The Blue Ridge Microwave Society 10 GHz Q65/CW Beacon

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Introduction

The Blue Ridge Microwave Society (BRMS) **[1]** installed a 1296 MHz (1296.24 MHz) beacon on Poor Mountain near Roanoke, VA (EM97we @ 3800 ft) in September of 2020. It has been on the air continuously since then and it has been copied as far away as EN41 in Illinois. The success of the 1296 beacon generated interest in a 10 GHz beacon. Discussions led to the suggestion that a WSJT Q65 waveform should be added to the traditional CW ID for a 10 GHz beacon.

Q65 would be a good addition. It can tolerate Doppler shift. It can be copied deeper into the noise than CW and it is good for scatter type propagation. Q65 would also enable long term automated monitoring. N6CA published a design for a 10 GHz Q65 beacon in 2022 **[2]**. N6CA's design was relatively complex because at the time there was no simple way to generate a Q65 beacon waveform but it was a useful starting point. Since N6CA's publication, software for the RFzero transmitter has been developed that will generate a beacon compatible Q65 waveform **[3]** and interest in Q65 beacons has been growing **[4]**.

This paper covers the development of the BRMS Q65/CW 10 GHz beacon and some of the relevant lessons learned from the BRMS 1296 MHz beacon.

Basic Beacon Design Considerations

- A beacon runs 24/7/365. It is desired that it operate indefinitely with minimal attention so components must be run conservatively with adequate heat sinking. The 1296 beacon has a 9 lb "boat anchor" class heat sink but no fan. In long term operation, fans tend to get dirty and fail and they are not appropriate for outdoor operation. If outdoor operation is contemplated, robust packaging and careful thermal analysis are required.

- Beacons typically run in a hostile RF environment. The 1296 beacon shares a location with three high power FM broadcast transmitters that radiate a total of 400 kW! Near by are additional TV/FM broadcast transmitters, cellular systems and dozens of repeaters. A beacon must be protected from interference but it must not generate interference either. Shielding, careful filtering and operation to commercial standards are a must. Then there are the buzzards that attack the cables!

- Because of the remote location, remote control is desirable as is some kind of telemetry to monitor beacon health. This can be done either via radio or through the Internet if it is available. The 1296 beacon has some front panel monitoring and it was configured for remote control but that was never fully implemented.

- A beacon will be used as a reference source. It should be clean and stable. Frequency accuracy/stability, timing accuracy and low phase noise are important considerations particularly for Q65. The 1296 beacon was not GPS referenced but it is only 10-20 Hz off frequency after 5+ years of operation due to its high performance ovenized crystal oscillator (OCXO).

Beacon Indoor Unit

Figure 1 is a block diagram of the beacon. It is essentially the transmit side of a transverter. The local oscillator (LO) starts with a Leo Bodnar GPS source **[5]**. It is programmed to generate 429 MHz and that is multiplied up to 10296 MHz. This is mixed with a 72.24 MHz RFzero generated Q65/CW waveform to produce an output frequency of 10368.24 MHz. 60D was chosen as the Q65 sub-mode. It is the recommended sub-mode for tropo scatter and rain scatter on 10 GHz **[6]**. **Figure 2** is the time signature generated by the RFzero. A JCA48-4111B1 amplifier following the mixer and a filter raises the output level to approximately 20 dBm.

The 50-200+ MHz range in the mountain top RF environment contains many signals some of which are quite strong. The presence of multiple FM repeaters in the 2 meter amateur band discouraged the use of a conventional 144 MHz based transverter design. There is a lightly occupied gap in the TV band between 72 and 76 MHz. 72.24 MHz was chosen as the IF to fall in that gap.

A computer mixer spur analysis was done to insure that there were no close in-band spurs generated by the mixing frequencies. A three resonator 72.24 MHz bandpass filter (BW: ~5 MHz) is included in the RFzero output to suppress close by TV signals and any potential RFzero output spurs. However, the use of 72.24 MHz as the IF required a high performance 10 GHz filter. A post coupled 5 resonator WR75 waveguide filter was designed with WGFIL **[7]**. The filter suppresses the LO by more than 55 dB and the image mixing product is suppressed to the limit of measurement at about 75 dB below the carrier. There appears to be no out of band spurious.

A word about the beacon frequency. With the GPS, the beacon carrier is exactly 10368.24 MHz. Tuning to that frequency in an USB mode, the carrier will be at zero beat and the Q65 will decode starting about 350 Hz higher. Tuning 500 Hz lower (10368.239500 MHz) will result in a 500 Hz carrier beat note and the Q65 decodes at approximately 840 Hz. This was confirmed with an IC905 with its 10GHz converter. In a CW mode, tuning to 10368.24 MHz gives a 500-600 Hz beat note and the Q65 will decode at about 840 Hz but the receiver IF filter must be wide enough to pass all the relevant frequencies.

Figure 3 is the block diagram of the local oscillator. It starts with a Leo Bodnar GPS programmed to output 429.000000 MHz. Since the Leo Bodnar outputs a square wave, it is followed with a 5 section 600 MHz low pass filter and a level setting attenuator. The output is multiplied by 12 in a MiniCircuits ZX90-12-63-S+ multiplier. An amplifier raises its output to drive a MiniCircuits ZX90-2-50-S+ diode doubler. The multiplier parts are cost effective and they can be ordered directly from MiniCircuits **[8]**. A 3 resonator WR75 waveguide filter tuned to 10296 MHz filters the doubler output and an amplifier following the filter outputs approximately 10 dBm for the mixer. The output is very clean with the exception of two spurs one at +/- 15 kHz and another at +/- 6.2 MHz of 10296 MHz. They are likely due to the Leo Bodnar but they are over 55 dB down so they aren't a problem.

The passive diode multipliers in the MiniCircuits parts introduce almost no excess phase noise. The LO phase noise was measured using an HP8673B microwave synthesizer as the reference. The HP8673 and the Leo Bodnar LO were locked to GPS so they both output exactly 10296 MHz. While the two sources were locked to a common source, their phase noise spectrum should be independent at least at the relevant offsets. The two signals were applied to a diode ring mixer. The phase noise spectrum is mixed down to baseband, and after mixer calibration, it was measured with an HP3561A dynamic signal analyzer (a FFT based low frequency spectrum analyzer) **[9]**. The measured phase noise at 10296 MHz is -84 dBc @ 1 kHz offset and -94 dBc @ 10 kHz offset. This is acceptably good and it is consistent with the published phase noise values for the Leo Bodnar. The phase noise may even be somewhat better as the measurement appears to be limited by the phase noise from the HP8673.

Frequency and timing stability and accuracy are particularly important for Q65 operation. The RFzero has a built in GPS receiver that establishes the Q65 timing. The Leo Bodnar GPS establishes the carrier frequency. The two GPS receivers share a common antenna through a MiniCircuits ZAPD-20-S+ power splitter. It was modified with a DC block for each receiver and with the addition of a bias tee and a voltage regulator for a 5V GPS antenna. It is a marine antenna that should be able to withstand the harsh RF environment and long term exterior operation.

The RFzero has several activity LED's. These were brought out to the front panel via feed thru capacitors. They are a useful guide to indicate that the beacon is operating properly.

Figure 4 is a picture of the indoor unit. It is built into a 3U rack box **[10]**. The box was chosen for its RF integrity. The RFzero is shielded in a die cast box and the RF modules, amplifiers and filters are all in RF tight enclosures.

The 10368.24 MHz output is fed through low loss microwave coax to the outdoor unit. Power is fed to the outdoor unit through a multiple twisted pair cable. The pairs are #22 wire. Given the length of the cable, they have significant resistance so several pairs are connected in parallel to reduce the resistance. These lines are protected with diode transient suppressors and feed thru capacitors with ferrite beads at each end of the cable. The cable has a copper shield with a tough weather resistant jacket. The Ethernet connection for the computer is a shielded RJ-45 dongle. Mains power is fed through a filtered power entry module. After the fuse, 130V varistors were placed line-to-line and line-to-ground to suppress potential line transients.

The beacon is powered by two Mean Well switching power supplies. While Mean Well supplies were successfully used in the 1296 beacon, they do require some additional filtering to suppress their switching noise. The chosen supplies have an 18V maximum output and low dropout linear regulators configured to minimize the switching noise are used to provide 12 V and 15V for the amplifiers in the indoor unit. Measurement suggests that the voltage regulators adequately suppress the Mean Well switching noise. Additional 7805 regulators provide 5V for the control computer, the RFzero, the Leo Bodnar GPS, and the GPS antenna. A 7808 provides 8V for the ZX90-12 multiplier. The 0.092" thick aluminum walls of the rack box adequately heat sink the voltage regulators and the microwave amplifiers.

The need for the second supply may not be immediately obvious. Power is fed up a cable to the driver and output power amplifier (PA) in the outdoor unit. Since the outdoor unit draws approximately 2 amps there will be a voltage drop in the cable. It is undesirable to have a voltage difference between the indoor unit and the outdoor unit so both the plus and minus outputs of the second supply are fed up to the outdoor unit where the supply minus is grounded. That eliminates the voltage difference but there is now a voltage drop in both the positive and negative feed.

Outdoor Unit

Figure 5 is the outdoor unit. It is built into a Hammond EJ12108AL (12” X 10” X 8”) aluminum enclosure. It is rugged but it was more expensive than the corresponding steel enclosure. However, the aluminum enclosure is much lighter than the steel and it won’t rust. The aluminum adds to the heat sink area. A 10” X 9” X 1.25” heat sink was placed in the rear panel. It plus the enclosure provides adequate heat sinking for the PA without a fan. The metal enclosure offers shielding that a plastic enclosure would not.

The microwave coax that connects the indoor unit to the outdoor unit is LDF1-50. Its measured loss is approximately 16 dB at 10 GHz for a 100 feet of cable. The main components in the outdoor unit are a 26 dB gain driver amplifier and a 4W PA from PE1RKI **[11]**. The gain of the driver amplifier compensates for the loss in the cable and its effective gain was adjusted with an attenuator to set the drive for the PA. The output of the PE1RKI amp was set at approximately 2.0 watts. While the PE1RKI amplifier is capable of higher power, it is limited by the available drive. MIC29502 and LM1084 low drop out voltage regulators supply 12V for the PA and 6V for the driver amplifier respectively.

Since the outdoor unit is exposed to the outside environment a thermal analysis was part of its design. A weather station located near the top of Poor Mt. had several years of recorded temperature data. The min/max temperatures on the mountain were estimated to fall between -26°C and 35°C (-15°F to 95°F). The outdoor unit dissipates about 25W and the measured heat sink thermal resistance is approximately 0.3°C/W. Thus the heat sink will run approximately 7-8°C above the ambient: -18°C to 43°C (0°F to 110°F).

The outdoor unit amplifiers and heat sink were temperature tested from approximately -4°C to 43°C (25°F to 110°F) in a household freezer and oven. While the temperature specifications for the amplifiers are unknown, the temperature performance of the PE1RKI amplifier was acceptable in the test. It replaced a 2 W Harris 076-108687-001 amplifier that was used in the original design. The performance of the Harris amplifier was disappointing as it exhibited more than 3 dB of power variation over the test temperature range. While many low cost plastic packaged devices are specified for operation between 0°C to 70°C, all the components used in the outdoor unit were specified to operate down to at least -25°C. The transistors used are in hermetically sealed metal packages.

Antenna

Figure 6 is a 16 slot WR90 beacon waveguide antenna. It is a proven design from W1GHZ **[12]**. The addition of a pair of side “wings” result in a more uniform omnidirectional pattern. The slots were placed with a Taylor amplitude distribution. The wings and the amplitude distribution make for a cleaner pattern at the price of a small reduction in antenna gain.

A three screw tuner was placed in the waveguide for matching. The measured return loss exceeds 20 dB. The beacon’s effective radiated power is approximately 15-18 watts.

A section of 6 in diameter Schedule 40 PVC pipe protects the antenna from the elements. The PVC was checked for loss by running a piece of it in a microwave oven. It got slightly warm so a test was devised to determine if the PVC antenna shroud introduced unacceptable loss. The antenna was excited with approximately 0.25W at 10368 MHz. The radiated power was measured with 15 dB gain horn and an HP435 power meter located approximately 4 meters away. There was no substantial difference in the measured power with or without the shroud although the shroud slightly changed the antenna's return loss. The antenna shroud and the outdoor unit were sealed with an electronics grade non-corrosive RTV silicon rubber (ASI 388). Weather proof vents were installed in the beacon enclosure and antenna shroud to prevent condensation. They are screened to keep the critters out.

The slot antenna acts as a relatively narrow band output filter and the WR90 waveguide won't support anything below about 6.5 GHz. A ferrite isolator in the PA output offers additional protection from signals that may enter through the antenna. The isolator prevents external signals from reaching the PA where they can be mixed in the PA's non-linear output stage and the mixing products re-radiated to cause interference. An evanescent mode bandpass filter and a ferrite isolator serve the same function in the output of the 1296 beacon.

Telemetry

Since the outdoor unit is exposed to the environment extremes, remote monitoring of the outdoor unit heat sink temperature and the PA output power was desired.

The temperature is monitored with a thermistor embedded in the outdoor unit heat sink. The resistance value of the thermistor is sent down on a twisted pair. The thermistor is electrically isolated from the outdoor unit. It is powered from the indoor unit and the control computer calculates the temperature. Given the low current involved, there is little voltage drop in its twisted pair.

A 20 dB directional coupler and a 10 dB attenuator with a diode detector monitors the PA output power. It outputs an analog voltage of approximately 1.5 V for a 2 watt output. The detector drives two LMC6482 rail-to-rail op amps configured as a voltage controlled current source **[13]**. The current is sent down on a twisted pair to a resistor in the indoor unit. There the resistor scales the current into a voltage. The computer reads the voltage and squares it to estimate power using a linear curve fit. Detector non linearity tends to limit the accuracy of the power estimate below approximate 0.5 watt. The current source makes the resistance of the twisted pair irrelevant. Both the thermistor leads and the output of the controlled current source are sent through ferrite beads and feed thru capacitors with diode transient suppressors at both ends of the cable.

Computer Control

Remote control through the Internet with either WiFi or wired Ethernet was available on Poor Mt. To avoid potential radio problems in the RF environment, the wired Ethernet was chosen. The control computer is an Arduino Uno with an Ethernet shield. An IP address, a username and a password are required to access the control software. The user interface is simple text but it gets the job done.

Arduino analog to digital converters (A/D) read the voltage generated by the thermistor circuit and the scaled PA output voltage power. The heat sink temperature and the RF output power can be read remotely over the Internet. The computer also controls an additional Arduino shield with power relays. One relay can disconnect the DC that powers the outdoor unit, A second relay is available to control the 1296 MHz beacon. Switches on the back panel of the indoor unit permit normal computer control or bypassing the computer to turn the beacon permanently on or off.

Installation

The completed beacon was successfully run on the bench for several weeks. While the 10 GHz beacon is much more complex than the 1296 beacon, it hoped that it will be just as robust.

The beacon should be on the air by spring. Arrangements for installation with the 1296 MHz beacon on Poor Mountain are underway. Mounting to protect it from the icing that is common on the mountain is being studied.

Conclusion

While most of this paper describes the technical aspects of the beacon, it is important to realize that successful beacon development and operation is more than just hardware. The BRMS 10 GHz beacon has been a team effort. The idea for a 10 GHz beacon with Q65 came from discussions on the BRMS group site. As a result of those discussions, K4RCA researched and obtained a number of the beacon components including the Leo Bodnar GPS, the RFzero and the PE1RKI power amplifier. WA4PGI provided the computers. He wrote the telemetry and the Internet control software and programmed the RFzero with the Q65 software. KE4RGY provided the microwave coax with its connectors and the cabling for the power, the computer and the GPS antenna. W4YN, a professional machinist, made the antenna on a CNC machine. We thank W1GHZ for the published antenna and waveguide information. W4KZK located the Poor Mt. weather data. KF4YLM and his team arranged for hosting and installation. While it is not possible to acknowledge everyone, our thanks go to a number of others who have offered helpful suggestions and supplied various components. With the Internet control, several of us have the responsibility to keep an eye on the beacon to insure its proper operation.

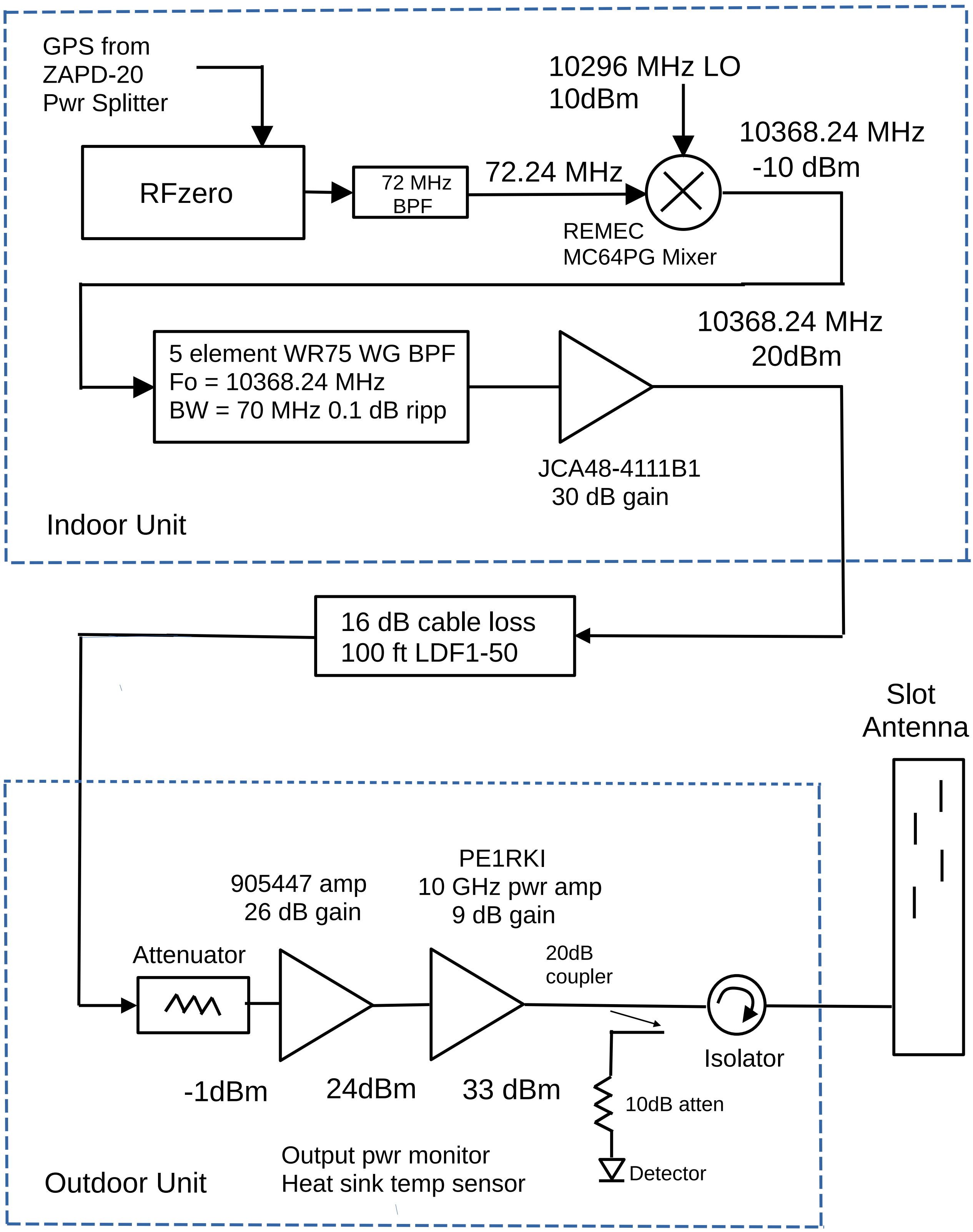

Figure 1: Beacon Block Diagram. Gains and power levels are approximate.

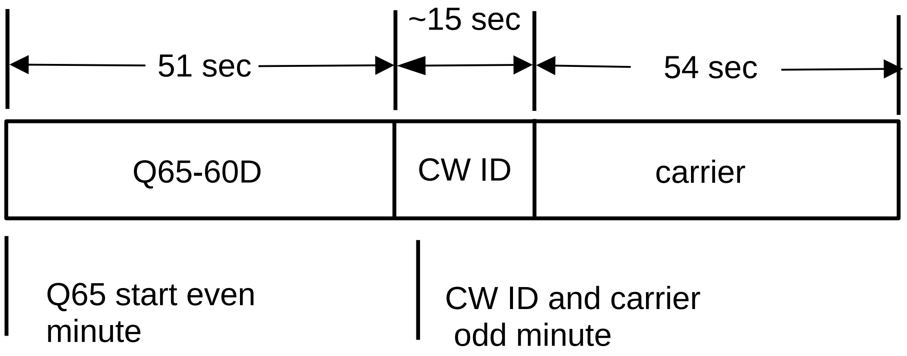

Figure 2: Beacon timing. In the absence of GPS lock, the RFzero transmits only the CW.

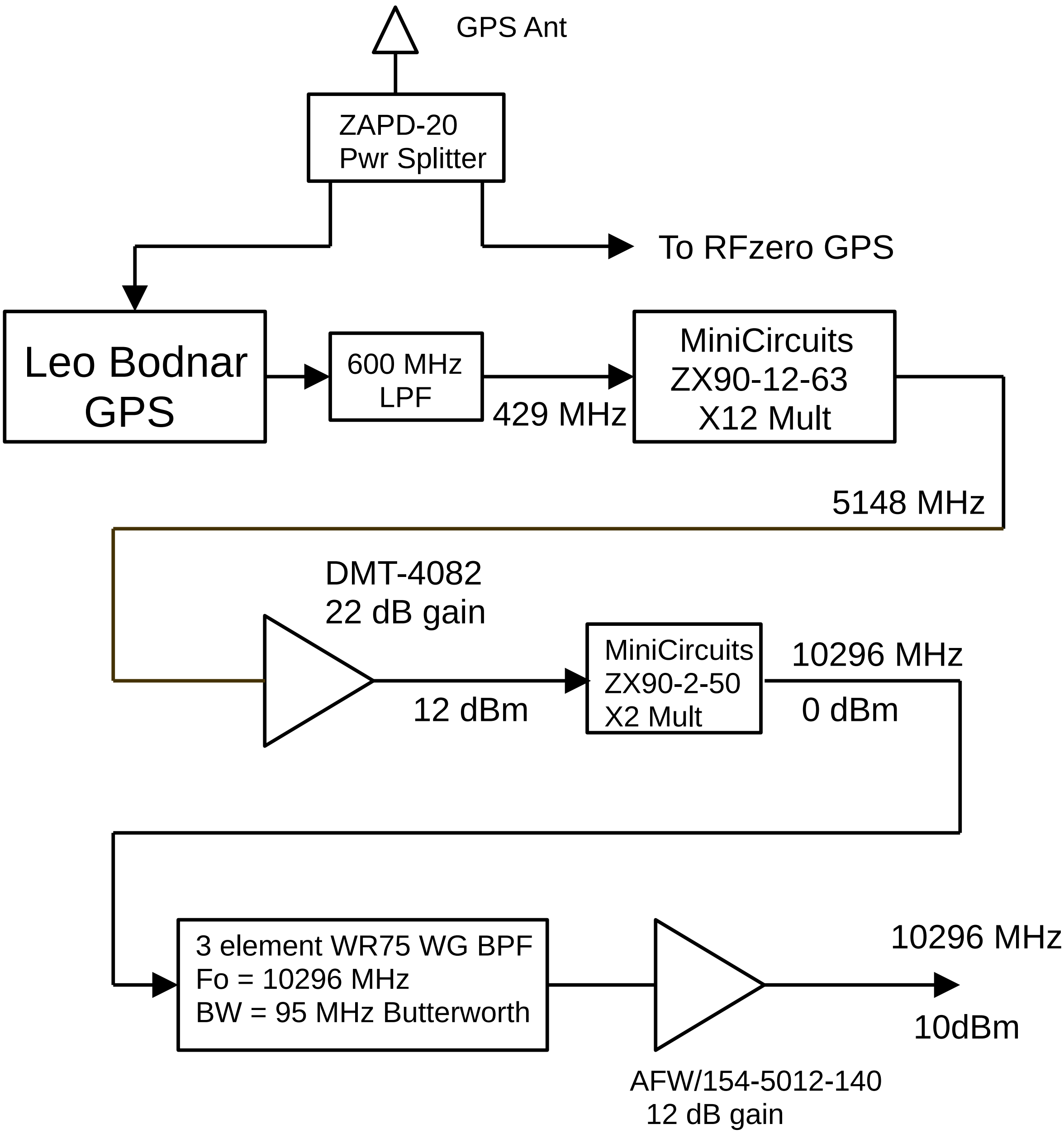

Figure 3: 10 GHz beacon local oscillator (LO). The MiniCircuits X12 has modest filtering so only an output filter is required. Gains and power levels are approximate.

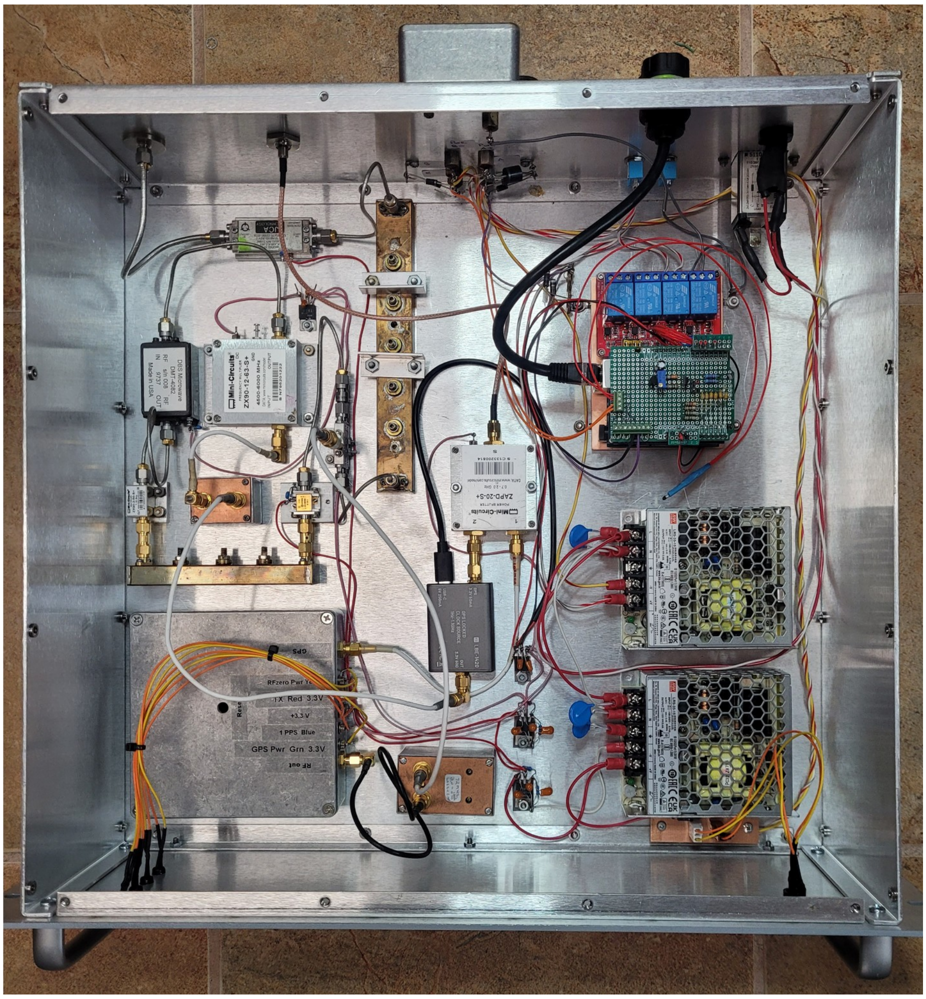

Figure 4: The indoor Unit. On the upper right is the control computer and below it are the power supplies. The RFzero is in the box on the lower left. The LO and the up converter are above it. In the center is the Leo Bodner GPS and the GPS antenna splitter. The 72.24 MHz filter is below them. The voltage regulators are between the Leo Bodnar and the filter and the power supplies.

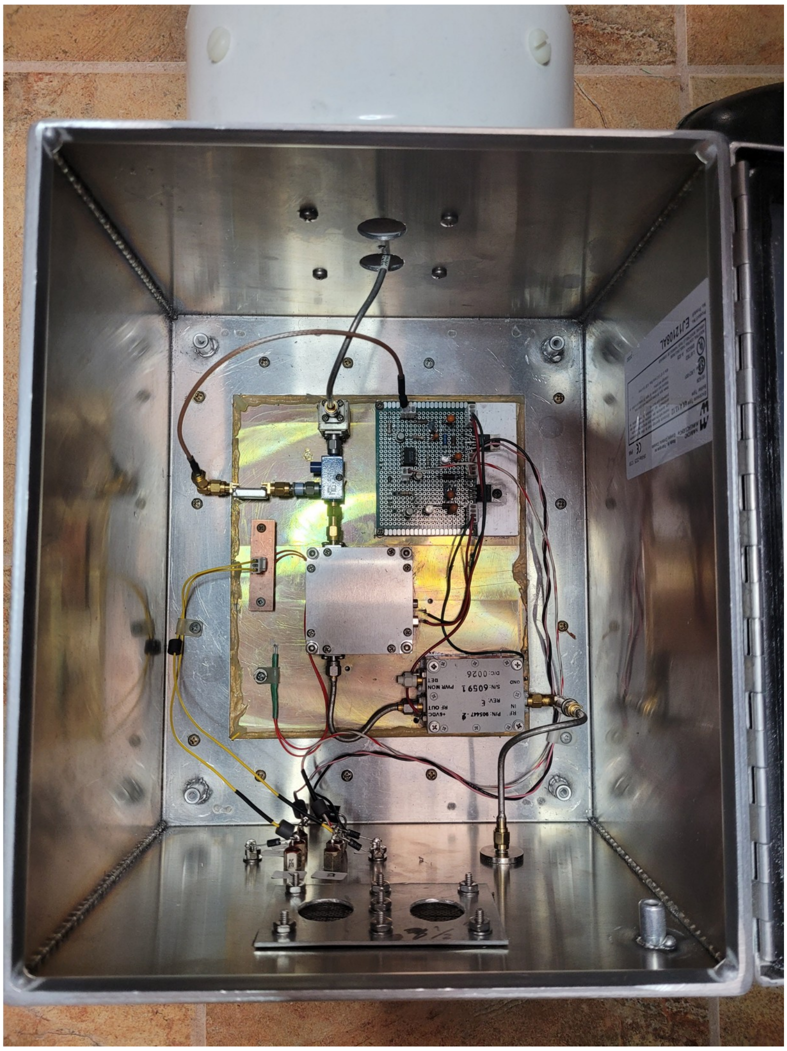

Figure 5: Outdoor Unit. The driver amplifier is in the lower right. The PE1RKI amplifier is in the center. The voltage regulators and output current source are on the upper right. To the left of it is the directional coupler and power detector. The back wall is the heat sink.

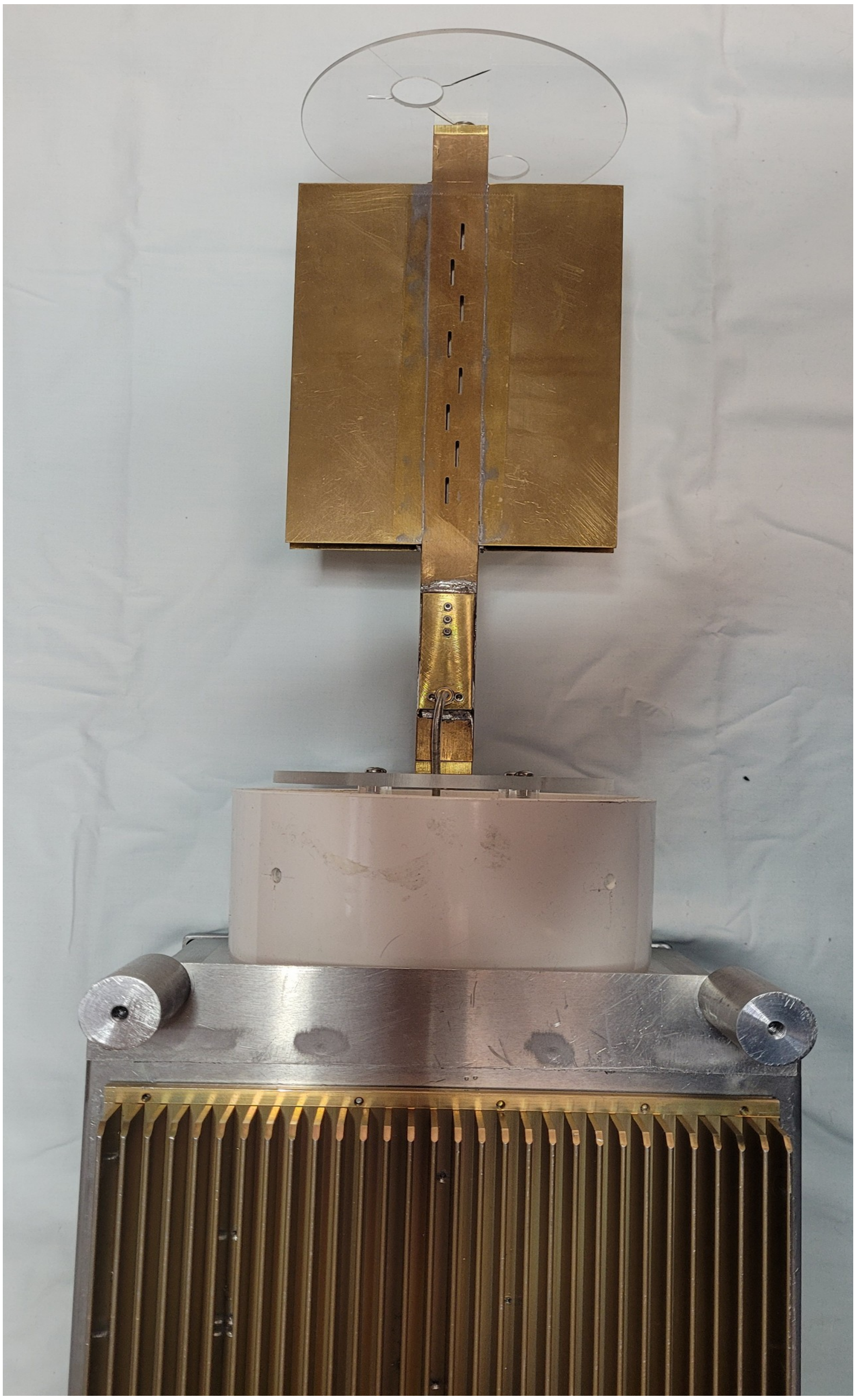

Figure 6: Antenna and outdoor heat sink. The PVC shroud is removed.

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