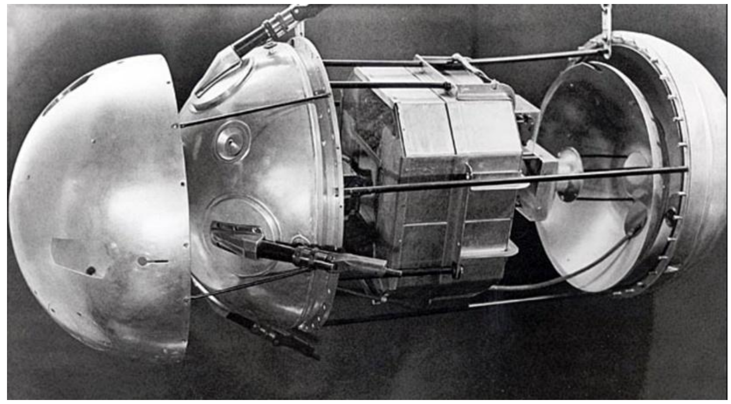
SPUTNIK -1

ANALYSIS AND RECONSTRUCTION OF THE SPUTNIK-1 D-200 TRANSMITTER & MANIPULATOR.

Dr. H. Holden. May 23. 2023.



INTRODUCTION:

There is no doubt that Russia's Sputnik-1 started the Space Race. This Satellite, at the time in 1957, was an awe-inspiring accomplishment in the field of Space Exploration and a credit to the Russian Engineers who designed it.

I am beyond impressed with what the Russians achieved with Sputnik-1. And it must have been a fantastic day at the Russian Space Agency and for the people of Russia, back then. Just imagine being able to announce to the World that your country put the first artificial Satellite into Space?

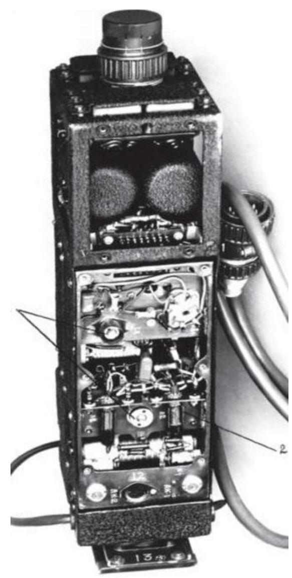
The Sputnik-1 Satellite helped to confirm that not only could an object be deployed from a rocket into Space, into a basically stable orbit, but that it could also carry a functioning radio transmitter, which could survive the trip. The transmitted signal, in the field of view of the Satellite, could be easily received by many shortwave radios on the Earth.

Since the pathway of radio waves and light are generally reversible, it also indicated that very likely Satellites could be used as Radio Relay Stations in Space. Perhaps simultaneously receiving on one frequency and transmitting on another. The Physics suggested that a Satellite could also be placed in a Geostationary Orbit. This idea was postulated by Arthur C. Clarke in 1948. Yet, at that time, few people took him seriously, because he was a Science Fiction writer. However he was really a writer of Science Fiction and Science Fact.

Sputnik-1, as well as inspiring the World, triggered the formation of NASA. It also inspired Artists as well as Scientists. Later, some very beautiful postage stamps and artwork of Sputnik-1 appeared. The impact of Sputnik-1 on Space Science and Popular Culture was very significant.

I first saw images of Sputnik-1 in the early 1960's, as a boy. It stirred my imagination in Electronics, General Science and Space Travel. I didn't imagine back then, that one day in the future, I would have a go at reconstructing SPUTNIK-1's Radio Transmitter & Manipulator.

SPUTNIK-1's D-200 RADIO TRANSMITTER:



The Satellite was as simple as it could possibly be, carrying two independent radio transmitter modules inside the one D-200 Transmitter unit. One module is seen in the photo above, the other is on the reverse side of the unit. The D-200 unit was surrounded by batteries and a cooling fan assembly. Essentially, inside the spacecraft, the battery assembly formed a large octagonal nut like structure and the transmitter was in the hole in the middle.

The inside of the 0.58m diameter polished sphere, which comprised the Satellite's body,was pressurised to 1.3 atmospheres and filled with dry Nitrogen. One transmitter ran at 20.005 MHz, the other at 40.002 MHz. The Carrier Wave was derived from a separate crystal controlled oscillator in each module. The antennas were essentially close to ¼ wavelength dipoles, folded into a V shape with the Satellite body in between. They were physically shorter than exact ¼ wavelengths of the operating frequencies. The angled arrangement of the antennas on the Satellite body helped the Satellite physically fit into the nose-cone area of the launch rocket. Also the effectively bent dipole had a more uniform signal distribution than the typical “figure of 8” pattern of a straight dipole antenna.

The transmitter output power was 1 Watt per transmitter module. However, the two transmitter modules were alternately switched on and off by an oscillating relay system called the Manipulator. These interesting relays are the two cylindrical objects seen near the top of the D-200 unit in the photo above. There was no RF carrier modulation, just simple interrupted carrier wave (CW) transmission. Due to the two transmitters, alternately switched on and off by the Manipulator, no more than one Watt of radio frequency power was transmitted at any time. There were three 2P19B miniature Pentode tubes in each transmitter module. One for the oscillator and two in push pull for the RF power output stage.

Sputnik-1 carried three specially made Silver-Zinc batteries for its flight inside the octagonal housing. One battery powered the Ventilation Fan, the other two were the low voltage battery for the 2P19B tube filaments. And a high voltage battery, for the Plate and Screen and Suppressor grid supply of the 2P19B tubes. Also a 21V tap on the high voltage battery powered the Manipulator circuit.

The batteries were designed to power the craft for 14 days minimum. However, Sputnik-1, launched on October 4, 1957 transmitted for 3 weeks, the transmissions stopped on October 26th. The Satellite did not fall to Earth until January 4th 1958. Sputnik-1 had a fairly elliptical orbit, the Satellite's apogee turned out to be 947km and perigee 228km.

The designers used two transmission frequencies and two transmitter modules for redundancy, but also to ensure that under worse expected conditions in the Ionosphere, on a Winter afternoon at that time of year, one of the signals would make it through the F layers.

The F1 and F2 layers are regions in the ionosphere, bombarded by UV light from the Sun, where the pressure is low and free electrons and ions can move for a long time before recombining to become neutral atoms. The ionized layers react with electromagnetic waves and can absorb some of their energy, reflect them away, or let them pass through, depending on the angle of incidence and the wave frequency. The ionisation can depend on the season, time of day and the year. The 11 year sunspot cycle affects it too, because it affects the UV levels.

The designer's calculations were based on the Satellite on view above the horizon, 700km above the Earth's surface and 3000km line of sight. The transmitted signal, passing through the F1 & F2 layers, from the Satellite to the observer (radio receiver). The designers concluded that it would require a 1 Watt transmission power. Though, they did mention, in the design document, that with a super sensitive professional receiver, 10mW of power might be adequate. But the average member of the public would not have this equipment.

The designers were clearly intent that average citizens, especially in the USA, should be able to tune into the Satellite's transmissions. This was one reason the carrier wave frequency of one module was chosen to be 20.005MHz, because it was 5kHz away from the WWV 20.000 MHz time signal channel and therefore a heterodyne (Beep) could be heard on a common garden shortwave radio without a BFO (beat frequency oscillator).

THE MANIPULATOR:

It appears since the release of Sputnik's D-200 Transmitter design document over a decade ago, the Manipulator circuit has been largely ignored by Electronics Historians who have focussed more on the transmitters. Only brief remarks that "relays switched the transmitters on and off". It does not appear that anybody has investigated the Manipulator or exactly reproduced it and documented its features before. There was a paucity of information in the design document on the theory and function of Manipulator.

The Manipulator worked by alternately switching off the Screen supply voltages to the transmitter module's two 2P19B output tubes, thereby killing the transmitter output when the Screen voltage abruptly fell to zero.

The actual Manipulator circuit was comprised of two commonly available (at the time but not now) Russian made twin coil super sensitive magnetically latching change-over relays, the PnC4 model PC4. 520.350.

Sputnik -1 did not transmit any internal continuously changing Satellite conditions, such as variable Telemetry information. However, there were three simple switches only (called "error switches" in this document). These three switches changed the Manipulator's duty cycle and frequency, in the event of certain extremes of pressure & temperatures in the spacecraft being exceeded.

There was an additional separate internal thermal switch which operated the Ventilation Fan system; switching it on if the temperature climbed over 30 degrees C and switched it off, if the temperature dropped below 23 degrees C.

In Sputnik -1's actual flight, none of the error switches deployed, so the signal from the two transmitters remained with a close to 50% duty cycle for each. Though the switching frequency dropped as the battery powering the Manipulator discharged over time.

Manipulator Design Concept - Relays as Oscillators:

One thing about using a relay as an oscillator, with a capacitor in the relay coil circuit and some resistors; while the principle appears simple enough (you will find many relay oscillator circuits on the internet) what is not so simple is how to acquire a perfect 50% duty cycle from them.

The reason is that the charge and discharge cycle of the capacitor, due to its charging and discharging source resistances are not always equal. This can be matched by diverting the discharge via an additional contact to a load. However, it is still difficult to match these exactly on each half cycle. There are the electro-mechanical properties of the particular relay to consider and the delay to magnetically latch and unlatch. For efficiency in operation, in this Satellite application, magnetically latching relays had to be used.

If you apply a voltage to the coil of a relay, to get the relay to actuate, you will find there is a delay before anything happens. Part of this delay is the current rising in the inductance of the relay coil and establishing the magnetic field. Another part of it is the time it takes for the mass of the Armature (moving mechanical arm) to be accelerated and arrive at its new mechanical position. Typically, in a relay example, the Armature carries the relay contacts.

This combined "electro-mechanical delay" process, could take, typically, depending on the relay design and physical size, in the range of 1mS to 300mS or more.

It raises the very interesting question, how did the designers of the Sputnik-1 Manipulator get the relay oscillator to result in a near perfect square wave switching pattern?

Part of the answer is that they used a symmetrical electrical circuit which incorporated latching relays in a Master and Slave configuration. Latching relays contain a permanent magnet which holds the armature (and its contact) in its current position once it is latched. This also makes them very energy efficient. Only pulses of current are required to change the state of the relay, or a drive waveform with a higher leading edge that can decay later. The wasteful direct holding current, required to hold a conventional relay (with an armature return spring) in one state, is not required.

The usual way to reset the latching relay, is by either applying an opposite polarity pulse to the same coil that set its position, or applying a separate pulse to another coil on the relay bobbin that has an opposite phase to the coil which caused the relay to latch.

In addition, for a balanced square wave oscillator, using magnetically latching change-over relays, it is required that there is a perfect magnetic balance, in that both “halves” of the relay have a near identical coil current sensitivity to initiate a change in state. This balance is heavily affected by the mechanical adjustment of the relay’s magnetic pole pieces.

The Manipulator’s designers used a system where each half of the full operating cycle is related to an 8uF capacitor’s charging profile, which, in a symmetrical (mirror) circuit, matches electrically. That is a good start. Then it only requires that coil pole pieces on each side of the relay are in an exact position so that the magnetic forces balance. By modifying the resistor values on each side of the charging circuit, feeding the master relay coil, they could alter the duty cycle of the oscillation away from a balanced 50:50 condition. This was done to transmit the possible “error” or fault conditions.

The Manipulator system they created using two Russian made “twin coil magnetic latching relays” is astonishingly energy efficient. They quoted less than 20mW power consumption in the design document.

The relays being deployed as a Master and Slave configuration, is somewhat analogous to the idea of a master-slave Flip Flop. The DC resistance of the coils in the Slave relay, at close to 6k Ohms, provide the charging resistance for the timing capacitors for the Master and this saves on parts too.

When the timing capacitors are sufficiently charged, the voltage across their terminals becomes high enough, in conjunction with a series resistor with the Master relay coils, to cause the Master relay to change state.

In the design document, they argued against having a Tube based Manipulator, because it consumed more power. They also argued against a Gas Discharge tube relaxation oscillator as a Manipulator, because the lamp is more sensitive to acceleration and vibrations. The system had to survive accelerations of up to 20g.

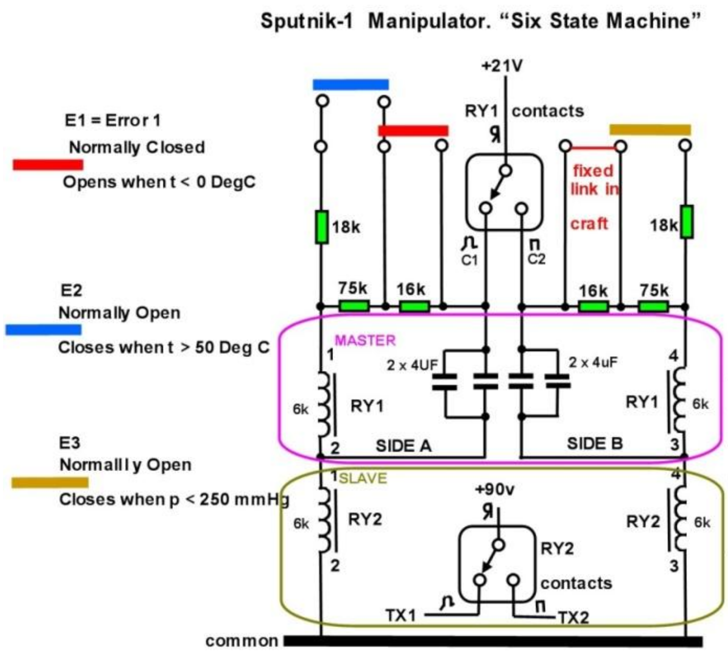
The design result they achieved was six possible distinctly different patterns or duty cycles and frequencies of the switching of the two transmitters. However, as noted, none of these occurred during the 21 day flight to the point of flat (discharged) batteries.

The error switches:

1) One switch was for a Temperature in the craft of less than zero degrees C and Sputnik was freezing to death. This was a normally closed switch, which opened in that case.

2) One switch, which closed, when the temperature was greater than 50 degrees C and Sputnik was cooking up.

3) One switch, which closed if the pressure inside the craft dropped below 250mmHg. In other words Sputnik-1 had sprung a leak, possibly perforated by a small meteor.



Total resistor values with
Error conditions:

	Side A	Side B
E1	91k	75k
NORMAL	75k	75k
E2	14.5k	75k
E3	75k	14.5k
E2 & E3	14.5k	14.5k
E1 & E3	91k	14.5k

E1 and E2 error conditions are mutually exclusive.

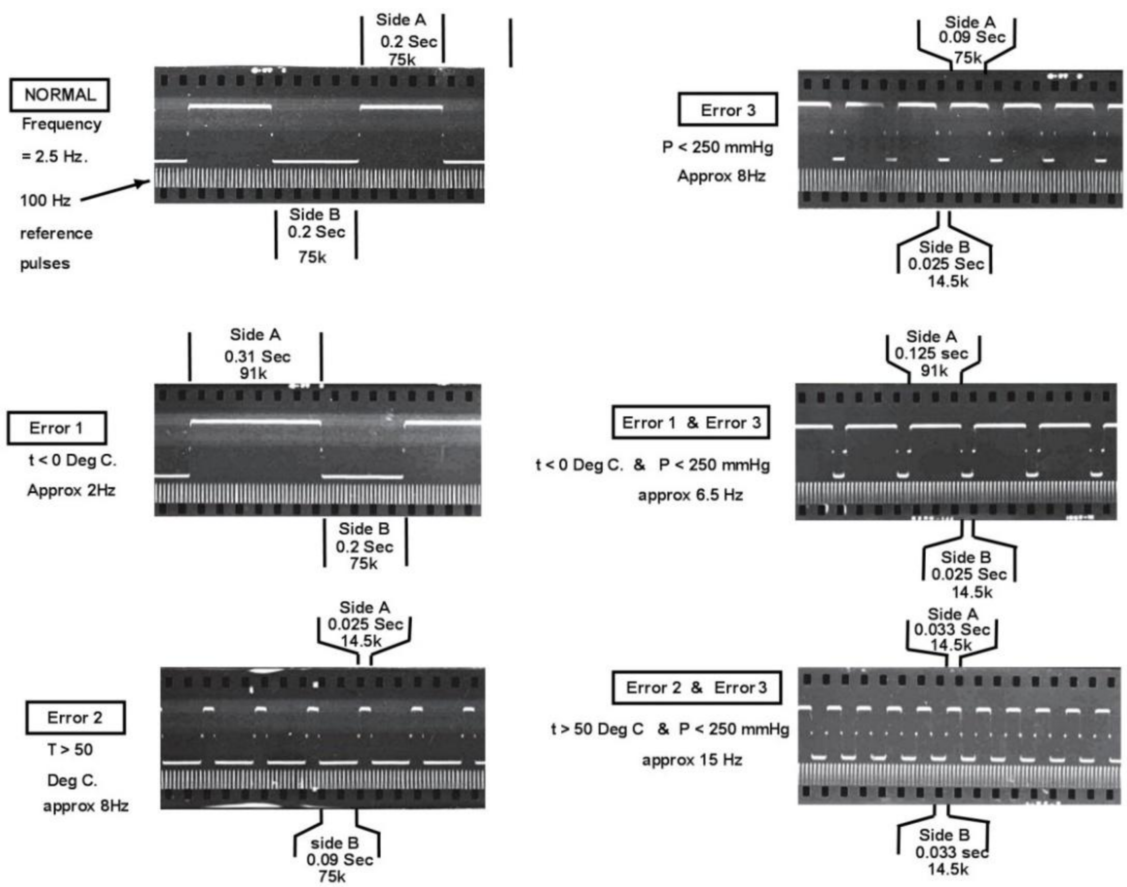
I had to deduce the way these switches were connected into the wiring diagram on the Manipulator in the design document, so as to agree with the duty cycle patterns in the design document. These patterns were recorded on what appeared to be 35mm rolling film. The film has a time marker signal on it. From recordings on the internet of Sputnik's transmitter, taken a few days into its flight, with fresh batteries, I was able to deduce that the time marker signal, also exposed on the film, is 100 Hz.

The design document (link to pdf) also makes a reference regarding the Manipulator of 0.4 seconds. However, it was not made clear if this related to the full period of a Manipulator cycle, or the period for which one of the transmitters was turned on. If the latter were the case though, Sputnik-1's received signal, heard as beeps at the receiver, would have only been75 per minute.

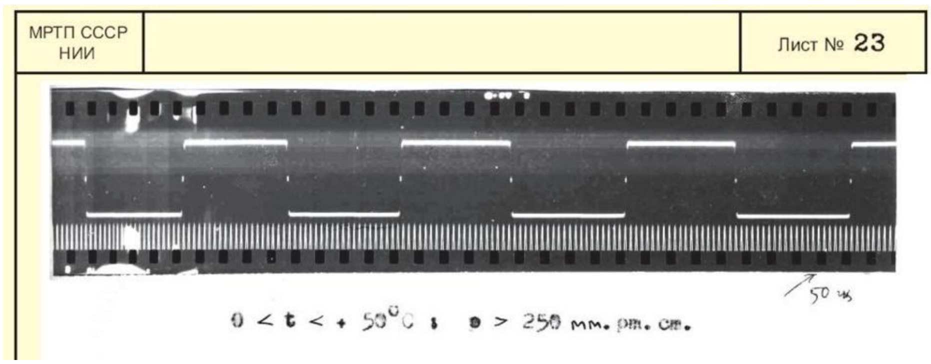
Examination of the Amateur radio audio recordings on the internet, early in the flight of Sputnik-1, indicate that the beep rate to be around 144 to 150 per minute. This confirms that the 0.4 seconds referred to in the design document was for a full Manipulator timing cycle and that each transmitter had an "on time" that was close to 0.2 seconds long, early in the fight with fresh batteries that is.

The diagrams below, with the film recordings (modified to add data) were taken from the design document, show how the error condition switches affect the Manipulator timing by altering the resistances in the circuit. When side A is active, the 40MHz transmitter is on and when side B is active, the 20MHz transmitter is on. To have created these film recordings, the designers would have used a dual trace CRT, with the output of the central relay contact, on the slave relay, used to deflect the beam vertically.

Unlike an oscilloscope, there would have been no horizontal beam deflection. They likely used a positive and negative voltage supply connected to the two slave relay contacts. And the film would have been rolling past the CRT's face to expose it.



They added a calibration signal so that the film speed itself was not a factor in the measurement. Though, it appears that somebody scribbled 50mS on the diagram (below), indicating that this was the time spacing between the sprocket holes in the film, in other words related to the film speed. But, comparing that with the 100Hz calibration pulses, the gap between the Sprocket holes looks closer to 46 to 48 mS, not exactly 50mS.



The typical spacing of sprocket holes in 35mm film is 0.1870 inches or 0.47498 cm. Since there are, from the film recording above, close to 13 sprocket hole gaps over close to 590mS using the notion of a 100Hz calibration pulse, then the speed of the film, running across the CRT's face, would have been in the order of approximately 10. 4 to 10.5 cm/s. Probably the film speed, at the time of the recording, was close to 10 cm/sec, the sprocket holes close to 47.5mS (not 50mS) spacing and the calibration signal likely being 100Hz.

Most likely, the calibration pulses were derived from a full wave rectified line power source, since the line power frequency in Russia is 50 Hz. Or they may have been created by a divided down crystal source.

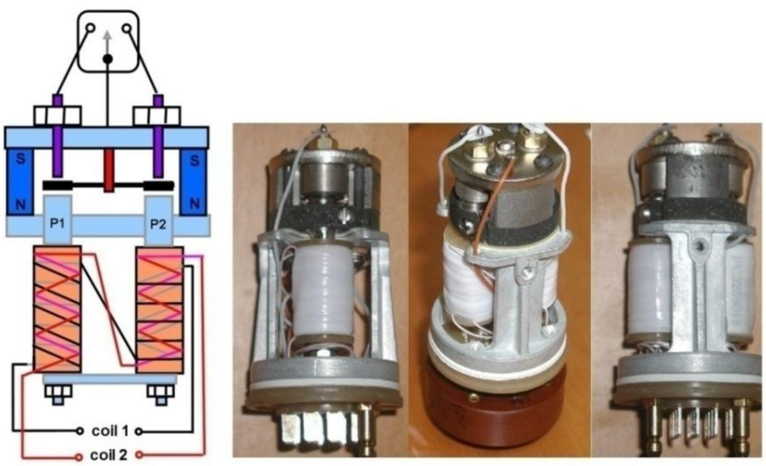
Notice, the small "dead time" corresponding to when neither of the slave relay contacts are closed.

When none of the error condition switches were active (as they turned out not to be in the actual flight) the duty cycle of the manipulator was close to a square wave, alternately switching on each of the transmitters at close to 0.2 seconds on time and 0.2 seconds off time for each transmitter and a period of 0.4 seconds or around 2.5Hz.

The PnC5 Relays:

The photo below shows the PnC5 relay, which has the same form factor as the PnC4.

The PnC5 relays shown below out of their canisters and a diagram to explain them:



Of note, each coil has two windings and either using the one winding to set and reset the coil by reversing the polarity of the applied DC voltage, or the other winding can be used to achieve the same effect.

I could not acquire an exact PnC4 relay, however an almost identical relay is the PnC5. The main difference (I discovered) being that the two pole pieces P1 and P2 have a slightly different adjustment. Though I think there would also have been a difference in the way the armature was suspended. Probably the PnC4 would have used a friction free pivot.

When the pole pieces P1 and P2 (referring to the diagram above) are open enough, the PnC5 does not latch and the armature returns to a neutral position. The armature is suspended on a thin strip of metal and it acts like a taught band suspension.

However closing up the pole pieces just a little on their adjustments allowed the armature to latch in either position. Then the PnC5 relay behaves in the same way as the PnC4 and becomes a latching relay. After I made this initial discovery and adjustment, it became clear that the overall sensitivity of the relay also depended of the combined average position of the pole pieces.

If one considers using a capacitor as a timing element, ignoring the 75k resistor in the capacitor charging process, as it is large compared to the resistance of the slave relay coils at about 6K Ohms each, we can test some assumptions:

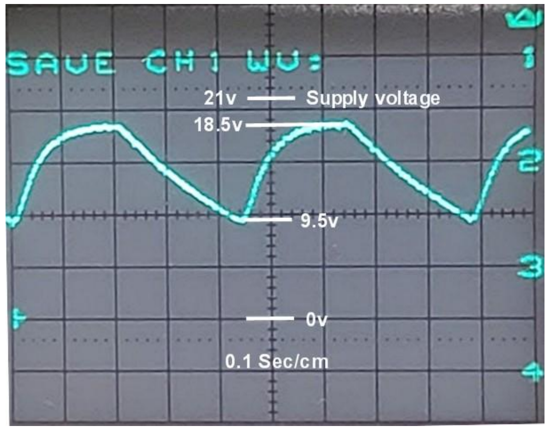
In most RC timing circuits, a capacitor is seldom charged beyond one to two time constants to reach some threshold to initiate a state change. The reason is that the voltage profile across its terminals is flattening out and timing errors become more significant. One RC time constant charges the capacitor to 63% of the supply voltage, 2 time constants to about 86.5%, by 3 time constants 95%, by 4 time constants 98% and by 5 time constants the capacitor is 99% charged and its terminal voltage is changing little over longer time frames after at that point. At this late stage in the charging process, it is not very practical to detect a threshold for a timing event.

I found using the PnC5, once properly adjusted into a latching version and correct magnetic balance (see later), they ran normally in the Sputnik circuit, but required a 36k resistor, rather than 75k, to achieve the correct running frequency of 2.5Hz with the 8uF capacitors.

This indicated that the relay sensitivity with the adjustment I had achieved was a little lower than the PnC4 would have been. The sensitivity increases opening the pole pieces, but if one goes to far the relay won't latch reliably and it will revert to a non-latching condition similar to the PnC5. This is the effect of the taught band suspension in the PnC5 design. A small amount of addition energy is required to overcome that.

Considering the master-slave arrangement, for test and measurements only, I deleted the slave relay and replaced its coils with two 6.2k resistors. This had little if any effects on the behaviour of the master (oscillator) relay.

One thing that intrigued me was the coil current into the master relay's coils and what current they would change state at. I made a voltage recording with a fully isolated scope (Tek 222ps), across the 8.2uF capacitor in the initial test setup (see scope recording below). Later I would move to the original Russian pairs of 4uF 160V PIO types for the transmitter replica.



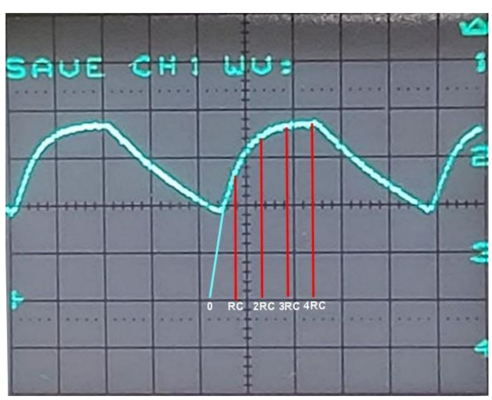
Considering coil 1, or pins 1 & 2 RY1, the master relay:

The capacitor C1 charges up when the relay contact C1 feeding is closed, eventually the master relay deploys when the threshold is reached and the relay changes state, magnetically latching to the opposite condition and initiating the charging process of C2 via contact 2.

As seen from the recording above this occurs when the voltage across the capacitor's terminals has climbed from 9.5V to 18.5v. Therefore 9V is required to cause the PnC5 Master relay to change state, in conjunction with the 36k resistor and the 6k coil resistance.

This corresponds to a coil current of 9/42k = 214uA. Close to but not quite as sensitive as the original PnC4 relay which would have to have toggled at a mere approximately 9/81k = 111uA.

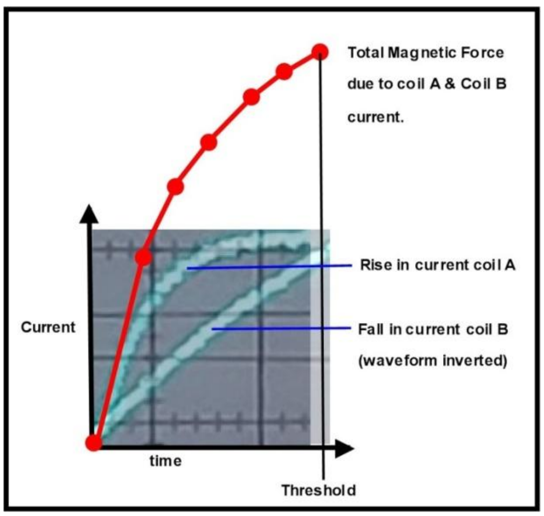
The capacitor discharges at a slower rate because in the interval when the contact C1 is open, the capacitor is discharging into the relay coil via the 36k resistor.



The modified recording above shows that the inverted exponential charging curve seen is close to that that of a 4 time constant RC charge. The charge time approximately matches an 8uF capacitor, charging via a 6.2k resistance (the slave relay coil), from a 21V source voltage. Superficially, this does not seem ideal, in terms of setting a timing threshold, where one or two time constants would have a steeper approach. Of course, this is just considering the magnetic effects of the current in ***one*** of the master relay coils, but what about the other coil?

As the applied voltage and therefore the current via one coil is climbing, the voltage on the other coil is falling, and the currents have opposing magnetic effects due to the polarity of the two coils.

If we chop up the scope recordings and invert the wave on coil side B and add it to the wave from coil side A, we can get a better idea of the way in which the Master relay, from the *magnetic point of view*, approaches a change in state. And the approach to threshold is much steeper, resembling more like a two time constant inverted exponential curve:

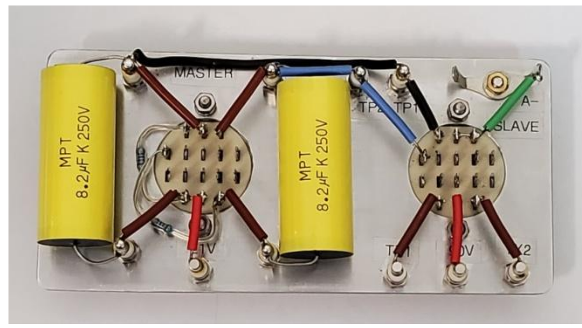


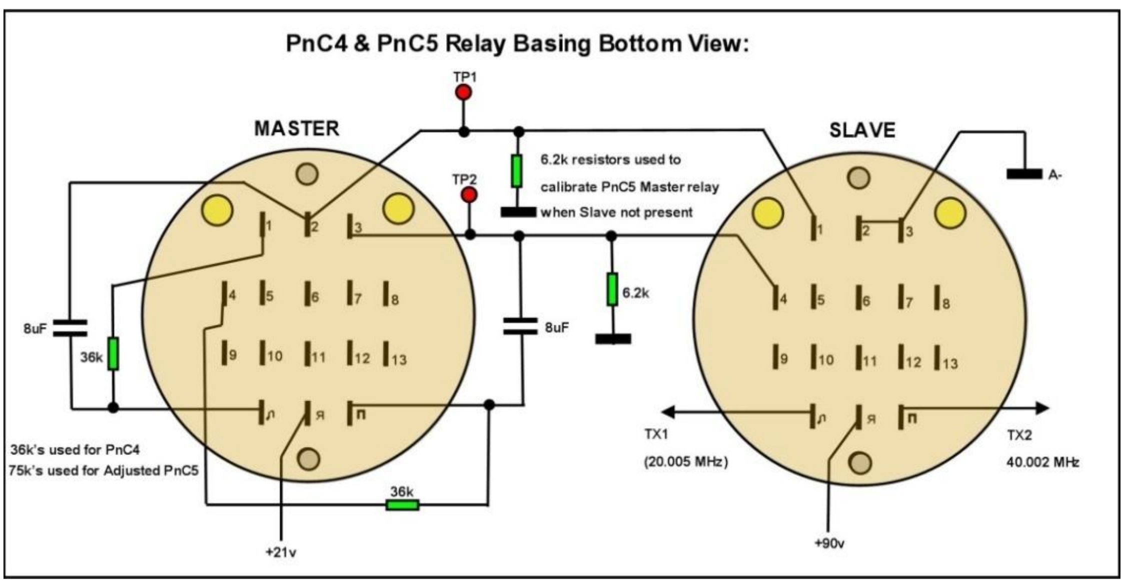
I have never seen any other large latching relay types that can deploy state changes with coil currents in the order of 100uA to 200uA. Even the most sensitive relays I have seen before appear to require at least 500uA to 1mA coil current, most much more.

After finally finding the PnC4 data sheet, for the part number PC4.520.350 used in Sputnik-1, it confirmed that the relay coils are 6500 Ohms +/- 1300 Ohms and that the relay operates in the range of 87uA to 174uA, consistent with the conclusions that I had made about it, switching at around 111uA.

I suspect that the makers of these relays supplied “especially tested and very well adjusted” versions of the PnC4 relay to the Russian Space Agency. I found out for myself, the pole-piece adjustments, for the master relay, especially for a perfectly symmetrical switching waveform, are very critical. Once they are adjusted though, the relay behaviour seems very predictable.

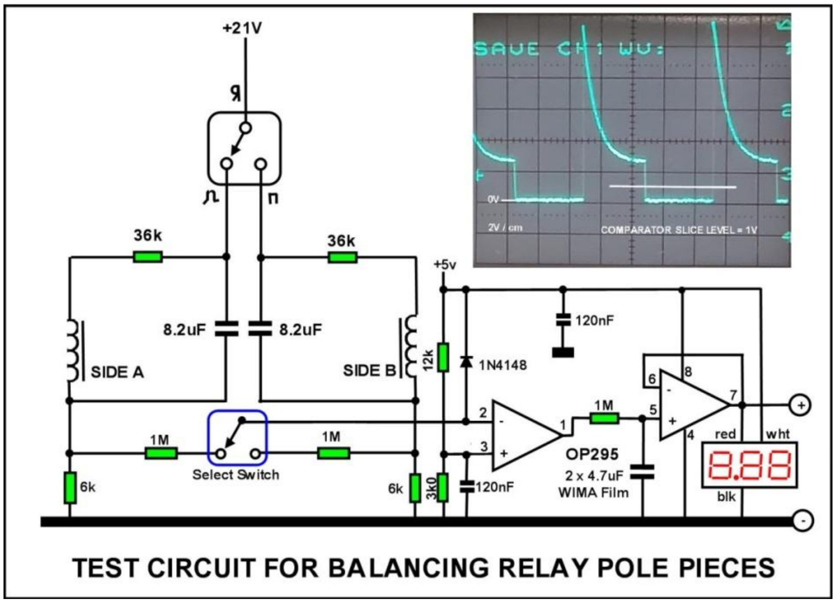
To assist in setting up the PnC5 relays and adjusting their pole pieces, I built a custom circuit to monitor the duty cycle of the timing set by the A & B sides of the master relay. It also required a “test jig” with sockets to hold the relays:





Part of the setup involved not using the slave and using dummy coil 6.2k resistors to take its place. The voltage developed across those is used to activate a comparator, with a 1V slice level, with a stable 5V pp output.

A custom circuit using an OP amp was built to assist in adjusting the PnC5 relays:



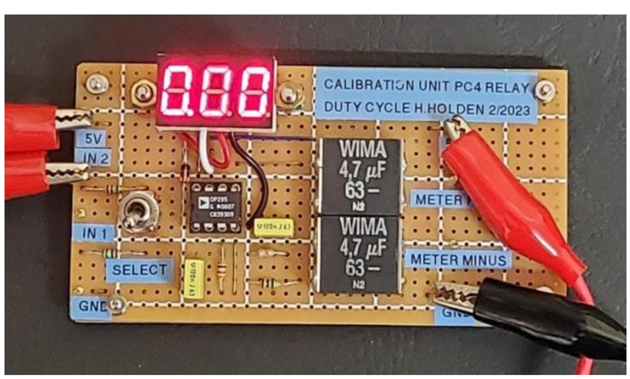
The output of the OP295 OP amp swings rail to rail. The signal is heavily time integrated. I found that the exact duty cycle was affected a little by the operating frequency, so I did the relay pole piece adjustment at the operating frequency of close to 2.5 Hz.

One might expect that with an exact 50:50 duty cycle the output from the integrator should be 2.5V with this circuit. However, the exact value, when in perfect balance is achieved is around 2.66V because of the small gap in the timing where no contacts are closed (about 4mS on each side of the pulse) and the circuit being triggered by a low across the 6k resistor and the stage of inversion by the 1st OP amp. A quick calculation suggested the measured (time integrated) voltage would be in the order of (208 / 200) x 2.5V = 2.60V

The exact voltage value around the 2.66V figure is of no concern though, provided the voltages match exactly up when the select switch is changed over between the A & B sides. In other words both halves of the relay have identical magnetic properties & timing.

When the relay is not in perfect "magnetic balance" (the pole pieces incorrectly adjusted) one voltage result is lower than 2.66v and the other higher on the meter. And when in perfect balance the two voltages meet in value, or cross over again if the adjustment goes too far.

Photo of the actual calibration unit I designed for the task of setting up the PnC5 relay pole pieces, with one test inputs held high. The board has an insulating sheet screwed to its base so it doesn't short out to anything on the bench.



Obviously this circuit could be doubled up on and the time integrated voltage across each of the 6k resistors could be fed into another comparator. However it would have to have a window over which range of voltage difference would be acceptable difference. I found in practice it was better to do it watching the display on the meter and switching the select switch to double check the timing of each half of the relay matched up.

The Relays Running:

With the complete Manipulator system running, master and slave relay, the sound that they make is very similar to a ticking watch or clock.

It is probably the first time since Sputnik-1 launched that this clicking sound would have been heard again by a person. This sound would have been heard by the designers in the Lab where Sputnik was made and tested and it would have been audible inside Sputnik-1 if there was a microphone in there.

It is easy to imagine the Sputnik-1 flying around the Earth in 1957 at 8000m/s with the relays inside it clicking like a clock. There is something quite magical about this, rather than it being deathly silent in there.

I doubt if this circuit would have been re-created again for any other application since Sputnik-1 launched. This is probably the first time ever that the clicking sound of the original Manipulator running has been recorded, at least in this part of the World. The design documents only appeared in the last decade and it requires the now very difficult to get special vintage Russian PnC4 or PnC5 magnetic latching relays, in good order and proper adjustment to make it work properly.

Unfortunately, it turned out these relays contained valuable precious metals and most of them in Russia and Ukraine have been sent for recycling (have been destroyed) because the plants doing it, have offered good money for them.

Link to the sounds of the Manipulator relays:

The ticking is fairly quiet so you made need to turn up the volume on your computer:

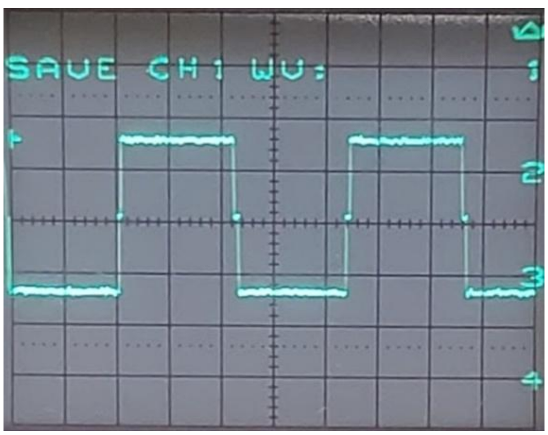
https://drive.google.com/file/d/1Pni2rdbJeOk3TVQXptz2FYgjh5PfqDAi/view

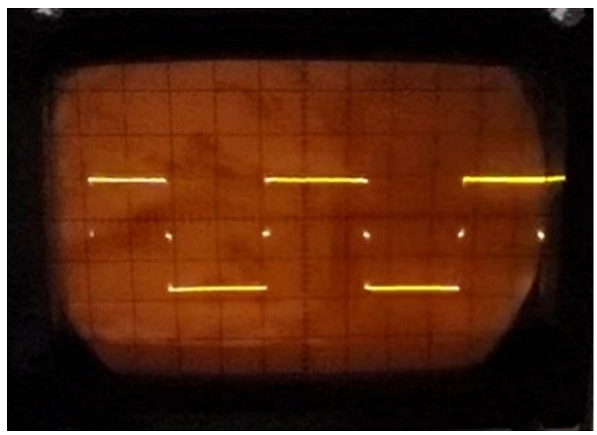
The manipulator sound is also heard on a video link at the end of this article.

As noted it was stated in the design document that the power consumption of the Manipulator was less than 20mW. I have tested this in the workshop. It measured a mere 14mW with the PnC5 relays and it may have been just a little lower with the PnC4s.

It almost seems out of the realm of an electro-mechanical device of the late 1950's era to perform this function at such low power consumption. Whew I saw this figure and the 75k resistors in series with the Master relay coils I could hardly believe it and thought it might have been a misprint. There were no relays I know of, on this side of the Iron Curtain, which could do it, though some may exist somewhere. I had to await the PnC5 relays to arrive from Ukraine to verify that the circuit really did work at such an astonishingly low power.

If the Slave Relay contacts are connected to a plus and minus voltage source, the following recordings can be made, which show, just as it did in the recordings of the original Manipulator on 35mm film, the small steps, where for a moment, neither contact is closed:





The recording on the left is from the Tek 222ps scope. Not shown in this shot, the digital sampling sometimes misses the small step in the waveform which is interesting. The recording on the right is from a vintage Telequipment D52 model Analog scope with a long persistence phosphor CRT.

A video of the Analog scope trace:

https://www.youtube.com/watch?v=k15GSKK_UY0

The Manipulator's oscillation frequency slows down as the power supply voltage is lowered. As the voltage is lowered from 21V down to about 13V, the oscillator runs at half speed. Probably most of the recordings indicating that each transmitter was on alternately for 0.2 seconds, were in the early phase of the flight of Sputnik-1, and the slower recordings where it appeared to be closer to 0.3 seconds were in the later stages as the battery voltage was dropping. The oscillator stops when the applied voltage is below 9 to 10V with the PnC5 relays.

Another observation which confirms that the original time for each transmitter to transmit was 0.2 seconds (period approx 0.4 seconds) in the design document, referring to the Relays:

The factory guarantees 4 million operations. In the nominal mode, the number of operations for 14 days should add up to about 3 million.

There are 1209600 seconds in 14 days. $3 \times 10^6 / 1.2096 \times 10^6$ = 2.48 Hz, close to the 2.5 Hz corresponding to a full cycle of relay oscillation being "0.4 seconds" non-specifically referred to in the design document.

This corresponds closely to a transmission time of 0.2 seconds for each transmitter. This is consistent with many actual recordings I have heard.

In summary; there is an overwhelming body of evidence that the Sputnik-1, at least in the few days after launch, with fresh batteries transmitted alternating bursts of unmodulated carrier waves at 20.005 MHz and 40.002 MHz that were very close to 0.2 seconds long each. Although a number of internet sources quote 0.3 seconds.

When the transmission is received on an Amateur radio with a BFO they appeared as "beeps". The pitch of which were typically *determined by the BFO knob position on the amateur radio* and the frequency of these beep-beep-beeps heard on the radio, or the "beep rate", was close 2.5Hz or 150 beeps per minute.

What was it that finally stopped the transmissions after 21 days?

The 7.5V filament battery for the tubes was rated at 140Ah. The total filament consumption being about 180 to 200mA, for the two transmitter modules combined. The filament battery should have lasted about 700 hours or 29 days based on 200mA drain, but with the voltage falling the current drops and it could have lasted in excess of 30 days probably. However the calculation to full discharge might not be helpful, because the oscillators in the units could have stopped at 2/3 of full discharge or around 20 days. As the tube filament temperature drops, so does its transconductance and at some point, this would stop the oscillators.

The tapped HT battery supplying the Manipulator's +21v had negligible current, less than 1mA @ 21v.

On testing the single transmitter with its output loaded to give 1 Watt of RF power, the average 130v supply current, operating at its normal 50% duty cycle (under manipulator control) was in the region of 24mA and the total average screen current for the three tubes in the order of 7mA. This makes the transmitters' "ON" power consumption from the HT battery (0.007 x90) + (0.024 x 130) = 0.63 + 3.12 = 3.75 Watts.

In the transmitter's "OFF" condition the 130V current (due to the oscillator anode)measured 7mA and the 90V current (for the screen grid of the oscillator) measured 3mA.The power then being (0.003 x 90) + (0.007 x 130) = 0.27 + 0.91 = 1.18 Watts.

With two transmitters alternately switched on & off, the total power would therefore be 1.18 + 3.75 = 4.93 Watts. I we assumed for simplicity that this power came entirely from the 130V battery terminal, the current taken from the HT battery for Sputnik-1 would be close to 38mA.

The HT battery was rated at 30Ah. Therefore the HT battery should have lasted about 789 hours or about 33 days to completely discharge or perhaps a day less, accounting for the tiny current consumption by the Manipulator. This is not dissimilar to the calculated life to full discharge of the heater battery, at around 30 days and the "probable running time" for the circuitry, before the voltages were too low, about 2/3 of that, accounting for the 21 day practical life.

And since the heater power was 7.5v x 0.1A x 2 = 1.5W, then one could say that basically Sputnik-1 was a "6.5 Watt machine", with a 1 Watt RF output.

In the design document there was a remark that the battery capacity, of the 7.5v battery exceeded that of the HT batteries. And it would be necessary to pre-discharge the 7.5V battery to some extent, before using it. Though this notion seemed somewhat odd, unless they were worried about the initial high voltage, which was apparently 8.2 to 8.3 volts with a new battery. At least Sputnik-1's operational duration of 3 weeks well exceeded its "design margin" of 14 days, which is very impressive. It took a 50kg battery pack to do it.

Sputnik -1 and the Doppler Effect:

What about the Doppler effect, the Satellite being low on the horizon and moving away from, or toward the observer (radio receiver). Could this have affected the historical audio recordings? The transmitted carrier has a frequency of ft. Since the pitch of the sounds the observer heard, were a beat note, typically in an amateur radio with a beat frequency oscillator (BFO) the audio pitch heard depended on the position of the BFO knob that the radio user set.

However it was still possible to hear beeps with a domestic shortwave radio, on the 20.005 MHz frequency:

As mentioned, the selection of 20.005 MHz by the designers was a stroke of genius, because, it was 5kHz away from America's Time frequency channel WWV on 20.000 MHz. This would beat with Sputnik-1's carrier wave transmission and create a 5kHz audio beep, that could be heard on a common garden short wave radio without a BFO, if it was tuned to the 20 MHz region. So that many American citizens could grab a short wave radio and tune close to WWV and hear Sputnik-1, if the Satellite was in radio view. If we consider this latter method of hearing the signal as beeps and the Doppler Effect:

The observed frequency, fo, at the receiver = (c/(c+v))ft for the transmitter moving away from the receiver and fo = (c/(c-v))ft when the transmitter is moving toward the receiver. The speed v of Sputnik-1, was approximately 8000 m/s and c = 3 x 10^8 m/s. Ignoring curvature of the path, when the Satellite is travelling away from the receiver, the observed carrier wave fo will appear to drop in frequency by a factor 0.99997334, or when travelling toward the receiver increase by a factor 1.000026667.

Applying that to the 20.005 KHz carrier the frequency, this will appear as 20.0046667 MHz and 20.00553347 MHz.

The beep's tone (remembering this is generated at the receiver as a beat note of two frequencies) therefore could change in pitch from around 5.53kHz as the satellite breached the horizon view to 5kHz(overhead) to 4.66 kHz with the satellite going down on the far horizon, due to the Doppler effect. It would probably be less of a shift in practice due to the curved path.

However, if we consider the beep rate (not the beep pitch) of 2.5 Hz: this would not really appear to change as the satellite went from horizon to horizon, as it would shift over a range of 2.500066675 Hz , through 2.5Hz to 2.49993335 Hz and the listener would never notice that.

Some of the historical audio recordings of Sputnik-1's signal have more of a spooky "phasing in and out effect" typical of multi-path short wave radio reception. It was thought that Doppler effects, as well as the two different transmission frequencies might also help provide more information on the ionosphere.

In some of the historical recordings of Sputnik-1, people are turning the BFO knobs on their radios during the recording altering the beep pitch. This just confused people about the nature of the transmitted signal and misrepresents what is really happening. Also, to make matters worse, on tape loops, the pulses appeared on some to change spacing abruptly, but this was due to poorly spliced loops. On top of this, Russian transistor oscillator circuits have been published with a small speaker that make “beep beep” sounds and purported to be the sounds of Sputnik-1, but really they have no relevance to it at all.

There was interest in the American camp to see what Telemetry might have been encoded into the transmissions. There was none, just alternate bursts of carrier wave at the two transmission frequencies at the 2.5Hz rate set by the Manipulator. Since none of the error conditions occurred (high or low temperature and/or depressurization of the craft) the Manipulator’s duty cycle remained at 50/50, during the whole flight. Possibly this disappointed the CIA, or perhaps made them anxious, in case they had missed something “secret” embedded in the transmissions. Part of the genius of Sputnik-1, was the simplicity of it and no doubt the CIA, at the time, tried to over-think it.

Transmitter Details:

Each transmitter is based on the small Pentode type 2P19B. These pentodes are readily available.

2P19B

SHARP-CUTOFF PENTODE

Subminiature coated-filament type used as rf oscillator and power amplifier in radio equipments. Tube characteristics tally with Standard DL3.309.000JT-II.

Height (without leads)	≤ 45 mm.
Diameter	≤ 10.2 mm.
Weight	≤ 5 grms.
Filament Voltage*	2.2 volts.
Filament Current	100 ma.
Interelectrode Capacitances:	
Input	≤ 4.5 μμf.
Output	≤ 7 μμf.
Grid No. 1 to Plate	≤ 0.03 μμf.
Plate to Filament	≤ 0.05 μμf.
Service Life	≥ 1000 hrs.
Life Standard:	
Transconductance	≥ 1450 μmhos.

* The filament should be operated within the voltage range of 1.8 to 2.5 volts.

CLASS A1 AMPLIFIER

Maximum Ratings:

Plate Voltage	200 max volts.
Grid-No. 2 Voltage	130 max volts.
Plate Dissipation	1 max watt.
Grid-No. 2 Dissipation	0.35 max watt.
Cathode Current	15 max ma.
Service Life for limiting filament voltages:	
At filament volts=2.4 to 2.5	200 hrs.
At filament volts=1.8 to 2.0	300 hrs.

Characteristics:

Plate Voltage	120 volts.
Grid No. 1 Voltage	-5 volts.
Grid No. 2 Voltage	90 volts.
Grid-No. 3 Voltage	0 volt.
Plate Current	7.6±2.2 ma.
Grid-No. 2 Current	≤ 3.5 ma.
Transconductance	≥ 1700 μmhos.
Grid-No. 1 negative Voltage for plate current cut-off (Ia ≤ 100 μa)	≤ 25 volts.

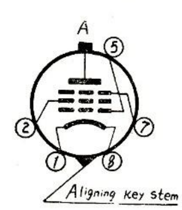
OPERATING CONSIDERATIONS

1. Tube operating values should be kept within the Permissible ranges specified here, and any two or more of them should not reach their respective limiting values simultaneously, otherwise the tube may be damaged or made inoperative.

2. This tube is not recommended for circuits employing series-connected filaments.

3. Flexible leads must not be bent within 5 mm from the glass base.

BASING DIAGRAM



1. Filament.	7. Grid No. 3.
2. Grid No. 2.	8. Filament.
5. Grid No. 1.	A. Plate (top lead).

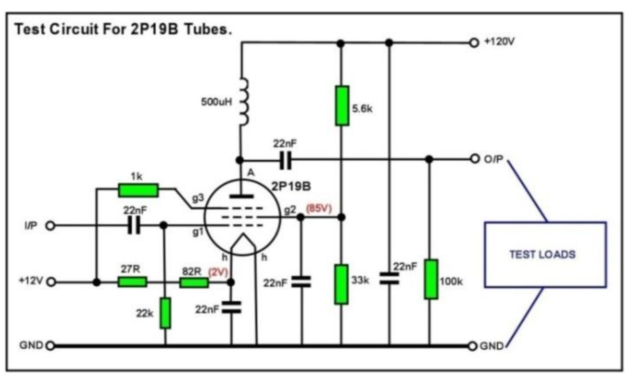
2P19B (71.8 0-5)

Acquiring and Testing 2P91B Tubes:

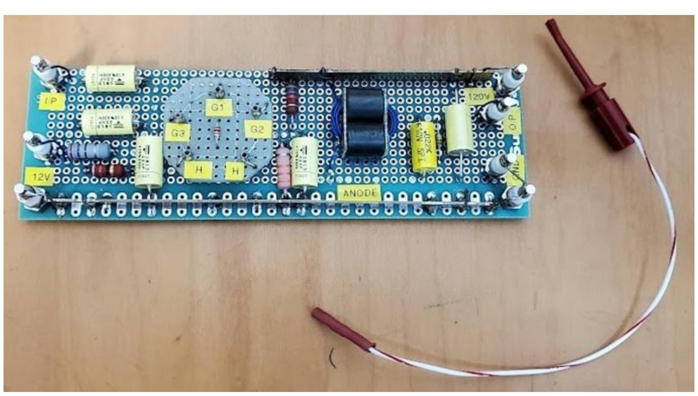
Of note the data sheet above shows the customary bottom view of the tube's base. There is another Russian 2P19B data sheet that shows screen and suppressor grid connections reversed as if the base diagram is viewed from the top, but it is easy to see examining the tube that the above data sheet is correct.

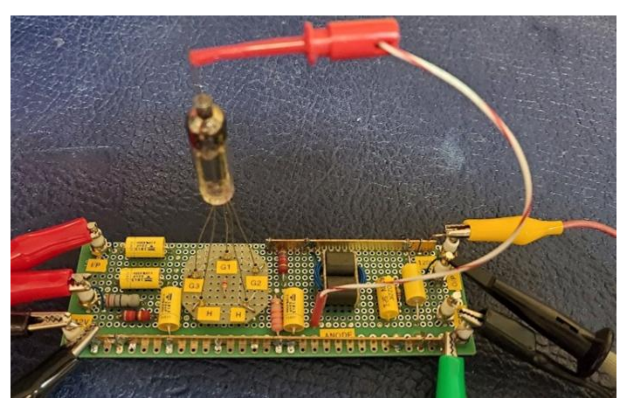
Before doing anything in the way of building the transmitter, I built a Test Jig so that the stocks of 2P19B tubes I had bought could be tested and verified for normal function. They had been stored in corrugated cardboard rolls with a thin paper wrapping, not ideal as that had encouraged some corrosion on the Tinned Copper leads. So this had to be cleaned off, scraping it initially and then smoothing the lead with 1000 grade paper and being very careful not to bend the wires near where they enter the glass envelope.

The main point of the Test Jig was to confirm the tubes I had bought were normal. Three were defective. Two had low gain and the other one had let in air. I tested over 30 tubes to be a fair statistical sample, to determine the "normal behaviour" for these tubes.



2P19B Test Jig:





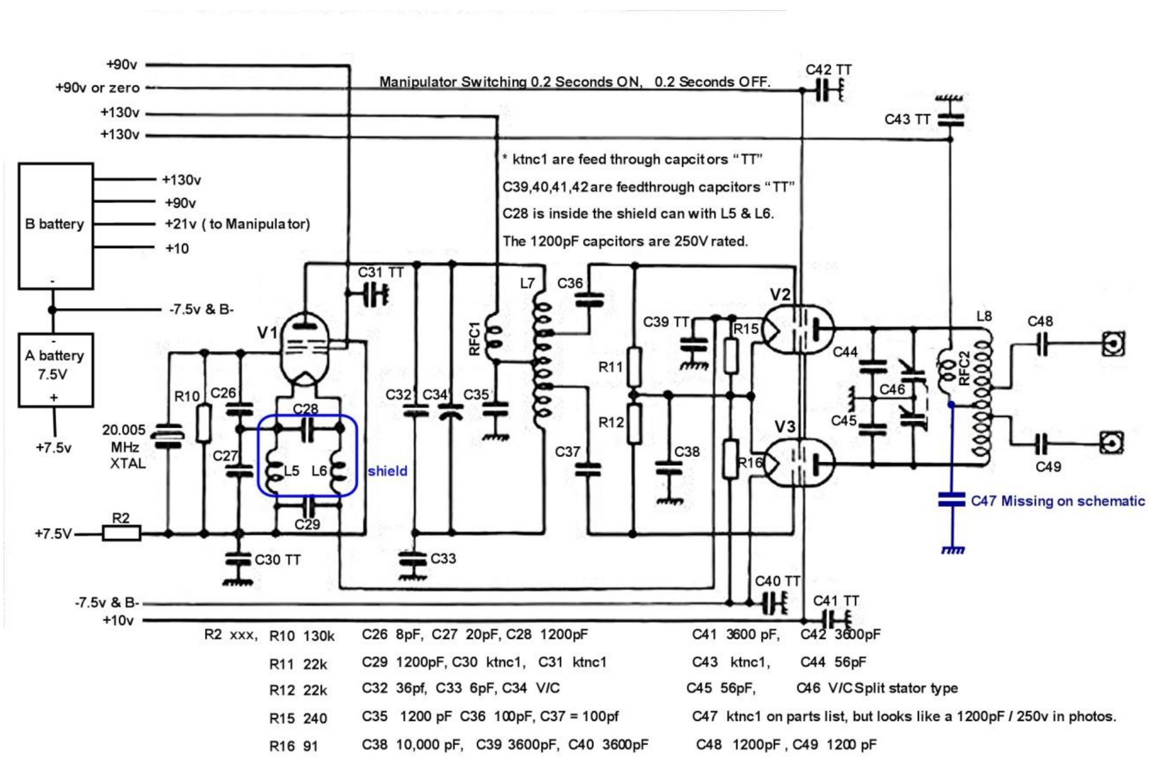
The sockets on the Test Jig which receive the wires from the 2P91B tube were taken from some Machine Pin IC sockets. I tied the g3 grid to +12V rather than ground, because it was tied to +10V in the original Transmitter output stage. The 1k series resistor was used to avoid an accidental short between g3 and the heater pin applying 12V to the heater. I used a 12V Gel cell to power the filament circuit. I had used my dual 0-60V CPX-200D bench power supplies, in series, to obtain the 120V test voltage. This was before I had completed the formal Sputnik-1 Battery eliminator (see end of article on how this was made).

The Design of the Sputnik-1 Transmitter 20.005 MHz module:

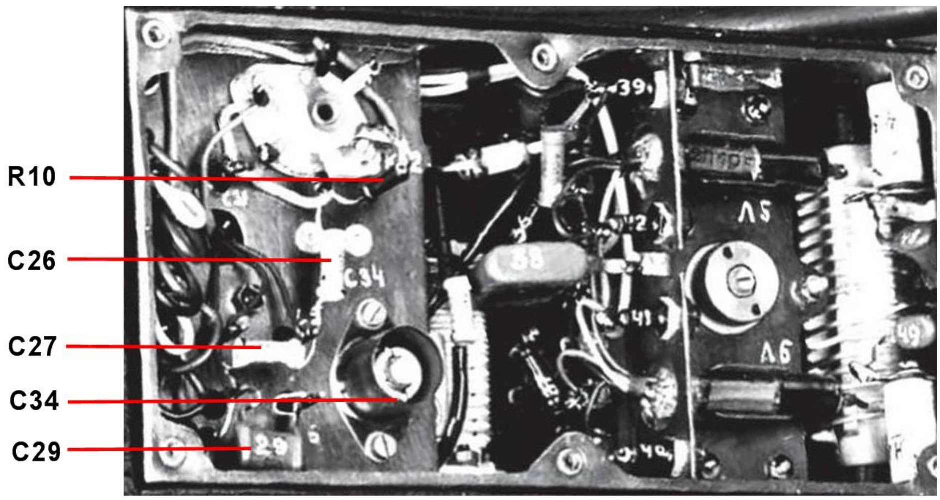
Referring to the schematic below, V1 is deployed as a crystal controlled Oscillator, another two V2 & V3 as the output push pull power amplifier.

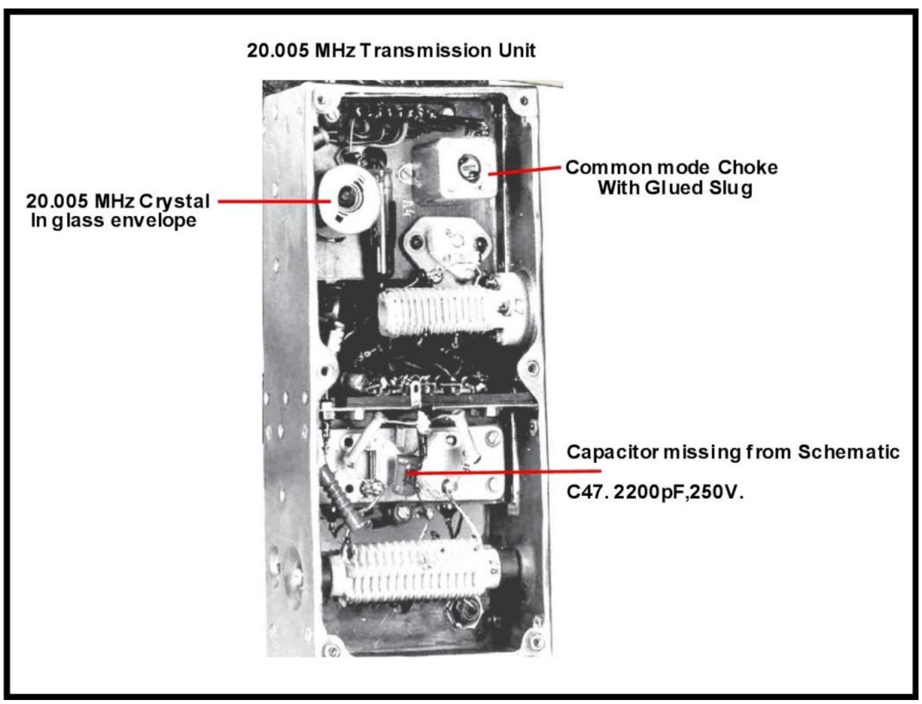
Of note the tubes have a 1 Watt plate dissipation, so a pair running in an output stage, sharing the load, will have no difficulty generating 1 watt of RF output, provided there is adequate drive voltage, which is close to 40v peak at the g1 grids.

The circuits for the 20.005MHz and 40.002MHz transmitters are practically identical, aside from the coil and capacitor values. In the 40.002MHz unit, the main change was they did not tap off the main tank circuit, for an impedance match with the Antenna, as they did for the 20MHz unit. Instead they used a capacitive divider.



Not alluded to in the original circuit diagram, the coils that comprise L5 and L6 are built into a rectangular can, and not only that the capacitor C28 is not visible in any historical photos , so most likely it was in the shield can along with L5 and L6. C29 is visible in the photos though.





One interesting thing about the photo of the original unit above, it appears that the shield around the glass body crystal projects a little above the height of the housing. But the shield can for L5 and L 6 does not look that tall. The size of the transmitter chassis was derived from study of the photos and size scaling from the image details and the limited geometry data from the design document. This indicated the housing width around the transmitter modules was 93mm wide and it suggested the chassis has an external perimeter 90mm wide x 180mm long x 60mm deep.

It was ok that the crystal shield did project a little above the chassis height in the original unit, because this side of the transmitter module faced the interior of the D-200 housing where there was clearance. The width of the main unit, which carries the two transmitter chassis, from the original document, on that axis, was 132mm. More than enough to accommodate two 60mm deep units with 12mm to spare where a midline panel and wiring could run through the main body of the unit.

Lead Dress for the 2P19B:

The photo below shows the selected tubes with lead dress. Later I changed this dress away from PCV tubing and used Teflon instead.

Replicating the Transmitter - Electronic versus Mechanical Engineering:

When it comes to making replicas of vintage electronics apparatus the most difficult part is the Mechanical Engineering aspect of the project. If not done well, the final result does not convey very well how the unit actually worked and looked.

It also takes quite a while examining the historical photos to figure out where the components were placed in the original module and the geometry of the internal and external panel work.

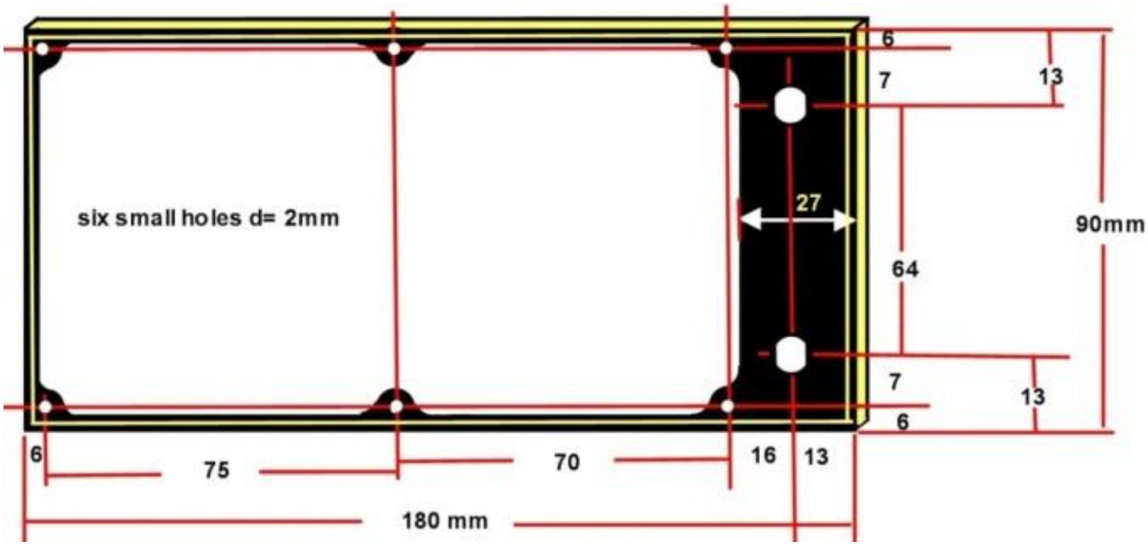
A good replica also requires tracking down most of the original Russian components, where possible, as well. Not just the Tubes, but also resistors and capacitors, because they have a characteristic look to them. This especially includes the Russian chassis mount and RF feed through capacitors.

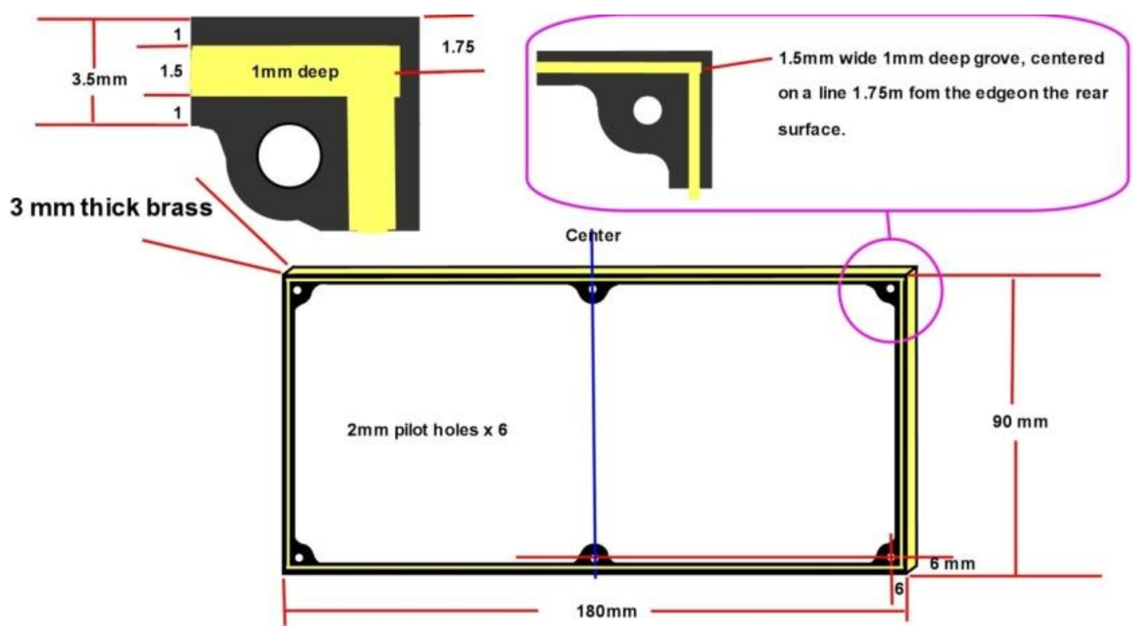
Also, the reality is that for Radio Frequency Apparatus, especially operating at frequencies over 5MHz to 10MHz, the physical layout and shielding considerations become very important. This also includes the mounting clips which attach the 2P19B Tubes to the module body. These serve as partial shields and they also conduct some heat away from the tubes as well. Therefore it is better to stick to the original physical layout closely, for RF equipment replication.

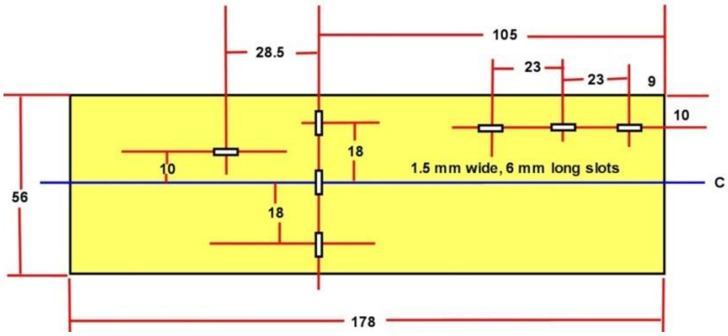
To construct the transmitter module’s metal chassis to be exactly the same as the original would require the same tooling which created the original metalwork. The metalwork had been riveted and soldered together in places too. Without this tooling at hand, there are other methods to create a nearly identical looking metal module of nearly exactly the same geometry.

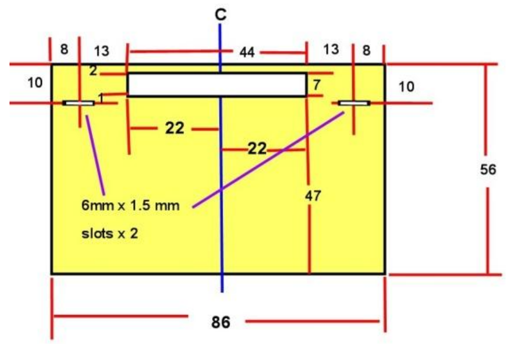
I decided to make the module metalwork out of brass, which is easily soldered. To replicate the top and bottom faces of the module I used 3mm thick plate. This was routed and engraved with a groove to fit the side panels, made of 0.8mm thick Brass. The internal panels, of which there are three, where also CNC machined. This all fits together and are soldered together too. This method avoided having to fold any of the metal panels. Folding induces various distortions in the material.

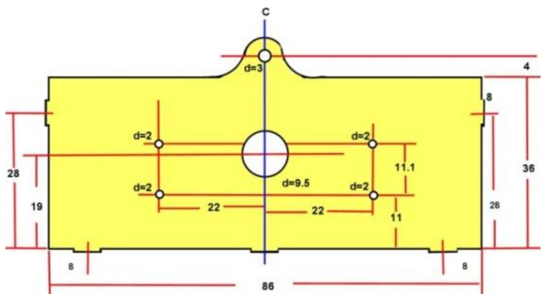
I prepared the diagrams below to help with this task. The CNC machining was done by Troy, at Sunquest Industries, in Warana, Maroochydore.

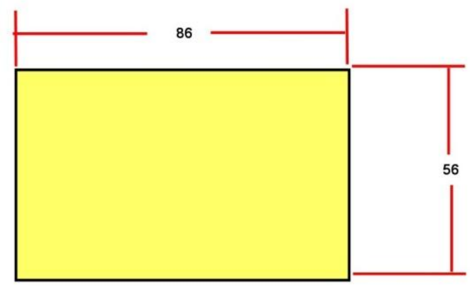

six small holes d= 2mm
6
7
13
27
90mm
64
7
13
6
6
75
70
16
13
180 mm

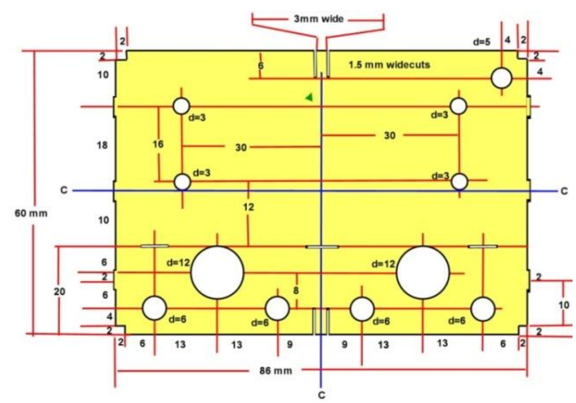

1
3.5mm
1.5
1mm deep
1.75
1
1.5mm wide 1mm deep grove, centered on a line 1.75m fom the edgeon the rear surface.
3 mm thick brass
Center
2mm pilot holes x 6
90 mm
6 mm
6
180mm

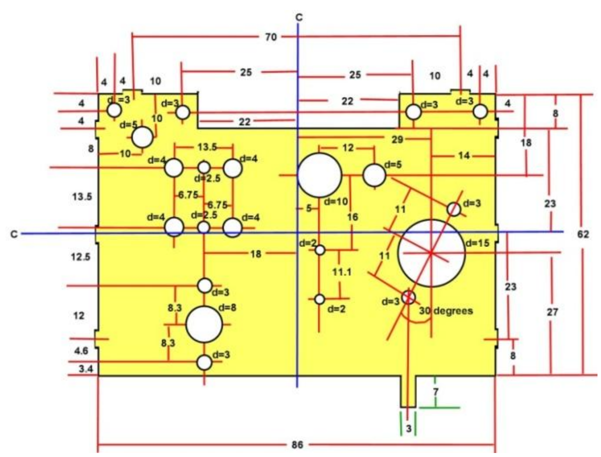










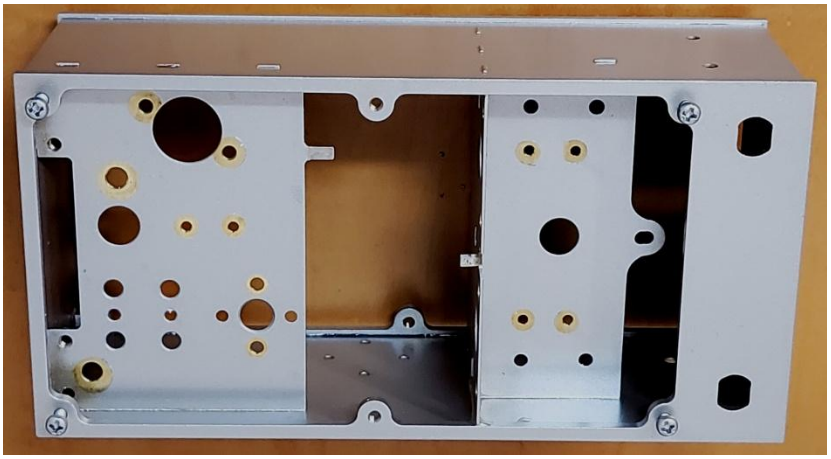


The projections on the sides of the plate are 1.5mm tall and 5mm wide. The slots they pass into, in the other panels, are 1.5mm wide and 6mm long. These are soldered together.

Once the housing plates had been CNC machined, I soldered them together with the aid of the Gas Stove:

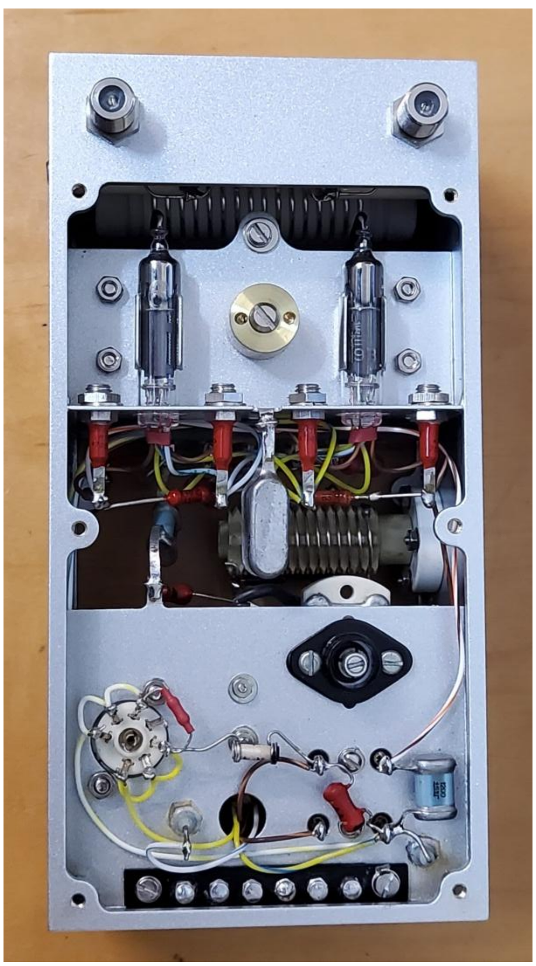
Then the case was finished with 1000 grade paper and spray painted. Temporary screws were used to prevent paint entering the threads and the various Earth points were masked.

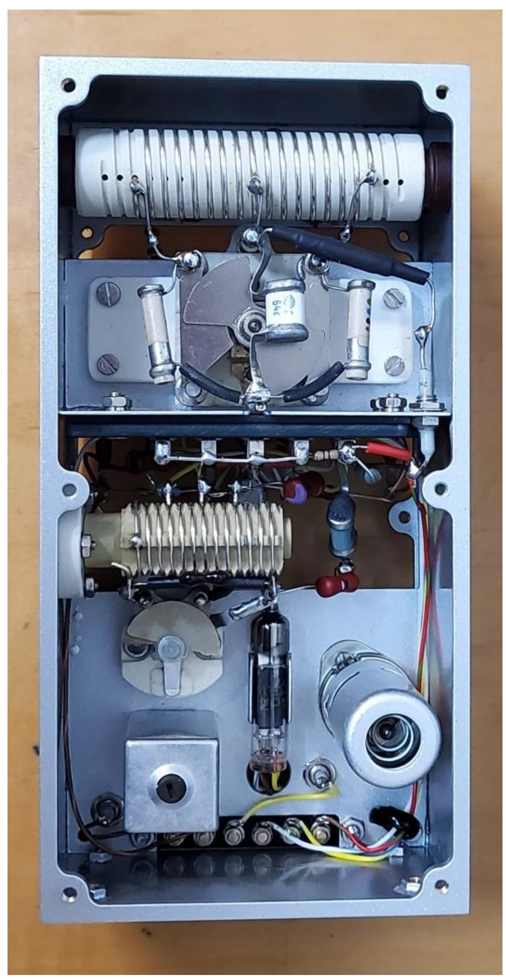
As a side note, there are very few paints which stick to polished or shiny Brass well. I have been experimenting with paints for this application for many years. One excellent product is the clear Dupli-Color spray number DS-117. It helps not having any pigments or fillers such as aluminium powder. The Brass is better coated with the clear coat first. After 24 Hrs drying the silver spray DS-110 is applied. Once that has dried a final coat of clear is applied. This makes for very scratch resistant paint with a good finish and maximum surface adhesion. The other option which gives superior adhesion and scratch resistance is powder coating. Or the housing could have been electroplated too, however both of those latter options would have meant sending it away to a factory which I was reluctant to do.



(The Phillips screws shown in the above photo were used to keep the holes clear of paint. In the final transmitter slot head screws were used to match the original unit)

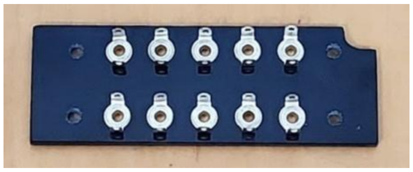
The photos below show the completed Transmitter unit with the final design 16:3 output coil:

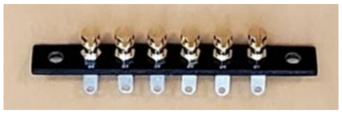




Terminal Strips:

The original unit appeared to contain two terminal strips holding 5 tags each and each mounted with two screws & nuts and a thinner underlying insulating plate. I decided to custom make this as one 3mm thick black fibreglass plate, using four mounting holes and a rear 1.6mm insulating plate. It may have been this way originally. I made a custom connector strip for the unit's rear wiring connections. I used a 6 row rather than 8 row connector strip as this was all that was required and it was less crowded.





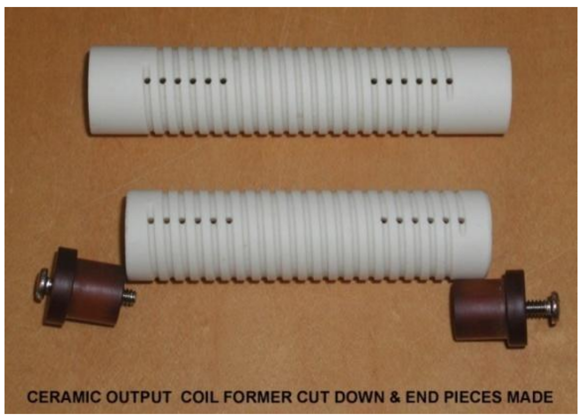
Replica Oscillator and Output tank coils:

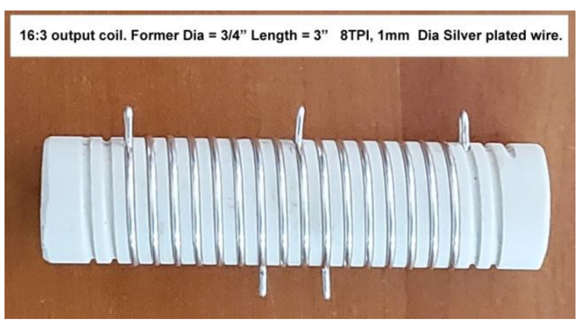
I started a search for ceramic coil formers that lasted some weeks. I had determined the diameter of the original ceramic coils and the approximate numbers of turns from the photos in the design document. The formers have slots for the winding wire. Most likely, the originals would have been a pre-made part intended for Amateur Radio projects in Russia. Generally the wire used on these sorts of formers is Silver plated copper.

The closest oscillator coil form I could find was acquired from the UK. It required a machined base which I made out of Bramite, to help match the original appearance.

I wound this coil with 0.9mm diameter Silver plated copper wire. My first attempt was a 12 Turn coil with a 5 turn CT secondary. It required an additional 10pF parallel capacitance to bring it to the correct frequency. It is possible the original trimmer capacitance had a higher centre value than the one I selected. However, the photos of the original a suggested a 13T coil and that would give the option of a 6 turn or 4 turn CT secondary. Experiments showed that the 4 turn secondary provided inadequate drive to get the output stage to full power and 6 turns were required. It requires close to 40V to 42v peak to each grid of the two output tubes to attain the full power output of 1 Watt.

The closest ceramic former I could find for the output Tank coil, which closely matched the geometry of the original coil, was obtained from Surplus Sales Nebraska. It was close to the right diameter with the correct number of groves so the turns/inch (or turns/cm) was correct, but it was too long. To solve this problem I bought a Diamond Cutting Disc on eBay and fitted it to my bench circular saw, to cut it down to size, removing 7mm of ceramic material from each end. The end mounting pieces were machined from Phenolic rod similar to Tufnol and a threaded machined brass inserts were fitted into those for the retaining screws:





Due to the fact that Sputnik-1's antennas were a bent dipole with the 0.58 meter diameter ball in the middle, it is likely the antenna feed impedance would have been higher than the 72 Ohms, typical of a straight dipole. Probably in the range of 70 to 150 Ohms I suspect. It would be possible to find the exact value by making a mock-up from a metal sphere and some antenna rods. Also, the antenna rods themselves were a little shorter than a ¼ wavelength each. When this is the case, for the basic dipole at least, the antenna behaves as a resistor with a capacitor in series and represents a reactive load where the current leads the voltage. Though, this may have helped to an extent tune out the inductive reactance of the 3 turn coupling coil on the 20.005MHz unit.

From the original document images I could see the output coil had close to 15 turns. Since the centre tap supplying the 130V to the coil appeared to be on the same side as the end connections, this suggested an even number of turns. 14 turns was also a possibility. Initially I wound an experimental 15:3 coil and later moved to a 16:3 for the final output coil.

To conveniently measure the output power into a 50 Ohm load, I made a number of coupling Baluns which presented the transmitter output with a range of loads:

4:4 Load = 50 Ohms, Pout = 0.81W

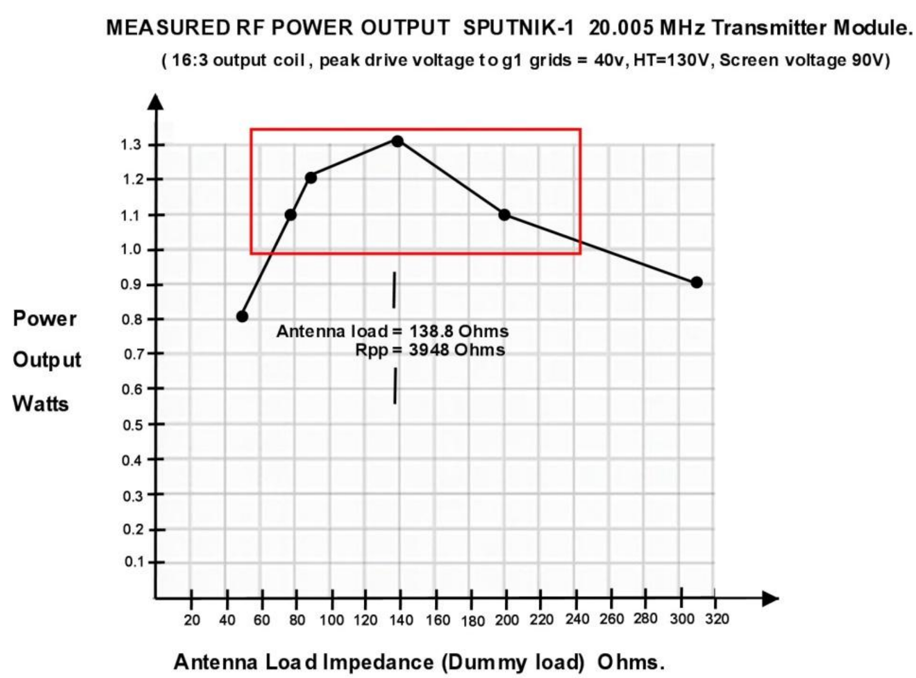
5:4 Load = 78.1 Ohms, Pout = 1.1W

4:3 Load = 88.9 Ohms, Pout = 1.21W

5:3 Load = 138.8 Ohms, Pout = 1.32W

4:2 Load = 200 Ohms, Pout = 1.1W

5:2 Load = 312.5 Ohms, Pout = 0.9W



The transmitter appeared to be very tolerant of a large range of load resistances from 70 to around 240 Ohms and be able to maintain at least 1W output into these loads.

With the 16:3 coil and applying antenna dummy loads I determined that the output power peaked to 1.32W with a load of close to 138.8 Ohms. At this point the plate to plate load resistance for the 2P19B tube pair is close to 4000 Ohms.

One thing I noticed is that the exact tuning of the Tank coil, with the Butterfly capacitor, is affected by the applied load resistance. If the output is peaked with a low range load resistance around 70 Ohms, it tends to down-shift the graph of load resistance versus power output. If the tuning is peaked with a higher load resistance of around 300 Ohms, it tends to up shift the graph. Presumably the D-200 transmitter modules were tuned for maximum power output when connected to the actual antennas in the Sputnik-1 spacecraft to optimize the power output.

Also, at full power output, the plate voltage of the 2P19b with the 138.8 load Ohm fell lower than its screen voltage. The *rms* voltage swing across the 16:3 output coil primary with the load resistance of 138.8 Ohms and the Rpp of 3948 Ohms, for the 1.32w power output is 72v and the peak voltage from plate to plate, across the coil primary is close to 102v. Each plate sees half of this, so that the plate voltage dips down to around 51v below the 130v HT voltage, which is a dip to 79v, which is 11v below the screen voltage of 90 volts. This is not an issue for most Pentodes, unless the plate voltage is very much lower than the screen voltage and then there can be excessive screen grid current. I measured the screen grid current under all conditions of output loading, even when the plate voltage dipped much lower to 23v below the screen voltage with the 312 .5 Ohm load, and the screen current altered very little. Also the output waveform remained normal.

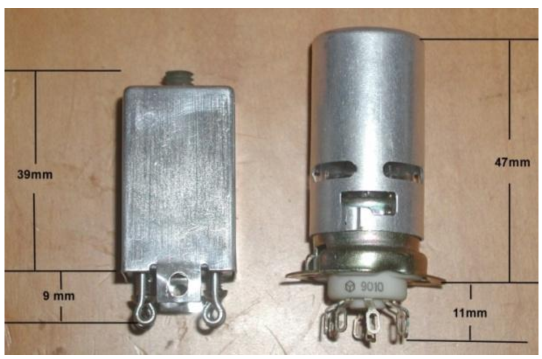
With lower load resistances than the 138.8 Ohms, the plate voltage swing is less. For example with the 78.1 Ohm load the plate voltage dips down only 35V below the 130v HT and stays 5V above the screen voltage.

Replica air-variable capacitors:

The transmitter contains two Air-Variable variable capacitors. To help match these up as best possible I machined a matching looking nut for a Johnson-Viking butterfly capacitor and attached it to a white Bramite plate (this resembles ceramic). Also I machined a shroud around the original adjusting nut for the Oscillator trimmer capacitor and painted that black, so as to resemble the original parts. It was made from a vintage Germanium transistor mounting clamp and a machined brass insert:

Replica Common Mode Choke:

The photo below shows the relative heights of the crystal socket and shield and the common mode choke in the replica:

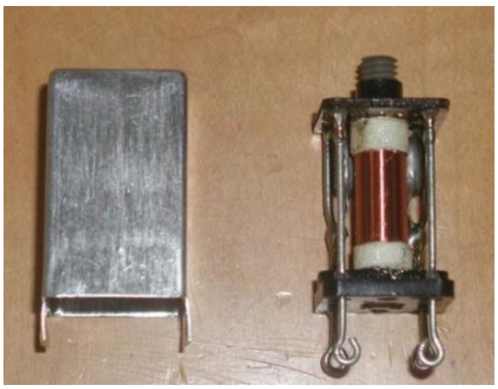


Coils L5 & L6 were likely wound as a “common mode choke” on the one ferrite core. The photos show a single ferrite slug. They made this choke tuneable. I think altering is value allowed a small amount of fine adjustment of the exact frequency provided by the crystal.

The idea behind the choke was to make sure the cathode (filament) of the 2P91B ,V1, has a very high impedance with respect to the common, or ground so the oscillator can work correctly. Generally in a typical Colpitts style Crystal oscillator for medium wave frequencies up to 2MHz, the cathode (or in this case filament) choke is typically chosen to be around 1mH inductance, with an inductive reactance at that frequency of around 12.5k.

In the case of the 20MHz oscillator, 100uH or thereabouts choke is satisfactory with about the same reactance. One thing about making an RFC (radio frequency choke) it is important to keep the self capacitance low. The self capacitance is in parallel with the capacitor C27, a 20pF type. This means that the construction of the choke must either be a single layer coil, or a wave wound low capacitance coil, to keep the self capacitance below a few picofarads. I could have simply used two 100uH axial chokes, but that would not be a good looking replica.

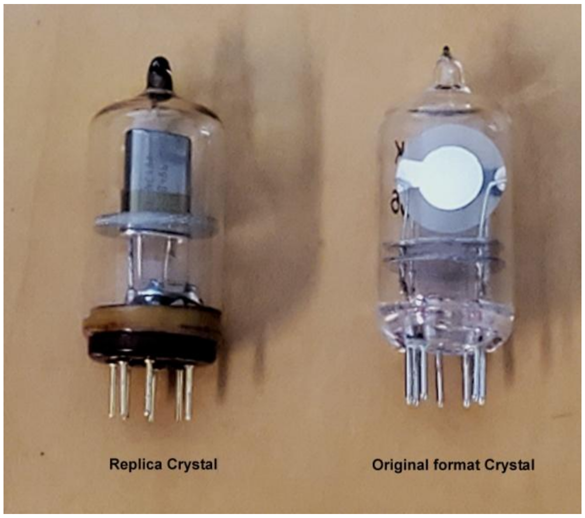
Therefore I made a single layer coil (bifilar wound) with an inductance of 85uH and a self capacitance of 3pF determined on a self resonance test. I fitted C28 (a Russian made 1200pF capacitor) inside the can. Probably this arrangement is similar to the original part.



The choke also serves the purpose of providing some of the DC resistance required in the heater chain. Each tube has a 2.2V heater, accounting for 6.6V. The battery supply is 7.5V.The DC resistance of each coil is 4 Ohms and the filament current is close to 100mA. The value of R2, a resistor in series with the filament string, was not specified in the design document. The total voltage drop due to the choke is 0.8 volts. That would then make the value of R2 close to 1 Ohm for a 7.5V supply. Though, possibly they may have run the filament chain 15% "over voltage" with fresh batteries. The 2P19B data sheet says the filament should be operated in the range of 1.8 to 2.5V.

Replica Crystal:

The Crystal was an interesting challenge. The original crystal was in a 7 pin glass envelope, typical of many of the late 50's era. While these crystals are still sometimes available from Ukraine, I could not find one at 20.005 MHz. A typical 1MHz crystal is shown in the photo left below. To make a replica crystal I cut the top of a 7 pin tube (using a Diamond file in the Lathe) and made a 7 pin base for it, initially only fitting three pins as a trial. The closest crystal I could find was 20.004864 MHz.



After I had cut the glass tube, I heated the cut glass edge to red heat to melt the glass edge with a blowtorch. This helps to ensure that microscopic cracks in the cut edge don't start to spread through the glass wall later. Also, to get the modern smaller crystal to operate properly in the circuit, I had to add an additional 12pF parallel capacitance. I put this inside the replica crystal.

RF output connectors:

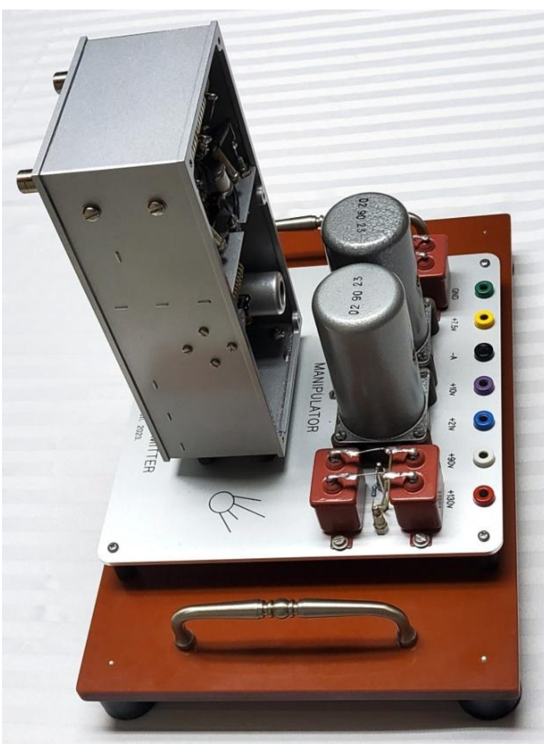
The photo of the original unit shows what appear to be two round RF connectors. To help replicate these I used F connectors.

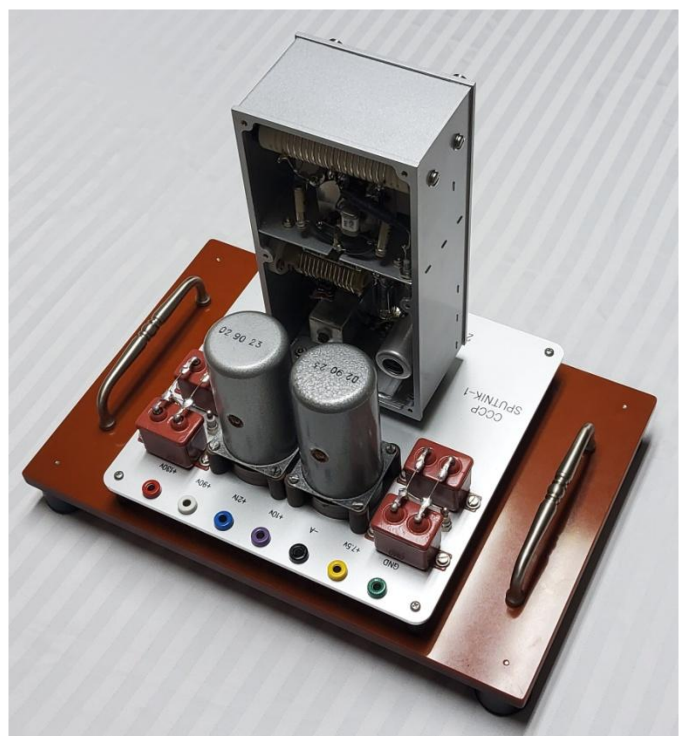
When the module was finished, it was then time to combine it with the manipulator. I had looked at the issue of replicating the entire D-200 housing which contained the two transmitters and the manipulator relays. But, I decided against this. The main reason is that when the transmitter module is mounted inside the D-200 casing, it is not possible to inspect one side of it.

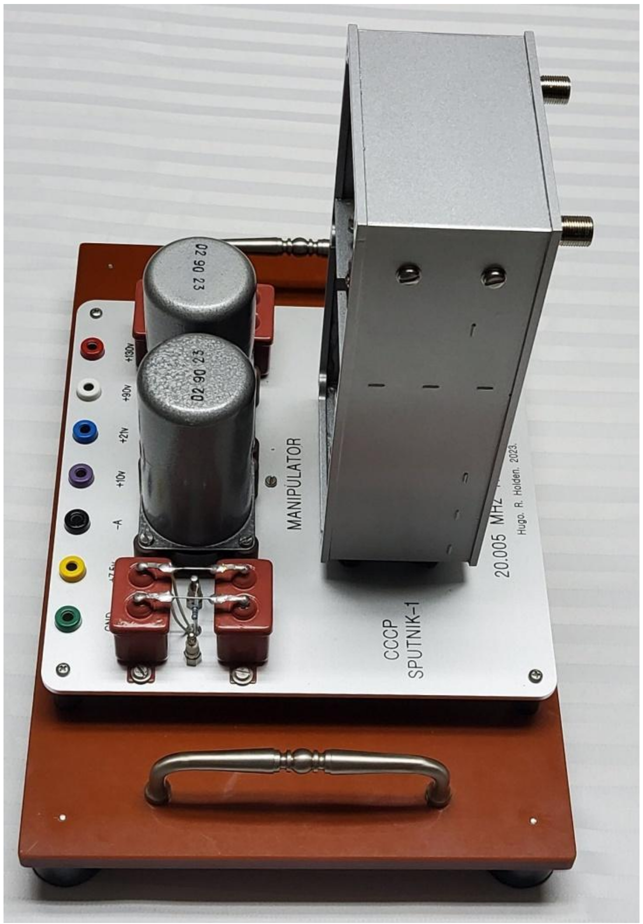
I decided a better move would be to mount the transmitter module on a rectangular plate, with it being visible on both sides, along with the Manipulator relays and the timing capacitors. This way all parts of the design are readily seen.

The achieve this, a natural anodised 3mm thick Aluminium plate was CNC machined and engraved, filled with black paint. The plate then mounts on top of an insulated base.

The transmitter is fixed on one side to the engraved plate and the plate fitted to a Phenolic base-board:

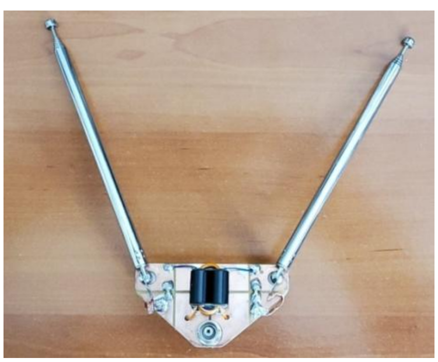






TRANSMISSION TEST & VIDEO DEMONSTRATION:

Since one does not want to transmit a 1 Watt carrier at 20.005 MHz, because it might cause some interference. I simply fed the transmitter output into a dummy load to absorb the power, but, by having some small whip antennas, the leakage was enough that I could receive the signal on a shortwave radio in the next room. I assembled a 5:3 Balun to attach to the transmitter and had a 50 Ohm dummy load to present the transmitter with the ideal 138.8 Ohm output load:



Video Links:

https://youtu.be/9N26pkGGPew Video of transmitter working.

https://youtu.be/_Rq2yrdeGK8 Transmission received on a shortwave radio.

SPUTNIK – 1 BATTERY ELIMINATOR.

This power supply was designed and built to support and demonstrate the replica of the Sputnik-1 Manipulator and its 20.005 MHz radio transmitter module.

Vintage ***portable*** Tube based radio and transmitter apparatus typically ran from batteries.

An "A" battery was to power the tube Filaments. The "B" battery was to provide the high tension voltages for the Tube Anode and Screen Grid circuits. Sometimes there was a "C" battery to provide bias voltages.

In the absences of batteries, the common method to power the radio or amplifier, in a home or laboratory setting, was to power the unit from a line voltage power supply. These power supplies were called "Battery Eliminators".

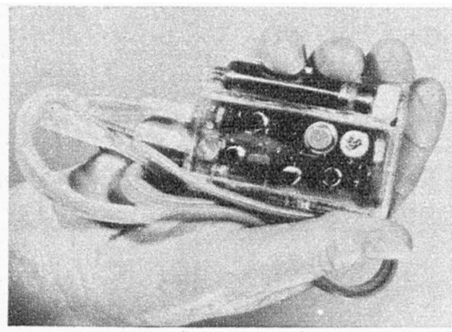
Since the Satellite Sputnik-1, was about as portable as any tube apparatus could ever get in 1957, flying in an orbit around the Earth at a speed of 8000 meters per second the transmitters obviously had to be battery powered.

Could Sputnik-1 have been Nuclear powered?

There were some Nuclear power sources at the time that could have powered Sputnik-1. This could have become a big problem, with radioactive debris dispersal on re-entry. A similar problem occurred when a company in the UK, in 1969, made a Nuclear powered (Plutonium based) Pacemaker. The worry was they could lose contact with patients who had them. Later on, the Pacemaker could get unwittingly cremated, thus creating "mini-nuclear accidents" at Crematoriums. Aside from that, it was a very clever idea. Out of interest, here is a photo of the Nuclear powered Pacemaker, which is much more exciting than a boring Lithium battery powered unit:

Isotope-powered cardiac pacemaker

An isotope battery to supply power to implanted cardiac pacemakers has been developed by the Atomic Energy Research Establishment at Harwell, England. The battery (shown here fitted in a pacemaker and immediately below the fingertips) converts the spontaneous heat generated by the radioactive isotope plutonium 238 into electricity by using a thermopile. The battery is matched to the pacemaker by a DC-to-DC converter which can be designed to suit any pacemaker circuit. The design life of the unit is said to be ten years, substantially greater than the life of conventional batteries, thus reducing



the frequency of replacement surgery. Care has been taken in the design and manufacture of the unit to ensure that no radiation hazard exists for the patient.

Electronics Australia, August 1969.

Back To Sputnik-1's Battery Pack:

Sputnik-1's Silver-Zinc batteries (not available to the public at the time) were especially manufactured for the task. The high tension battery was tapped at +10V,+21V,+90Vand +130V.

The 10V supply was used for the suppressor grids in the two 2P19B output tubes in the transmitter. The suppressor grid current is negligible. The 21V was used to power the Manipulator relays.

In the Sputnik design document, they referred to the common (negative) connection of their B battery, which also connected to the negative connection of the 7.5V filament battery as "-A" so I decided to stick to that on the front panel labelling of this battery eliminator.

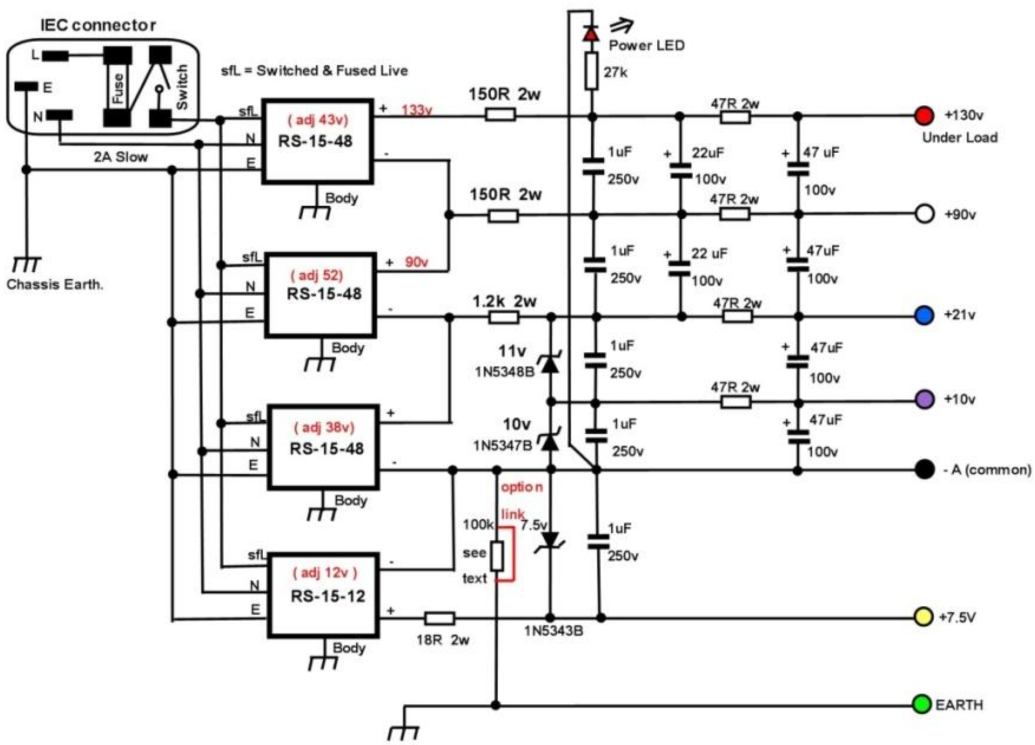
The design version here is based on four 15 Watt rated Mean Well switch mode power supplies the RS-15 model.

As time has past, these supplies have become very economical and very compact. Their outputs are isolated. The supplies are overload protected. They are available as 3.3,5, 12, 24 and 48 volt units. Their outputs are also, to an extent, adjustable too, with the on board potentiometer. This is a very helpful feature. Since the output of each one is isolated, they can be imagined to perform the same job as an adjustable battery (Except for switching noise-see below).

By selecting these supplies appropriately, a large range of output voltages can be accommodated. These outputs can then be further modified by Analog regulation (shunt or series regulation) on their outputs to tailor them to the exact requirements. Also, generally, the 3.3V, 5V and 12V units are the ones rated at higher currents and these are used to run the Tube's filament supplies. While the 48V and/or some 24V units can be used in series to create the correct B+ voltages.

Battery eliminator Design:

The diagram below shows, how for this application four RS-15 supplies were wired up. Since the +21V supply is to supply the Manipulator power (only 20mW required, just under 1mA) and the +10V supply is used to bias the suppressor grid of the output tubes, the current requirement here is very low.



When the replica transmitter unit was finished and running with the Manipulator, loading the supply, I simply set the 90V and 130V levels to be exactly those at the supply's output. The +7.5V +10 and +21 supply outputs required no adjustments.

The power supply module outputs are floating (aside from 2nF of capacitance to the unit's housing), which to some extent makes them safer, because a one handed contact to the +90 or +130V rail won't result in significant current through the body to ground.

It is still better to tie the outputs to Ground electrostatically, so that they don't float up to some unknown value. An anti-float resistor (100k) is used to discharge them. The values is so high, that it limits the one handed contact current to the +130V terminal to around 1mA which is perfectly safe.

I decided to use robust 5W rated Zeners and these require a modest current to get their terminal voltage to the labelled value. However, there is plenty of steam in the RS-15 supplies which are 15w rated.

There is a 0.24W loss in the 1200 Ohm resistor, which is a 2W part. Also a 1.25 Watt loss in the 18 Ohm 2W rated part. Also 1.875 Watts loss in the 5W rated 7.5V Zener, which drops to 1.125W under load. And only 0.3 Watt losses in the combined 10 & 11V Zeners. This makes the total "Zener Regulator" losses, in use, close to a modest 3 Watts.

The shunt Zener method turns out to be highly beneficial for another reason:

These switching supplies have significant switching noise on their outputs, in the order of 80mV peak to peak on measurement. This noise is sourced from a very low output resistance. For example, adding a capacitance of 100uF directly on the supply output terminals does little to it. However the series resistance and the Zener's low dynamic resistance, of a shunt Zener regulator, creates a voltage divider which flattens most of the noise out, even without significant filter capacitors added, especially for the +7.5, +10 and +21V outputs.

The 90v and 130 V output required a series R-C filter to get the switching ripple low and under 3mVpp, just as it is on the outputs with the Zener shunts.

The Line Power safety:

These issues are looked after by a few features:

A switched and fused IEC panel connector is used on the rear panel. This has multiple advantages:

a) This avoids a cord dangling from the instrument when not in use.

b) This avoids having to run line wiring to a front panel switch and issues of insulation there.

c) The IEC connector contains a very short physical link between the Live pin and the Fuse in the IEC module. The link is easily protected with an added sheet of insulation with slots punched for three pins. Some constructors put silicone rubber over this metal link, but I don’t subscribe to that as it can fall off. Another option is an insulating boot, but these are somewhat bulky.

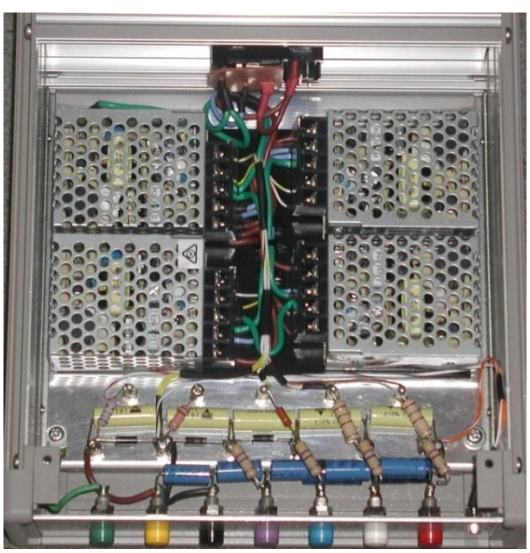
d) Two Earth wires attach to the Earth pin of the IC connector. One wire connects directly to the metal housing with a shake-proof internal star Lug. The other Earth wire connects to all the earth’s on the RS-15 terminal strip, which are all also grounded to the case by their mounting screws. This double Earthing makes the earth wiring a lower resistance with a higher current carrying capability and more electrically robust than the single wire connections comprising the Live & Neutral wiring.

e) The wires are soldered to proper flat circular lugs to suit the screws on the RS-15 units and heat shrink insulation is applied. It is a bad idea to put stranded wire under the screw connections directly, as single strands can break.

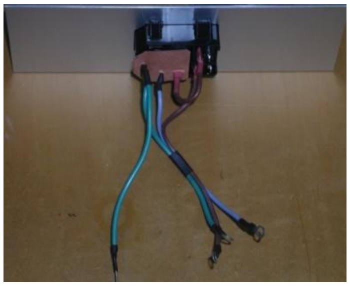
g) High temperature appliance wire is used on the Line side wiring. (I use 750v rated Silicone Rubber harsh environment wire made by Permanoid in the UK). This has the advantage that the insulation does not melt and is not damaged even at very high soldering temperatures.

h) The plastic covers over the screw connections, which come with the RS-15-xx units are retained. This helps prevent any finger contact with the line side wiring, while working on the inside of the unit, while it is powered.

i) The unit is built into a very high quality extruded & cast Aluminium Enclosure MS66-21-23G, supplied by the mail order service of Takachi in Japan. It has the internal chassis option and the Tilt feet option. (Also carry handles are available as an option too which also have an instrument tilt function). I chose the Tilt feet for the final design.

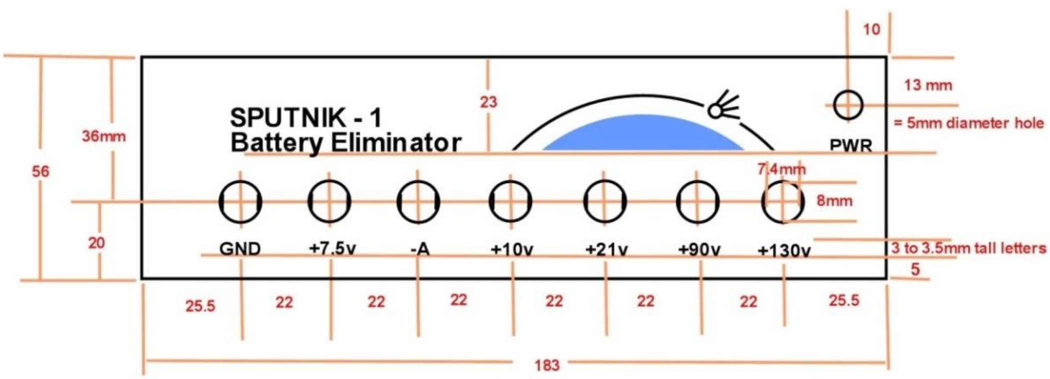


The rear panel carrying the IEC connector is shown below, only one pole of the switch is used. The unused pins are isolated:



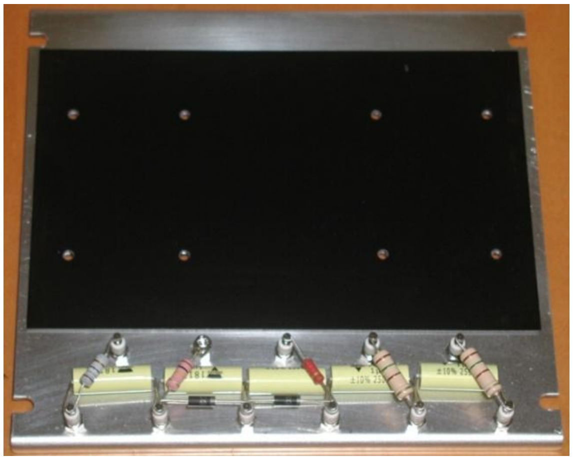
The RS-15 supplies can be screwed directly to the metal surface of the internal chassis. However, for some additional insulation in the region of the connectors, especially with the line wiring exiting downwards, toward the surface, I chose to add an insulating black FR4 fibreglass sheet. However, the bodies of the units are still double earthed to the chassis by their pairs of fixing screws and by their individual Earth wires.

The front panel dimensions and panel artwork are shown below. This was made as a transparent Sticker by Stickerman:



Of note the holes for the 4mm Banana plug connectors (made by Hirschmann) are not round, but have flats to prevent the connector rotating when it is tightened up. This means that you have to drill the hole out to about 7mm, file the flats out to 7.4 mm and then finish the hole on the opposite axis with a round file to create the shape, as I did.

The photo below shows the sub-chassis, still under construction and awaiting one 7.5v Zener diode. The insulating layer under the PSU units is black FR4 fibreglass. The 11 solder terminals are single 3mm screw mount Teflon insulated types. One is a solid 10mm tall threaded Hex Earth post for the 100k anti-float resistor.



Another good aspect of the enclosure and “sub-Chassis” system, created by Takachi, is that you can assemble everything, including the sub-chassis, front and rear panel assembly (shown below), before you “drop” these into the main housing.

The base of the Takachi housing is fitted with their wonderful Tilt Feet:

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