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W-band Transmission Imaging by Photonics-Based Millimeter-Wave Synthesizer and High-Power Traveling-Wave-Tube Amplifier

Atsushi Kanno Norihiko Sekine Akifumi Kasamatsu Naokatsu Yamamoto

National Institute of Information and Communications Technology
4-2-1 Nukui-kitamachi, Koganei, Tokyo, 184-8795 Japan
E-mail: {kanno, nsekine, kasa, naokatsu}@nict.go.jp

Abstract We configure and demonstrate an electromagnetic-wave transmission imaging system with a photonics-based W-band synthesizer, traveling-wave tube amplifier (TWTA) and focal-plane transistor array. High-power TWTA with multi-watts output power will enhance the quality of obtained images.

Keywords W-band imaging, optical modulation, traveling-wave tube amplifier.

1. Introduction

A non-destructive testing (NDT) is promising for inspection of concealed materials in a box and a baggage in airports and logistic centers to enhance the security and safety. Traditionally, X-ray transmission imaging system and metal detector are used for the inspection, but the energy of the X-ray might damage the items such as photography films. Nowadays, radio-based imaging system is now being developed for whole human-body inspection, and is already installed at airport security checkpoints in USA [1]. This technology is with a millimeter-wave radio irradiation at a frequency of approximately 30 GHz; the wavelength of 10 mm limits the image resolution [2]. Using the W-band (75–110 GHz) radio, a shorter wavelength of 3 mm at 100 GHz can improve the resolution, however, high attenuation coefficient by air and materials reduces a signal-to-noise ratio (SNR). Particularly in the inspection in checkpoints and logistics, real-time feature is highly demanded with better SNR.

In this study, W-band transmission imaging system is configured and demonstrated with photonics-based signal generation and traveling-wave tube amplifier (TWTA) [3]. High-output-power TWTA will improve the SNR of the images and the resultant throughput.

2. Demonstration

2.1 Experimental setup

Figure 1 shows an experimental setup for W-band transmission imaging system. In the W-band signal generation, an optical-modulation-based generator driven by a microwave synthesizer operated at 22 GHz provides an optical two-tone signal with a frequency separation of 88 GHz (Fig. 2) [4]. After transmission over a single-mode optical fiber, a high-speed photomixer (PM) converts the optical signal to a 88-GHz electrical signal (Fig. 2). The W-band signal is boosted up by a semiconductor-based driver amplifier (DA) with an isolator (ISO) and the TWTA. Finally, the amplified W-band signal is emitted from a standard horn antenna with an antenna gain of 24 dBi. The maximum output power of the 88-GHz signal at the output of the TWTA is estimated approximately 2 W. In the receiver side, we used a focal-plane transistor array (FPTA), which is provided by TeraSense (TeraSense T30/64/64), operated at a frame rate of 10 frames/s. This is configured by 64×64 plasmonics-enhanced GaAs high-electron mobility transistors, which is utilized as a detector element, with a separation of 3 mm [5].

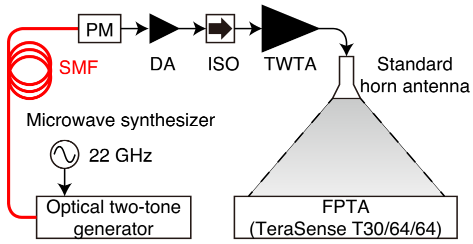

Fig. 1 Experimental setup.

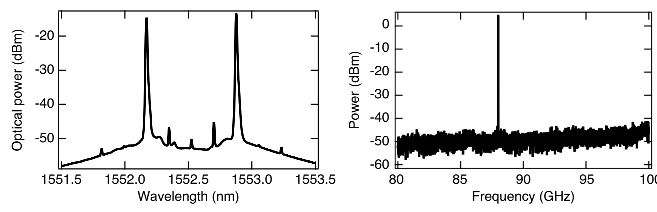

Fig. 2 Generated (left) optical and (right) electrical spectra at 88 GHz.

Application of photonics technology for generation of the millimeter-wave signal has an advantage on high scalability of a number of transmitters with high signal coherency. In a synthetic aperture imaging system, which enhances a spatial resolution by extension of an effective aperture of the antenna, coherency of signal, that is synchronization of the transmitters, are important to synthesize the resultant images. In this sense, a centralized seed-signal generator by photonics with a large number of remote transmitters with the PM can easily generate and distribute the synchronized signals over a low-transmission-loss optical fiber network to the optical to millimeter-wave converters [6]. High functional imaging will be realized by the photonics-based signal generation and distribution technologies.

2.2 Results and discussions

Obtained transmission images for tea-bag packages and a smart card are shown in Fig. 3 with standard optical reflection images. In the W-band image, the tea-bag through an outer package is clearly observed although corresponding optical image shows just the package. This is because the material of the package is not made from thin metal, but thin plastics. In addition, an internal electrical circuit including an antenna is observed in the smartcard.

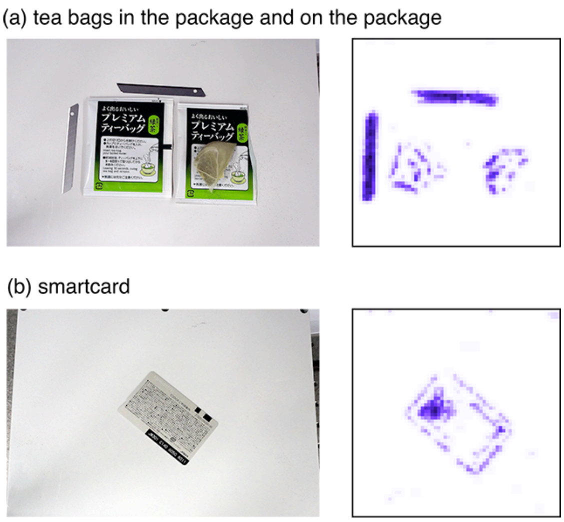

Fig. 3 (left) optical image and (right) W-band transmission image of (a) tea-bags with packages and (b) a smartcard. Two cutter blades set along with the tea-bag packages are for the reference in (a).

For application to security inspections, object items could be contained in a case such as cardboard box. Figure 4 shows a transmission image for scissors and ceramic knife through a standard one-layer cardboard with a thickness of 6 mm. Although the SNR is degraded owing to the attenuation by the cardboard, the object items are clearly observed. Therefore, the W-band transmission imaging technique is applicable for the NDT.

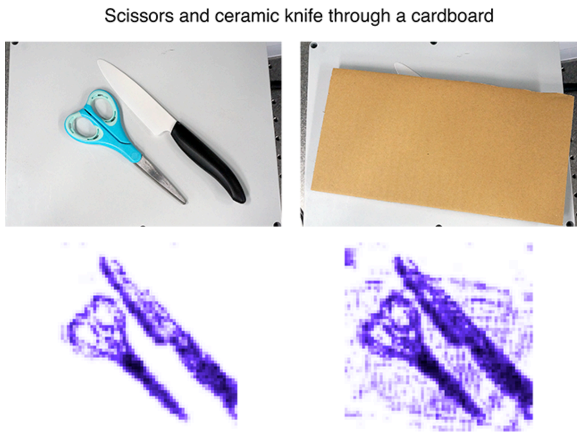

Fig. 4 (top) Optical images and (bottom) W-band transmission images for (left) the items (scissors and ceramic knife) and (right) through a cardboard.

Detection of concealed materials in an post envelop is important to avoid critical incidents in terrorism. In addition, to keep postman's and customer's safety, edged tools in the envelop should be detected before opening the envelop. Figure 5 shows brief results for detection of concealed cutter blade in cushioning and post envelops. A conventional envelop for an express mail services (EMS) as well as a cushioning envelop seems transparent to the W-band signals. Therefore, any knives, cutter blades and scissors can be detected by the W-band transmission imaging system over cardboards, cushions and envelopes.

Fig. 5 Optical images of (left) Target of a cutter blade for detection in a cushioning envelop and (middle) the cushioning envelop in an EMS envelop. (right) Obtained W-band transmission image through the EMS envelop is shown. The location of the contained cushioning envelop is indicated with translucent image and dashed lines.

3. Conclusion

The W-band imaging system with photonics-based synthesizer is successfully demonstrated using the TWTA and FPTA. High-power TWTA enhances the SNR and the throughput of the images, and therefore, these technology is capable for security inspection on airport and logistics to enhance the safety.

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References

[1] R. Appleby, "Passive millimeter-wave imaging and how it differs from terahertz imaging," Phil. Trans. R. Soc. Lond. A, vol. 362, pp. 379–394 (2004).

[2] D. McMakin and D. Sheen, "Millimeter-wave advanced imaging technology," 2011 Joint American Assoc. Physicists in Medicine and Canadian Org. Med. Physicists (AAMP/COMP), Vancouver, Canada, WE-G-301-4, Aug. 2011.

[3] N. Masuda, M. Yoshida, Y. Fujishita, K. Okamoto, A. Kanno and N. Sekine, "Development of 0.1/0.3 THz-band power modules," IEICE Tech. Rep. to be published in Japanese (2015).

[4] A. Kanno, S. Honda, R. Yamanaka, H. Sotobayashi, and T. Kawanishi, "Ultrafast and broadband frequency chirp signal generation using a high-extinction-ratio optical modulator," Opt. Lett., vol. 35, no. 24, pp. 4160–4162 (2010).

[5] V. M. Muravev and I. V. Kukushkin, "Plasmonic detector/spectrometer of subterahertz radiation based on two-dimensional electron system with embedded defect," Appl. Phys. Lett., vol. 100, 082102-1–3 (2012).

[6] A. Kanno and T. Kawanishi, "Broadband frequency-modulated continuous-wave signal generation by optical modulation technique," J. Lightw. Technol., vol. 32, no. 20, pp. 3566–3572 (2014).