S/X Feed Horn Properties at 2025 to 2120 MHz

and

S Band Feed System Tuning Procedures

George Behrens, Gary Anderson, Galen Watts and Glen Langston

00 November 15

Overview

This document describes measurements of the Green Bank Interferometer and 20 m antenna S/X band feed horn at the NASA S-Band Uplink frequencies. These measurements were made to determine the suitability of this horn for use in a Satellite communications design. The S band portion of the horn is dual circularly polarized and was designed to operate well in the 2200 to 2400 MHz range, which includes the Satellite Downlink frequency range. Test data were needed in the 2025 to 2120 MHz range to determine the feed horn beam shape, polarization purity and isolation.

The NASA standard S band Uplink band is 2025 to 2120 MHz and by convention the satellite downlink is phase locked to the uplink frequency with turn around ratio 240/221. The downlink frequency range is 2200 to 2300 MHz. For the Japanese Halca Satellite, the uplink frequency is 2084.4 MHz and the downlink frequency is 2263.6 MHz. Measurements indicate that the feed horn is suitable for use in the frequency range 2025 to 2120 MHz. The feed horn components were tuned for improved performance in the transmit band.

Test Setup

The measurements were made on the NRAO Green Bank antenna range using a linearly polarized feed horn and also using two conical helix antennas. At the transmit horn an HP synthesizer was tuned to frequencies in the S band uplink range and power output was set to +10 dBm. A 20 dB directional coupler was used at the transmit horn to provide the Scientific Atlanta test receiver with a phase stable reference frequency.

The test receiver was located at the base of the tower holding the feed. The test receiver was locked to the transmit frequency and generated a LO frequency that was equal to the reference frequency plus or minus 45 MHz. The test signal received by the feed system mixed with the receiver L.O. signal at a coaxial mixer connected to one of the Orthomode Transducer (OMT) ports. The mixer down converted the received frequency to 45 MHz. The test receiver was used to measure the amplitude and phase of the received signal. The test receiver is somewhat difficult to adjust, so care was taken to adjust the signal levels to maintain proper lock of the test receiver.

Transmit Frequency (MHz)	Isolation Helix 445 (dB)	Isolation Helix 442 (dB)	Axial Ratio (dB)
2025	-11	-17.3	4.6
2050	-15	-16.0	3.7
2083	-8		
2100	-9	-8.4	2.6
2120			3.0
2210	-16	-20.0	0.9

Table 1: Measurements of Polarization Isolation and Axial Ratio

Beam Pattern Measurements

The amplitude and phase beam patterns were made for the forward OMT port of the horn in both the E and H planes. The forward feed OMT port was determined to be the RCP port, using the LCP polarized helix feeds. (Note that for RCP uplink transmissions, the LCP polarized, rear, port will be used, when the feed is at the antenna prime focus.) The beam patterns for a number of frequencies in the band are shown in figures 1 to 10. The measurements at 2210 MHz, shown in figures 9 and 10, were performed to confirm the measurement process, by comparing the results with previous measurements. The new measurements were found to agree with the previous data.

The polarization Isolation and Axial Ratio were measured and listed in table 1. A number of repetitions of the Isolation measurements were made due to inconsistency in the measurements. It was finally determined that the Helix feed serial number 445 from American Electronic Laboratories had poor properties in this frequency range. Helix feed serial number 442 from the same manufacturer was used and found to give more consistent results. The measurements of Table 1, Helix 442 results are considered most reliable. The Axial Ratio measurements were made using a rotating linearly polarized transmitting feed horn. The Axial Ratio was determined by measuring the difference between maximum and minimum received signal level as the polarized transmitting horn was rotated ± 180 degrees.

Return Loss and Isolation Measurements

Measurements of return loss and isolation were made in the lab, using a network analyzer. The test setup placed the transmit signal on the rear port, and the isolation was measured on the front port. The return loss of the OMT ports could be adjusted by changing the iris width at the ports. The S band feed horn transition includes a metal "tuning ring" mounted inside a Polystyrene Foam Support (PFS). Adjustment of this ring, by moving the PFS in and out, allowed improving the polarization isolation in different frequency ranges.

The measurements of the return loss and polarization isolation in the frequency range 2000 to 2500 MHz are are shown in figures 11, 12, 13 and 14. In figure 11, the feed is in the unmodified configuration. The return loss measurements match reasonably well with previous data, however the polarization isolation is very flat at about -10dB, somewhat poorer than was shown in previous measurements in the 2200 to 2300 MHz region.

In figure 12, the same data were taken with the matching iris in the rear port widened from its initial 2.25 inch width to 3.28 inches, in order to improve the return loss in the transmit band. The return loss is significantly improved in the transmit band, being no worse than -12.4 dB, but the receive band shows between -8.8 and -6.3 dB return loss. The isolation in this configuration is not significantly modified.

In figure 13, the iris is returned to the original configuration, but the PFS containing the tuning ring was moved back 2.51 inches from the front surface of the X band horn. In this configuration, the return loss remains high, -5.4 to -8.4 dB in the transmit band, but the polarization isolation is improved to between -14.3 and -21 dB.

In figure 14, the wide rear port iris was used in conjunction with the repositioned tuning ring. Both the isolation and return loss are improved in the transmit band. The return loss is between -12.5 and -22 dB and the isolation is between -12.4 and -15.5 dB. The return loss is worse that the original configuration in the downlink band, between -15.5 and -9.3 dB but the isolation is much improved, between -23 and -13.7 dB. The measurements of isolation shown in figure 14 are similar to the measurements made immediately after the feed was constructed.

Satellite applications will use narrow up and down link bandwidths (> 1 MHz), the return loss and isolation parameters can be tuned to yield good properties at specific link frequencies. In the fully tuned configuration (figure 14), for the HALCA uplink the return loss is -21 db and the isolation is -13 dB. For the HALCA downlink, the return loss is -12 dB and the isolation is -18 dB.

In figure 15, the return loss and isolation are shown with the tuning ring adjusted for maximum polarization isolation in the uplink band. Notice that although the isolation in the uplink band is improved to better than -17 dB, the isolation in the downlink band has degraded to between -12 and -8 dB.

Conclusions

The amplitude and phase beam patterns at frequencies in the range 2025 to 2210 MHz were symmetric and showed proper shape in the range ± 60 degrees.

Measurement of return loss and isolation in the laboratory indicate that the S band horn tuning ring had shifted from its original position. Readjustment of the tuning ring and modification of the rear port iris yielded much improved performance. The placement of the tuning ring and size of the iris opening should be matched to the specific up and down link frequencies of the mission.

Appendix A: Procedure for tuning the S/X Feed

The following are some recommendations and comments regarding the tuning of the S/X Feeds that are presently installed at the GB Interferometer, the 20 Meter Telescope and the one that was installed on the the telescope in Kokee Park, Hawaii. The tuning is performed by first calibrating a network analyzer then attaching the forward OMT port to the transmit side of the network analyzer and attaching the rear OMT port to the receive side.

Please refer to Figures 2 and 3 of the report that appeared in the Proceedings of the IEEE of May 1994 entitled "Design and Implementation of a Low-Noise Prime Focus S/X Receiver System for Radio Astronomy", by Roger D. Norrod, George H. Behrens, Jr, Frank D. Ghigo and Burton J. Levin. These figures are included here as Figures 16 and 17.

As shown in Fig. 16, the S-Band section of the Feed is composed of items 1 through 12. A description of these components is given in the paper. However, a review of their purpose and interaction is given here as an aid to understanding the tuning procedure.

The S-band Section of the S/X Feed System consists of three sub-assemblies- 1) the Feed, 2) the Polarizer and 3) the Orthomode Transducer (OMT).

The Feed:

The Dual Depth Corrugated horn (Item 1), is excited by the Coaxial Waveguide (item 5) where the X-Band waveguide (Item 14) serves as the center conductor of the S-Band waveguide.

Impedance matching of the Corrugated Horn to the Coaxial Waveguide is achieved by the tuning ring (Item 3) which is held in place by the Polystyrene Foam Support (PFS).

The Polarizer:

The S-band Polarizer (Item 6) is comprised of two cross-linked polystyrene plates that also act as supports for the X-Band Waveguide. The length of the polarizer is such that it provides a differential phase shift of approximately 90 degrees for waves that have E-Fields parallel and perpendicular to the polarizer plates.

Impedance matching of the polarizer to the circular waveguide is achieved by the steps milled on the ends of the polystyrene plates.

The Polarizer plates are oriented such that the E-fields excited by the two Orthogonal Slot Coupled T-Junctions (Items 7 and 9) are rotated 45 degrees with respect to a plane parallel to the polarizer plates. Such orientation causes that component of the E-field parallel with the Polarizer plates to lag that component that is normal to the plates by 90 degrees-the criteria required for circular polarization.

The Orthomode Transducer (OMT):

The S-band OMT Sub-Assembly, is comprised of Items 7 thru 12. The Forward Slot coupled T-Junction (Item 7) couples energy from the S-Band WR-430 Waveguide to the Coaxial Waveguide. Item 7 is oriented with respect to the Polarizer Plates to provide Right Circular Polarization at the Feed. Similarly, the Rear Slot Coupled T-Junction is oriented with respect to the Polarizer to provide Left Hand Circular (LHC) at the Feed.

The Septum (Item 8) acts as a back short for the Forward Junction and channels RHC energy received by the Feed to the RHC WR-430 waveguide. As RHC energy propagates down the coaxial waveguide it is converted to a linear polarized wave by the polarizer. The polarization of the E-Field is such that it is parallel to the septum and therefore is reflected back towards the feed. However since the septum is located approximately 1/4 wavelength beyond the Forward Junction, it appears as a high impedance as seen at the junction and little energy propagates beyond the junction. Essentially all the energy is then coupled to the the RHC rectangular waveguide.

In the case of LHC energy received by the Feed, the polarizer converts the circularly polarized signal such that its E-Field is oriented normal to the Septum and therefore the Septum appears essentially transparent to the signal. The signal then propagates to the Rear T-Junction (item 9) where it is coupled to the LHC WR-430 waveguide after being reflected at Back Short (Item 10).

Tuning of the feed system over a limited frequency range is achieved by setting the feed impedance match and the OMT match.

S-Band Feed System Tuning Procedures

Feed Impedance Match:

As mentioned above, the S-Band Feed is matched to the Coaxial waveguide by adjusting the dimensions and position of the Tuning Ring (Item 3) which is held in place by the Foam Support (Item 4). During the original tuning of the Feed it was optimized over the 2.2-2.3 GHZ Band. The dimensions and position of the Tuning Ring was determined empirically by measuring the Isolation between the RHC Coupler (Item 7) and the LHC Coupler (Item 9). The dimensions of the Tuning Ring and its position were changed until maximum isolation was obtained.

It is assumed that the feed is optimally matched under this condition because when the test signal is injected into the RHC Coupler and propagates thru the polarizer it gets converted to a RHC polarized signal. This RHC signal continues to propagate to the feed. If the feed is perfectly matched all the energy will be propagated into free space. However if the Feed is not perfectly matched, a portion of the test signal will be reflected at the Throat of the Feed (the Feed/Circular Waveguide Interface). Since reflections of Circular Polarization signals are converted to the opposite sense, the reflected portion of the RHC test signal becomes a LHC signal and appears at the LHC (Rear) Coupler. Hence, the Isolation measurement is directly related to how well the feed is matched.

If the Feed is to be matched for a specific frequency, measure the isolation between the RHC and LHC Couplers and slide the Foam Support which houses the Tuning Ring until maximum isolation occurs over the desired band. Measure the Isolation using the Network Analyzer in the Dual Channel Mode so that both Return Loss and Isolation can be observed simultaneously. Ensure that when adjusting the tuning ring, that there is little change in Return loss and that S12 is the same as S21 and that the Return Losses S11 and S22 are similar.

OMT Matching:

The RHC and LHC Couplers are matched to the WR-430 Rectangular Waveguide by empirically adjusting the back short (10), the Septum (Item 8), and Tuning Irises (Items 11 and 12).

In the original development of the OMT, the OMT was terminated with a sliding Coaxial Waveguide Load. The Network Analyzer was calibrated in WR-430 waveguide and the Admittance looking into the RHC port was measured for different positions of the Septum. The Reference plane during calibration was the junction of the WR-430 waveguide and the RHC Coupler. The Septum position was adjusted to cause an admittance locus that could be tuned by using a Inductive Iris at the Junction or at some point away from the junction and inside the WR-430 Waveguide. The width of the Iris was adjusted to obtain the best match over the 2.2-2.3 GHZ Band.

The LHC Port (Rear Port) was tuned in a similar fashion except that the Back short was adjusted instead of the Septum. A location of the Septum was found that would permit a Shunt Inductive Iris in the WR-430 waveguide that would optimally match the LHC Port over the 2.2-2.3 GHZ Band.

If the OMT is to be tuned for another Band, it is recommended that the total feed system be connected and that the Network analyzer be calibrated for a Full Two Port Measurement. Connect the Network analyzer to both ports and measure simultaneously the Return Loss (S11) and Isolation between the RHC and LHC Port (S12) by using the dual channel mode on the network analyzer. Vary the width of the window to obtain the best Return Loss and observe S12 to ensure there is no interaction. Wider openings in the window of the iris will permit lower frequency operation.

E and H plane measurements at 2025 MHz

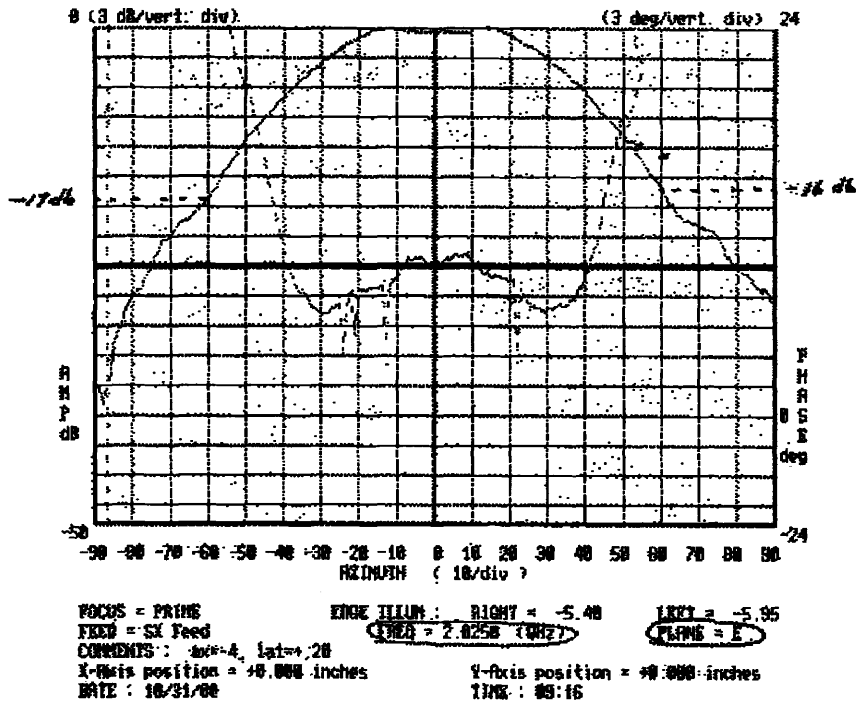

Figure 1: S Band Horn Amplitude and Phase versus orientation relative to linearly polarized horn E plane.

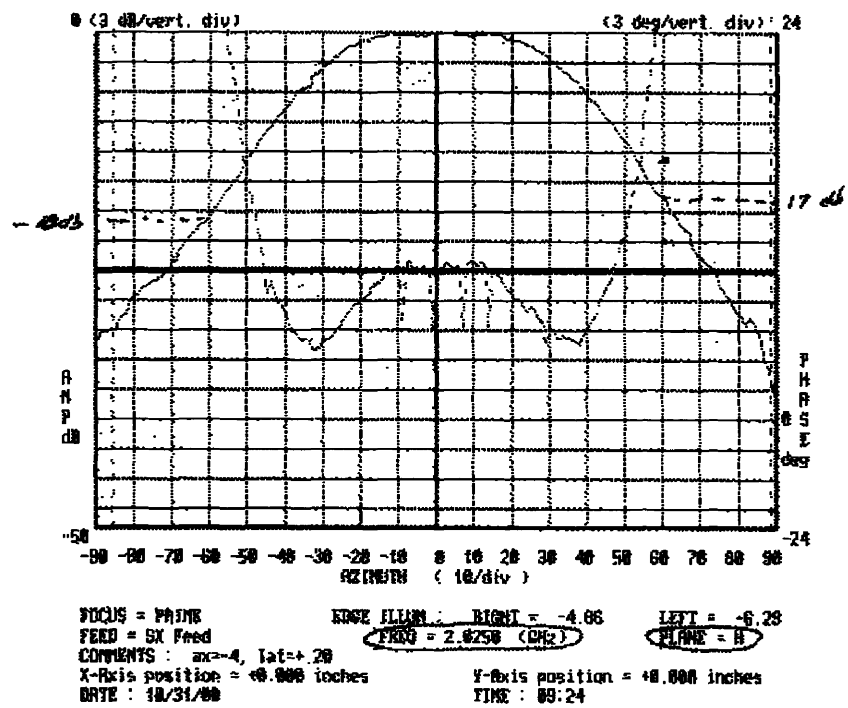

Figure 2: S Band Horn Amplitude and Phase versus orientation relative to linearly polarized horn H plane.

E and H plane measurements at 2050 MHz

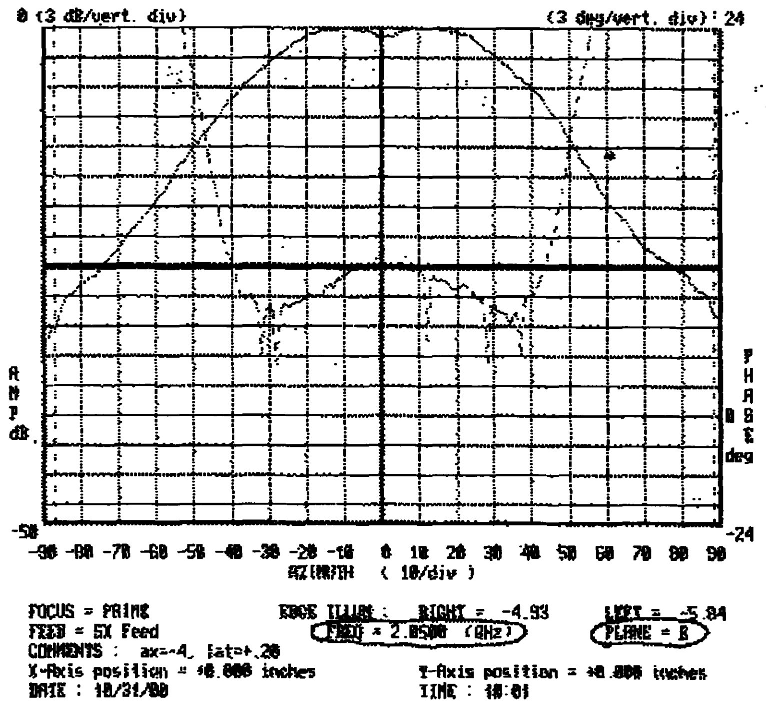

Figure 3: S Band Horn Amplitude and Phase versus orientation relative to linearly polarized horn E plane.

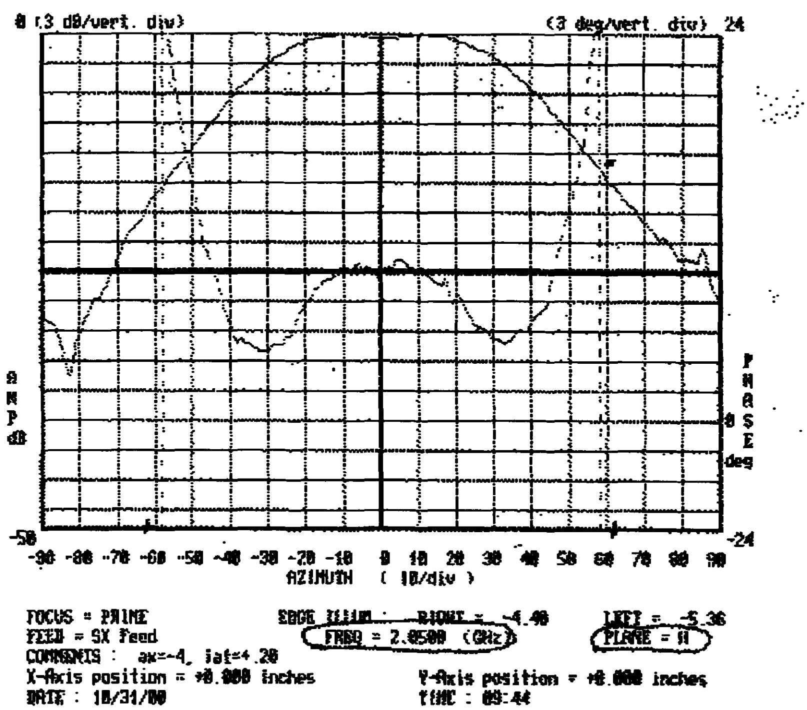

Figure 4: S Band Horn Amplitude and Phase versus orientation relative to linearly polarized horn H plane.

E and H plane measurements at 2100 MHz

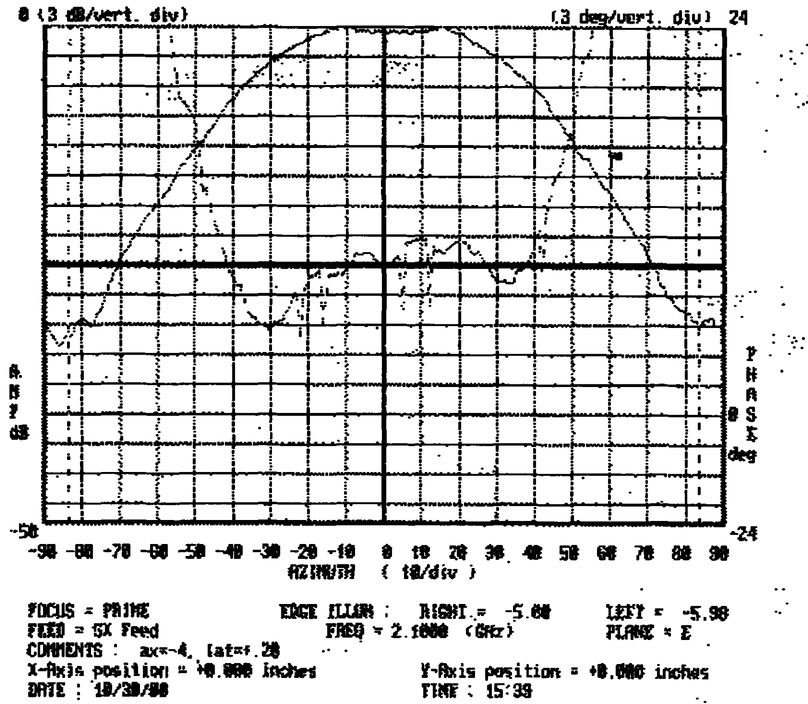

Figure 5: S Band Horn Amplitude and Phase versus orientation relative to linearly polarized horn E plane.

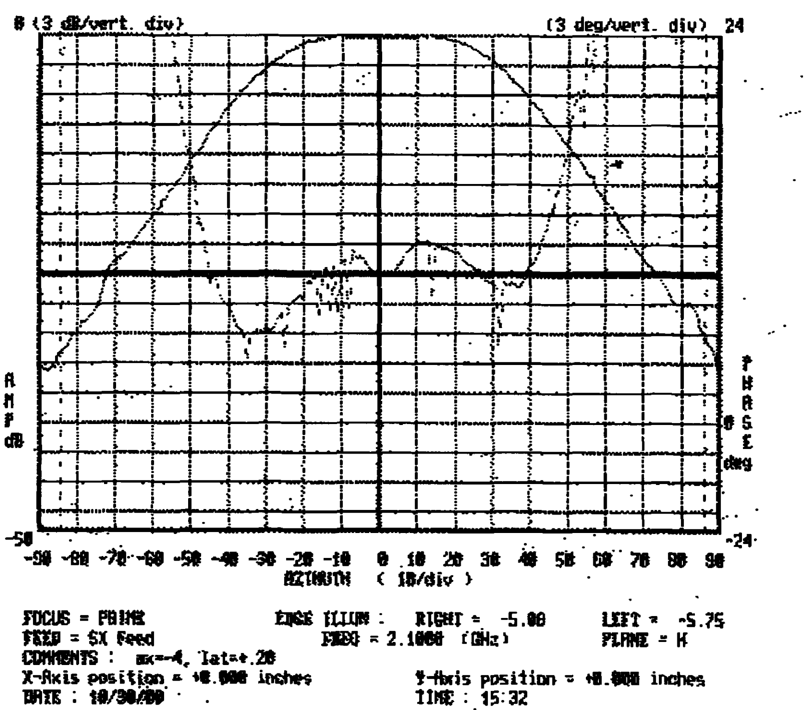

Figure 6: S Band Horn Amplitude and Phase versus orientation relative to linearly polarized horn H plane.

E and H plane measurements at 2120 MHz

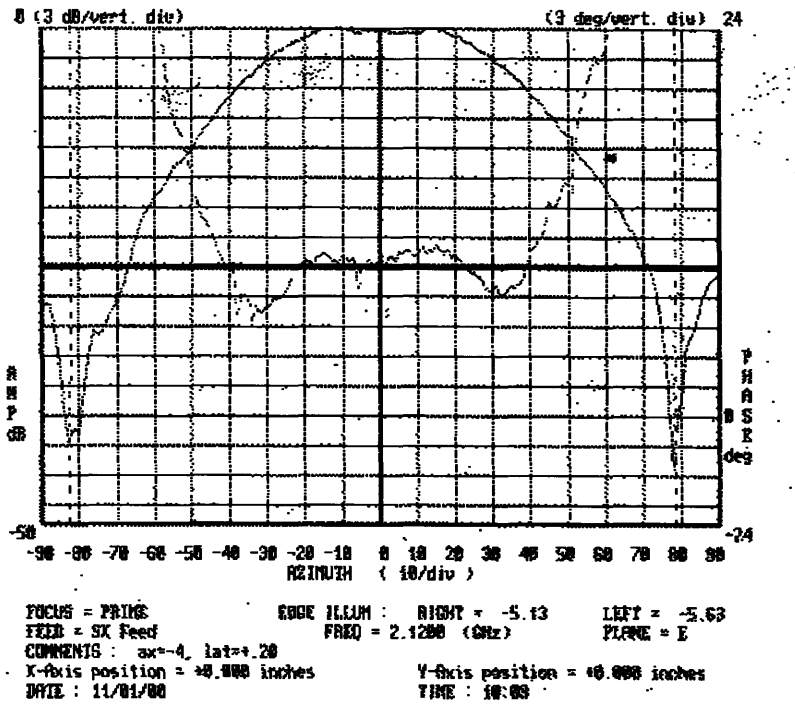

Figure 7: S Band Horn Amplitude and Phase versus orientation relative to linearly polarized horn E plane.

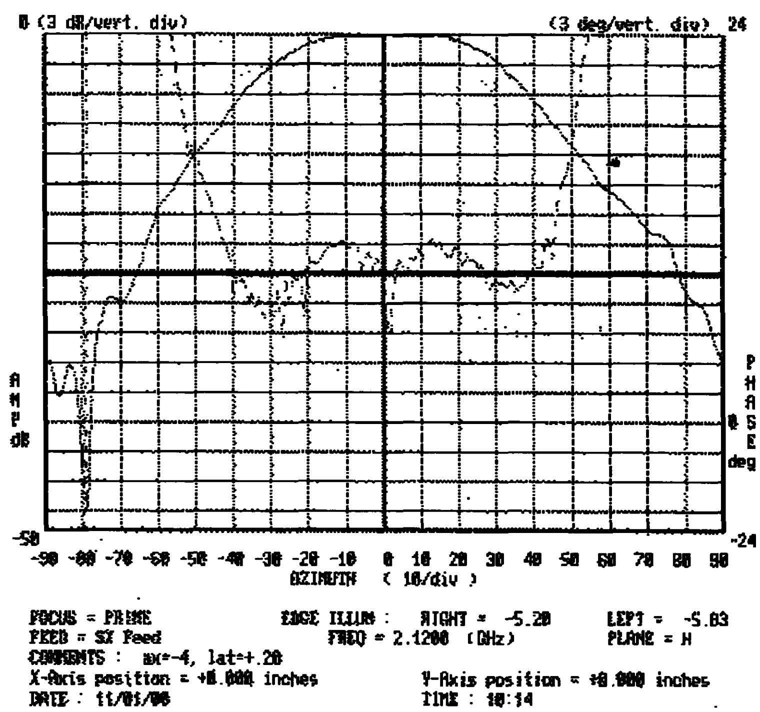

Figure 8: S Band Horn Amplitude and Phase versus orientation relative to linearly polarized horn H plane.

E and H plane measurements at 2210 MHz

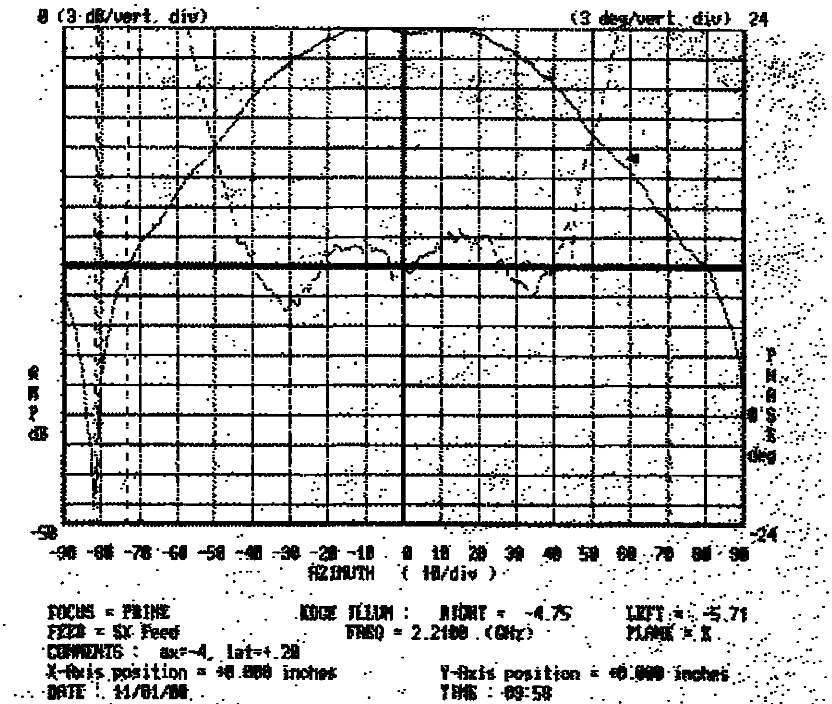

Figure 9: S Band Horn Amplitude and Phase versus orientation relative to linearly polarized horn E plane.

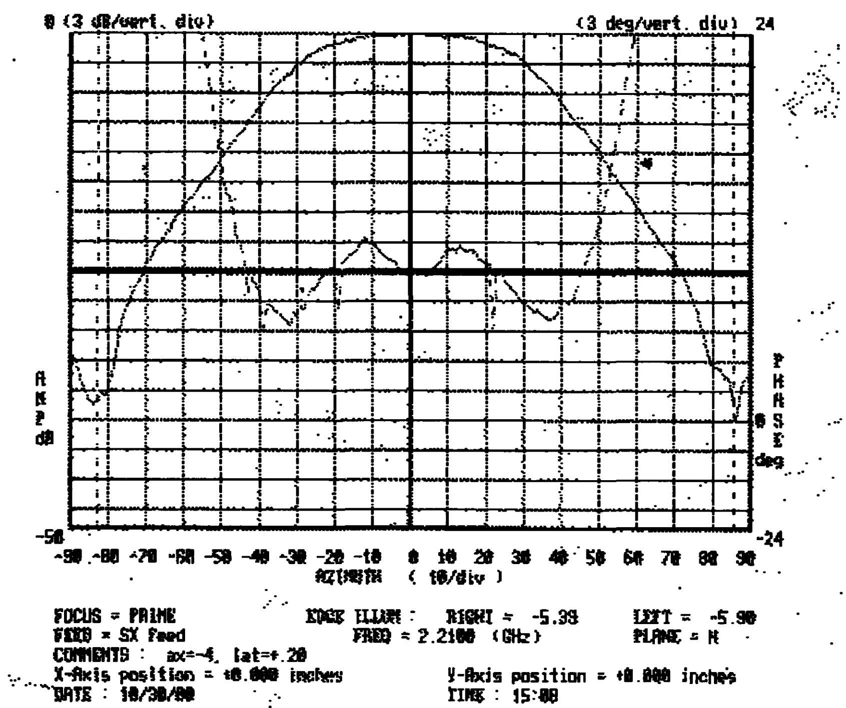

Figure 10: S Band Horn Amplitude and Phase versus orientation relative to linearly polarized horn H plane.

Rear Port Return Loss and Polarization Isolation

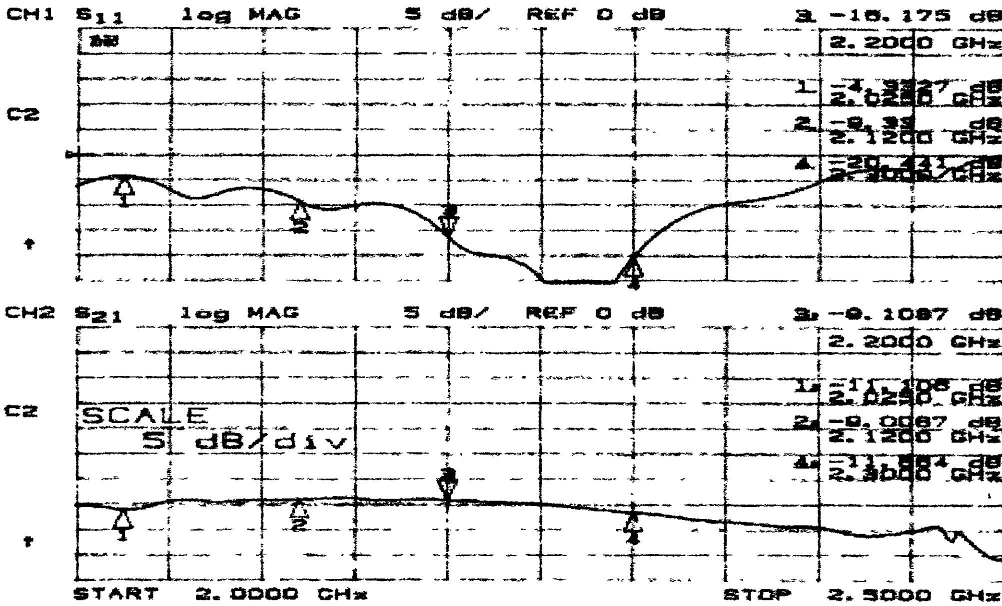

Figure 11: S Band Horn return loss (top) in the frequency range 2000 to 2500 MHz. Polarization isolation is shown below, indicating nearly constant isolation value of -10 dB. The rear port iris opening width was 2.25 inches.

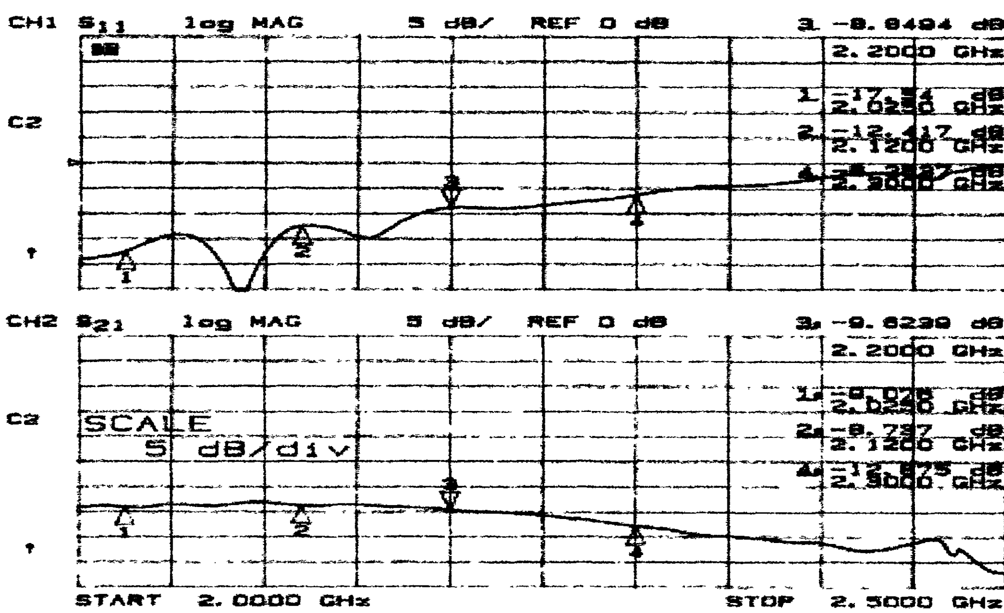

Figure 12: S Band Horn return loss (top) in the frequency range 2000 to 2500 MHz with the rear port matching iris width increased to 3.28 inches. Polarization isolation is shown below, indicating the isolation is not effected by the front port matching iris.

Rear Port Return Loss and Polarization Isolation

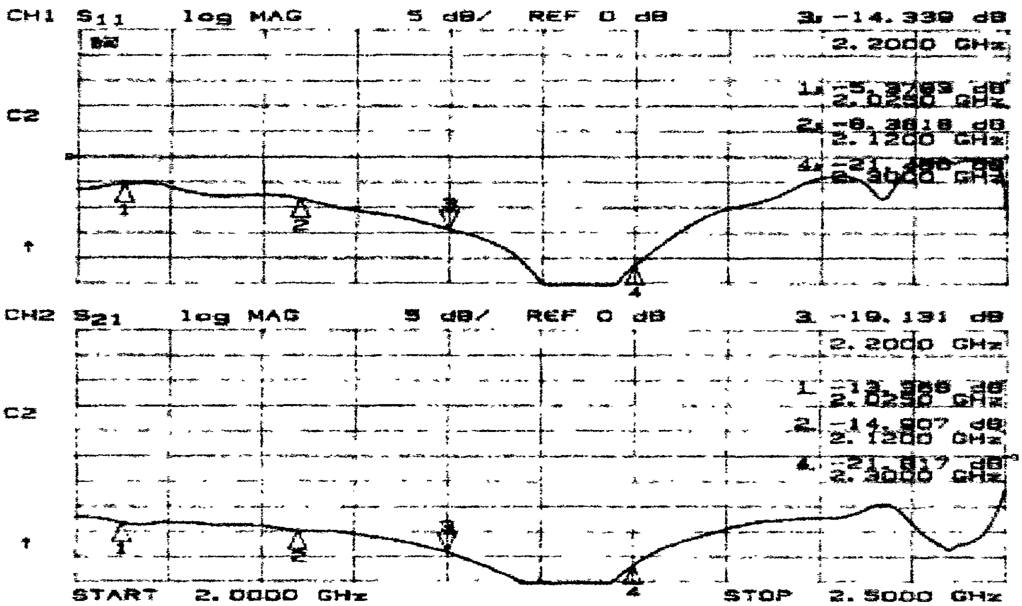

Figure 13: S Band Horn return loss (top) in the frequency range 2000 to 2500 MHz. Polarization isolation is shown below, indicating nearly constant isolation value of -10 dB. The rear port iris opening width was 2.25 inches, but the tuning ring near the front of the S band horn was moved to a position of 2.51 inches from the horn surface.

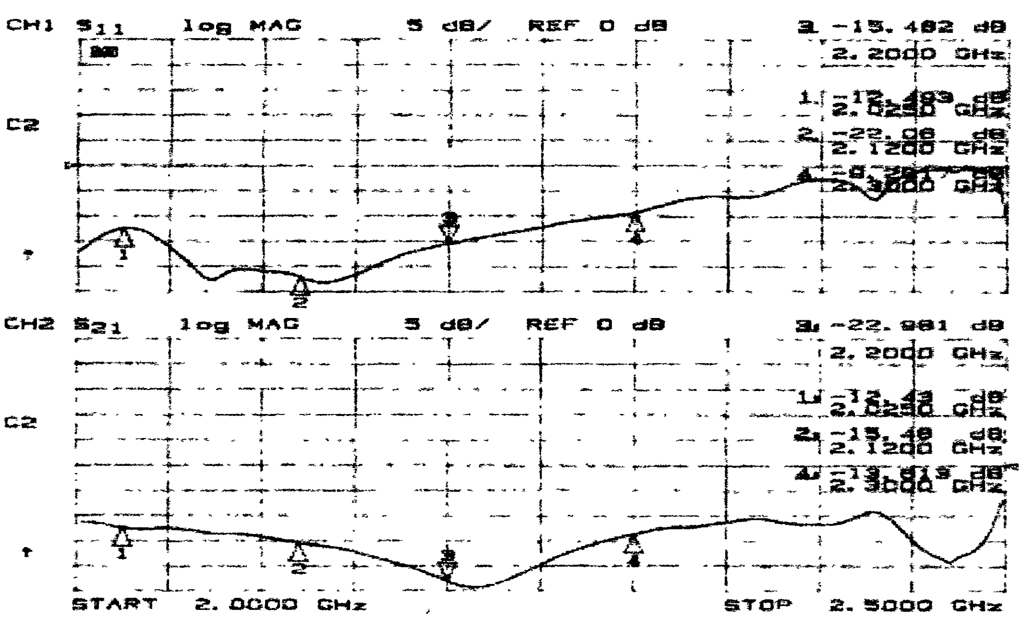

Figure 14: S Band Horn return loss (top) in the frequency range 2000 to 2500 MHz with the rear port matching iris width increased to 3.28 inches, and tuning ring adjusted as above.

Rear Port Return Loss and Polarization Isolation

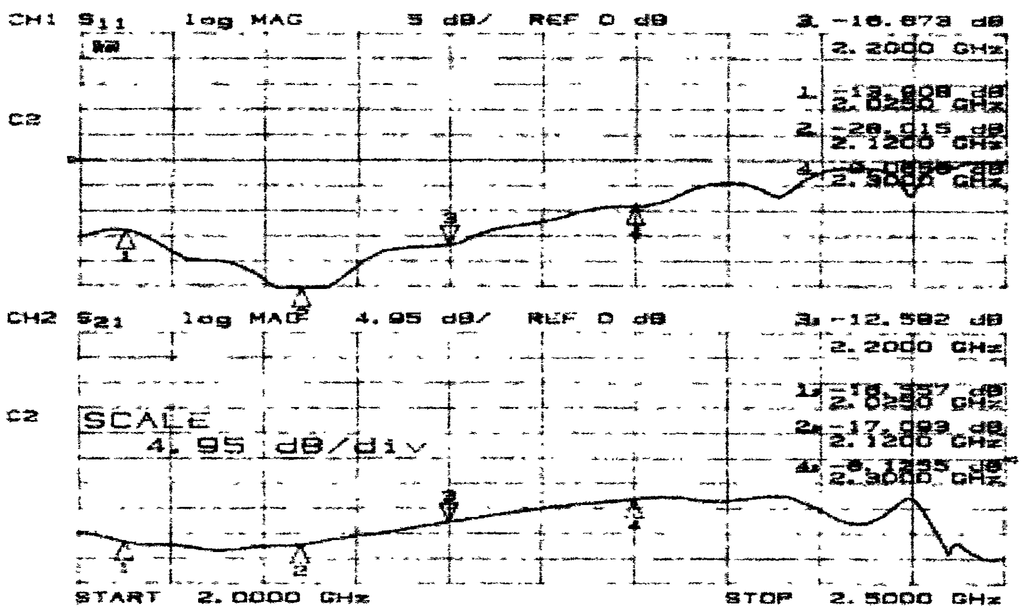

Figure 15: S Band Horn return loss (top) in the frequency range 2000 to 2500 MHz. The feed tuning ring is adjusted for maximum isolation in the uplink band. The rear port iris width is 3.275 in.

From "S/X Receiver System for Radio Astronomy"

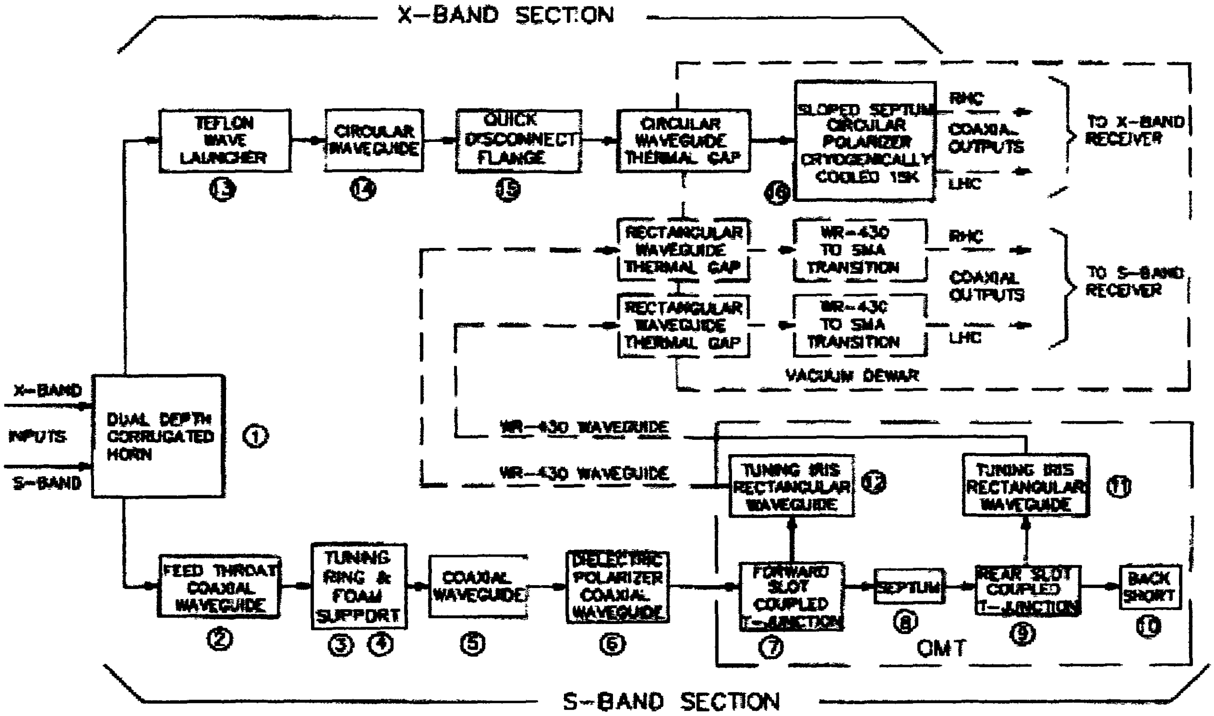

Figure 16: Block diagram of S/X Band system.

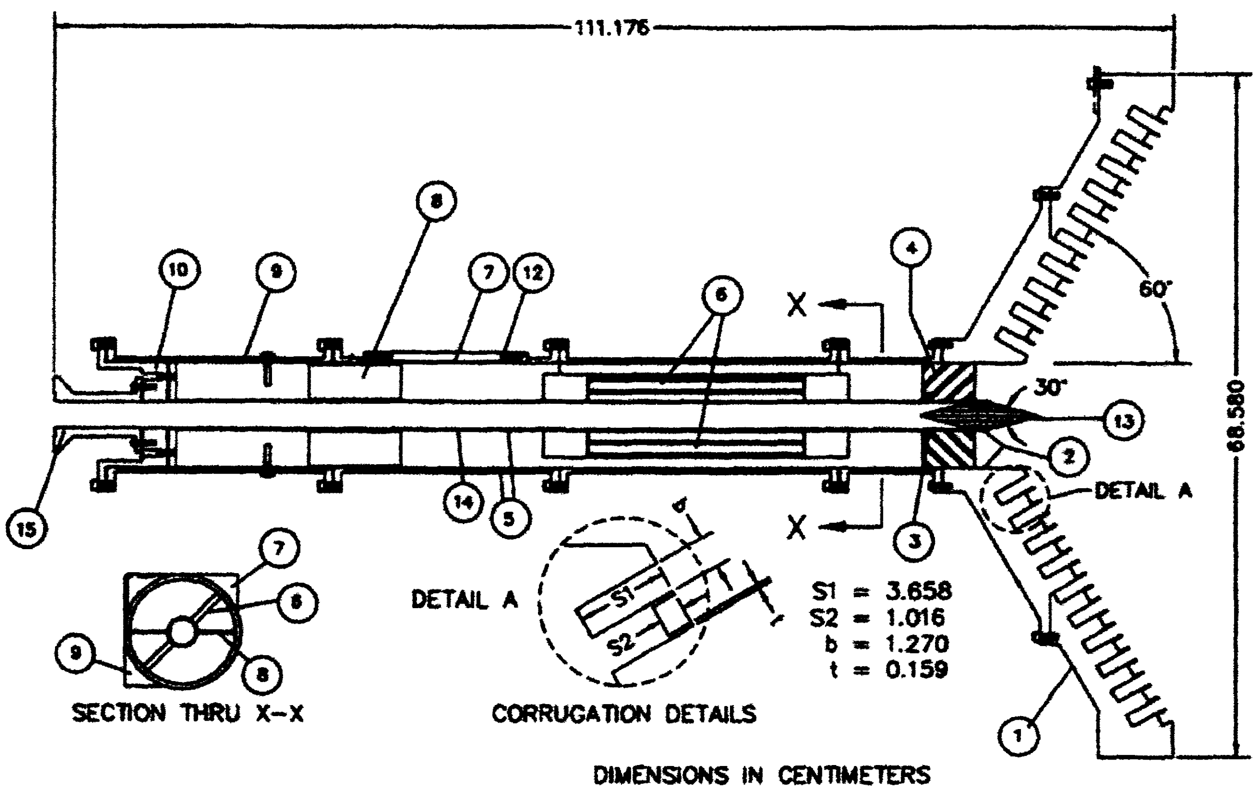

Figure 17: Cross section diagram of S/X Band system.