Hybrid HF Transmitter

This single-band design mixes solid state circuitry with vacuum tube final amplifiers.

Yosef Pinhasi, 4Z1VC

The single sideband (SSB) transmitter shown on the left side of Figure 1 is a hybrid of solid state devices and two vacuum tubes in the RF power stage, designed to operate upper SSB phone in the 20 meter band. You can easily modify it to work in another band and to add lower SSB. I kept the design simple and compact by using integrated devices and direct coupling. Each printed circuit board has its own power supply and voltage regulation circuitry. For electromagnetic compatibility, I separated the RF power stages from the VFO and receiving sections (the cabinet on the right side of Figure 1).

Figure 1 — Hybrid transmitter (left) and VFO/receiver (right). The transmitter knobs upper row (left to right) are Band Selector (optional), and Microphone Level; knobs lower row (left to right) are Load Capacitor, Plate Capacitor, Metering Selector (optional); switches (left to right) are Tone, 12 V, TR, 500 V, 250 V, Power off/on; input jacks are Auxiliary (left), and Microphone (right).

Figure 2 shows a block diagram of the entire transceiver incorporating the transmitter described here, and identifies signal connections A – D, which are referenced in the schematics. The receiver (not described in detail) is a single conversion superheterodyne design based on the SA605 mixer. This article focuses on the transmitter section. The transmitter consists of the Motorola MC1496 balanced modulator, which generates a double sideband signal at the 455 kHz IF, a band-pass SSB filter, upconversion SA602 balanced mixer, pre-driver transistors, 12BY7A driver pentode, and 6146B power beam tetrode final, producing 25 to 30 W PEP. The transmitter and receiver share a DDS VFO. *You should be very careful and take all necessary precautions due to the dangerous high voltages involved.*

Balanced Modulator

The modulator schematic diagram (Figure 3) uses a Motorola MC1496 balanced modulator IC.[1] A photo of the modulator board and additional relevant photos can be found on the *QST* in Depth web page.[2]

Audio signals from microphone, external auxiliary line or internal tone generator are combined in operational amplifier U103. The MICROPHONE signal feeds Q105, enabling use of a standard 600 Ω dynamic or an electrostatic microphone. The gain of the microphone pre-amplifier can be adjusted by R114, which sets the modulation level. Phase-shift oscillator Q106 generates a tone of approximately 1 kHz. This TONE oscillator can be switched ON (S101) for transmitter testing and tuning. Trimmer R133 sets the tone modulation level. An AUXILIARY input allows signals from an external audio device, such as a computer line-out. The impedance is 47 kΩ, similar to that of standard audio inputs. The voltage gain of U103 is four, producing 500 mV peak to the signal input of balanced modulator U102.

Modulator U102 generates a DSB suppressed-carrier signal centered on 452 kHz (3 kHz below the mid frequency of the SSB filter). Since this is the lower edge of the piezoelectric ceramic band-pass filter Y102 (mounted on a small PC board on the modulator board), the lower sideband is removed, resulting in the upper sideband at A.

BFXO Q101 produces the 452 kHz subcarrier. I used a common 455 kHz ceramic resonator and warped its frequency with capacitor pair C101 and C102. Find the appropriate value of C102 that lets C101 adjust the oscillation frequency to 452 kHz. Two stage amplifier Q102 and Q103 buffers the BFXO output and delivers a 100 mV peak 452 kHz IF sine wave to the balanced modulator. The BFXO buffer and balanced modulator U102 are switched on only during transmission when 12 V dc from the power amplifier TR circuitry appears at point C, the base of Q104. This mutes the RF signals during reception. Adjust trimmer R128 for best carrier null at the output. The peak voltage of the SSB signal at the filter output A is 500 mV.

[1]Notes appear on page 39.

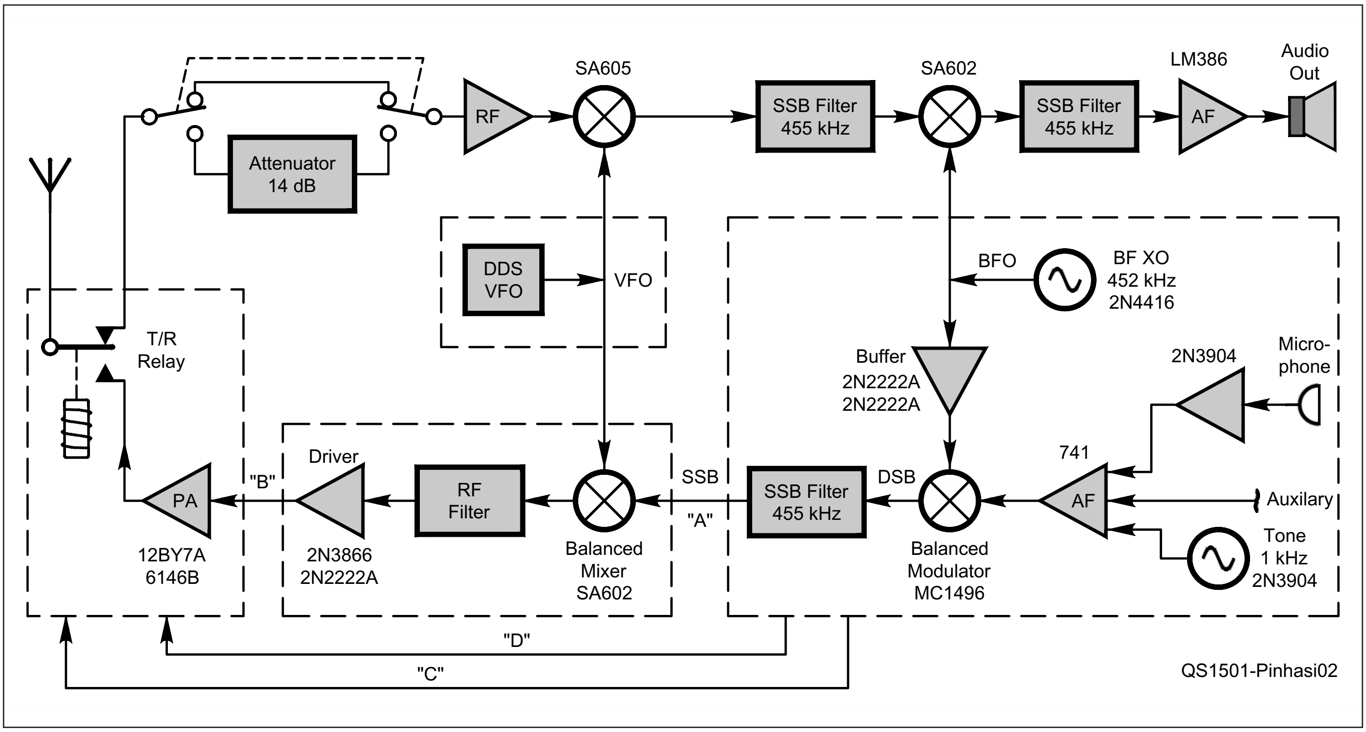


Figure 2 — Block diagram of the transceiver showing circuit block connections. The transmitter includes (lower right to left) the audio section; the BFO, buffer amps, and balanced modulator; SSB filter; DDS VFO, balanced mixer with RF filter and driver; and the tube RF power amplifier with TR switch.

Upconversion Mixer

U202 (Figure 4) supplies 6 V to the upconversion double-balanced mixer U201.[3] The SSB, suppressed-carrier signal A from Y102 feeds Pin 1 of U201 via C202 and R202. U201 has an internal local oscillator, but my attempts to build a VFO around it led to frequency instabilities and drift.[4] Instead, I used the DDS-2 kit from D. C. Pongrance, N3ZI, as the transceiver VFO.[5] After amplification, it produces a 1 V P-P pure sine wave at the difference between the radio frequency and the 452 kHz intermediate frequency. The DDS signal feeds Pin 6 of the upconversion mixer U201 via C201 and R201. Adjust trimmer R204 for best carrier null at output B. The band-pass network following the mixer output is centered at 14.128 MHz.

Power Amplifier

The RF power amplifier stage shown in Figure 5 is based on pentode driver V301 followed by beam power tetrode V302. Here, the plate voltage is set to 250 V and the screen voltage is regulated to 150 V by 5 W Zener diode D306, resulting in a total cathode current of about 30 mA.

The 30 – 40 V peak RF signal from driver V301 feeds the grid of V302 through a parallel resonant network tuned to the center of the band. The high Q of the circuit helps remove the image products from the upconversion mixer, and suppresses parasitic oscillations that may result from instabilities. Neutralization was not necessary in this design. The resonant frequency of the parallel LC circuit (C310 and L303) is set to the center of the 20 meter amateur band. Set the GRID trimmer capacitor C310 for maximum amplitude of the driving signal when the V302 is installed, but the transmit switch is OFF.

V302 operates as a class AB_1 linear power amplifier. The dc plate voltage can be set either to 250 V for low level 2 – 5 W output or to 500 V for 30 W PEP. The screen voltage is 200 V regulated by 5 W Zener diode D307. The grid bias is fixed to –48 V, resulting in about 20 – 30 mA cathode quiescent current. The output Pi network converts the 50 Ω load to the impedance required by V302. For the 20 meter band, tank inductor L305 is seven turns of #16 AWG enameled wire on a 3.6 cm diameter plastic cylinder. It can be seen up against the front panel in Figure 6. High voltage is supplied to the anode of V302 through RF choke L302, which must handle at least 250 mA. The parasitic suppressor L306 is wound on 1 W resistor R307.

V302 cathode current is measured by a 1 mA dc milliammeter connected in parallel with R309 cathode resistor via R310, producing a maximum scale reading of 200 mA.

I placed my transmitter chassis in a ventilated cabinet made of a transparent thermoplastic. [You may wish to use a ventilated metal enclosure to minimize RF leakage and to reduce exposure to RF. — *Ed.*]

TR Relay

Transmit/receive relay K301 is controlled by voltage signal D from the modulator board (the upper board seen in Figure 6). During transmission, signal D from Q104 to opto-coupler Q301 activates relay K301, connecting the antenna to the output of the power amplifier and shorting the receiver connection to ground. Opto-coupler Q302 drives an open collector transistor Q303 to produce a TR indicator for the receiver (or for an external high power linear amplifier). The TR circuit is mounted on the mixer PC board (lower board seen in Figure 6) and uses the same 12 V regulator U203.

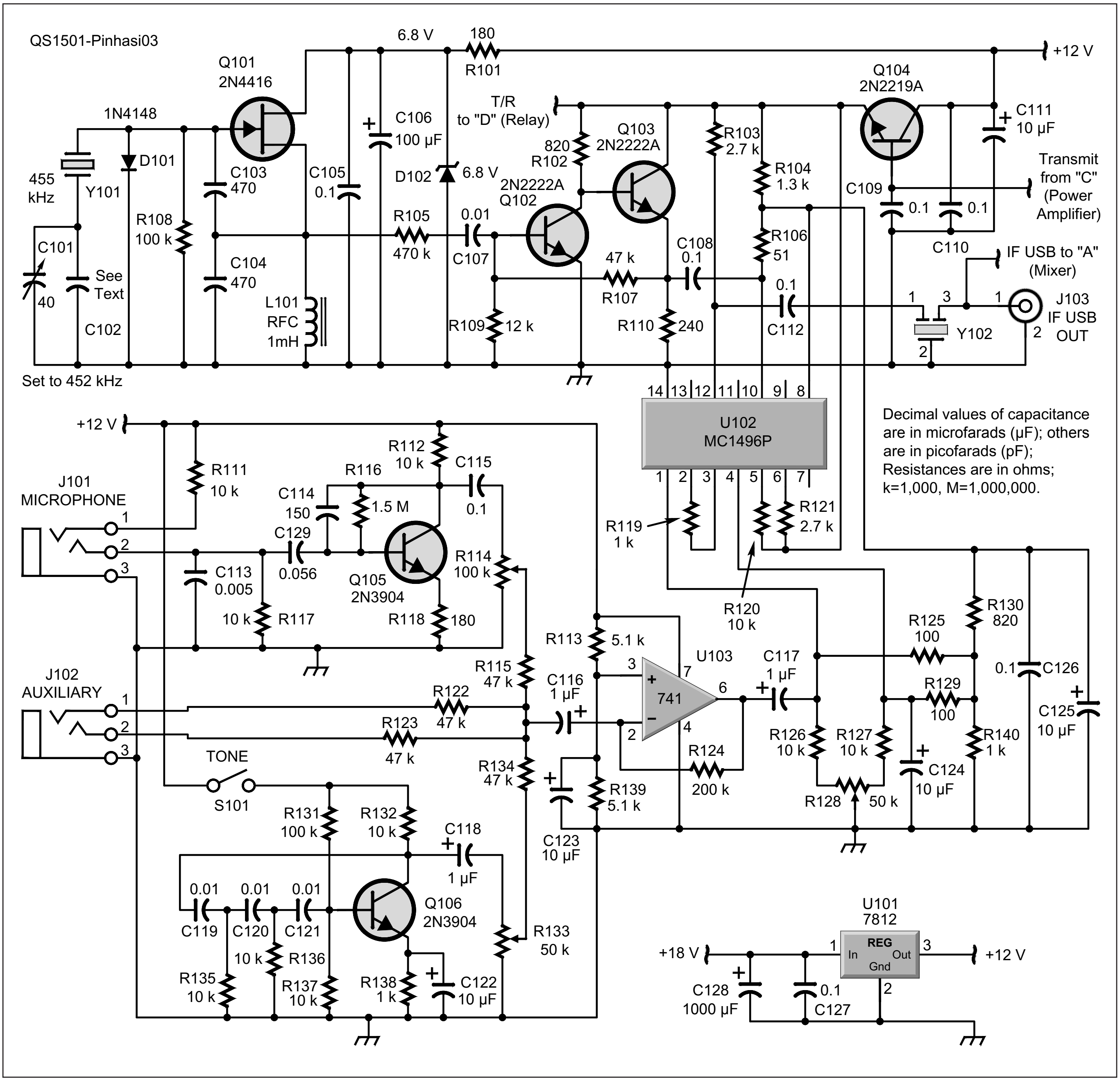


Figure 3 — Audio input, beat frequency oscillator, balanced modulator, and SSB filter schematic.

C101 — 40 pF variable capacitor
C102 — (see the "Balanced Modulator" section of the text)
C103, C104 — 470 pF capacitor
C105, C108 – C110, C112, C115, C126, C127 — 0.1 µF capacitor
C106 — 100 µF capacitor
C107, C113, C119, C120, C121 — 10 nF capacitor
C114 — 150 pF capacitor
C116, C117, C118 — 1 µF capacitor
C122 – C125 — 10 µF capacitor
C128 — 1000 µF capacitor
C129 — 56 µF capacitor
D101 — diode, 1N4148
D102 — Zener diode, 6.8 V
J101 — microphone jack
J102 — auxiliary jack
J103 — RCA jack
L101 — 1 mH RF choke
Q101 — 2N4416 transistor
Q102, Q103 — 2N2222A transistor
Q104 — 2N2219A transistor
Q105, Q106 — 2N3904 transistor
R101, R118 — 180 Ω resistor
R102, R130 — 820 Ω resistor
R103, R121 — 2.7 kΩ resistor
R104 — 1.3 kΩ resistor
R105 — 470 kΩ resistor
R106 — 51 Ω resistor
R107, R115, R122, R123, R134 — 47 kΩ resistor
R108, R131 — 100 kΩ resistor
R109 — 12 kΩ resistor
R110 — 240 Ω resistor
R111, R112, R117, R120, R126, R127, R132, R135 – R137 — 10 kΩ resistor
R113, R139 — 5.1 kΩ resistor
R114 — 100 kΩ potentiometer
R116 — 1.5 MΩ resistor
R119, R138, R140 — 1 kΩ resistor
R124 — 200 kΩ resistor
R125, R129 — 100 Ω resistor
R128, R133 — 50 kΩ potentiometer
S101 — SPST switch
U101 — regulator, 12 V, 7812
U102 — balanced modulator, MC1496P
U103 — op amp, 741
Y101 — 455 kHz resonator
Y102 — SSB filter, ceramic 455 kHz, Murata CFWLA455KJFA-B0 (**www.murata.com/products/comm_filter/pickup/index.html#if**)

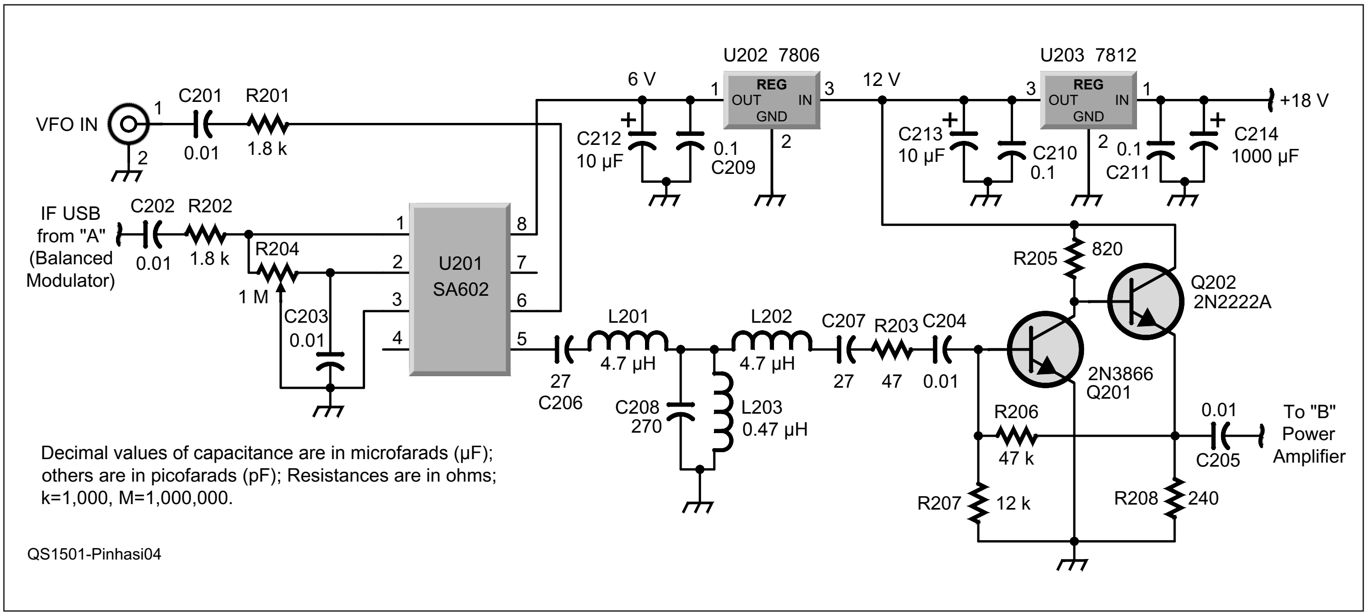


Figure 4 — Upconversion balanced mixer, RF filter, and driver amplifier.

C201 – C205 — 10 nF capacitor
C206, C207 — 27 pF capacitor
C208 — 270 pF capacitor
C209 – C211 — 0.1 µF capacitor
C212, C213 — 10 µF capacitor
C214 — 1000 µF capacitor
L201, L202 — 4.7 µH inductor
L203 — 0.47 µH inductor
Q201 — 2N3866 transistor
Q202 — 2N2222A transistor
R201, R202 — 1.8 kΩ resistor
R203 — 47 Ω resistor
R204 — 1 MΩ potentiometer
R205 — 820 Ω resistor
R206 — 47 kΩ resistor
R207 — 12 kΩ
R208 — 240 Ω resistor
U201 — balanced mixer, SA602
U202 — voltage regulator, 6 V, 7806
U203 — voltage regulator, 12 V, 7812

Power Supply

Figure 7 shows a schematic of my power supply, which is based on a 220 V ac power source. The 250 V and 500 V dc are supplied by a 360 V ac center-tapped 400 mA transformer (on the lower left in Figure 6) via a full wave rectifier D401A-D and filter. Bleeder resistors R401 and R402 discharge capacitors C401 – C404 after the power supply is turned off. It takes approximately one minute until the capacitor voltages decrease to safe values. *Be very careful not to touch hazardous high-voltage terminals during operation.*

A voltage multiplier connected to the 6.3 V ac generates an unregulated 18 V dc for the solid state circuitry. Regulator U401 supplies 5 V to the transmitter cooling fan (visible in Figure 1). The fixed negative bias voltage for V302 tube is obtained by using a small reverse-connected low current 220 V to 12 V transformer. Its 12 V secondary is connected to the 6.3 V ac, attaining above 100 V at the primary. Half-wave rectifier D404 and 47 V Zener diode D406 in series with LED D405 produce –48 V dc. Initially, set the slider of trimmer R403 to ground potential.

Operation

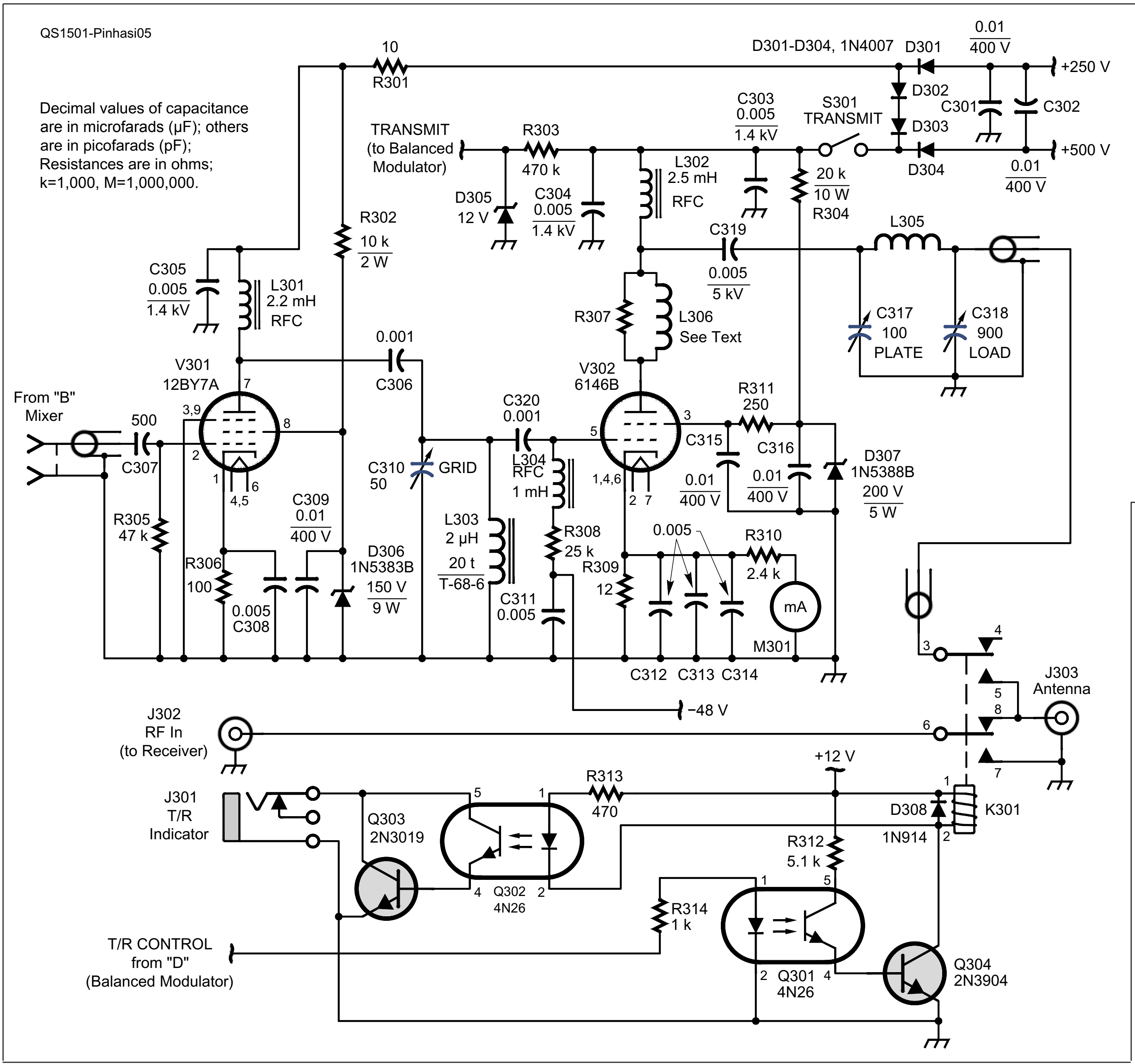
Turn all the switches OFF. Connect the DDS-VFO and attach a power meter and a dummy load rated for at least 50 W to antenna connector J303 of the transmitter. Turn ON the power mains switches of the transmitter. Allow at least a minute for the tube filaments to warm up. Carefully change the position of bias trimmer R403, raising the voltage until LED D405 lights up. Do not increase the voltage any further. D405 and Zener diode D406 ensure that the voltage is fixed to –48 V and the LED light indicates that the tube is biased properly. Using a voltmeter, verify that the bias of the final power tube grid is stable at the required –48 V.

Supply 250 V (S403) to the driver and 12 V (S404) to the mixer. Tune the VFO to the middle of the 20 meter phone portion of the band (14.230 MHz) and switch ON (S101) the tone oscillator. Rotate the PLATE capacitor to the middle and the LOAD capacitor to the maximum capacitance. Switch ON the transmission (S301) and trim GRID capacitor C310 to obtain the maximum reading on the power meter. Tune the PLATE capacitor to obtain a dip in the cathode current. Then change the LOAD capacitor to bring the cathode current to a maximum. Readjust C310 to maximum power. In this setting, the output power will be approximately 5 W.

Now turn on the 500 V switch (S402). Slightly readjust the GRID, PLATE and LOAD capacitors to obtain maximum output power. The expected RF output power will be 25 – 30 W PEP, resulting in a 100 – 120 mA cathode current in V302. You do not need to trim C310 anymore, just the PLATE and LOAD. Turn OFF the tone and connect a microphone. During transmission, adjust the modulation level for a maximum PEP at the output without signal clipping.

Notes

[1] R. Motorola Semiconductors, Hejhall: "MC1496 Balanced Modulator," Application Note AN531/D, Jan 2002.
[2] **www.arrl.org/qst-in-depth**
[3] Philips Semiconductors, "High sensitivity applications of low-power RF/IF integrated circuits," Application Note AN1993, Aug 2007.
[4] Philips Semiconductors, "Reviewing key areas when designing with the SA605," Application Note AN1994, Nov 2007.
[5] D. C. Pongrance: "N3ZI DDS 2," **www.pongrance.com/super-dds.html**.



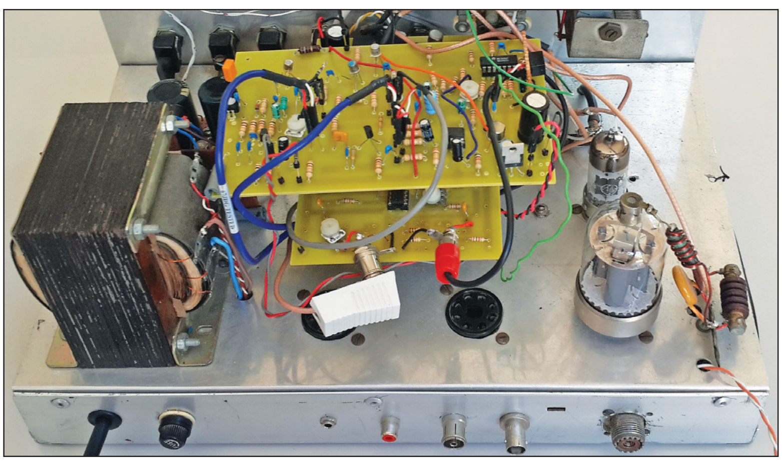


Figure 6 — Transmitter interior and rear view. The rear connections are (right to left): SO239/ antenna, BNC to receiver, VFO input, IF upper SSB, TR to receiver.

Figure 5 — The transmitter power amplifier and TR switch schematic.

C301, C302, C309, C315, C316 — 10 nF 400 V capacitor
C303 – C305, C308, C311 – C314 — 5 nF 1.4 kV capacitor
C306, C320 — 1 nF 1.4 kV capacitor
C307 — 500 pF 500 V capacitor
C310 — 50 pF variable capacitor
C317 — 100 pF variable capacitor
C318 — 900 pF variable capacitor
C319 — 5 nF 5 kV capacitor
D301 – D304 — 1N4007 diode
D305 — 12 V Zener diode
D306 — 150 V 5 W Zener diode, 1N5383B
D307 — 200 V 5 W Zener diode, 1N5388B
D308 — diode, 1N914
J301 — phone jack
J302 — BNC female connector
J303 — SO239 female connector
K301 — DPDT relay
L301 — 2.2 mH RF choke
L302 — 2.5 mH RF choke
L303 — 2 µH coil, 20 turns #24 AWG on T-68-6 core
L304 — 1 mH RF choke
L305 — 7 turns of #16 AWG enameled wire on a 3.6 cm diameter plastic cylinder
L306 — 5 turns of #18 AWG enameled wire wound on R307
M301 — meter, dc 1 mA full scale
Q301, Q302 — opto-isolator, 4N26
Q303, Q304 — transistor, 2N3019
R301 — 10 Ω resistor
R302 — 10 kΩ 2 W resistor
R303 — 470 kΩ resistor
R304 — 20 kΩ 10 W resistor
R305 — 47 kΩ resistor
R306 — 100 Ω resistor
R307 — 47 Ω 1 W resistor, use as coil form for L306
R308 — 25 kΩ resistor
R309 — 12 Ω resistor
R310 — 2.4 kΩ resistor
R311 — 250 Ω resistor
R312 — 5.1 kΩ resistor
R313 — 470 Ω resistor
R314 — 1 kΩ resistor
S301 — SPST switch
V301 — miniature pentode vacuum tube 12BY7A
V302 — power tetrode vacuum tube 6146B

Photos by the author.

ARRL member Prof Yosef Pinhasi, 4Z1VC, is the Dean of the Faculty of Engineering at the Ariel University of Samaria. He investigates utilization of electromagnetic waves in a wide range of frequencies for various applications such as communications, remote sensing, and imaging. The space-frequency approach, which he developed, is employed to study propagation of wide-band signals in absorptive and dispersive media in broadband communication links, and wireless indoor and outdoor networks as well as in remote sensing radars operating in the millimeter and Tera-Hertz regimes. He is a member of the Israel Amateur Radio Club (IARC) and can be reached at the Faculty of Engineering, Ariel University, P.O. Box 3, Ariel 40700, Israel, or **yosip@ariel.ac.il**.

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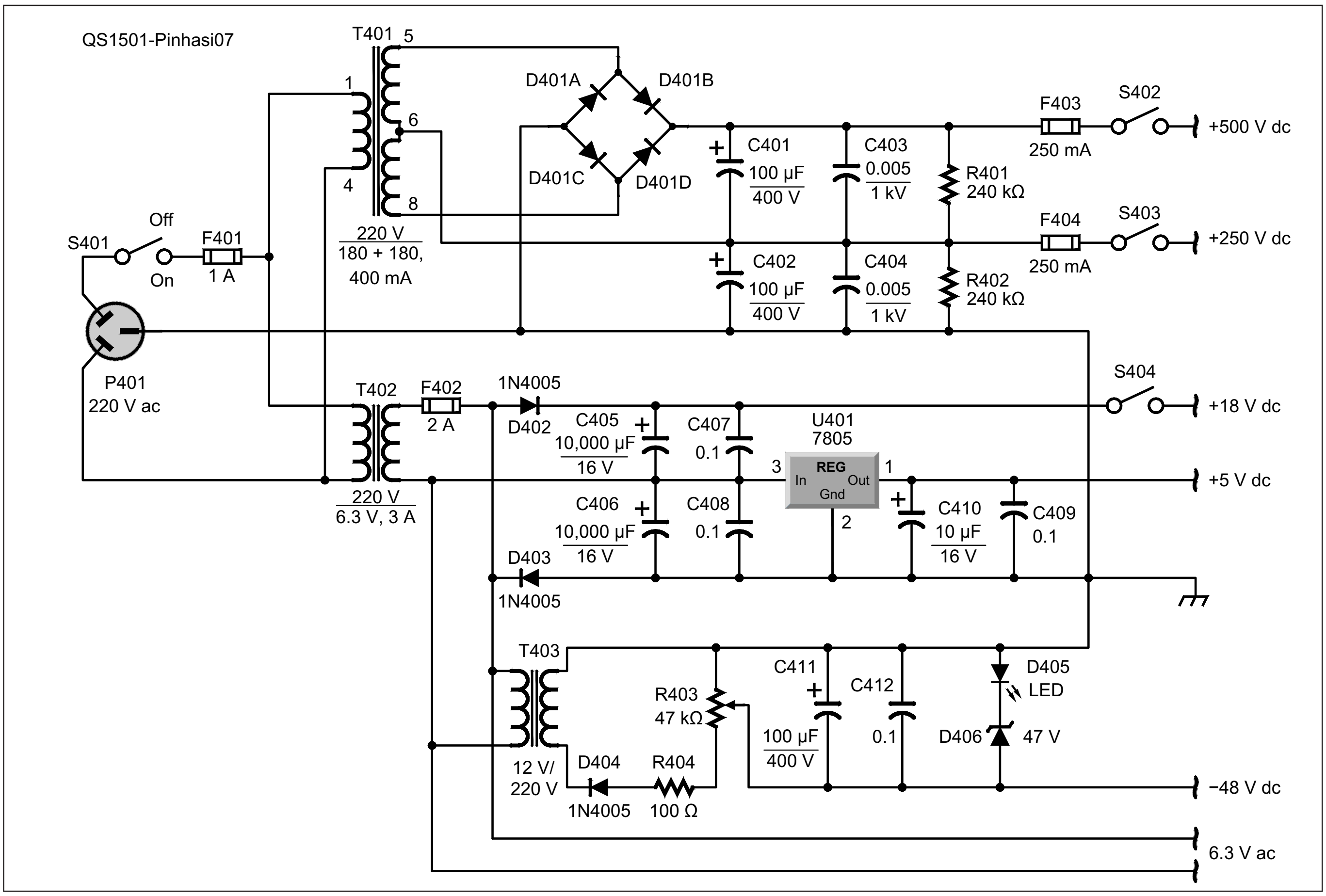

Figure 7 — The power supply.

C401, C402, C411 — 100 µF, 400 V capacitor
C403, C404 — 5 nF, 1 kV capacitor
C405, C406 — 10,000 µF, 16 V capacitor
C407 – C409, C412 — 0.1 µF 100 V capacitor
C410 — 10 µF, 16 V capacitor
D401A-D401D — full wave diode bridge, or four 1N4007 diodes
D402-D404 — diode, 1N4005
D405 — LED
D406 — Zener diode, 47 V
F401 — fuse, 1 A
F402 — fuse, 2 A
F403, F404 — fuse, 250 mA
P401 — male plug, 220 V ac
R401, R402 — 240 kΩ resistor
R403 — 47 kΩ potentiometer
R404 — 100 Ω resistor
S401 – S404 — switch, SPST
T401 — transformer, pri. 220 V ac, sec. 360 V ac center tapped
T402 — filament transformer, pri. 220 V ac, sec. 6.3 V ac, 3 A
T403 — transformer, pri. 12 V ac, sec. 220 V ac
U401 — voltage regulator, 5 V, 7805.