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ANALYSIS OF COMPACT ANTENNA TEST RANGE CONFIGURATIONS

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ABSTRACT

To fulfill the future demand of highly accurate antenna and payload testing of large spacecraft, MBB is constructing a new antenna test center at Ottobrunn consisting of two large test ranges: a Near-Field Test Range and a Compact Test Range. This paper describes the results which had been obtained during the analysis and definition phase of the compact range (CR). After a general review of the compact range principles it presents the predicted co- and cross-polar contour plots of different CR alternatives in the specified quiet zone of 5 m x 7 m. Compensation and optimization principles for the cross-polarization and amplitude behaviour are explained. The results show that from the electrical point of view the Front Fed Cassegrain CR Concept is the most favourable solution. On the other hand the Two Cylinder Parabola Concept is the most attractive solution concerning the mechanical and manufacturing aspects.

1. INTRODUCTION

Verifying antenna performance generally means measuring the electromagnetic far-field characteristics.
Far-field radiation pattern of microwave antennas can be measured in two basic ways:
- directly or
- indirectly.

With the direct method, a semi-plane wave is being created by placing a transmitting and receiving antenna far apart. The plane wave approximation of the transmitted spherical wave becomes better with increasing distance. The well-known far-field criterion, $R = D^2/\lambda$, introduces a phase variation of approx. 22° across the aperture of the test antenna, the amplitude variation is very small and may be neglected.
When more accurate measurements are required, the distance between both antennas has to be increased.
Only electrically small antennas with low gain figures, e.g. feeds, can be measured indoors (anechoic chamber) with this direct method.

Applying the indirect method means measuring the field near the aperture of the antenna, instead of the far-field. The far-field characteristics of the antenna can then be obtained by performing a Fourier transform operation on the measured near-field data. All near-field measurements are indoors, which is a major advantage /1/. Drawbacks with this method are the rather long measuring and computational times required.

Combining the advantages of both methods, the optimum test facility should allow for indoor measurements under far-field conditions. This combination can be obtained by applying a Compact Antenna Test Range (CR), which collimates a spherical wave with uniform amplitude, coming from a point source, into a plane wave by means of one, two or more reflectors.
Theoretical and experimental investigations on Compact Ranges have already been carried out and are reported in the literature. Two basic configurations with spherical sources (see Figs. 2-1a,b) have been studied in detail, a single paraboloid reflector concept /2/ and a dual cylinder parabola concept /3/. Experimental results achieved with a Scientific Atlanta single reflector CR have been published in /4/. For the dual reflector CR, where a prototype is installed at the Technical University of Eindhoven, experimental results are presented in /5/.

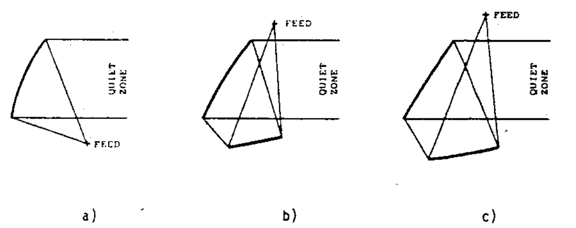

Fig. 2-1: DIFFERENT COMPACT RANGE GEOMETRIES
a) single offset parabola
b) two-cylinder parabolas
c) two-doubly curved reflectors (Front Fed Cassegrain Antenna)

The rather poor cross-polarization performance which is inherent to both concepts for linear polarization cannot be accepted for high quality measurements of frequency re-use satellite antennas. Own studies performed under an ESA contract on satellite multibeam antennas with good scanning performance in combination with very low cross-polarization /6/ led us to a third Compact Range concept using two doubly-curved reflectors (Front Fed Cassegrain System, Fig. 2-1c). This concept was then analyzed in more detail concerning its capability to fulfill the performance requirements of a Compact Antenna Test Range.

2. CONCEPTS OF COMPACT ANTENNA TEST RANGES

A Compact Antenna Test Range can be realized with a lens or one, two or more reflectors. The feeding system generally consists of a spherical point source as well as a cylindrical line source depending on the selected system. All systems are optimized to generate a plane wave with low amplitude ripple and small phase distortions. Almost all practical Compact Ranges apply reflectors in combination with a spherical point source. The source is supposed to provide a uniform amplitude distribution over the reflector, any amplitude taper of the feed-pattern is directly being translated into the plane wave test zone (quiet zone).
The basic geometries of reflector compact ranges are shown in Fig. 2-1. All practical ranges apply one or maximal two reflectors. A dual reflector concept has several advantages compared to single reflector CR's, as there are:

- Larger equivalent focal length
- Larger quiet zone dimensions with same main reflector dimensions
- Better compact geometry.

A large focal length is favourable because it improves the amplitude uniformity and reduces the cross-polarization component of the plane wave.

The aperture efficiency ratio of a single reflector CR is approximately two times less than the ratio of the dual reflector concept, this means that the reflector dimensions of a single reflector range are two times larger than the dimensions of a dual reflector range for given quiet zone dimensions /7/.
For these reasons, only dual reflector compact ranges will be further investigated.

3. DUAL REFLECTOR CONCEPTS

Several promising configurations have been considered such as:

- Gregorian,
- Cassegrain,
- Front Fed Cassegrain,
- Two-cylinder parabolas /3/ and
- Shaped dual reflector systems.

The standard Cassegrain and Gregorian configurations are less attractive because of the small subreflector (diffraction effects and poor scanning capability) in combination with the large feed spillover in the plane wave zone direction.
The spillover problem can be solved by shaping both the sub- and the main reflector. Nevertheless the shaped CR exhibits some disadvantages which have to be considered for a frequency independent system with a large quiet zone:

- High complexity and cost of manufacturing
- Performance degradation over frequency due to frequency dependence of feed pattern (shaping is based on one fixed feed pattern)

The geometries of the remaining solutions are shown in Fig. 3-1.

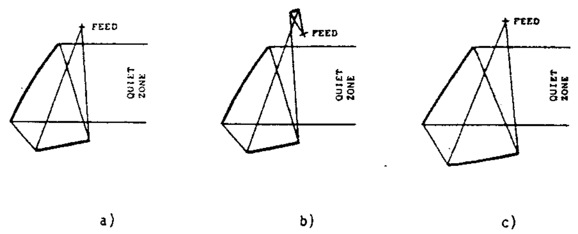

Fig. 3-1: INVESTIGATED COMPACT RANGE GEOMETRIES
a) two-cylinder parabolas
b) two-cylinder parabolas with third, small feed reflector
c) front fed Cassegrain system.

With the configuration in Fig. 3-1b, using an additional small feed reflector, an attempt has been made to compensate for the inherent cross-polarization of the cylinder parabola concept.

The developed computer software for the calculation of the electrical performance of the different configurations is based on the theory of geometrical optics. Therefore the presented designs are basically, independent of frequency. The edge diffraction effects have not been included in the calculations, as this effect will be separately considered and cancelled by serrations mounted at the reflector edges.

The results to be presented show the co- and cross-polar behaviour of the different compact range types in the quiet zone (test area). For the illumination of the reflectors a feed pattern model with no cross-polarization and an edge taper of -0.2 dB is assumed. This allows to show the geometry induced cross-polarization behaviour which is independent of the feed characteristics. The co-polar pattern results for linear and circular polarization are very similar. For circular polarization the geometry induced cross-polarization is zero. Therefore all further results are presented for the more critical linear polarization.

In the last two years the European Space Agency has initiated specific studies to investigate a large compact range with respect to its electrical and mechanical performance characteristics /8/.

The proposed geometry uses two cylinder parabolas for the realization of a quiet zone of 5 m x 7 m. Starting from those requirements which are rather close to the requirements stated for a new antenna test center at MBB, Ottobrunn, a trade-off study between the different concepts has been performed and will be shortly summarized in the subsequent paragraphs.

3.1 CYLINDER PARABOLA CONCEPT

The investigated compact range consists of two cylinder parabolas, with the following parameters:

- Subreflector	: Dimensions	6.5x7.5 m	(WxH)
	Focal Length	14.0 m	
- Main Reflector:	Dimensions	11.3x7.5 m	(WxH)
	Focal Length	17.4 m	

The predicted co- and cross-polar performance data of this CR are shown in Fig. 3.1-1. The analyzed quiet zone dimensions are 7 m x 5 m (W x H).

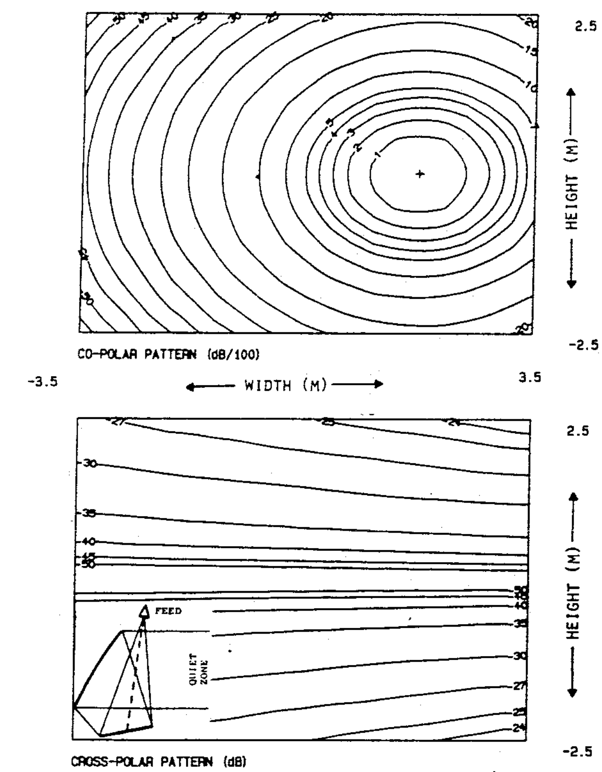

Fig. 3.1-1: CO- AND CROSS-POLAR CONTOUR PLOTS OF QUIET ZONE OF A STANDARD DUAL CYLINDER PARABOLA CR

Due to the offset geometry, the co-polar pattern is asymmetric in the horizontal plane and the maximum of the pattern is shifted by 1.75 m. The cross-polar performance is good in the horizontal plane, but rather poor in the vertical plane.

The shifted co-polar pattern can be corrected by tilting the feed 7.4 degr. in the horizontal plane (Fig. 3.1-2).

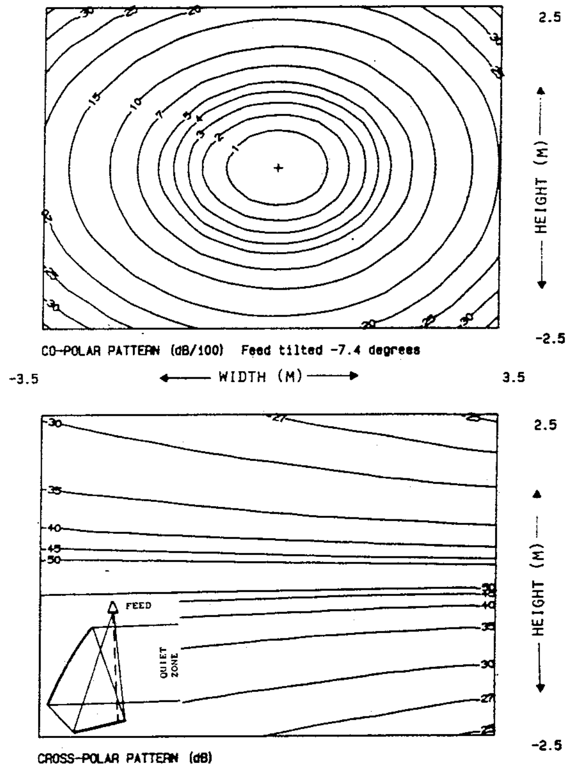

Fig. 3.1-2: CO- AND CROSS-POLAR CONTOUR PLOTS OF QUIET ZONE OF A CYLINDER PARABOLA CR WITH TILTED FEED

The co-polar performance has considerably improved by tilting the feed. The geometry induced cross-polarization remains almost unchanged but by tilting the feed the maxima of the cross-polarization of the feed itself is directed towards the subreflector, which will then be directly translated into the quiet zone.

3.2 COMPENSATED CYLINDER PARABOLA CONCEPT

The poor cross-polarization and the shifted co-polar maximum make the cylinder parabola concept less attractive. An attempt has been made to compensate these features with a small elliptical or hyperboloidal feed reflector. The results shown in Fig. 3.2-1 are calculated for an elliptical feed reflector, the results for an hyperboloidal feed reflector are very similar. Principally, it is possible to compensate the geometry induced cross-polarization with a third reflector. But this causes a significant degradation of the co-polar pattern.

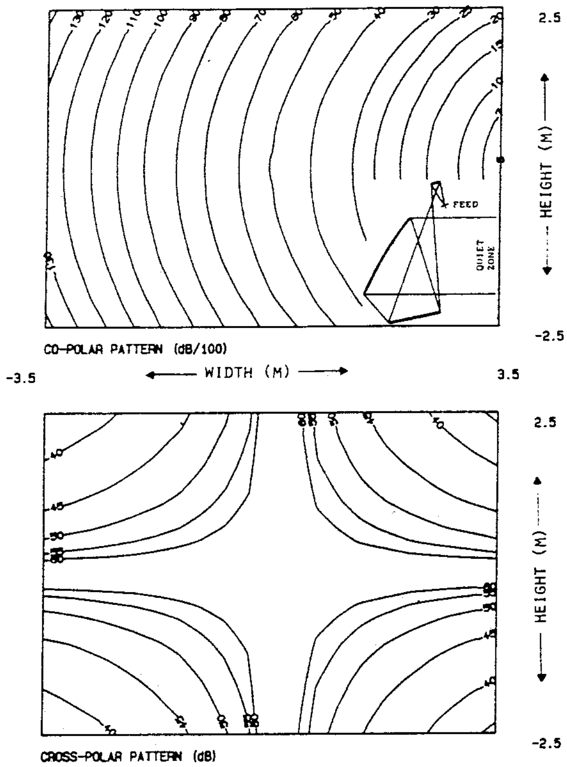

Fig. 3.2-1: CO- AND CROSS-POLAR CONTOUR PLOTS OF QUIET ZONE OF A CROSS-POLARIZATION COMPENSATED DUAL CYLINDER PARABOLA CR

A compensation of the asymmetric co-polar performance of the dual cylinder parabola CR is also possible with a feed reflector but in that case the cross-polarization of this CR version remains unchanged with respect to the basic system (Fig. 3.2-2). Besides all of that the diffraction effects of the small feed reflector have to be considered.

If the cross-polarization is compensated with the feed reflector and the co-polar performance is compensated by tilting the feed, a CR system is established where the feed axis does not furthermore hit the feed reflector (see Fig. 3.2-3).

With such a system, the cross-polarization of the feed will be imaged in the quiet zone. The co-polar performance will be strongly frequency dependent since any change in the feed pattern will now occur as amplitude variation in the quiet zone.

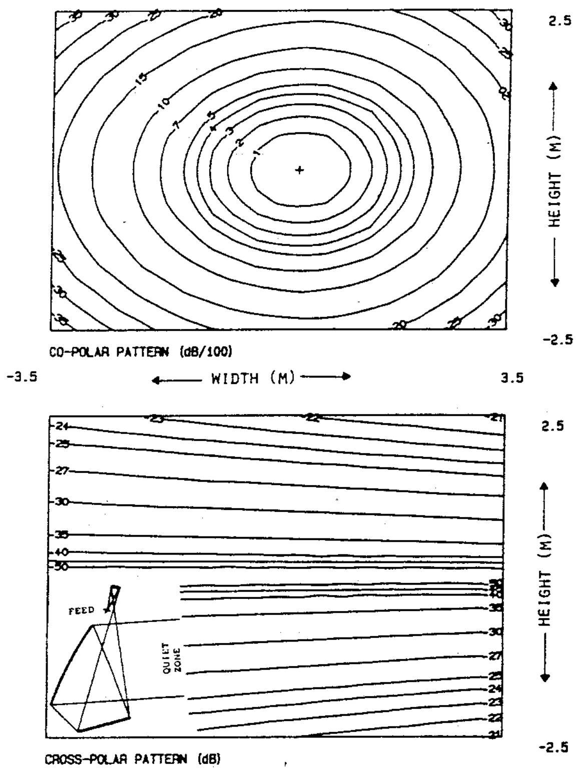

Fig. 3.2-2: CO- AND CROSS-POLAR CONTOUR PLOTS OF QUIET ZONE OF A AMPLITUDE COMPENSATED DUAL CYLINDER PARABOLA CR

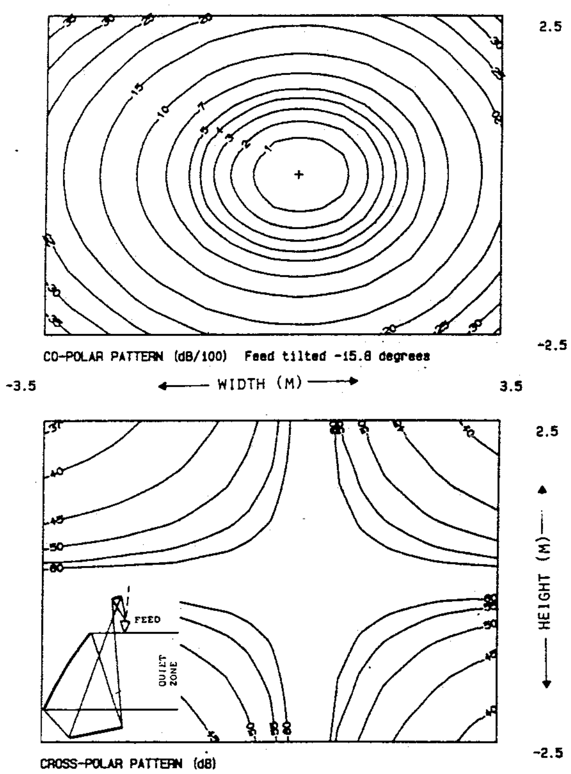

Fig. 3.2-3: CO- AND CROSS-POLAR CONTOUR PLOT OF QUIET ZONE OF A FULLY COMPENSATED DUAL CYLINDER PARABOLA CR

3.3 FRONT FED CASSEGRAIN CONCEPT

The Front Fed Cassegrain Concept is built-up with two doubly curved reflectors. The system is fully compensated concerning cross-polarization and consists of a hyperbola as subreflector and a parabola as main reflector. For comparison reasons the same quiet zone requirements (7 m x 5 m) are assumed for the further investigations of the Front Fed Cassegrain concept.
The parameters are:

Subreflector	: Dimensions	8.8x6.9 m (WxH)
	Focal Length	28.9 m
Main Reflector:	Dimensions	11.3x7.5 m (WxH)
	Focal Length	38.8 m

A contour plot of the co-polar pattern within the quiet zone is shown in Figure 3.3-1. The geometry induced cross-polarization is zero for all polarizations.

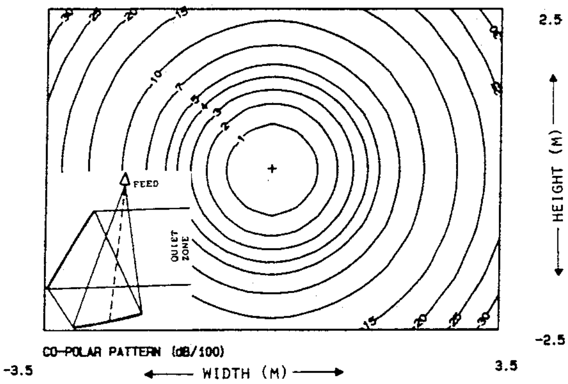

Fig. 3.3-1: CONTOUR PLOT OF CO-POLAR PATTERN OF A FRONT FED CASSEGRAIN CR. THE GEOMETRY INDUCED CROSS-POLARIZATION IS ZERO

The co-polar pattern is symmetric in both the horizontal and vertical plane. The extremely large equivalent focal length guarantees for good amplitude uniformity (mainly feed pattern image).

3.4 COMPARISON OF RESULTS

The predicted performance results of the two most promising CR concepts i.e. the Dual Cylinder Parabola CR and Front Fed Cassegrain CR are summarized in Table 3.4-1.

The scanning performance of both CR concepts is very good as illustrated for the dual cylinder parabola concept in Fig. 3.4-1 (scan angle vertical 2°, phase errors $\leq \pm 7°$ at 20 GHz).

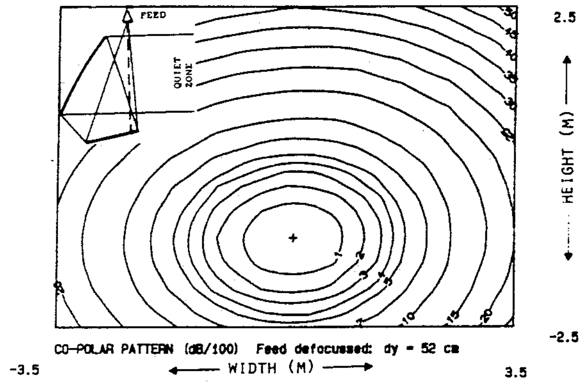

Fig. 3.4-1: CO-POLAR CONTOUR PLOT OF 2 DEGR. VERTICALLY SCANNED DUAL CYLINDER PARABOLA CR

	DUAL CYLINDER PARABOLA CR	FRONT FED CASSEGRAIN CR
QUIET ZONE	5 m x 7 m	5 m x 7 m
FEED PARAMETERS:		
- feed tilted	no	no
- reflector edge illum.	-0.2 dB	-0.2 dB
- feed cross-polar.	-999 dB	-999 dB
CO-POLAR PATTERN:		
- vertical	symmetric	symmetric
- horizontal	asymmetric	symmetric
- max. shifted	yes (1.75 m)	no
- max. amplitude taper	-0.55 dB	-0.30 dB
CROSS-POLAR PATTERN:		
- vertical	symmetric	
- horizontal	asymmetric	no cross-pol.
- maximum level	-24 dB	
SCANNING CAPABILITY:		
- scanning range	good	good
- plane wave quality (phase, amplitude)	good	very good

Table 3.4-1: PERFORMANCE DATA OF INVESTIGATED CR CONCEPTS

4. CONCLUSION AND OUTLOOK

A trade-off study between different types of compact ranges concerning its applicability for highly accurate satellite antenna and payload testing has shown that the Two-Cylinder Parabol Concept is an attractive candidate concerning the mechanical and manufacturing aspects (single curved reflectors, low cost manufacturing). On the other hand this CR type exhibits poor cross-polarization performance in one principle plane which is system inherent. This is overcome with the proposed Front Fed Cassegrain CR which inherently has no geometry induced cross-polarization and has also a slightly better co-polar performance in the quiet zone. To achieve this advantage two doubly curved reflectors have to be applied which require more expensive and complex manufacturing processes.

For its own compact range MBB has designed a Front Fed Cassegrain System with a quiet zone of approximately 5 m x 6 m applicable for a frequency range up to 40 GHz.
The already established test chamber has the dimensions of 24 m x 17 m. The facility will be operational at the end of 1987.

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