AN UNCOMPROMISING DUAL FREQUENCY ANTENNA FOR TELEMETRY TRACKING APPLICATIONS

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ABSTRACT

Currently, the majority of telemetry tracking systems in use throughout the world operate in the S-Band frequency range. While this frequency band serves as an adequate vehicle for most applications, some require an additional higher frequency for high bit-rate data. This requirement necessitates use of a dual frequency antenna and, more often than not, suffering an attendant performance compromise at both frequencies which is typically realized in such a device. One agency had such a requirement but was unwilling to accept the usual compromise in the S-band and X-band down-links used in aircraft testing.

The design implemented by EMP Inc. satisfied the S-band requirements with the reputable, EMP developed, RADSCAN conical scan feed positioned at the focal plane of an eight foot paraboloidal reflector. The RADSCAN feed radome was redesigned, shaping the frontal surface to form a hyperboloidal dichroic subreflector for the X-band Cassegrain antenna. The subreflector was transparent to S-band while presenting a highly reflective surface to X-band energy. The hyperboloid was fed by a profiled corrugated horn mounted at the vertex of the paraboloidal reflector.

The X-band Cassegrainian system produced optimum performance with no degradation whatsoever from the S-band Newtonian antenna. The degradation of the S-band system was less than 0.15 dB. The system provided simultaneous reception of both bands with collimated beams. The S-band system also included a side lobe comparison antenna which precludes acquisition of a target vehicle on a side lobe.

INTRODUCTION

The trend toward dual frequency operation has accelerated in recent years, most notably in the field of commercial and military satellites but also, to a lesser degree, the area of in-flight testing. The reasons for dual frequency operation vary from the increased reliability associated with frequency diversity to satisfying a need for increased data bandwidth. Regardless of the motivation, it is highly desirous that the frequencies (usually separated by several octaves) be handled by a single antenna system, sharing a common beam axis. Such antenna systems have been designed and deployed so there is no intent that this paper should create the impression that EMP has broken the boundaries of technical knowledge and achievement. The purpose of this paper rather, is to describe how EMP combined proven technologies to produce a unique system. The system described herein is a state-of-the-art, two axis, automatic tracker that performed beyond expectation. To our knowledge this is the first time the dichroic technique has been employed in a telemetry tracking application.

The key to the antenna system is the frequency-selective surface of the subreflector for the X-band Cassegrain antenna. The surface of the dichroic reflector appears solid and highly reflective to X-band energy while transparent to S-band. The principles of this surface treatment have been known for a couple of decades. Indeed, several excellent papers have been published describing the theory in great detail. Only in recent years, however, have these principles been put into practice. It is safe to predict an accelerated interest in the dichroic reflector in the near future.

FREQUENCY SELECTIVE SURFACE

The frequency selective surface (FSS) consists of an array of crossed dipoles etched on a dielectric sheet. The dipoles are designed to be resonant at the higher of the two operating frequencies. The resonant array appears as a solid surface to the higher frequency while the same dipoles are so small relative to the lower frequency that they are transparent. It is this property that makes the dichroic reflector such a key element in the design of the dual frequency antenna system.

Dipole length, width and spacing, the dielectric constant and thickness of the base material, the shape of the surface and the mutual influence of each of the above must be given due consideration in the design phase. These are amply documented in various publications so will not be dealt with at this time.

THE ANTENNA SYSTEM

The dual frequency system produced by EMP was designed to receive and automatically track in the 2.2 to 2.4 GHz, S-band telemetry band and simultaneously receive the 7.2 to 8.6 GHz portion of X-band with an antenna system which, including the feeds, is entirely symmetrical. Several concepts were analyzed and discarded before it became obvious that the best approach by far, though not the simplest, would be to add X-band receiving capability to an existing EMP S-band tracker design by making the X-band portion a

Cassegrainian type with a dichroic subreflector. The results certainly support the validity of the decision to proceed with that approach. The frequency selective surface of the subreflector performed as expected, with no adverse effect at all at X-band and less than 0.15 dB degradation at S-band. Both antennas have simultaneous outputs of right hand and left hand circular polarization. Fiqure 1 pictures the completed system. Figure 2 shows the geometry of the dual frequency antenna. Tables 1 and 2 list the characteristics of the System and the Antenna Assembly, respectively.

S-band

Satisfying the S-band portion of the performance requirement was the easy part. Several years ago EMP developed a unique conical scanning feed called RADSCAN which set new industry standards for telemetry tracking antennas. Automatic tracking at elevation angles at or near the horizon became routine due the excellent antenna patterns, exhibiting side lobes of -25 dBm nominally. RADSCAN has been updated and improved through the years and still sets the standard for performance, reliability and simplicity.

A drawing of RADSCAN, with the radome modified to include the dichroic subreflector, is shown in Figure 3. A pair of stationary, orthogonal, printed circuit dipoles are used to excite the TE_{11} mode in the rotating circular wave guide which has its axis displaced from the boresight axis. The displacement of the phase center of the rotating waveguide causes the beam to be conically scanned. The one moving part is driven by a hollow shaft, brushless, two phase motor (no gears or belts). A solid state optical commutator provides azimuth and elevation reference signals in the form of two square waves in phase quadrature. An integral weather proof enclosure houses bandpass filters, preamplifiers and etc. A 90 degree hybrid, located in the housing, converts the linear outputs of the dipole assembly to RHCP and LHCP.

A quadrapod supports the RADSCAN feed assembly, placing the phase center at the focal plane of an eight foot paraboloidal primary reflector. Since the dichroic subreflector for the X-band antenna is the “nose” of the RADSCAN radome, its proper position in relation to the primary reflector is always assured.

X-Band Dichroic Subreflector

Unlike the S-band portion which was essentially “off-the-shelf” hardware, the X-band Cassegrain antenna required many hours of design time and computer analysis since the success or failure of the entire project hinged on a single item -- the frequency selective surface of the subreflector.

The analytical effort yielded values of 0.665 inches for dipole length and spacing and 0.060 inches for the dipole width. The substrate upon which the dipoles are etched is 0.010 inch thick kevlar. The optimum diameter of the hyperboloid is slightly over 12 inches, yielding directivity of about 44 dB and efficiency approaching 70%. These values were well supported by empirical data, needing only minor alteration to adapt to the local environment. The typical pattern of crossed dipoles is shown in Figure 4. Crossed dipoles are used instead of single to make the array insensitive to the polarization of the wave front.

At S-band a single layer of the frequency selective surface produces an impedance mismatch. This effect is tuned out over the S-band frequency range by placing a second layer of FSS one quarter wave length behind the first one. This is analogous to tuning out the effect of a shunt susceptance across a transmission line with a second identical susceptance. Thus, the final configuration of the dichroic subreflector that is both reflective to X-band and transparent to S-band consists of two layers of frequency selective surface separated by a low density polyfoam core.

X-Band Feed Horn

Many Cassegrainian antenna designs fail to yield the anticipated efficiency and performance. This shortcoming is often due to overlooking or ignoring the effects of placing the reflector within the near field of the feed. These phenomena have received due consideration in the design of a profiled, corrugated horn as the feed for the X-band antenna. Figure 5 shows the corrugations or grooves machined in the inner surface of the horn. The grooves equalize the E and H-plane beamwidths, producing circularly symmetrical primary patterns and optimizing the illumination of the subreflector. The center-of-phase of the corrugated horn is the same for all pattern planes, assuring perfect focus at all aspect angles. It is called a profiled horn because the taper from the input to the aperature does not have a constant flare angle. This results in a somewhat shorter horn for the same electrical performance. It is also a near field design in that it produces the optimum pattern at the subreflector distance rather than in the far field. The horn has an aperature diameter of 5.75 inches and is 13 inches long.

X-Band Circular Polarizer

The final component of the dual frequency antenna is the circular polarizer. This device is of the disappearing septum type. Physically it appears as a short length of square waveguide, one end of which mates with the feed horn and the other divides into two rectangular waveguide outputs. The square transition contains a tapered “disappearing” septum and is designed to produce quadrature phase between the two modes supported by the square waveguide and, thus produce circular polarization. The two rectangular wave guides output the left and right hand senses of circular polarization.

Ancillary Antennas

Three additional antennas were included in the complement of the antenna assembly. Although not pertinent to dual frequency operation, they will be described briefly. The Side Lobe Comparison antenna is located in the rear area of RADSCAN, aimed along the same boresight (looking away from the reflector). Its gain approximates the level of the first side lobe of the tracking antenna and the output serves as a reference for circuitry which rejects any attempt to acquire and autotrack a side lobe. A single dipole, oriented at an angle of 45 degrees is mounted near the vertex of the primary reflector. It provides a test signal source for off-mission trouble shooting, evaluation and calibration of the S-band receiving system. A waveguide horn serves in a similar capacity for the X-band system.

THE REST OF THE SYSTEM

The antenna is mounted on and positioned by an EMP Model 100, two axis (elevation over azimuth) pedestal. The servo is all solid state and operates as a modified type II. The Antenna Control Unit is an EMP Model ACU-6, a microprocessor based unit, with unbelievable power and versatility. A Handwheel Control Panel (position or rate control) and a display of Commanded Position complete the installation.

CONCLUSION

Application of the principle of the frequency selective surface is certainly a viable solution to high quality dual frequency antenna systems. Dual frequency systems may be the solution to successful performance of missions that may now be in jeopardy due to limited data bandwidths in the traditional L and S telemetry bands. The outstanding performance of the system described herein certainly indicates that the time of the automatic tracking, dual frequency telemetry receiving system has arrived.

ACKNOWLEDGMENT

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TABLE 1

SYSTEM CHARACTERISTICS

Parameter	Parameter Value
Frequency Range:	2.2 to 2.4 GEz and 7.9 to 8.6 GHz
Antenna Gain:	31.0 dBi at S-Band, 43 dBi at X-Band
Polarization:	Simultaneous Right and Left Hand Circular
Antenna Sidelobe Level:	-22 dBp Maximum
Tracking Feed:	Conical Scan at 29 +/- 1 Hz
Crossover Loss:	0.4 dB Maximum
Pedestal Output Torque:	430 ft-lb Peak
Pedestal Brake Torque:	550 ft-lb Nominal
Angle Coverage:	
Azimuth:	+/-180 degrees
Elevation:	-6 Deg to + 87 Deg: Tracking -8 Deg to +92 Deg Mechanical
Tracking Capability:	30 deg/sec, 60 deg/sec^2 Minimum
Angle Readout Error:	0.2 Degrees Peak
Environmental:	
Temperature (0perational):	Outside,-40 Deg C to +52 Deg C Plus Solar Inside, 5 Deg. C to 35 Deg. C
Winds:-	To 40 MPH Operational (150 MPH Stowed)
Rain:	9 cm/hr Wind Driven
Ice:	2 cm Radial
Vibration and Shock:	Commercial Transportation and Shipboard
Weight:	
Antenna Assembly:	150 Pounds Maximum
Pedestal Assembly:	400 Pounds Maximum
Counterweight:	250 Pounds Maximum
Control Unit:	30 Pounds Maximum
Commanded Position Display Panel:	4 Pounds Maximum
Handwheel Control Panel:	2 Pounds Maximum
Analog Display Panel:	10 Pounds Maximum
Input Power:	117 +/- 5 V rms, 1Ø, 60 +/-3 Hz at 5 Amps Maximum

TABLE 2
ANTENNA ASSEMBLY CHARACTERISTICS

Tracking Antenna:

Reflector:	8 Foot Diameter Solid Paraboloid
Tracking Feed:	RADSCAN at 29 +/-l Hz Scan Speed*
Gain (at 2.4 GEz):	31 dBi Minimum
Beamwidth (at 2390 MHz):	3.5 Degrees Minimum
Crossover Loss:	0.4 dB Maximum
Polarization:	Simultaneous Right and Left Hand Circular
Feed Channel Isolation:	20 dB Minimum
Sidelobe:	-22 dBp Minimum
Backlobe (180 +/-80 Deg.):	-30 dBp Minimum
VSWR (In Receiver Bands):	2.0:1 Maximum
Antenna System Noise Temp: (for Elevation angle above 4 Deg.)	300 Deg. K Maximum
Scanner Input:	115 +/-5 V rms,60 Hz at 2 Amps Peak
Reference Commutator Output:	Orthogonal Square Waves 22 V p to p
Assembly Weight:	150 Pounds Maximum
Structural Resonance:	16 Hz Nominal

Sidelobe Reference Antenna (S-Band):

Gain:	7.0 dB Minimum
Beamwidth:	60 Degrees Nominal
Polarization:	Simultaneous Right and Left Hand Circular
VSWR:	2.0:1 Maximum

Test Antennas (S & X-Band):

Gain:	5 dB Nominal
Beamwidth:	85 Degrees Nominal
Polarization:	Linear Slant 45 Deg.
VSWR:	2.0:1 Maximum

Cassegrain Antenna

Gain (at 7.9 GHz):	43 dBi Minimum
Beamwidth (at 8.6 GHz):	1.0 Degree Minimum
Polarization:	Simultaneous Right and Left Hand Circular
VSWR:	1.5:1 Maximum

*Scan Speed is approximately one half the primary power line frequency.

FIGURE 1 DUAL FREQUENCY ANTENNA

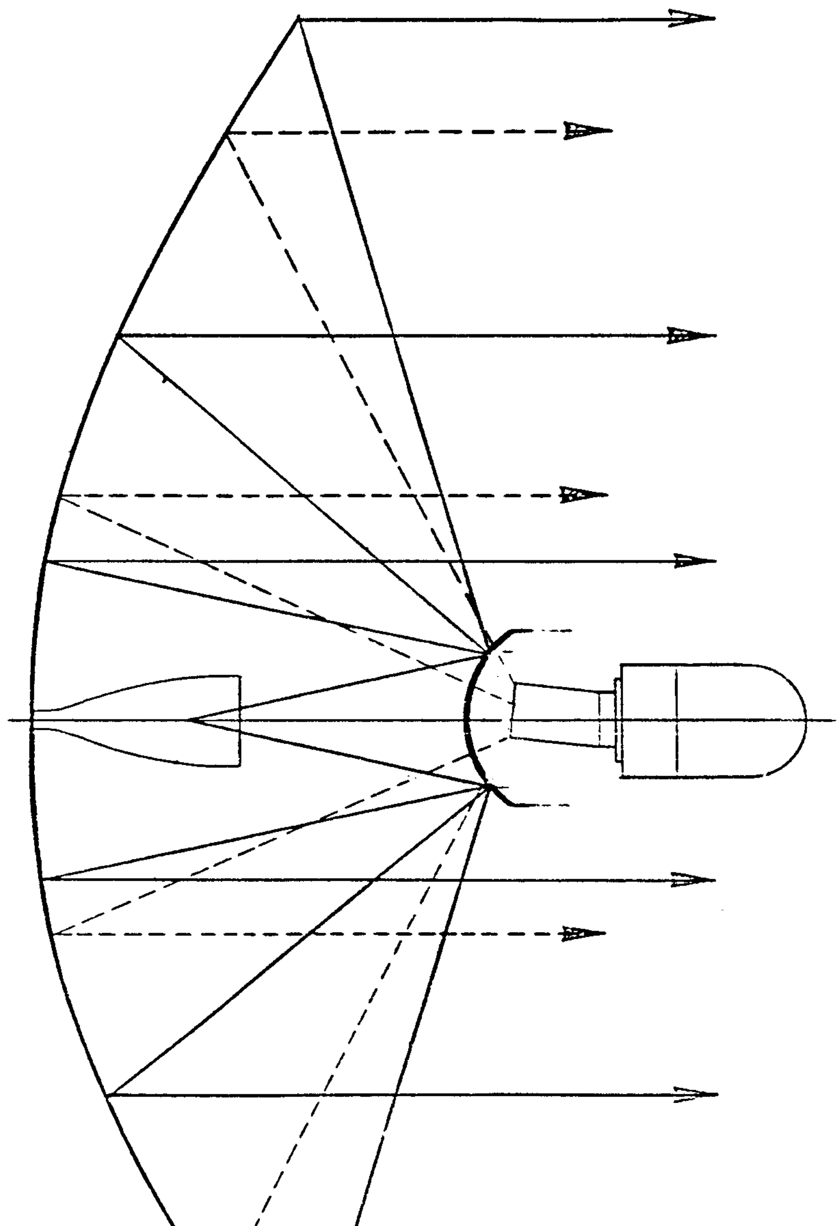

FIGURE 2 DUAL FREQUENCY ANTENNA GEOMETRY

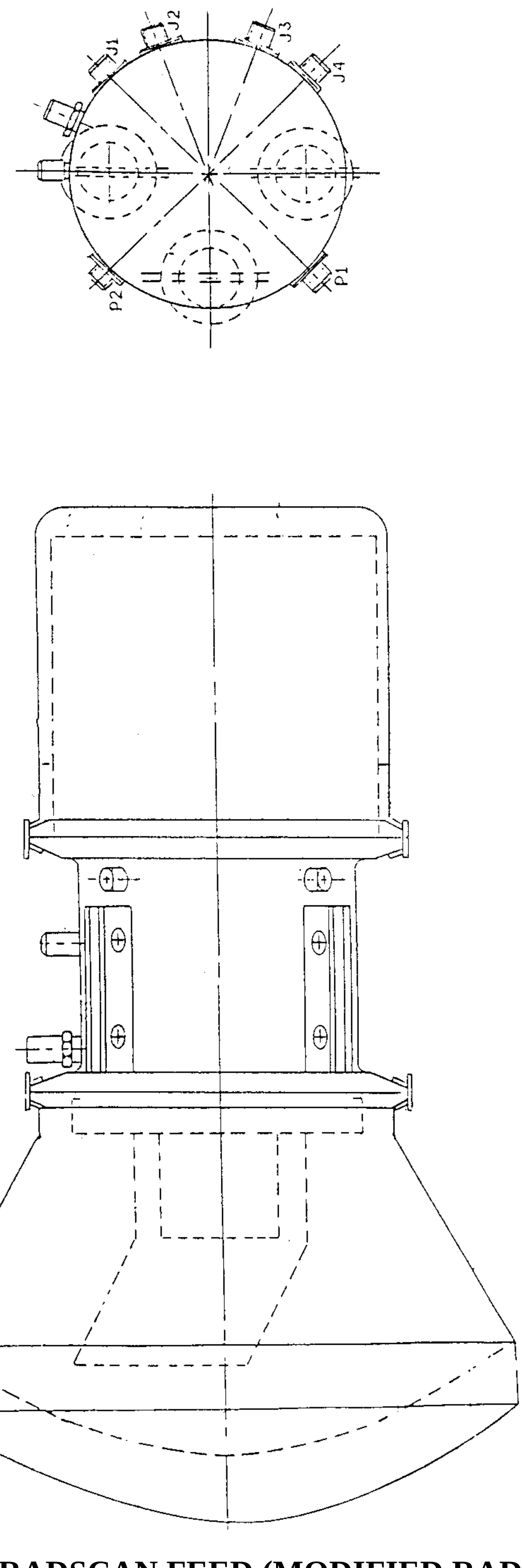

FIGURE 3; RADSCAN FEED (MODIFIED RADOME)

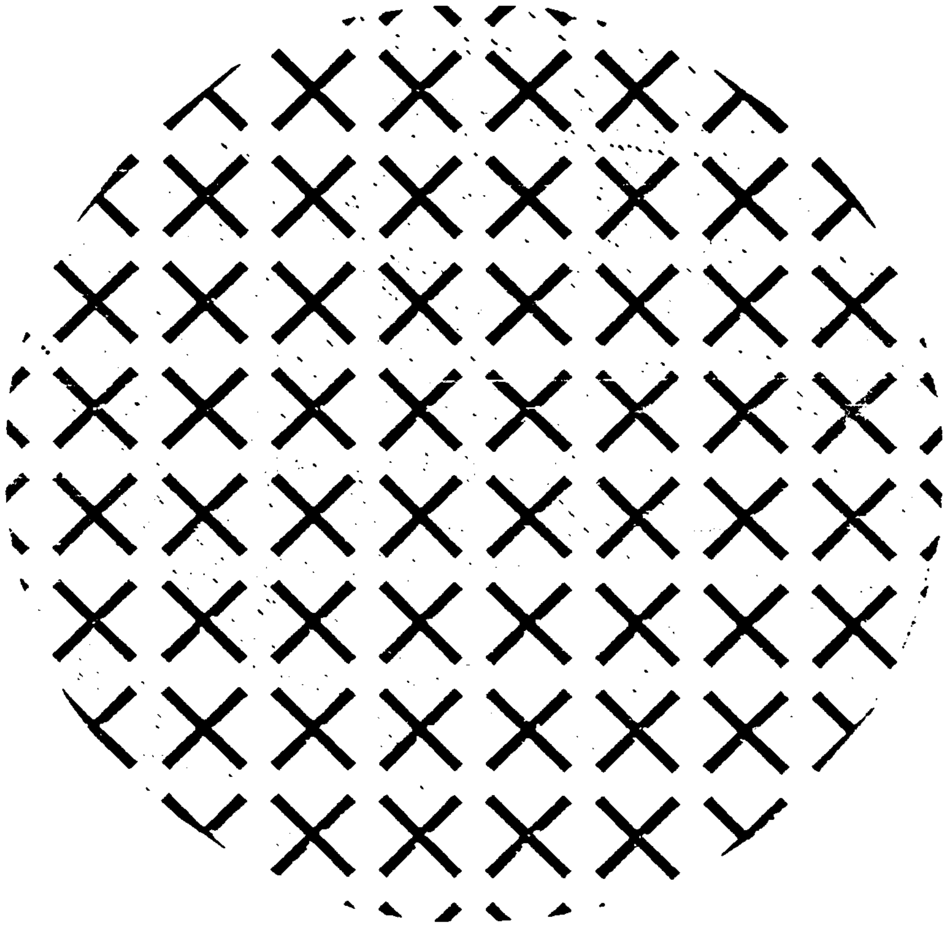

FIGURE 4 DICHROIC SUBREFLECTOR SURFACE

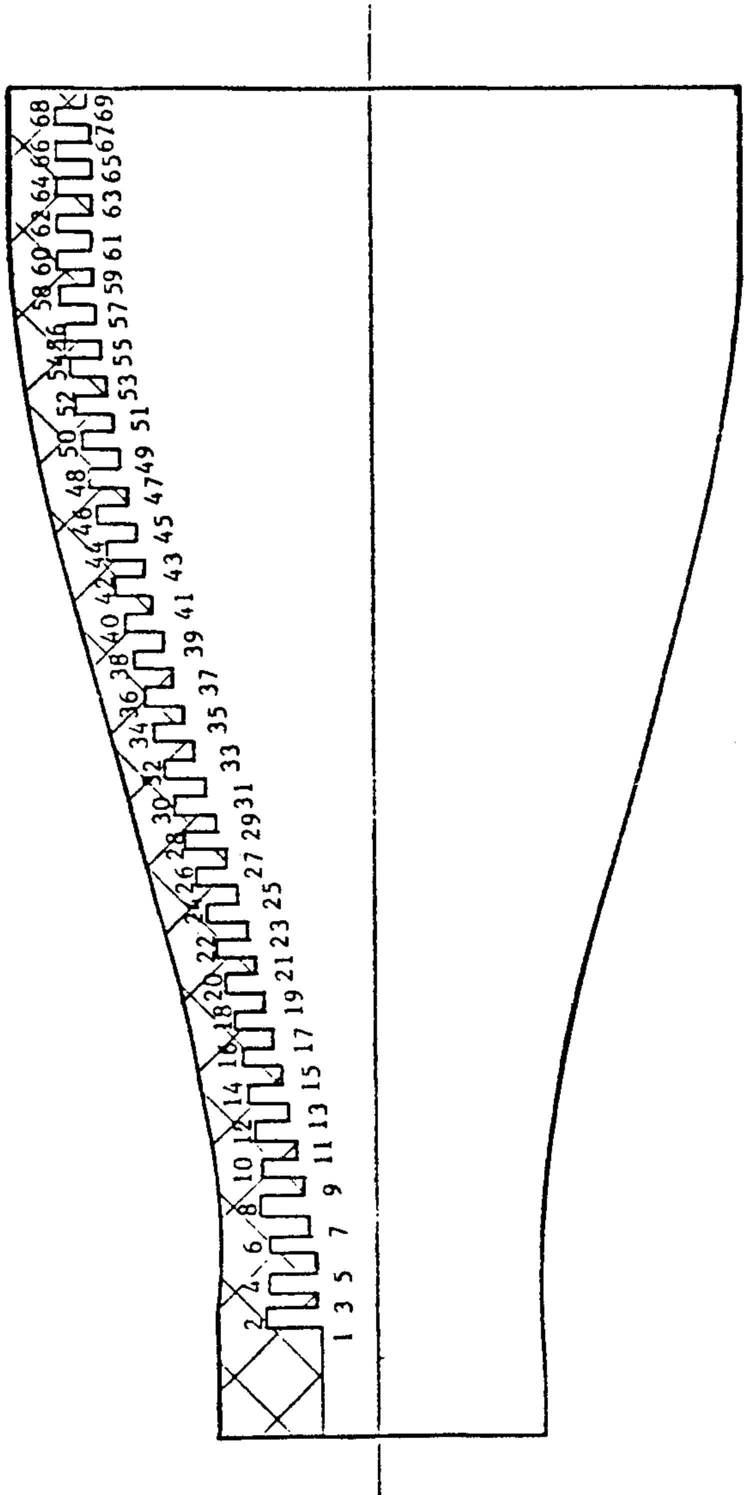

FIGURE 5 PROFILED CORRUGATED HORN FEED