

# A Prototype DSN X/S-Band Feed: Model III Development<sup>1</sup>

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*This article is the seventh in a series documenting development of a prototype X/S-band common aperture Cassegrain feedhorn for DSN use. A Model III combiner has been developed to increase S-band bandwidth to include the Highly Elliptical Earth Orbiter band from 2025 to 2110 MHz, and to provide a 400-kW CW S-band uplink and a possible planetary radar band near 2320 MHz. The combiner uses eight S-band waveguide injection slots arranged in four pairs. The problems of this design geometry associated with rejection filtering and X/S-band matching are discussed.*

## I. Introduction

This is the seventh in a series of reports (Refs. 1 through 6) documenting development of a common aperture, two-frequency band Cassegrain microwave antenna feed system for specialized DSN use. This report briefly summarizes previous work and discusses problems associated with the most recent configuration, Model III. The problems are documented with the expectation that future efforts of a similar nature will necessarily be undertaken. It is hoped this report will provide future investigators with a valuable background, and increase the efficiency of the probable future development cycle.

<sup>1</sup>At inception of the DSN dual frequency common aperture feedhorn development series, it was usual practice to identify the various microwave frequency bands by letter designations, e.g., X- and S-bands. Since then the impreciseness of such letter designators has become apparent, and the use of numerical frequency designators was instituted as the DSN standard. Because of the long series of reports on this development, we retain the X/S designator to maintain the continuity and interrelationship of each report in the series. Wherever cited, S-band is defined to be 2.1 – 2.3 GHz and X-band 8.4 GHz.

## II. Previous Work

For many years, DSN 64- and 34-m operational tracking antennas have functioned simultaneously in the 2.1 (transmit), 2.3 (receive), and 8.4-GHz (receive) bands. Proper antenna RF performance parameters are obtained in the two widely separated frequency bands by the reflex-dichroic feed system (Ref. 7). This feed system spatially separates the S- and X-band feed beams and then directs those individual beams to (or from) appropriate single-band, high performance feedhorns. Although it is capable of nearly unlimited CW uplink power and no measurable degradation to S-band receive performance, the reflex-dichroic approach does impact X-band receive noise temperature at the 2-kelvin (0.5-dB G/T) level. For this reason alone, investigations into alternative approaches were indicated to improve the critical X-band performance, even at the cost of a slight impact to S-band performance, if necessary.

Following work which showed generally poor performance of one kind or another from a variety of simple approaches

(such as horn-within-horn), a common aperture feedhorn approach was undertaken. This approach uses a very large feedhorn operating in a beamwidth saturation mode at X-band, such that the radiation pattern at X-band is very similar to that at S-band. Corrugations are used so that the necessary capacitive surface impedance is realized in both bands. The groove depth at S-band is about  $0.35 \lambda_0$ , while at X-band it is about  $1.35 \lambda_0$ . This corrugation "harmonic" principle ensures that the horn aperture fields are well tapered in all planes, yielding desirable horn pattern functions at both frequency bands. In fact, an additional band at  $0.85 \lambda_0$  groove depth is available (as are others at harmonics above  $1.35 \lambda_0$ ) but is unused. As stated, the horn is large—more than  $7 \lambda_0$  in aperture diameter at S-band and over  $28 \lambda_0$  at X-band. Yet the saturation phenomenon (caused by phase error in the aperture) functions at X-band to produce  $-10$  dB pattern beamwidths that are nearly the same as at S-band. Little trouble was experienced in the development of the horn portion of this feed system. When separately excited with appropriate single-band throat sections, suitable performance is attained.

The challenge associated with the DSN X/S-band common aperture feed development effort lies in designing the combiner (or separator) portion; that is, extraction (or insertion) of the longer wavelength band at an appropriate horn diameter while providing an uninterrupted propagation path for the shorter wavelength band to exit (or enter) the normal throat region. The basic combiner concept adopted is shown in Fig. 1 of Ref. 2.

Three separate and distinct combiner developments have been made. Model I, described in Refs. 1 through 4, provided approximately 50 MHz of S-band bandwidth, sufficient only to prove the concept. The height of the four circumferential S-band waveguide injection slots was 8.9 mm (0.35 in.). The slots were arranged in a radial line configuration, providing minimal interruption to the X-band axial wave, even given the possibility of imperfect radial line X-band rejection filtering. These reject filters attempt to provide a virtual short-circuit of X-band impedance at a specific location near the corrugated waveguide wall. The specific location is the same as the root, or bottom, of the normal corrugations. In this manner, it was expected that the X-band wave would undergo no discontinuity in the transmission line (the horn).

In Model I, isolation of the X-band wave into the S-band ports was excellent—in excess of 40 dB with consequently good, however not perfect, X-band radiation patterns across a wide band of 7 to 8.5 GHz. Some evidence of  $EH_{11}$  moding was present at X-band, as evidenced by small variations in the detailed shape of the various X-band radiation patterns.

Model II, described in Ref. 5, successfully extended the S-band bandwidth to 200 MHz (2100 to 2300 MHz), with slight but acceptable further degradation to X-band patterns. The height of the S-band waveguide injection slots necessary for bandwidth improvement was 12.7 mm (0.50 in.). Off-axis crosspolarization at X-band was maintained at  $-26$  dB in the usual 45-deg pattern planes. Evidence of  $EH_{11}$  moding at X-band remained but was acceptable. Model II was designed for as high as possible S-band transmit power. Due to the necessity of a narrow height (3.12-mm or 0.123-in.) impedance matching section of waveguide within the S-band tuner-transformer portions of the combiner, a conservative S-band CW power limitation was specified (5 kW to each of four ports). It is possible, theoretically, that 100 kW (25 kW to each of four ports) could be reliably handled; a test would be required. Testing to 20 kW has been accomplished, but not to 100 kW. It is clear that 400 kW (100 kW to each port) would cause breakdown at normal gas temperature, pressure, and material (air or nitrogen). In order to provide for a higher power application, an alternative Model II tuner-transformer was designed (Ref. 5). This high-power tuner-transformer uses a 12.3-mm (0.484-in.) minimum height waveguide section and should allow 200 kW (50 kW to each of four ports) to be reliably handled. Full 400-kW power is a possibility but would require testing. However, the high-power version tuner-transformer provides only two narrower bands at S-band within which VSWR remains below 1.2:1—about 2090 to 2130 and 2260 to 2310 MHz. The lower power use of the Model II 3.12-mm height tuner-transformer provides continuous 2100- to 2300-MHz matching.

Finally, for the Model II development, Ref. 6 describes a four-function feedcone system that was built to demonstrate the Model II horn combiner and provided to the research and development station, DSS 13. The four functions are 20-kW S-band receive/transmit and X-band receive/transmit, the latter at 20 kW at 7.1 GHz. With requisite thermal design details added, X-band is expected to be capable of 400 kW. In one test of that feedcone (without the reflector antenna, with the feedcone on the ground simply radiating vertically to the sky), 20 kW was simultaneously transmitted at S- and X-bands. It is not known if the presence of reflector surfaces, with presumed non-linear junctions on a micro scale, would produce receive band intermodulation products arising from the dual-band uplinks, but the Model II combiner and horn was found capable of basic two-band transmission without breakdown. For the DSN 34-m high efficiency antennas (initially DSS 15 and 45), the common aperture horn/Model II combiner feed system was selected and successfully implemented. Thus, three stations are fitted with this equipment as of January 1986. DSS 65, the third 34-m high efficiency antenna, is scheduled for completion in 1987 and will similarly use the common aperture horn/Model III combiner.

### III. Current Work

Two requirements guided development of a Model III combiner, intended to further increase S-band bandwidth to include the Highly Elliptical Earth Orbiter (HEO) band from 2025 to 2110 MHz, as well as to provide an assured 400-kW CW S-band uplink in both the full operational uplink band (2025 to 2120 MHz) and possible planetary radar band (near 2320 MHz). A key feature of the Model III combiner is the use of eight S-band waveguide injection slots, arranged in four pairs. The height of each slot was maintained at 12.7 mm (0.50 in.) because of the power handling requirement. Figures 1(a) and 1(b) show the Model II and Model III combiners for comparison. In both the Model I and Model II combiners, it was physically possible to arrange the X-band rejection filter structure on both the top and bottom surfaces of the single S-band slot. But in the paired-slot arrangement of the Model III combiner, only single-sided rejection filter geometry is possible due to the thin septum between the slots. Early concerns about obtaining sufficient X-band rejection (undesired coupling of X-band from the X-band horn throat terminal to any of the S-band slots) were allayed by initial testing, which showed sufficiency (approximately 50 dB). However, the combiner junction at that point was not yet matched for S-band, and later testing revealed that the rejection filtering was inadequate in the final configuration, including matching elements.

In all three combiner models, it was necessary to obtain S-band matching by a laborious and time-consuming process. It is a principle of wideband matching in dispersive lines (rectangular waveguide in this instance) that the best results are obtained by placing matching elements as close as possible to the initiating (undesired) reflection. In the case of the basic X/S combiner geometry used here, it was found necessary to actually enter the multi-mode radial line region (Figs. 2(a) and 2(b)) and to experimentally determine placement of matching elements (wide inductive posts in this instance) in order to achieve an acceptable bulk reduction of unmatched reflection. With the combiner roughly matched by experimental means (about 2:1 VSWR or -10 dB reflection) over a wide band, analytic methods are then applied in the 12.7-mm-high single-mode uniform transmission lines. Figure 3 shows a Smith chart presentation of the matched Model II combiner, referenced to full size WR430 waveguide impedance.

As stated above, when the Model III combiner was matched at S-band, the X-band rejection was affected. In some parts of the band, particularly near 7.2 GHz, the rejection was only -25 dB. At first it was expected that such leakage could be cured by additional and distant (from the combiner) simple rejection filtering, such as a (so-called) waffle iron lowpass type. In terms of the leakage level reaching sensitive components (the S-band maser for example), the above is true. But this approach fails to take into account where the reflected leakage finally exits the system, since it is not absorbed within. The conflict facing designers is how to achieve needed S-band wideband matching, a challenge in itself, while maintaining high (more than 40-dB rejection) performance of the X-band rejection filtering with the radial line (which is potentially a multi-mode region).

Radiation patterns were examined in both S- and X-bands of the "leaky" Model III combiner/horn system. As expected, S-band performed without incident, but X-band was found to be seriously degraded by the finite isolation of -25 dB in some parts of the 7- to 8.5-GHz band, particularly near 7.2 GHz (the needed X-band uplink). X-band radiation patterns are variable and generally unpredictable; they are dependent upon what is connected to the S-band lines (uniform WR430 with a 180-deg tee junction or 90-deg hybrid junctions<sup>2</sup>). In a worst-case setup, reflecting the undesired X-band leakage back into the horn in an adverse phase (a possible situation in a full-feed system), the 7.2-GHz radiation pattern is seriously affected and is predicted to cause approximately 1 dB of final reflector antenna system gain loss. Figure 4(a) shows expected normal (high X-band isolation) radiation pattern near 7.19 GHz. Figure 4(b) shows a finite isolation pattern causing 1 dB of final reflector antenna system gain loss. The loss components are illumination (-0.55 dB), cross-polarization (-0.15 dB), and phase (-0.34 dB). Overall, a typical high performance (shaped) dual-reflector antenna system fed with the affected radiation pattern shown in Fig. 4(b) would produce only 57% aperture efficiency (down from a normal 72%). This is considered grossly unacceptable performance for the DSN, and work on this effort has been terminated, at least temporarily. Future work is likely, and the authors hope this summary will provide a valuable starting place.

<sup>2</sup>Implementation of these junctions is dependent upon how the S-band polarization network is configured.

## References

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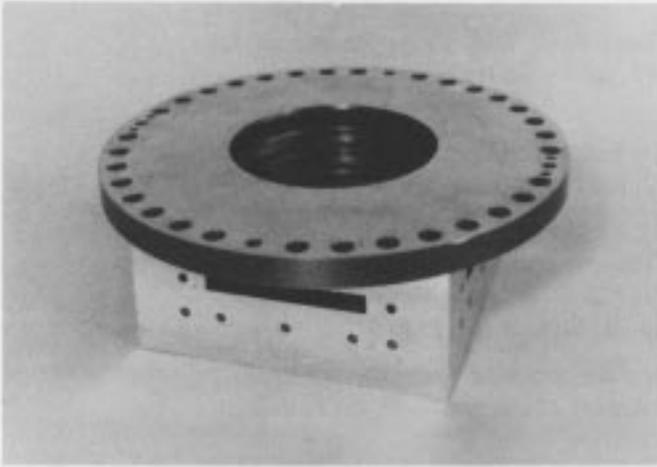


Fig. 1(a). Model II X/S combiner

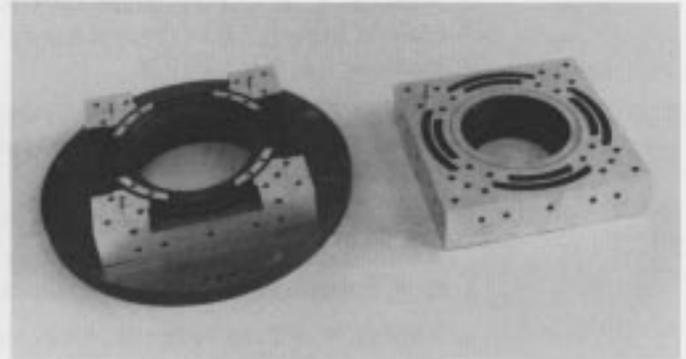


Fig. 2(a). Model II combiner showing radial line region

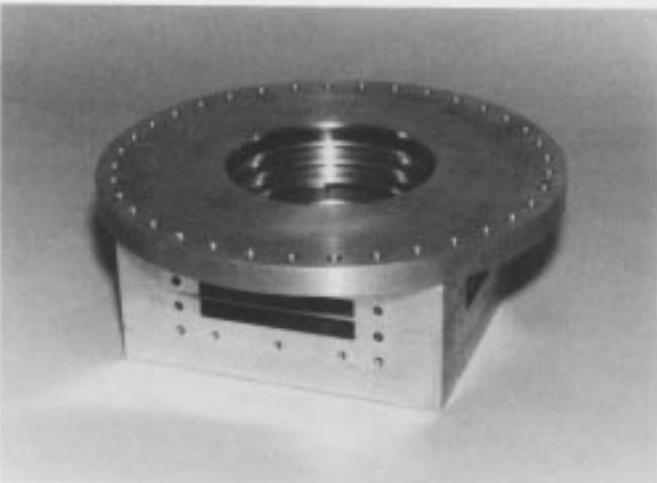


Fig. 1(b). Model III X/S combiner

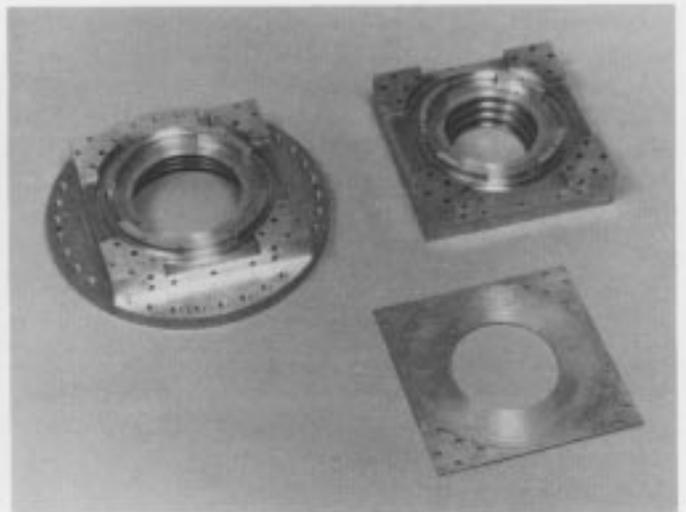


Fig. 2(b). Model III combiner showing radial line region

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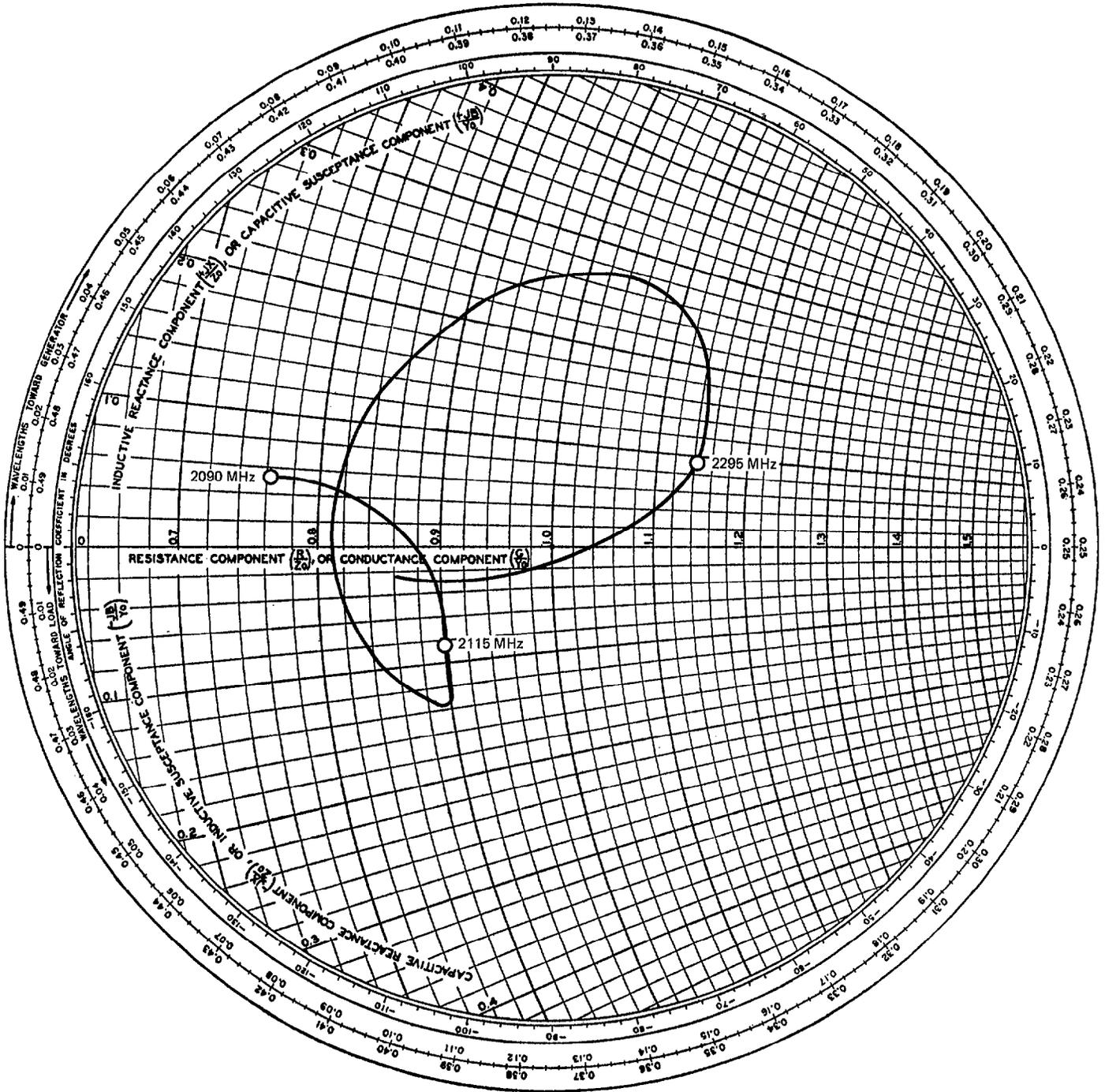


Fig. 3. Smith chart presentation of Model II X/S combiner referenced to WR430 admittance

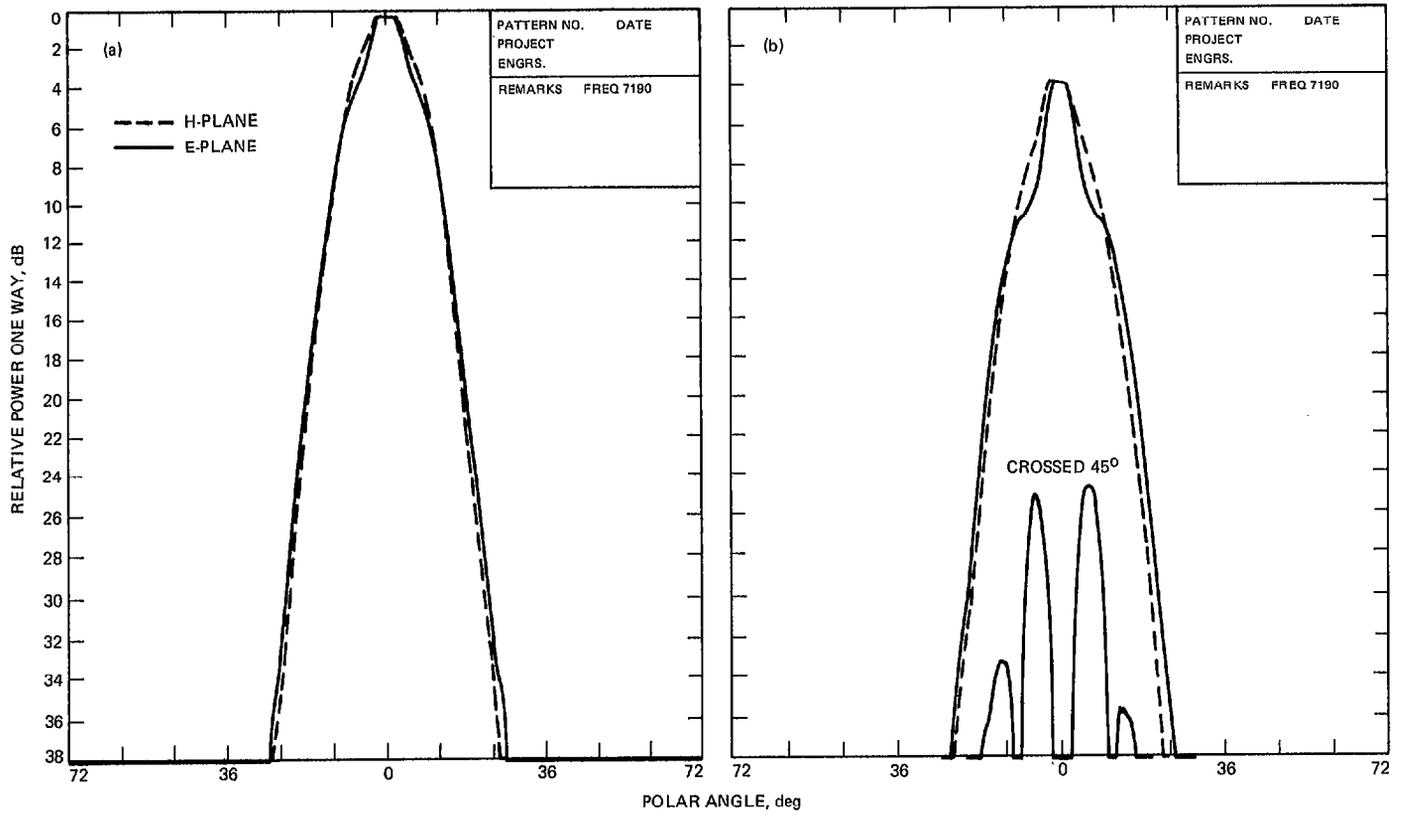


Fig. 4. Radiation patterns of feedhorns in X-band at 7.19 GHz: (a) Model II E- and H-plane patterns, (b) Model III E- and H-plane patterns