# Reactive/Radiating Near-field Propagations of a Ka-band Horn Antenna

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## Abstract

This paper presents wave propagation passing through reactive/radiating near-field regions at the Ka-band. Electric-field distributions with amplitude and phase information are measured non-invasively in the overall near-field regions. An electro-optic field probe and its associated imaging system for vector-stabilized electric field visualization are presented. The spatial and temporal evolutions of the radiating fields at reactive/radiating near-field distances over the aperture of a Ka-band horn antenna are discussed in detail.

**Keywords:** Reactive Near Field, Radiating Near Field, Antenna Propagation, Electro-Optic Sensor

## 1. Introduction

Far-field radiation patterns are one of the most important characteristics of antennas because most of them are supposed to deliver signals or power efficiently at far remote places. However, this often requires huge, expensive test environments, such as anechoic chambers or open area test sites. To obtain far-field patterns without measuring directly, measurement techniques for near-field distributions of antennas have been developed as an alternative solution for the design and performance evaluation of antennas [1]. This is because near-fields – emanating from the antenna – eventually evolve into far-fields as they propagate through media; thus they can give clues for extracting far-field information. The amplitude and phase distributions (*i.e.*, vector components) of far-fields at a fairly long distance from the antenna can be readily calculated by spatial Fourier transforming those of the near-fields.

The near-field can be categorized into two regions according to the distance from antennas [2]. One is the radiating near-field region (within several wavelengths of an antenna). Measurements in this region, a photonic sensor with a minute metallic dipole, has been suggested as a good solution for maintaining reasonable sensitivity while significantly diminishing the invasiveness of the probe, and thus the complicated probe compensation [2] for conventional metallic probes can be avoided [1].

The other is the reactive near-field region: typically within a wavelength of an antenna. In measuring such a close region, it is highly recommended to avoid any metallic components due to the possibility of scattering and distorting the fields [3]. The electro-optic (EO) sensing technique realizes minimally-invasive electric-field measurements. The unique, electrically-transparent aspect of all-dielectric field probes is immune to reactive coupling with antennas during testing.

Such a photonic-assisted electro-optic system has successfully served as a planar reactive or possibly radiating near-field measurement technique [1,3]. As the scanning distance is the wavelengths-scale, the whole system can be managed compactly at a tabletop scale for most high frequency antennas. The scanning areas for compact high frequency antennas are generally small because most valuable field information resides close to the antenna aperture.

As the very near-field information is crammed into a smaller surface than that of far-field information, a possible tiny fluctuation in the near-field area could impact the far-field pattern significantly. Hence, the stability of the electro-optic scanning system for near-field mapping is a critical concern. Here, we present techniques for system stabilization and discuss the vector-stabilized near-field analysis of a Ka-band horn antenna.

## 2. Stabilized Near-field Scanning System

The vector stabilized electro-optic system for planar near-field scanning is presented in Fig.1. The basic implementation is identical to our previous system [5] except for the sensor part and its associated stabilization loop. For high frequency sensing, a photonic down-mixing technique is employed and its sensing efficiency degrades for higher frequency as the conversion loss to intermediate frequency (IF=|RF-LO|) increases. We used a highly sensitive EO probe using balanced-interferometric modulations, which uses the steep slopes of sharp interference fringes of a sensor crystal to obtain effective EO sensing [4]. In our recent work [4], the sensitivity was greatly enhanced by sharpening the modulation slopes. The laser wavelength was tuned to the steep point over the fringes. This wavelength worked as a modulation bias point and could drift over abrupt fringes. Such bias instability can be overcome by locking the bias at fixed points over the fringes. The coupled power from the probe indicates the amount of drift which is to be compensated for by fine wavelength tuning. The dotted lines in Fig. 1 construct a thermo-electric control (TEC) wavelength lock loop.

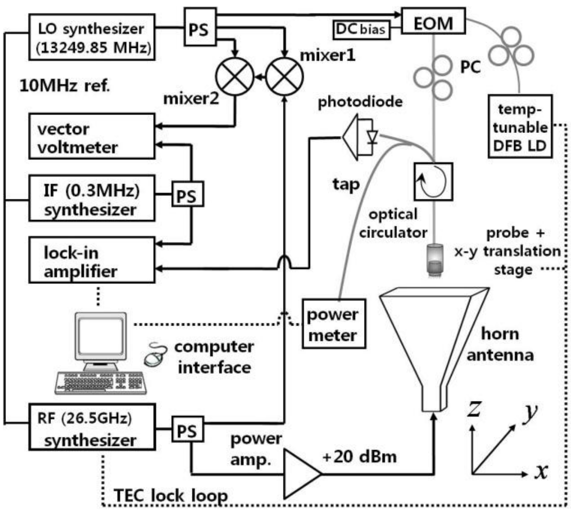


Figure 1: Stabilized electro-optic near-field scanning system for a planar antenna. (EOM: electro-optic modulator, DFB LD: distributed feedback laser diode, PC: polarization controller, PS: power splitter)

For high frequency antenna analyses, phase information is quite important for determining polarizations and radiation patterns as they eventually evolve to far-fields. The high frequency phase signals are readily resolved through lock-in detection with a down-mixing technique. To realize the down-mixing scheme, two separate high frequency sources are required for respective RF and LO. Although they can be readily synchronized by sharing a reference channel, each source often drifts significantly and independently for high frequency over the K-band. Hence, the down-converted IF components, which possess the original RF signals, are more drifted than the irrespective sources.

To address this issue, we implemented a real-time microwave calibration scheme in the system, which included a standard Ka-band horn antenna operating at 26.5 GHz (= RF). Local oscillator (LO = 13.24985 GHz) light modulation is needed for downshifting the sensing signal into the acoustic bandwidth of a lock-in amplifier (RF-LO = 0.3 MHz). The frequency-folding light modulation technique is used to lower the driving frequency for the LO light modulation and enhance the extinction ratio of the modulator.

Figure 2 compares the phase distribution of the electric field in the *y* direction at the distance of one wavelength over the Ka-band horn. Fig. 2(a) shows the apparent and uniform phase signals over the antenna aperture (dotted box) whereas Fig. 2(b) does not.

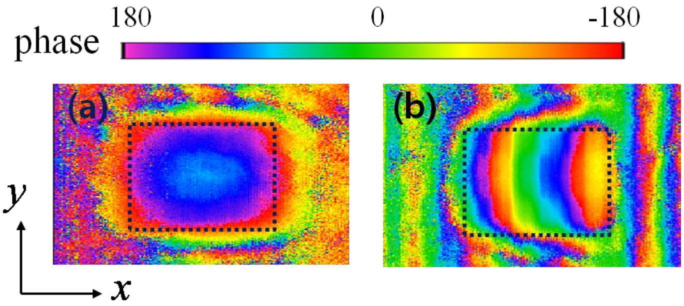


Figure 2: Transverse-vertical (= *y*-direction) electric field phase distributions of the horn antenna at 1 λ distance: (a) phase corrected, (b) phase non-corrected.

The amplitude distributions of the electric fields for the same antenna are presented in Fig. 3. Each figure shows the distribution for a different distance from the aperture. The four measurement distances are 1, 2, 3, and 4 *λ*, respectively for Fig. 3 (a)-(d). This covers the reactive to radiating near-field crossing its border, so that the evolution of the field distributions could be explored associated with those of the corresponding phase.

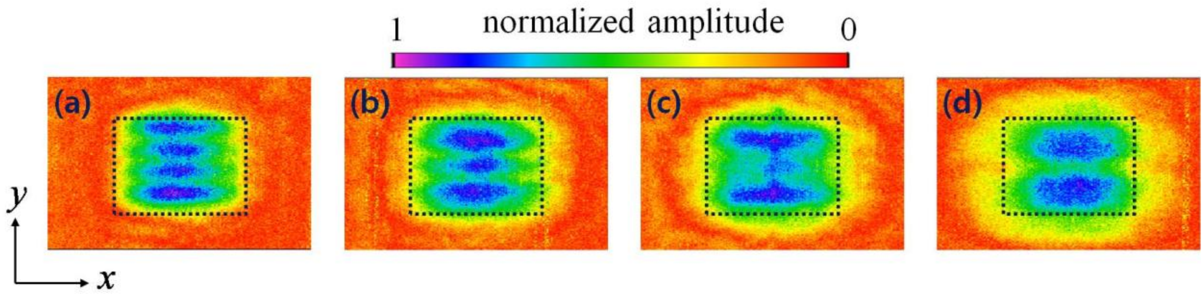


Figure 3: Transverse-vertical (= *y*-direction) electric field amplitude distributions of the horn antenna: (a) at 1 λ distance (b) at 2 λ distance (c) at 3 λ distance (d) at 4 λ distance

For instance, at the 1 *λ*, four locally maximum fields are observed in the middle of the aperture. The four ripples evolve to three and two at 2 and 4 *λ* as they propagate via their intermediate status, namely, 3 *λ*. The relative strength among the ripples changes and this confirms how they evolve. In additon, the number of ripples reduces and finally converges to a single and distinct peak at the center as the main lobe before reaching the far-field region.

The phase distributions are uniform and symmetric where the amplitude signals exist mostly over the aperture as observed in Fig. 2(a). Such uniformity is valid for any distance, not only for 1 *λ*. This confirms that all the amplitude components are uniformly and linearly polarized in the same direction (here the *y* direction). In addition, the magnetic fields can be inferred from the measured electric fields and thus the resulting pointing vector which propagates vertically out-of the aperture could be extracted.

By virtue of the stabilized phase information as seen in Fig. 2, the amplitude images in Fig. 3 can be animated [5]. The animated-visualization of the electric fields of the antenna is presented at various distances in Fig. 4. The phasor bar was normalized and four snap-shot flames with a $\pi/2$ phase step at each distance show the one cycle evolution of the animated-vector fields with relative strength.

We will provide the more detailed near-field data set of the antenna reaching to the far-field pattern. The complete field transitions with full frames from the reactive/radiating near field to its far-field region and their use for far-field prediction are to be discussed at the presentation.

## 3. Conclusions

An electro-optic imaging system that provides measurement of stabilized vector field distributions for the reactive/radiating near-field regions of high-frequency horn antennas was presented. The techniques for system stabilization and its use for the electric field visualization of a Ka-band horn antenna have been successfully demonstrated. Such a photonic-assisted system for electric-field imaging – at close but not destructive distances for the probe/antenna – can be a valuable solution to evaluate horn antennas in a compact and cost-effective way.

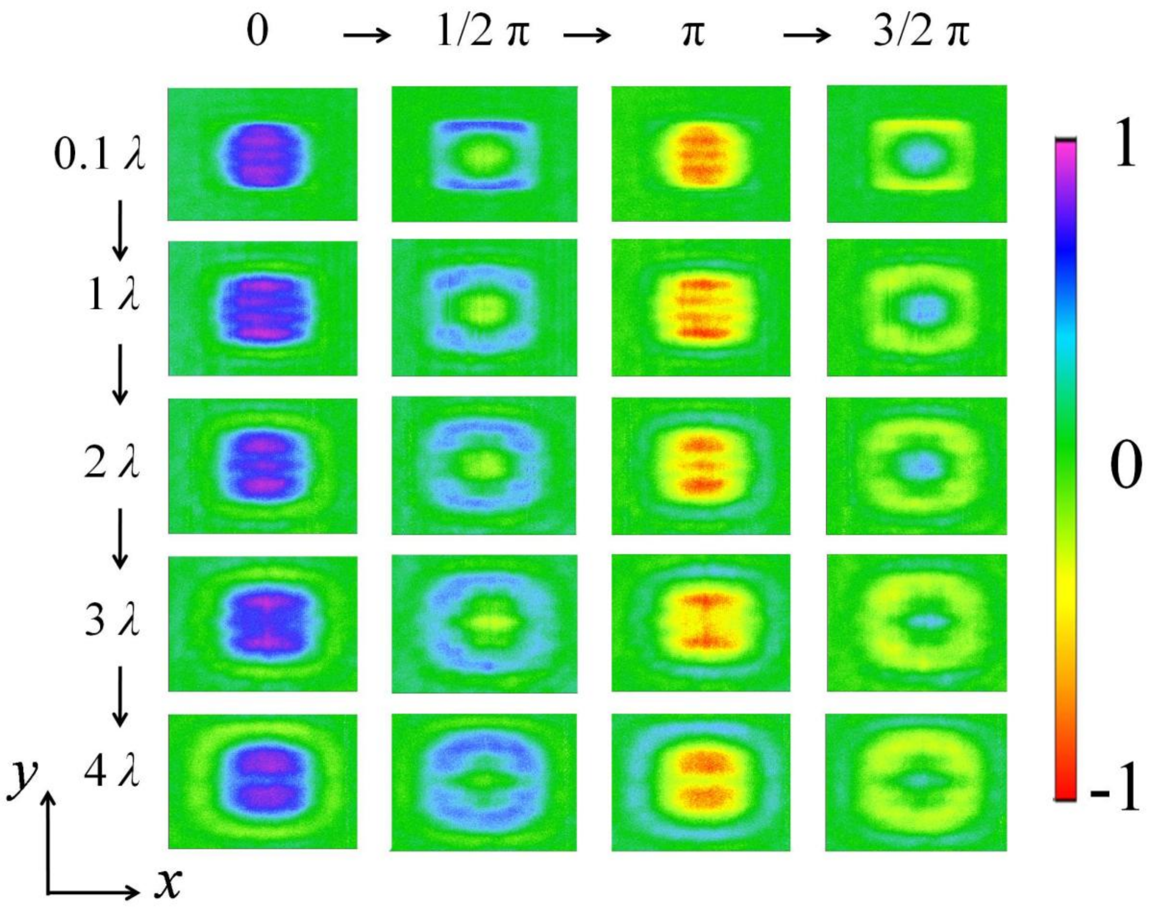


Figure 4: One cycle evolution of a transverse-vertical (= *y*-direction) vector electric field (at distances of 0.1, 1, 2, 3, 4, 5 $\lambda$ with $\pi/2$ phase step) of the Ka-band antenna (with a normalized phasor bar).

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