Wide Band Feed Technologies for Arecibo

By Germán Cortés M.
National Astronomy and Ionosphere Center
Cornell University

I. INTRODUCTION

In order to support the radio astronomical communities growing interest in very wide band receivers systems, we have been analyzing different wide band feed alternatives and developing solutions of our own. The premise is to have very wide band receivers systems with competitive levels of sensitivity and noise characteristic with current radio astronomical receivers.

II. WIDE BAND FEED TECHNOLOGY: 2:1 BANDWIDTH FEED SYSTEMS

Let's start with initial 2:1 bandwidth systems; although, not truly "ultra-wide", these systems had the advantage of achieving very high sensitivities with technology that is readily available for Arecibo in the short term.

Key elements of these systems are: a wide band feed horn, a wide band Ortho-Mode Transducer (OMT) and a wide band low noise amplifier.

Wide Band Feed Horns: the most recent corrugated horn designs already installed in Arecibo have excellent performance over 1.8:1 in frequency. With a further optimized design it is possible to extend this performance up to 2:1 without changing technology. This will be in the form of a Ring-loaded conical feed scaled in frequency from the current L-Band wide system.

Ortho-Mode Transducer (OMT): corrugated feed technology is often limited not by the feed horn performance but by the OMT bandwidth. I have designed a 2:1 OMT based on rectangular quad-ridge waveguide with single transition from the rectangular quad-ridge section directly to a circular waveguide of the appropriate diameter, which provides a return loss better than 22 dB over a 2.2:1 bandwidth. See Figure 1. Our current Coax to rectangular Quad-Ridge Transition design, based on a series of discussions with Paul Lilie who has introduced a novel back short termination in his NRAO OMT design, has also a 22dB return loss over 2:1 bandwidth.

Wide Band Low Noise Amplifiers: We already have in operation a 5K noise temperature amplifier (cooled at 15K), from 4 to 12 GHz, developed by Sandy Weinreb in Caltech. He still continues to improve on his designs, therefore we expect to have available a number of wide band low noise amplifiers required to implement a few 2:1 feed systems.

In essence, an ultra low noise cryogenic 2:1 feed system is perfectly feasible with today's technology[1].

[1] Such an 800MHz to 1.6 GHz, Single pixel.

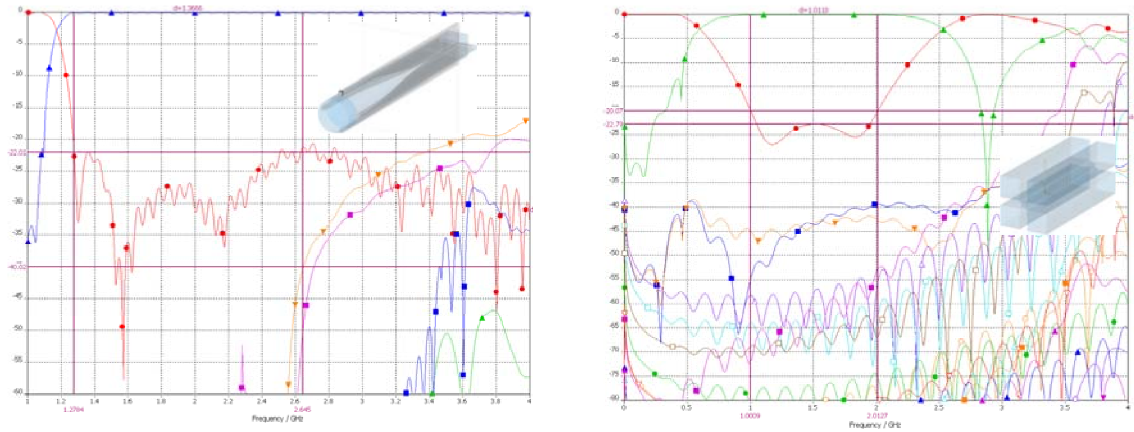

Fig. 1 S-Parameters for a square Quad-Ridge transition to Circular Waveguide (right) (● S_{11}, ▲ S_{21}). And a Coax to Quad-Ridge Transition (left) respectively with a return loss better than 22dB over a 2.0:1 bandwidth. (● S_{11}, △ S_{21})

III. Ultra Wide Band Feed Technology Alternatives, 10:1 Bandwidth Feed Systems

There are only a handful of ultra wide band feed systems, with the appropriate low noise characteristics required for astronomical use, which have been initially studied in collaboration with different institutions within the framework of the US SKA (Square Kilometer Array). A more detailed comparison of these different alternatives for the SKA will be addressed in the upcoming TDP project to be initiated later this year. These include, of course, the ATA (Allen Telescope Array) feed, the Chalmers Feed, the Quad-Ridge Lindgren feed Horn, and our new QSC feeds.

During the past year we have been working on the development of ultra wide band systems for use for both SKA and Arecibo. As a result of this effort, we have discovered a new ultra wide band Quasi Self Complementary (QSC) family of feeds capable of operating with a 10:1 bandwidth or more. An initial 300 MHz to 3 GHz prototype is currently under development.

Let's review here briefly these ultra wide feed alternatives devoting more attention in a separate section to this new QSC feed.

The ATA Feed, developed for the Allen Telescope Array, has good input matching (better than -14dB) over a very wide frequency band, from 0.5 to 12 GHz **[1]**. The -10 dB beam width is about 43° over the frequency band. Nevertheless, it has two main drawbacks, one is its relative large aspect ratio $[(0.65\lambda_{max})^2 \times 2\lambda_{max}]$, where λ_{max} is the wavelength at the minimum operating frequency. The second is that the location of the feed's phase center varies as a function of frequency. This means that the receiver system cannot take full advantage of its large bandwidth with the highest sensitivity for simultaneous observations using the full bandwidth **[2]** or has to be limited to a narrower bandwidth with the aide of a motorized re-focusing mechanism. The expected Tsys is approximately 40K from 1 to 11 GHz **[3]**. Nevertheless, the noise performance goal in the high frequency portion of the band has proven difficult to achieve **[4]**.

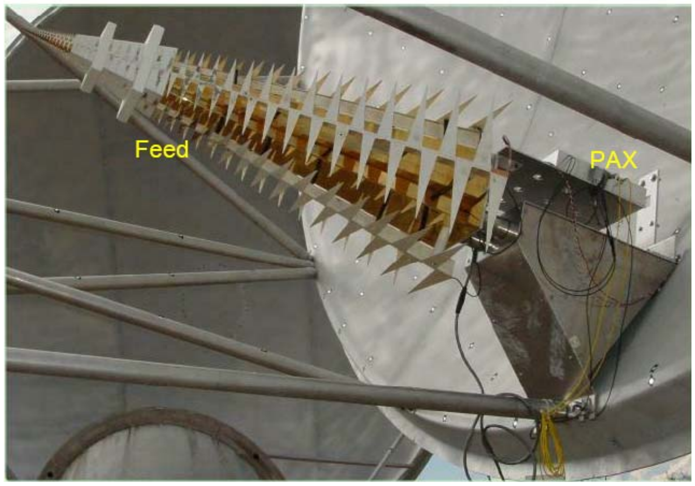

Figure 2. The ATA feed mounted on the ATA antenna [3]

The Chalmers Feed developed by P-S. Kildal and his students [5] is a compact sized feed [(0.65λmax)² x 0.21λmax] with a 11:1 bandwidth. In addition to its small size advantage, the Chalmers feed has a frequency invariant phase center location. The -10 dB beam width is about 60° over the frequency band. Unfortunately, one major drawback of this feed is its somewhat poor input matching (at some frequencies only better than –7dB) that reduces its effective frequency band coverage. We already have made an initial evaluation of Chalmers' feed at Arecibo based on calculated radiation patterns from 1.5 to 12 GHz [6]. When used at Arecibo's Gregorian focus, the expected antenna sensitivity is approx 1.5 to 2 K/Jy lower than current receiver systems, and Tsys is expected to increase by 5 or 6 K due to excess noise from spill over the tertiary reflector edge.

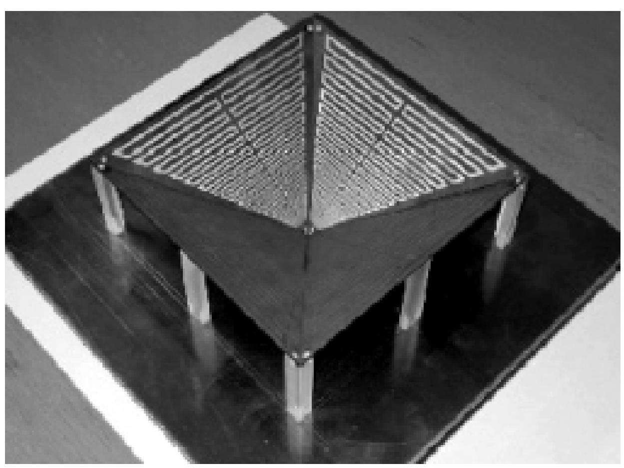

Figure 3. Photograph of dual polarized laboratory model of the Chalmers Feed. [5]

The Quad-Ridge Lindgren Horn is a commercially available feed horn based on a quad-ridge design [7]. It has a frequency bandwidth of 7:1, with a reasonable size [(1.1λmax)² x 1.2λmax]. Unfortunately, it has poor input matching, with input matching varying between -6dB and -8dB. In addition, both the phase center and pattern beam-widths change with frequency. An integration of a 2.2 to 15 GHz Quad-Ridge Lindgren feed in a cryogenic dewar was recently implemented by S. Weinreb [8]. In This implementation a cylindrical interior shield at 15K covered with absorber was used, to eliminate internal field reflections. The best measured Tsys was <35K in the 4GHz to 15GHz interval. Even though, the absorber reduces the feed efficiency (expected to be at 45% or 50%), it actually improved the patterns beam width variation with frequency. The -10dB taper angle varies between 55° to 45°, although, at the upper portion of the band is somewhat constant.

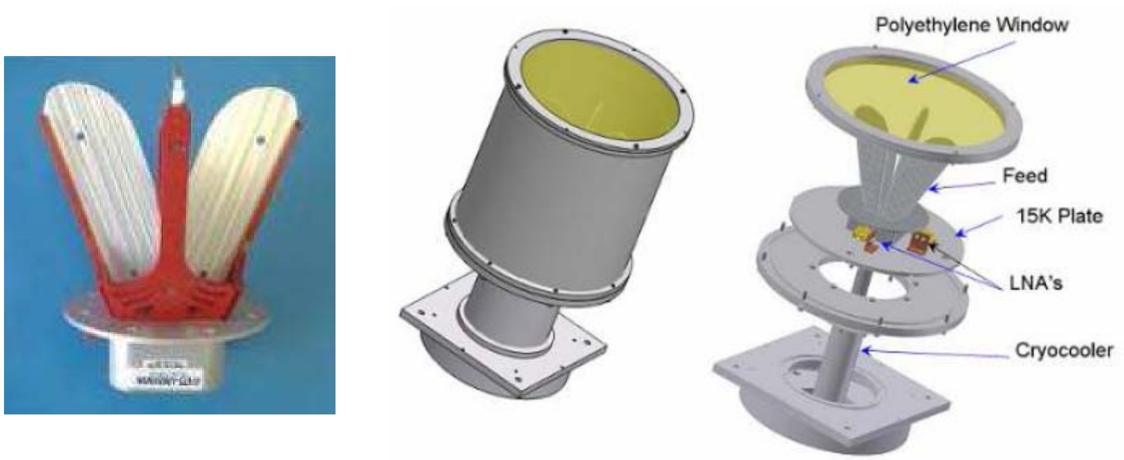

Figure 4. (*right)*: Integration of a Quad-Ridge Lindgren Horn (*left*) with a cryogenic dewar.[8]

III. QSC Feed

Feed Description. The antenna has four arms with a 3-D log-periodic configuration in a quasi-self complementary fashion (i.e., not-strictly 3-D self-complementary). The overall antenna has 4-fold azimuth symmetry, i.e., its aspect remains invariant to rotations of 90°. The feed is dual polarized, a single linear polarization is achieved by exciting two opposite arms. The feed arms are located over a ground plane with an inclination angle that may be optimized to minimize cross-polarization. The feed is very compact with a diameter of approximately 1.2λmax by 0.25λmax in height. The 3-D shape and position of the log periodic arms is carefully chosen to minimize return loss over the frequency band [9].

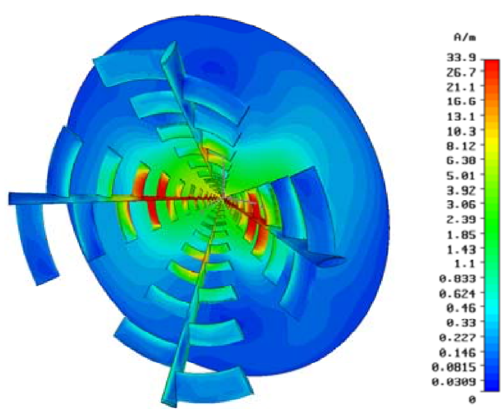

Figure 5. Intensity of the H-Field at 4 GHz at the feed's E-plane [9]

Calculated Feed Performance. The numerical field calculations to study this feed were performed using CST Microwave Studio. Figure 5 shows a sample of the surface current of the feed at 4 GHz. The calculated feed input matching, given in terms of VSWR, is shown in Figure 6. The maximum VSWR value is 1.6:1 over the frequency band, (i.e., -13dB return Loss) . The input impedance is quite high but manageable (270 Ω). Currently we are collaborating with Dr. S. Weinreb at Caltech, towards the integration of the QSC feed with a high impedance active balun.

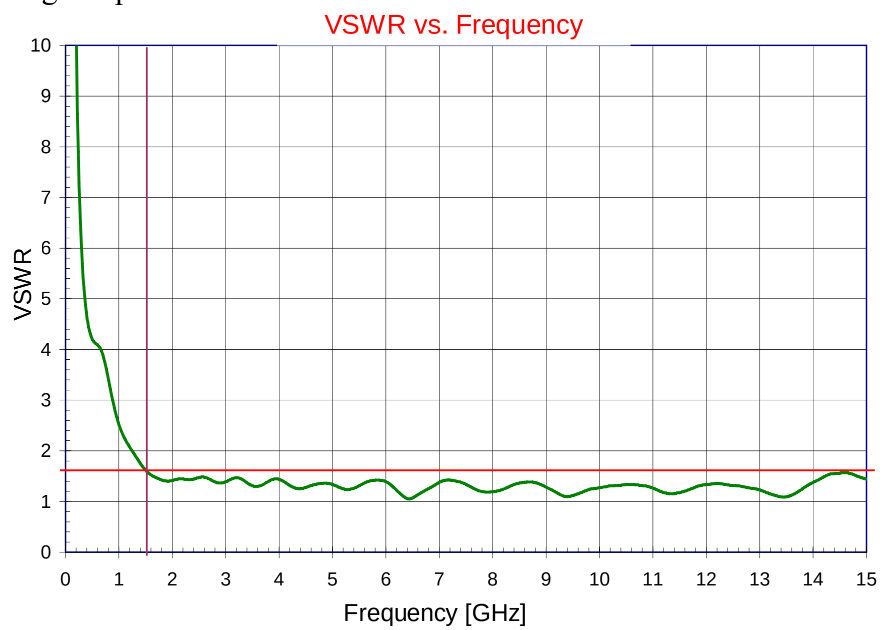

Figure 6. Feed VSWR as a function of frequency [9]

Figure 7 below shows the calculated antenna directivity as a function of frequency.

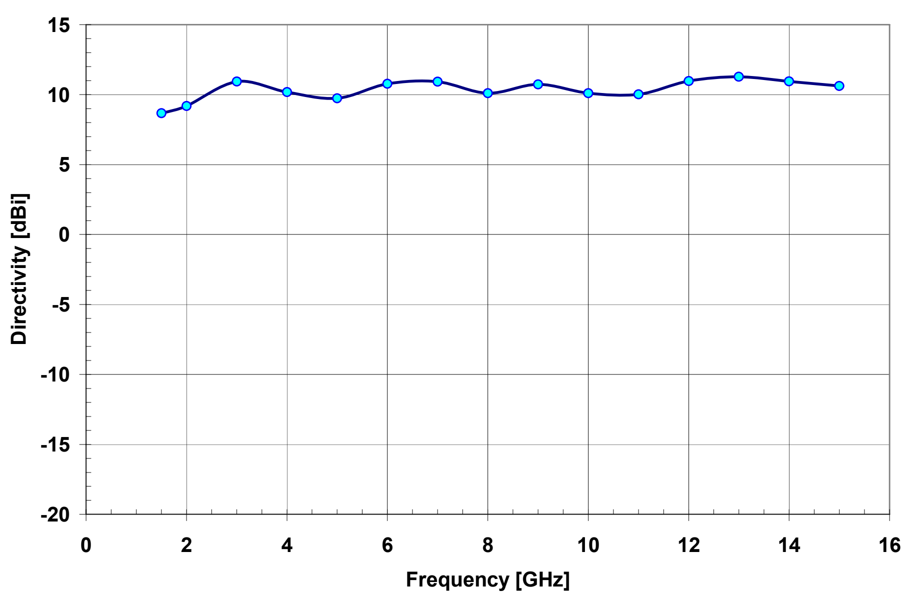

Figure 7. Calculated Antenna Directivity as a function of frequency [9]

Figure 8 shows the calculated feed's Co-polar and Cross-Polar pattern cuts at φ=0°, 45° and 90° for six different frequencies: 1.5 GHz, 3 GHz, 6 GHz, 12 GHz, 14GHz and 15 GHz, respectively. The calculated frequency average –10dB half beam width is approximately 66°.

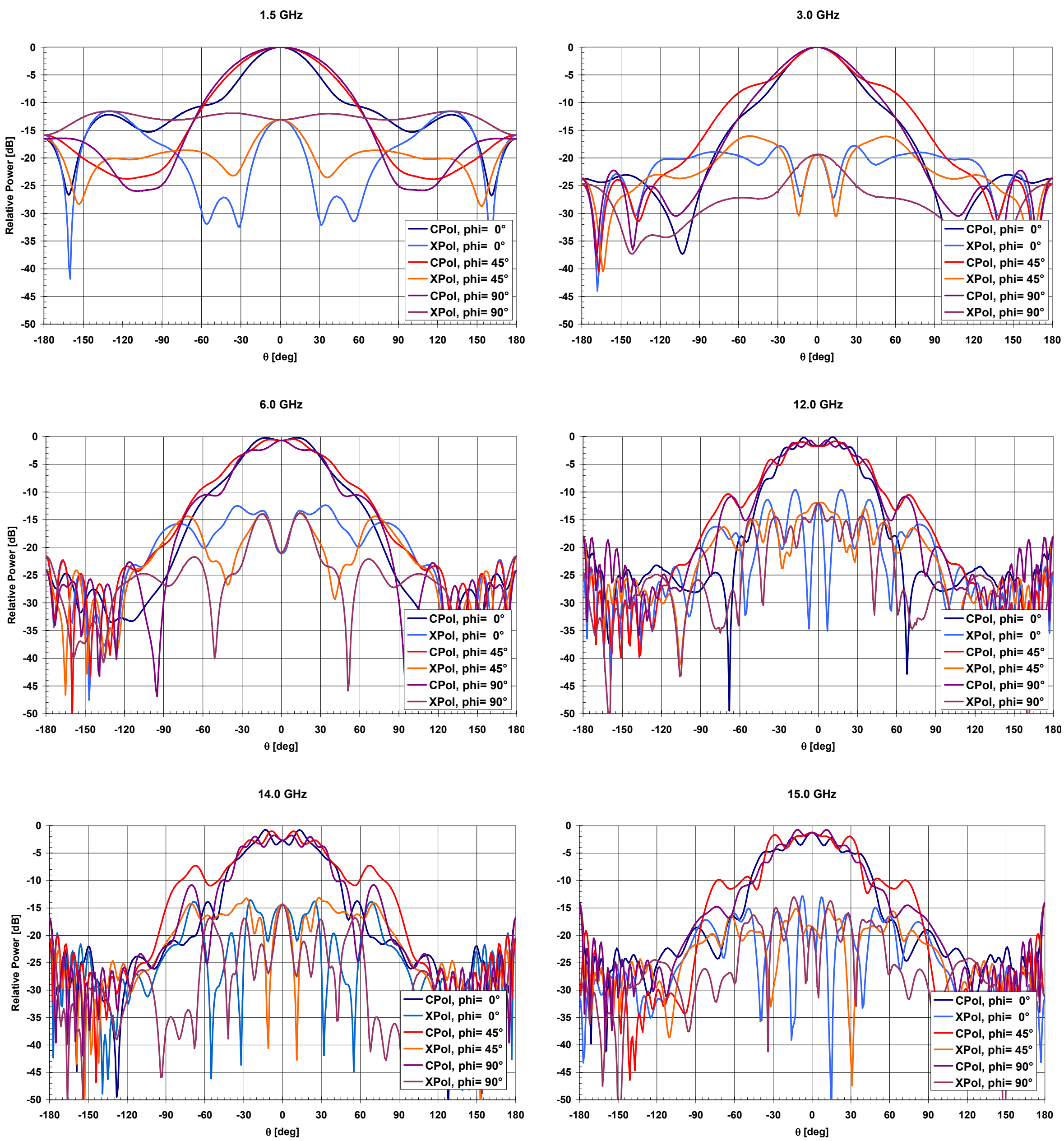

Figure 8. Feed Co-polar and Cross-Polar pattern cuts at φ=0°, 45° and 90° for four different frequencies: 1.5 GHz, 3 GHz, 6 GHz, 12 GHz, 14GHz and 15GHz [9]

This feed has very good polarization characteristics, with cross-polarization peak values at 45° better than –10 dB over the frequency band shown in Figure 9.

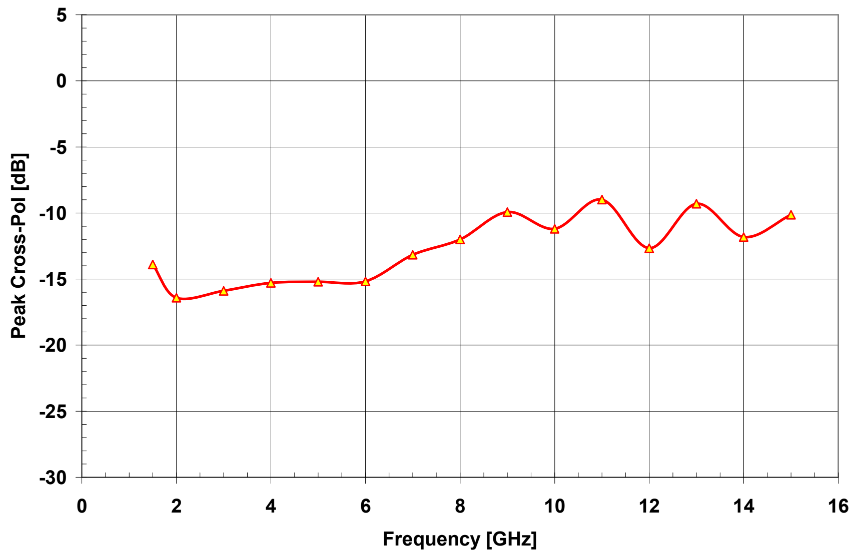

Figure 9. Peak values of cross-polarization at φ=45° [9]

A Family of Ultra Wide Band Feeds. This feed is in fact part of a family of ultra wide band feeds with very similar 3-D geometric characteristics (See Figure 10) but slightly different radiation pattern, which provides a portfolio of ultra-wide band feeds to be used for both Arecibo and SKA [9].

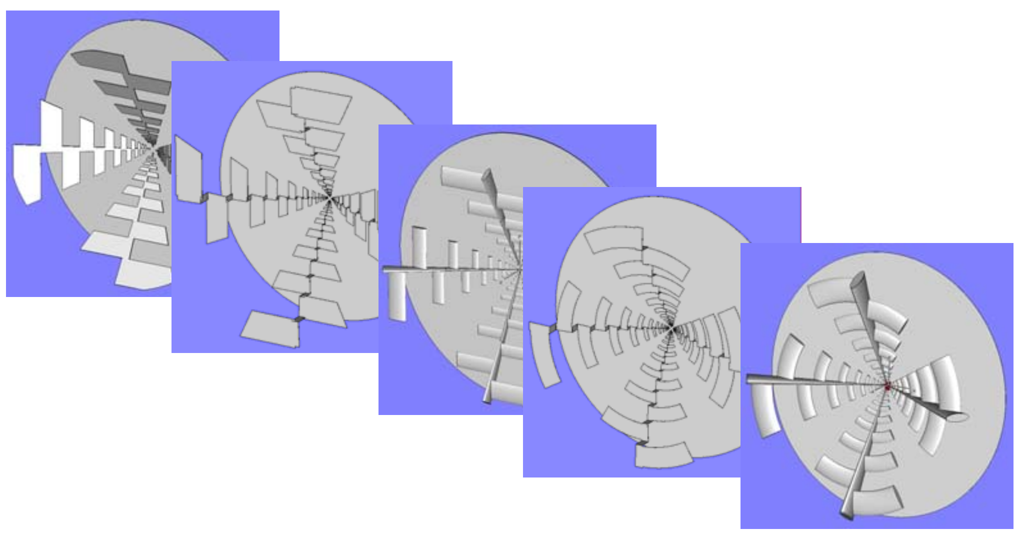

Figure 10. Family of QSC feeds with initially calculated bandwidths in excess of 10:1 [9]

300MHz to 3GHz Prototype. We are currently developing a 300MHz to 3GHz prototype to verify the feed performance. Additional prototypes are expected to be fabricated, at a higher frequency, i.e., 1 to 10 GHz feed, for integration with S. Weinreb active baluns and cryogenically cooled to test for noise temperature and performance on an actual telescope. More complete measurement of this feed performance at Arecibo is under way.

IV. Conclusions

We have presented a summary of current technology possibilities available to implement ultra wide band feed systems at Arecibo. With some technologies more mature than others, very low noise performance 2:1 bandwidth technology is available now. Cryogenically cooled feed systems based on the quad-ridge feed with bandwidth in excess of 4:1 are also feasible after some improvements. Ultra wide band systems based on our QSC feeds or Chalmer's feeds still require additional work for LNA integration, common effort for both types of feeds that will take place in the Technical Development Program within the US-SKA framework.

V. References

[1] G. Engargiola, "Non-Planar log-periodic antenna feed for integration with cryogenic microwave amplifier", *IEEE Trans. Antennas Propag Int Symposium* 2002.

[2] R. Dybdal, "Defocusing loss for a log periodic-fed reflector", *IEEE Trans. Antennas Propag.* Vol. 33, No. 7, pp. 809 - 812, July 1985.

[3] David R. DeBoer et al. "Frequency Coverage of the ATA Front-end", ATA Memo 64, SETI Institute, University of California at Berkeley,

[4] G.C. Bower: "The Allen Telescope Array", *URSI 2007 CNC/USNC - North America Radio Science Meeting,* July 22nd - 26th, 2007 Ottawa, ON, Canada

[5] R. Olson, P. Kildal and S. Weinreb, "The Eleven Antenna: A compact Low-Profile Decade Bandwidth Dual Polarized Feed for Reflector Antennas" *IEEE Trans. Antennas Propag.* Vol 54, No.2 Feb 2006.

[6] G. Cortés. "The Future: Ultrawide Band Feeds and Focal Plane Arrays", NAIC AUSAC Meeting , Mar 2005.

[7] V. Rodriguez, "A multi-octave open-boundary quadridge horn antenna for use in the S to Ku-bands," *Microwave Journal*, March, 2006, pp. 84–92.

[8] William A. Imbriale, Sander Weinreb and Handi Mani. "Design of a Wideband Radio Telescope", *IEEE 2007 Aerospace Conference*, Big Sky, Montana, March, 2007.

[9] G. Cortés, "Novel Non Planar Ultra Wide Band Quasi Self-Complementary Antenna". *IEEE Antennas and Propagation International Symposium.* Hawaii, June 2007.