W1TS VINTAGE TRANSMITTER

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INTRODUCTION

The inspiration for this project manual was nostalgia! I wanted a vintage, vacuum tube transmitter to fire up for the annual ARRL Straight Key Night on New Yearôs Eve (2011). Since I generally operate QRP, having a vintage rig that fell within the definition of a QRP transmitter (a maximum of five watts output) would allow me to stay legitimate with respect to QRP contacts while reveling in the tube technology of my misspent youth! There are a great many beginner/low-power transmitter designs that appeared in ***QST*** between say 1965 and 1970, all of which can be located and downloaded via the **Archive Periodical Search** available to ARRL members on the League website (www.arrl.org). The project I settled on was a very basic but solid design presented by Don Mix (W1TS) in the October 1968 issue of ***QST***. This little gem has a maximum input of 10-12 watts so will typically produce around 4 or five watts of output ï a vacuum tube QRP transmitter! If you have worked mine (which is set up for 4-watts out), you know how nice it sounds and you may be tempted to build one. If your personal history includes building tube-type gear somewhere in the 50ôs or 60ôs, all you will likely need is a copy of the ***QST*** PDF download and a soldering iron! If you came into Amateur Radio in the age of solid state devices, you may still be tempted to build one, but there are a lot of new ñoldò things you will have to learn. This project manual should help. If you are interested in building another period rig, there is still a lot you can learn, so give this package a read!

CIRCUIT DESCRIPTION

I have included my own version of the schematic for this transmitter because I think it is easier to understand than the original. You can follow the discussion using the QST version if you wish.

6C4 Oscillator. The 6C4 triode (V1) is set up as an unturned oscillator by feeding back the output from the plate into the tubeôs grid input. Since there is no tuned plate circuit, the tube would be expected to produce power over a very wide range of frequencies from audio up through RF. However, a quartz crystal (X1) cut for the desired frequency of operation is placed in the feedback loop, limiting the output of the oscillator to that frequency. The 47 ohm resistor limits the current that flows through the crystal and helps to stabilize the oscillator stage. The oscillator will readily function on any Amateur band between 80 and 20 meters. The 1 mH choke isolates the RF output from the power supply bus. The oscillator is keyed (turned on and off) by grounding the cathode. When the key is open, no current flows and there is no RF output from V1. Closing the key allows the stage to draw power and oscillation commences. The .01 mF capacitor at the cathode provides RF bypassing while the 100 ohm resistor and 0.47 mF capacitor shape the keyed waveform. Most of the output from the oscillator is fed back from the plate to the grid via the 0.01 mF feedback capacitor, but a small percentage is routed to the final amplifier (V2) via the 0.001 mF coupling capacitor. This minimizes the loading of the oscillator by the final output stage and further contributes to oscillator stability. A simple but significant modification that I made to the oscillator stage is the addition of two 51V 5W series connected 1N5369 zener diodes in the plate circuit. These two diodes, along with the 16K dropping resistor from the 275V bus, essentially regulate the oscillator plate voltage to 100V, key-up or key-down. This modification is absolutely necessary. The transmitter, as originally designed, will work just fine with vintage crystals but keying is completely unacceptable with modern crystals. The problem is excessive crystal current (by modern standards), causing crystal heating and excessive frequency shift (ñchirpò) when the oscillator is keyed. This true even with the ñFT243ò crystals sold by Brian Carling (AF4K), since these are actually high-quality HC49 crystals enclosed by vintage FT243 holders! I have ten of Brianôs crystals for 40 meters and none were useable with the stock transmitter and 275V on the plates (4-5 watts output). With the 6C4 plate voltage regulated to 100V, nine of the crystals yield perfectly acceptable keying!

5763 Final Amplifier. The RF signal from V1 is applied to the grid of V2, a 5763 pentode. Like the oscillator stage, a 1 mH RF choke is used to decouple the RF output of V2 from the plate supply. Screen voltage is derived from the HV bus via a 6800Ý dropping resistor. Power from the amplifier plate is coupled to a Pi-network consisting of L1 and the TUNE and LOAD capacitors. The output tuned circuit suppressed the radiation of harmonic energy and matched the high-impedance plate circuit to 50 ohms. The 1 mH choke at the output of the pi-network is a safety feature. If the input capacitor (0.01 mF) to the network were to fail, high-voltage DC would be applied to the transmission line, antenna, and the various plate circuit components. Should this occur, the choke provides a DC ground connection, shorting the power supply output and blowing the fuse!

S2 provides simple manual transmit/receive (T/R) switching. Like the oscillator, the operation of the final amplifier is controlled by keying the amplifier cathode circuit. With the key open, V2 draws no current and is essentially off. When the key is closed, the cathode of V2 is grounded through the 100Ý cathode resistor and the tube generates RF output. The cathode current (essentially equivalent to the plate current drawn by V2) is measured by measuring the voltage drop across the 100Ý cathode resistor using a voltmeter made up of a 0-1 mA panel meter and a 10KÝ series resistor. With this arrangement, the meter will read 1.00 mA with 10V input. The voltage drop across the cathode resistor is a function of the current passing though the resistor and is easily calculated using Ohmôs Law:

$$\mathbf{E = IR}$$

If, for example, the final were drawing 50 mA (0.05A), the voltage drop across the 100Ý cathode resistor would be:

E = 0.05A x 100Ý = 5.00V

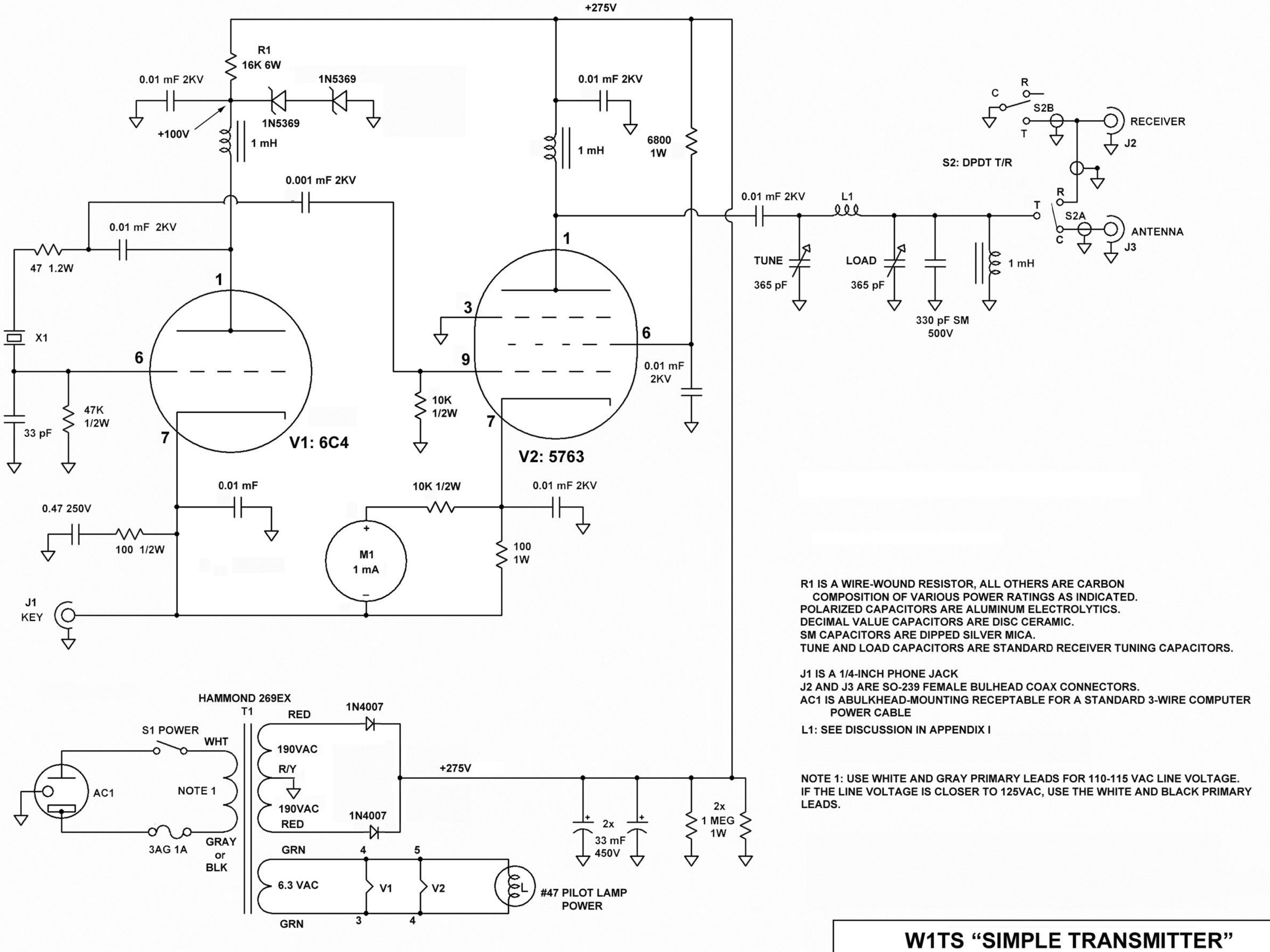
At that current the meter will thus indicate half-scale (0.50 mA) and the actual cathode current is the meter value multiplied by 100. This particular metering scheme could be replaced by a basic 100 mA current meter in series with the keyed line from the final cathode (+ on the tube side, - on the key side), but such meters are harder to find (and more expensive) than the very basic 0-1 mA panel meter used here.

Power Supply

High Voltage Circuits. The center-tapped high voltage secondary of the power transformer drives a conventional full-wave rectifier network with an effective 66 mF (two 33 mF capacitors in parallel) filter capacitor. The B+ voltage at the output pretty-much determines the output from the transmitter. With the Hammond 269EX transformer specified the HV output will be 275-280V and you can expect 4-5 watts of RF output. Two 1 megÝ 1 watt resistors in parallel are used to create a 500KÝ -2 watt ñbleederò resistor. This resistor will not draw much current at a nominal 275V (about 0.5 mA/1/8 watt), but it will serve to discharge the high-voltage filter capacitors once the power supply has been turned off. It will take about one minute to discharge the capacitors to a relatively safe voltage. You can use four of the 1 megÝ resistors in parallel to reduce the discharge time to ~30 seconds with no impact on the operation of the power supply.

Filament Circuits. The Hammond transformer has a 6.3VAC filament winding (green leads) with no center-tap. This is the voltage required by the filaments of both the 6C4 and the 5763 final. The filament supply also supplies the voltage for the POWER pilot lamp.

Primary Circuits. There are two options for the primary wiring of the power transformer which are covered in **NOTE 1** of the schematic.



R1 IS A WIRE-WOUND RESISTOR, ALL OTHERS ARE CARBON
COMPOSITION OF VARIOUS POWER RATINGS AS INDICATED.
POLARIZED CAPACITORS ARE ALUMINUM ELECTROLYTICS.
DECIMAL VALUE CAPACITORS ARE DISC CERAMIC.
SM CAPACITORS ARE DIPPED SILVER MICA.
TUNE AND LOAD CAPACITORS ARE STANDARD RECEIVER TUNING CAPACITORS.

J1 IS A 1/4-INCH PHONE JACK
J2 AND J3 ARE SO-239 FEMALE BULHEAD COAX CONNECTORS.
AC1 IS ABULKHEAD-MOUNTING RECEPTABLE FOR A STANDARD 3-WIRE COMPUTER POWER CABLE
L1: SEE DISCUSSION IN APPENDIX I

NOTE 1: USE WHITE AND GRAY PRIMARY LEADS FOR 110-115 VAC LINE VOLTAGE. IF THE LINE VOLTAGE IS CLOSER TO 125VAC, USE THE WHITE AND BLACK PRIMARY LEADS.

THE TRANSFORMER PRIMARY, SECONDARY, AND +350V BUS VOLTAGES ARE POTENTIALLY LETHAL IF APPRPRIATE PRECAUTIONS ARE NOT OBSERVED!

W1TS "SIMPLE TRANSMITTER"		
D. MIX W1TS 1968 R.E. TAGGART WB8DQT	Rev 1.0 12/28/2010	PAGE 1 of 1

CATEGORY	DESCRIPTION	QUANT.	VENDOR	STOCK #
TUBES	6C4	1	A	6C4/EC90
	5763	1	A	5763
TUBE SOCKETS	7-PIN MIN.	1	A	P-ST7-201MXB
	9-PIN MIN.	1	A	P-ST9-213MX
	OCTAL	2	A	P-ST8-808
PANEL METER	0-1 Ma	1	M	541-MSQ-DMA-001
INDUCTORS	1 mH RF CHOKE	3	M	542-70F103-RC
	PLUG-IN COIL FORM	1	N	NPG-1
TRANSFORMERS	HAMMOND 269EX	1	A	P-T269EX
DIODES	1N4007 (1000 PIV/1A)	2	A	P-Q1N4007
	1N5369 ZENER	2	M	863-1N5369BG
FIXED RESISTORS	47 1/2W	1	M	588-0F470JE
	100 1/2W	1	M	588-0F101JE
	100 1W	1	M	588-0A101KE
	16K 6W	1	M	71-CW5-16K
	6800 1W	1	M	588-0A682KE
	10K 1/2W	2	M	588-0F103JE
	47K 1/2W	1	M	588-0F473JE
	1Meg 1/2W	2	M	588-0A105KE
DISC CAPACITORS	0.001 mF 2KV	1	M	140-202P6-102K-RC
	0.01 mF 2KV	7	M	140-202P9-103K-RC
TUBULAR CAPACITORS	0.47 mF 250V	1	A	C-TD47-400
ALUM. ELECTROLYTIC CAPACITORS	33mF 450V	2	M	146-XAL450V33-RC
DIPPED SILVER MICA CAPACITORS	33 pF 500V	1	M	598-CD10ED330J03F
	330 pF 500V	1	M	598-CD19FD331J03F
VARIABLE CAPACITORS	365 pF	2	A	C-V365
FUSES	3AG 1A	1	A	F-ZF010
	PANEL MNTG. FUSE HOLDER	1	A	S-H205
PANEL INDICATORS	#47 PILOT LAMP	1	A	P-47
	LAMP HOLDER	1	A	P-L110+P-L116

POWER CABLES	RECEPTACLE	1	A	P-SP2-106
	3-WIRE CORD	1	A	S-W123
TOGGLE SWITCHES	SPST (POWER)	1	A	P-H495
	DPDT (T/R)	1	A	P-H35-146
CHASSIS	HAMMOND 12W x 8D x 3.3H	1	m	546-1944-24
TERMINAL STRIPS	5-TERM CNTR GND	10	A	P-0501H
BULKHEAD CONNECTORS	SO-239 COAX (FEMALE)	2	M	523-83-1R
	¼-IN. PHONE JACK	1	A	W-SC11
MISC. HARDWARE	1.5-IN. KNOBS	2	V	
	4-40/1/4-IN. BINDER HEAD SCREWS		V	
	6-32/1/4-IN. BINDER HEAD SCREWS		V	
	#4 NUTS		V	
	#4 LOCK-WASHERS		V	
	#6 NUTS		V	
	#6 LOCK-WASHERS		V	
	#6 SOLDER LUGS		V	
	RUBBER GROMMETS	2	A	P-G005
	MISC. HOOK-UP WIRE		V	
	BELDEN 8216 COAX	4-5 FT.	V	NOTE 1

Note 1: This miniature coax can usually be purchased by the foot from local suppliers. Cost is prohibitive from the major supply houses due to minimum spool length. Standard RG-58 coax (Radio Shack or local suppliers) can be used in the T/R circuits but will be harder to work with due to its larger diameter.

Vendor Key:

A ï Antique Electronic Supply (http://tubesandmore.com/)
M ï Mouser Electronics (www.mouser.com)
N ï National R.F (www.nationalrf.com)
V ï Various some hardware stores, Radio Shack, local electronics suppliers, or Mouser and/or Digikey (www.digikey.com)

BASIC CONSTRUCTION NOTES

Chassis Metal Work

Amateurs have struggled for decades to arrive at practical ways to finish aluminum cabinets and chassis assemblies. Without finishing, enhanced oxidation (particularly of fingerprints) will soon render the equipment an unpleasant mottled gray. My solution is quick and easy compared to most. A use a pad of Scothbrite^{TM} and thoroughly buff all exposed aluminum surfaces under running water. When dry, the chassis will have a lustrous silver sheen that will be quite impervious to normal handling.

Many holes have to be drilled in the aluminum chassis as part of this project. Many of them are beyond the capabilities of a standard set of drill bits:

- 3/8-inch ï potentiometers
- 1/2 ï inch - grommets and many old-style toggle switches. Modern sub-miniature toggle switches mount in modest 1/4-inch holes, but these look completely out of place in a vintage project!
- 5/8-inch ï 7-pin miniature tube sockets
- 3/4-inch - 9-pin miniature tube sockets
- 1/16- 1 1/8-inch ï octal sockets

ñBack in the dayò we all had complete sets of Greenlee chassis punches to make quick work of Creating the many holes for sockets, switches, and connectors. You can purchase such punches today, but one of each of the sizes you will need will probably destroy any budget you might have. An alternative is a ñstep-bit suchas this Greenlee Model 3614:

Although it costs about $55 (essentially the same as one small chassis punch), it will cleanly drill all your holes from 3/8 to 1 3/8-inches. If you still have your punches or know another Amateur who still has theirs, all well and good. Otherwise, check out this unit on the internet or at Lowes (www.lowes.com) stores ï stock number 158038
.
Mounting the meter and the AC power cord receptacle requires rectangular holes. A sheet metal ñnibblerò can do that job:

This one costs about $13 and is available from tool houses and many electronics outlets. This particular model is also available from DigiKey (Stock #GC395-ND). If this is likely to be your only project of this sort, your best solution might be to see help from another Amateur with a well-equipped workshop. When the chassis is done you could take him/her out to dinner and still be way ahead in terms of costs!

Layout

The cover photo provides a reasonable overview of how I laid out the major pieces of my transmitter, but there is no need to adhere to this layout if you want to try something different. It is useful, however, to stick with a few basic principles:

- The crystal socket should be relatively close to the oscillator and the socket for V1 (6C4) should be oriented so the grid pins are close to the crystal socket.
- The grid side of the oscillator tube should face away from the final (V2) while the plate pins face toward V2.
- The grid side of V2 should face V1 while the plate pins face away.
- The plug in coil socket should be relatively close to the plate pins of V2 and the coil should not be too far from the plate and loading capacitors

Wiring

Building a collection of modern circuits consists mostly of installing components on a printed circuit board. The board is designed to complete most of the component interconnections, leaving comparatively little old-fashioned ñwiringò. A vintage tube project could not be more different. Everything is hand wiring. One or more component leads connected to tube or connector pins, individual lugs of terminal strips, and even to each other. Component interconnections are relatively non-critical with respect to lead length in the HF frequency range, so you can arrange components if a very formal and structured way if you choose to do so. Much of the RF gear that I built back then was for VHF or UHF where very direct connections were required to minimize lead length and old habits die hard. For this project I just waded in and wired the different circuit modules as I went along.

No matter how you approach the task, the schematic is your guide. You might want to make a few extra copies and then use colored pencils or felt-tipped markers to verify connections as you go. If you have done this sort of thing before, I expect that you will probably just start wiring until it is all done!

Final Tank Coil

One of the advantages of most vintage transmitter in the low-power category is that you will typically have only one coil to deal with ï in this case L1 in the Pi-network matching the plate impedance of the final (V2) to the 50-ohm coax output. In the original W1TS article, this coil was a 27-turn segment of a piece of 1-inch diameter, 16 turns/inch pre-formed coil stock:

Such pre-formed coils were produced by several vendors but are now generally unavailable outside of the surplus market. All 27 turns were used on 80 meters, while just half the coil (13.5-turns) were used for operation on 40 meters.

I wanted to use the plug-in coil form from National RF that is noted in the parts list as I had always liked the look of transmitters such as the Ameco AC-1 that featured integral power supplies and plug-in coils. You may not want the bother of trying to space-wind coils at a specific pitch and/or you may well want to use a piece of PVC or other plastic pipe as your coil form. The table on the next page is set up for using #20 enameled wire, close-wound, with forms ranging from 0.75 to 2.00 inches in diameter. The wire must be wound tightly around your form with each turn tight up against the adjacent turns. If you spread the turns out, the resonant frequency will change and the coil may not resonate within the range of the TUNE capacitor. The values for a coil diameter of 1.5 inches should be used for the National RF plug-in coil form on the parts list. Coil values are shown for 80, 40, and 30 meters. Operation on 80 and 40 has been tested but 30 meters has not. I expect that keying chirp and drift may be a problem with 10 MHz crystals, but have not verified this one way or the other.

FORM DIAMETER	**80 METERS 8.5 µH**	**40 METERS 3.5 µH**	**30 METERS 2.1 µH**
0.750	27.5	14	10
0.875	22.5	12	8.5
1.000	19	10.5	7.5
1.125	17	9.5	7
1.250	15	8.5	6.5
1.375	14	8	6
1.500	**13**	**7.5**	**5.5**
1.625	12	7	5.25
1.750	11.5	6.75	5
1.875	10.5	6.5	---
2.000	10	6.25	---

Coil configuration using form diameters from 0.75 to 2.00 inches. The values for a coil diameter of 1.5 inches should be used with the National RF plug-in coil on the parts list. The table assumes the use of #20 enamel wire, close-wound (~32 turns/inch) tightly on the selected form.

TESTING AND CHECKOUT

The initial checkout of the transmitter is the most hazardous part of the project, especially if you do not have experience working with high voltage circuits. Here are few basic rules which **YOU SHOULD NOT BREAK**:

- NEVER WORK ON OR TOUCH ANY OF THE COMPONENTS OR WIRING INSIDE THE CHASSIS WHEN THE UNIT IS ON (POWERED UP) UNLESS YOU MUST MAKE WORKING VOLTAGE MEASUREMENTS!
- IN MAKING VOLTAGE MEASUREMENTS:
  - USE A CLIP LEAD TO GROUND THE NEGATIVE LEAD OF THE VOLTMETER
  - HANDLE THE INSULATED POSITIVE PROBE WITH ONE HAND
  - KEEP THE OTHER HAND IN YOUR POCKET.
- TO WORK ON THE INTERIOR WIRING:
  - TURN THE POWER SWITCH OFF
  - DISCONNECT THE POWER CORD FROM THE AC MAINS
  - WAIT AT LEAST ONE MINUTE
  - SHORT THE B+ POWER BUS TO GROUND WITH A TEST LEAD

The following procedure will assume that you have completed all transmitter wiring, a suitable 40 meter crystal is installed in the crystal socket, and the final tank coil has been plugged into the coil socket, the ANTENNA jack is connected to a wattmeter/dummy load with a short piece of coax (if you do not have a dummy load, borrow one or test the transmitter in the shack of an Amateur who does have one), both the 6C4 oscillator and the 5763 final tubes are removed from their sockets, and a key is connected to the KEY jack.

POWER SUPPLY

- Be sure to observe all the precautions noted in #2 above.
- Connect the AC power cord to the Mains socket
- Turn the unit ON.
- Verify that the POWER pilot light comes ON
- Measure the voltage on the B+ bus. It should fall somewhere between 175 and 270 volts DC, depending upon your choice of power transformer.
- Measure the voltage at the junction of the 16K wire-wound resistor and the 1 mH plate choke for V1. It should be somewhere between 100 and 110V (probably around 104 or 105V).
- Turn the POWER switch off. The POWER pilot lamp should go out and the measured B+ voltage should start to decline. Within a minute it should be below 50V.

OSCILLATOR STAGE

1. Plug the 6C4 tube (V1) into its socket.

2. Turn the POWER switch ON.

3. Wait ~30 seconds for the tube filament to warm up. The tube filament should obviously be on.

4. Set up a nearby receiver to CW on the frequency of the crystal

5. Cycle the T/R switch to TRANSMIT

6. Hold down the key and tune the receiver for a beat note. The beat tone should sound clean and stable ï no obvious frequency change. If it is not, see the discussion of crystals in **Appendix I**.
7. Operate the key ï the note should key cleanly on and off with no clicks, frequency changes (chirp) or other anomalies.

8. Cycle the T/R switch to RECEIVE and turn the transmitter OFF.

FINAL AMPLIFIER

1. Plug the 5763 tube (V2) into its socket

2. Preset the TUNE and LOAD capacitors to mid-range.

3. Connect the antenna output to a 50-ohm dummy load so that you can measure power output, setting the power range as appropriate for 5-10 watts.

4. Connect a key to the KEY jack and cycle the T/R switch to TRANSMIT.

5 Turn the Transmitter ON and allow at least 30-seconds for warm-up.

6. Close the key and quickly adjust the TUNE control for a peak output reading. This point should be somewhere near mid-range and it will be a reasonably sharp adjustment. The point of peak output should correspond to a sharp but not extreme drop in the reading on the meter in the cathode circuit.

7. Adjust the LOAD control for peak output, going back and forth between #6 and #7 until maximum power output has been achieved.

8. Turn off the transmitter, allow the power supply to discharge (1-2 minutes, and turn the chassis over and look at the LOAD capacitor. If it is at maximum capacitance (plates fully meshed, wire a 220 pF SM capacitor across the LOAD capacitor and repeat steps #6-8 until the peak power output is achieved within the range of the LOAD capacitor. When you are done, the transmitter will typically be generating 4-5 watts output.

CONGRATULATIONS,

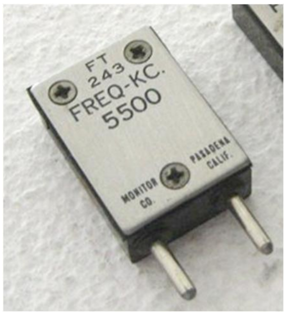
YOU HAVE A WORKING VINTAGE TRANSMITTER!

APPENDIX I
STABILITY OF VINTAGE CRYSTAL OSCILLATORS

You will not need to refer to this Appendix if you are simply duplicating the version of the W1TS transmitter that I constructed. However, you will find this section useful if you are working on another vintage design and face the need (as you probably will) to stabilize the keying when using ñmodernò crystals.

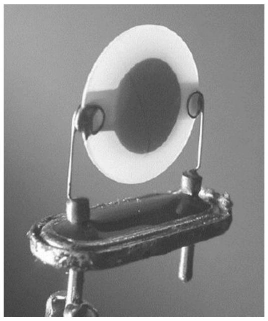
The Problem

Almost any crystal-controlled vacuum-tube transmitter from the post-war period (1945-1970) used crystals mounted in FT-243 holders:

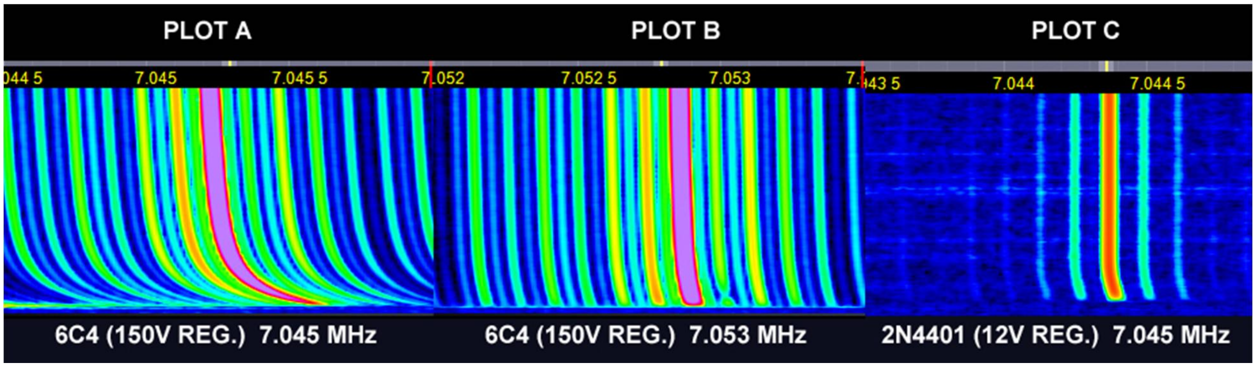


The active element was a quartz-crystal ñblankò about half the size of a postage stamp and, for 40 meters, a bit less than 1mm thick. This small ñslabò of quartz was held between two copper compression plates that provided the electrical connection to either side of the blank and also provided a large area that served to conduct heat away from the crystal blank. Such crystals required moderate crystal current to sustain oscillation of a tube-type oscillator, but the mass of the crystal, together with the built in capacity to transfer heat, meant that the crystal would tend to show good short and long-term frequency stability.

Enter the age of modern crystals. Shown below is the very delicate blank of an HC-6 crystal and the electrodes that are attached to the crystal surface by a very thin layer of metallic plating:



This blank is VERY delicate compared with the FT-243 and this is a large blank by modern standards (most are much smaller than this). Modern crystals are designed to operate in solid-state circuits with very modest crystal current. The crystal currents employed in most vintage oscillators are excessive by modern standards and can even fracture a modern crystal! In virtually all cases, if the crystal doesnðt fracture, the result will be heating of the crystal and modern plated crystals are not designed to dissipate significant heat. The crystal blank will expand as it heats and the result will be a drop in its frequency as the blank becomes thicker as it heats and that will decrease the operating frequency of the oscillator. In short, when the oscillator is keyed, it starts to drift down in frequency. Un-key the oscillator, the crystal cools, and the next time it is keyed, it will start at a higher frequency and then drift down. The magnitude of this heating-induced drift can be significant:



Each of the three plots represents the performance of three oscillator configurations as displayed on the panafall display of my Flex 1500 SDR. Each plot represents 18 seconds (starting at the bottom) and the width of each plot is ~1500 Hz. The crystals under test were ñFT243ò s from Brian Carling (AF4K) that he makes available on the Internet (http://www.af4k.com/crystals.htm). It is important to realize that these crystals are not vintage FT243s but rather vintage holders into which a small, modern HC-49 crystal has been installed. The HC-49 crystals are very small and thus quite susceptible to heating, as we shall see.

PLOT A shows the basic 6C4 oscillator from the W1TS transmitter with a regulated 150V plate supply (more on the regulation issue in just a bit). With a 7.045 MHz crystal, the oscillator drifts over 370 Hz, most of that drift in the first 5-seconds) and has not reached equilibrium with respect to frequency after 18-seconds. The various spurious products on either side of the primary (central) signal trace are spurious responses as the receiver was handing the very strong signal from the transmitter final amplifier! The point is, crystal heating/frequency drift were so severe with this crystal that it could not be used on the air as both signal drift and chirp were very bad. The problem gets worse with higher plate voltage on the oscillator as that increases the crystal current! At 275V B+ in the stock W1TS circuit none of the nine ñmodernò FT243 crystals were useable. With a 150V regulated voltage on the oscillator, six of the crystals were still too bad to put on the air. Just to demonstrate that the problem is not a defective crystal, **PLOT C** shows precisely the same crystal used to create Plot A, but this time it is in a solid-state test oscillator circuit. Total drift in this case was about 30Hz and it was completely stable in a few seconds. That oscillator can be keyed with no problem.

Of the remaining three crystals when used in the 6C4 circuit, two were marginal (I would use them only if desperate), and only one, shown in **PLOT B (**7.053 MHz**)** operated within acceptable limits.

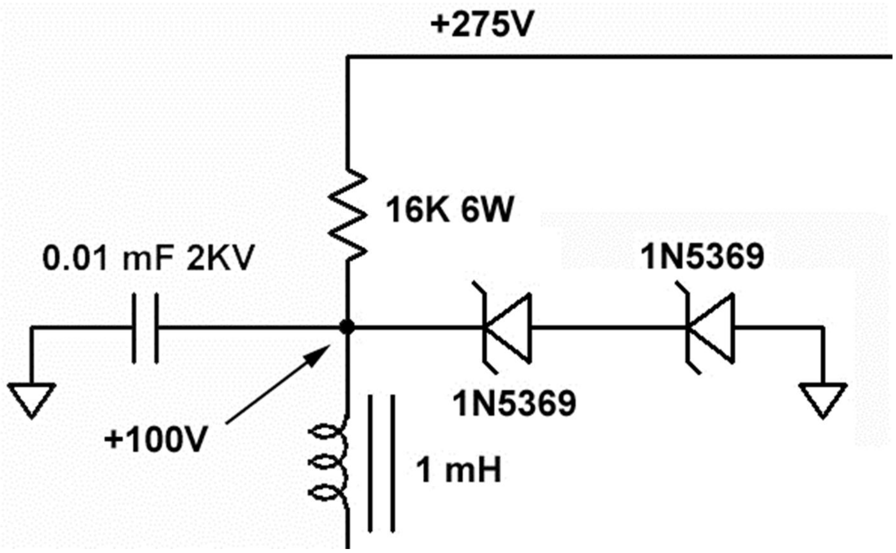
It should be clear that most vintage transmitters will not demonstrate acceptable stability and keying when used with modern crystals. There are several approaches that you could take to remedy the problem:

Use Vintage Crystals. The robust crystal blanks in ñrealò FT243 crystals are relatively immune to crystal heating and will provide acceptable results in most well-designed circuits. However, such crystals are hard to find (especially on useful frequencies), so this ñsolutionò will leave you operating on just one or two frequencies if you are lucky enough to find suitable ñrocksò.

Use a VFO. A modern DDS or solid-state VFO will require some care to interface, but should solve the problem. That said, I have lots of perfectly good state-of-the-art equipment if I need frequency agility. I wanted to recreate the experience of operating a crystal-controlled (ñrock-boundò) transmitter, so the VFO option was not what I wanted, but it would certainly work.

In-board/Outboard Solid-state Oscillator. Plot C demonstrates that modern crystals will, as expected, perform well in a transistor oscillator circuit. Such an oscillator, with one or two buffer stages and suitable impedance matching would solve the problem. Built as an outboard unit, it would be a good solution if you have a number of vintage transmitters you would like to operate.

Oscillator Plate Voltage Regulation. Now all these options are fine, but I had a perfectly good transmitter that certainly would have yielded satisfactory keying ñback in the dayò and it seemed that I should be able to get it to work if I could find a way to limit the crystal current. My solution took advantage of the fact that the W1TS transmitter has an oscillator stage that is independent of the final amplifier. The lower the plate voltage on the oscillator, the lower the crystal current, which will reduce the thermal drift and chirp. At 275V on the plate of the 6C4, none of my nine crystals could be used. At 150V, one crystal worked fine and two others were border-line. If I continued to reduce the plate voltage, the situation could get better, up to the point where the oscillator would have trouble starting and oscillator output was compromised. The ñsweet spotò turned out to be 100V. At that voltage the oscillator keyed well with eight of my nine crystals, and there was still plenty of drive to get 4-5 watts out of the final at 275V on the 5763 plate. In order to get 100V for the oscillator plate supply without adding to the complexity of the power supply, I elected to use a simple zener-diode regulator, as shown on the next page. I will go through the design procedure in case you need to try the same approach in a different circuit configuration. Zener regulation of high-voltage plate circuits is not any more difficult than for low-voltage circuits, but you have to do the math. If you use estimate and simple ñcut and tryò, you can easily blow the regulator circuits and possibly do more damage. Here is the circuit I ended up with, followed by an analysis of how I got there:



As a starting point for design, we need to know the working voltages ï 275V for the main B+ bus and 100V for the 6C4 plate in my case, and the operating current. When I first fired up the transmitter, the current draw for the oscillator was ~10 mA through the 3300 ohm plate resistor specified in the original design. The oscillator will draw less current at a lower plate voltage, so 10 mA seemed like a conservative design value.

For the moment, letôs just assume that we have a 100V zener of indeterminate wattage that connects to the 275V bus through a series dropping resistor. We want the zener to draw 10 mA (0.01A), so we must select a resistor that will drop 175V, the difference between our supply voltage (275V) and our regulated voltage (100V) when drawing 10 mA. Enter old Ohms Law:

$$E = I * R$$

Where E is our 175V voltage drop, I is our target current (0.01A) and R is the unknown resistor value. Since we know E and I, we can re-arrange the equation to solve for R:

$$E / I = R$$
$$175 / 0.01 = R$$
$$17,500 = R$$

So we would need a resistor of 17.5K ohms to get the required voltage drop at 10 mA. That is not a common value, so letôs try 16K. Since it is a lower resistance, we would expect a somewhat higher current draw, but how much higher? Back to Ohms Law, this time with knows of 175V and 16K (16,000) ohms:

$$E = I * R$$
$$175 = I * 16{,}000$$
$$175 / 16{,}000 = I$$
$$0.0109 = I$$

OK, 10.9 mA (0.0109A) is close enough. No matter what the operating state of the oscillator, the 16K resistor will be dropping 175V at 0.0109A and this will dissipate 175 * 0.0109 or 1.9W. To allow a comfortable margin of safety, I would want at least a 5W resistor. The one specified in the parts list is rated at 5W in the Mouser catalog, but the actual resistor is marked at 6.5W. It does get hot, but it wonôt burn out even with the restricted ventilation under the transmitter chassis.

Now to the business of zener selection! When the key is open, the diode must draw the entire 10.9 mA since the oscillator is not drawing any current with the cathode circuit open. If the oscillator is drawing 8 mA, the diode need only draw 2.9 mA (10.9-8.0). Obviously, peak diode current occurs with the key open and the transmitter will be operating with the key open most of the time. This, we use the worst-case value of 10.9 mA to select our diode. The diode needs to drop 100V at 10.9 mA or a total of 100 * 0.0109 or 1.09 watts. We could use 100V-5W zener, but it would get hot (especially under the chassis) and the regulated voltage would change slightly. Instead I opted to use two 51V in series, so each diode is dissipating just over ½ watt ï nice and conservative.

The final configuration holds the plate voltage at 104-105V key up and key down, nothing gets dangerously warm, the transmitter puts out 4-5 watts (the 5763 plate is operating at 275V), and eight of my nine crystals are nice and stable. Mission accomplished!

Important Note:

If you use a different plate voltage and/or you want to use a different regulated voltage on the oscillator, you will have to go through the steps shown here to arrive at your own project-specific values. In some projects, the oscillator is a pentode (6AG7, 6CL6, etc.). In that case you will want to regulate the screen voltage rather than the plate. The principles are the same and you can use this procedure.

APPENDIX I
COIL FABRICATION

You will not need to use this appendix if you are simply duplication my version of the W1TS transmitter as I have supplied coil-winding data that should fit most tank circuit options. However, if you are working on a different project, cloning the final tank circuit with different coil stock or coil forms can be tricky. This section will get you through that with minimal use of math!

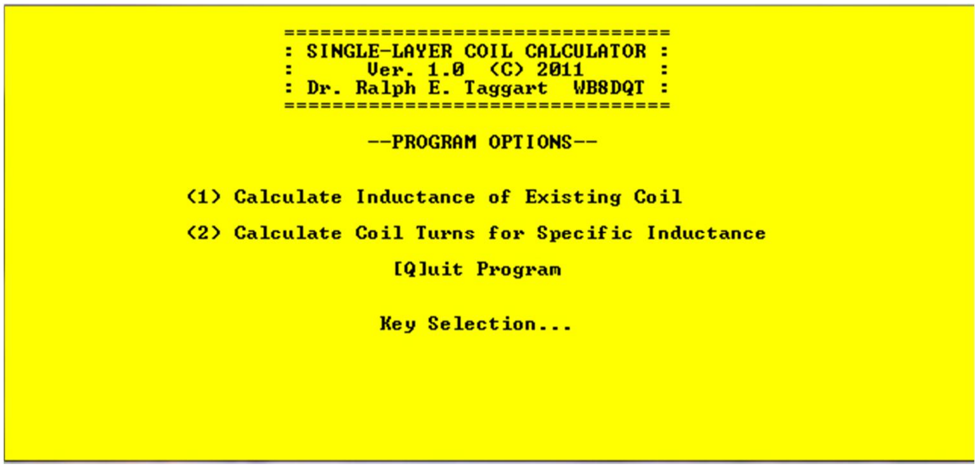
A low-powered vintage transmitter will typically have just one coil ï the final tank circuit - that you will have to fabricate. Many of the designs of the period used commercial coil stock that was widely available in a variety of sizes (diameter, turns-per-inch). This was certainly the case with the W1TS transmitter:

Unfortunately, such coil stock is rarely found on the surplus market today, so you will have to fabricate your own final tank coil. The particular coil stock used was 1-inch in diameter with 16 turns-per-inch (tpi). The entire coil (for 80 meters) consisted of 27-turns with a total length of 1.7-inches (27 turns/16 tpi). The coil was tapped at the half-way point for 40 meters, so the coil for 40 meters had the same diameter but just 13.5 turns and half the length of the 80 meter coil.

If you had access to a 1-inch form and wound an identical number of turns spaced at 16 tpi, you would expect to be able to tune the transmitter to either 80 or 40 meters, depending upon the number of turns. Problems arise however when you want to use some other coil diameter and/or something other than 16 tpi for the windings. My choice for a coil form was the NPG-1 plug-in form listed in the Parts List. I suspect this was due to the fact that, early in my career, I really like to look of the old Ameco AC-1:

My problem was to determine the number of turns on my coil form to achieve the same inductance that Doc Mix had achieved with his coil. The first step is to calculate the inductance of the original coil in the ***QST*** version and then compute the number of turns needed with my coil form. The calculation of the inductance of the original coil is not particularly complex, but figuring out the specs for the new coil is a bit tedious. I wrote a simple little program, COILS.EXE, to do the job and I have included the software in the download package so that you can design your own coil if youôre not duplicating the original. The program is Windows compatible up through Win 7, but will not run under DOS or on a Mac computer.

Just double-click on the COILS.EXE icon and the software will launch in its own window. After and introductory screen, you will see the Main Menu with three options:



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: SINGLE-LAYER COIL CALCULATOR :
:      Ver. 1.0  (C) 2011      :
: Dr. Ralph E. Taggart  WB8DQT :
================================

--PROGRAM OPTIONS--

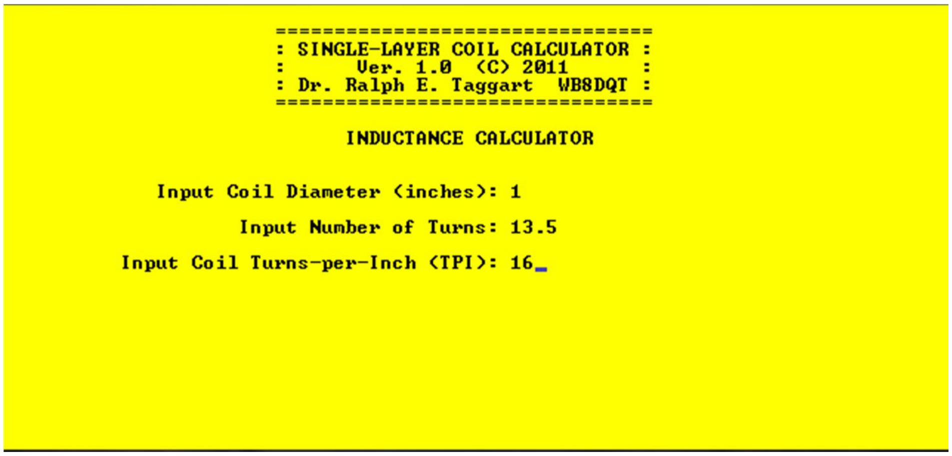
(1) Calculate Inductance of Existing Coil

(2) Calculate Coil Turns for Specific Inductance

[Q]uit Program

Key Selection...
```

Selection [1] will compute the inductance of the coil for the published project while option [2] will clone the coil with other dimensions. Letôs start with [1] by pressing the ñ1ò key. You will be asked to key in (in sequence) the coil diameter, the number of turns, and the turns-per-inch (tpi).



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                 :      Ver. 1.0  (C) 2011      :
                 : Dr. Ralph E. Taggart  WB8DQT :
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                       INDUCTANCE CALCULATOR

     Input Coil Diameter (inches): 1

            Input Number of Turns: 13.5

  Input Coil Turns-per-Inch (TPI): 16_
```
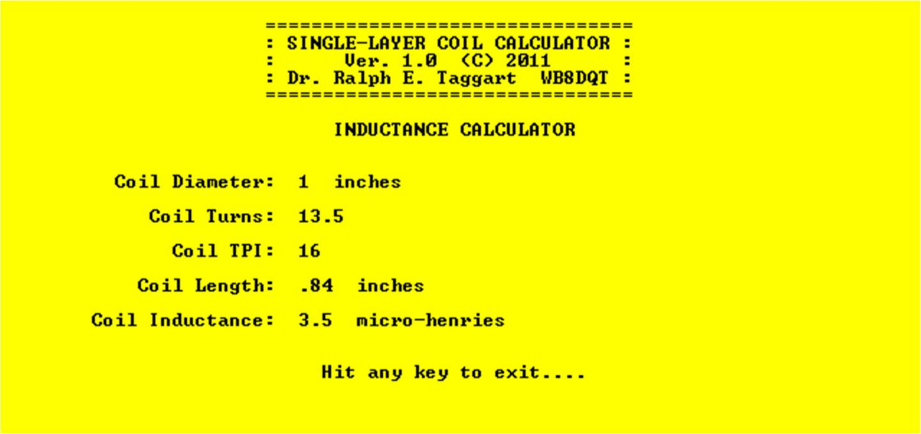

Here is the screen with all the data entered for the 40 meter coil just prior to hitting [ENTER] for the tpi value. Once you do hit [ENTER] for the last data item, the program will quickly calculate the inductance and display it along with the other coil parameters:



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                 :      Ver. 1.0  (C) 2011      :
                 : Dr. Ralph E. Taggart  WB8DQT :
                 ================================

                       INDUCTANCE CALCULATOR

     Coil Diameter:  1  inches

        Coil Turns:  13.5

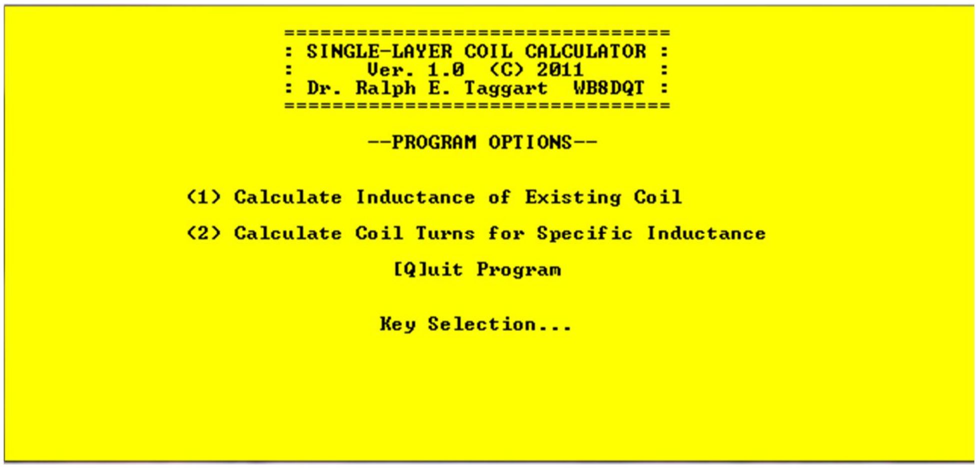
          Coil TPI:  16

       Coil Length:  .84  inches

   Coil Inductance:  3.5  micro-henries

                      Hit any key to exit....
```

While most of the screen that will be posted repeats your data input, the new element here is that the program has calculated the inductance of the 40 meter coil and given us its length as a bonus. Write down the inductance value (3.5 in this example or use whatever comes up with the coil you want to clone). Now hit any key to return to the Main Menu:



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: SINGLE-LAYER COIL CALCULATOR :
:      Ver. 1.0  (C) 2011      :
: Dr. Ralph E. Taggart  WB8DQT :
================================

        --PROGRAM OPTIONS--

(1) Calculate Inductance of Existing Coil

(2) Calculate Coil Turns for Specific Inductance

             [Q]uit Program

            Key Selection...
```

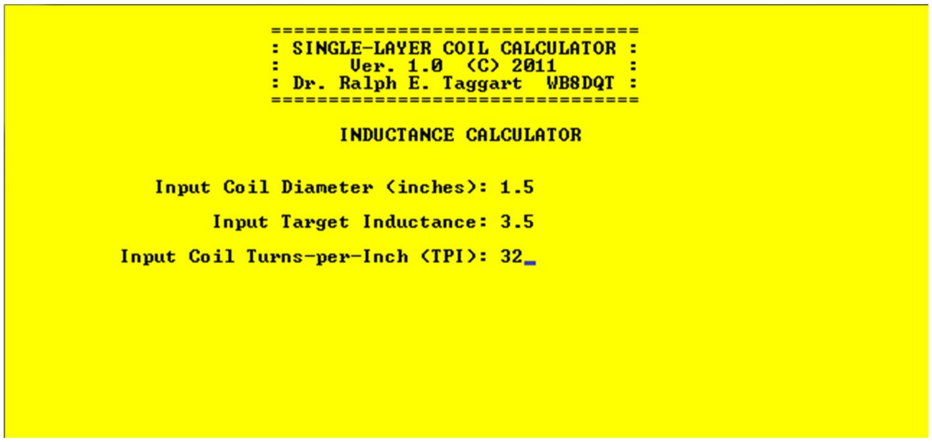
Before we key [2} and start calculating our new coil, we need three items of information at our fingertips:

Target inductance of the new coil - (the 3.5 micro-henries in my example or your value if you are working on another transmitter.

The diameter of the coil form ï 1.5 inches for my plug-in coil form. If you are using another form, you need to measure the outside diameter of the form you intend to use.

The number of turns-per-inch (tpi) for your coil. How closely you wind the turns has a very large impact on the inductance of the coil and, of course, changes the coil length. The simplest approach is to close-wind the coil such that every new turn is tight up against the previous winding. This will require using insulated wire (enameled is traditional but vinyl-covered hook-up wire does fine). The wire size can be anything between #18 and #22 at the modest power levels of the transmitters we are talking about. #12 or #14 would be more appropriate for a 75-100W transmitter. To determine the TPI value for your new coil, close-wind some of your wire around a pencil until the coil is slightly over 1-inch in length. Holding the coil in place, count the turns in a 1-inch interval. That is your TPI value ï mine was 32 with #20 enameled wire.

OK, from the Main Menu, key [2] and enter the requested values in sequence:



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                    : SINGLE-LAYER COIL CALCULATOR :
                    :      Ver. 1.0  (C) 2011      :
                    : Dr. Ralph E. Taggart  WB8DQT :
                    ================================

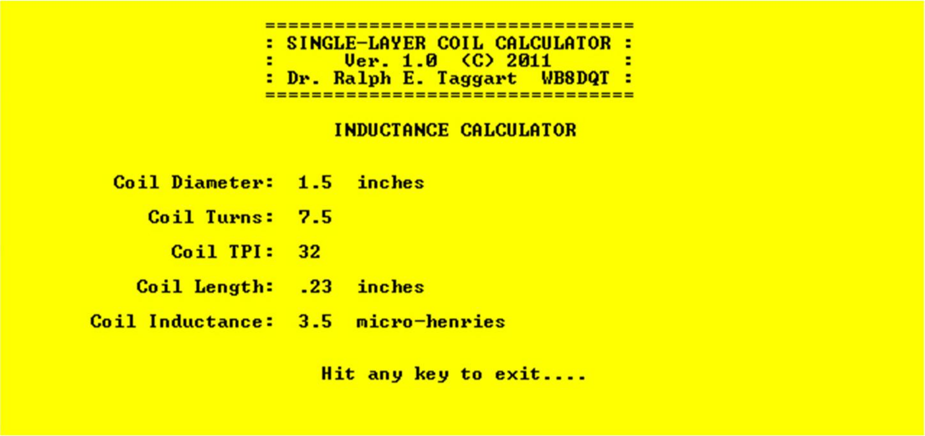
                          INDUCTANCE CALCULATOR

          Input Coil Diameter (inches): 1.5

               Input Target Inductance: 3.5

       Input Coil Turns-per-Inch (TPI): 32_
```

Here I have used my values and, once the last item (theTPI value) has been keyed in, you will get a display like this:



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                    ================================
                    : SINGLE-LAYER COIL CALCULATOR :
                    :      Ver. 1.0  (C) 2011      :
                    : Dr. Ralph E. Taggart  WB8DQT :
                    ================================

                          INDUCTANCE CALCULATOR

          Coil Diameter:  1.5  inches

             Coil Turns:  7.5

               Coil TPI:  32

            Coil Length:  .23  inches

        Coil Inductance:  3.5  micro-henries

                         Hit any key to exit....
```

This display shows the input values, but also includes the number of turns, the calculated coil length, and the inductance of the final coil. The latter is a perfect match to our target. In all cases the program should generate a coil within +/- 0.1 or 0.2 micro-henries and that is all you need.

The **coils.exe** software saves a lot of effort on the math side and was used to generate the coil table in the main text. The calculated coil (which works perfectly) is show on the cover of the manual. The huge difference in my coil and the one in the original project highlights the need to do your homework if you change the coil parameters. The software will take the effort out of the coil-cloning process.