Adaptive receive telescope array for coherent free-space laser communications

Andras Kalmar, Klaus H. Kudielka, Walter R. Leeb
Institut für Nachrichtentechnik und Hochfrequenztechnik,
Technische Universität Wien,
Gußhausstraße 25/389, A-1040 Wien, Austria
Phone +43 1 58801-3530, Fax +43 1 5870583

Introduction

Free-space optical communication requires receive and transmit antennas in the form of telescopes. In comparison with single-aperture ("monolithic") telescopes mainly considered so far, a phased telescope array offers many fundamental advantages:

- reduced size of optical elements,
- inherent modularity, therefore
- redundancy (i. e. graceful degradation instead of total breakdown in case of a subtelescope failure),
- reduced overall size and mass,
- non-mechanical fine pointing.

In present, conventional system concepts for laser line-of-sight communications, mechanical coarse- and fine-pointing units have to be implemented, resulting in a massive and bulky setup. Taking advantage of the phased array's inertia-free steering capability reduces the requirements on the fine-pointing mechanism and could even make it unnecessary.

We are currently designing, breadboarding and testing an engineering demonstrator of a phased telescope array, to be used as a receive terminal in a coherent intersatellite laser link. This work is being done under contract of the European Space Agency (ESA).

In the following we describe the phased telescope array's principle of operation and the design of the engineering demonstrator. We also present the results of a performance analysis derived from predesign experiments and by computer simulation.

Principle of operation

The architecture of a phased receive telescope array with $N = 2$ apertures is shown in Figure 1. The

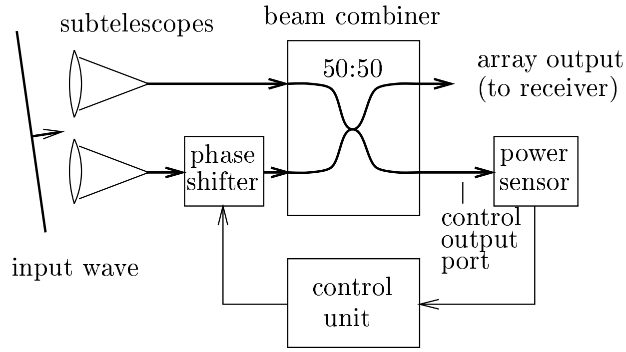

Figure 1: Basic concept of the phased telescope array

incident plane optical wave (transmitted by an optical point source at very large distance) strikes the subtelescopes' focussing optics. The subfields' phases are adjusted by piston actuators in the form of phase shifters. Furtheron, the subfields are superimposed by a beam combiner comprising $N-1$ symmetric directional couplers. In case the pistons are perfectly set and the subfields are of equal strength, the power level detected at the beam combiner control output port is zero, and the coherent sum of the incident subwaves is directed to the array output. With the help of a minimum finding control unit driving the optical phase shifters, the subfield pistons are always set to interfere constructively, and an automatic tracking of the direction of the incident optical field is achieved (within an angular range limited by the diffraction angle of a single subaperture).

Besides setting the subtelescope pistons, the control unit also caculates the angle of incidence of the input wavefront, which is an important input to the mechanical coarse pointing unit.

Engineering aspects of the demonstrator design

According to the ESA specifications summarized in Table 1, the engineering demonstrator shall be representative of a laser communication telescope in geostationary orbit in terms of equivalent aperture size and optical throughput. The automatic fine tracking of the optical source must compensate for typical short-term terminal attitude jitter.

Although all measurements and tests will be performed in a laboratory environment, our design implements space-worthy concepts wherever possible.

The engineering demonstrator has been designed to operate at a wavelength of $\lambda = 1.064\mu m$. It comprises a subtelescope array of 16 identical apertures arranged on a 4×4 Cartesian grid (see Figure 2), a fiber optics unit and a control unit (see Figure 3). The incident wave is coupled by diffraction-limited 3-lens objectives (diameter $25mm$, focal length $92.5mm$) into 16 polarization-maintaining single mode optical fibers. To convert the circular state of polarization of the input field into a linear polarized light required by the optical fiber, we attached a quarter-wave plate at the end of each subtelescope fiber. To compensate for long-term mechanical drifts mainly caused by thermal influence, the fiber end can be shifted in two dimensions orthogonal to the subtelescope axis, thus allowing to minimize subtelescope misalignment.

Fiber stretchers are used as optical phase shifters. The fiber is wrapped around piezoelectric tubes with $14mm$ diameter. By applying a voltage, the tubes change their diameter and thus the length of the fiber.

The beam combiner shown in Figure 3 is realized by a binary tree of 15 polarization-maintaining $3dB$ fiber directional couplers.

Photodetectors using InGaAs photodiodes and low-noise operational amplifiers sense the power level at the beam combiner's control output ports. Since optimum phasing is achieved by minimizing the power at these ports, noise introduced by the photodetectors results in phasing errors and thus a reduction of the array's output power. By optimizing the power sensor circuits we were able to achieve a noise-equivalent input power density of $50fW/\sqrt{Hz}$.

Parameter	Specification
Equivalent aperture size	$10 \ldots 16cm$
Number of subapertures	$8 \ldots 16$
Optical throughput	> 0.45
Wavelength of operation	$0.8 \ldots 1.1\mu m$
Optical bandwidth	$5 \times 10^{-3} nm$
Total optical input power	$10 \ldots 200nW$
Input state of polarization	circular
Output state of polarization	linear
Tracking response ($-3dB$ cut-off frequency)	$2kHz$
Tracking angular range	$> 20\mu rad$

Table 1: Engineering demonstrator specifications

Figure 2: Subtelescope array

The control unit of the engineering demonstrator is realized by a dual ADSP-21020 digital signal processor board. The piston control loops implement the dither algorithm described in [1]: a small periodic piston disturbance is applied and synchronously demodulated, resulting in a sinusoidal phase detector characteristic. To arrive at the required $-3dB$ cut-off frequency of $2kHz$, the dither frequency amounts to $20kHz$.

Expected performance

Computer simulation of the phased telescope array resulted in the expected performance values given in Table 2. Figure 4 shows the predicted receive characteristic and array characteristic. The array characteristic automatically adapts itself to the direction of the incident wave.

Summary

The design of an adaptive receive telescope array for coherent optical intersatellite communications has been presented. Simulation results indicate that such a telescope array could be a promising alternative to

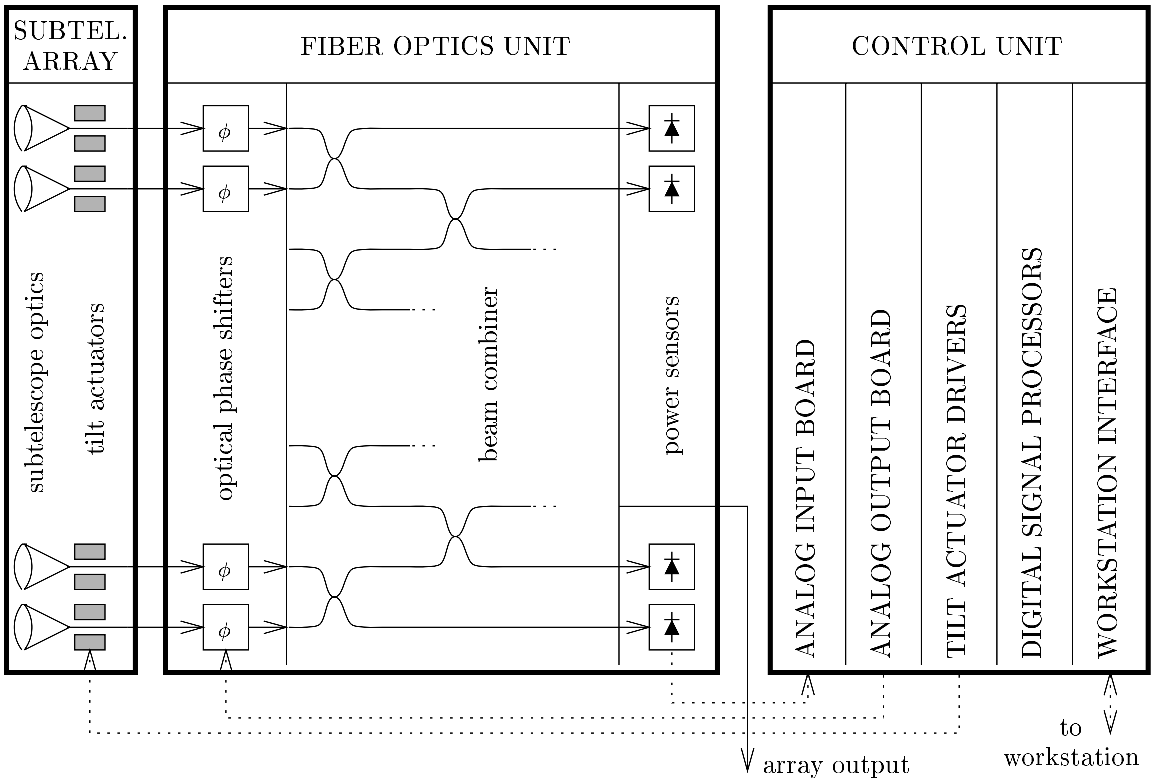

Figure 3: Block diagram of the 16 aperture engineering demonstrator

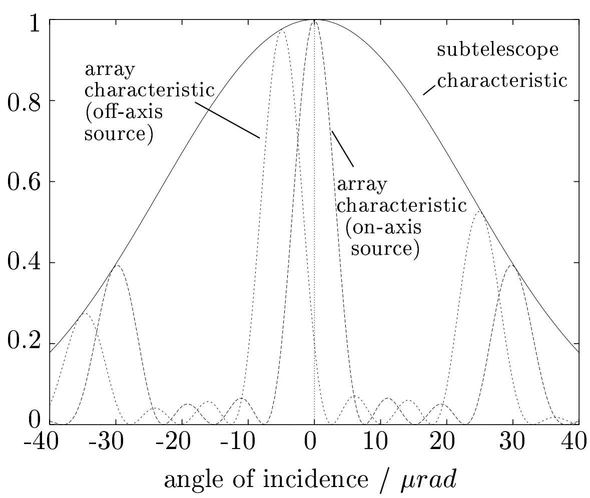

Figure 4: Cross-section of the normalized subtelescope characteristic and of the normalized array characteristic

Parameter	Expected value
Optical throughput	0.48
Output polarization extinction ratio	$18.5dB$
$-1dB$ tracking angular range	$28\mu rad$
Tracking cut-off frequency	$2kHz$

Table 2: Expected performance parameters of the phased telescope array demonstrator

single-aperture designs. We are currently testing an engineering demonstrator consisting of 16 apertures.

References

[1] K. H. Kudielka et al. Adaptive optical multi-aperture receive antenna for coherent intersatellite communications. In *Proc. SPIE*, volume 2210, pages 61–70, 1994.