Progress Toward 47 GHz EME

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Introduction

Over the last four years I've been working on developing 47 GHz EME capabilities. At this point in time the station is just reaching completion and echo testing will start in the next few weeks. While I would like to be able to report first echo's on 47 GHz the station wasn't ready in time for the conference proceedings. I will have more news to report at the conference.

History

My interest in attempting 47 GHz EME began when I found a surplus Hughes 8901H millimeter-wave TWT. With help from W0EOM I was able to find a specification sheet on the tube that indicated it should be capable of more than 32 watts output at 47 GHz. Unfortunately the spec. sheet didn't document the color coding used on the tube leads and based on some simple resistance measurements it didn't seem to follow the standard Hughes color code. Further attempts to obtain information were unsuccessful and for a couple of years the project was stalled.

When Al W5LUA acquired a Hughes millimeter-wave TWT the interest in pursuing the project was renewed and Al, Barry VE4MA, Will W0EOM and myself started working on receiving systems and making sun noise measurements. With sun noise results that looked promising it was time to tackle putting together the rest of the station.

A donation to the Stanford ARC (W6YX) of a trailer mounted positioner from the estate of Tay Howard W6HD greatly accelerated the building activity. I decided to build the station on the W6YX site since my own location is surrounded by large trees and has an extremely small moon window. A 1.8 meter Prodelin dish was purchased and mounted on the positioner and further sun noise measurements indicated excellent performance and tracking.

Testing by Barry of the TWT he uses at 24 GHz indicated that it would not produce sufficient power at 47 GHz for EME so he started searching for an alternative power source. At this point I was lucky to acquire a complete working Hughes 8030H millimeter-wave amplifier so I was able to loan the 8901H TWT to Barry for use at his end. Along the way I also found a Hughes 25 watt combined IMPATT amplifier but based on the experience of W0EOM in retuning single IMPATT amplifiers at 47 GHz this was left for the future since it would require the tuning of 36 individual IMPATT amplifiers!

An additional year was spent building a locked LO chain, the microwave up and down converters, T/R control systems and system assembly. As I'm writing this paper the station is very near completion for echo testing in late June 2004.

47 GHz EME Path loss

Will 32 watts be sufficient for EME at 47 GHz? As DJ7FJ described the path loss calculation at 10 GHz and above when using large dishes cannot be done with the standard RADAR equations. On the transmit side using a 1.8 meter dish the 47 GHz 3db beamwidth is about .25 degree, significantly under illuminating the moon. The 47 GHz energy reflected by the moon relative to an isotropic radiator can be estimated as:

+45 dbm (32 watts transmit)
-2db (Atmospheric attenuation)
-12 db (Moon reflectivity)
+3db (Moon reflector gain over isotropic)
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+34 dbm EIRP

Atmospheric loss at 47 GHz is significant due to oxygen and water absorption. I estimate that at 45 degree elevation and 0.2 db/km loss the atmosphere looks like a 2 db attenuator. Using +34 dbm EIRP reflected from the moon the standard path loss equation can be used to calculate the received signal:

-232.8 db (Free space pathloss = 32.45 + 20log(47000) + 20log(222000))
+56 db (1.8m antenna gain, 50% efficiency)
-2 db (Atmospheric loss)
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-144.8 dbm received signal

The receiver sensitivity at 47 GHz is limited in two respects: noise figure and bandwidth. State-of-the-art amateur LNAs can achieve noise figures in the low 4 db range. Due to Doppler smear the receiver bandwidth will likely need to be 1 KHz wide so the receiver sensitivity is then calculated as:

-142 dbm (10log(kTB) T=400K, B=1000Hz)

So the S/N ratio is –2.8 db! This seems close enough to working that it needs to be tried. Several factors are uncertain: Doppler smear, atmospheric attenuation, moon reflectivity at 47 GHz … so maybe with some luck it could work. Notice that due to the under illumination of the moon the earth-moon distance only effects the moon to earth path loss but it's still helpful to have a high elevation moon (minimum atmospheric loss) at perigee (minimum path loss). The Doppler smear at 47 GHz should be greater than at 10 or 24 GHz due to the shorter wavelength but the narrow antenna beamwidths may offset this factor.

Early Sun Noise Experiments

47 GHz receivers were constructed by VE4MA, W5LUA and AD6FP &W0EOM in early 2002 in order to make sun noise measurements and test various dishes that were available. For most of my measurements I used a 3' TRG precision dish that had previously worked well at 76 GHz. Although this dish showed reasonable sun noise (5.8 db) it was lacking when compared to W0EOM's 2' dish. The conclusion was that the efficiency was low due to improper illumination of the cassegrain feed system. This 3' dish would also be too small for EME as evidenced by the path loss calculations so a search for a larger dish was started. Barry's measurements of various Prodelin single piece offset dishes made for Ku band looked promising so a Prodelin 1.8m dish was acquired.

Power Amplifier

Hughes 8030H 32 watt TWT Amplifier

The power amplifier is the key component required to be able to attempt EME at 47 GHz, all the other system components readily available but 47 GHz high power amplifiers are extremely scarce. Over the course of four years I was lucky to find three millimeter-wave power amplifiers. As previously mentioned the IMPATT amplifier was shelved in favor of the TWTAs since they are easier to work with and provide more output power. The Hughes 8030H amplifier uses the same 8901H tube that I had previously acquired so the job of deciphering the TWT lead color codes was thought to be solved. Unfortunately after opening the 8030H amp. I found that while it used the same TWT there were differences in the tube construction so the lead correspondence was not obvious. Several calls to DynamicWave finally resulted in a complete operation and service manual for the 8030H amplifier that explained all of the mysteries of the 8901H TWTs. VE4MA is now working on adapting a power supply to use with the spare 8901H TWT. I only had to make one modification to the 8030H to remotely switch the beam current on/off from the T/R controller.

W6HD Positioner

The positioner is mounted on a trailer that W6HD had been using for 10 GHz EME. It's a 1950s vintage unit that has gone through numerous modifications and repairs. Both of the brackets holding the elevation gears have been welded to repair major cracks and the drive system has been retrofitted with 24v DC motors.

W6HD Positioner

Tay had been in the process of adding US Digital A2 encoders to the positioner but hadn't completed the modifications. I wound up mounting an A2 encoder directly to the elevation axle by drilling and tapping the axle for a ¼-20 bolt. A zero backlash flexible coupling ties this bolt to the shaft of the A2 encoder which is then weather proofed using a plastic food container as seen in the photo. This arrangement has worked reliably for the last two years. The Azimuth A2 encoder replaces a synchro that had been originally used in the positioner.

A KK6MK controller board interfaces the motors and encoders to a PC running the F1EHN EME-system. After careful leveling of the trailer and calibration using a remote beacon, the sun and the moon the positioner seems to reliably track to less than 0.1 degree accuracy. The US Digital encoders and KK6MK interface have been a joy to use.

The Dish

For years I've been using a 1.2 M Prodelin offset dish for terrestrial 10 and 24 GHz contesting. Although these dishes are only spec'ed for Ku band they seem to perform well at 24 GHz and VE4MA reported good results using his 2.4 M dish at 47 GHz so it seemed worth a try. The 1.8 M size seems to be the largest size that Prodelin currently

Prodelin series 1183 1.8 meter dish

offers in single piece construction and I had concerns about the surface accuracy of a 2 or 4 part dish so I ordered a 1.8 M single piece Prodelin series 1183 dish. Being quite familiar with the size and weight of their 1.2 M offset dish I was surprised at the difference, the 1.8 M dish requires two people to lift and even at that it's quite a task! The initial sun noise measurements with the 1.8 M dish were disappointing, about 5 db sun noise, no better than the 3' precision dish. Based on VE4MAs experience I tried covering the surface of the dish with aluminum foil. Using 3M "77" adhesive, strips of household aluminum foil were glued in overlapping sections to the dish surface. The difference was remarkable, sun noise measurements are now consistently 8.9 to 9.2 db depending on the Sun elevation.

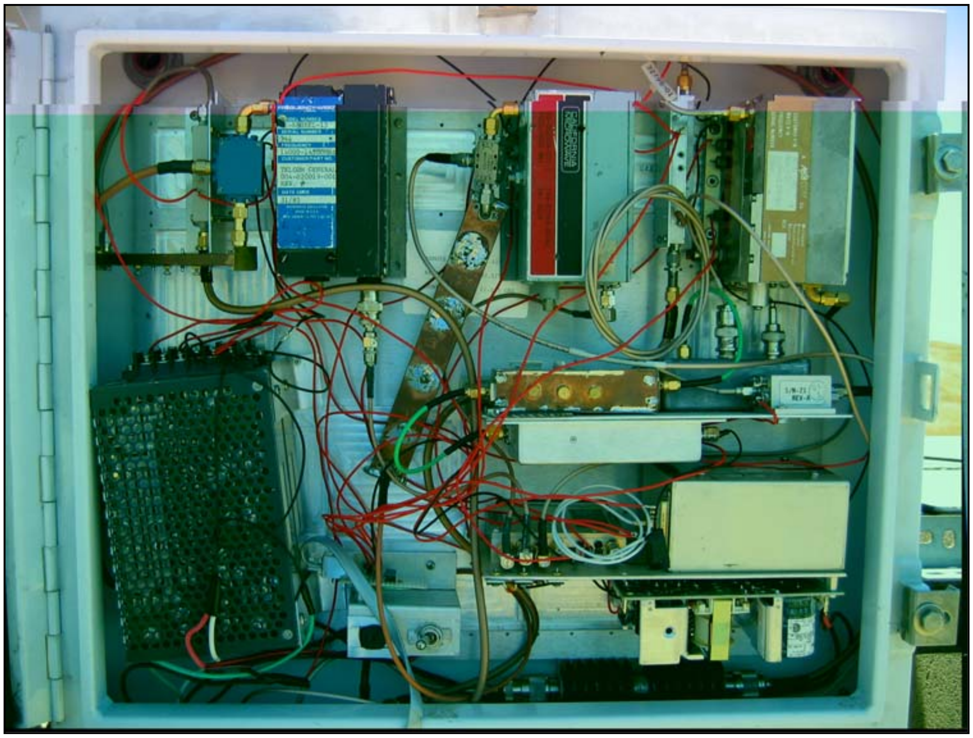
Feedhorn

The feedhorn being used is a W2IMU type dual mode horn. Its construction is similar to that described by VE4MA being machined out of a piece of brass rod with the transition angle cut with a drill bit reground to the correct angle. A piece of hobby brass tubing is used as circular waveguide soldered into the brass horn and then tapered to a rectangular wr-22 flange. A 6 inch piece of wr-22 flexible waveguide is used to isolate the feedhorn from any motion due to the weight of the Power Amplifier and microwave frontend mounted just below the feed point. The feedhorn photo shows the nice negative horizon at the W6YX site to the Southeast.

Dual Mode W2IMU Feedhorn

Local Oscillator Chain

Most of the RF construction work of this project went into building the local oscillator chain. The LO chain is housed in a weather proof box mounted on the backside of the dish. Three six foot long coaxial cables feed the LO and IF signals to the millimeter-wave frontend that is mounted below the feedhorn at the front of the dish. As seen in the photo heavy use was made of surplus components ("bricks", mixers and amplifiers) to construct the LO chain.



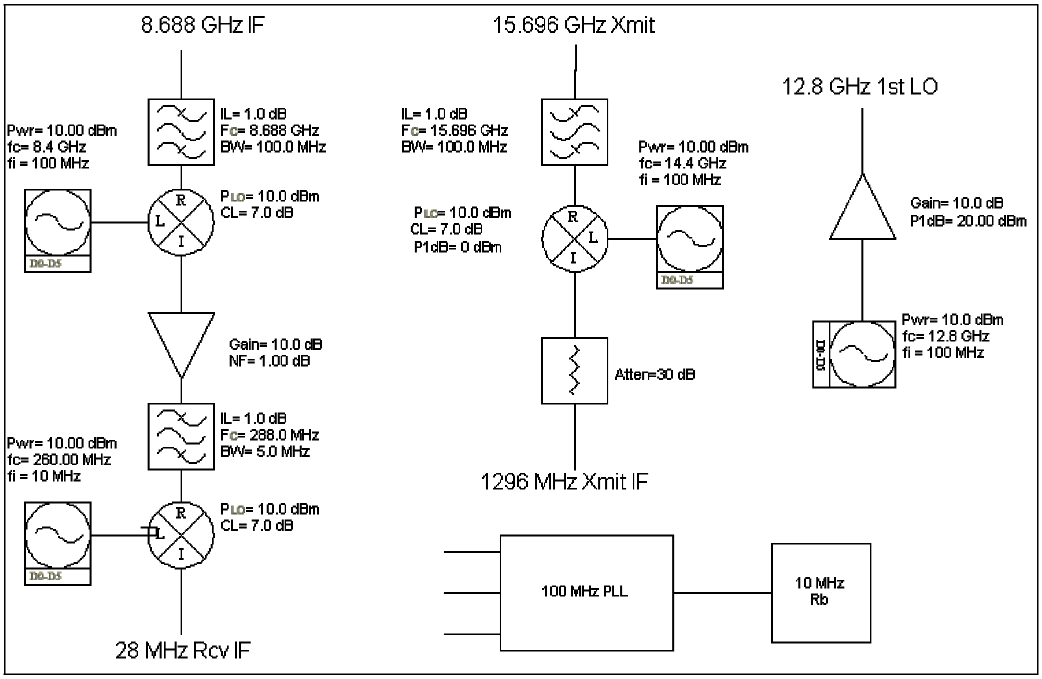
47 GHz LO Chain

Several decisions drove the design of the LO chain:

1) Double conversion on receive with a high first IF
2) Use of a X3 multiplier on transmit as a TWT driver
3) Everything locked to a Rubidium oscillator

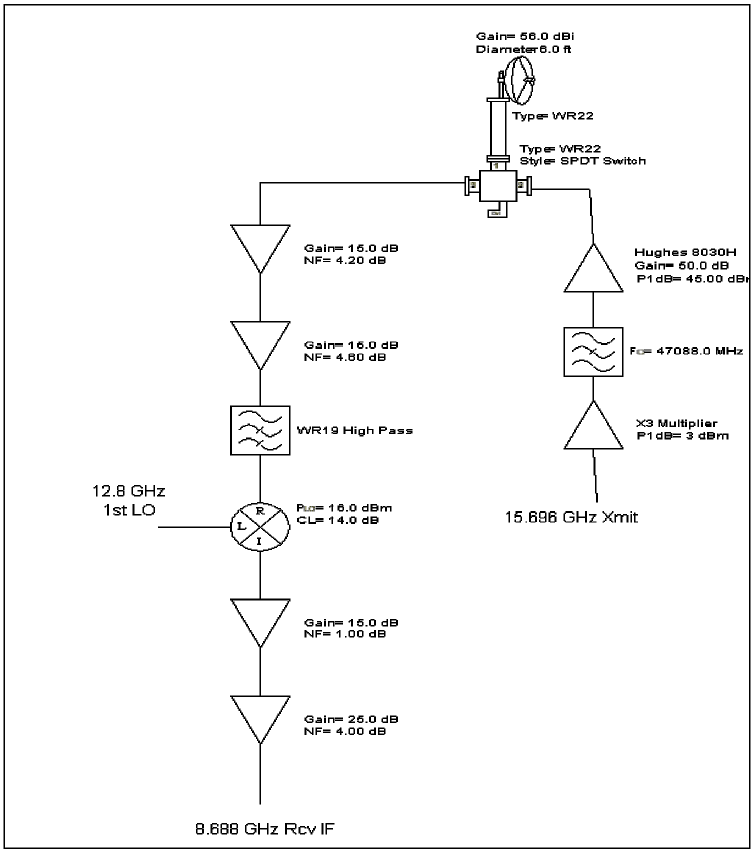
The high first IF (8688 MHz) was chosen so that the image frequency of 47088-2*8688 falls below the cutoff of wr-19 waveguide. This lets me use a short piece of wr-19 as an image filter ahead of the 47 GHz mixer. The X3 multiplier was a piece of surplus that was on hand and could provide the 0 to 1 dbm of drive required by the TWTA. Finally my terrestrial microwave experience is that it's nice to remove any frequency uncertainty from the process of making weak signal contacts so locking to a precise reference was required.

I wanted to minimize the number of PLLs required to lock everything to the 10 MHz Rubidium so after doodling around with a calculator I came up with the LO scheme shown in the block diagram:

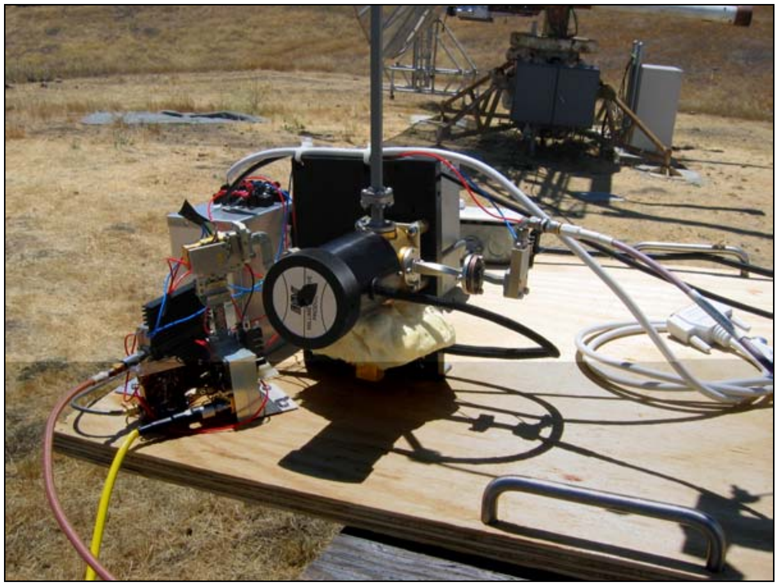


All of the microwave bricks use a common locked 100 MHz PLL as a source. The second receive conversion locks directly to the 10 MHz rubidium. Using a TS-2000x as the IF rig in satellite mode allows me to simultaneously receive on 28 MHz while transmitting on 1296 MHz. This gives me a simple “loop back” check that the system is working and the frequencies are correct. In addition the three bricks, two PLLs and Rubidium all have lock status LEDs that can be monitored from the operating position.

Microwave Frontend



The 47 GHz up and down conversion sits out at the front of the dish just under the feedhorn in order to minimize transmission line loss. The first receive LNA is mounted below the waveguide switch so that a dewar of liquid nitrogen can be used to cool it. The waveguide switch is a Hughes stepper type that requires 6 pulses to step it between stops. Optical feedback is used to ensure the switch is in the correct position before the beam of the TWT can be enabled or the TWT drive is applied. The control of the waveguide switch is done with a PIC 16F84A embedded microprocessor. The 47 GHz receive mixer is a Philips 39 GHz upconverter that was commonly seen on the surplus market. With correct bias, high LO drive and input matching these 39 GHz upconverters perform reasonably well as 47 GHz receive mixers.



47 GHz preamps, mixer, X3 multiplier, waveguide switch and 8.688 GHz post amps under the feedhorn

Calibration Beacon

As a means of calibrating the positioner as well as a weak signal check of the receiver a 47 GHz weak signal beacon was constructed. The QTH of Lars AA6IW is 3.9 km from the trailer and line-of-sight; it provides an excellent location for the weak signal beacon. The beacon is quite simple, just a 23.5 GHz DMC brick driving a diode doubler providing about 100 microwatts on 47091 MHz. The beacon has also been useful as an antenna range to measure the dish pattern and side lobe levels as well as finding the focal point for the feedhorn.

Cooled LNA experiments

Since the calculated signal margin is negative I decided to investigate the most likely path for gaining a bit more margin: LNA cooling. This has been used in the past by amateurs on lower frequencies and at NF measuring contests but of late has not been required since room temperature device noise figures are sufficient through 24 GHz. The case is different at 47 GHz with the best amateur achievable noise figures in the 4+ db range.

My first experiments were with dry-ice cooling of the 4.2 db NF preamp. By packing the preamp in dry-ice and giving it several minutes to cool down the noise figure dropped to the 3.0 – 3.2 db range, a nice improvement! With this encouraging result I decided to go all out and try LN2 cooling.

After looking for an LN2 dewar for several months one finally showed up at a local surplus dealer. The local cryogenic gas supplier is willing to fill my 8L dewar with LN2 for $40. The dewar will hold the LN2 for over a month and for my purposes 8 Liters is a lot of LN2.

Stealing a commuter vacuum insulated stainless steel coffee cup from the kitchen to use as a mini-dewar I started fabricating a test setup. Using construction spray insulating foam I made a new top for the coffee cup that was molded around the LNA. The results have been quite good: consistent noise figures in the 1.5 – 1.7 db range have been measured on the bench. This may just provide the additional signal margin that is necessary to hear echoes or make a QSO.

Summary

A multi-year project of this scale requires help and advice from many others. I'd like to thank VE4MA, W5LUA, W0EOM, AA6IW, W6QI and the W6YX club for providing valuable assistance.

References

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