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OPTICAL ANTENNA MEASUREMENT SYSTEM USING THE COMPACT RANGE APPROACH

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ABSTRACT

In optical intersatellite links (ISLs), ultra high gain optical antennas which can emit extremely narrow beam will be used. We have been engaged in the research and development of a measurement system for these antennas using the compact range approach. The main advantages of this approach are not only the development of an accurate and stable measurement system, but also the possibility of simulating a fully bidirectional link incorporating dynamic pointing/tracking errors which are considered to be optical ISL critical degradation factors. The measurement system developed now achieves an angular resolution of less than 1 μrad in far field pattern (FFP) measurement of optical antennas.

1. INTRODUCTION

Because of the short wavelength/high frequency of lightwaves and no absorption/scattering materials in space, applying optical technologies to ISL systems is expected to realize large capacity/interference free links using compact equipment.[1] Optical antennas used in these optical ISLs will have an ultra high gain with relatively small apertures. Examples of transmitting optical antenna parameters used for optical ISLs which are currently under development by several leading organizations in the world [2, 3, 4] are listed in Table 1. The transmitting optical antennas are expected to have a gain of over 90 dB with aperture sizes only few hundred millimeters in diameter.

It is quite a challenging problem for state of the art technology to fabricate, assemble and maintain adequately such ultra high gain transmitting optical antennas capable of emitting extremely narrow beams(, while receiving antenna gain is less important due to detector's large active areas compared to wavelength). Accurate measurement methods supporting these technologies are also required, and some research efforts have just been started to establish measurement methods which can distinguish the super fine structures of an extremely narrow optical beam with an angular resolution of μrad order.[5]

European Space Agency (ESA) is conducting a research and development project on optical ISL systems named SILEX, and plans to evaluate optical antenna performance using the far-field range approach at a special open site over a 145 km rang.[6, 7] Alternatively, a huge optical interferometer may be used for this purpose, which is somewhat similar to the near field range approach, but it is unrealistic in terms of technology and cost.

Table 1. Optical ISL System Projects and Antenna Parameters

ORGANIZATION	CRL[2]	ESA[3]	NASA[4]
PROJECT NAME	LCE	SILEX	LCT
DIAMETER [mm]	75	250	203
GAIN [dB]	105.5	119.6	90.41
Commments	Beam Expander	Cassegrain	Aperture Shared by 3 Beams

We chose the compact range approach which is well known as a microwave antenna measurement technique.[8] Because of the natures of optical antennas mentioned above, the optical compact range measurement system has some features as follows, which are different from that of the microwave. That is,

(1) The system is constructed for transmitting antenna, while microwave systems are for receiving antenna.

(2) Planar scanning on the focal plane is adopted acceptably instead of angular scanning.

(3) Total power emitted actually can be measured easily by a simple power meter.

The optical compact range has the same advantages as those widely recognized for microwave antennas, that is, measurements can be easily carried out within a room inside a building, which leads to stable and accurate results. Moreover, this approach can simulate a fully bidirectional link incorporating dynamic pointing/tracking errors which are considered to be optical ISL critical degradation factors.

2. PRINCIPLE

The principle of the compact range approach is shown in Fig. 1. Suppose an optical antenna emits an optical beam with an intensity and phase distribution of $F(\xi, \eta)$ at the antenna aperture. The beam is diffracted to another intensity and phase distribution of $u(x, y, z)$, which is calculated using the diffraction theory. According to this theory, the Fraunhofer approximation is valid in the far field region at which the distance r from the source is larger than the far field criterion D^2/λ, where D is the antenna diameter and λ is the wavelength. In the near-field region, however, the more accurate Fresnel approximation must be used.

In a compact range measurement system, a lens (or mirror) is used to add a certain amount of parabolic phase shifts to the lightwave emitted from the optical antenna. The lightwave passed through the lens forms a far field pattern virtually only on the focal plane of the lens even if the plane lies in the near field region. The far field pattern is captured by a camera corresponding to planar scanning, from which we can calculate the directive gain of the antenna being measured. Because almost all rays are concentrated around the focal point, the total power emitted actually is measured simply by a power meter, and we can also identify antenna loss or efficiency.

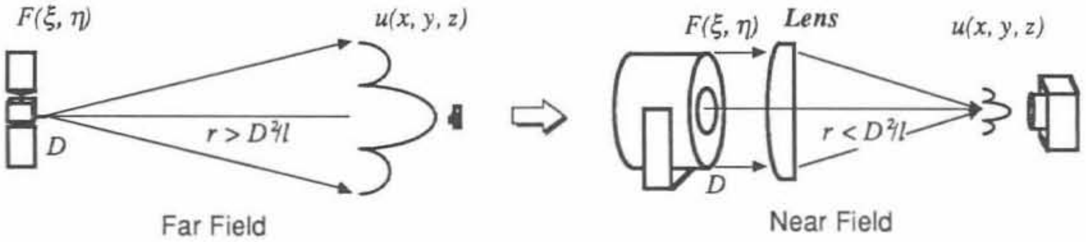

Figure 1. Compact Range Approach

3. DEVELOPMENT

An optical antenna measurement system has been developed using the compact range approach. A large aperture and long focal lens as shown in Fig. 2 were polished up to achieve diffraction limited performance. The aperture size was 260 mm in diameter to cover actual sizes of on-board communication terminals for optical ISLs. The focal length was 17.5 m to measure the far field pattern with sufficient angular resolution. To capture optical antenna far field patterns, a CCD camera with a 13 µm square pixel and an image processing system were used. This system had a nominal angular resolution of 0.75 µrad.

The whole system was housed in a long and narrow room called the "Eel's bedroom" as shown in Fig. 3. In this system, two optical benches, on which optical antennas and measurement equipments were mounted, were placed at both ends of the room, separated by 17 m. A "scintillation-free chamber" was laid between them to cover a optical path with a vacuum.

It was observed that measurements were substantially affected by atmospheric turbulence even though the system was placed inside a quiet room. To reduce these effects the "scintillation-free chamber", as shown in Fig. 4, was introduced. The chamber was 250 mm in inside diameter and 16 m long, and kept its internal pressure below 10^{-2} Torr as a vacuum. After introduction, quite stable measurement conditions continue to be obtained, which are considered to be identical to those in space.

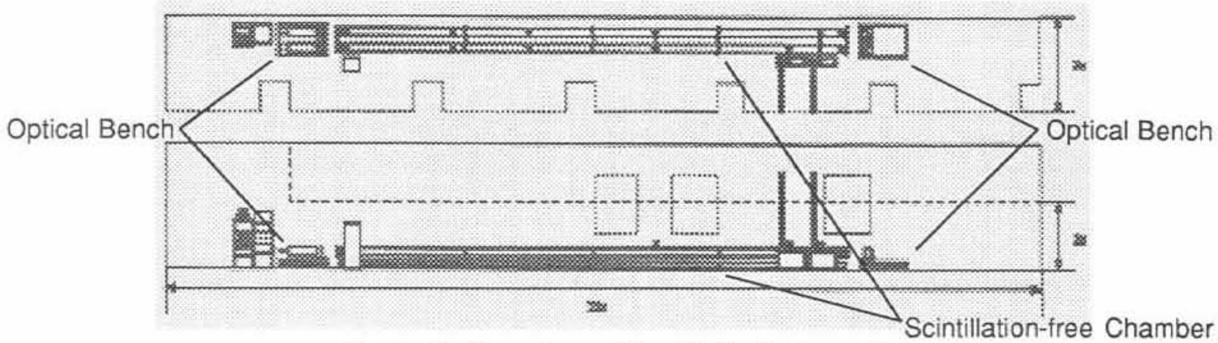

Figure 3. Overview of the "Eel's Bedroom"

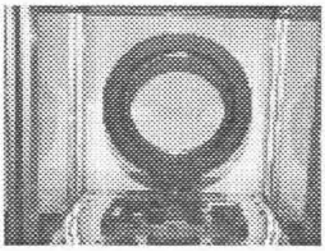

Figure 2. Large Aperture Long Focal Lens

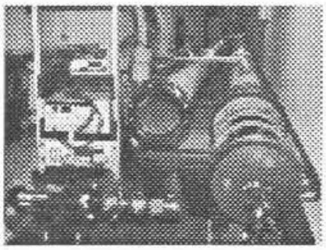

Figure 4. Scintillation-free Chamber

4. MEASUREMENTS

First, the diffraction limited performance of the lens, which is the key component of this system, was confirmed. The experimental setup for this lens performance test is shown in Fig. 5. The lens being tested was mounted on an optical bench together with a high precision mirror and circular aperture stop. An optical fiber as an ideal point source and a CCD camera were set at the focal plane of the lens on the anouther optical bench. At first the lens collimated the spherically diverging light from the point source and formed an nearly ideal plane wave, then the aperture stop defined its diameter and the mirror reflected it. At last, the lens projected the FFP of the plane wave onto the camera placed on the same focal plane of the lens.

Comparing image peak intensity with that from theoretical calculations, that is the "Strehl definition"[9], it is possible to evaluate small wavefront aberrations of the nearly ideal plane wave induced by the surface error of the diffraction limited lens being tested and the high precision mirror. The results were plotted in Fig. 6 as a parameter of the aperture stop diameter. It shows that the errors of the lens were less than $\lambda/10$ rms over a 200 mm aperture.

The experimental setup to measure a prototype optical antenna is shown in Fig. 7. This antenna which is center feed Cassegrainian with an aperture of 200 mm in diameter, was expected to have a beamwidth of about 3 μrad (FWHM), but the measurement result shown in Fig. 8 reveals that it deteriorated considerably due to antenna mirror surface imperfections, and had four large sidelobes due to secondary mirror support structures.

Measurement accuracy will continue to be improved by eliminating environmental disturbances, such as floor vibration. Also, the measurement system will evolve to a fully bidirectional link simulator by incorporating dynamic pointing/tracking errors.

5. CONCLUSION

We have developed an optical antenna measurement system using the compact range approach. The system is easy to operate and provides quite stable and accurate angular resolution measurements of less than 1 μrad. A lens performance test confirmed that the lens had a diffraction limited performance of less than λ/10 over 200 mm. The fine angular resolution achieved at this time was demonstrated by a sample FFP of a prototype optical antenna. Measurement accuracy improvement and system function evolution will be future work.

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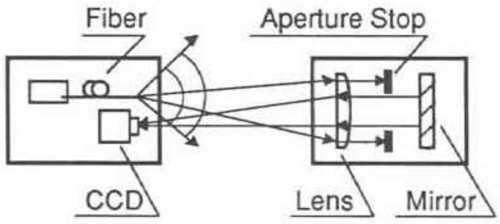

Figure 5. Lens performance Test Setup

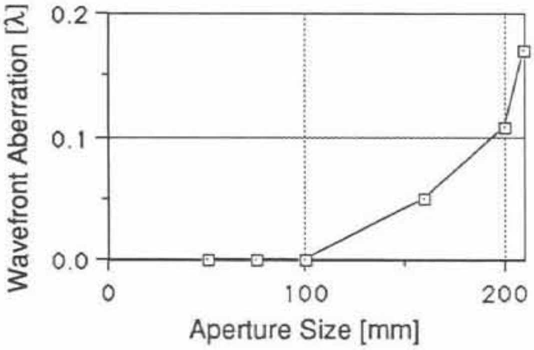

Figure 6. Wavefront Aberration by the Lens

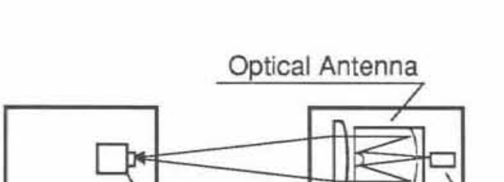

Figure 7. Antenna Measurements Setup

Figure 8. Example of Optical Antenna FFP