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Real-time monitoring system of RF near-field distribution images on the basis of 64-channel parallel electro-optic data acquisition

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Abstract: Described in this paper is a system for the real-time image monitoring of electromagnetic near-field distributions over devices and circuits at a specific radio frequency (RF), which is the first to the best of our knowledge. It is based on a 64-channel parallel electro-optic heterodyne detection scheme, in which arrays of photodiodes and mixers allow simultaneous acquisition of 8×8 pixel data. Its highest frame rate of 10 Hz enables even a motion picture display of RF near-field images. It has been applied to a patch antenna and a moving RF emitter for performance demonstration.

Keywords: electro-magnetic field measurement, real-time monitoring, electrooptic probing

Classification: Photonics devices, circuits, and systems

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1 Introduction

Development of advanced RF/high-speed devices and circuits has been always quested enthusiastically because of the high demand for better performance, more functionalities, and increased compactness of electronic apparatuses. This trend eventually increases complexities and, therefore, difficulties in manufacturing and packaging those devices and circuits. To identify causes of malfunctions and eliminate those quickly, highly required are useful techniques for intuitive analyses and diagnoses of their operations. Electromagnetic field measurement techniques based on photonic methods, such as electro-optic (EO) or magneto-optic probing, are attractive for this purpose because of their low invasive nature together with their high temporal resolutions and high sensitivities [1, 2, 3]. Indeed, these techniques have been successfully applied to acquisition of RF near-field images in laboratories [4].

However, image acquisition time of such photonic RF imagers is too long for their practical usage. Even in a state-of-the-art system demonstrated by Sasaki and Nagatsuma, it takes 20 seconds to acquire an image of approximately 2500 pixels [5]. It corresponds to a data acquisition rate of approximately 125 pixels per second (pps), which is still insufficient for the real-time image monitoring. In addition, a pair of mechanically moving mirrors is indispensable there, which suggests a limitation to further improvement of the data acquisition speed.

One way of overcoming this limitation is to use the parallelism in photonics. In fact, a system based on a charge coupled device was successfully demonstrated in the THz regime [6]. However, an intense THz source with a kV-order voltage applied is needed there to electro-optically convert a THz wave pattern into a corresponding photon density pattern. Such intense fields are not available regarding standard RF components and, therefore, necessary is a more sensitive data acquisition scheme that is not only suitable to EO signals of low modulation depths but also compatible with the photonic parallelism.

Here, we claim and demonstrate that the combination of photonic heterodyne and arrayed EO detection schemes meets the demand. Described in this paper is the first system for the real-time EO image monitoring that supports even motion-picture-like imaging of RF near-field distributions. Simultaneous measurements with 64-channel arrays of photodiodes and mixers provide high-speed monitoring of images at a frame rate of 10 Hz, corresponding to a data acquisition rate of 640 pps. Although the number of pixels for each

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frame, 64, is not satisfactory, the concept of the present scheme would lead to a new era in photonics-based imaging techniques for the RF near-field distributions.

2 EO image monitoring system

Figure 1 (a) shows a schematic diagram of the system. It can grab instantaneously and iteratively a two-dimensional image of an electric near-field distribution over a device-under-test (DUT) driven at a specific radio frequency f_{RF}. Acquired images are displayed on a screen and refreshed within a second as a moving picture is being displayed through an ordinary video camera. One can expect that information given by such a system could contribute to failure detections of RF devices and circuits in an extremely prompt manner.

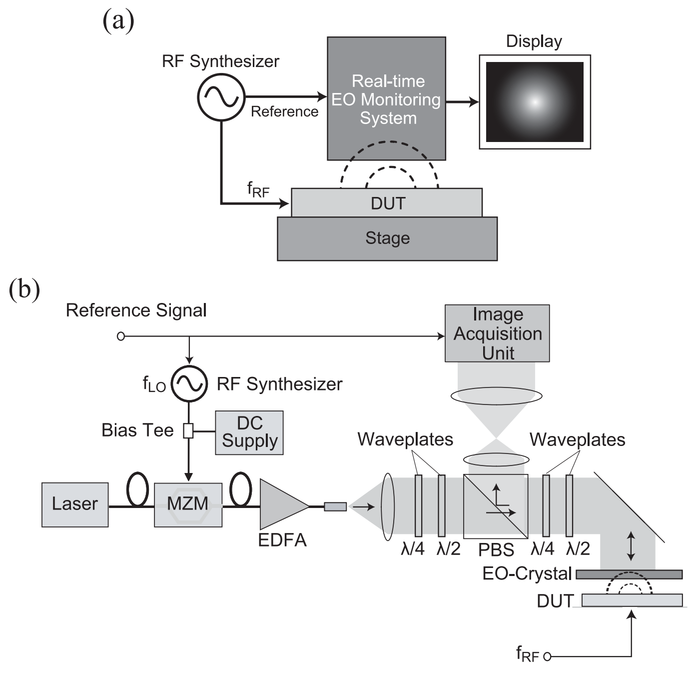

Fig. 1. (a) Schematic diagram of the real-time image monitoring system of RF near-field distributions. (b) Photonic system embedded within the real-time EO monitoring system in (a). MZM: Mach-Zehnder modulator, PBS: polarization beam splitter, EDFA: Er-doped fiber amplifier.

The photonic system used for the scheme is shown in Fig. 1 (b), in which photodiode and mixer arrays provide parallel detections of EO signals and, consequently, a high-speed image acquisition. More detailed explanations are as follows; 1.55-μm light of a distributed feedback laser diode is launched into a $LiNbO_3$ Mach-Zehnder interferometer modulator (MZM) and modulated sinusoidally at f_{LO}. The modulated light is amplified to 30.5 dBm by

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an erbium-doped fiber amplifier, collimated, and illuminates a 25-mm square area of an EO crystal (ZnTe) plate, which is placed above the f_{RF} signal driven DUT. The crystal orientation is chosen to provide its sensitivity to electric fields parallel or perpendicular to the crystal plate. Its surfaces are coated with dielectric layers to obtain high transmission on the top and high reflection on the bottom. The reflected light from the crystal bottom is analyzed via a polarization beam splitter and a corresponding photo-mixed light signal is generated at the difference frequency ($f_{LO} - f_{RF}$). The light signal is detected two-dimensionally by an 8×8 array of InGaAs photodiodes. The photocurrent generated at each photodiode is amplified and launched into a mixer together with a local oscillator input at the difference frequency. Finally the parallel signals thus down-converted are digitized at a rate of 100 ksamples/s and sent to a computer.

3 Measurements

The details of the photonic heterodyne measurement at each pixel were preliminarily reported in [7] and will be described elsewhere. One should note here that it is nearly impossible to apply the balanced detection (BD) scheme to the present PD array, although it is a standard and efficient technique for noise suppression in conventional photonic probing systems. This is the reason why the photonic heterodyne method was chosen in this work, which provides a comparably low-noise feature to a BD system. In addition, the present scheme of light modulation is beneficial since it is possible to adjust f_{LO} continuously. This continuous adjustability is not available in the EO sampling scheme where needed is an optical pulse source with a nearly fixed repetition rate.

The bandwidth and sensitivity of the system were evaluated in a separate experiment. The measured 3-dB bandwidth, 2.5 GHz, is dominated by the speed of the present MZM modulator, and, therefore, can be extended. The minimum detectable power of the system is −20 dBm with respect to an RF signal on a 50-ohm microstrip line, corresponding to 22 $\mathrm{mV}/\sqrt{\mathrm{Hz}}$. These details will be reported elsewhere.

3.1 Prompt imaging of patch antenna electric near-fields

Electric near-field patterns of a patch antenna were systematically measured as shown in Fig. 2 (a). Its shape and resonant frequency are 10 mm square and 6.7 GHz, respectively. Here, a $\langle 110 \rangle$-oriented and 0.9-mm-thick ZnTe crystal was used with two orthogonal crystal orientations employed: the system was sensitive either to x or y component of the field. The crystal was set 1 mm above the antenna plane, and the field of vision was chosen to be 20 mm square.

Figures 2 (b) show the measured images, in which adjacent pixel data are numerically interpolated. Results for the x-component measurements are shown in the top row, and those for the y-component are in the bottom. Parameter ϕ is the relative phase of the mixer input signal of the difference

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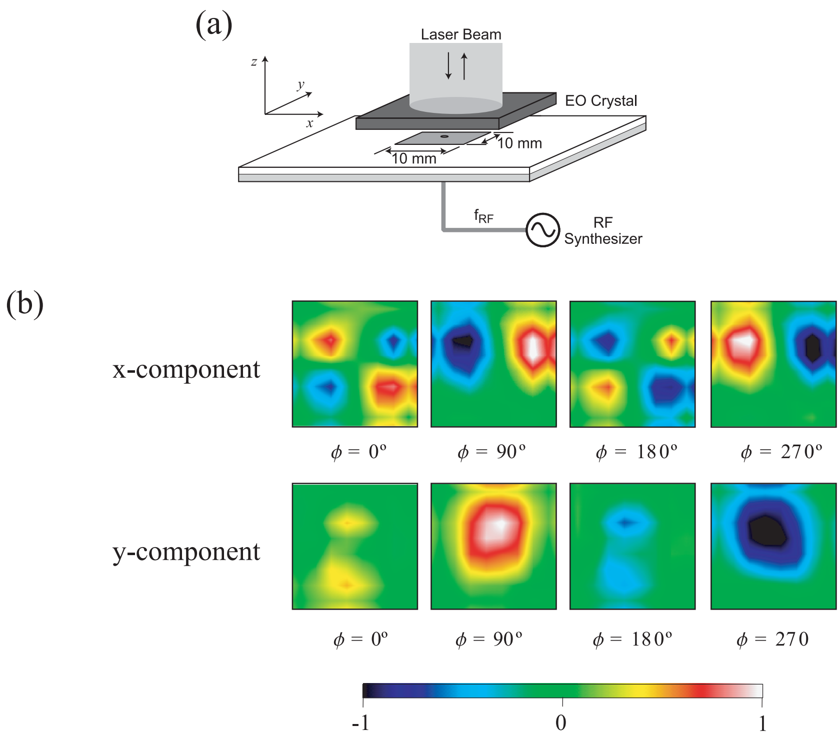

Fig. 2. (a) A 10-mm-square patch antenna was placed as a DUT beneath a ZnTe EO crystal plate. (b) Normalized electric field patterns measured at a height of 1 mm above the antenna. ϕ is phase of the difference frequency signal inputs to the mixers. Frequency and power of the antenna input are 6.65 GHz and 22 dBm, respectively. Images in the top row are dependence of x-components on ϕ, and those in the bottom are of y-components.

frequency. Theoretically expected characteristic features of the field distributions can be clearly pointed out in the figures. For example, typical for an antenna of square shape are peak and valley structures around the corners of the antenna and their ϕ dependence, appearing in the x-component patterns [4]. Note that a series of these images were taken almost instantaneously.

3.2 Near-field monitoring of a moving RF emitter

To evaluate the performance for the real-time image monitoring, a movable RF emitter was prepared with an SMA connector attached to a printed circuit board, and its electric field distributions were measured dynamically. The emitter, whose cross-sectional view is shown in Fig. 3 (a), was placed on a set of translation stages and moved along a V-shaped trajectory as shown by the dashed lines in Fig. 3 (b). The motion speed was 1.9 cm/s, and the x-component of the field was monitored within a 20 mm square field of vision. The highest available frame rate of the system, 10 Hz, is given by the minimum value of averaging time τ at the mixer array output.

Dynamics of its electric field distributions are shown by a series of frame

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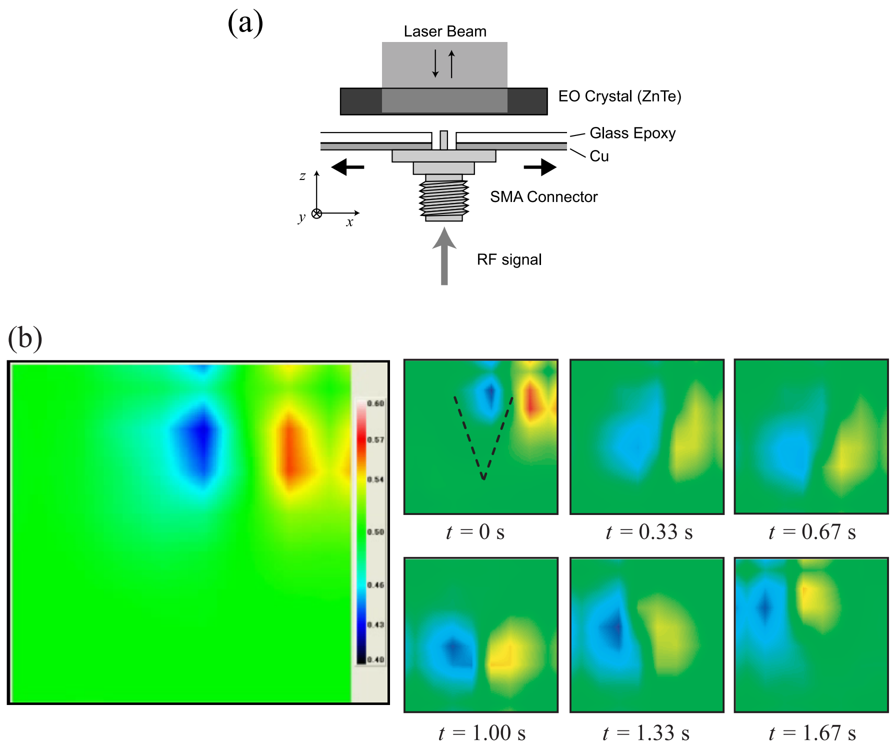

Fig. 3. (a) Schematically drawn cross-sectional view of the fabricated RF emitter for the dynamical image monitoring test. The EO crystal is also depicted. (b) Series of frame images acquired for the moving RF emitter are shown with time intervals of 0.33 s. Dashed lines indicate the trajectory of the emitter motion. A movie file is also attached.

images in Fig. 3 (b) with 0.33-second intervals and a corresponding movie file is attached. These sequentially changing images indicate clearly that the system did capture the motion. Note that the image was less intense and spatially fuzzier after the RF emitter started moving. This is due to the persistence of vision, which results from a rather long average time τ of 3.0 s in the particular case. When τ was reduced to its minimum, 0.1 s, the persistence effect was sufficiently suppressed with reasonable sacrifice of the signal-to-noise ratio of the vision. Its details will be reported elsewhere.

4 Conclusion

We reported on the first real-time monitoring system of RF near-field images, which is based on the photonic method: arrayed electro-optic heterodyne detection. Its pixel acquisition rate at maximum is 640 pps, which is five times higher than any previously reported. The photonic parallelism enables such a high rate without high expense of measurement sensitivity. These results are expected to mark an epoch in photonic-based techniques for the RF near-field distribution imaging although we must further increase the number of pixels.

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