QEX

A Forum for
Communications Experimenters

January/February 2026
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Beacon assembly for the 241 – 250 GHz Transverter.

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About the Cover

Andrew Anderson, WQ1S, builds a 1 mm band transverter based on the TRA_240_091 prototype chip from Indie Semiconductor in "The Top Band (1 mm) Is Within Reach: 241 – 250 GHz Transverter."

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1) provide a medium for the exchange of ideas and information among Amateur Radio experimenters,

2) document advanced technical work in the Amateur Radio field, and

3) support efforts to advance the state of the Amateur Radio art.

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Ron Diehl, NQ8W

Perspectives

Happy New Year! I always enjoy the clean slate that comes with turning the calendar page. It's a natural time to reset, make new goals, and plan the next round of experiments. The good news for us is that amateur radio never runs out of new directions to explore — from antennas and DSP to propagation studies and, increasingly, artificial intelligence.

AI is finding its way into nearly every corner of our lives, and amateur radio is no exception. In this issue, we look at a practical and very "shack-friendly" application: an AI-based voice synthesizer system that can augment our operating procedures. By combining modern text-to-speech engines with familiar station control software, this project shows how AI can become another tool on the bench, helping with everything from routine messages to more accessible operating for those who need it.

At the opposite end of the spectrum — literally — we also visit the extreme top of our operating privileges. You'll find an article describing the construction of a 241 – 250 GHz transverter that opens the door to experimentation on the 1 mm band. Working at these frequencies demands careful RF design, creative mechanical solutions, and a willingness to push beyond the comfort zone of "conventional" microwave work.

Pushing even further, another article in this issue explores how to achieve higher data rates in the so-called THz gap. Earlier demonstrations using black-body radiator techniques proved that communication is possible there, but often at very low symbol rates. Our author demonstrates how careful system design and modulation choices can move those experiments from proof-of-concept into more practical territory.

None of this innovative work would be possible without the foundations laid over radio's 129-year history. That is why we also revisit some core concepts and instructional themes that underlie everything we do, from basic circuit analysis and electromagnetics to measurement technique and good documentation. Mastering these fundamentals is what allows today's experimenters to build AI-driven station tools, millimeter-wave transverters, and THz data links with confidence.

As you sketch out your goals for the coming year, I hope this issue nudges you to pair solid fundamentals with a willingness to experiment at the edges — whether that edge is in software, spectrum, or both. Here's to a year of learning, building, and sharing what you discover.

Writing for *QEX*

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The Top Band (1 mm) Is Within Reach: 241 – 250 GHz Transverter

A 241 – 250 GHz transverter built around Indie's TRA_240_091 RFIC eliminates high-order multipliers, uses a 2 meter IF and PLL lock, and enables full-duplex FM and CW operation.

Introduction

In this article I describe a new approach to getting on the top amateur radio band at 241 – 250 GHz without the use of high order external multiplier chains and passive mixers. The approach is based on a newly released chip, the TRA_240_091 from Indie Semiconductor (formerly Silicon Radar). The chip covers the entire amateur primary and secondary allocations in the 1 mm band from 241 – 250 GHz. The chip will cover 222.5 – 267.5 GHz. The chips are very new and considered research and development prototypes, so they are expensive, at $600 each at the time of writing. Data on the chip can be found on the web at **https://downloads.ffo.indiesemi.com/datasheets/Datasheet_TRA_240_091_V0.1.pdf**.

The TRA_240_091 has everything we need plus some more bells and whistles to make a 1 mm band transverter using a 2 meter (144 – 148 MHz) intermediate frequency (IF) on RX. On the TX side, the chip supports CW and FM operation directly. The TRA_240_091 has a low-noise amplifier (LNA) in the RX chain as well as an active mixer. This improves the RX noise floor significantly over passive diode mixers. The receiver local oscillator (RX LO) of the chip has an integrated voltage-controlled oscillator (VCO) which runs at frequency output (Fo) divided by 18 (13.38 – 13.88 GHz). This internal VCO can be locked directly using an external phase-locked loop (PLL). As a new feature, an external signal source can be injected in place of the internal VCO to potentially give improved phase noise and stability. In this approach, we use the internal VCO to keep things simple. The TRA_240_091 also has a direct monitor out-

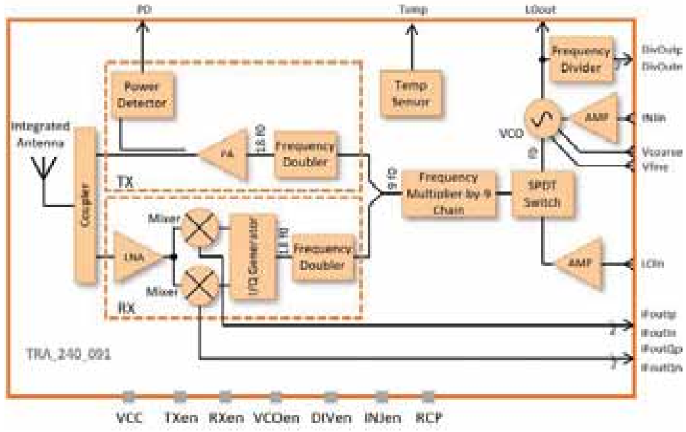


Figure 1 — The TRA_240_091 block diagram.

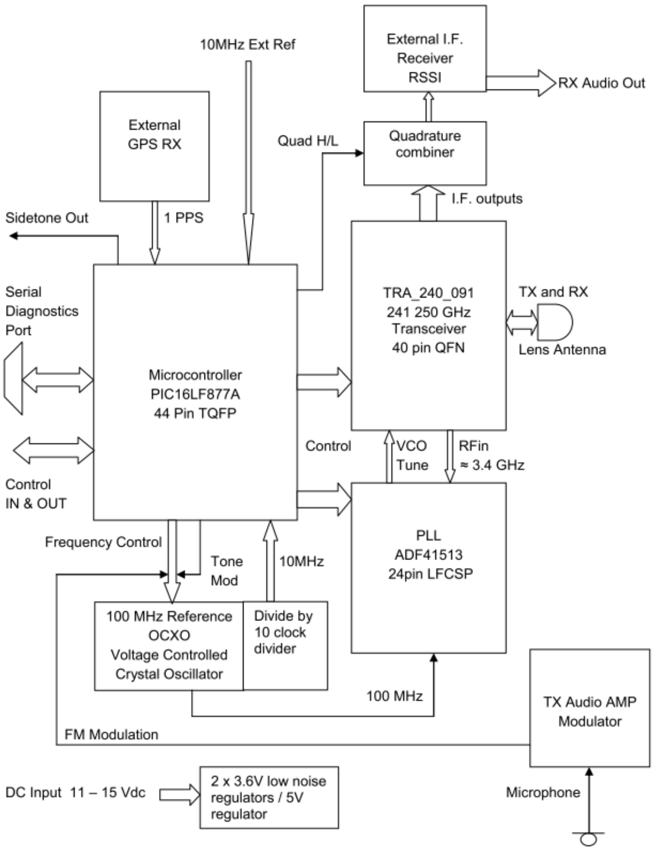


Figure 2 — The system block diagram.

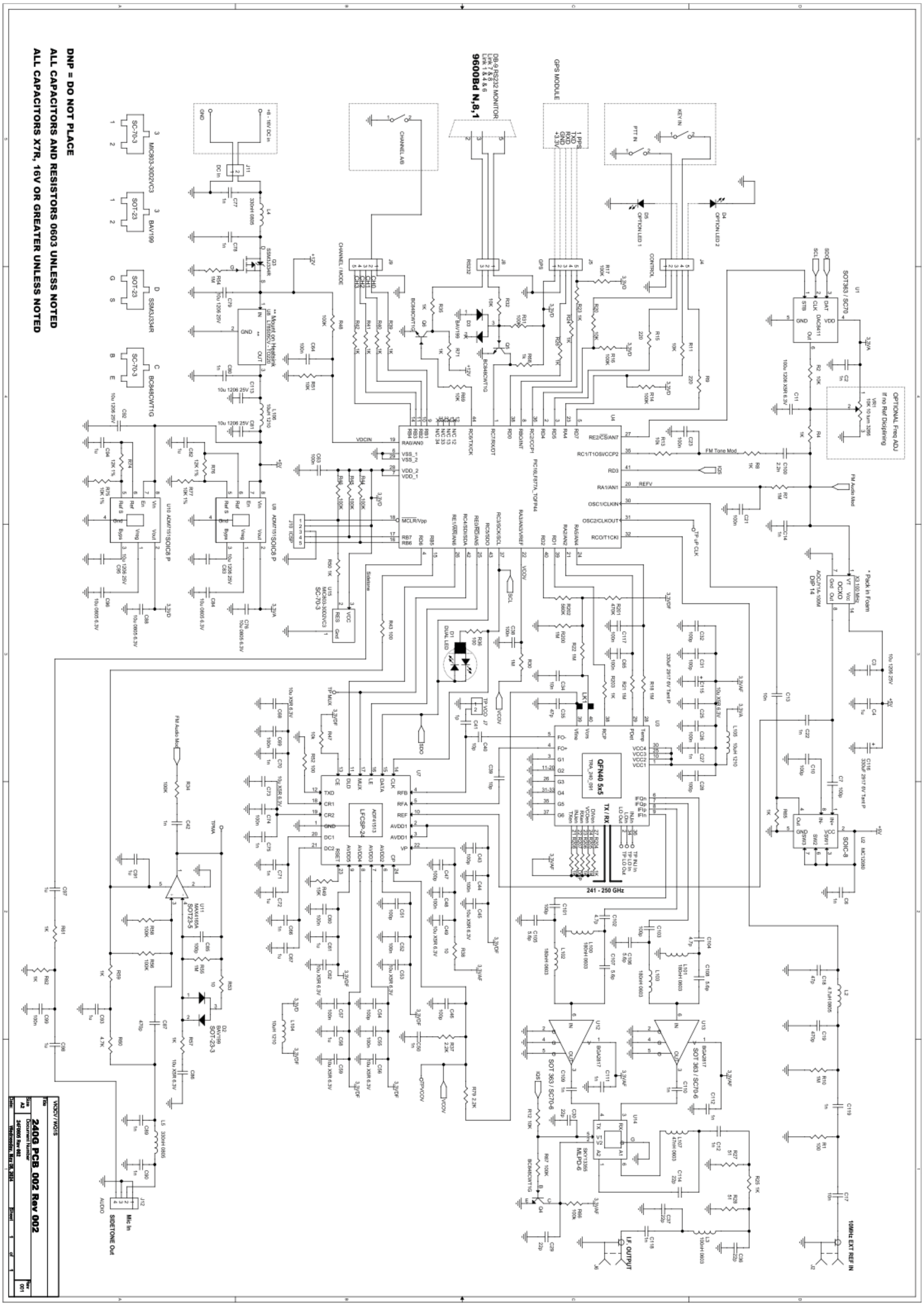
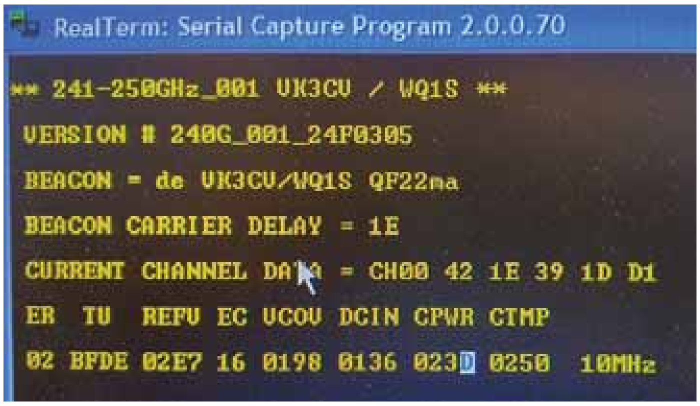


Figure 3 — The circuit schematic.



```
RealTerm: Serial Capture Program 2.0.0.70
** 241-250GHz_001 UK3CU / WQ1S **
 VERSION # 240G_001_24F0305
 BEACON = de UK3CU/WQ1S QF22ma
 BEACON CARRIER DELAY = 1E
 CURRENT CHANNEL DATA = CH00 42 1E 39 1D D1
 ER  TU  REFU EC UCOU DCIN CPWR CTMP
 02 BFDE 02E7 16 0198 0136 0230 0250  10MHz
```

Figure 4 — The serial diagnostic display.

put of the VCO at Fo/18 as well as a further divided output at Fo/72 to allow easy interface to a PLL between 3.34 – 3.47 GHz. We use the Fo/72 divider output to enable common low-cost PCB substrates to be used, thus avoiding signals above 10 GHz being necessary on the main PCB.

Some other new features of the TRA_240_091 are two additional analog outputs that allow us to measure the chip temperature and the RF power out of the TX.

The chip also has a built-in RF coupler (diplexer) for the TX and RX subsystems and thus uses a common antenna for both, avoiding physical alignment errors when using a high-gain external antenna. Simultaneous TX and RX operations allow for a full duplex FM voice mode. The increased versatility of the new chip means more pins are needed and the chip now has 40. This is packed into a 5 × 5 mm package which is challenging to mount using amateur resources. This chip is like others used previously in having two balanced I and Q RX mixer outputs which allow for the use of a quadrature combiner to further improve the RX performance. A block diagram of the TRA_240_091 is shown in **Figure 1**.

Design

The 1 mm band transverter hardware design is based on similar designs described previously on the 122 and 134 GHz bands. A block diagram of the system is shown in **Figure 2**.

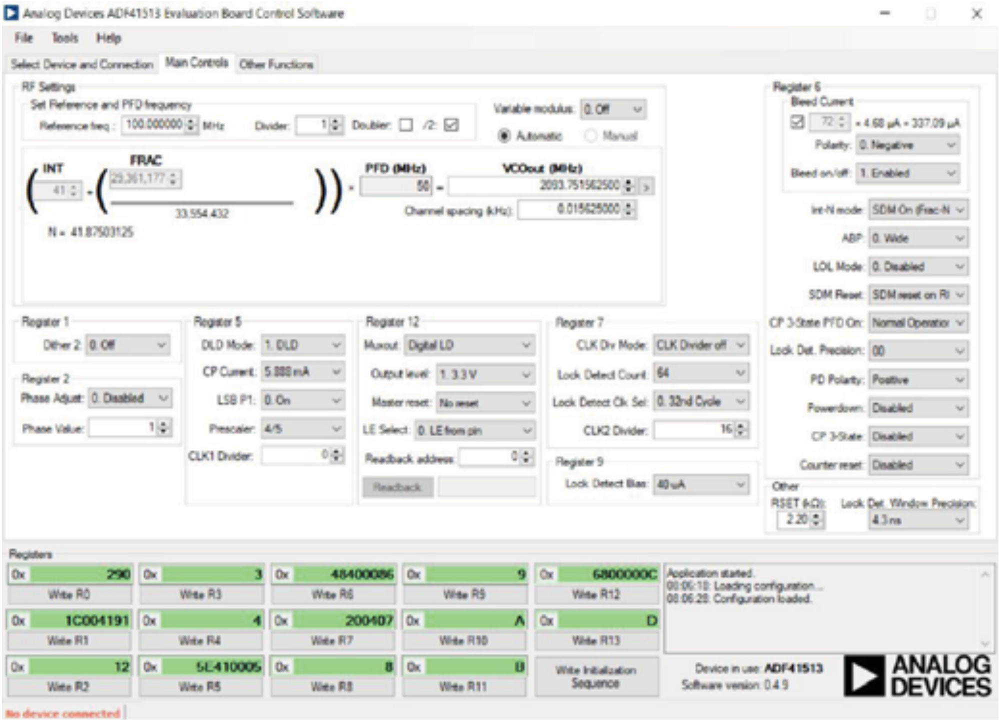
A notable difference from previously published designs is the fact that the new 241 – 250 GHz chip has a common antenna used for both TX and RX. This eliminates the need for an external coupler and is now included within the TRA_240_091 chip. This has the added advantage of eliminating pointing errors between TX and RX antenna patterns when used with high-gain external lenses or reflector antennas.

All the schematics, images, and software are available at **www.arrl.org/QEXfiles**.

Circuit Theory of Operation

An external power supply of 12 V DC is applied through a reverse polarity protection circuit to a 5 V linear regulator which must be mounted on a heatsink, and then on to two 3.6 V low-noise regulators that supply all the active circuits. All functional control for the board is managed by a PIC16LF877A microcontroller. The clock for the microcontroller and reference signal for the PLL are provided by a voltage-controlled, oven-controlled, crystal oscillator (VCOCXO) running at 100 MHz. The VCOCXO is connected to the 5 V rail and draws significantly more current during warm-up. The clock for the microcontroller is supplied through a divide-by-10 chip to give a 10 MHz clock which is also powered from the 5 V rail.

The TRA_240_091 transceiver chip is controlled by the microcontroller in addition to being frequency locked by the PLL (ADF41513). The 241 GHz TX and RX circuitry is all contained within the TRA_240_091 chip. A divided-by-72 output of the internal 241 GHz voltage-controlled oscillator in the TRA_240_091 chip is fed to the PLL, which is then able to lock its internal VCO to the desired operating frequency. The VCO in the TRA_240_091 is always operating either on the TX or RX LO frequency, determined by the control data sent to the PLL chip by the microcontroller. Note that the PLL operates in the region of 3.4 GHz. A test point is available to observe this 3.4 GHz signal to allow testing of the system. Two VCO tunable inputs are available on the chip, a coarse and a fine VCO tune. The PLL phase comparator output is fed via a loop filter to the fine tune input of the TRA_240_091 which results in lower phase noise. The coarse VCO tune input is fed by a



Reference freq.: 100.000000 MHz Divider: 1 Doubler: ☐ /2: ☑
Variable modulus: 0. Off ● Automatic ○ Manual
INT 41 FRAC 29,361,177 / 33,554,432 PFD (MHz) 50 VCOout (MHz) 2093.751562500
Channel spacing (kHz): 0.015625000
N = 41.87503125

Dither 2: 0. Off
Phase Adjust: 0. Disabled
Phase Value: 1
DLD Mode: 1. DLD
CP Current: 5.888 mA
LSB P1: 0. On
Prescaler: 4/5
CLK1 Divider: 0
Muxout: Digital LD
Output level: 1. 3.3 V
Master reset: No reset
LE Select: 0. LE from pin
Readback address: 0
CLK Div Mode: CLK Divider off
Lock Detect Count: 64
Lock Detect Clk Sel: 0. 32nd Cycle
CLK2 Divider: 16
Lock Detect Bias: 40 uA
☑ 72 × 4.68 μA = 337.09 μA
Polarity: 0. Negative
Bleed on/off: 1. Enabled
Int-N mode: SDM On (Frac-N
ABP: 0. Wide
LOL Mode: 0. Disabled
SDM Reset: SDM reset on R
CP 3-State PFD On: Normal Operatior
Lock Det. Precision: 00
PD Polarity: Positive
Powerdown: Disabled
CP 3-State: Disabled
Counter reset: Disabled
RSET (kΩ): 2.20
Lock Det. Window Precision: 4.3 ns

0x 290 Write R0	0x 3 Write R3	0x 48400086 Write R6	0x 9 Write R9	0x 6800000C Write R12
0x 1C004191 Write R1	0x 4 Write R4	0x 200407 Write R7	0x A Write R10	0x D Write R13
0x 12 Write R2	0x 5E410005 Write R5	0x 8 Write R8	0x B Write R11	Write Initialization Sequence

```
Application started.
00:06:10: Loading configuration...
00:06:28: Configuration loaded.
```

Device in use: ADF41513
Software version: 0.4.9
No device connected

Figure 5 — The ADF41513 configuration.

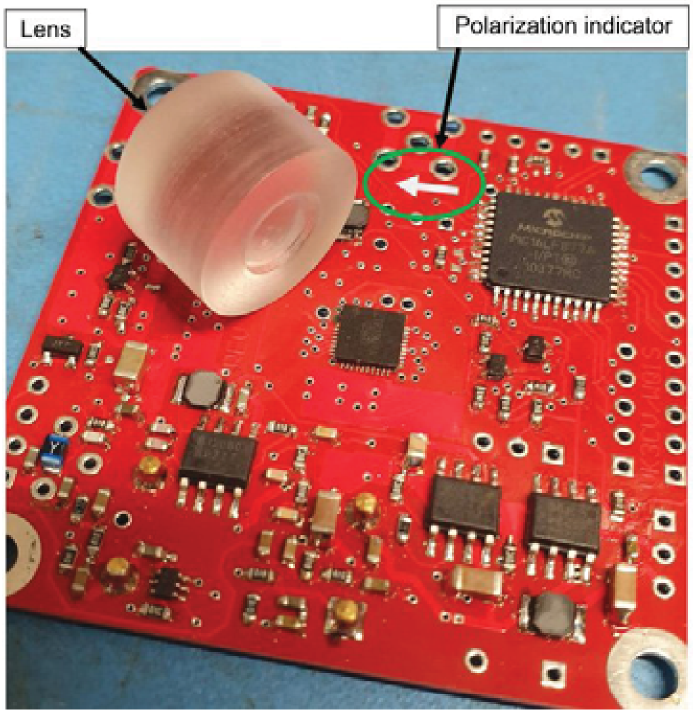


Figure 6 — The PCB and beacon lens. The lens sits on top of the RF chip (center).

well-filtered DC voltage which is sourced by a resistive divider from an output of the microcontroller. This coarse line is used as a VCO steering input allowing the RF chip to lock over the entire 241 – 250 GHz range.

The VCO tune voltage is monitored by the microcontroller as well as the PLL lock signal to ensure the PLL is correctly locked. Voice and tone modulation inputs are included in the 100 MHz VCOCXO section to allow modulation of the PLL, resulting in FM modulation of the VCO with a nominal 5 KHz of FM deviation. The voice modulation signal is supplied from a simple modulation-limiting microphone amplifier which is connected to an external electret-type microphone.

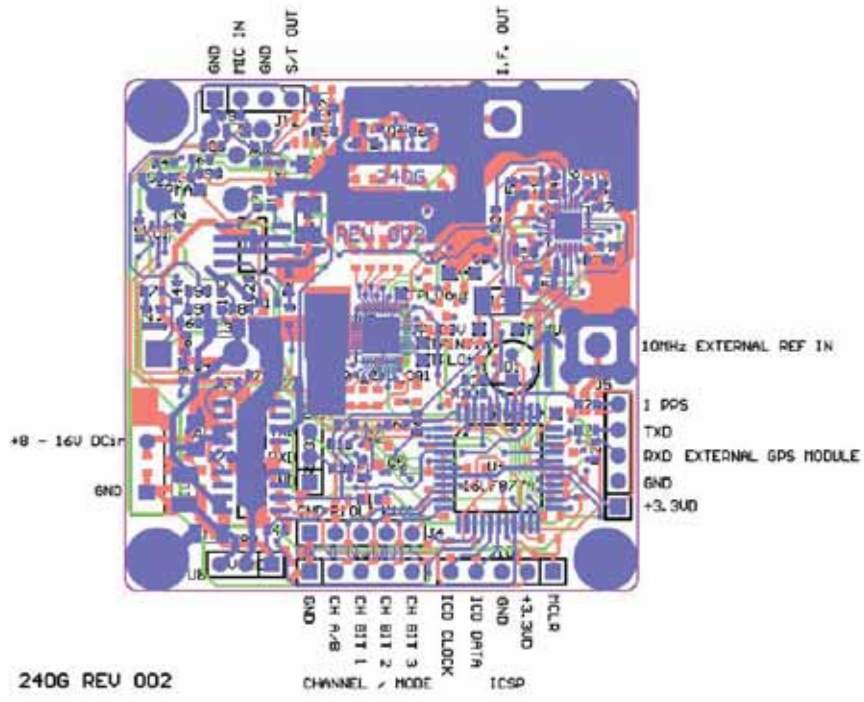


Figure 7 — The PCB design (top side view).

The VCOCXO DC tune voltage is derived from a 16-bit digital-to-analog (D/A) converter driven by the microcontroller. The microcontroller provides frequency control of the internal 100 MHz VCOCXO derived by an external GPS 1 Pulse per Second (1 PPS) signal or alternately through a 10 MHz external reference signal. Note that the 10 MHz external reference must be present at power-on to be recognized. The required level of the 10 MHz external reference is between 200 mVp-p and 3 Vp-p. A nominal level of 0 dBm (223 mV rms, ≈ 630 mVp-p) is a good choice. The input impedance is ≈ 50 Ω. Two optional LEDs, OL1 and OL2, are included to show the status of the external reference frequency tuning system. OL1 flashes at either 1 PPS showing external 1 PPS GPS pulses have been detected or flashes at around 5 PPS to show external 10 MHz frequency control has been detected. OL2 shows if the frequency steering system is locked. This typically takes around 5 minutes from a cold start.

The TX and RX signals inside the TRA_240_091 are combined in a coupler on the chip to a single bowtie dipole which sits slightly offset in the center of the chip package upper face. The advantage of this approach means no millimeter-wave RF is carried by the main PCB, which is just as well because fiberglass FR4-G10 PCB material is a very effective attenuator at 1 mm band frequencies. See the marker arrows on the PCB (**Figure 6**) for the linear E field polarization direction. Also shown in Figure 6 is a specially designed lens made from cross-linked polystyrene (Rexolite 1422) which ensures optimum radiation off the chip and provides a small amount of gain for use with the beacon system. The lens sits directly on top of the TRA_240_091 chip in the center of the PCB. A lens is not required on the dish system as the chip radiation pattern is close to optimum for the dish used with the chip bare.

Received signals from the internal chip antenna on 241 GHz are first amplified and then converted down to the IF by a mixer inside the TRA_240_091 chip.

The IF signals are available as I/Q differential signals. The I/Q signals are first converted from balanced double-ended to unbalanced single-ended using fixed-value discrete baluns. The IF is 144 – 148 MHz. The two I/Q signals are then combined in a quadrature combiner which re-enforces either the upper or lower conversion response. This I/Q manipulation improves the receive sensitivity by up to 3 dB by reducing the overall noise power by suppressing the unused conversion response. The upper or lower quadrature conversion response is selected under control of the microcontroller by an on-board RF analogue switch. Typical upper to lower quadrature rejection is around 15 dB.

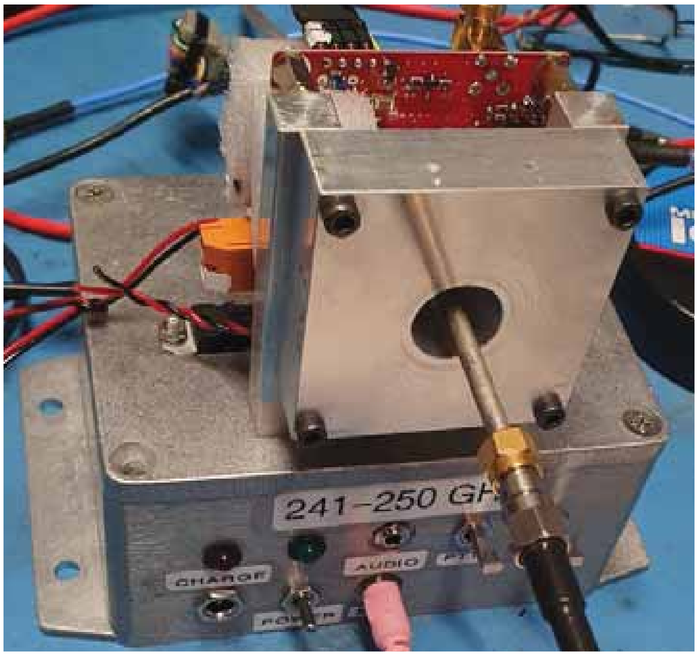


Figure 8 — Beacon system including test multiplier.

There is some degradation in the signal-to-noise performance of the system due to the inherent phase noise of the TRA_240_091 local oscillator. Using the narrowest bandwidth FM IF demodulator available will give the best results on FM. Note that as the VCO in the TRA_240_091 is always running, full duplex operation is possible in FM mode. This is done by having the local system and the remote system operating on frequencies separated by the IF.

Transmit signals on 241 GHz originate from the VCO inside the TRA_240_091. They are then fed via an internal RF TX amplifier and then on to the internal chip antenna.

Note that there are three unused pins and connections to test points on the TRA_240_091. Two of these are for external oscillator injection use and the last one is a monitor of the local oscillator (LO).

They are connected on the PCB to unused test points and can be used if desired for testing or experimenting using an external LO source. The three pins are INJ in, LO in, and LO out. These can be seen in Figure 6 near the center RF chip.

Software Operation

The microcontroller takes input from several sources which it then uses to control various features and functions of the system under control of the internal software. The microcontroller has control of the following: bi-color red/green status LED, option LEDs OL1 and OL2, FM modulation tone generation, external sidetone generation, GPS reference frequency steering, 10 MHz reference frequency steering, microphone amplifier enable, PLL RF frequency, serial diagnostics port, TRA_240_091 mode, external mode control inputs, and channel selection. Note that all 16 channels are pre-programmed. The channel information is contained in non-volatile EEPROM. Each channel frequency requires 5 hexadecimal bytes of data, and the most significant byte also contains a control bit which sets the required RX conversion, upper or lower side conversion, and quadrature control bit.

The system software is contained in flash memory within the microcontroller. Software programming is achieved via the provided in-circuit serial programming (ICSP) J10 port on the board. Refer to the relevant microchip data sheets for information and software programming details if changes from the standard version are required. Channel frequency programming and control of some of the operational parameters of the board are possible by serial command. The full software source code is available via **QEXfiles**.

On power up, the microcontroller configures all the required inputs and outputs and initializes the required internal registers and external peripherals. A dual-color status LED is available to give operator feedback on operation. The status LED will initially be red during power on and then change to green to show correct operation and that the PLL is locked. If the PLL is

Figure 9 — The dish system.

Figure 10 — Packing the VCOCXO in insulating foam.

not locked, the LED will remain red and flashing. The LED will also go to steady red when the system is in TX mode. A rapidly alternating red/green LED flash indicates low DC input voltage (less than approximately 10.7 V). A steady green on the LED indicates RX mode.

Depending on the selected mode of operation, the microcontroller has a built-in Morse code keyer available which can provide a continually repeating Morse code beacon message, such as the call sign of the transmitter, to aid with testing and for use as a beacon. The transmitted string can be changed either in the source code or via a serial "B" command. Note that serial commands are only accepted when the system is in RX mode.

Default strings are in the string definition section near the end of the assembly language file.

Diagnostics/Serial Communications Port

A serial port is available which outputs data to allow monitoring of the system during operation. The port is set to a 9600 baud rate, no parity, 8 data bits, and 1 stop bit, that is, 9600, N,8,1. The port outputs data for diagnostics and is used to input data for control commands. The output voltage swing is 0 V/12 V which will work with many USB serial converters.

Various commands are available to configure the board as required as well as to change the EEPROM storage locations which have channel frequency data. A PC application has been written to calculate the correct PLL data for any desired frequency and is available at **QEXfiles**. A typical data display from the serial diagnostic port is shown in **Figure 4**.

Figure 12 — The prototype test multipliers.

The second-to-last line labels and the last line shows the current status values in hexadecimal. These are as follows:

- ER = Frequency steering Error Result
- TU = Current 100 MHz VCOCXO reference TUne value
- REFV = Current 100 MHz VCOCXO REFerence tune Voltage
- EC = VCOCXO Error Count since last correction (Lock Quality indicator)
- VCOV = Current VCO tune Voltage
- DCIN = Current DC INput voltage
- CPWR = TRA_240_091 Chip tx PoWeR output
- CTMP = TRA_240_091 Chip TeMPerature

Status messages or the _> "Command" cursor appear at the end of the final line.

Serial Command Input

Commands are input using a terminal program with the same serial port settings 9600,N,8,1. Ensure the unit is in RX mode (status LED steady green) to correctly receive commands. Either upper- or lower-case characters are acceptable. To input

Figure 11 — The microwave signal source and amplifier.

Figure 13 — The final test multiplier.

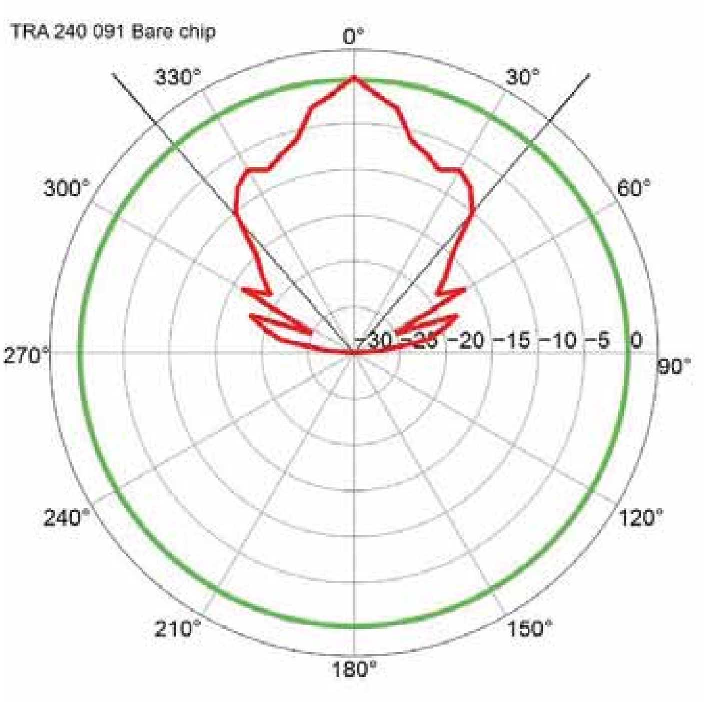


Figure 14A — The bare chip, 80 degree – 10 dB beamwidth.

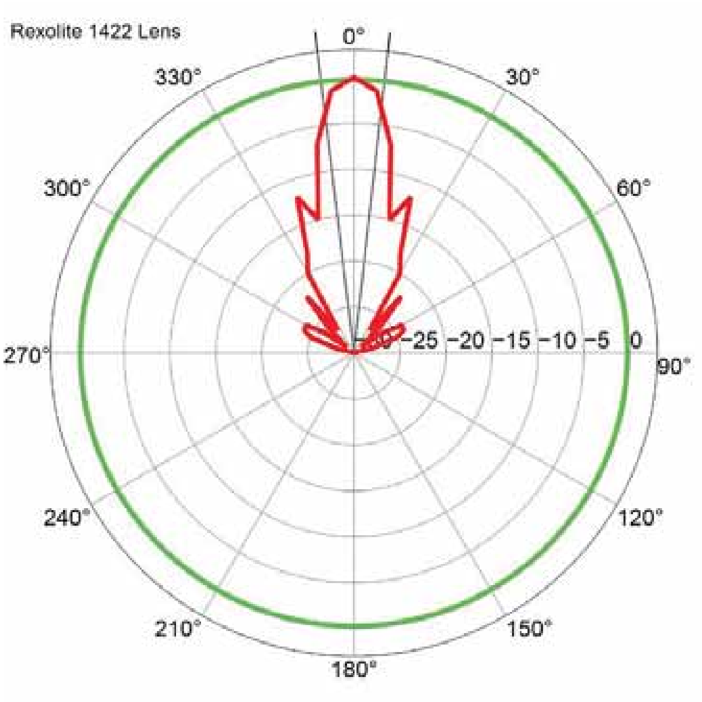


Figure 14B — The chip with Rexolite 1422 lens,10 degree – 3 dB beamwidth.

a command, simply start typing and a command prompt will appear.

Note that backspaces or deletes cannot be used to fix input errors. Use the Esc key and repeat the command.

Serial Command B = Beacon String

```
Syntax Bxxxxxxxxxxxxxxxxxxxxxxxx<Enter>
B = character to start command
xxxxxxxxxxxxxxxxxxxxxxxx = up to 24-character
Beacon String, (letters, numbers, space, and /
only)
<Enter> = Enter Key = Execute command
Example: COMMAND ? >_ Bde VK3CV TEST<Enter>
```

The B command sets the beacon Morse code string value. Note that it can be up to 24 characters long and can include letters, numbers, space, and forward slash (/) only. The letters can be either upper- or lower-case. It is stored in EEPROM and is non-volatile. Up to 24 characters are allowed to include, for example, a call sign and an extended Maidenhead locator.

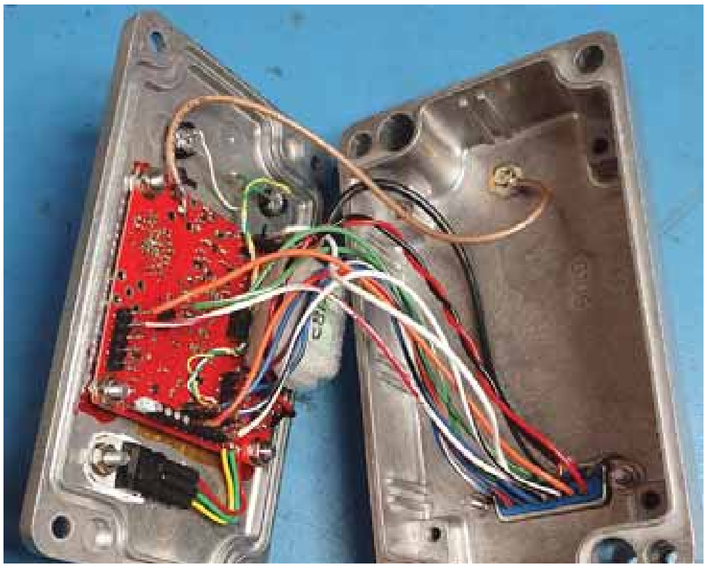


Figure 15 — Dish system circuit board mount.

Serial Command C = Beacon Carrier Delay

```
Syntax Cxx<Enter>
C = character to start command
xx = Two new hexadecimal Beacon Carrier Delay
values in seconds (0-9, A-F only)
<Enter> = Enter Key = Execute command
Example: COMMAND ? >_ C1E<Enter>
```

The C command is used to input the carrier delay time in seconds. This is the time in seconds that the carrier will run between idents when in beacon mode. Its value is in hexadecimal, and it has a range from 00 – FF (0 – 255 decimal). The value is stored in non-volatile EEPROM.

*Serial Command E = Enter Channel EEPROM Frequency Data (**Use with Caution**)*

```
Syntax Exxcccccccccc<Enter> (E+12 bytes of data
are required)
E = character to start command
xx = channel number 00 – 0F
cccccccccc = 10 characters of hexadecimal chan-
nel frequency data (0-9, A-F only, no spaces)
<Enter> = Enter Key = Execute command
Example: COMMAND ? >_ E00421E391DD1<Enter>
```

The actual data required for the E command must be calculated by the user. There is a PC application available to do this in the archive called **240G_Freq_001.exe**. This application will take the desired user frequency and calculate the closest match to the required frequency. Note that the minimum step size of channels is 1 kHz, due to limitations of the PLL chip. All channels are available for user programming. The first two charac-

Figure 16 — The control box assembly.

ters of the E command contain the required channel number (00 – 0F). All the frequency data bytes are stored in non-volatile EEPROM. The first byte of the channel data also contains a control bit for the quadrature setting. This bit is automatically calculated by the PC application.

Channel Data Band Bit and Quadrature Control Bit

The first binary bit of the first frequency data byte contains the state of the quadrature side.

First byte, Bit7 = Quadrature side, 0 = Lower side conversion, 1 = Upper side conversion.

Serial Command DC = Default All EEPROM Channel Frequencies to Factory Defaults

```
Syntax DC<Enter>
```

Figure 17 — The beacon assembly.

This command will set all RF channel frequencies to the factory default values.

*Serial Command T = Tune Reference Control Voltage Value (**Use with Caution**)*

```
Syntax Txxxx<Enter>
T=character to start command
xxxx = new hexadecimal ref tune value (0-9, A-F
only). Valid range from 0000 to FFFF
<Enter> = Enter Key = Execute command
Example: COMMAND ? >_TC000<Enter>
```

The T command is used to input a new value into the reference tune register. This will change the frequency of the 100 MHz reference oscillator. It should only be used during initial set-up of the PCB in conjunction with test equipment to adjust the 100 MHz reference oscillator to exactly 100 MHz. If this command is used accidentally, then use the following default command: TC000<Enter>. Don't confuse numerical zero "0" with the letter "O" in this command, use zeros ("0") only. This command will reset the unit to the factory default value of C000h. The value is stored in EEPROM and is nonvolatile. This value can also change automatically via the GPS 1PPS or 10 MHz external frequency reference steering system.

Serial Command Accepted

The <Enter> key will cause the command input to be processed. If the command is correct, a "COMMAND OK" prompt will be displayed, then the system will reboot to update the internal parameters. Commands that exceed 24 characters will be truncated to 24 characters and an <Enter> will automatically be appended to execute the command.

Serial Command Abort (Esc)

Commands can be aborted by hitting the "Esc" key at any time during the command. The command will be ignored, and another can then be started. This is useful if an error is made during input.

Note that backspaces or deletes cannot be used to fix errors in input commands. Use the "Esc" key and repeat the command from the start.

Serial Command Time Out

Each command character must be input within approximately 15 seconds. If this time is exceeded the command will automatically abort and will be ignored. A "COMMAND ERROR" message will appear.

Serial Invalid Commands

Commands that start with characters other than those supported will be ignored. A "COMMAND ERROR" message will appear.

ADF41513 PLL Configuration

A PC application is available from Analog Devices to aid in the configuration of the PLL chip ADF41513 (U7). Use the Analog Devices website to obtain this application if desired.

The PLL register settings are stored in the microcontroller with fixed registers values being stored in flash memory

(Program memory) and channel-related data being stored in EEPROM. The EEPROM values are related to the ADF41513 R0 and R1 registers only. The other registers are fixed in value. Note that there are 14 registers in total available for programming in the ADF41513.

It is possible to change these settings in the microcontroller to experiment with different settings of the PLL chip if desired. Also refer to the ADF41513 data sheet available from Analog Devices. The default register settings are stored in a section labeled "SYNTHEN" in the PIC assembly language file.

A screenshot of the application is shown in **Figure 5**. The data used in the registers is highlighted in green.

Note that changing the ADF41513 data registers could have unintended results. It is suggested that changes are only attempted by those with the necessary test equipment to observe the operation of the board if changes are made.

PCB Construction

Use the Gerber format (GBR) files in **QEXfiles** to get the artwork for the PCB. Note that the design is a four-layer board with an almost continuous internal ground plane to keep all the s4-layers where they are supposed to be. Most multilayer PCB manufacturing companies will be able to take the Gerber files as they are and produce good quality boards. The bill of materials (parts list) and component placement legends (component overlays) are also available on **QEXfiles**.

Mounting the TRA_240_091 chip itself will be challenging. Good optical magnification, a steady hand, and a heat gun or reflow oven are required. There are many YouTube videos on how to do it. It is suggested to place the TRA_240 chip first. Observe basic anti-static practices, but the chip is quite robust in this respect. Once the chip is down, as a connection check, test all the chips signal pins with a multimeter on a diode check range to ground to check if there is a diode junction present on all the connected pins. (The diodes seen are the ESD protection diodes on all the pins of the chip.) Reflow again if there are any issues. Everything else can be placed and soldered manually using a small-tipped soldering iron with the assistance of optical magnification. If the part value is DNP (Do Not Place), then do not place this part. Note that the 100 MHz VCOCXO reference is mounted to the PCB using special PCB socket pins. See the parts list for details.

The PCB is a four-layer FR4 board designed using a now-obsolete PCB design package called Autotrax. An image of the PCB design is shown in **Figure 7**.

Physical Systems

There are two configurations of systems that have been built. These are a standalone beacon system as shown in **Figure 8**, and dish focal point mounted system as shown in **Figure 9**.

The VCOCXO is sensitive to external temperature changes due to stray air currents. To mitigate most of these effects, it is a good idea to enclose the VCOCXO in a foam-insulated block as shown in **Figure 10**. Polystyrene or LDPE foam is a good choice.

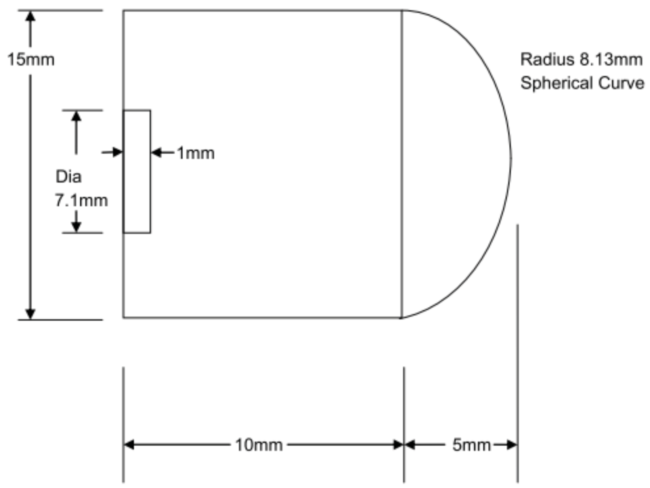


Figure 18 — Beacon lens cross-section diagram.

Testing and Optimization

The system as shown in Figure 8 has a test multiplier to allow testing of the RX system with an 18.549555 GHz signal being multiplied by 13 in a specially built test fixture. This arrangement places the test multiplier directly above the TRA_240_091 antenna. The 18 GHz signal source is a microwave signal generator (HP8673B) with an external amplifier to give a high-power level (50 mW) to drive the high order test multiplier. The test setup is shown in **Figure 11**.

Test Multipliers (for RX Testing)

The test multiplier used is based on MACOM MA4E1318 diodes. The prototypes are shown on the left in **Figure 12**. On the right side of Figure 12, an alternative is shown which is a mixer diode recovered from a Ku band satellite TV down converter RX mixer. The MACOM diode will work better but the Ku band mixer diode will do the job if that is all that is available. The actual test multiplier used is shown in **Figure 13**.

The MACOM MA4E1318 diodes are quite difficult to get soldered, as they are super small. You will need a microscope, but it is still a challenge to get a connection. They are a parallel anti-pair which means there are two diodes connected in parallel with the diodes orientated in opposite directions. Use small-gauge tinned copper wire to bridge the connection distance on the two points on the coax or connector. Experimenting with the diode position relative to the ground point changes the efficiency on a particular harmonic. It is a particularly good idea to use a connector saver if using the SMA route; the slightest movement on the center pin will fracture the diode connection.

The final test multiplier was built on a section of 1/8-inch hardline using a MA4E1318 diode. This was enclosed in a custom-made fixture to place the test multiplier directly above the 241 GHz chip as shown in Figure 13. An SMA connector on the other end of the coaxial hardline allows easy connection to the 18 GHz drive power.

The drive amplifier used was an Avantek AWT-18035, which is specified to cover 8 – 18 GHz, but it still has gain up to 20 GHz. The amplifier will go up to 100 mW at saturation, but you

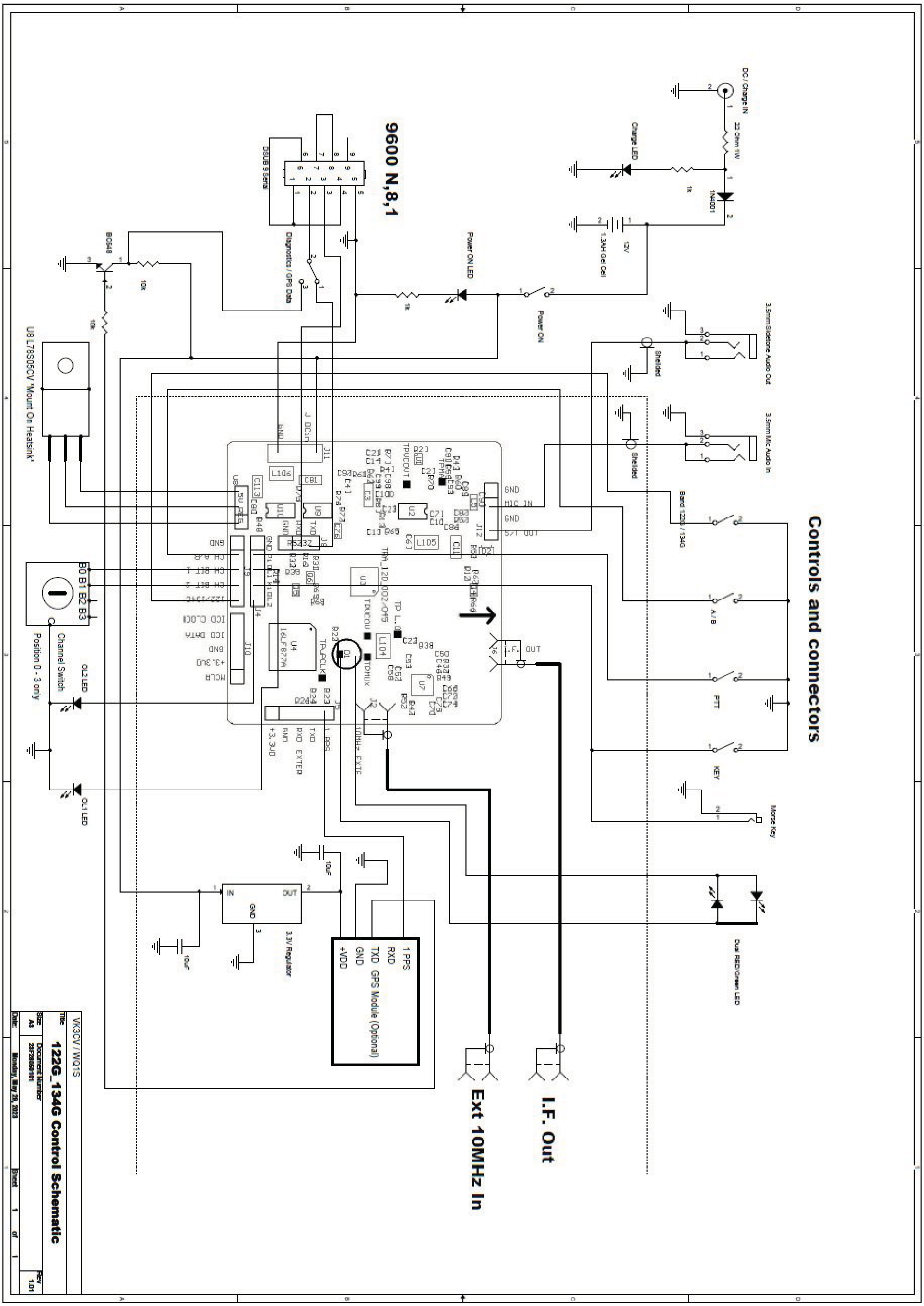


Figure 19 — Control box schematic diagram.

will likely damage the multiplier diodes at this level. Around 50 mW of drive at the multiplier diode is a good choice, allowing for cable and connector losses. A more modern microwave signal generator will possibly have enough output to drive the test multiplier directly. Another possibility is to use a standalone synthesizer or LO chain which can generate an 18 GHz signal at 50 mW.

Final System Integration and Optimization

The setup of the final dish system is challenging due to 1 mm wavelengths meaning changes in position of any part of the antenna system as small as 0.1 mm will have an effect. Mechanical stability and repeatability are paramount.

The beacon lens was developed on a computer EM simulator and further optimized by trial and error on a test range of around 25 meters in length. Note that this range distance is nowhere near long enough to have the 600 mm dishes develop full gain and a final radiation pattern. The far field on 241 GHz with a 600 mm dish will not be seen until after 580 meters of distance. This makes final optimization of the dish feed impossible in practice on a short test range.

Optimization of the Dishes Is Best Done at a Range of 1 Kilometer or More

Optimization means that the realized gain is maximized and the telescopic sight target and main antenna lobe are in the same position. It was found that due to the near-optimum beamwidth of the bare chip, no lens is required on the prime focus dish systems.

By using different lenses, it is possible to optimize the PCB to almost any type of direct or indirect reflector antenna.

Measurement of the radiation patterns was done in a lab environment without absorbing material adjacent to the test setup so results must be taken as approximate only. The measured patterns of the bare chip and chip with lens are shown in **Figures 14A** and **14B**.

Note the use of Kapton tape on the dish systems to keep dirt and moisture away from the chip. The chip aperture is a 15 mm diameter hole with the chip seen on the PCB below. The two LEDs on the dish feed point system are OL1 and OL2.

Control Box

A high-resolution copy is available at **QEXfiles**.

Lens Details

The beacon system lens is made from Rexolite 1422 which is a type of cross-linked polystyrene. A sketch of the lens is as shown in **Figure 18**. The lens is attached to the PCB using very thin double-sided tape. The lens material is quite easy to machine and was made on a small lathe.

Conclusion

The system described has been used to make dish-to-dish contacts over a path of greater than 2 kilometers with reliable results.

The dishes appear to function better than expected with a single very sharp main lobe. It is unlikely that the dishes give anywhere near the theoretical gain, however, which is 60 dB. It is likely the real gain is much lower than this due to the curve accuracy required being much smaller than the physical dish curve accuracy. The dishes were designed to work up to 15 GHz, so accuracy in the region of 2 mm at best could be expected. This will have a detrimental effect on the practical gain achieved with the dishes at 241 GHz.

Using the system in practice is straightforward apart from allowing time for the VCOCXO to warm up and stabilize (allow about 10 minutes). I found that by running the systems for some time (an hour or so) in a stable location with either a 1PPS GPS reference or a high-quality 10 MHz GPSDO will allow the boards time to frequency calibrate themselves. This allows field use without worrying about having a GPS signal connected as the hold overvalues stored in the EEPROM or each board will ensure that the frequency calibration of the systems is close enough for making contacts. The pre-programmed frequencies can be found near the end of the PIC code .ASM file. I used the channel “0” frequency for testing which was 241000.1 MHz. Operation using FM is a breeze if the signals are strong enough. Using CW is a bit more challenging due to the short-term frequency stability of the system making it sound more like a free-running pre-1929 tube HF transmitter. After all, we are asking a lot from our VCOCXO. A 1 Hz error at the 100 MHz reference translates to a 2.4 kHz error at 241 GHz.

The TRA_240_091 chips are expensive so be careful if you undertake the task of trying to build these systems. Luckily all my chips worked correctly when placed on the PCB.

Good luck and hopefully there will be more than a very few who are able to QSY to the top band.

Andrew Anderson was first licensed in 1976 as a novice in Australia as VK3NQU. At age 15, he built his first station, primarily home brew, while still at high school, including construction of a 50-foot tilt-over tower. Studying at R.M.I.T. in Melbourne, Australia, from 1979 to 1983, he received an associate diploma in electronics. He has worked in the aviation and communications industries since then, founding his own company which he has run for over 40 years. In the late 1970s he held a limited (technical class) license, VK3YPD. He became interested in VHF and above, and over the years, has been active on the VHF/UHF/SHF bands with a mix of modified commercial and home brew equipment. In 1980, he combined his two old call signs into a novice/limited call (VK3KAJ), later becoming VK3CV.

Living near Boston, Massachusetts, on and off since 2001, he sat for the US Technician-, General- and Amateur Extra-class licenses all on the same day in 2009. He was issued the call sign AB1LA, and was later granted his current vanity call, WQ1S. Now retired, he spends most of his time in Australia, researching, designing, and building everything from scratch as much as possible.

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The Stepped Line Transformer, Part 2: Matching Complex Impedances

Practical formulas, plots, and examples show how stepped line transformers can be designed with standard cables to match complex impedances at a given frequency.

Introduction

My May/June 2024 *QEX* article focused on the design of stepped (transmission) line transformers (SLTs) that match resistances R_1 and R_2 at a given frequency **[1]**. This article extends those results to the design of SLTs that match complex impedances Z_1 and Z_2, where:

$$Z_1 = R_1 + jX_1 \qquad \textbf{Equation 1a}$$

and

$$Z_2 = R_2 + jX_2 \qquad \textbf{Equation 1b}$$

This article presents explicit design formulas, discusses design limitations, provides examples of SLT applications, and presents practical advice on making SLTs.

As **Figure 1** shows, the SLT consists of two cascaded transmission lines TL_a (length L_a, characteristic impedance Z_{oa}) and TL_b (length L_b, characteristic impedance Z_{ob}). The goal is to construct SLTs using combinations of standard cables having characteristic impedances of 50, 75, 300, or 450 W.

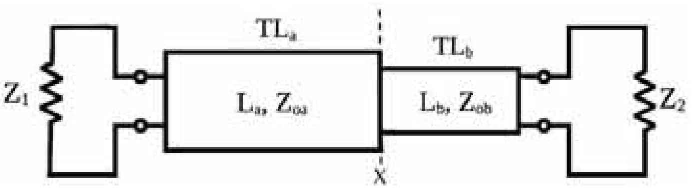

Figure 1 – SLT with complex source and load impedances. The SLT consists of transmission lines TL_a (Z_{oa}, L_a) and TL_b (Z_{ob}, L_b).

When the input and output ports are matched, there is a conjugate match at cut line X, shown in Figure 1. Let Z_A be the impedance looking into TL_a from line X, and Z_B be the impedance looking into TL_b from line X. Using the asterisk to denote the complex conjugate, the following formulas apply:

$$ZA^* = ZB \qquad \textbf{Equation 2}$$

$$Z_A^* = Z_{oa}\left[\frac{Z_1^* - jAZ_{oa}}{(Z_{oa}+jAZ_1)^*}\right] \qquad \textbf{Equation 3a}$$

$$Z_B = Z_{ob}\left[\frac{Z_2 - jBZ_{ob}}{Z_{ob}+jBZ_2}\right] \qquad \textbf{Equation 3b}$$

where,

$$A = \tan\,(2\pi L_a/\lambda) \qquad \textbf{Equation 4a}$$

$$B = \tan\,(2\pi L_b/\lambda) \qquad \textbf{Equation 4b}$$

$$\lambda = {}^{300}/_{f_{MHz}} \qquad \textbf{Equation 4c}$$

Then, the electrical wavelengths of the line sections are:

$$L_a/\lambda = \arctan(A)/2\pi + k_a/2 \quad k_a = 0, 1, 2...$$

Equation 5a

$$L_a/\lambda = \arctan(B)/2\pi + k_b/2 \quad k_b = 0, 1, 2...$$

Equation 5b

Equations 5a and **5b** show that any number of half-wavelengths of transmission line may be added to either section of the SLT while keeping the match at the design frequency.

Resolving **Equations 3a** and **3b** yields two simultaneous non-linear equations solved for A and B with the help of the SageMath computer algebra program **[2]**.

$$AB\left(X_2Z_{oa}^2 + X_1Z_{ob}^2\right) + (R_1R_2 + X_1X_2)(AZ_{ob} + BZ_{oa})$$
$$-Z_{oa}Z_{ob}\left(BZ_{ob} + AZ_{oa} + X_1X_2\right) = 0$$

Equation 6a

$$AB\left(R_2Z_{oa}^2 - R_1Z_{ob}^2\right) + (AZ_{ob} + BZ_{oa})(R_2X_1 - R_1X_2)$$
$$+Z_{oa}Z_{ob}\left(R_1 - R_2\right) = 0$$

Equation 6b

There are two solution pairs, [*A1*, *B1*] and [*A2*, *B2*], given by **Equations 7a – d** below.

$$A_1 = Z_{oa}\left(-Q+\sqrt{P}\right)/D \quad \textbf{Equation 7a}$$

$$B_1 = Z_{ob}\left(U+\sqrt{P}\right)/E \quad \textbf{Equation 7b}$$

$$A_2 = -Z_{oa}\left(Q+\sqrt{P}\right)/D \quad \textbf{Equation 7c}$$

$$B_2 = Z_{ob}\left(U-\sqrt{P}\right)/E \quad \textbf{Equation 7d}$$

The quantities *Q*, *U*, *D*, *E*, and *P* are defined in the Appendix. An Excel spreadsheet that performs the design calculations is available for download from **arrl.org/qexfiles**. The spreadsheet accepts values for Z_{oa}, Z_{ob}, Z_1, and Z_2, determines whether a physical SLT is possible, and computes the transmission line lengths.

Matching Range and Feasibility Plots

Given Z_1, Z_{oa}, and Z_{ob} , it is instructive to decide what range of Z_2 can be matched using a SLT. Since the electrical line lengths in a physical SLT are greater than zero, it is possible to make an SLT when both A_1 and B_1 are positive, or both A_2 and B_2 are positive. A feasibility plot shows the areas in the Z_2 plane where one or both conditions hold. Although Equations 7a – d form the basis for the plot, a mathematical analysis based on those equations is complicated, so it is easier to make a computer program that scans the Z_2 plane to find the possible regions. The author's program prompts the user to enter values for R_1, X_1, Z_{oa}, and Z_{ob}, set the area to be scanned, and specify a maximum value for *LR*, the ratio of the longer SLT section length to the shorter section length. Keeping the *LR* within a practical range, limits inaccuracies caused by connection lengths and cable cutting errors. **Figure 2** shows the feasibility plot for Z_{oa}=300 W, Z_{ob} = 50 W, and Z_1 = 50 W. The plot shows regions for *LR* = 3, 5, and 7. Note that the matching range shrinks as the *LR* decreases.

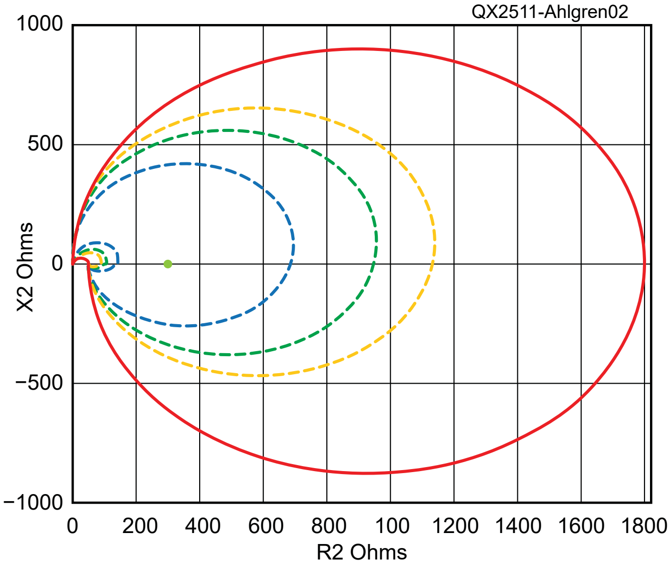

Figure 2 – Feasible region plot for Z_{oa}=300 W, Z_{ob} = 50 W, Z_1 = 50 + *j*0 W (red boundary). Boundaries shown for length ratios *LR* = 7 (Yellow), *LR* = 5 (green), and *LR* = 3 (blue). Position of the Bramham transformer is indicated by the green marker.

Special Cases

There are two cases that follow from **Equations 4a – d**. The first, described by Bramham, is the two-section transformer that matches a resistance *R1* to a load resistance R_2 using line sections of equal length **[3]**. The characteristic impedances are fixed such that, $Z_{oa} = R_2$ and $Z_{ob} = R_1$. Applying these conditions to Equations 7a-d yields explicit equations for designing Bramham's transformers:

$$A = B = \sqrt{\frac{R_1R_2}{R_1^2+R_1R_2+R_2^2}} \quad \textbf{Equation 10}$$

$$\frac{L_A}{\lambda} = \frac{L_B}{\lambda} = \frac{1}{2\pi}\arctan(A) + k/2 \quad k = 0, 1, 2\ldots \quad \textbf{Equation 11}$$

The green mark in Figure 2 represents the point in the R_2-X_2 plane standing for a Bramham transformer in which $R_1 = Z_{ob}$ = 50 W and $R_2 = Z_{oa}$ = 300 W. At that point, *LR* = 1.

The second special case was described by the author in an earlier article **[1]**. That article showed that dropping Bramham's equal-length requirement makes it possible to build SLTs that use standard transmission lines to match a wide range of resistances. The reader is referred to that article for details.

Examples

The examples below illustrate the application of SLTs designed using the formulas presented in this article.

Example 1: Reviving an Old Ground Plane Antenna

Design a SLT to match a 50 W cable to the complex load impedance presented by a long-retired ground plane antenna. Resonant at 29.5 MHz, the antenna consists of a 2.66 m vertical element and four radials, each 2 m long. Mounted 6 m above ground of average quality, the antenna will be used to transmit a 28.3 MHz (l = 10.6 m) beacon. The goal is to design an SLT to match the antenna's input impedance at the beacon frequency, Z_1 = 23 – *j*28 W, to the source impedance, Z_2 = 50 W.

Choosing Z_{oa} = 75 W, Z_{ob}= 25 W, and k_a = *kb* = 0, the scanning program calculates the feasibility plot shown in **Figure 3** (make a 25 W cable by connecting two 50 W sections in parallel). A maximum length ratio *LR* = 5 is specified. The plot shows that it is possible to realize an SLT. Applying the design equation yields: L_a/ l = 0.0967, L_b/ l = 0.1192, and *LR* = 1.23. The SWR response is simulated using *4nec2* **[4]** and is shown by the red curve in **Figure 4**. Note that adding one wavelength of 75 W line to the SLT (k_a = 2, L_a/l= 1.0967) supports the match at the design frequency but decreases the SWR bandwidth (Figure 4, dashed red curve).

Example 2: Matching the Ground Plane Antenna to an SDR

In this example, the antenna impedance, Z_1=23 – *j* 28 W, from Example 1, is matched to a SDR receiver. The SDR's input equivalent circuit is 80 W in parallel with 50 pF capacitance. The SDR's input admittance at the beacon frequency is, there-

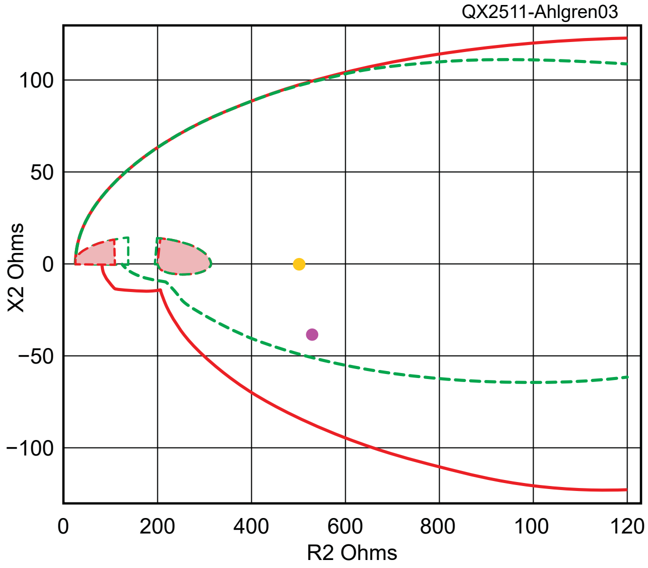

Figure 3 – Feasibility plot for Z_{oa} = 75 W, Z_{ob}= 25 W, Z_1 = 23 – *j*28 W. SLT realizations are possible inside red lines except within red shaded areas. The possible region for $LR \leq 5$ lies within the dashed green lines. Yellow mark (see text for Example 1), Z_2 = 50 W. Violet mark (see text for Example 2), Z_2 = 53.13 – *j*37.78 W

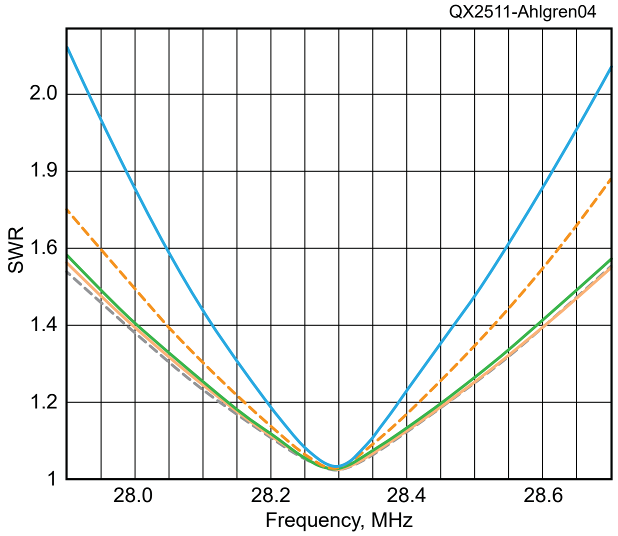

Figure 4 – SWR curves. Example 1, $k_a = k_b = 0$ (red), k_a=2, k_b=0 (dashed red); Example 2 (green); Example 3, k_a=2 (blue); back-to-back SLTs with 50 W extension cable (dashed black).

fore, $Y_{in} = 0.0125 + j\,0.00889$ S. The equivalent series impedance is, $Z_2 = R_2 + jX_2 = 53.13 - j\,37.78$ W. This point is noted by the violet mark, which lies inside the possible region (Figure 3). For $Z_{oa} = 75$ W, $Z_{ob} = 25$ W, and $k_a = k_b = 0$, Equations 4 – 9 yield $L_a/l = 0.12995$, $L_b/l = 0.04413$, l=300/28.3=10.6 m, L_a=1.377 m, and L_b=0.46784 m. For this SLT, $LR = 1.377/0.46784 = 2.943$. A perfect match at the design frequency requires that the admittance presented by the *Zob* line to the receiver be the complex conjugate of Y_{in}; i. e., $Y_{in}^* = 0.0125 - j\,0.00889$. Computing the SWR vs. frequency curve requires calculating, at each frequency, the load Z_2, the impedance Z_s looking back into the line, and the complex reflection coefficient, $r = (Z_2 - Z_s^*)/(Z_2 + Z_s)$. Then, the SWR is then calculated using the equation SWR = $(1 + |r|)/(1 - |r|)$, where $|r|$ represents the magnitude of the reflection coefficient. Simulation runs with *4nec2* predicted the values for Z_s and Z_2 at each frequency. The resulting SWR response is shown by the green curve in Figure 4.

Example 3: The Better Way to Extend the SLT

This example compares two methods to extend the feedline when using SLTs:

(1) To lengthen sections of the SLT by half-wavelength increments so that $k_a > 0$ and/or $k_b > 0$ in Equations 5a and b or

(2) To use two SLTs, one to match the source *Z1* to an extension cable's characteristic impedance and the second to match the extension cable to the load Z_2.

To evaluate the first method, the SLT from Example 2 was extended by one wavelength, ($k_a = 2$). As in Example 1, the match at the design frequency is preserved. As frequency moves further away from the design frequency, the added length of line differs increasingly from a multiple of a half-wavelength. The result is a 35% lowering of the simulated SWR = 1.5 bandwidth, shown by comparing the blue and green curves in Figure 4.

To evaluate the second method, the SLT from Example 1 matches the source impedance $Z_1 = 23 - j\,28$ W to a 50-ohm extension cable approximately 3*l* long. A second SLT matches the cable to load $Z_2 = 53.13 - j\,37.78$ W. The latter SLT has, $Z_{oa} = 25$ W, $Z_{ob} = 75$ W, and $k_a = k_b = 0$, yielding $L_a/l = 0.04502$, $L_b/l = 0.1523$, L_a=0.4772 m, L_b=1.6149 m, and $LR = 3.384$. In contrast to the first option, the double-SLT design preserves the SWR bandwidth (dashed black curve in Figure 4) and is the preferred extension method.

Discussion

This article presented explicit formulas for designing two-section stepped line transformers that match general complex impedances at a given frequency. The article considered design limitations and gave three examples of SLT applications. The examples employed ideal lossless transmission lines with velocity factors equal to one.

The theory presented here has practical application for radio amateurs designing matching networks using real transmission lines. When making real SLTs, calculation of section lengths must include the velocity factors of the lines. Note that there is a tradeoff related to line losses in the SLT; as the design frequency increases so do line losses, but section lengths decrease. Hence, line losses may be a minor issue. Radiation from coaxial cables caused by current flow on the outside of shields can be minimized by placing enough ferrite chokes on each section, and sections made with parallel lines can be kept away from other conductors. Cut sections carefully, stabilize the SLT mechanically, keep connections as short as possible, and waterproof the junctions. Finally, to minimize cutting and connection errors, aim for a length ratio *LR* less than 4 or 5.

An Excel spreadsheet to calculate the quantities Q, U, D, E, and P, defined in the Appendix, is available for download from **www.arrl.org/QEXfiles**.

David Ahlgren, K1BUK, started in amateur radio with the Novice-class call sign KN1BUK in 1957 and upgraded to K1BUK in 1958. He operated as W8IXX in Michigan in the early 1970s. David returned to the hobby in 2015 after retiring from the faculty at Trinity College, where he taught courses in digital and analog electronics, computer-aided design, and robotics. He holds an Extra-class license and operates CW, SSB, and FT8/FT4 on the HF bands, 160-6 meters. He has earned WAS on nine bands as well as DXCC. Current projects involve designing antennas, tuners, and baluns using the 4nec2 *and* EMCoS Studio CAD *tools. He earned his B.S. from Trinity College, his M.S.E.E. from Tulane University, and his Ph.D. in EE from the University of Michigan, Ann Arbor.*

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Appendix

Equations for Q, U, D, E, and P

$$Q = \left(Z_{oa}^2 - Z_{ob}^2\right) R_2 X_1$$

$$U = \left(Z_{oa}^2 - Z_{ob}^2\right) R_1 X_2$$

$$D = R_2 Z_{oa}^4 + Z_{ob}^2 R_2 \left(R_1^2 + X_1^2\right) - Z_{oa}^2 R_1 \left(R_2^2 + X_2^2 + Z_{ob}^2\right)$$

$$E = R_1 Z_{ob}^4 + Z_{oa}^2 R_1 \left(R_2^2 + X_2^2\right) - Z_{ob}^2 R_2 \left(R_1^2 + X_1^2 + Z_{oa}^2\right)$$

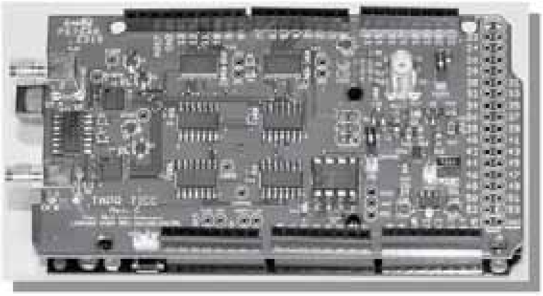
$$P = P_0 + P_1 + P_2 + P_3$$

$$P_0 = \left(R_1 - R_2\right)\left[\left(R_1 R_2 - Z_{ob}^2\right)\left(Z_{oa}^2 - R_1 R_2\right)\left(R_1 Z_{ob}^2 - R_2 Z_{oa}^2\right)\right]$$

$$P_1 = X_1^2 R_2 \left[R_1 \left(R_2^2 + Z_{ob}^2\right)\left(Z_{oa}^2 + Z_{ob}^2\right) - Z_{ob}^2 R_2 \left\{X_1^2 + 2\left(R_1^2 + Z_{oa}^2\right)\right\}\right]$$

$$P_2 = X_2^2 R_1 \left[R_2 \left(R_1^2 + Z_{oa}^2\right)\left(Z_{oa}^2 + Z_{ob}^2\right) - Z_{oa}^2 R_1 \left\{X_2^2 + 2\left(R_2^2 + Z_{ob}^2\right)\right\}\right]$$

$$P_3 = X_1^2 X_2^2 \left(Z_{oa}^2 + Z_{ob}^2\right) R_1 R_2$$



TICC

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Achieving Higher Data Rates in the THz Gap

Using a carbon-blackened metal-ceramic heater as a black-body source and a mechanically chopped beam, this project demonstrates THz-gap communication at up to 10 b/s over a 1-meter path — about 60 times faster than earlier work — and analyzes the modulation, receiver, and sampling limits that point toward higher-rate and even voice-capable THz links.

Introduction

Black body radiators have been used to achieve THz communication at a record distance of 160 meters. However, these experimenters used QRSS6, a modulation method with a data rate of 0.167 b/s **[1]**. A black body radiator is any object with a greater than zero Kelvin temperature. The frequency at which peak radiation is emitted at a temperature is given by Wien's Law **[2]**, which shows that an object at 520 K will have peak radiation at 30 THz.

Goal

The goal of this project is to achieve a much higher data rate using black body radiation transmitters within the THz gap.

Method

Transmitter

The transmitter uses a black body radiator to generate THz gap radiation (**Figure 1**). Per Wien's Law, an ideal black body radiator at a temperature of 520 K has peak emissions of around 30 THz. However, due to imperfections in the real application of black body radiators, the metal ceramic heater (MCH) used as the black body radiator in this project operated at 575 K. Additionally, to maximize emissivity and therefore signal generation, the MCH was painted black with carbon-based ink.

Modulator

Mechanical modulation is required to modulate THz radiation. Because black body radiators are heaters with significant temperature rise and fall time, electrical modulation is impractical at this time. Mechanical modulation requires the movement of an object into the beam of radiation to control the passage of radiation to the receiver. The researcher programmed an Arduino to control the modulator, which uses a motor to move a paper card to block or unblock the THz beam emitted from the MCH. The blockers were made of thick card stock paper to prevent the need for safety shielding and due to their opaqueness to THz radiation.

Receiver

The receiver (**Figure 2**) uses the MLX90614 pyroelectric sensor. A high-density polyethylene (HDPE) Fresnel lens was placed in front of the sensor to reduce noise. This lens heavily attenuates all emissions outside of the range from 21 – 37 THz, filtering out most non-THz gap noise. The receiver's output was connected to a controller, which reads and logs the data and can later be used for decoding.

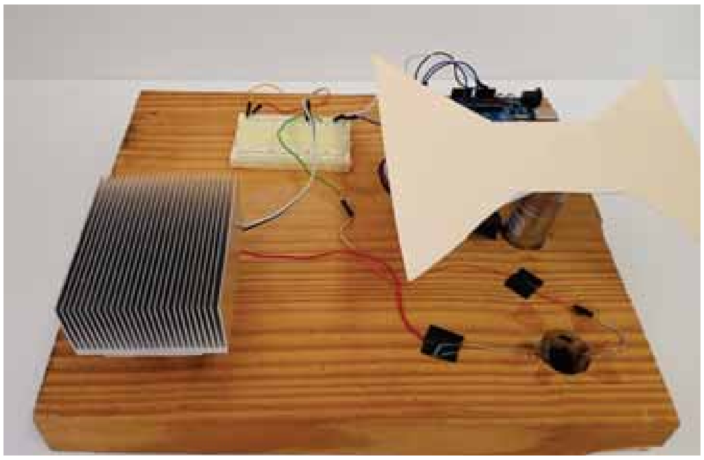


Figure 1 – The terahertz gap transmitter.

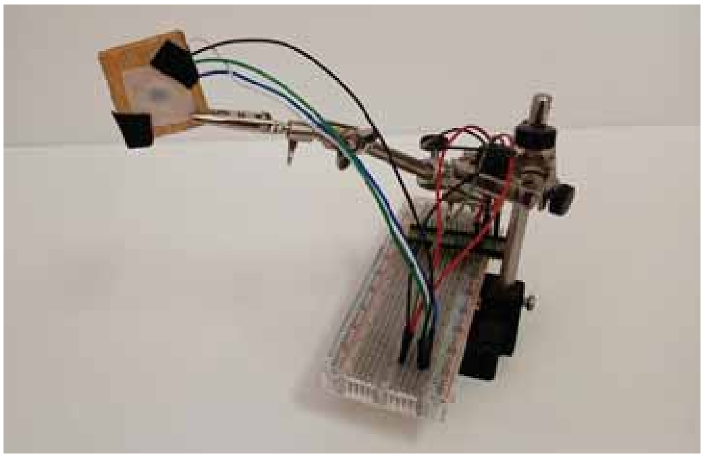


Figure 2 – The terahertz gap receiver.

Testing

The transmitter and receiver were separated by an air gap of one meter (**Figure 3**). A controller logged the data from the receiving sensor and then exported it to an Excel file for analysis. In Stage 1, an Arduino controller was used for both the transmitter and receiver. In Stage 2, the receiver controller was switched to a Raspberry Pi Pico to simplify exporting data. Additionally, the shape of the blocker was changed from a semicircle in Stage 1 to an hourglass shape in Stage 2, doubling the bit rate per revolution.

Discussion

In Stage 1, the mechanical modulator motor rotated at 15 r/min, creating a data stream of 0.5 b/s. The receiver sampled at 4 Hz and collected 720 data points at 250 ms intervals. The results show that the device decoded a 0.5 b/s signal at 1 meter with an SNR of 11 dB. When the beam from the radiator to the receiving sensor was unobstructed, the sensor sent a correspondingly high signal to the receiver controller. When the mechanical modulator blocked the beam, the sensor output dropped to a low level. The modulator in this stage had one blocker in the shape of a half-circle. With this modulation scheme, the expected output is a square wave, as seen in **Figure 4**.

In Stage 2, several changes were made to improve the transmitter and receiver. The mechanical modulator motor speed was increased to 330 r/min, and the number of blockers on the modulator was increased to two configured in an hourglass shape. These changes created a data stream of 11 b/s. The receiver controller/data logger was changed to a Raspberry Pi Pico, requiring re-programming in MicroPython instead of C, which was used in Stage 1. The receiver sample rate increased to 1,000 Hz, allowing collection of 7,000 data points over 7 seconds. The results of Stage 2 show that the receiver only partially decoded the data. Upon later data analysis, the controller queried the receiving sensor at 1,000 Hz, the sensor output changed at only 20 Hz. The Nyquist rate to fully decode data must be at least two times the data rate, meaning that to decode the data stream in this test, the sensor needed a sample rate of at least 22 Hz. **Figure 5** shows these results, and the waveform present follows the expected output of an 11 b/s data stream sampled at 20 Hz. Although the device did not decode all the data in this test, the results do show that the receiver sensor has a sample rate of 20 Hz, meaning that it can decode data at 10 b/s.

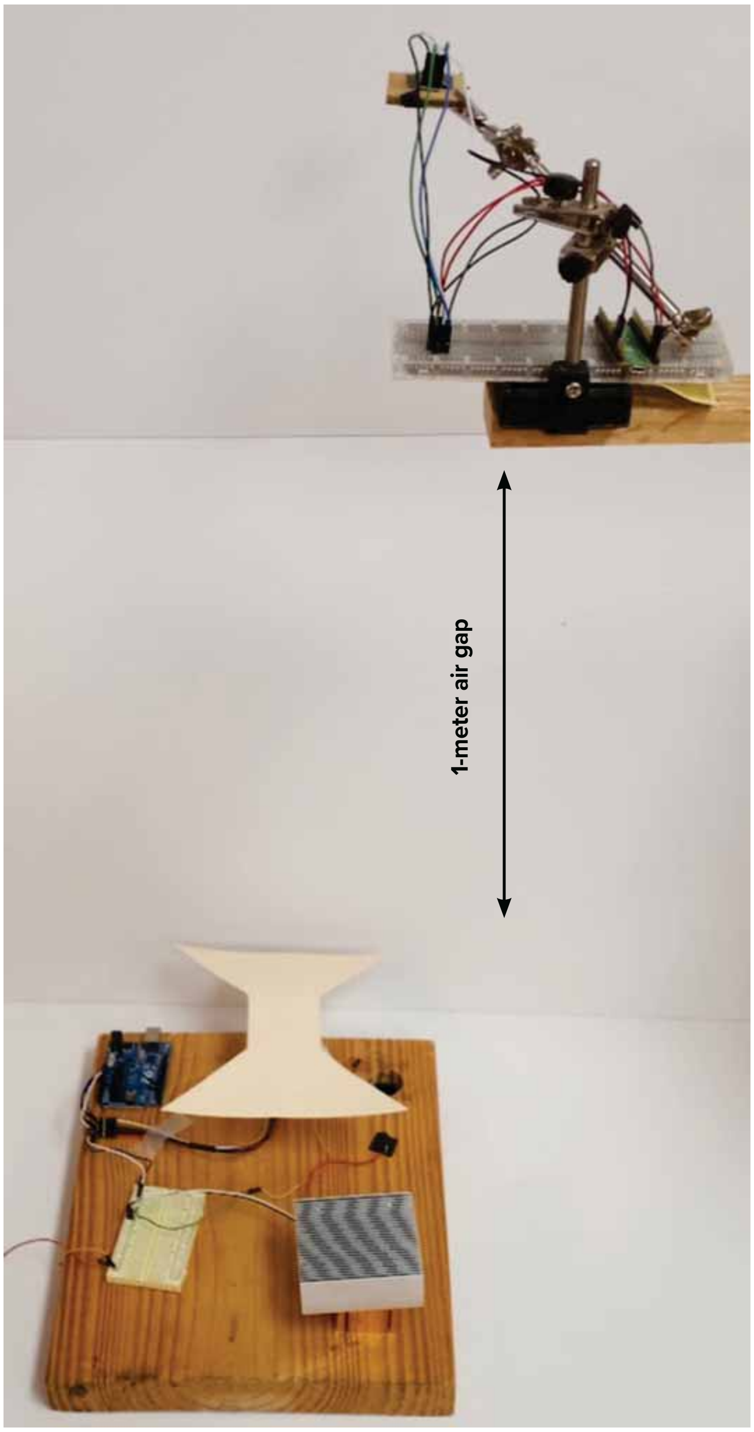


Figure 3 – The device under test.

Conclusion

The current prototype's maximum possible data rate is 10 b/s, 20 times better than Stage 1. While this data rate is still inordinately slow by data transfer standards, it is 60 times faster than earlier black body devices operating in the THz gap. The device achieves an 11 dB SNR, high enough to distinguish

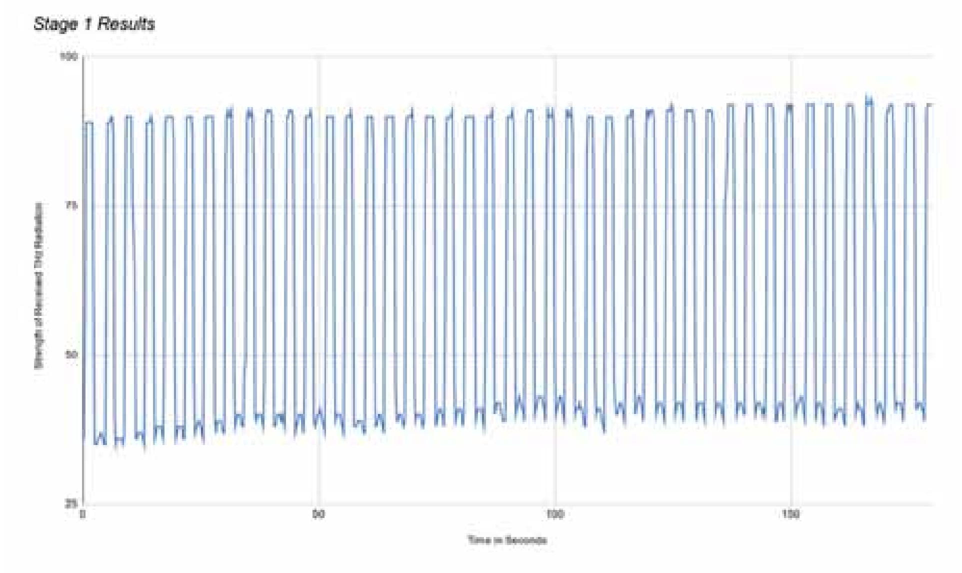


Figure 4 – The results from Stage 1's slower transmitter.

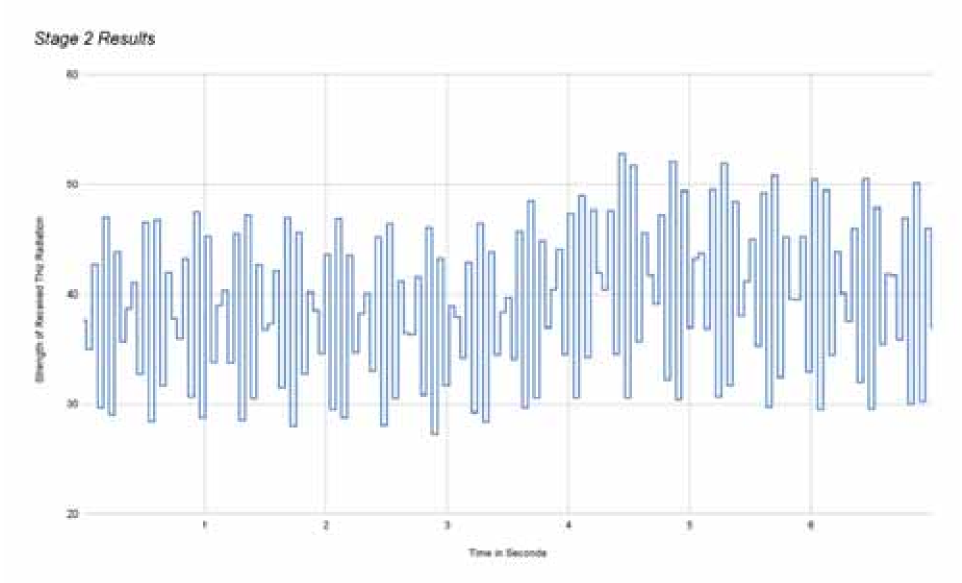


Figure 5 – The results from Stage 2's faster transmitter.

when a signal is present at 1 meter. The current receiver uses no method of confining the field of view, meaning there are many ways to increase the range.

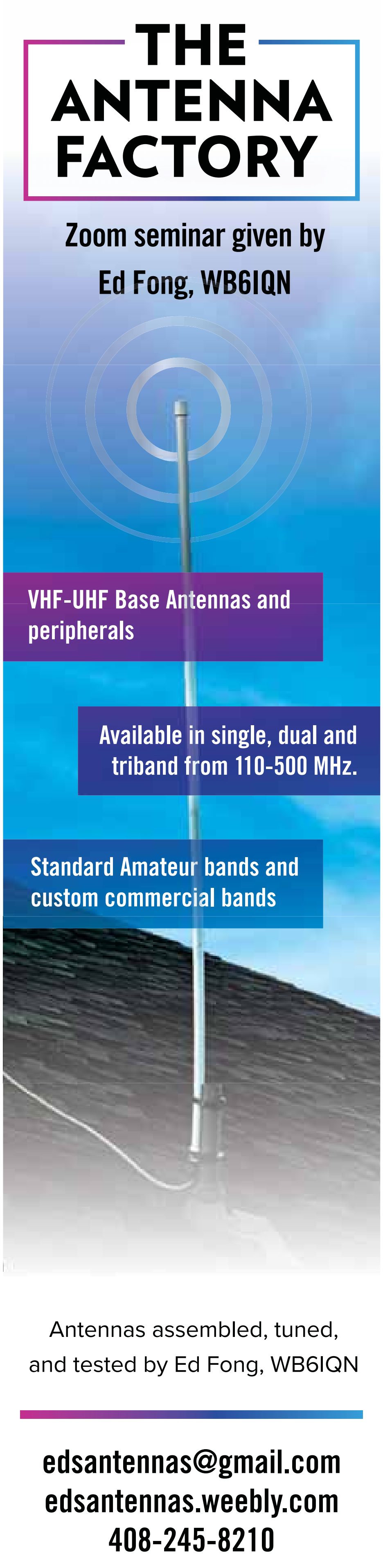
The researcher is currently implementing a method of sending AM voice over the THz gap, which will significantly increase the data rate.

Jonathan Dorminy, KN4LGM, is a first-year student at MIT from McDonough, Georgia. He first became interested in amateur radio in 2018 and quickly earned all three licenses. In high school, he experimented with interesting electronic applications of radio topics and explored the history of radio sciences, winning many national and international awards.

Notes

[1] H. Lecybyl and R. Lecybyl, "*30 THz Experiment Over 100 m Distance*," QEX, pp. 23–28, July/Aug. 2023.

[2] B. Chambers, "*30 THz – It's Radio, But Not As You Know It*," QEX, pp. 3–8, Mar./Apr. 2022.



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The WT3J AI-Based Voice Synthesizer System

Build a shack-local AI voice keyer you can converse through. CT9/WT3J combines Piper TTS, a Pi 5, and a small PTT/audio switch to deliver immediate SSB speech — typed text, phonetic expansion, and 32 programmable sequences — while preserving mic-through operation. No recordings, no cloud, and reproducible on the bench.

Introduction

I highly suggest reading the "Second Century" column by ARRL CEO David Minster, NA2AA, in the April 2024 issue of *QST,* entitled "The Road Ahead." In it, he presciently discusses potential current and future uses for Artificial Intelligence (AI) in amateur radio. As David says, "Think about how you might use the emerging AI tools in your shack. Be a connector by getting involved with the teams progressing this revolution." This article and project will show you exactly how you can do this, in a very interesting and useful manner.

The software described here is a modification of what is in an article I wrote in the July 2024 issue of *QST* entitled "The WT3J GUI-Based Morse Code Controller." It incorporates many of the same graphical user interface (GUI) and software features. But instead of calling a Morse code generator, it uses an open-source text-to-speech software package called *Piper TTS* to generate real-time, high-quality speech audio. *Piper TTS* uses state-of-the-art machine-learning AI to develop voices, providing users with multiple language options and both male and female voices.

Advantages of This Implementation

There are modern radios that allow short, recorded audio sequences to be played on demand into the transmitter. Also, there are designs available on the internet to implement recorded audio to do the same thing. I occasionally hear amateurs calling CQ with recorded voices, especially in contests. But they all require the user to pre-record any audio they expect to use and cannot be changed "on the fly."

What is different about this design is that there are no recordings. All audio is generated on demand and in real time, with an AI text-to-speech (TTS) software package. This allows many audio sequences to be used and enabled via a click of a mouse or with a finger on a touchscreen monitor. Also provided is the ability to type in text via a keyboard and immediately convert it to live audio with the synthesizer. In this manner, this system is usable for people with voice disabilities, ranging from basic help with a voice contact, to the real possibility of completing an entire conversational contact without needing to speak. Imagine the possibilities for the voice-impaired who would still like to make contacts without having to use CW or digital modes!

Design Considerations

To effectively use a system like this, it is necessary to have the ability to quickly output a high-quality voice stream in an economical manner. This has only become possible in the last few years due to advances in machine learning and artificial intelligence.

There are basically two ways to generate synthesized speech audio from text. This can be accomplished remotely by software "in the cloud" or locally on a shack computer. My feeling is that the former solution is not practical for this application as it requires an internet connection that might add random response time delays, and worse, total unavailability of voice models at times. As such, I have chosen to have the speech synthesizer software run locally on a Raspberry Pi 5 microcomputer.

Various text-to-speech software engines were researched and tested, and the clear leader in response time, ease of integration, number of available voices, quality of the voices, and the ability to train my own voice, was *Piper TTS*. This package is optimized to run on the Raspberry Pi microcomputer, which is commonly available, easy to use, and very inexpensive. More information on *Piper TTS*, including audio samples, can be found at **https://github.com/OHF-Voice/piper1-gpl**.

Main Components Required

The following hardware items are needed to implement this project:

- A Raspberry Pi 5 microcomputer. I recommend a Raspberry Pi 5 with 8 GB of RAM, as it is the model that I currently use successfully. It is possible to use a Raspberry Pi 4, but it should be updated to Python 3.11 for this application for library and package compatibility.
- 4K resolution monitor with analog audio output capability.
- External speaker to hear the synthesized voice audio.
- The hardware Voice Interface Module that is described in this article utilizes few, inexpensive parts and is easy to build. This module provides physical and electrical connections between the Raspberry Pi GPIO bus, microphone, analog audio source, and your radio.

You will also need the following software items:

- A Python 3 software application designed and written by me that also includes a separate data file containing 32 user-definable voice sequences is provided for downloading. This software will run on your Raspberry Pi as a complete Python software development environment and is pre-installed as part of the Raspbian operating system.
- *Piper TTS,* an open-source text-to-speech synthesizer package, available for download on GitHub (**https://github.com/OHF-Voice/piper1-gpl**). Instructions are provided in the comments of the software noted above.

Microphone and Audio Interfaces

My main radio is a FlexRadio FLEX-6400M with an INRAD M650 microphone. This microphone uses a Yaesu-style connector, with an adapter cable that splits into two separate cables for use with this radio. One is for audio with a 3.5 mm connector, and the other is for PTT with an RCA connector. The microphone is connected to the Voice Interface Module in this manner. If your microphone has a different connector, you may need to adapt this part accordingly. The other input is another 3.5 mm audio connector interfacing via a short audio cable to another 3.5 mm audio connector on the back of my 4K monitor. This is the source for the synthesized voice audio generated by the Raspberry Pi.

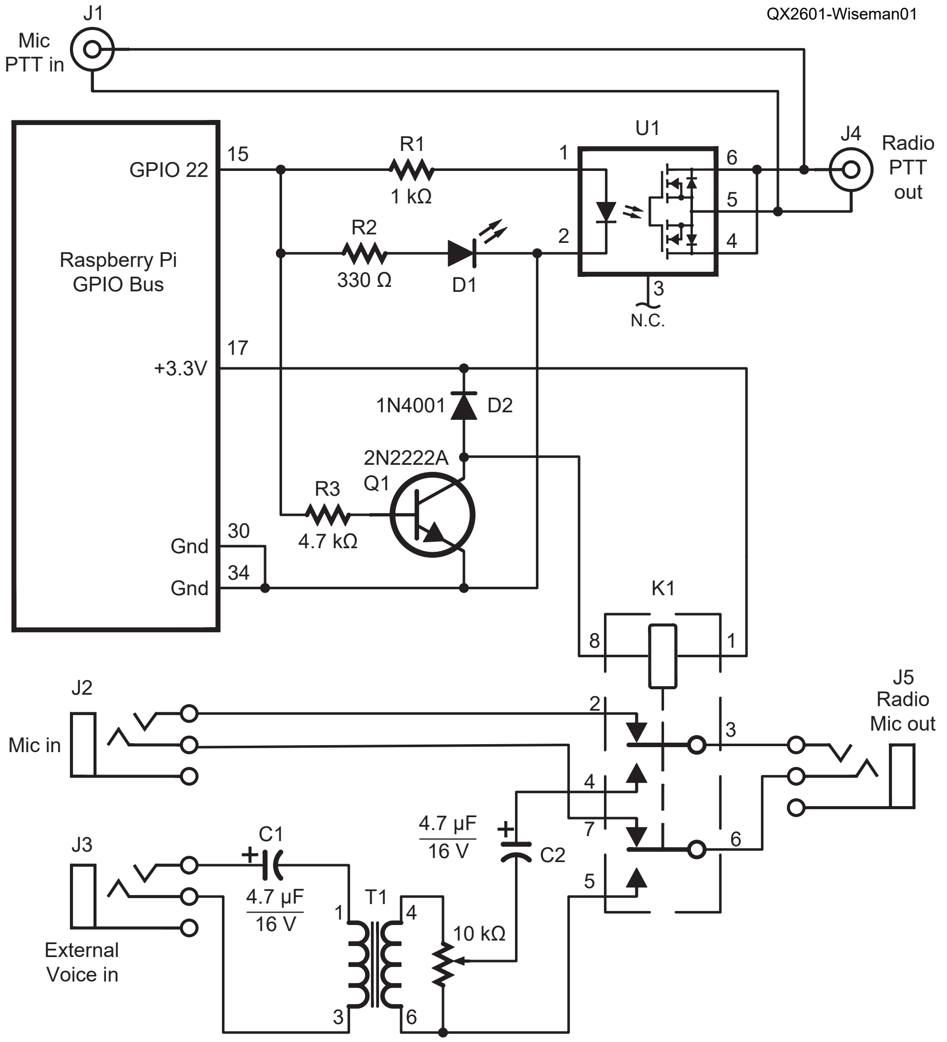


Figure 1 – Voice interface module schematic.

When a button is pressed in the GUI and synthesized speech is generated, the software first enables the GPIO control signal. This does three things. First, an optically isolated PTT signal is sent to the radio. Second, it is used internally by the Voice Interface Module to switch from the microphone to the analog synthesized audio for output to the radio via an isolation transformer. Lastly, an LED is enabled to show the user that the

Table 1 – Parts List

Qty	Reference	Description
2	J1, J4	RCA Female Connector
3	J2, J3, J5	3.5 mm Audio Female 3-conductor connector
2	C1, C2	4.7 µf, SOV electrolytic
1	R1	1 kΩ, 1/8 W
1	R2	330 Ω, 1/8 W
1	R3	4.7 kΩ
1	D1	LED, any color
1	D2	1N4001
1	Q1	2N2222A
1	K1	DPDT 2A 3V Relay, Digikey PN: PB1092-ND
1	T1	600 Ω Audio Transformer, Digikey PN: 237-1121-ND
1	U1	Solid-State Relay, Digikey PN: VOR1121AG-ND

How is the audio quality of my speech synthesizer?

CT9/WT3J

- US English Male Voice - 1
- US English Female Voice - 1
- US English Male Voice - 2
- US English Female Voice - 2

- Voice Rate - 2X Speed
- Voice Rate - Normal
- Voice Rate - 1/2 Speed

- 5 9, Thank you.
- CT9/WT3J
- CQ DX, CQ DX, Charlie Tango Nine Stroke Whiskey Tango Three Juliette
- Roger, Roger, QSL
- I am using a software text to speech synthesizer so please understand
- I will ask, how do you copy me, when I am finished transmitting
- How do you copy me, From CT9 stroke WT3J
- Your signal report is
- Signals have QSB
- Signals have QRM
- Signals have QRN
- Band conditions are very good today
- My name is John, Juliette Oscar Hotel November, John
- QTH is Madeira Island, Madeira Island
- Roger, fine business on everything
- What is your name?
- What is your QTH?
- My rig here is a FlexRadio 6400M running 100 watts of power
- My antenna is a simple 20, 15, and 10 meter fan dipole on my roof
- Besides amateur radio, I also enjoy riding my motorcycle around the island
- I also like to work with stained glass
- You can find more information on QRZ dot com
- The weather here in Madeira today is sunny and warm, about 29 degrees C
- How is the weather at your QTH?
- Back to you for your final from CT9 stroke WT3J
- Thanks for the QSO, I wish you good DX and 73 from CT9 stroke WT3J

Figure 2 – Voice Controller GUI screenshot.

transmitter is being enabled, which is useful if your monitor speaker is at low volume or shut off. To support these functions, a four-wire ribbon cable is used to connect to the Raspberry Pi. Besides the control signal, a +3.3 V line and two ground signals are also used.

If the Raspberry Pi is powered down or even removed entirely from the Voice Interface Module, the PTT optical coupler will not engage, and the audio switch will default to the microphone selection position. As such, the microphone will remain totally functional. In this manner, there is no need to move and reconnect the microphone to the radio if the microcomputer is not being used. Being able to switch instantly between the microphone and this system during a contact without moving cables or switching inputs is a great advantage.

My final version uses a custom circuit board, built by *ExpressPCB*. I can provide design files for this board on request. Prototype board implementation will also work if good low-level analog signal design and construction techniques are used. It is also highly recommended that the audio microphone input cable to the Voice Interface Module and the output cable to the radio be as short as possible to minimize potential low-level audio noise.

To hear the synthesized speech as it is being streamed to the radio, I use an audio splitter cable between the monitor audio source and the Voice Interface Module to connect to an external speaker that has its own volume control. In this manner, I can adjust the voice level I am transmitting to any level appropriate for my shack, while still maintaining the same fixed level to the radio.

Voice Controller GUI

The Voice Controller GUI has three basic sections. The voice option selections are located in the lower left-hand portion of the GUI. Four different voices are provided, two male and two female, all English speaking with US accents. The initial default setting is for US English male voice and can be switched at any time. The software provides comments explaining how to add other speaker voices if desired.

Figure 3 – Complete voice interface module.

The second voice option is for the speaking rate, with the default being normal speed. For contests it is often desired to speak quickly, so a two-time speed rate is provided. Quite often we are asked to repeat information such as our call signs more slowly, so a one-half speed option is also provided. Again, these parameters can be changed at any time during an exchange.

The upper left-hand portion of the GUI contains three distinct text input buffers. The top one is for typing a unique sentence via a keyboard and then converting to speech whenever ready with the associated transmit button. This is very useful when a speech response is needed that is unique to a particular question and is not contained in the stored radio button section. The way the software is currently configured is to clear this buffer automatically each time it is used.

The middle text input buffer is using the power of software to allow speech to be generated quickly and efficiently with phonetics. For example, if CT9/WT3J is typed into this buffer, when the transmit button is clicked, the speech will output "Charlie Tango Nine Stroke Whiskey Tango Three Juliet" automatically. The information in this buffer will remain there until modified and can be reused at any time.

The bottom text input buffer is used to modify the first radio button sequence on the right at any time. The other 31 radio button sequences on the right-hand side of the GUI are defined in the file `SSB_Program_Data.py` and are loaded automatically when the program is first initialized.

Setting Up the Software

The Python source code and the required stored sequence data file may be downloaded from **www.arrl.org/QEXfiles**. The application code is named `WT3J_SSB_V1.py`, and the data file is SSB_Program_Data.py. A suggested directory for both files is /home/pi/QST/venv and my examples use this. The /venv portion of this path is set up to be a Python virtual environment, which is necessary for successful use and future maintenance of the various libraries and packages.

You will need to change the WT3J-specific radio buttons for your own call letters, station specifics, personal information, etc., located in SSB_Program_Data.py before using the program on the air. This is a simple task using a basic text editor, following the directions located in the comments of the file itself.

Since there are no separate compiling or linking steps for Python programs, this software may now be run by typing WT3J_CW_V1.py into a command window when in the proper directory, or by opening the file within the Thonny IDE and running from there. Once you know that the software is running successfully, you can implement a more efficient Raspberry Pi task bar icon to launch the program.

Analog Audio Level Setting

Most video monitor analog audio outputs will likely be at “line level” output. This means that the level of the audio will be in the range of a few hundred millivolts. Mine is about 500 mV peak-to-peak. It is necessary to attenuate this signal significantly to the range of a few tens of millivolts to use the standard microphone input of most modern radios. To do this, adjust the audio level with the 10 K potentiometer in the Voice Interface Module to match the output of your microphone when you are speaking normally. I have used the audio meter on my rig to match both signals and then confirmed levels using a separate radio. An oscilloscope can help with this level matching but is not necessary.

Transmitting Synthesized Voice Sequences

Now that either the default settings or updated ones are chosen, it is time to send a synthesized voice to the radio. Set your radio at minimum power and click any of the radio buttons in the GUI. The LED on the Voice Interface Model should light up, the PTT signal to the radio should be enabled, and you should hear the appropriate voice sequence in your external speaker. You are now ready to experiment on the air!

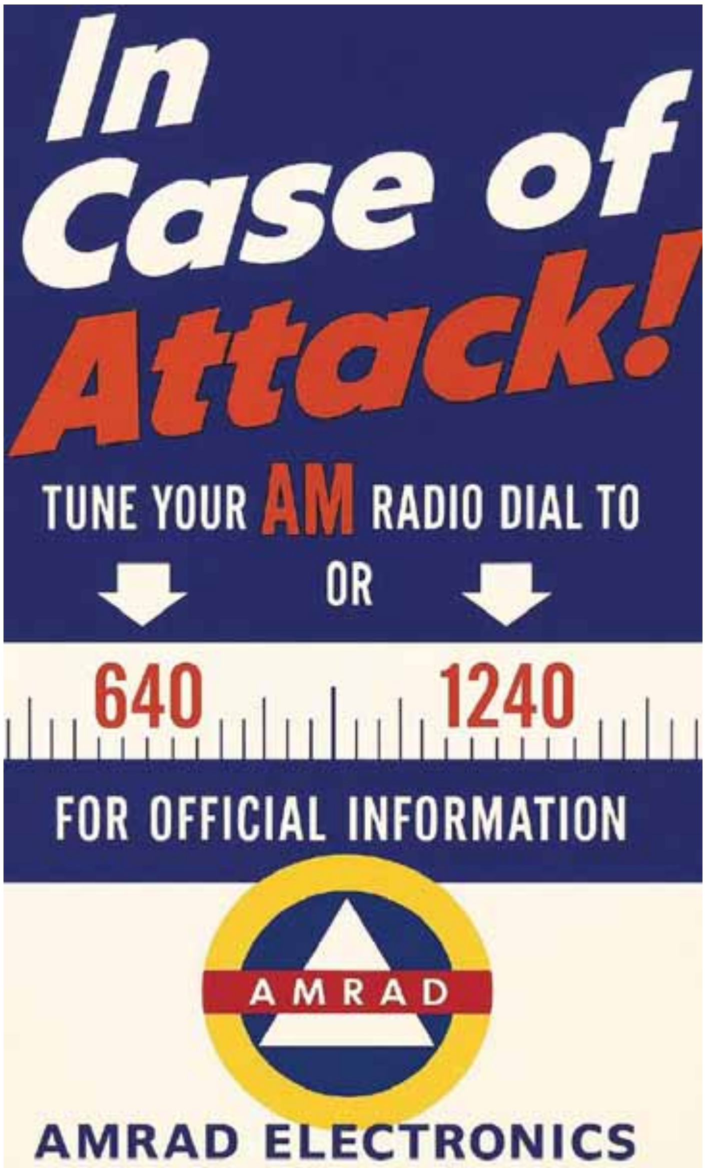
Current and Future Enhancements

The voice models used in this project were generated by training actual recorded voices using machine learning, a subset of artificial intelligence, and are available now in *Piper TTS*. I am currently working with advanced *Piper TTS* AI software to train my own voice to better suit my personal amateur radio needs. I also am learning Portuguese and will be looking to add this to my voice synthesis capabilities soon.

I have made many contacts with this system, from contest-style rapid exchanges at double speed, to much longer contacts with the transmission of more information, such as my working conditions, the local weather, etc. All feedback solicited on audio quality and comprehension has been very good to excellent.

Once you get going with a system like this, there is no reason you cannot do the same and experiment with your own ideas. I highly encourage you to get involved in this aspect of state-of-the-art AI for amateur radio. I am sure that David, NA2AA, would agree!

John Wiseman, WT3J, was first licensed in 1985 as KA5WTO. John holds a BSEE from the University of Massachusetts, Amherst and a MSEE from the University of New Mexico. He is retired from a 40+ year career specializing in video technologies and applications. He enjoys designing hardware and software projects for his shack, especially utilizing new technologies. He and his wife recently moved to Madeira Island, where he is using the call sign CT9/WT3J. When not in his shack, he can often be seen riding his motorcycle around the island, searching for the perfect espresso.



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Self-Paced Essays— #31 Circling Back

Revisit several foundational concepts in radio theory and instruction — the essential building blocks of modern communications technology.

I recently mentioned that I've been doing these essays for about five years now, and it might be time to revisit some topics I covered early in the series.

Angular Frequency

Let's take another look at angular frequency. A while back I explained how the *degree* is not a fundamental physical unit, while the *radian* is. The lower-case omega, ω, is the symbol for angular frequency, and its formula is $\omega=2\pi f$, where f is the frequency in Hertz. Besides being more accurate (theoretically), angular frequency notation is more compact. For instance, inductive reactance as we hams generally use it is $X_L = 2\pi fL$. Using angular frequency, inductive reactance is simply ωL. When you're working out a multi-step problem, you can see how things are a bit less cluttered using angular frequency. This is standard practice amongst electrical engineers. However, it's probably a good idea to become comfortable with angular frequency as well as degree frequency. Using either one properly will result in the same answer, but angular frequency is generally considered the more fundamental approach.

Conventional Versus Electron Flow

The angular frequency versus degree frequency argument, if it even qualifies as an argument, is similar to the conventional versus electron current flow debate. At the risk of opening a Pandora's Box by acknowledging that there even was/is such a debate, I should at least give a little bit of background on this. From the very earliest days of electronics (and even before the term *electronics* was coined), current flow was defined as flowing from the positive terminal of a battery (or other voltage source) toward the negative terminal. A little history will show that this made some sense, since Ben Franklin, who initiated this standard, worked primarily with electrolytic solutions (electroplating and such), long before the electron was known to exist. He was observing the flow of ions, which move in the opposite direction of electrons.

However, with the advent of the vacuum tube, where electrons are the prime movers, it made more sense to define current flow as the direction in which actual physical electrons moved, from the negative terminal to the positive terminal. The former is still known as *conventional current flow*, while the latter is known as *electron current flow*.

Like the two different kinds of frequency, the two different types of current flow will always give you the correct answer; just be consistent when you choose your preferred standard.

Pi in the Sky

Some of you may recall an anecdote I told about significant digits. Inevitably, in any of my classes, a student will ask, "What should we use for pi: 3.1416 or 3.14159?" I always say, "How about 3.1?" And then proceed to explain that it makes little sense to calculate pi out to five or six significant digits when the typical carbon resistor only has two significant digits. Well, as it turns out, metal film resistors have all but replaced carbon composition resistors, and those are marked with three significant digits plus a multiplier. (Plus, sometimes a few extra stripes for tolerance, temperature characteristic and such.) So, recently I've had to revise my policy. My students are now "allowed" to routinely use 3.14 as pi. (Of course, for precision instrumentation or frequency controlling circuitry, much greater precision is called for.) I still always drive home the importance of paying attention to significant digits.

A Feel for Things

In my General Radio Operator License classes, I always try to give my students some physical handle they can use to grasp what could be somewhat abstract concepts. I'm a big fan of electronic circuit modeling, using various flavors of *SPICE*, but I also am careful to always return to the lab. It's important to understand the relative size of electrical values, for instance. To give students an idea of just how small a picofarad is, I take two 8-inch aluminum pie tins and nest them with a layer of Saran Wrap between them. This "kitchen capacitor" comes out close to 1,000 picofarads (or one nanofarad, which is about the smallest capacitance value you can measure with a typical digital multimeter). This demonstration gives a graphic example of how small the values of capacitance are that we routinely work with. In fact, a picofarad is so small that it didn't even have a name until recently in radio history. You don't have to go far back in the archives to find *micromicrofarads* (µµF) on schematic diagrams. On the other end of the spectrum, we didn't have gigahertz until recently, but rather kilo-megahertz or even kilomegacycles.

Good Practices

It's always a good idea to review the basics occasionally. We can take a cue from our chemistry friends, who are very diligent about paying attention to standard temperature and pressure (STP) when setting up experiments. Good lab procedure demands that you have a consistent experimental environment. This applies to electronics as well as chemistry, though sometimes in less obvious ways.

One exercise I give my students is to hand them an old-school 100-watt incandescent bulb and ask them to calculate what the resistance should be. So, they grind away on their calculators and figure out that 100 watts divided by 120 volts gives 0.833 amps, and 120 divided by 0.833 should be around 144 Ω. Then I have them measure the resistance of the bulb, and lo and behold, it's around 15 Ω. I let them ruminate on the discrepancy for a while. Eventually, one of the students suggests that the resistance at room temperature is not the same as when the bulb is lit. Voila! In fact, there's about a 10:1 resistance ratio between a cold tungsten filament and a white-hot tungsten filament. Something one doesn't normally think about. In fact, at the instant you throw the switch, the lamp consumes about 1,000 watts! This is the reason bulbs usually burn out when you throw the switch, not normally after sitting there glowing for days on end. Anyway, it's a simple but revealing exercise.

Insights from RMS

I've confessed several times in this series that I was always lousy at math in my formative years, and it was electronics that gave me the insights necessary to become reasonably competent at math. I've learned some cool things about math in the process.

Let's look at where this root mean square (RMS) thing comes from, why it works, and why we need it to calculate effective power of an ac "signal" across some load resistance. Why can't we just use a "normal" average to figure this out? Well, if we were to simply take the average voltage of an ac signal over many cycles, we'd come out with zero! This is because we have as many negative voltages as positive ones, assuming a perfectly symmetrical sign wave.

Now let's assume that power is always going to be E^2/R at any instant of time. This means that at any point in time, regardless of whether the signal is positive or negative, the *power* is always going to be a positive value. This is the amazing thing about squaring a number: whether the original value is positive or negative, the result is always positive — something we all know, though we may not fully appreciate its significance. Knowing this, we can now take a large number of voltage samples (which directly translate to power samples), take the mean average of all these samples, and come up with a power number equivalent to dc. This is the *root mean square*, which is the special and useful average with which we're familiar.

What I find both odd and amazing about this is that if you take an infinite number of samples and perform the RMS average (which incidentally requires a bit of calculus), that ubiquitous 0.707 (the square root of two divided by two) pops up its pretty little head. Why should this be? What is it about our universe that the square root of two, or the square root of two divided by two, seems to be embedded *everywhere*? I don't have the answer, but it does lead one to really appreciate the math that holds the universe together.

Well, there *is* a way of doing this without calculus, as demonstrated here: **https://youtu.be/SUMecxGfw7E**. But after watching this explanation, it would probably be easier to learn calculus!

Only Three

One thing that's always impressed me with electronics, and why I have never been bored, is that everything we do relies on only three ingredients: resistance, capacitance, and inductance. That's it! No matter how complicated a circuit may be, there are only three ingredients. Now, these ingredients may be highly variable, as they might be in a transistor, or LDMOS device, or a vacuum tube, but there are still only three entities. And yet, there are infinite combinations of them, and a very deep rabbit hole of subtleties associated with them.

Parallel Universe

One thing that's always bothered me about most electronics classes is that they relegate the inverse impedance functions to mere footnotes if they mention them at all. I always bring them up front and center at the same time as I introduce the primary functions. They are:

Conductance (G) = $1/R$
Susceptance (B) = $1/X$
Admittance (Y) = $1/Z$

These values are extremely useful for calculating complex parallel circuits. They are all expressed in mhos (siemens, in modern nomenclature). And it's easy to remember that with mo' mho, you have mo' current flow. What could be more poetically insightful?

Plumbing the Depths

I've always used plumbing analogies wherever possible to describe electrical circuits. Plumbing is fairly intuitive for most people, even non-plumbers, and completely parallels electronic circuits in many instances. There are cases where the plumbing analogy is completely compatible and translatable when describing two of the most important principles we'll ever use: Kirchhoff's Current and Voltage Laws (KCL and KVL, respectively). This is probably a good place to begin our next essay.

Thank you for abiding this quick journey down memory lane. If you're like me, you can use a reminder (or several) of topics we've discussed. — *Until next time, 73, Eric, KL7AJ*

Upcoming Conferences

HamCation 2026

February 13 – 15, 2026
Orlando, Florida

www.hamcation.com

HamCation 2026 will take place February 13 – 15, 2026, at the Central Florida Fairgrounds and Expo Park in Orlando, Florida.

Utah Digital Communications Conference

February 28, 2026
Sandy, Utah

https://utah-dcc.square.site

The Utah Digital Communications Conference will take place February 28, 2026, at the Conference Center at Miller Campus at Salt Lake Community College in Sandy, Utah.

SCaLE 23x

March 5 – 8, 2026
Pasadena, California

www.socallinuxexpo.org/scale/23x

The 23rd Annual Southern California Linux Expo, SCaLE 23x, will take place March 5 – 8, 2026, at the Pasadena Convention Center in Pasadena, California.

Hamvention 2026

May 15 – 17, 2026
Xenia, Ohio

https://hamvention.org

Hamvention 2026 will be held May 15 – 17, 2026, at the Greene County Fair and Expo Center in Xenia, Ohio.

EME Conference 2026

May 28 – 31, 2026
Puerto de la Cruz, Tenerife, Canary Islands

https://eme2026.moonbounce.info

The EME Conference 2026 will be held May 28 – 31, 2026, at the Hotel Botánico & The Oriental Spa Garden in Puerto de la Cruz, Tenerife, Canary Islands.

DFW Ham Expo 2026

June 5 – 6, 2026
Lewisville, Texas

www.dfwhamexpo.com

The DFW Ham Expo 2026 will be held June 5 – 6, 2026, at the Vista Mall Events Center in Lewisville, Texas.

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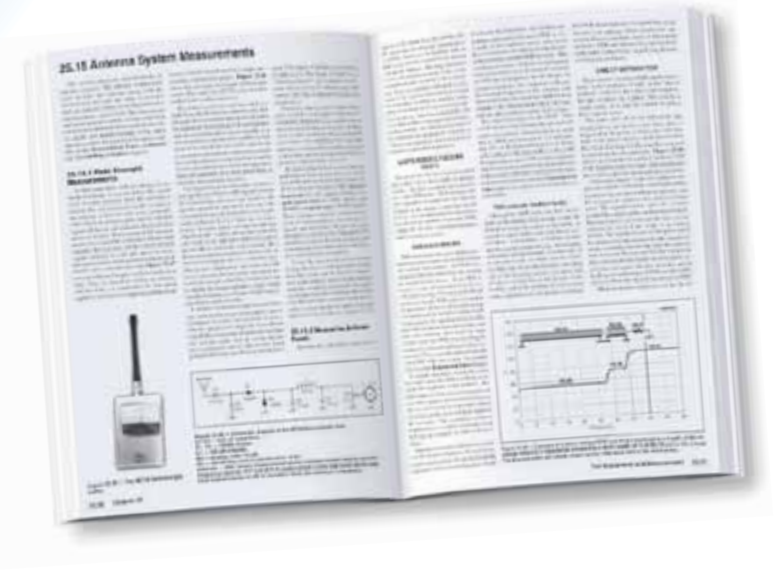

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