

# High-Power Millimeter-Wave Electromagnetic-Field Sensing Using Compact Slotted Patch-Antennas with Electro-Optic Modulator

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**Abstract** We report a demonstration of high-power millimeter-wave electromagnetic-field (EMF) sensing using compact slotted patch-antennas with electro-optic (EO) modulator. The EMF can be detected by the patch-antennas and directly converted to lightwave through the Pockels effects of the EO crystal in this technique. The measured millimeter-wave EMF characteristics can be transferred through low-loss optical fibers with immune to the environmental noises. Magnitude and polarization of the millimeter-wave EMF can be observed and identified easily. Preliminary demonstration of this technique for 90GHz millimeter-wave frequency with 33dBm millimeter-wave power are discussed and reported.

**Keywords** Electromagnetic-field sensing, millimeter-wave bands, high-power, antenna, optical modulator

## 1. Introduction

Electromagnetic-field (EMF) sensing is important in human life for measuring characteristics of an electronic equipment to operate properly without generating electromagnetic pollution to the environment [1]. The EMF radiation and susceptibility of the electronic equipment must be controlled/ regulated based on approved standardization in the some countries or regions. In order to check the electronics equipment, EMF sensing is required with precise measurement and low unwanted noise response.

Nowdays, EMF sensing is developed and applied in technology with microwave bands (below 10GHz) to measure current available electronic equipment in the market. The technology with microwave bands will be saturated in the near future due to the user demands for high-quality, high-speed, and high-resolution electronic equipment. One promising candidate is using higher operational frequency in millimeter-wave/ terra-hertz bands for future applications. Therefore, EMF sensing for millimeter-wave/ terra-hertz bands should be provided also.

In millimeter-wave/ terra-hertz bands, several characteristics must be considered carefully where they are propagation loss, matching condition, unwanted distortion and noise, etc. In order to minimize the unwanted characteristics, radio-over-fiber (RoF) technology can be adopted. The RoF technology can improve the propagation

loss, minimize circuit matching condition requirement, reduce unwanted distortion and noise, and observe safely a high-power millimeter-wave EMF [2]. The key important device in this technique is millimeter-wave EMF sensor for receiving free-space EMF and converting it to lightwave.

In this paper, demonstration of high-power millimeter-wave EMF sensing using compact slotted patch-antennas with an electro-optic (EO) modulator is discussed. The antennas are used for receiving free-space millimeter-wave EMF and the EO modulator is used for converting the EMF to lightwave through the Pockels effects of an EO crystal. The converted lightwave can be propagated to an optical fiber with its characteristics of immune to the environmental noises. Demonstration of this technique are reported for 90GHz millimeter-wave frequency with about 33dBm observation power in free-space.

## 2. Experiment

Figure 1 shows an experimental setup for high-power free-space millimeter-wave EMF sensing using compact slotted patch-antennas with an EO modulator. In the millimeter-wave generation, an optical-modulation-based generator driven by a microwave synthesizer operated at about 22.5GHz provides an optical two-tone signal with a frequency separation of about 90GHz [3]. After transmission over an optical fiber, a high-speed photo-detector (PD) converts the optical signal to 90GHz electrical signal. The millimeter-wave signal is amplified by

use of millimeter-wave amplifiers with an isolator (ISO) and a travelling-wave tube amplifier (TWTA). Then, the amplified millimeter-wave signal is radiated to the free-space by use of a standard horn antenna with 24dBi antenna gain. The maximal output power of the millimeter-wave signal after the TWTA is estimated approximately 33dBm.

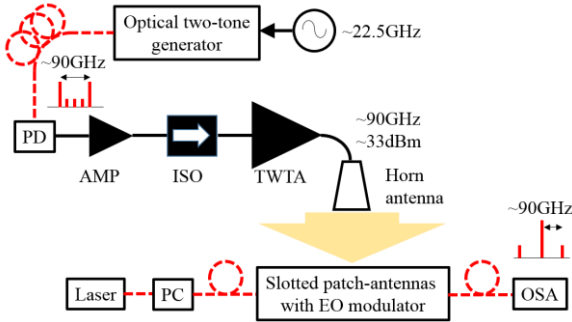


Fig. 1 Experiment setup.

The high-power millimeter-wave signal was observed by the fabricated slotted patch-antennas with an EO modulator. A lightwave was also coupled to an optical waveguide in the fabricated sensor using an optical fiber where a polarization controller (PC) was inserted them. The lightwave output was observed using an optical spectrum analyzer (OSA). As a result, observed millimeter-wave signal in optical domains can be obtained which is indicated by optical sidebands in the spectrum.

### 3. Results and Discussion

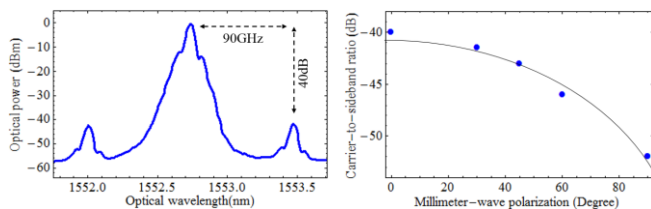


Fig. 2 The measured optical sidebands spectrum (left) and millimeter-wave polarization dependence (right).

Figure 2 shows the measurement results of millimeter-wave EMF sensing using compact slotted patch-antennas with an EO modulator. When millimeter-wave signal of 33dBm power was observed, the measured ratio between optical carrier to sidebands of about -40dB can be measured. Since the observed power ratio is below unity ( $<1$ ), it can be used directly for indication of the EMF sensor sensitivity/ efficiency [4]. The millimeter-wave polarization was also observed using the fabricated sensor where 0 degree is indicated for optimum position for the EMF sensor detection. The measurement results have good agreements with calculation results. Based on the results, high-power millimeter-wave EMF amplitude and polarization can

be observed using the proposed slotted patch-antennas with an EO modulator as the EMF sensor.

### 4. Conclusion

We have reported a demonstration of high-power millimeter-wave EMF sensing using compact slotted patch-antennas with EO modulator. 90GHz millimeter-wave frequency with about 33dBm observation power in free-space was used in the demonstration. The measured sensitivity of about -40dB was obtained. We believed that the proposed sensor is power full for EMF sensing in the high-frequency operation with its low distortion and high-power free-space observation with safety condition. Now, we are trying to improve the sensor sensitivity by adopting an array structure, new antenna type, or using additional millimeter-wave collimators/ lens [5].

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