Experiences with Focusing a Cassegrain Dish

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A few years ago I was fortunate to acquire a three-foot-diameter precision cassegrain dish. Being a surplus purchase it of course didn't come with any documentation or even manufacturer and model number information. It was however complete with feed horn and sub-reflector so I figured it shouldn't be too hard to get on the air with it.

Figure 1 Surplus 3' Cassegrain Dish

The first step was to measure the feed horn that came with the dish. The feed was a conical horn with 0.55-inch diameter mouth, 3.9-inches long and with a 0.09-inch circular waveguide back end. This was certainly a millimeter wave setup, I figured it was previously used at 94-GHz!

Rather than do a bunch of measurements and calculations to determine if the dish setup made sense I decided to get on the air with the original feed on 80-GHz. Bob Johnson KF6KVG and Will Jensby W0EOM were working on extending the distance record on

80-GHz and welcomed me to join them so with a loan of a mixer I quickly put together a rig using the new cassegrain dish. I was concerned that the 0.09-inch back end circular waveguide would be cut off at 80-GHz so I did bore it out to 0.1-inch keeping my fingers crossed that the feed pattern wouldn't be disturbed from the small change.

In side-by-side MDS tests with Will and Bob, the rig seemed to be comparable to their rigs; so even though I couldn't get a distinct focus peak by moving the feed in and out, I thought it was working well enough to get on the air. Will and I drove to Mount Saint Helena and Bob went to Dave Lesson's house for our first attempt at the 80 GHz record, a distance of 177 KM. Surprising to me, we all completed QSOs on this first try and I was then convinced the dish was working superbly, after all, it had just set a world record.

At this point W6QI and I decided to try and extend the 47 GHz record and this dish seemed a natural to use at one end. Frank built a 47 GHz feed horn for it based on the geometry of the original 94 GHz horn and we proceeded to setup a test range to measure the performance. Much to our surprise the dish performed poorly, there was no observable focal peak and the pattern was too broad. We decided to start from square one and measure the sub-reflector to confirm both the sub-reflector and horn positioning.

Using a milling machine table and a dial indicator we measured the curvature of the sub-reflector, and Frank wrote a MatLab program to curve fit a hyperbola to the measured data, and this indicated that the sub-reflector magnification was 2 rather than 5 where the original feed horn was positioned. So we built a new feed horn and positioned it much closer to the sub-reflector and proceeded to remeasure on the test range.

This time the dish pattern was cleaner, but we still couldn't find a distinct focal peak on either the feed horn or the sub-reflector. In any case, we decided to go into the field and try some record breaking paths. Over the course of the next year we were able to extend the 47 GHz record three times, so once again I concluded the dish must be performing well.

About a year ago Tony KC6QHP built a very capable 47 GHz rig and was interested in trying to further extend the record, so I hauled out the cassegrain dish with the 47 GHz feed. Tony and I started by testing our radios over shorter LOS paths, I went to the corner of four grid squares in the Mojave Desert and Tony setup on Frazier peak north of Los Angeles. We easily completed QSO's over this path with good signal margins so felt we were ready for some record attempts. Over the course of the last year we've made over five attempts at breaking the record, some over land, some over water, but none successful. On our last attempt Doug K6JEY set up mid-way between us and was able to easily copy my signal so I tried sweeping the dish through azimuth as he replayed my signal back over the liaison link. While the dish pattern seemed clean, it was far too broad for a 3' dish at 47 GHz so once again I decided to go back to square one and remeasure and recalculate all of the dish geometries.

I carefully remeasured the sub-reflector curvature again using a milling machine table and a dial indicator. This time however, I included a correction factor for the tip curvature of the dial indicator. Plugging this data into an Excel spreadsheet I did a curve-fit by hand by tweaking the A and B parameters for the hyperbola: the spreadsheet is shown in figure 2. It didn't take much tweaking of A and B to quickly reduce the RMS curve-fit-error to about one-thousandth of an inch at which point I figured it was good enough for amateur work. This time the magnification factor agreed with the original 94 GHz feed position so I built a 47 GHz rectangular horn with the correct gain to illuminate the 1.6 f/d of the sub-reflector.

Y offset	Measured X offset	Hyperbola X offset	A	B	C
			2.7	2.9895	4.028289
0	0	0			
0.1	0.001	-0.001510133	2.60236E-07		C-A
0.2	0.004	-0.006035476	4.14316E-06		1.328289
0.3	0.012	-0.013560943	2.43654E-06		
0.4	0.022	-0.024061671	4.25049E-06		C+A
0.5	0.036	-0.03750342	2.26027E-06		6.728289
0.6	0.052	-0.053843127	3.39712E-06		
0.7	0.071	-0.073029562	4.11912E-06		e
0.8	0.093	-0.095004104	4.01643E-06		1.491959
0.9	0.12	-0.119701567	8.90625E-08		
1	0.146	-0.14705109	1.10479E-06		M
1.1	0.175	-0.17697704	3.90869E-06		5.065381
1.2	0.21	-0.209399915	3.60102E-07		
1.3	0.244	-0.244237226	5.62762E-08		Fhyp
1.4	0.281	-0.281404337	1.63488E-07		8.056577
1.5	0.321	-0.320815253	3.41316E-08		
1.6	0.362	-0.362383347	1.46955E-07		Fdish
1.7	0.407	-0.406022011	9.56463E-07		0.378695
1.8	0.452	-0.451645237	1.25857E-07		
1.9	0.5	-0.499168121	6.92023E-07		Dsub
2	0.55	-0.548507292	2.22818E-06		4.2
2.1	0.6	-0.599581275	1.75331E-07		
		RMS Error	0.001289605		

Figure 2 Hyperbola calculation spreadsheet

To convince myself I was on the right track and confirm the spreadsheet calculations, I decided to throw together a ray tracing model of the sub-reflector in SciLab. SciLab is a numerical calculation tool similar to MatLab that is free to download and use: http://www.scilab.org. Figure 3 shows the ray tracing from the virtual focal point 1.33" behind the sub-reflector apex produces a second focus 6.73 inches in front of the sub-reflector apex. This nicely matched the spreadsheet calculations for the foci. A second ray tracing experiment shown in Figure 4 then gave me intuitive insight into the criticality of the sub-reflector position. By moving the virtual focus behind the sub-reflector by 0.1", Figure 4 clearly shows the large defocusing impact on the second focal point in front of the sub-reflector. While the feedhorn "sees" a 1.7 f/d virtual dish with a less critical focusing requirement, the sub-reflector "sees" the 0.36 f/d real dish and consequently has a very critical focusing requirement.

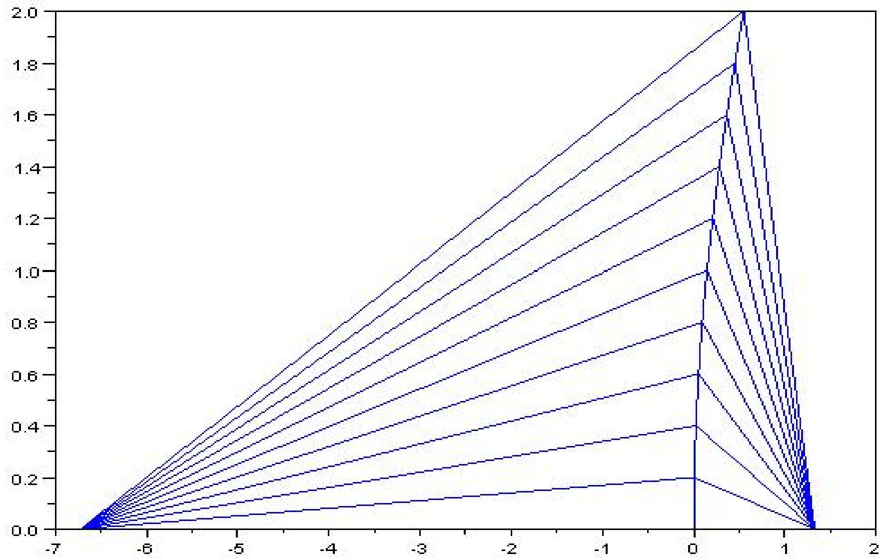

Figure 3 Ray tracing of focused sub-reflector

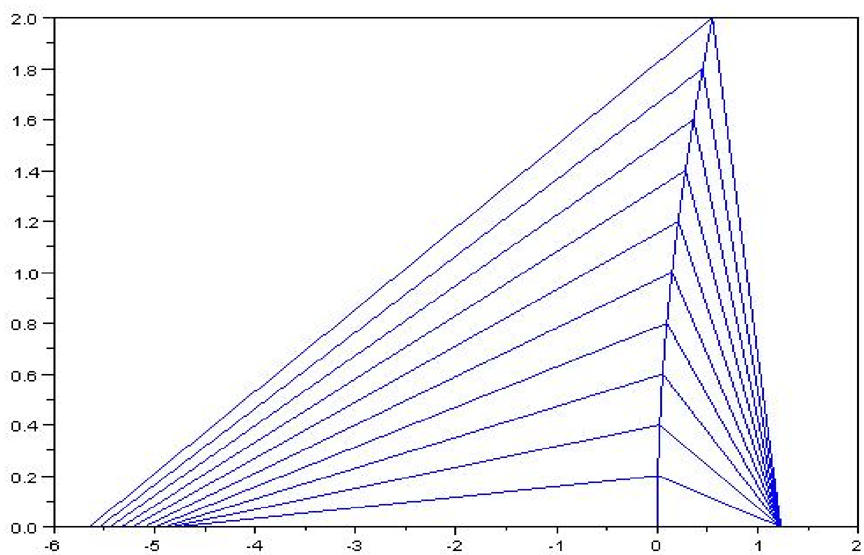

Figure 4 Ray tracing of 0.1" defocused sub-reflector

At this point I was ready to go into the field and confirm the performance and focusing of the sub-reflector and new feedhorn. Since Bob KF6KVG has a 47 GHz beacon on Mt. Leeson I thought I would just setup my radio at a spot with line-of-sight to the beacon and peak the feed and sub-reflector positions. Of course Murphy ensured that it wasn't going to be that easy. I setup about 20 Km from Bob's beacon and could easily copy it 20 to 25 db out of the noise, on peaks. The fades over this length path were easily 15+ db over a 20 second period and it was quite frustrating to try and find a focal peak on the IF radio s-meter in the presence of the fading. After 45 minutes of moving the sub-reflector and feedhorn and not seeing any repeatable results I gave up and decided to try another approach.

What I needed was a shorter distance antenna test range that wouldn't experience the deep fading. A quick calculation of the Rayleigh distance for this 3' dish at 47 GHz:

Rayleigh distance = 2D^2 / lambda
D = 36 inches
Lambda = 0.25"
Rayleigh distance = 10368" or 864 feet

showed that the antenna range would have to be quite long, far longer than my yard could accommodate. The Stanford radio club W6YX is located on a hill that has line-of-sight to a few places nearby so I went up there with a pair of binoculars and scouted out some spots for the far end of an antenna range. Luckily one of the spots is a dirt parking lot adjacent to a horse corral with enough room to setup the radio. I used Google Earth to determine the distance from the Stanford site W6YX to the parking lot and it easily satisfied the Rayleigh criteria at 3533 feet, see figure 5.

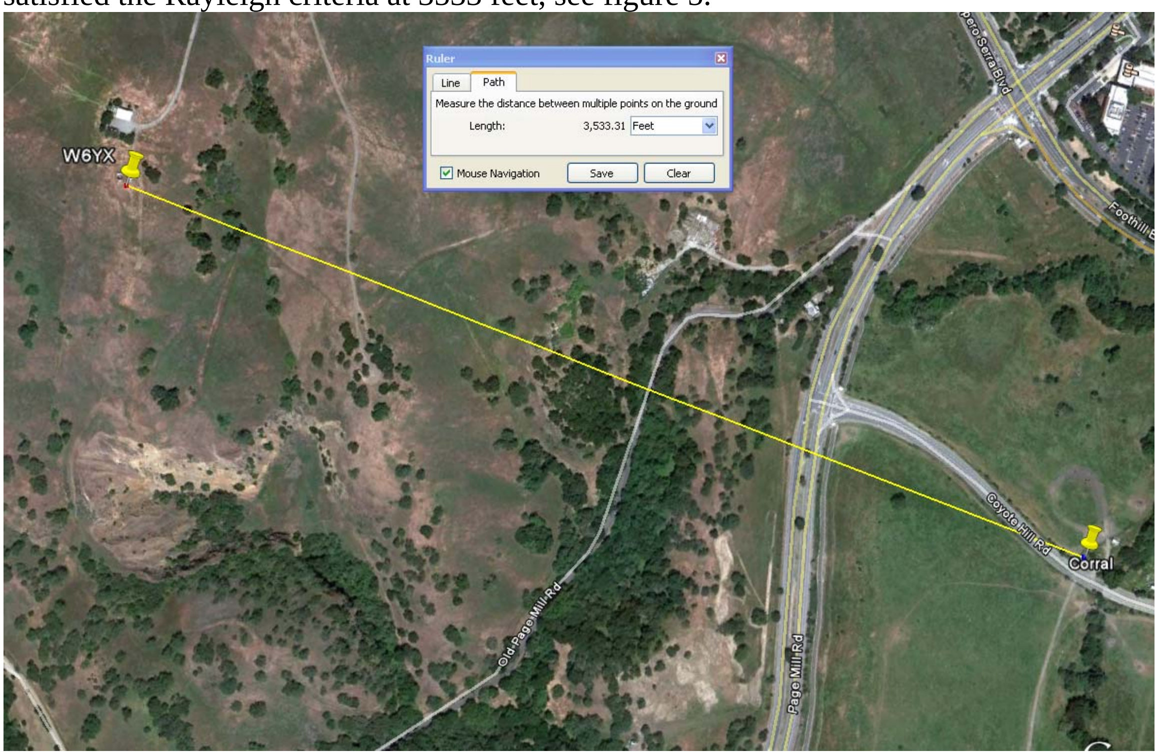

Figure 5 Google Earth view of antenna range

I needed a transmitter to use on the W6YX end of the range so I put together a simple low power 47 GHz beacon. A DMC brick at 11772 MHz driving a x4 diode multiplier produced 20 micro-watts at 47 GHz on the bench, when mounted on an old Pcom 12" 30 GHz dish it makes a fairly nice source for the antenna range. Figure 6 shows the transmitter at the W6YX site setup on a tripod and pointing toward the parking lot.

Figure 6 Antenna range transmitter

At the receive end of the range I used my 47 GHz radio as a down converter but rather than use the s-meter of the IF radio for peaking I used a GR-1236 meter. The GR-1236 provides a large analog meter which makes peaking exceptionally easy as well as ticks marks every 0.2 db which make it possible to resolve differences of tenths of a db. The combination of eliminating the path fades along with the GR-1236 made it quite easy to find the focal peaks of both the feedhorn and the sub-reflector.

On the antenna range I easily found a smooth sub-reflector focal peak of about 6 db over a 0.5" range of sub-reflector position. With iterative peaking of the sub-reflector and the feedhorn positions I was able to optimize the dish performance on the antenna range, the whole process took only 10 minutes and it was a pleasure to see repeatable stable measurements.

Figure 7 Antenna range receive end with GR-1236

To verify the dish performance after the focusing I measured the half power beam width. This turned out to be easy to do using a couple of different techniques. The cassegrain dish has a spotting scope attached that I use for optical azimuth and elevation alignment. By sighting optical references in back of the antenna range transmitter at the half power points I was able to determine the angle. I measured the distance between the visually-sighted half power points at 30 feet so knowing the range distance and using the equation:

Angle = arctan (30/3533)

I determined the half-power beam-width to be 0.49 degrees. Checking this against the theory for a 3’ dish I get:

HPBW = 70* lamda / d
Lamda = 0.25”
D = 36”
HPBW = 0.486 degrees

The agreement is quite good! The second technique I used for measuring the half-power beam-width uses a sun noise measurement. Due to the subtended angle of the sun being comparable to the beam width I was concerned about the accuracy of this technique. The measurement is done by positioning the dish for maximum Sun noise and then measuring the time to the half-power point. Again using the GR-1236 as the IF measurement device I was able to see 6.5 db of sun noise and timed a 68 second duration for the sun to drift to the half-power point. Assuming a 24-hour earth rotation time the Sun moves at the rate of 360/(24*60) degrees per minute or 0.25 degrees per minute. Multiplying by 68/60 gives a half-half-power beam-width of 0.28 or a full-half-power beam width of 0.56 degrees. I think this produces a pessimistic HBW due to the large subtended angle of the Sun but it's good to see rough agreement using different measurement techniques.

While at times it was a bit frustrating, I learned a number of valuable lessons from this endeavor to focus the cassegrain dish:

- Don't assume your equipment is performing well just because you're making QSOs or hearing as well as others.

- When measuring the surface of a sub-reflector with a dial indicator, correct for the radius of the indicator probe.

- A stable antenna range makes optimization infinitely easier than trying to do it on a long path. If you can't setup your own antenna range, many clubs run yearly MDS and antenna measuring events, take your radio to one of these events and have it measured.

- Using the correct equipment (GR-1236 noise meter) makes measurement and optimization far easier.

- Check your measurements and calculations using several different methods, if they don't agree then something is wrong and start over. Persist until all methods produce consistent results.

SCILAB Ray tracing Program

```
a=2.7
b=2.9895
c=sqrt(a^2+b^2)
def = 0.0

x=[]
y=[]
slope=[]
fslope=[]
ref=[]
ref1=[]
f2slope=[]
f2=[]
f=[]

for i=1:101
   y(i)=(i-1)/50
   x(i)=sqrt((1+y(i)^2/b^2)*a^2)-a
   slope(i) = (a^2*y(i))/(b^2*sqrt(a^2*(1+(y(i)^2/b^2))))
   fslope(i) = y(i)/(c-a-x(i)-def)
   if (slope(i)==0)
     ref1(i) = 0
   else
     ref1(i)= 90+atand(1/slope(i))
   end

   ref2(i) = 180-atand(fslope(i))
   ref(i) = ref2(i)-ref1(i)
   f2slope(i)=tand(ref1(i)+180-ref(i))
   if f2slope(i)==0 then
     f2(i)=0
   else
     f2(i)=-y(i)/f2slope(i)+x(i)
   end

   if fslope(i)>0 then
     f(i) = x(i)+y(i)/fslope(i)
   else
     f(i)=0
   end
end

plot (x,y)

for i=1:10:101
  plot ([x(i),f2(i)],[y(i),0])
  plot ([x(i),f(i)],[y(i),0])
end
```