# Experiments Using Mother Nature's
# ELEVATED ANTENNA RANGE
## At Thacher Park, Near Albany, New York

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Making an accurate antenna measurement is one of the most difficult things to do well in engineering radio communications systems. And yet, getting the most out of the antenna system is so very important for overall success. Measuring an antenna requires interacting with the real world. Ultimately we must abandon our computers and understand how our physical antenna interacts with other objects in the environment. And interact it will! We will almost always be amazed at how "little things" will upset our measurements and what "we think" is really going on. The experience will almost always be very frustrating, usually illuminating, sometimes rewarding, but it is certain to be interesting.

My reason for jumping into this morass was to learn how well a number of our larger microwave dish antennas perform above 900 MHz. We wanted to measure antennas ranging from 2 ft to 6 ft in diameter. For dishes 4 ft and larger, it is very desirable to mount the dish on a car, especially when making measurements at higher frequencies so the antenna pointing would be stable and could be slowly and carefully adjusted for the largest possible signal. This means at least one end of the test range should be easily accessible to a car. We decided to start at 5760 MHz where the feeds we were using are most in question. The goal of these experiments was to learn how to use an elevated range to measure large dish antennas accurately and to determine if Thacher Park can be used for this work.

Antenna ranges can be grouped in 3 general categories: An indoor antenna range in an anechoic chamber, an outdoor "reflection range" and an outdoor "elevated range" (sometimes called a "free space range"). I do not have access to a large indoor range in an anechoic chamber especially one where a 6-ft dish can be measured on 10 GHz. So we had to settle on an outdoor range of some kind. The most common type used by hams is the reflection range very well described by W1GHZ in his web Antenna Book.[1] Paul does a great job of describing how to make accurate antenna measurements using a reflection range with the receive end elevated. But this approach does not work very well for measuring large, heavy dish antennas. Typically antennas as large as we wanted to measure would need to be held 8 feet high or more and carefully pointed and adjusted to less than 1 degree at that height. This would not be easy with a 6-ft dish weighing 50 lbs or more. As an alternative, we decided to investigate the alternative outdoor antenna range: The Elevated Range.

But first, let us consider some requirements for ALL antenna ranges. It all about reflections! For accurate measurements, reflections must either be controlled or eliminated. A reflection range uses and controls the reflections – an elegant solution. An elevated antenna range avoids the problem by eliminating the reflections (almost) completely. To do this well usually requires more space such as using tall buildings or towers or maybe unique topographic features. I suppose the ultimate elevated antenna range would be conducting antenna measurements between 2 satellites in space, with nothing else nearby.

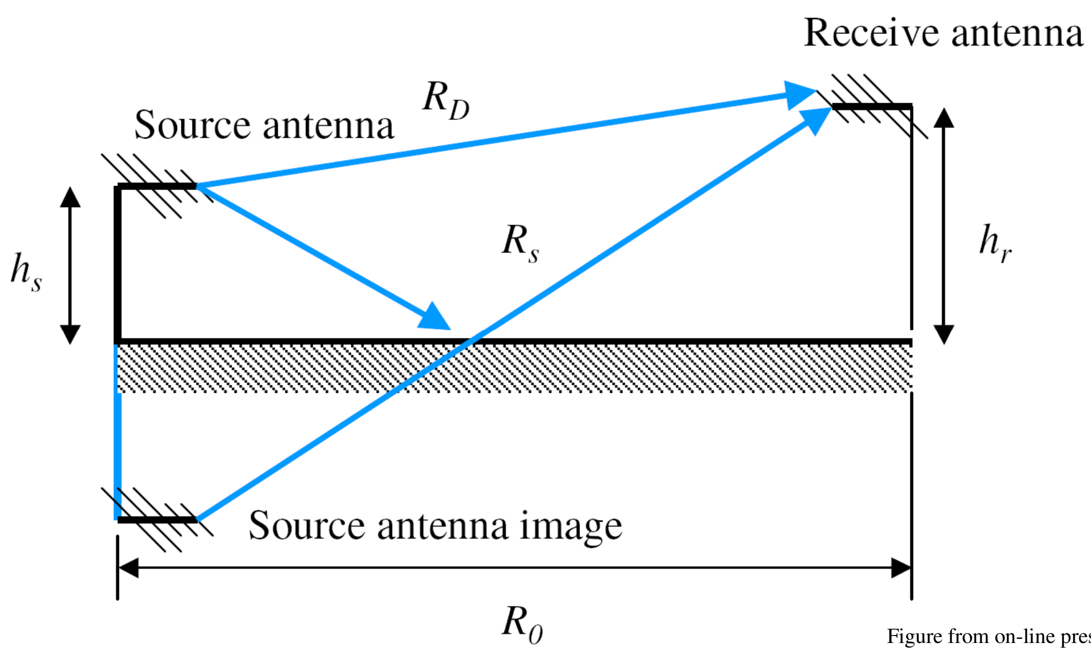



Figure from on-line presentation: "Antenna Measurements", Robert H. Caverly Villanova University, 800 Lancaster Ave, Villanova, PA

**Reflection Antenna Range**

Manages the Reflections

In a reflection antenna range, the signal from the source reaches the receive antenna directly and also by reflecting from the ground between the between the 2 antennas. This effect can be modeled as a second source antenna below the ground called an image antenna. The total signal power seen at the receive antenna is then the vector sum of the direct signal and the reflected signal and varies with the height of the receive antenna (the antenna being tested). Note that at a minimum the antenna under test

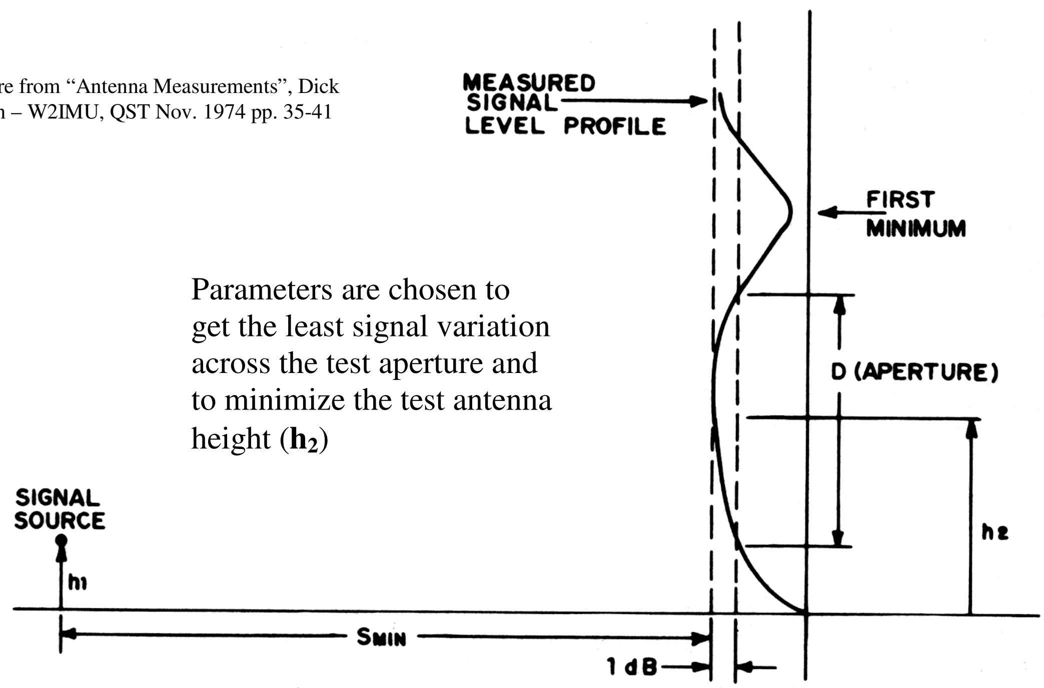



Figure from "Antenna Measurements", Dick Turin – W2IMU, QST Nov. 1974 pp. 35-41

Parameters are chosen to get the least signal variation across the test aperture and to minimize the test antenna height (**$h_2$**)

**Reflection Range Signal Level**

must be held at an angle to point at the other end of the range. This can make holding a large antenna very difficult. By comparison, an elevated antenna range endeavors to avoid reflections entirely.

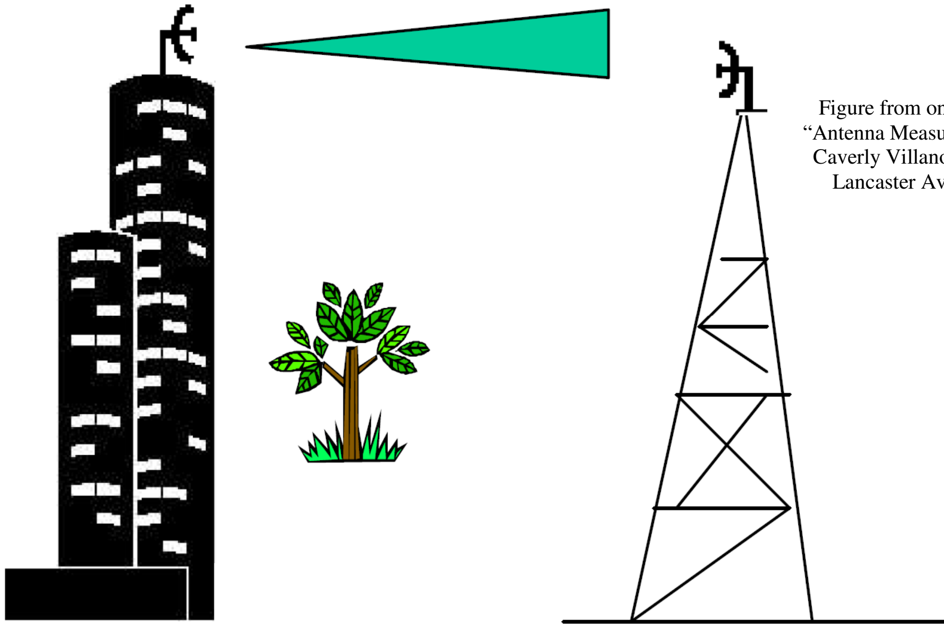


Figure from on-line presentation: "Antenna Measurements", Robert H. Caverly Villanova University, 800 Lancaster Ave, Villanova, PA

**Elevated Antenna Range**

Avoids Reflections Entirely

Some attributes of an elevated antenna range include:

1. Elevated ranges are best to measure physically large, high-gain antennas. I have used one near Syracuse, NY on the 2 sides of a steep, deep valley built to measure large radar antennas.

2. An elevated range requires two high locations with nothing between them. Buildings and towers work well.

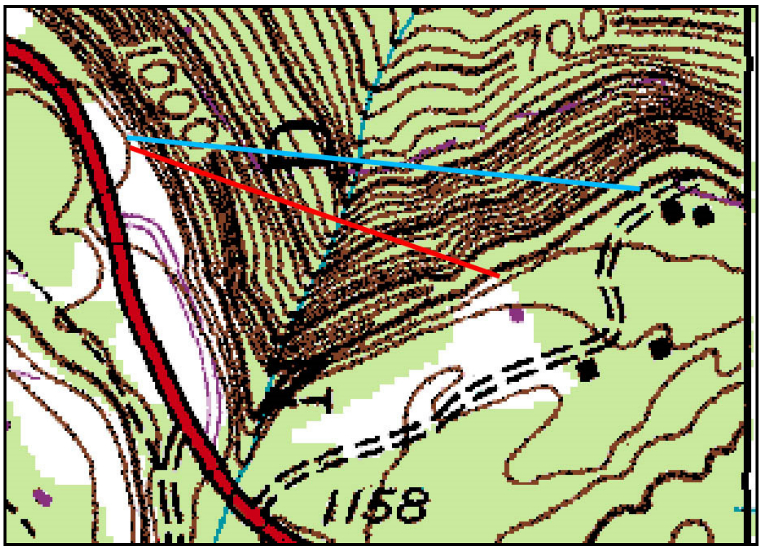
3. The longer the range, the deeper the gap between them should be for best results.

4. Use a high gain (narrow beam) transmit antenna at the source. This reduces reflections from objects near the source.

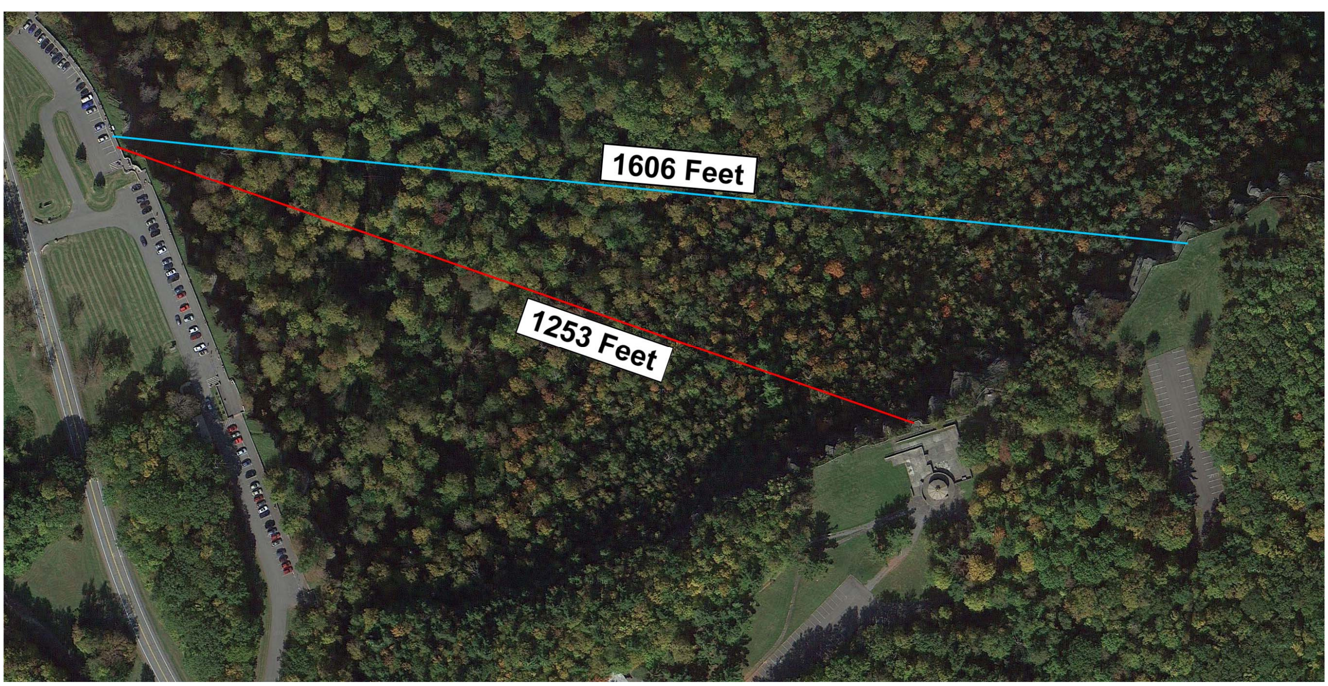
5. In theory, the range can be as good as you want to take the time to make it. This is actually true of all antenna ranges!

Some practical considerations of an elevated range require that its length must be greater than $2D^2/\lambda$ for a phase error less than $22.5^o$ across the test aperture, but longer is better so long as the received signal strength is strong enough. A really long range gives weak received signals, but a high gain source antenna can keep the signal level up. Also the source antenna must be sturdy and stable so the wind can't push it around. A really long range must also be very deep. Using buildings or towers means we need to drag our antennas up to test them. All these thoughts led us to consider using a natural DEEP RAVINE. Then we could park a car at the receive end! Don't back up TOOOooo far!

Thacher State Park near Albany, NY is a unique geological formation that can make a good "elevated" antenna range. It has a gorge with steep cliffs on each side that drop immediately more than 100-150 feet. At the midpoint, the gorge is more than 350 ft deep. (Don't fall off that cliff!) A vehicle can park at one end and the source can easily be carried to the other end. Ranges from 1250 to 1600 feet are available. For reference, a range 758 feet long is needed to test a 6-ft dish at 10 GHz so this should do the trick for our needs. The image below from the USGS topographic map shows the deep ravine.

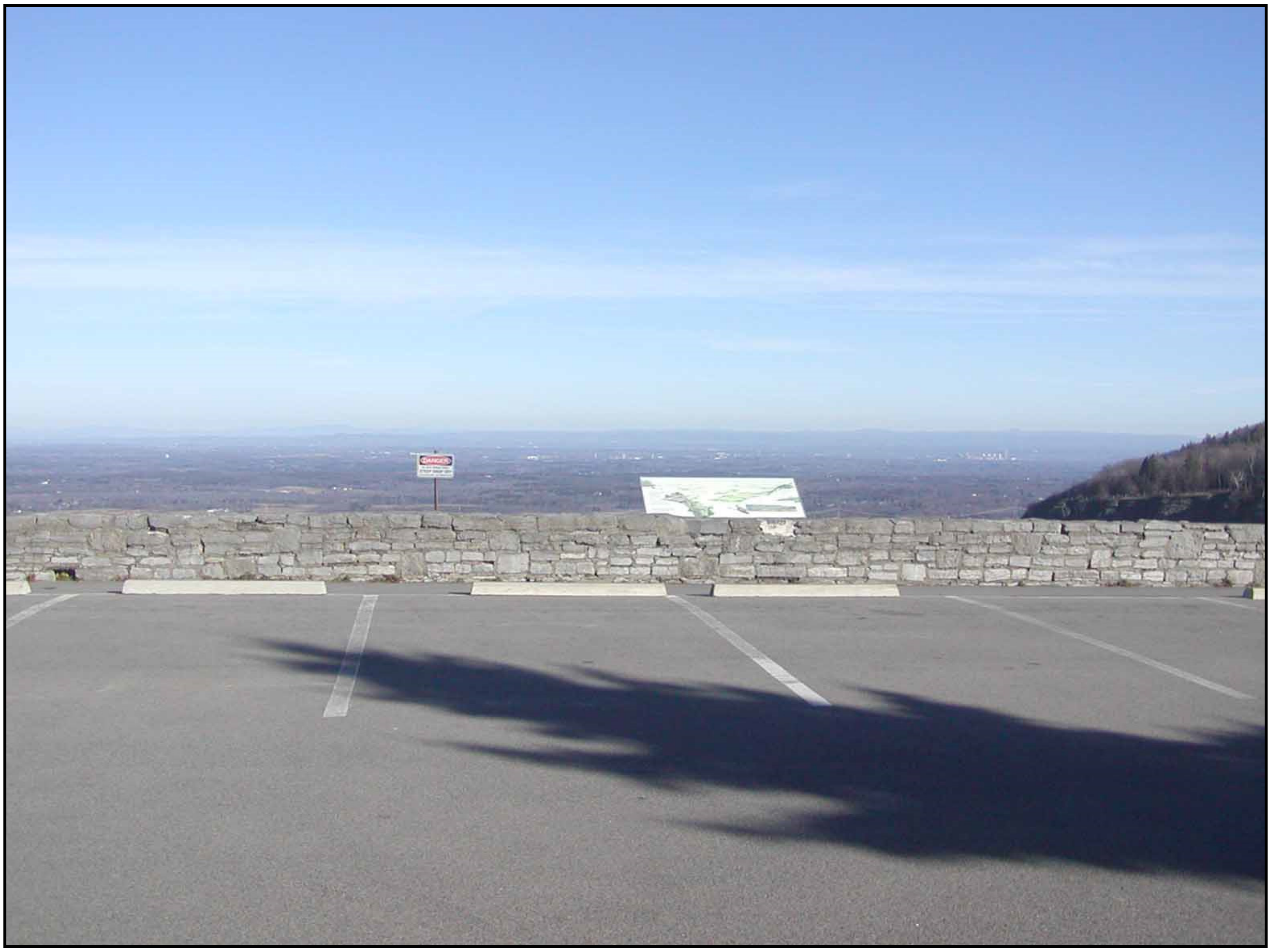



**Thacher Park Topography**




**Thacher Park Antenna Ranges** On-Line Google Photo

As is evident from the Google photo above, the west side of the antenna ranges is a paved public parking lot making it easy to set up the antenna measurement end of the range. The source ends are at the right side of the photo and are easily accessible by walking and it is even possible to drive a vehicle close to each source location to transport heavy equipment although we just walked in with our source.



**Cliff Edge Public Parking Lot at Thacher State Park**

The above photo shows the parking lot at the receive end of the antenna range. This is a public lot and is open every day from sunrise to sunset. This photo taken on a clear December morning shows very little activity, but later in the day a few dozen visitors showed up, just passing through. It would be best to avoid really nice days in the summer when the park is very busy. Quiet, wind-still, overcast days are probably best for making antenna measurements since they don't draw as many park visitors.

The source end of the 1600 ft antenna measurement range can be seen at the right edge of the picture. The line just above the stone wall is the edge of the cliff about 1600 feet away. Climbing over the stone wall at the parking lot is a serious mistake. The cliff drops immediately 100 to 150 feet and several visitors fall every year sustaining serious injuries and some have even died. The lucky ones fall into treetops below.

The next question that then arises is how much signal can we expect to receive over this elevated antenna range? The simple path loss calculation below is an example.

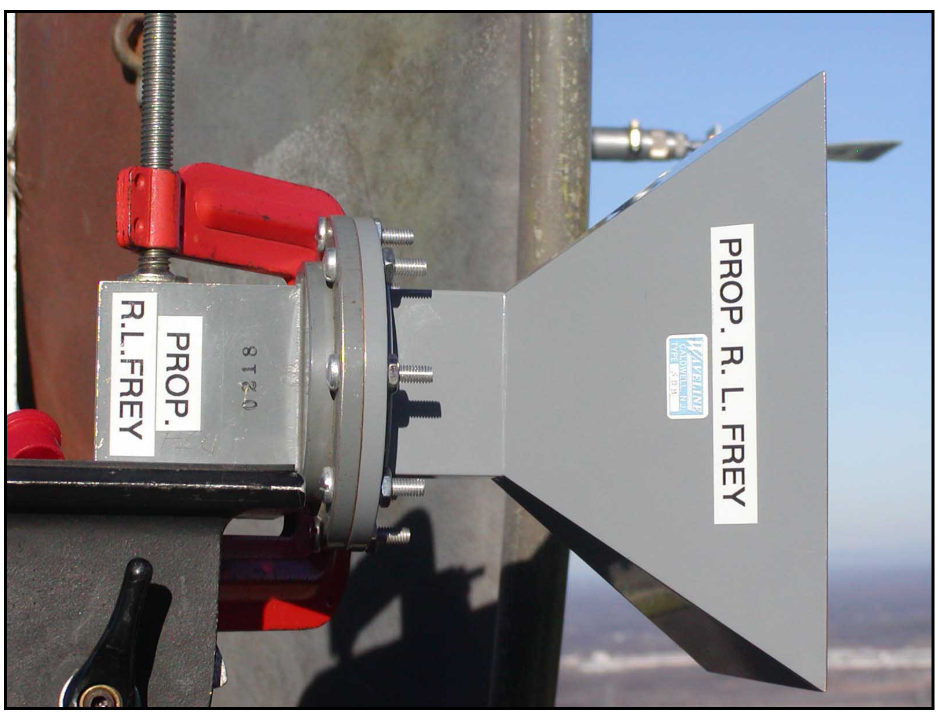
**Thatcher Park Antenna Test Range**
**5760 MHz Link Budget**

| **Transmit Signal Level Calculation** | **Value** | **Units** |
|---|---|---|
| Frequency of Operation | 5760 | MHz |
| Transmitter Power Output | 0.05 | watts |
| Transmitter Power Output | 17.0 | dBm |
| Transmitter Antenna Feedline Loss | 2 | dB |
| Transmitter Antenna Gain (dBi) (17 dB Horn or similar) | 17 | dB |
| Path Length | 0.24 | Miles |
| Free Space Path Loss - Isotropic to Isotropic Ant | 99.143 | dB |
| Antenna under test gain (dBi) (4-ft Dish) | 34.73 | dB |
| Receive Antenna Feedline Loss | 1 | dB |
| Signal Level at Receiver Input | -33.4 | dBm |
| Preamp gain before HP-432 Power Meter | 30.0 | dB |
| HP-432 Power Meter Reading Expected | -3.4 | dBm |

Typical Calculation Only, Does Not Describe Final Equipment Used

The link budget shows that simple equipment can be used to make measurements. A low power transmitter and horn antenna as a source is sufficient to give usable signal at the measurement end.

**Front View of Receive Site Set Up**

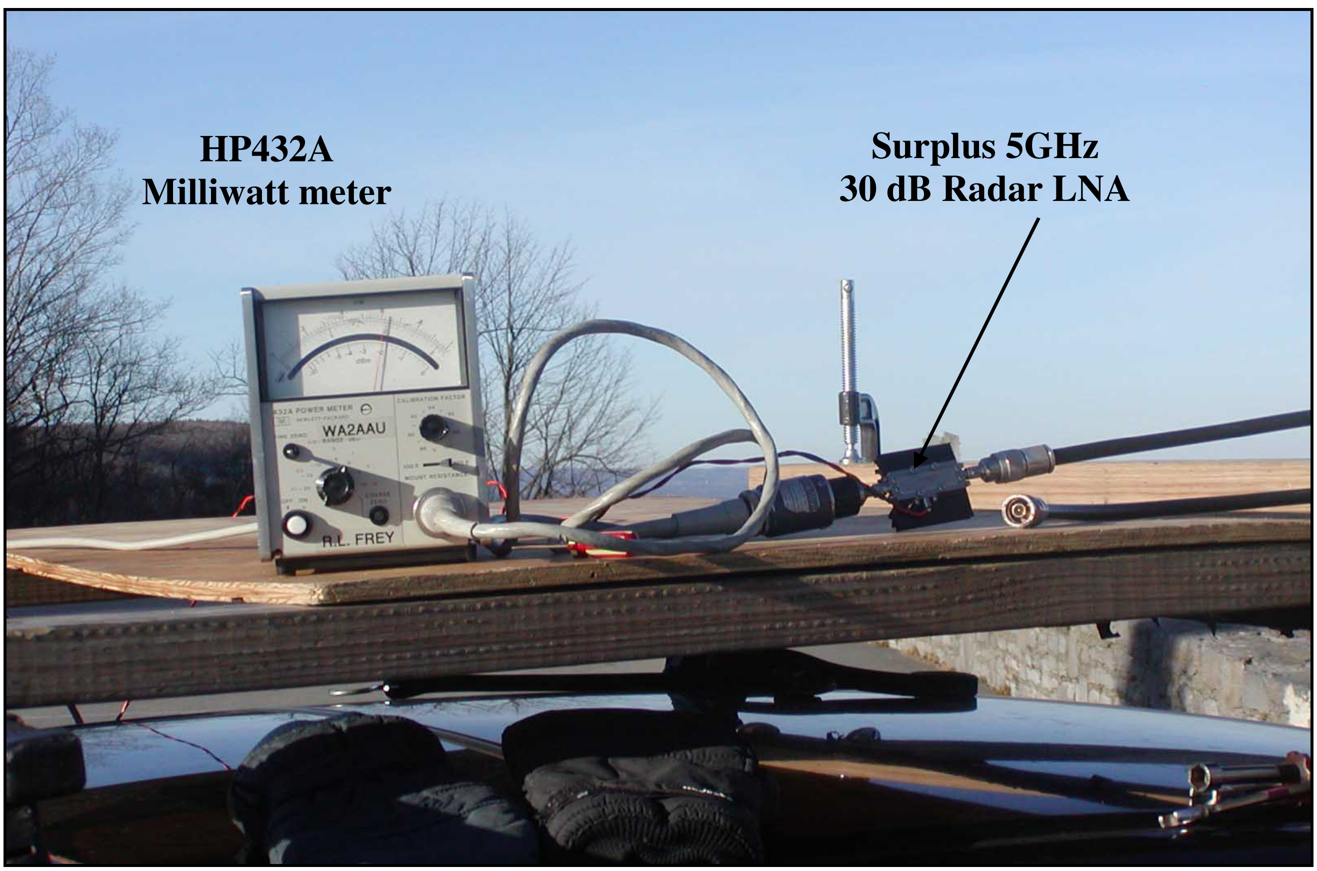



**Reference Horn Mounted To A Tripod With A C-Clamp**

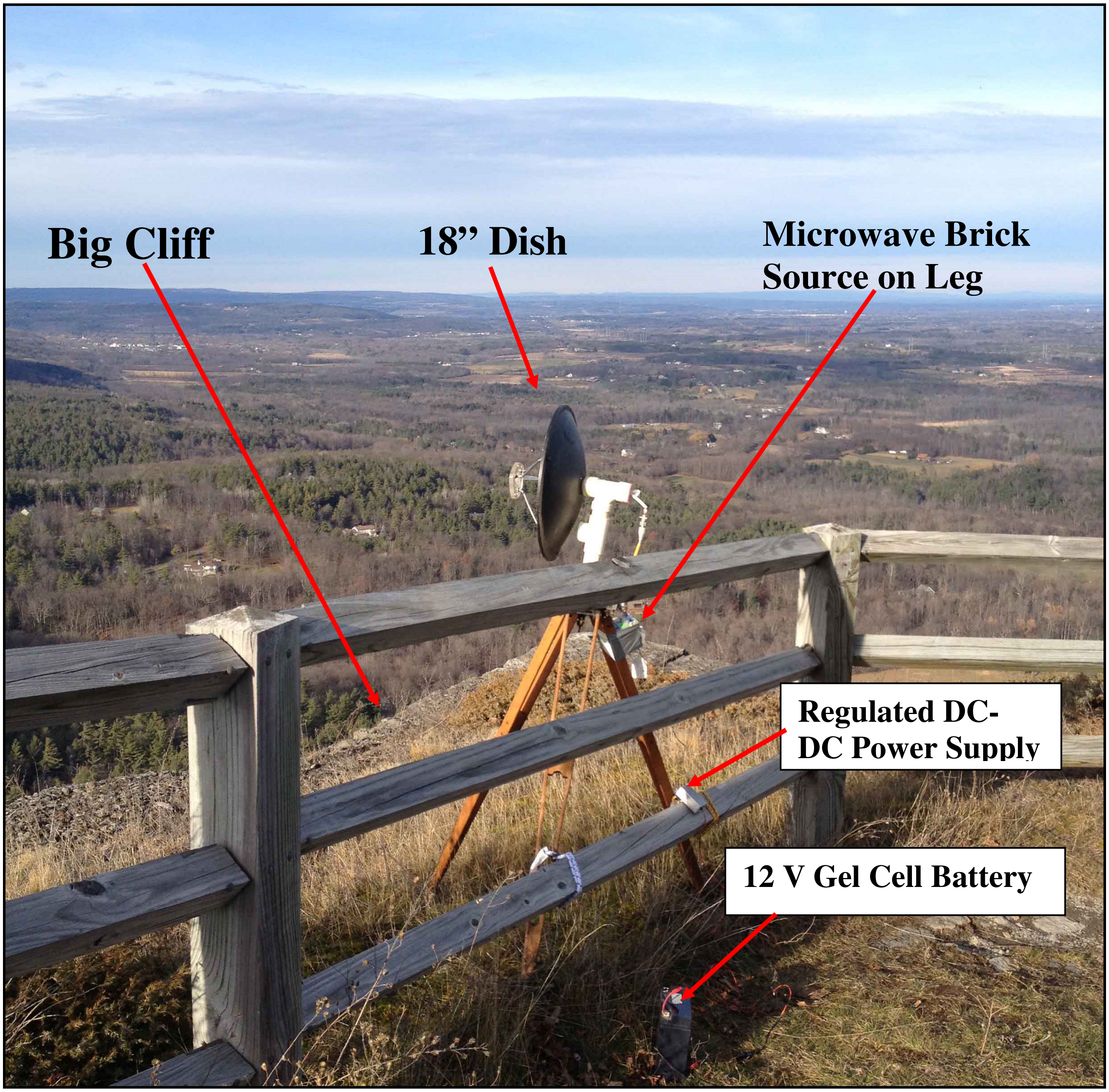
During this entire project, we wanted to keep things a simple as possible. For a signal source we used a surplus commercial phase-locked microwave frequency source (often called a “brick”), powered from a gel cell battery and a DC-DC regulated boost converter to make -20 VDC. The microwave brick delivered about 250 mW at 5760 MHz to the 18-inch dish used as the source. For receive, we decided to try the simplest receiving system possible, namely just a good quality power meter and an RF preamplier to raise the received signal level so it could be measured. We used an HP-432A milliwatt meter and surplus 5-GHz radar LNA with about 30 dB of gain. The LNA was powered directly from the car battery and the HP-432A was powered from a small inverter, also on the car battery. The signal level observed at the milliwatt meter was typically in the -10 to +5 dBm range well below where the LNA would compress.

To make meaningful measurements, we used a commercial horn antenna with a calibrated gain chart from the manufacturer. A relay was available to quickly switch between the antenna under test and the reference horn antenna, but signals were so stable, we found it easier to just switch antennas manually.

The antenna under test was mounted on a 2-inch mast attached to a roll-over board under the back wheel of the car and the upper part of the mast was braced with a 2x4 attached to the roof rack of the car. No one was permitted to sit in the car since that would cause the car to move enough to change the antenna pointing. The measuring electronics was simply placed on a small sheet of plywood on the car roof rack. The entire arrangement was just about as simple as it could get as is seen below.




**Receive Measuring Equipment On Top Of The Car**



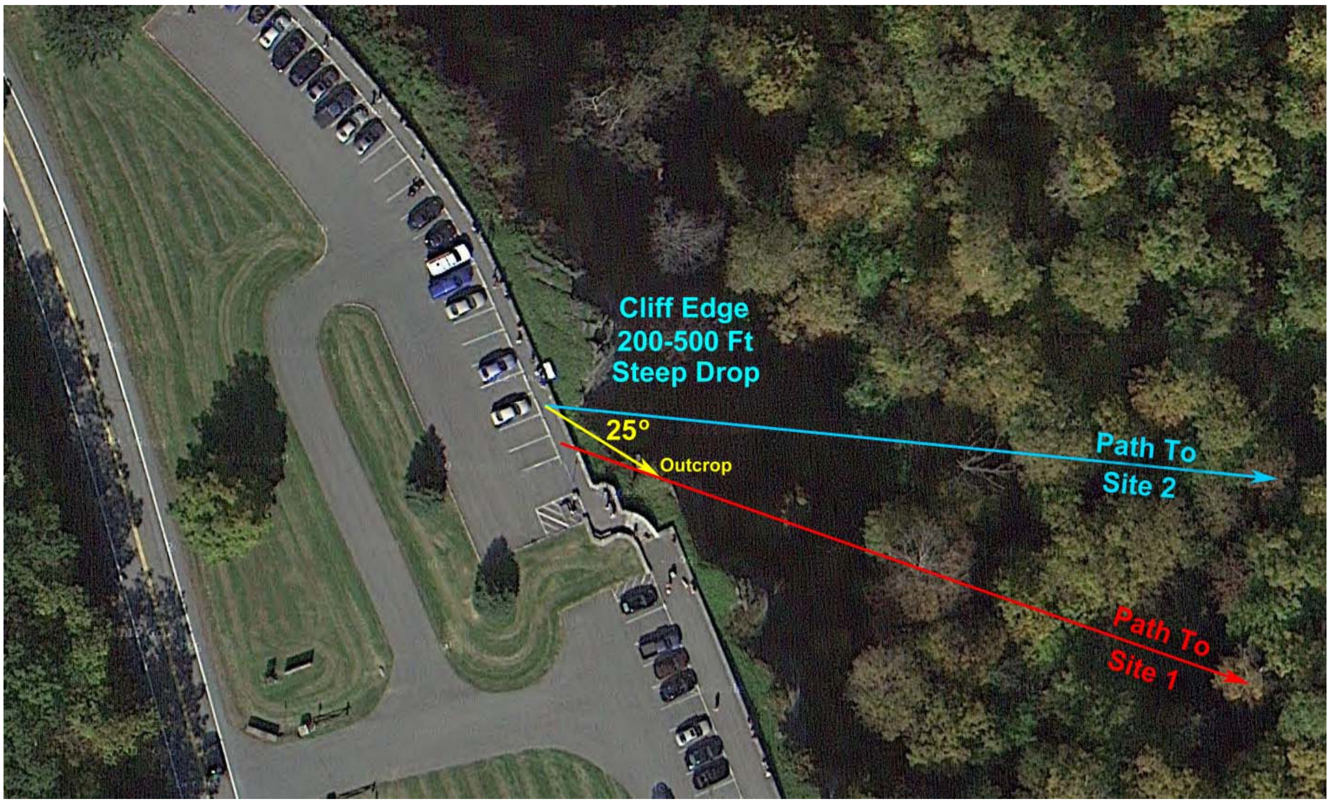

## 1600-Ft Range Source Setup

**Antenna Range Time Stability**

With this simple antenna measuring range we observed remarkably stable measurements. The received signal levels remained very stable over hours of testing without moving. The signal level would remain within a 0.2 dB range over periods of up to 4 hours. It just SAT THERE! A differential receiver may be needed if the LNA or source drifts more than ours did. It could be that the very simple equipment also made the results very stable. More complicated systems having more gain stages may be more prone to drift. Our biggest drift was the "brick" source power output decreased 0.4 dB in the first half hour but then stabilized. We avoided that by letting the source warm up for at least 30 minutes.

**Antenna Range Field Spatial Variation**

During the first testing session on 12/3/2012, signal levels from the reference horn varied about 2.0 dB as a function of horn height from peak to null. But the signal received by the dish did not vary as a function of its height. We think this effect was due to a rock outcrop in the beam width of the horn in front of the horn under the path. See the red path in the Google photo below. The dish does not show the effect because its beam width is much smaller and it does not "see" the reflection from the outcrop.



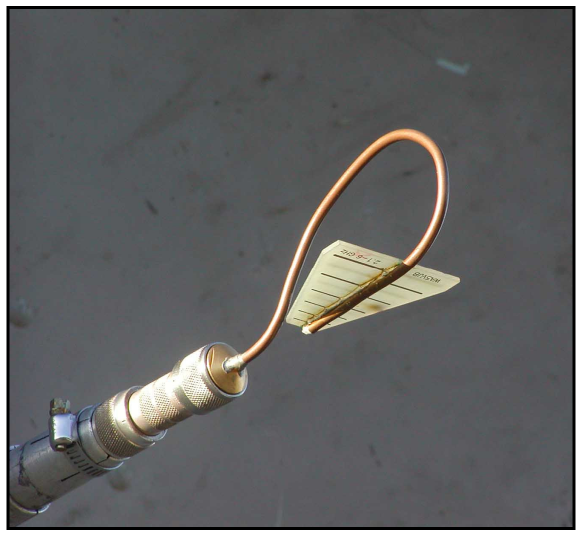

During the second testing session on 12/9/2012 we specifically chose a better path that also happened to be longer. The receive antenna testing location overlooked a steeper drop-off of the cliff as can be seen under the blue path in the Google photo above. The nearby outcrop was now about 25$^{o}$ to the right of the intended path well out of the beam of BOTH the reference horn and the dish antenna under test. At this new location the signal level received by the horn varied less than 0.4 dB peak-to-null, and often much less depending on the exact horn position. In general, the higher the horn was placed, the less variation was seen. This makes sense because nearby objects are further out of the horn's beam width when the horn is mounted up high.

This whole episode drives home the concept that the antennas under test AND THE REFERENCE ANTENNA must BOTH see the same direct and/or reflected signals so an accurate gain comparison can be made. This can cause serious errors on a reflection range if the broad beam reference antenna can see the (intentional) ground reflection but the high-gain antenna under test cannot see the ground reflection. As engineers, we must think hard about antenna range construction to avoid this trap. It is always best if the reference antenna and the antenna under test have about the same gain and beam width, but that is rarely the case when measuring large antennas. Elevated ranges may also be best for measuring large antennas because if you can avoid reflections affecting the reference horn, then reflections are unlikely to bother the larger antennas. On an elevated range, once the field as seen by the reference horn is free of spatial variations, especially variations with height, the gain measurements are likely to be correct.

**Antenna Gain Tests**

Although the main thrust of these experiments was to learn how to make measurements with an elevated antenna range and to determine if Thacher Park could be used as an elevated range, we did take some data on a 4-foot parabolic dish to see if our measurements would make sense. Our 4-ft dish had an f/d of 0.385 and was tested with a tri-band PC board feed designed by WA7RMX. It was also tested with a tri-band log periodic PC board feed designed by WA5VJB. See the photos below.


**WA7RMX Tri-Band Feed**



**WA5VJB Tri-Band LP Feed**

The 4-ft dish with the WA7RMX feed had a measured gain of 31.1 dB or 3.6 dB less than an ideal 55% efficient 4-ft aperture should have. This agrees pretty well with about what others have measured for this kind of feed. That really ain't great! But it is a multi-band feed. The same dish was also measured with a WA5VJB log periodic Yagi feed yielding a gain of 32.3 dB or about 1.2 dB better than the WA7RMX feed. This is 2.4 dB less than an ideal 4-ft aperture with 55% efficiency. Better, but still not very good compared with what should be possible with a simple little horn feed at the end of a wave guide. Multi-band feeds really are problematic. I have yet to find one that will do 2304, 3456 and 5760 and have gains equivalent to within 1 dB of a 55% efficient aperture on all 3 bands.

We also measured a number of smaller antennas rather quickly, but I hesitate to report the results here since I am not at all sure we have good solid measurement techniques worked out yet. In this summer season, we hope to get back to Thacher Park to make more measurements. Our plans include:

1. Make several waveguide feeds for the 4' dish to see if we can get close to 55% efficiency
2. Test our 6-foot main station dish with commercial waveguide feed. Do we get close to 55%?
3. Test several other 4-foot rover dishes and compare them to one another

4. Make sources for 2304 and 3456 as well as reference antennas and high gain source antennas
5. Test several 4-foot dishes on 2304, 3456 – Also try several MB feeds including W5LUA horn
6. Try a dual-dipole over GP "EIA standard" antenna as a feed for 2304, that models quite well

## Conclusions

- The elevated range over the ravine works well. Actually better than I expected.
- Received signals are stable within < 0.2 dB peak-to-null. Really quite good!
- Very simple measuring equipment works. A differential receiver did not seem necessary.
- Signal level vs. height from the reference horn varies <0.4 dB peak-to-null over test aperture.
- Range is long enough to measure a 6-foot dish at 10 GHz accurately.
- Robust mechanical mounting is essential to accurate, repeatable measurements.
- Preliminary antenna measurements agree closely with those made by others.

## Acknowledgements

I would like to thank all the guys who helped make measurements on 2 cold winter days in December. I could not have done it alone!!

- Sigurd Kimpel – KJ1K
- Ed Grosso – N1FGY
- Bob Bownes – KI2L
- Brandon Graham – KB3IGC
- John Crawford – N2OY

[1] W1GHZ Microwave Antenna Book at URL: http://www.w1ghz.org/antbook/contents.htm dated 1994 - 2006. By Paul Wade, W1GHZ.