 0.56mW (560uW) of power appears as radiated EM waves. And typically, for many hobby Pantry Transmitter setups, is only in the order of $1/500^{\text{th}}$ of that in the region of 1uW or less radiated EM wave power.

To make a “really good” Pantry Transmitter it requires significant processing of the Audio signal prior to a linear modulator. This involves compression of the audio levels (volume levelling) and peak clipping combined with arrangements to make sure that the actual modulation can never reach 100% and modulate the RF carrier right out. The design task here is equally as involved as the Transmitter unit itself, however, in many Pantry Transmitter kits, this facet of the design is completely neglected, contributing to poor results and distortion produced by some units.

The designs presented in this article:

The Audio Compressor/Limiter, Modulator, RF Amplifier and Antenna arrangement presented in this article results in a much lower power EM wave transmission and a much shorter transmission range than an optimal Part 15.219 compliant transmitter. This ensures any interference to others is extremely unlikely.

The designs presented here also have the advantage of being able to set the exact power of the output RF amplifier into a 50 Ohm test load. This makes it 100% certain that the regulation

transmitter output stage levels are never exceeded. Also this system has a very high linearity and low distortion of both the RF Carrier Wave and the Audio Modulation.

The Audio signal is highly processed, compressed and peak limited for uniform listening volume and set up to prevent over-modulation of the RF carrier.

The antenna in this design, being only about a 1 meter (3.3 foot long) telescopic Whip, harvested from a defunct set of TV Rabbit ears, is less cumbersome than a 5 to 10 foot wire. And it is easily retracted when not in use to make it more compact.

Analysis of the Part 15.219 Transmitter as an EM wave Generator:

These rules applying to home-hobby transmitters are Part 15.219, the essential features of which are referred to in figure 1.

FIG. 1.

FCC Rule	Applies To	Power Limit	Antenna Length	Field Strength Limit	Hobby Use?
§15.219	AM Band (510–1705 kHz)	100mW (input)	≤ 3 m total	✗ None	✔ YES
§15.209	General radiators	None	No antenna spec	✔ 24µV/m @ 30 ft	⊗ Only if 15.219 is violated

The 24µV/m electric field intensity @ 30 feet, is often brought up in conversations about Pantry Transmitters, but it doesn't actually relate to Part 15.219 hobby transmitters at all, unless they happened to violate the Part 15.219 rules. This low value field intensity is such that most good Superhet radios would be barely receiving a usable signal out of the noise. The 24µV/m specification applies to General Radiators under Part 15.209, not Part 15.219.

The main thing about the Part 15.219 rules for hobby use, is that the DC power input to the RF output stage is limited to 100mW (which in practice as mentioned limits the actual RF output power to about 90mW) and that the total antenna length (including any Earth wire) is no longer than 10 feet. The antenna length and the Earth are two of the main factors controlling the transmission range and actual radiated EM wave power.

The interesting thing about the FCC rules of Part 15.219, which surprised me on investigation, as the analysis will show, they are not particularly restrictive on transmission range at all. In fact the analysis shows that a technically near ideal low loss Part 15.219 compliant Transmitter-Antenna

setup running at 1.65MHz, can result in 558uW (about 0.56mW) of actual radiated EM Wave power. It doesn't sound like much, but this level can produce a field intensity E of about 4.4mV/meter at 30 meters from the antenna. And the signal could still be resolvable, in low noise conditions at 1000m from the antenna.

A NEC4.2 analysis has been performed on a compliant Part 15.219 Transmitter-Antenna assembly and it confirms my analysis, but it is copyright to Richard Fry 2018, so I cannot re-present it here. In his analysis he found that the electric field intensity E at 1610 meters (1 mile from the antenna) was 109uV/m and that may be enough for a good radio receiver to be able to resolve the signal if the interference was low. A copy of it, at this time, can be seen on this link:

<https://ham.stackexchange.com/questions/11696/true-near-field-distance-for-a-short-monopole-antenna>

However, anybody who has used Pantry Transmitter Kits knows full well that the above result, in practice, is never achieved, not even close to it.

Usually the transmitter kit hardly manages to transmit across three or four rooms in a House and barely makes it to the front gate of a typical house, let alone up the street. This is a good thing to the extent that it avoids transmitting signals that interfere with others and this should remain the goal, regardless of any other factors. The reasons for this much shorter transmission range with a "Practical Part 15.219 Transmitter –Antenna arrangement" will be explained in this article.

Analysis of the ideal Part 15.219 Transmitter-Antenna Arrangement:

My analysis yields similar results to the NEC4.2 analysis, but it is limited to the far field (>30 meters) and plotted on a Log-Lin graph rather than Log-Log. For this examination we will choose an operating frequency of 1.65MHz (1650kHz).

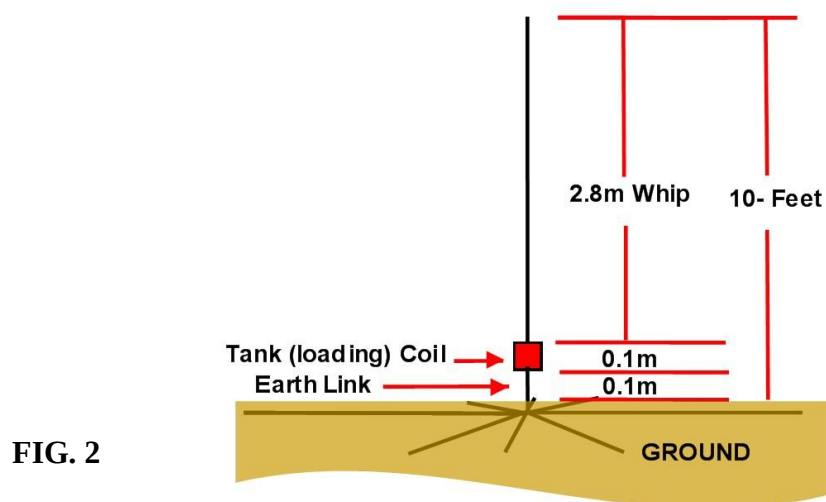
"Short" linear antennas are said to be short because they are small in length compared to the wavelength in use. For example a 1.65MHz EM wave has a wavelength of about 181.8 meters.

The 3 meter (approx 10 foot) Whip antenna is therefore only 1.65% of the wavelength. We will use a 2.8m Whip or about 9.2 foot high 1/4" diameter rod antenna in the analysis.

In essence the short Whip antenna behaves as a low value capacitance. The capacitance of which is very approximately 27pF for a 10 foot rod.

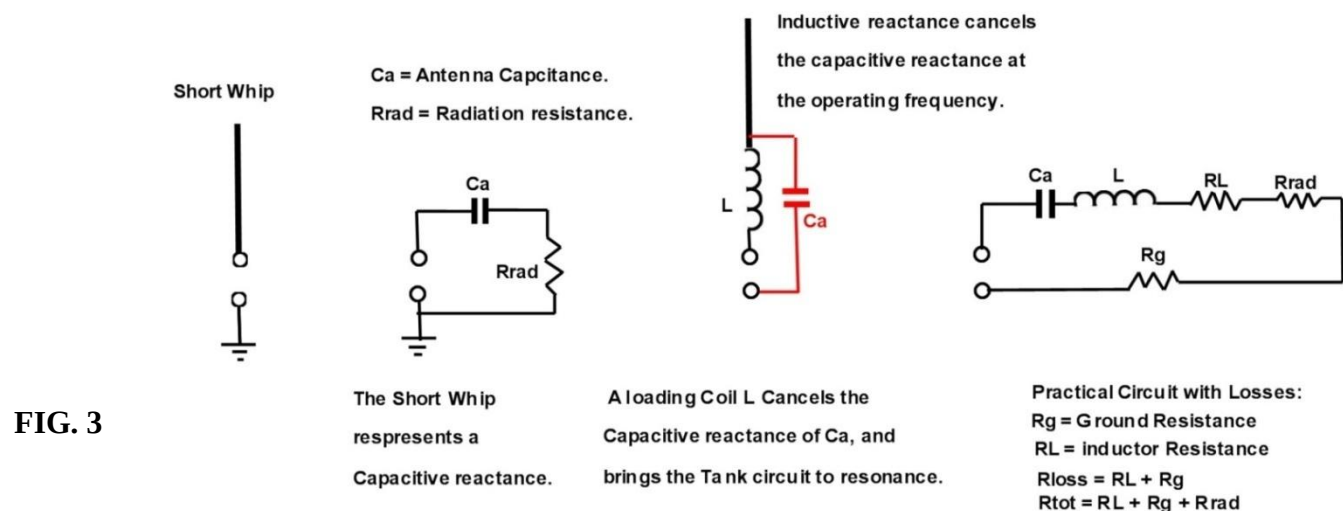
As will be seen, the exact antenna capacitance value is not required to calculate the radiated EM wave power, or the Electric field intensity at locations away from the antenna for that matter. It is implicit that the capacitance, whatever the exact value of it is, is the only capacitance that is in resonance with the loading coil (Tank coil) at the operating frequency and that the radio frequency current in the Tank coil is at its maximum possible value.

The Diagram of figure 2 below, depicts what would be an ideal Part 15.219 compliant Antenna arrangement:



The diagrams in figure 3 below indicate that any practical antenna circuit contains a total resistance R_{tot} made of three resistances, which limit the Tank circuit's current.

The loss resistance R_{loss} value (mostly ground loss) in the better designs often approximates about 10 to 15 Ohms. For now we will use 14 Ohms as a ground loss figure R_g and a Tank coil resistance of 1 Ohm. Making the loss resistance $R_{loss} = \text{Coil loss } R_L + \text{Ground loss } R_g$ together, to be in the order of 15 Ohms.



The Radiation Resistance Rrad:

Rrad, is the fictitious resistance in the antenna circuit that converts the actual rms antenna current Irms, into electromagnetic waves (EM waves) with some radiated wave output power Prad as shown in equation 1.

$$Prad = I_{rms}^2 \times R_{rad} \quad equ.1$$

Rrad is the only “useful” resistance here. The Inductor’s resistance RL and the Ground Loss resistance Rg simply waste applied power as heat. The problem with the short antenna scenario is that Rrad, as a value, is extremely low compared to the total loss resistance value.

The formula for the radiation resistance of a short monopole antenna with height h , at some wavelength λ , is:

$$R_{rad} = 40\pi^2(h/\lambda)^2 \quad equ.2$$

This relation makes a 2.8m long antenna have a very low radiation resistance and makes it a very inefficient radiator of EM waves with a 181.8m wavelength (1.65MHz frequency)

For a 2.8m Whip operating at a wavelength of 181.8m, Rrad is only 0.094 Ohms = 94 milli-Ohms.

This reduces the antennas efficiency n

$$n = R_{rad} / (R_{tot}) = 0.094/15.094 = 0.0062 \quad equ.3$$

Making the efficiency of the 2.8m antenna operating on 1.65MHz very low at about 0.62%

Already it is obvious that only a small fraction of the RF power delivered to the Tank circuit from the RF output amplifier is converted to actual electromagnetic waves, most is wasted as heat. Therefore, out of the 90mW applied RF power only $0.0062 \times 90mW = 0.558 mW$ is converted into an EM wave transmission. Another method can help verify this:

If we assume that we have a Tank coil, that is perfectly matched to a transmitter (actually producing about 90mW RF drive power) and that the only capacitance that is tuning the coil is the antenna’s capacitance, then the Tank coil’s circuit’s current and the tuning capacitor’s (antennas) current are the same:

The total rms current in the Tank coil, $I(tank)$, driven at a power P_o of 90mW and the total resistance losses + Rrad are 15.094 Ohms then:

$$I(tank) = \sqrt{(P_o/R_{tot})} = \sqrt{(0.09W/15.094 \text{ Ohms})} = 0.077A = 77mA \text{ rms} \quad equ.4$$

Applying equation 1, and multiplying the square of that current by Rrad we find the actual expected EM wave power emitted by the Part-15.219 Antenna is $(0.077)^2 \times 0.094 = 0.557\text{mW}$ or 557uW of radiated EM waves agreeing with the previous figure of 558uW from the antenna efficiency method of calculation.

Note: As another check on this calculation, the figure matches the result from an Internet Calculator, which gave 558uW radiated power with the same parameters entered:

<https://people.physics.anu.edu.au/~dxt103/calculators/Rrad.php>

This calculator also predicts that the antenna voltage to be 443V (the equations for this not included here) Of course if you touched the antenna, you would not get a shock, because it would be immediately de-tuned and the voltage drop to a very low value. However, it would light up a small Neon Lamp if one terminal of the lamp was touched on the antenna, while holding the other terminal of the lamp.

If the RF output stage could feed the 90mW into a 50 Ohm load and the Tank coil was matched to have a 50 Ohm input resistance, the rms drive voltage, out of the RF amplifier, directed to the Tank coil's matching network input is only 2.12 Volts. Therefore, the "transmitter module" itself only has to produce a 2.12V rms output (6V peak to peak) into a 50 Ohm system to deliver the 90mW power, provided it is properly matched to the Tank coil. The matching must be arranged so that at the resonant frequency the antenna's input impedance of 50 Ohms looks entirely resistive (voltage and current in phase)

Therefore one could say that the *implications of the Part 15.219 Transmitter specifications*, under the best (ideal) possible theoretical conditions of low range ground losses in the vicinity of 15 Ohms are:

The Part 15.219 compliant transmitter arrangement should not transmit more than 558uW of unmodulated EM wave carrier power under any circumstances.

Electric Field Intensity at locations away from the Antenna:

The equation for the field intensity **E**, in volts/meter, in the Far Field from the antenna, where G is the antenna gain, in this case G=1, P is the radiated electromagnetic wave power and r is the distance from the antenna in meters, is:

$$E = (\sqrt{30GP})/r \quad \text{equ.5}$$

Of note: Equation 5 was derived by equating the far field Power Density of $GP/4\pi r^2$ units Watts/m², to the power density of the electric field **E**, where the Power Density is E^2/Z_0 , and $Z_0 = 377$ Ohms. Therefore the factor of $377/4\pi = 30$, appears in equation 5.

The far field is defined as being greater or equal to $\lambda/2\pi$ meters from the antenna. In this case about $181.8/6.283 = 29$ meters or greater applies, therefore a distance of 30m away from the antenna, by definition, is the “Far Field”

In practical use though, with all real Pantry Transmitters, the radio receiving the signals is in the Near Field, because mostly they are usually within 10 to 20 meters or about 30 to 60 feet or so of the Antenna.

In the “Near Field” the reactive zone, near the antenna, the EM waves are not yet free from reactive antenna interactions. The ratio of the electric field $\mathbf{E}$ to the magnetic field $\mathbf{H}$ has not yet levelled out to the value of 377 Ohms as it has in the far field. This is not unhelpful, because for low power transmissions, the electric field intensity falls away more quickly at a rate of $1/r^3$ and $1/r^2$, nearby the antenna, rather than $1/r$ as equation 5 predicts for the the far field. Therefore, the rate of signal intensity drop off, with distance, is steeper in the near zone as we move away from the antenna, than it is in the far field.

This “near field effect” also explains why people have noticed with Pantry Transmitters, that if you walk away from the Antenna with a portable radio, the signal appears to fairly abruptly start to fade away. On the other hand you can walk a hundred meters further away from a far off radio station and practically notice little difference in the signal strength. It is a good “feature” because it results in a lower chance of interfering with anyone else, provided the transmissions are low level initially and do not extend to any extent outside your own house or property.

A graph of *equ. 5* is shown in Figure 4 for the electric field intensity $\mathbf{E}$ for an antenna radiating the part 15.219 ideal setup of 558uW (red line) and realistic 1uW (blue line) that is typical of home made Pantry Transmitters. Log scale on the Y axis and a Linear scale on the X axis.

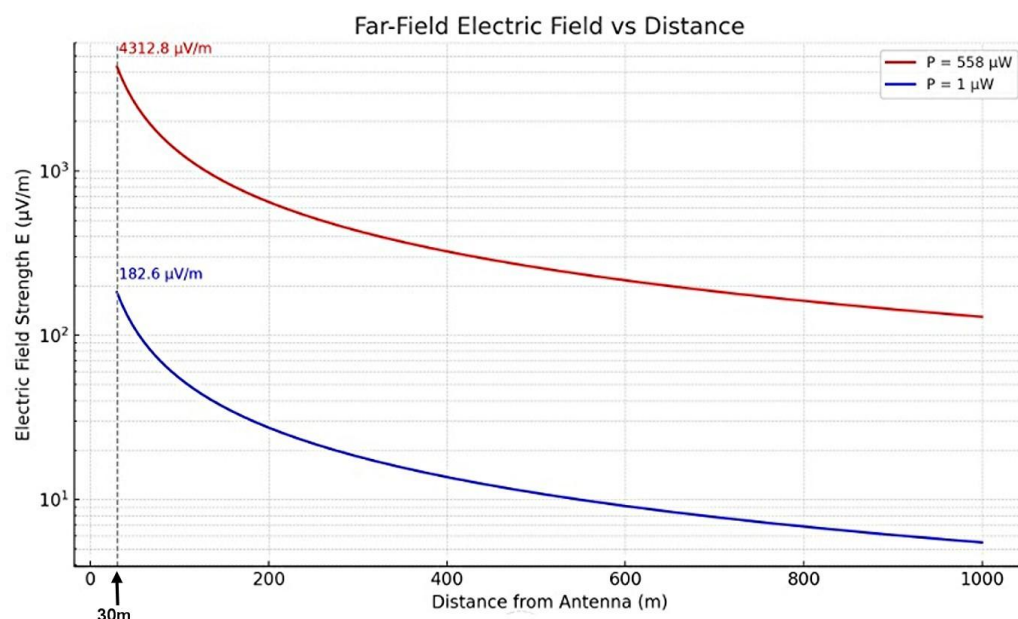


FIG.4

The FCC must have realised that the level of 558uW (about 0.56mW) radiated EM wave power from the ideal Part 15.219 arrangement would never likely occur in practice. It can only be achieved if you have your Earthing perfect with multiple ground radials in good soil and your 4 inch tall Tank Coil sitting only 0.1 meters (about 4 inches) above the surface of the ground, with a 2.8m Whip, in your back yard, on the Lawn. Nothing like this can sit on a desk in your Living Room or Pantry.

To better decide what the maximum EM wave radiation might be from a “Practical Part 15.219 transmitter-Antenna arrangement” we need to look at the various factors which in practice significantly lower the EM wave radiation below the possible 558uW result and also act to greatly reduce the practical transmission range.

Summary of losses in a practical compliant Part 15.219 transmitter-antenna system:

- 1) As indicated by *equ. 2*, when the antenna height h is reduced, the radiation resistance drops with the square of that change. If we had a 10 foot antenna (with a very short earth wire) and altered that to a 5 foot earth wire and a 5 foot high antenna, we halve the antenna height. The Rad drops by a factor of 4 and all else equal, the radiated EM wave power drops by a scale factor of 0.25.
- 2) Without the ground radials, a more realistic figure for the earth resistance and losses there would be in the order of 60 Ohms or more. When the loss resistance increases by a factor of 4 it lowers the antennas efficiency by a factor of close to $\frac{1}{4}$ because of the very small value of Rad, as seen by equation 3. Therefore, another scale factor of 0.25 applies. This assumes of course that despite the higher resistive losses, the RF output amplifier remains with an impedance match to the tank circuit and is still managing to deliver the 90mW power to it.
- 3) In practice, with a real Tank coil, rarely is the Capacitance of the Antenna the only capacitance tuning the Tank coil. Firstly there is the Tank coil's self capacitance, but secondly, generally, it is required that there is an additional tuning capacitor with the Tank coil to be able to manually tune it to the operating frequency. This is also required to allow a correct impedance match too, which can only occur at resonance. And also a lower L/C ratio is usually required, with increased tuning capacitance and lower inductance combination. This is to lower the Q so that the bandwidth is wide enough not to restrict the higher range audio frequencies.

This results in a split of the Tank circuit RF current i_1 , between that which passes via the antenna's capacitance i_2 and that which passes via the added lumped tuning capacitance i_3 on the Tank coil. See figure 5 below. Therefore we can assume for example the equivalent circuit, or similar might apply in the case of a split of capacitance:

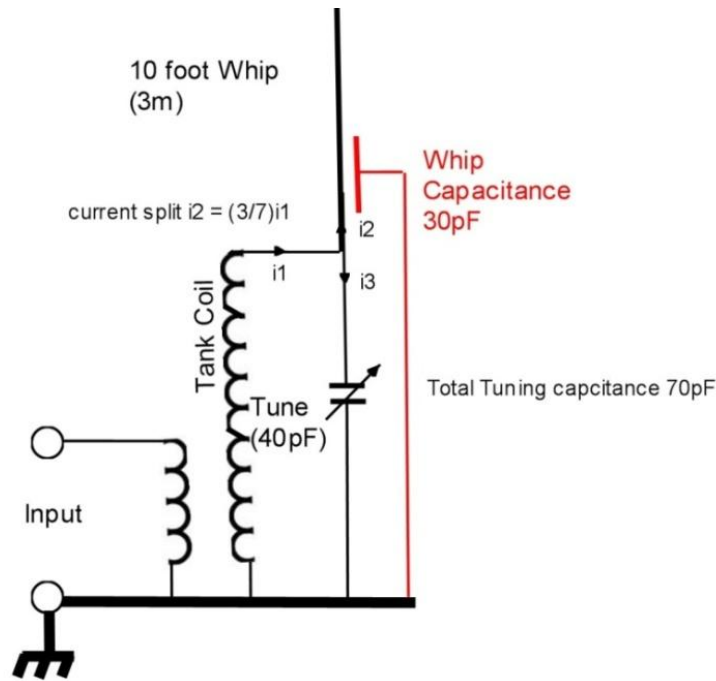


FIG.5

3/7 of the Tank current i_1 goes to the Whip's capacitance as i_2 and 4/7 to the lumped 40pF tuning capacitor as i_3 . Since the rms RF current in the antenna is reduced, the Radiated EM wave power is now decreased again by a factor of $(3/7)^2 = 0.184$ because, as previously noted from equ.1, the radiated power, P_{rad} , is proportional to the square of the antenna current.

Therefore assuming the arrangement still has a 90mW drive power delivered to the Tank circuit, the practical arrangement might have only $0.25 \times 0.25 \times 0.184 = 1/87$ th of the ideal 558uW figure, or about 6.4uW of actual radiated EM wave power compared to the ideal part 15.219 setup.

4) In addition there are other losses not considered which occur in the matching networks between the RF amplifier and Tank coil. Also, many designs of RF output Amplifier, regardless of the class of operation, may not deliver the 90mW value and many have a non standard output impedance and no practical methods are advised on how to verify the actual output power when they feed a very high antenna impedance (the design presented here solves that problem)

All of the factors above conspire to degrade the radiated RF output power and the transmission range of the Part 15.219 arrangement. Summary:

Perfect implementation of Part 15.219 = 558uW, Field at 30 meters = 4.31mV/m

Practical implementation of Part 15.219 = about 1uW, Field at 30 meters about 182uV/m

And a much lower radiated power occurs with poorer earthing arrangements and much larger values than the 60 Ohms ground resistance modelled here.

The radiated power from a typical Pantry Transmitter kit is likely well under 1uW that and the field strengths are lower, helping to explain the very short transmission range of some Pantry Transmitter Kit systems.

For example, many Pantry Transmitters sold as pcb kits are used without a separate earth wire and the user simply hangs a 10 foot wire on their output terminal. Some form of grounding can be acquired via the negative/common power supply terminal, to the Dwelling's Earth if the power supply design allows that.

Or if the Pantry transmitter kit is powered via an SMPS wall wart supply there is some capacitive coupling to the line power system via Y capacitors and a poor RF pseudo-Earth is created.

If the transmitter is powered by a battery, there may be no earth conductor at all and the earth itself simply represents capacitive coupling of the transmitter's pcb or housing to the environment. Or the user may be on the second floor of a building and there is no practical way to create a reasonably short earth connection.

One paradox here is that if the Earth is longer than 10 feet, in theory the Antenna length cannot be greater than zero in length, or it violates the rules. Yet having no earth connection at all would be equivalent to an infinitely long earth conductor. One possible solution to the "No Earth issue" could be to use a Dipole constructed from two 5 foot antenna sections, but that would be large and somewhat cumbersome. A better solution is a Loop for pantry transmitters that cannot acquire a reasonable earth.

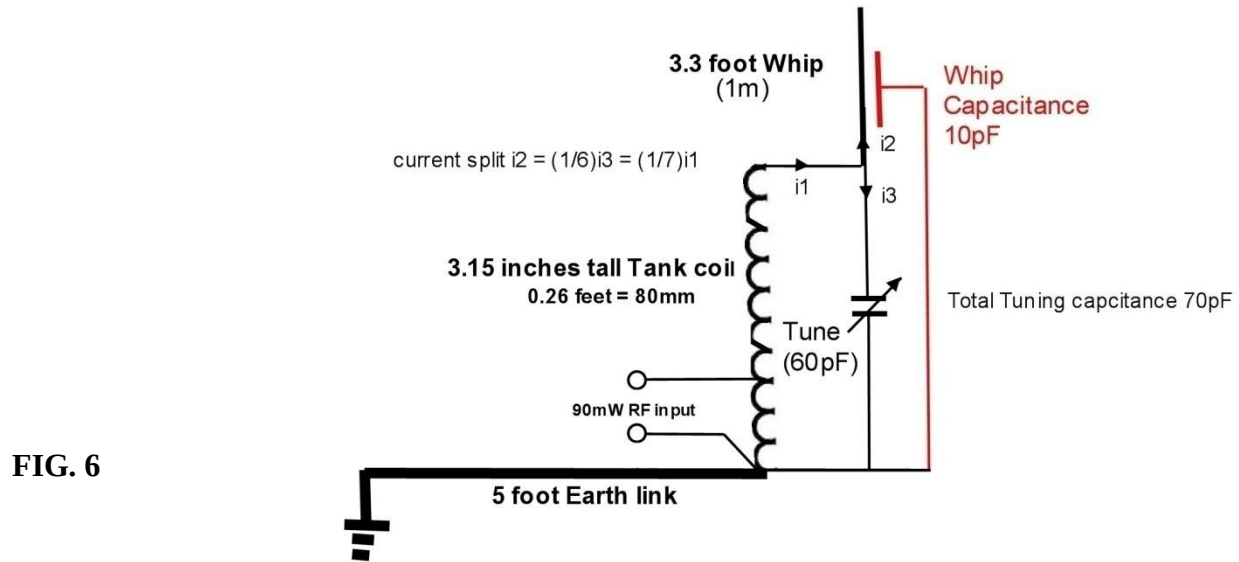
What does the Part 15.219 analysis indicate?

The analysis demonstrates something very important. The radiated EM wave power level that is achieved by a perfectly implemented Part 15.219 MW band AM Transmitter – Antenna assembly **is far too high** and 558uW of radiated EM wave power should never be a design target for a home Pantry Transmitter. This level could easily interfere with others, given the field strength at 30 meters of 4.312mV/m. A realistic and socially responsible target would be to never exceed about 1/50th or less of the possible radiated power from the perfect Part 15.219 implementation to avoid any interference issues.

I would recommend 10uW as being the Maximum radiated power and 0.1uW to 1uW is typically all that is required for the task of transmitting radio signals within the house and no further. The range of course is easily checked with a portable radio.

Designing a shorter Whip Antenna than 10 feet for a useful result:

Applying the above information to a shorter antenna of 1m tuned by the following capacitances as shown, the total tuning capacitance is 70pF, figure 6 below. The split in the capacitor ratios means that only 1/7 of the Tank current value goes to the capacitance of the antenna, shown in Figure 6, meaning that radiated output power drops by a factor of $\left(\frac{1}{7}\right)^2$ or 1/49.



Despite the reduction of radiated EM wave power, the advantage of the larger lumped tuning capacitance on the Tank coil is that it results in an antenna with a lower Q which is helpful to maintain a wide bandwidth for the audio modulation. The antenna described here has about a 10kHz bandwidth, there is no loss of the high range audio frequencies.

Also since the Rrad is proportional to the square of the antenna height, reducing the antenna height from about 3m to 1m results in a reduction of Rrad (and radiated EM wave power) by another factor of $\left(\frac{1}{3}\right)^2$ = a factor of 1/9 .

The earth resistance loss is also much greater than 15 Ohms of the near perfect Earth with 8 ground radials and is more likely in the order of 150 Ohms or more, causing a further reduction in the antenna efficiency, thereby reducing the radiated EM wave power by a factor of 1/10.

Thereby making the EM wave output power of this 1m antenna arrangement, compared to the ideal Part-15.219 setup roughly about:

$$1/49 \times 1/9 \times 1/10 \times 558\mu\text{W} = 0.000291 \times 558\mu\text{W} = 0.13\mu\text{W}.$$

This EM wave power corresponds (at 30 meters) *equ.5*, to a field strength E of about 64uV/m and few radios would be able to resolve this out of the noise. In other words, the signal is fading out. Although, this low radiated power level is still useful for within the house transmissions, without risk of interfering with others. Unless perhaps the house is a Mansion with more than 5 or so rooms.

A PRACTICAL LOW POWER PANTRY TRANSMITTER-ANTENNA:

Low Power 0.13uW or less Radiated Power (0.023% of the ideal FCC Part-15.219 setup)

Low Carrier wave Distortion.

Low Modulation Distortion.

Audio processing, prior to a MC1496 Linear Modulator.

- Compression & perceived Volume Levelling
- Peak Limiting & LED Indication.
- Over modulation prevention.

Linear Class-A RF Amplifier Set for 90mW.

- Verified into a 50 Ohm load, 2.12V rms or 6Vpp.

3.15 inch tall Tank coil configured for a 50 Ohm resistive input impedance.

1 meter (3.3 Foot tall) vertical Whip Antenna.

Maximum Earth conductor length 5 to 6 feet.

One interesting initial question could be:

Since it is always required that a short Whip antenna must have a Tank coil to resonate with the whip's capacitance at the operating frequency (cancel out the whip's capacitive reactance) then:

An antenna's Tank coil should be regarded as part of the antenna assembly, not part of the Transmitter assembly:

Many Pantry Transmitters include the Tank coil on the pcb in the unit, so that the user can simply attach the antenna wire and earth wire (if connection provided) to the pcb's output terminals. Or you can have the Tank coil built into the antenna's base.

The Tank coil required is less than six inches long and the coil itself produces negligible EM wave contributions to the transmission, due to its low cross sectional area. The coil simply exchanges its magnetic field energy with electric field energy of the capacitances throughout the operating cycle and doesn't radiate EM waves of any significance. However at resonance the Tank coil optimizes the RF current injected into the Whip. It does mean the Whip antenna itself (or wire) has to be shortened a little to accommodate the coil, while keeping the total Whip and Ground wire length within the FCC's 10 foot limit.

In the design presented here with a 1 meter (3.3 foot Whip) the Tank coil is 3.14 inches or 0.26 feet (80mm) long and 1.6 inches (41mm) in diameter.

On examining this interesting issue, there is a very good argument for keeping the Tank coil and matching components at or within the antenna's base. If they are inside the Transmitter's body instead, this makes the transmitter's output impedance, on its output terminals, be in the range of a few thousand Ohms. The exact value is not often known and connections to the output terminals, with any test equipment, results in significant de-tuning. And it is a non standard output resistance.

However, with the Tank coil and matching components built into the antenna's base, the antenna can then be arranged to present a standard 50 Ohm resistive load at the operating frequency. This means that the output power from the transmitter unit is easily tested & verified with standard 50 Ohm input power meters, or just as easily with a Scope measuring the voltage the transmitter unit applies to a 50 Ohm dummy load.

In addition, most transmitter RF output stages rely on their outputs being properly terminated into the correct load impedance. An unterminated state can be harsh on the RF output device. Generally in the unterminated case, the voltage rises to about double the normal value or more sometimes and that, on occasions, can damage the output RF device/s. In this case the design of the final RF output stage tolerates an unterminated output condition without damage because a very robust output transistor was selected.

Loops vs Whips:

The advantage of a Loop antenna to a Whip is that it produces a higher magnetic field **H**, in the near field than the electric field **E**. Again though, far from the antenna the ratio of **E/H** evens out

to 377 Ohms. However, the advantage of the loop in the near field is that it suits Transistor radios with Ferrite Rods or Tube radios with Frame Antennas as these respond well to the magnetic component of the field. And the loops are very directional in nature. Also the loop eliminates the need for a ground connection (much as a dipole antenna would)

On the other hand, vintage radios with linear wire antennas respond better to the electric component of the field. And also, testing with the Whip shows that the results with a transistor radio are still very good. The whip is less bulky than the Loop. Figure 7 below shows a comparison of the Whip described here with an experimental 50 Ohm Loop design:

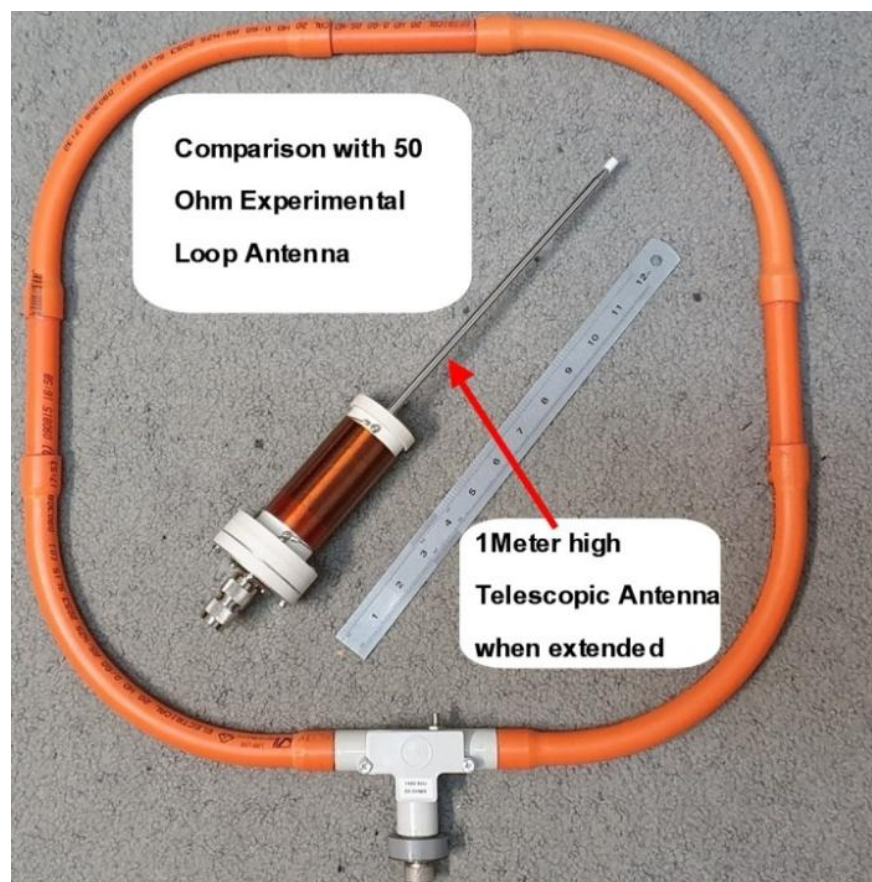


FIG. 7

The Whip described below figures 8 through 11 was made from a section of 41mm diameter plastic plumbing tubing and some rings machined out of 8mm thick insulating material. (I used Bramite which is similar to Garolite) but fibreglass FR4 or acrylic sheet would work to. The diagram below shows the basic features. A Male-Male PL-259 adapter is screwed onto it.

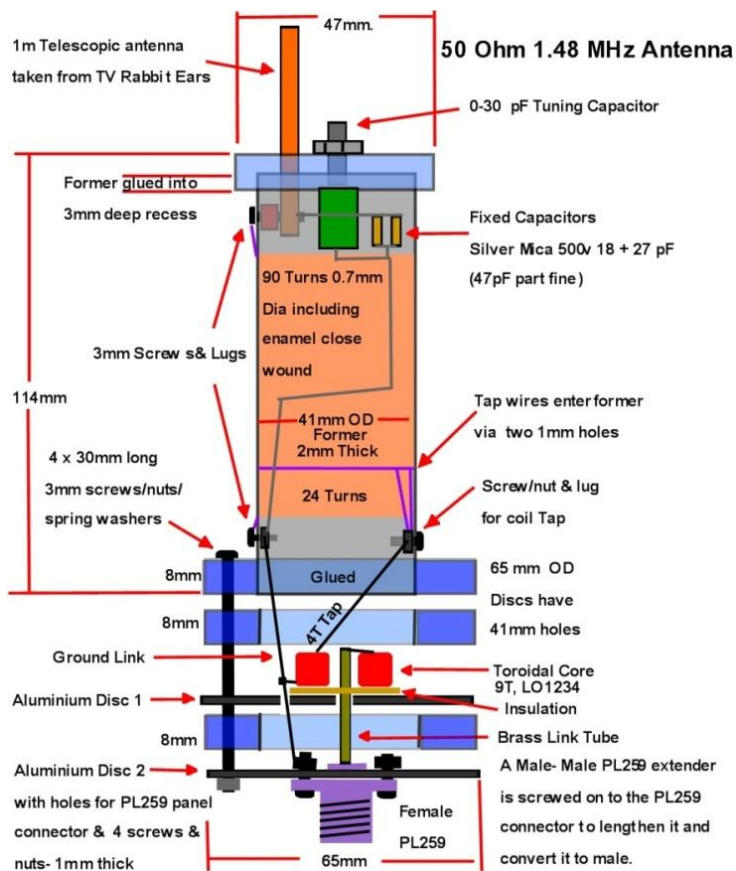


FIG.8

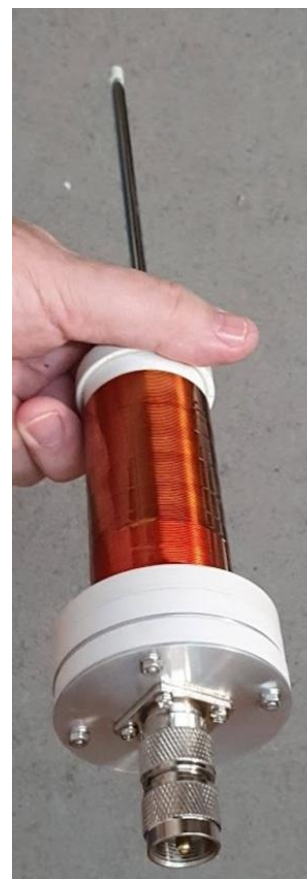


FIG.9

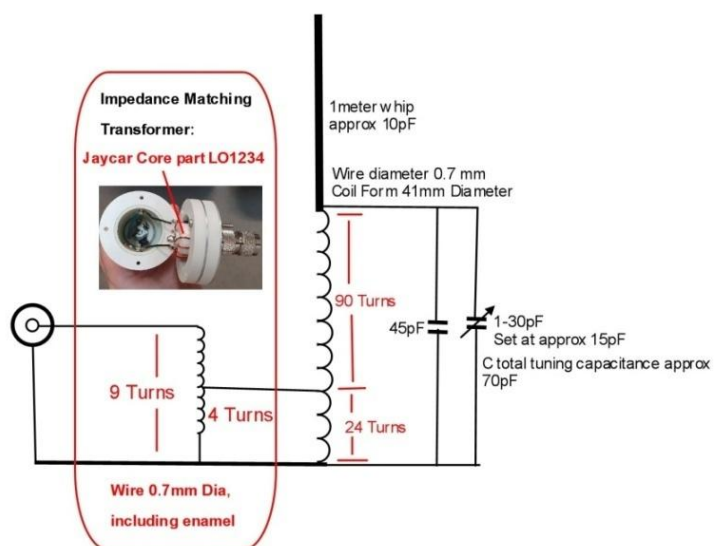


FIG.10

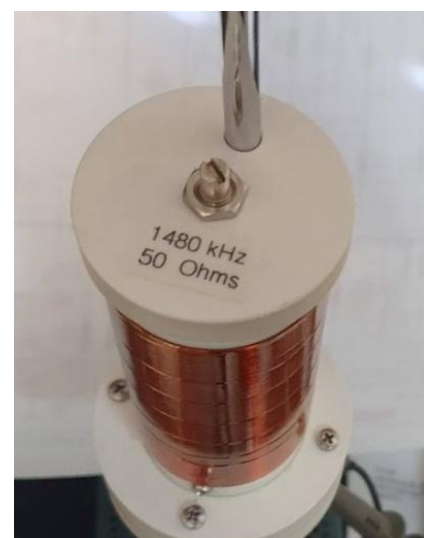


FIG.11

Verifying the Whip Antenna's Input Impedance:

Initially I made a test setup with a commercial 50R dummy load and a Modified Tek SG503 signal generator set on 1.48MHz. It had been re-configured for a 50 Ohm output resistance and to deliver 100mW into a 50 Ohm load. The result below is exactly as expected for the commercial 50 Ohm dummy load resistor, figure 12:

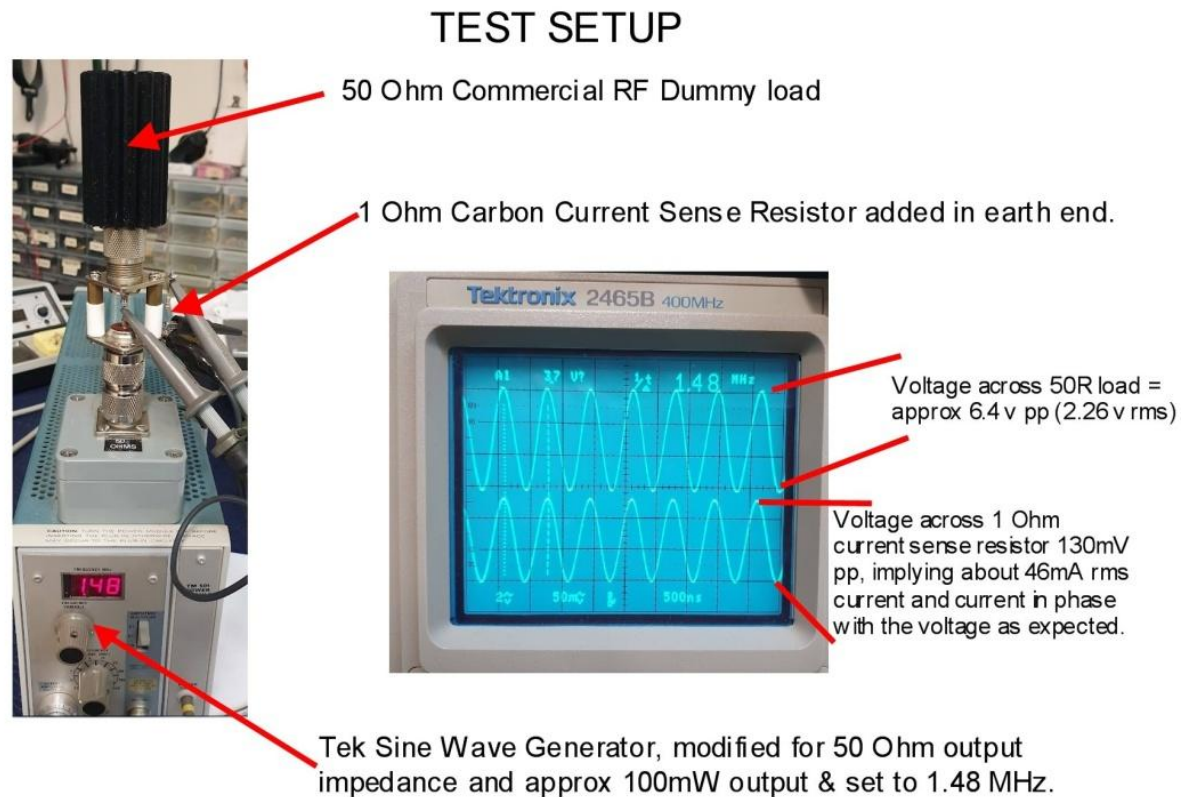
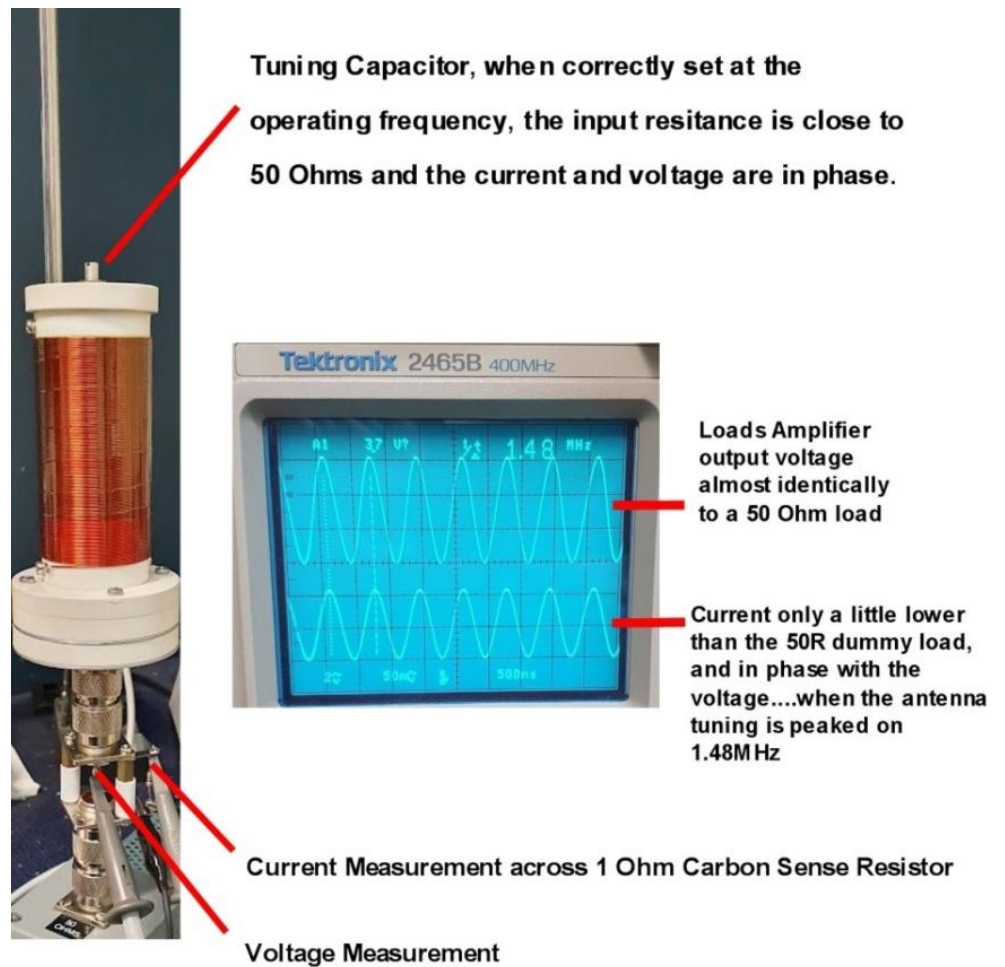


FIG.12

Then the Antenna, with the Whip fully extended, is substituted in for the dummy load and the Tuning adjustment is made, Figure 13:

FIG.13

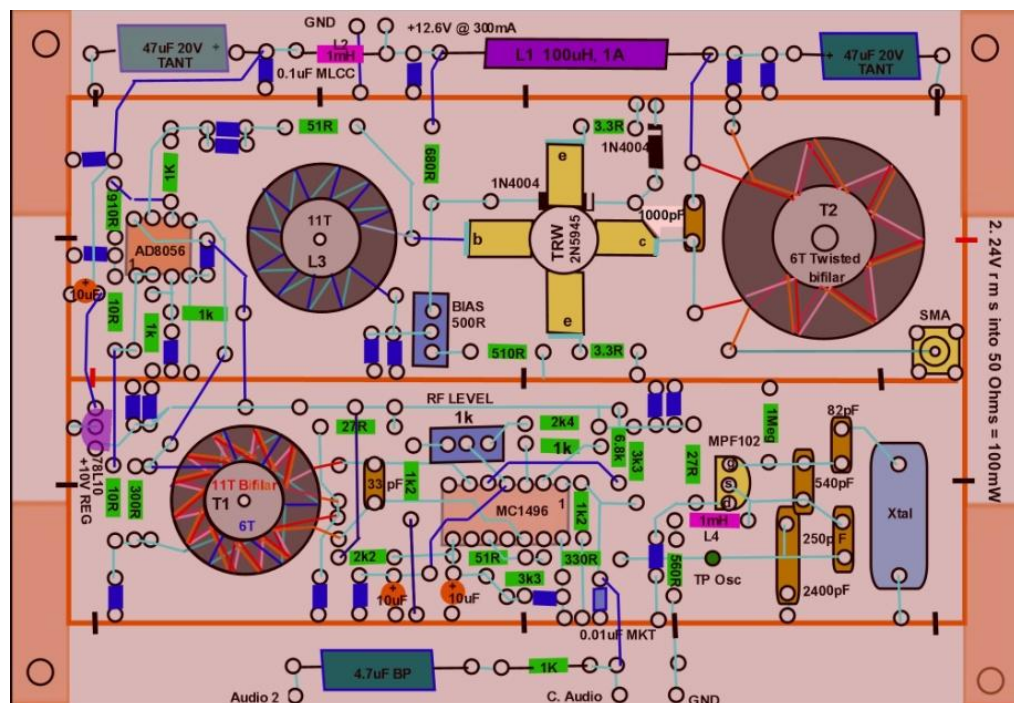


When the Antenna's tuning is correctly adjusted, its input resistance drops to a minimum (close to 50 Ohms) and also the current is in phase with the voltage. On either side of that exact Tuning Point, the current phase swings to either an early or a late position with respect to the voltage and the input impedance rises. Testing the antenna indicates its -3dB bandwidth is in the order of 10kHz . It does not roll off the high frequency audio modulation to any significance.

FIG.14



FIG.15



Since this prototype board I was working with is plated through hole spot board, I used another method as a substitute for a ground plane, by using some thick Brass vertically placed Bus Bars, so as to create a low Z earthing system or a pseudo-chassis:

**Prototype built on Sunhayato Plated through hole board part ICB-97GHD
1/4" tall Vertical Brass Bus Bars used in Lieu of top surface Ground Plane.**

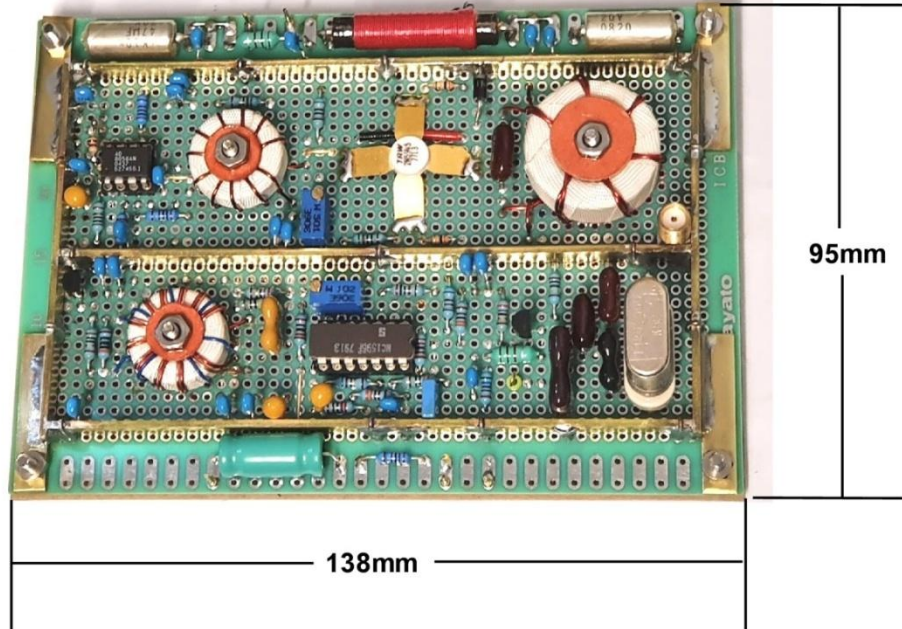


FIG.16

Easy to get Toroidal cores were used (from Jaycar Electronics) It pays before winding these to wrap them in Scotch 27 cloth tape, for two reasons; one it protects the enamel on the wire, but it also allows the wires to sink into a surface and stabilize their position. It makes it much easier to evenly space the turns. This board mounts on a metal plate with a cardboard insulator, figure 17:

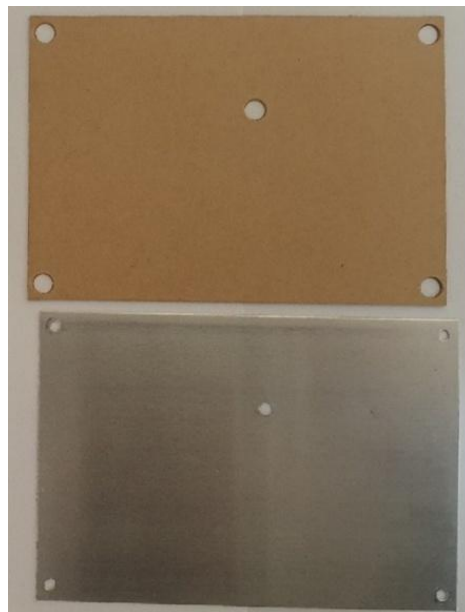


FIG.17

On account of the standing DC collector current in the Class-A output stage, being in the order of 250mA in this case, it results in about 3.4 Watts of wasted heat in the transistor. This means the output transistor requires a Heat Sink served by the metal plate and assisted somewhat by fitting the assembly to the die cast enclosure. However the high current value ensures excellent linearity of the RF output waveform even at full modulation.

A convenient sized metal sheet is the same size as the board perimeter and around 0.7 to 0.8mm thick Aluminium was used. The plate is spaced at its corners from the board's lower surface by four 3mm tall 6mm OD spacers with holes to clear a 3mm screw. The stud on the 2N5945 transistor is an 8-32 UNF thread. It requires a spacer that is 6mm OD and 4.5mm tall and has a 4.2mm clearance hole (for that I had to buy a 4.2mm drill bit that I did not have on hand)

The Schematic is shown below, figure 18:

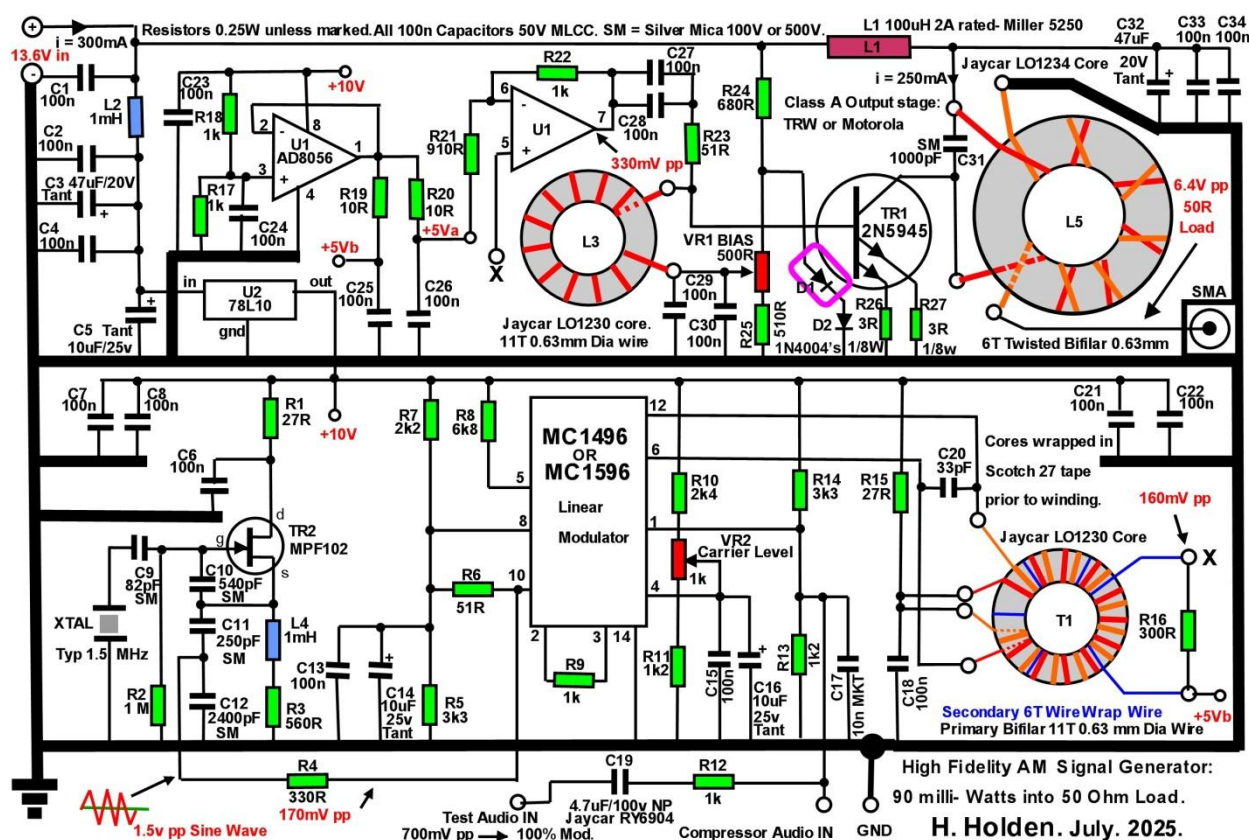


FIG.18

A crystal oscillator running at a nominal 1.5MHz is used (I used a 1.48MHz crystal that I had on hand) The circuit is based around an MPF102 Jfet Colpitts Oscillator. This results in a low distortion sine wave. That is fed to the MC1496 balanced modulator which has an offset to create the RF signal.

Without the offset the MC1496 (or MC1596) would be acting in a DSB suppressed carrier mode. The offset voltage provided by the preset potentiometer VR2 therefore sets the output carrier's voltage level. For example if 100mW was required that would be set so that the output level, into a 50 Ohm dummy load was 6.4V peak to peak (= 3.2V peak or 2.26 volts rms). Or in the case of 90mW the pp voltage across the 50R dummy load would be set at 6Vpp or 2.12V rms as measured on the scope.

(Obviously this low voltage at the transmitter output terminated into 50 Ohms is useless for transmitting, if a 10 foot wire was simply connected to it, because of the gross impedance mismatch. It requires that to achieve any reasonable transmitting range that a 50 Ohm input impedance antenna is connected to it)

There is one audio input for test purposes so that the modulation can be pushed to 100% for testing, with a 1kHz signal from a test audio generator. The Compressor & Peak Limiter (on the Audio board to be described below) prevents the audio signal delivered to the RF board from being high enough to reach 100% modulation.

The output from the MC1496 is passed via transformer T1 to an AD8056 RF capable OP amp to act as the output stage's driver.

The output from the MC1496 does not have a significantly low impedance or high enough power output to drive the output transistor directly. The reason for using the OP Amp, rather than a discrete transistor buffer arrangement, is that the OP amp is highly linear and it has a very low output resistance, equally able to source or sink current and it makes an excellent driver for the 2N5945 output transistor. Also, one of the OP amp units inside the AD8056 package is used to provide an effective split supply potential of 5V. The AD8056 was designed for a +/- 5V supply, or 10V total and it is not a particularly expensive part at about \$7.

As previously mentioned, the DC power consumption of a Class A stage is fairly stable, regardless of the output power. The energy it consumes is mostly wasted as heat. The power consumption (via the DC collector current) is required for linearity. There has to be enough magnetic energy stored in the output choke's core, to support the positive going excursions of the output waveform without distortion at full modulation when the output voltage swing doubles. The output voltage, on the Collector terminal can rise above the power supply voltage and that is only possible because of the energy stored in the core of the output choke. The output choke

shown in figure 19 below, has a twisted pair of wires to create a bifilar winding. This allows the the Collector voltage to appear as the output voltage but with the DC component removed.

The output transistor, a 2N5945 is shown in figure 20. These beautiful 2N5945 Transistors were made by both TRW and Motorola, intended typically for driver applications in 400-900MHz FM land mobile applications. Of course these work brilliantly at much lower frequencies too:

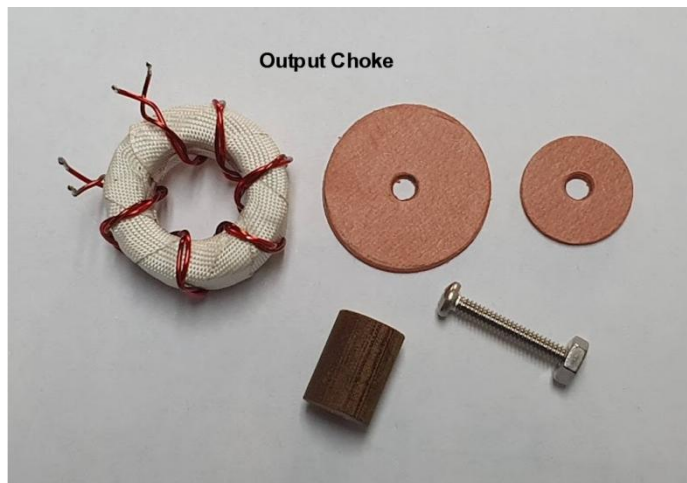


FIG. 19

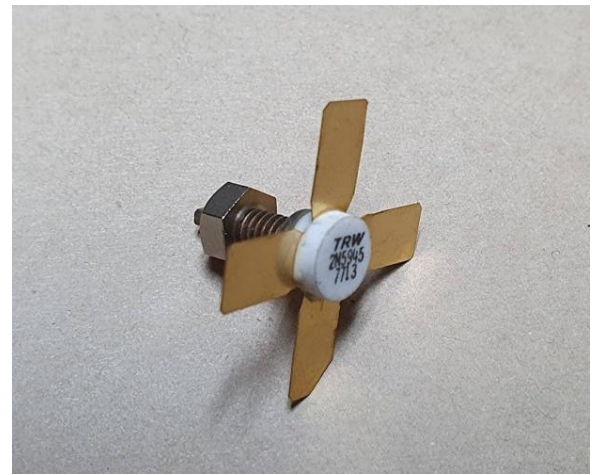


FIG.20

While there are modern TO-220 package epoxy cased transistors that will work for the application, for example the MRF475, they do not have the beautiful appearance, style, symmetry, pizzazz or appeal of the vintage Ceramic body 2N5945.

It is difficult to imagine a more perfect medium power RF transistor such as the 2N5945 where such form and function are so elegantly combined. These parts also have large flag like, twin Emitter and single Base and Collector connections. These can be useful to couple heat, via heat transfer compound into a bias Diode. The mounting stud itself on the 2N5945 part is isolated from the E, B & C connections too, which is also a very helpful feature (unlike the tab on a TO-220 device which is normally common with the Collector terminal)

The 2N5945, although a very vintage part, which dates back to the 1970's, is still readily available on eBay and they are usually in the vicinity of \$20 each, not exactly a "cheap part" but with these you really do get what you pay for.

As the schematic indicates, the 2N5945's collector current is stabilized with two methods. One is the emitter degeneration with two 3 Ohm resistors in parallel, both connected from the Emitter terminals to ground. Also, one of the 1N4004 bias diodes (D1) is in thermal contact with the transistor's body and MX-4 thermal compound is applied around the diode and one of the emitter

connections. This is so the diode's body temperature tracks that of the transistor. The thermal coupling helps to cancel the transistor's $-2.1\text{mV} / ^\circ\text{C}$ Base to Emitter junction voltage temperature coefficient and to stabilize the collector current with temperature increases.

Many historical circuits using the 2N5945 do not include any emitter resistors, but in this case, as little power is demanded from the transistor, compared to its maximum ratings (15W) the emitter resistors are included. This also helps raise the input impedance at the Base making the transistor easier to drive and reducing the distortion of the RF output sine wave.

Output waveforms:

Figure 21 shows the output 1.48MHz Carrier Wave as seen on a 50 Ohm dummy load resistor and it is 6.4vpp, a clean sine wave. It also remains clean like this at twice that voltage, so that at 100% modulation, it is not corrupted or distorted in any manner. Any small residual harmonics here will vanish to low levels in the antenna's Tank (resonant circuit)

FIG.21

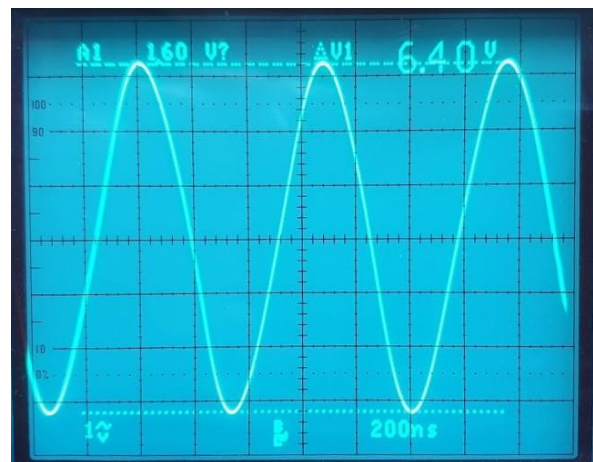


Figure 22 shows the result with a test 1kHz audio sine wave fed into the test audio input up to the point that 100% modulation is achieved. In actual use this modulation level never occurs because it is limited by the electronics on the Audio Processor/Compressor/Peak limiter board (see below)

FIG.22

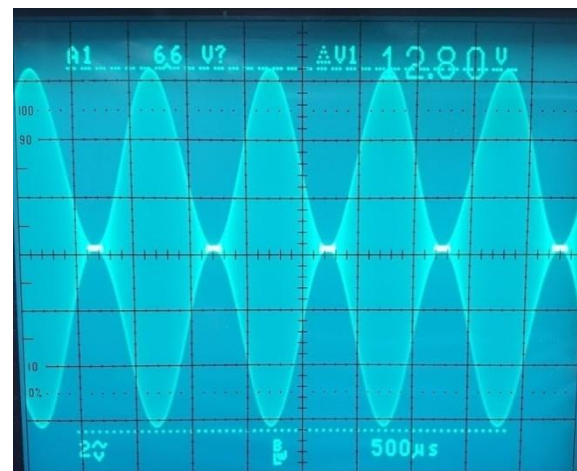
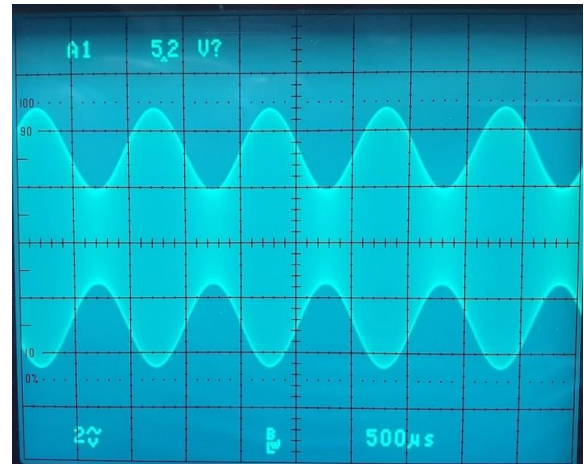


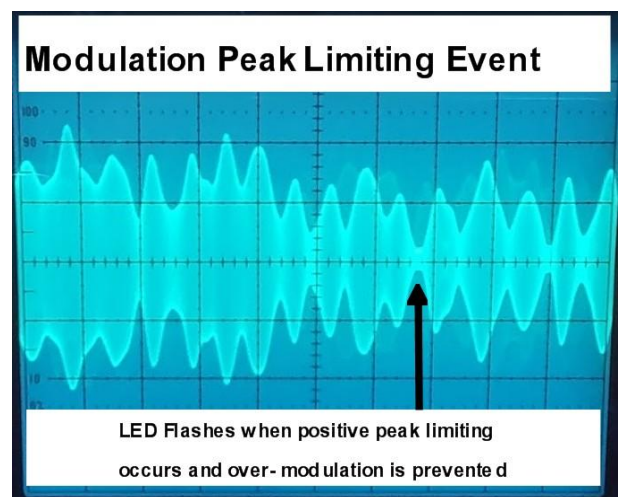
Figure 23 shows the result with a reduced modulation level. As can be seen from these three recordings, not only is the RF carrier wave very linear, but so is the modulation of it.

FIG. 23



The modulation limiter, to be discussed below, prevents over-modulation of the carrier from peaks on the audio waveform. Provided the drive level is not set too high by the user, the LED which activates when this limiting event occurs only lights up occasionally. Both the negative and positive peaks of the audio (after the compressor) are equally limited, but the LED only activates when a positive peak limit occurs. The reason for this is that a positive going signal to the MC1496 modulator circuit is such that it results in a reduction of carrier level.

FIG.24

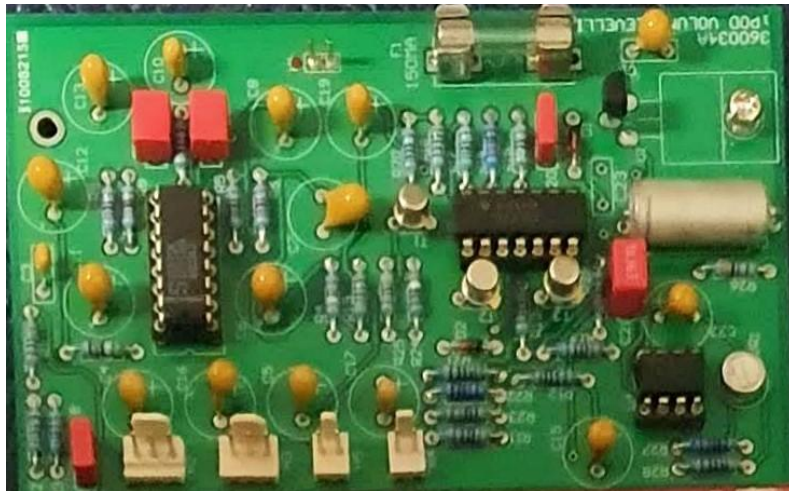


One thing to note, the RF amplifier should ideally always be terminated into a 50 Ohm load, either a 50 Ohm input antenna or a 50 Ohm dummy load. If there is no load the unterminated output voltage doubles. Fortunately, in this case, the drive level is low and the 2N5945 RF output transistor very robust and this does not harm the transistor. Still, it is always better for an RF output amplifier to have the correct load applied at all times.

The Audio Processor Board:

Apart from wanting to peak limit the audio signal to prevent over modulation of the RF carrier, there is another issue. Most people who listen to AM radio stations tend to notice that the “Listening Volume level” appears about the same across a wide variety of songs. This does not happen by accident. Figure 25 below shows this board:

FIG.25



Too Much or Too Little Compression?

This is an interesting question if there could ever be too much time averaged audio compression and volume levelling. For example there is a circuit configuration for the NE571 Compaander IC which creates an ALC (Automatic level control) where a 20dB increase in input level results in a 20dB decrease in gain so that all of the time averaged loudness variability is eliminated.

However, this extreme can limit the difference in the volume of segments within the same song or musical recording and can make it sound characteristically different than when the quiet and loud patches within the musical piece had more difference in perceived volume.

On the other hand, a compression level of a 6dB change in input level for a 3dB change in output level (the classic NE571 Compressor circuit) is not quite enough to diminish the wide variability of volume levels for different songs, especially those originating from iPod files. This results in still having to re-adjust the modulation level control from time to time.

Also, throughout the song, the sound energy can change greatly. Music has a very wide dynamic range between the quiet and loud times and impulses from percussion instruments can be much higher in level than lower level sounds from voices or strings. This can result in over modulation of an RF carrier unless steps are taken to prevent it and this is where the peak limiter circuit is required.

This issue of “volume levelling” or a perceived listening volume has also caused issues in certain industries other than Radio. For example in the Juke Box industry, due to the different average volume levels from the various 45 RPM records in the Juke Box. The manufacturers noticed that some records appeared quiet the others very loud. The Seeburg company (as one example) built a very clever volume levelling circuit, working as a slow acting AGC, into their MRA-5L6 Tube

Juke box amplifiers. This had the overall effect of volume levelling the different 45 RPM recordings that the customers played.

The NE571 Compressor IC (compressor or expander IC) was designed for Stereo use and the audio signal for the left hand and right hand channel passed through each section, usually set up for the 6dB to 3dB compression. On evaluating this part set up in its standard Compressor configuration, I found I could not quite achieve the level of volume levelling that matched what appears from a typical AM radio station.

I decided that since the signal being dealt with was Mono in this case, to evaluate the NE571 with its two stages configured for Compression, but cascaded as shown in figure 26:

Volume Compressing & Levelling with two cascaded NE571 Stages:

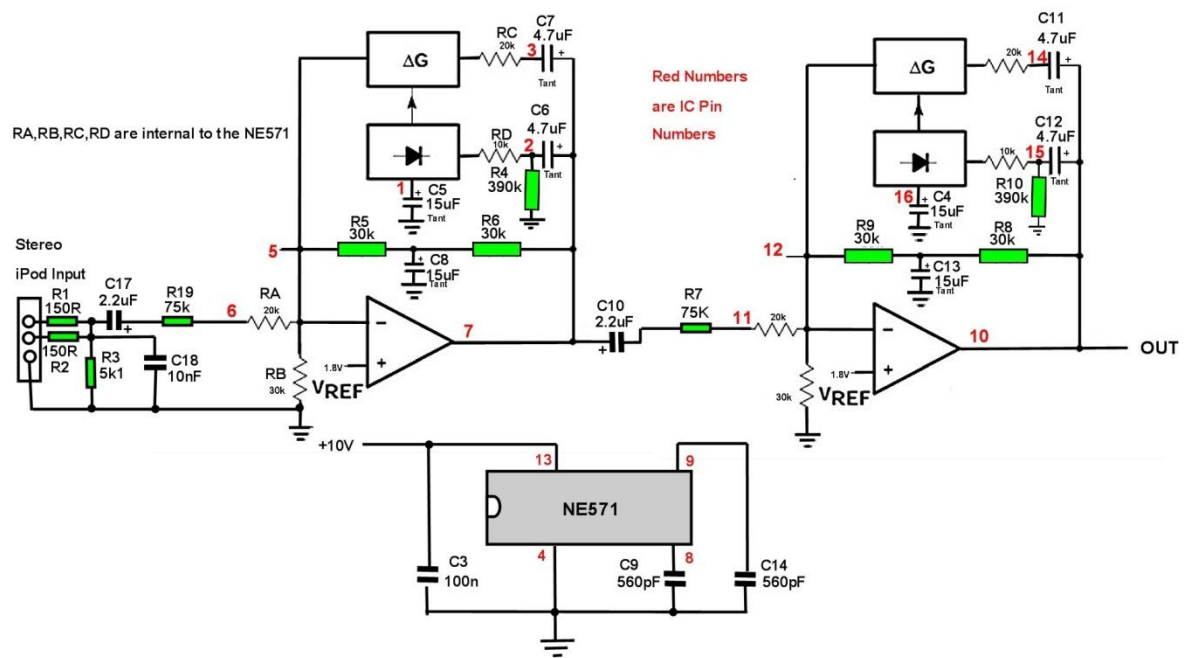


FIG.26

Each block of the NE571 performs a function where its voltage gain becomes essentially proportional to the square root of the time averaged input voltage. So if the input voltage of a constant wave doubles, the output only increases by a factor of root 2 or 1.41. This is another way of saying that if the input voltage increases by + 6dB the output voltage only increases by +3dB.

However, cascading two stages where the source signal for the second stage already has a square root relation applied and a second square root of that is taken, this results in a scenario where if the time averaged input voltage increases by a factor of 16, the output only doubles. It results in the output being proportional to the 4th root of the time averaged input voltage and this creates much greater compression. If the time averaged input voltage increases by a factor 2 or +6dB, the output only increases by a factor of $2^{0.25} = 1.189$ or +1.5dB. Or for example if the time averaged input voltage increases by a factor of 100, the output voltage increases by a factor of $(100)^{0.25} = 3.1$.

A graph is shown in figure 27 of the measured by experimental plot of *input and output voltage ratios* of the cascaded stages on testing, so as to visualize the system gain of the two cascaded stages and how it is affected by the time averaged input voltage. Peak to peak voltages were plotted because it is easier to measure these with my scope.

As noted the compression starts with a small input voltage of 10mVpp and at that point the output voltage (from pin 10 of the NE571) is around 91mV. The compression is so significant, that my lab function generator, delivering 30Vpp at the input, only gave an output voltage of 1.38Vpp.

While the mathematics of the Compressor function is easy to define for a constant time averaged sine wave signal, it is more difficult to define the listener's experience that results from the attack and decay time constants of the rectifier system with dynamically changing signals such as voice or music. The cascaded circuit subjectively provides excellent perceived volume levelling and it makes use of the entire contents of the NE571 IC in a Mono application. The two cascaded NE571 stages result in what appears to be uniform listening levels, regardless of the variations of music material from the iPod as a source. So that once the modulation level control (on the transmitter's front panel is set) it is generally not necessary to keep re-adjusting it for different songs.

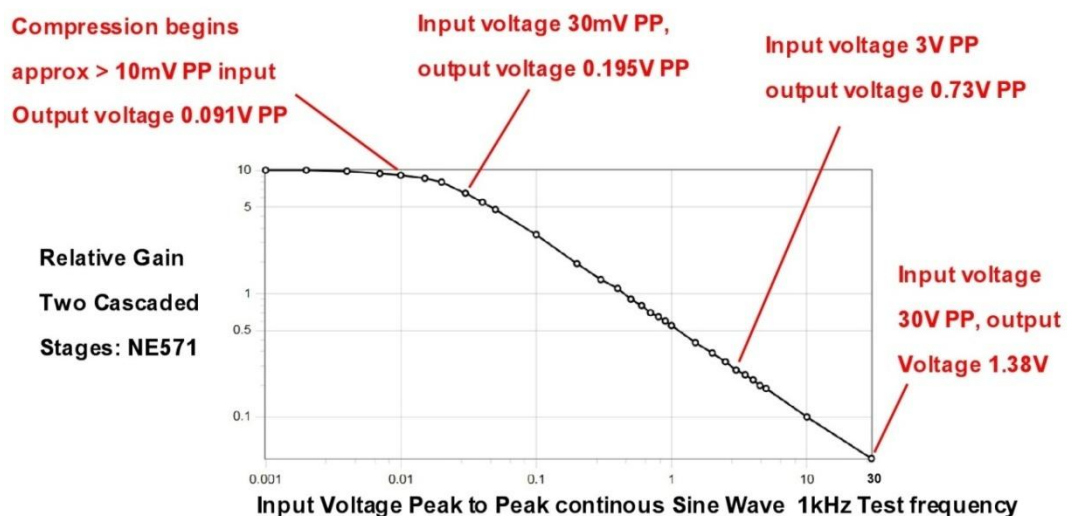


FIG.27

Note: Log-Log Scale

Across the input voltage range of 1mVpp to 30Vpp the relative gain of the cascaded stages, on measurement changes from a factor of +10 to +0.046.

Rather than showing the relative system gain (output voltage/input voltage) of the two cascaded stages, another approach to examining how the compression of two cascaded stages works, is to plot the rms input voltage versus the output voltage for a continuous input sine wave, figure 28. For this arrangement, where [Vin] is the time averaged rms input voltage, the output voltage Vout, is fairly close to the graph depicted by the equation: $0.257[V_{in}]^{0.25}$

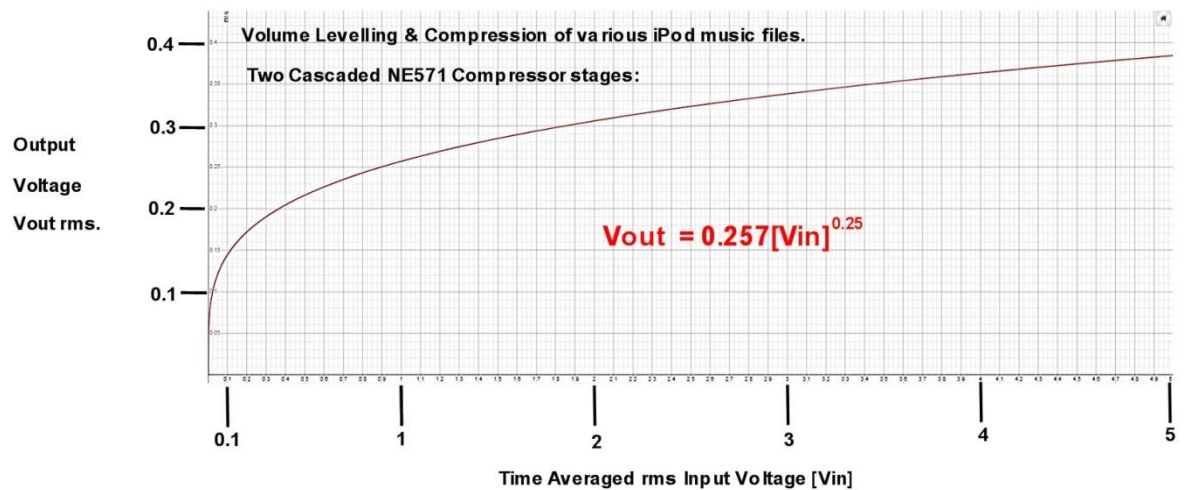


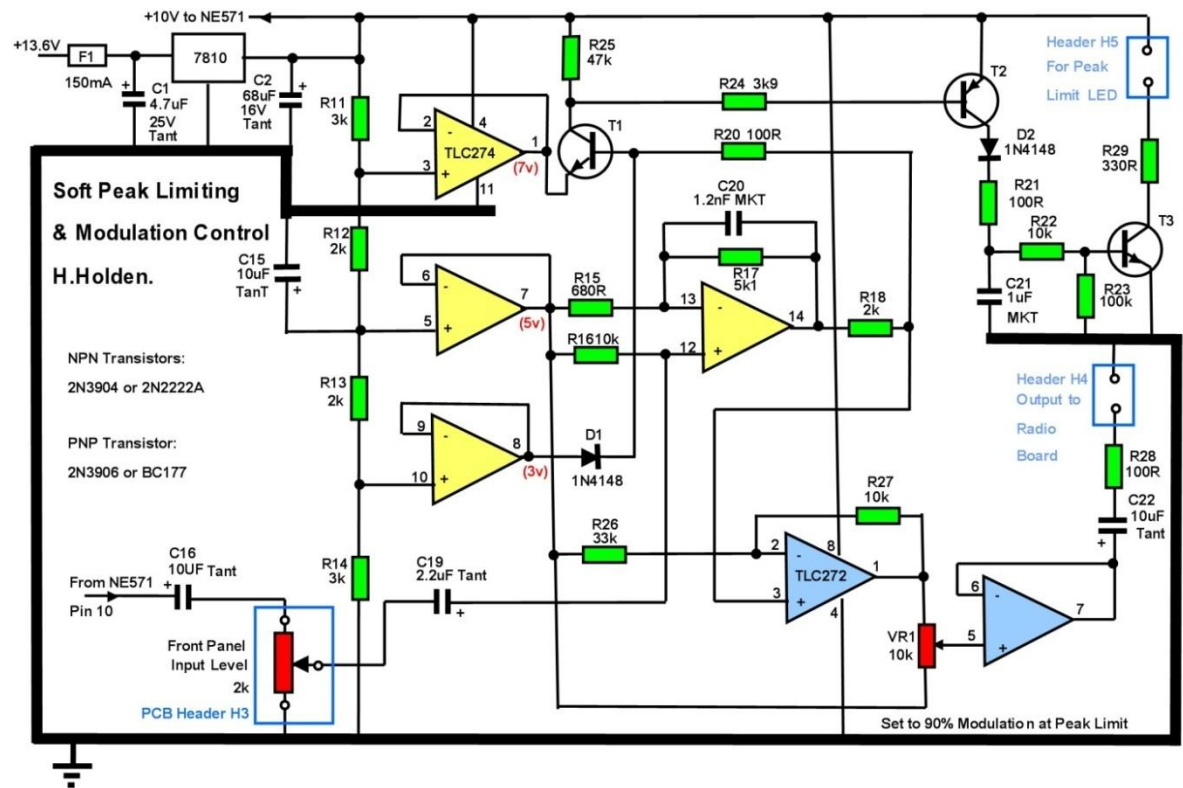
FIG.28

The Peak Limiter and LED Indicator:

The purpose of this circuit, installed after the Compressor, is to limit peaks on the audio waveform so that the maximum modulation depths induced by those peaks cannot drive the modulator past 90% Modulation.

When 90 % modulation is reached on peaks, the front panel LED which is connected to header H5 on the pcb lights up to indicate that limiting is occurring.

FIG.30



In practice, it is best to turn up the iPod (if that is the audio signal source) to full volume, then the front panel level control (connected to pcb header H5) is turned up while a song is playing, so that only occasionally is the LED seen to blink on the highest peaks of the audio signal indicating that limiting is occurring on those peaks.

When signal peak limiting occurs, it can be over a very short time frame. Not enough on its own to satisfactorily illuminate an LED.

The signal out of the compressor, which is in the 0.1 to 0.5V vicinity, is amplified up so that the peak limiter (voltage reference outputs from pin 1 and pin 8 of the TLC274) can be used to peak limit the audio waveform via conduction in the diode D1 on the negative peaks and the Base-Emitter junction of T1 on positive peaks. This allows only a +/- 2.7 voltage swing around the +5V reference level. When base current flows in T1, this activates T2, which via D2 acts as a charge pump to C21, this holds T3 in conduction long enough to see a good visual flash from the LED even when peak limiting occurs on very narrow peaks.

It was not necessary to have the LED flash on negative peak clipping, the reason being that the positive going peaks are the ones that drive the modulation direction such that the RF carrier is approaching zero, this is due to the direction of the offset voltage applied to the MC1496 modulator IC by the RF carrier level preset pot.

The TLC272 and VR1 were included because this Audio board may have been interfaced with a variety of different modulators, some requiring high drive levels and R26 could then be lowered to increase the gain and set the output voltage magnitude range controlled by VR1.

The setup is simple to arrange; a 1kHz sine wave audio signal is injected from a generator to the top leg of the Level control and increased until the Peak Limit LED just lights. Then preset VR1 is adjusted so that the RF carrier modulation is close to 90% or 80% if you wanted that to be the limit setting.

Physical Construction of the Transmitter:

The transmitter was built into a Jaycar diecast Aluminium housing size 222mm x 146mm x 55mm, Jaycar part HB5050 which was painted red with VHT enamel paint and baked in the home oven. The basic layout is shown in figure 31. Some ventilation holes were added so that air can circulate through the unit.

The power supply is a Mean Well 12V 1.3A unit, Jaycar part MP3296, with its preset turned up to 13.6V. These are available from major suppliers too.

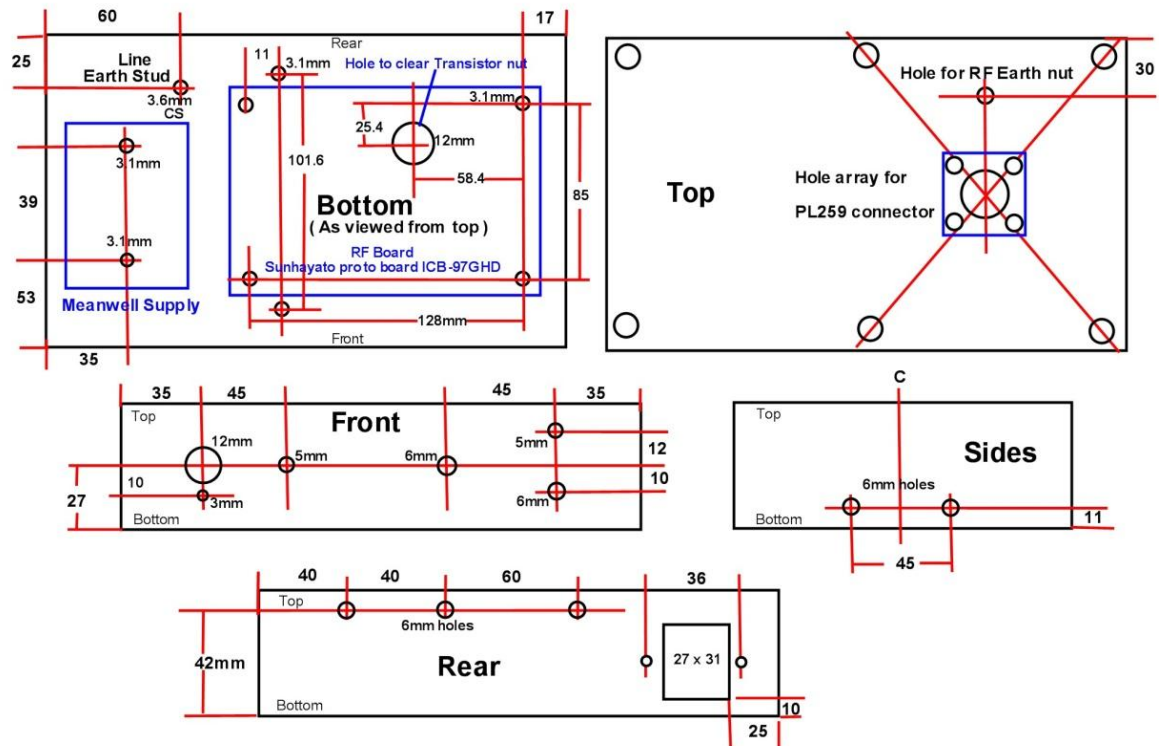


FIG.31

The Mean Well supplies do have some RF switching hash on their outputs. This is why for the signal circuits the voltage was down regulated to 10V with 78L10 Analog voltage regulators and extra filtering provided via the Miller 100uH RFC on the power feed to the RF output stage.

Coaxial Interconnect:

It is important that the SMA plug- coax cable is terminated well to the PL259 socket and there is proper strain relief. I cut up a right angled SMA plug to obtain its box like fitting with the usual crimp connected to it, and soldered that to a brass plate, figure 32 & 33:

FIG. 32

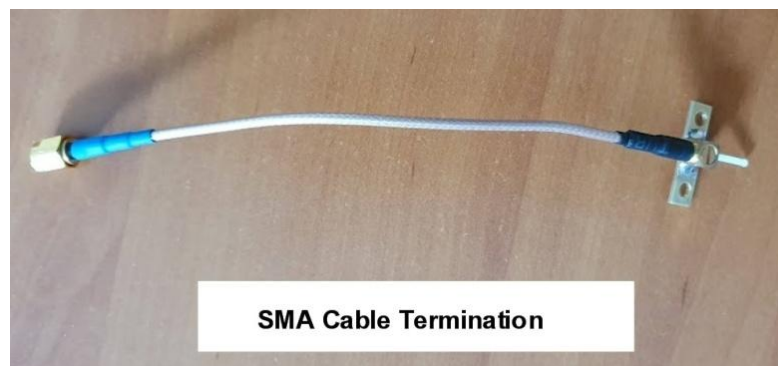
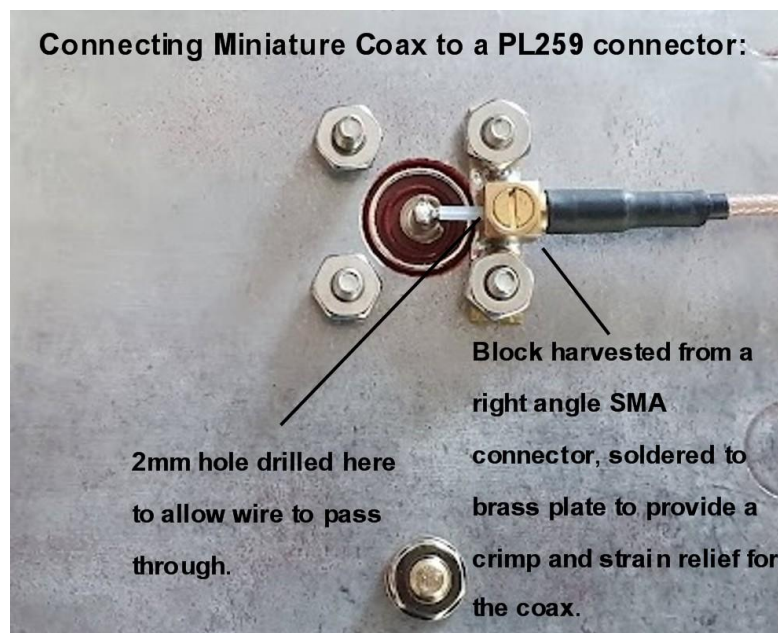


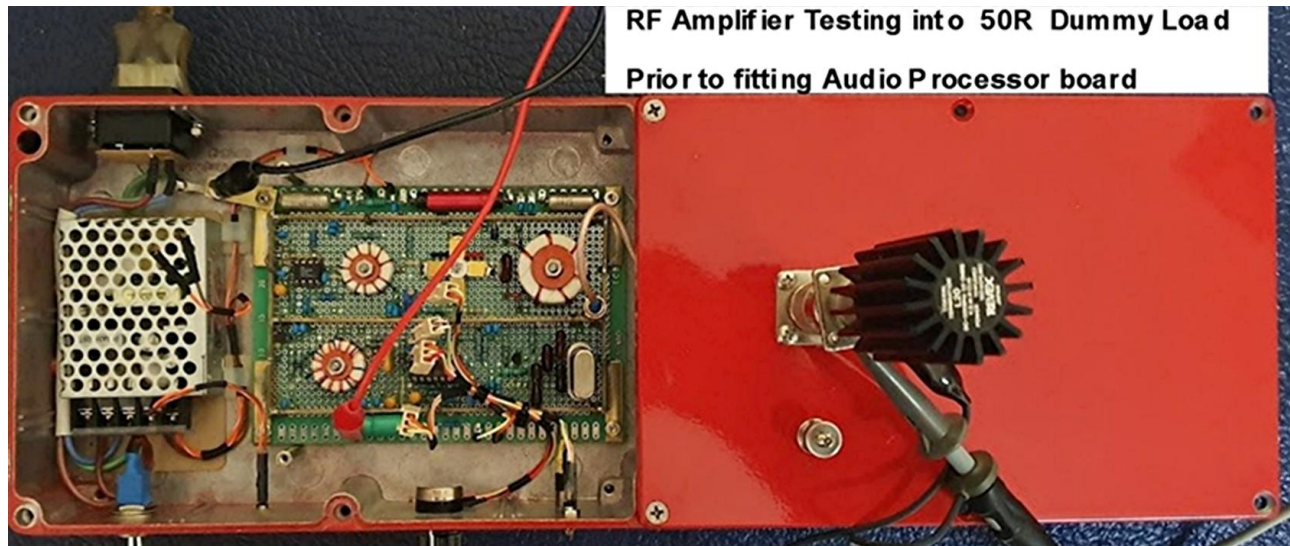
FIG.33



Initially the RF board is fitted (figure 34) and powered first so that the Bias control can be set for a total board current consumption of 300mA and the RF level control can be set so that the

carrier wave voltage is exactly 6V pp into the 50 Ohm Dummy load resistor, yielding 90mW output into that load. Rotating the top of the housing and fitting two of the screws it provides good access:

FIG.34



The Audio board is then fitted to the two 30mm tall posts, figure 35. As noted, the single preset potentiometer on the Audio Processor board is used to set the maximum possible modulation depth at the point that peak limiting occurs.

FIG.35



Useful Custom PL259 Test Adapters:

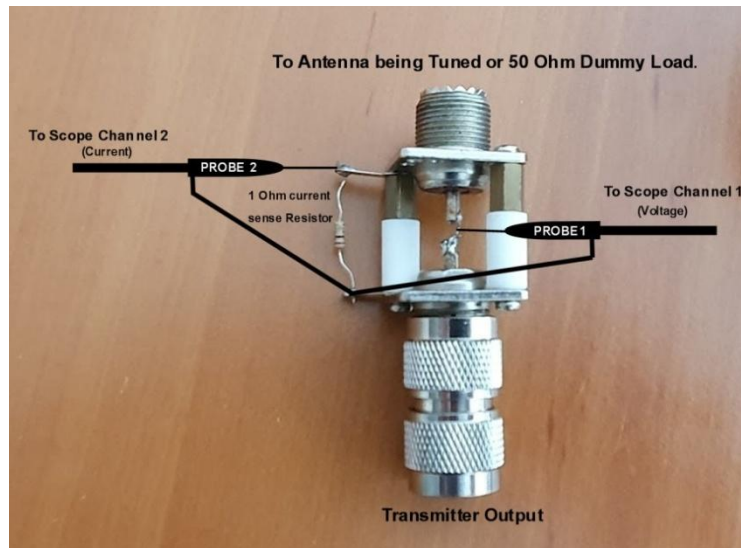


FIG. 36



FIG. 37

Figures 36 & 37 show adapters for testing. A useful adapter to make is one which separates the Earth and inserts a 1 Ohm current sensing resistor. This is so the Antenna Tuning can be optimized such that when it is tuned properly the voltage dips to the same level as a 50 Ohm dummy load and at the same time, the current waveform is in phase with the voltage.

General Construction:

A couple of construction hints. With the IEC fused and panel mount Line Voltage connector, it pays to use good quality appliance wire and fit it with a 1 Amp fuse. The Mean Well supply does have a Line circuit board fuse, but it is always better to have an additional fuse.

Two earth wires are soldered to the Earth pin on the IEC connector. One passes to a lug which connects to the 6-32 Earth stud, the other passes to the Earth screw on the Mean Well power supply. This connects to the body of the supply, which is also screwed to the housing, so the metal housing receives a Double Earth connection.

Also, take no short-cuts and make sure the wires that connect to the supply are terminated in proper lugs as shown in Figure 38. Don't put stranded wire directly under the screw terminals of the Mean Well supply. And add an insulating sheet over the rear of the IEC connector.

The Line earth stud is a 6-32 countersunk head steel screw, 1 inch long, that is tightened up with a socket wrench with a nut and Star Washer. This can be done before the case is painted and it is more obvious that this screw head should never be undone.

Also the wiring/solder connections to the ON-OFF line power switch should be well insulated.

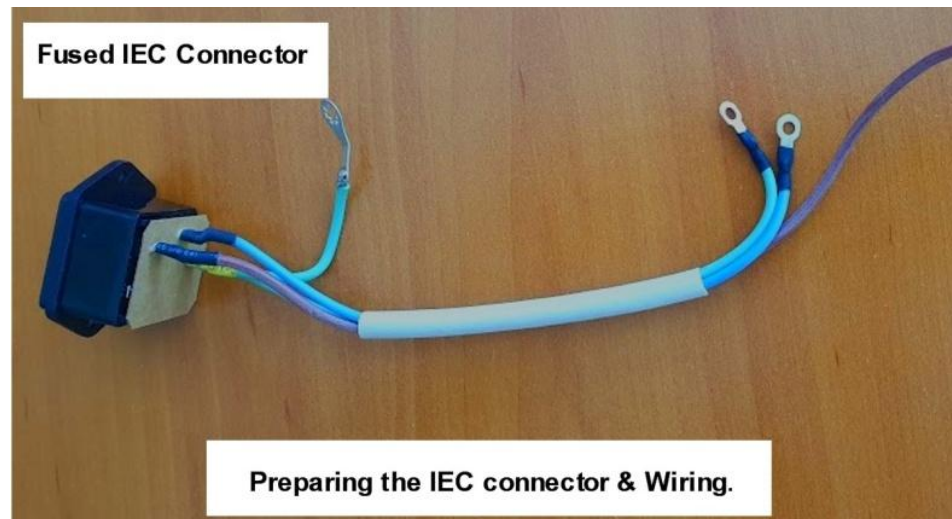


FIG.38

In addition, when the rubber feet are fitted to the case, use proper mounting screws and put a metal bush in the rubber feet. Adhesive stick-on rubber feet are “hopeless” and after a while they fall off, because the adhesive fails or melts. Also, without a metal bush, after the screw tightens up, the rubber compresses and then the screws will come loose later. See figure 39 for feet with a proper metal bush. I mainly have to make these metal bush parts myself.



FIG 39

A photo of the bottom of the unit is shown below, figure 40;



FIG. 40

Alternate Antennas:

A 50 Ohm input loop antenna, figures 41 & 42 can be used as an alternative to the 3.3 foot Whip.

As previously noted, especially in the near field, these tend to work well with Transistor Radios with Ferrite Rods or Tube Radios with Frame Antennas:



FIG.41

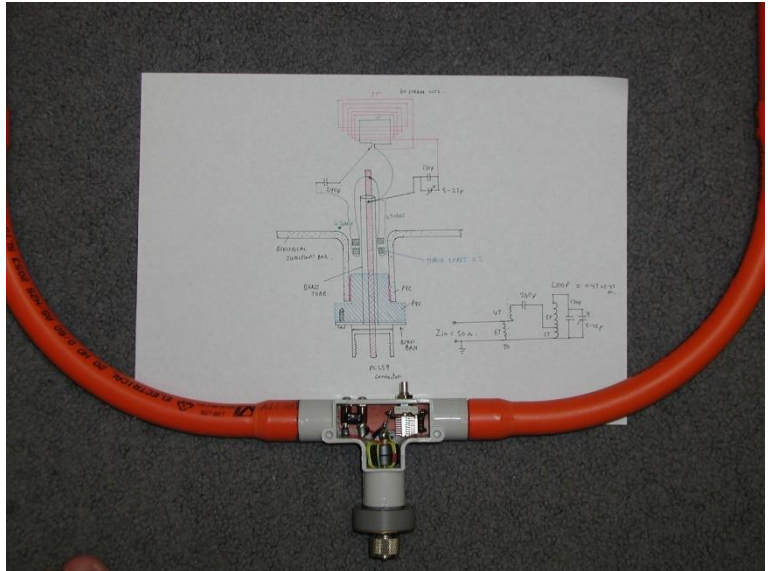


FIG.42

The geometry of the Loop shown in figures 41 & 42 is about 0.5 x 0.5 meters square. This has a similar transmitting range to the 1 meter (3.3 foot) high Whip & loading coil, perhaps a little more.

One advantage of a Loop antenna system, you do not need an Earth connection, it makes little difference to the performance of the Loop. To that extent, the Loop can be regarded as the **H** field magnetic equivalent of the electric **E** field *Dipole* antenna which would also not rely on an earth, unlike the monopole whip.

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Article summary in publishable format:

The Low Power Short Range "Ultra-Linear" Pantry Transmitter with Volume Levelling for Vintage MW Band AM Radios

Author: Dr. H. Holden

Abstract

This article presents a compact and low-power MW band AM transmitter designed to support vintage radio enthusiasts. With extremely low radiated electromagnetic (EM) wave power ($<1\ \mu\text{W}$), high linearity, and comprehensive audio compression and limiting, the transmitter ensures in-house-only coverage without interference. A theoretical and practical analysis of antenna efficiency, EM field strength, and compliance with FCC Part 15.219 regulations is provided. Construction details and design rationale for both the transmitter and antenna system are included.

1. Introduction

With many medium wave (MW) AM stations decommissioned, vintage AM radio enthusiasts often lack a strong, local signal to tune into. A low-power AM transmitter—often referred to as a "Pantry Transmitter" in the UK or "Part 15 Transmitter" in the US—can solve this by transmitting favorite music locally within a home.

Unlike many commercial or DIY kits, this transmitter has been engineered for ultra-linear performance, precise power control, and minimal radiated energy, thereby aligning with both ethical and regulatory constraints.

2. Regulatory Context: FCC Part 15.219

Key Constraints:

- Max DC input to final RF stage: 100 mW
- Total length of antenna and ground lead: ≤ 10 feet (3.05 m)

While the field strength limit of $24\ \mu\text{V/m}$ @ 30 m (from Part 15.209) is often quoted, it does not apply to compliant Part 15.219 systems. A perfect implementation at 1.65 MHz may radiate $\sim 558\ \mu\text{W}$, yielding $\sim 4.3\ \text{mV/m}$ at 30 m.

3. Efficiency of a Short Whip Antenna

Using a 2.8 m vertical whip (1.65% of λ at 1.65 MHz):

- Estimated radiation resistance: $94\ \text{m}\Omega$
- Ground + coil losses: $\sim 15\ \Omega$

- Efficiency $\eta = R_{\text{rad}} / R_{\text{total}} = 0.0062$ (0.62%)
- Radiated power from 90 mW input: ~ 0.56 mW

When degraded by practical losses (e.g., tuning capacitance, poor earthing, shorter antenna):

- Radiated power falls to ~ 0.13 μW , corresponding to 64 $\mu\text{V/m}$ at 30 m.

4. Antenna and Matching System

A 1 m whip antenna is tuned with a compact tank coil and lumped capacitance:

- Resonant with antenna's capacitance to maximize current
- Tank coil located at antenna base
- Presents 50 Ω input impedance at resonance

Advantages:

- Easily testable with 50 Ω dummy loads
- Ensures RF amplifier sees proper load
- Minimizes waveform distortion

5. Transmitter Architecture

Features:

- MPF102 jFet Crystal Oscillator & MC1496 balanced modulator
- AD8056 op-amp driver
- 2N5945 robust Class-A RF output transistor
- Output: 90 mW into 50 Ω ($6 V_{\text{pp}} = 2.12 V_{\text{rms}}$)

Performance:

- Clean sine wave carrier
- Excellent linearity at full modulation
- Heat managed via metal plate and housing

6. Audio Processor Design

Challenges:

- Wide variation in music track levels
- Preventing over modulation

Solution:

- Dual NE571 compressors cascaded for 4th-root compression
- Peak limiter using TLC274 and discrete clamping
- LED indicator for positive peak clipping

Benefits:

- Consistent listening volume
- Modulation depth reliably held below 100%

7. Construction Details

Enclosure:

- Diecast aluminium case, painted and ventilated

Power:

- Mean Well 12V supply, set for 13.6V
- Regulated to 10V for signal stages

Best Practices:

- Grounding via earth stud and supply chassis
- Fused IEC connector
- Use of PL259 test adapters for impedance verification

8. Alternate Antennas: The Loop Option

Loop antennas:

- Suit ferrite rod radios (magnetic H field coupling)
- Remove ground dependency
- Show slightly better range than the 1 m whip

Construction: ~0.5 m x 0.5 m square loop with internal tuning and 50 Ω impedance.

9. Conclusion

This transmitter, with a radiated power of only 0.13 μ W (0.023% of theoretical Part 15.219 max), provides ample in-house coverage with minimal risk of interference.

By focusing on low distortion, measurable RF output, and carefully limited field strength, this design embodies the spirit and engineering rigor of a responsible home AM transmission system.

Appendices

- Schematic diagrams
- Construction photos (Figures 8–42)
- Tank coil specifications
- Audio compression curves

References

1. FCC Part 15.219 Specification
2. NEC4.2 Analysis by Richard Fry
3. Radiation resistance calculator: ANU Physics
4. Historical references to transistor radios (e.g., Van Morrison - Brown Eyed Girl)