論文の内容の要旨

Impedance-controlled Bulk Linearly Tapered Slot Antenna for Millimeter-wave Security Imaging

（ミリ波セキュリティ・イメージングのためのインピーダンス制御バルク直線テーパスロットアンテナ）

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Abstract

The current situation of terrorism rises up the security issue in public places such as train station, airport and so on. Millimeter-wave (MMW) imaging is one of the solutions to screen the harzardous objects like liquid bombs under clothes of passengers. MMW imaging has merits in scanning human body since it is harmless to human cells compared to conventional X-ray imaging system. The operation of MMW imaging system is classified into two categories, passive and active modes. It is true that the passive mode requires no MMW source to illuminate objects whereas the active mode does. However, the active mode has a higher sensitivity and contrast. An MMW imaging system uses single or array of MMW antennas to transmit and receive MMW signal. Its key element is the MMW antennas.

In this dissertation, we propose a novel MMW antenna, called bulk linearly tapered slot antenna (Bulk LTSA) of which impedance is controllable by changing on its metallic fin thickness suitable for the active MMW security imaging system under consideration. Utilizing the impedance controllability of the bulk LTSA, we can realize the direct connection between the antenna and the following circuit by choosing the suitable fin thickness. We prefer to connect the antenna directly to the detection circuit without any impedance matching circuit because the matching circuit is complicated and lossy in high frequency band. We use the bulk LTSA with an envelope detector in the front-end of the MMW imaging system.

The contents of this dissertation are arranged as follows: Chapter 1 introduces the backgrounds of MMW imaging. We aim to fabricate an active MMW imaging system that scans the passengers using quick acquisition at the Shinkansen ticket gate. Our active MMW imaging system is called Envelope phase detection (EPD) system which illuminates the target with

amplitude modulated (AM) wave and extract its envelope. By processing the envelope signal in much lower frequency band, the system cost is drastically reduced.

Chapter 2 discusses the proposed bulk LTSA and its application in low-loss MMW EPD front-end. We analyze the impedance controllability numerically. We find that its impedance depends on not only the fin thickness but also the feeding gap size as we fix other design parameters. Due to the limitation of fabrication machine, the smallest gap size is 0.2 mm. We decide to fabricate the bulk LTSA with 1 mm fin thickness to connect it directly to 50 Ω detection circuit. In addition, the antenna with matched thickness has ultra-wideband characteristic over 20-110 GHz. We perform the experiment to compare the detected power from the bulk LTSAs with matched thickness (1mm) and conventional thickness (60 μm) to confirm our impedance analysis. The results indicate that the detected power from 1mm-thick bulk LTSA has 22 dB higher than that from conventional one. This result convinces us that the impedance of 1 mm-thick bulk LTSA is much closer to 50 Ω than the 60 μm–thick case. We measure power dependence on angle to plot the radiation patterns. The measured patterns agree well with the calculated ones. Bulk LTSA has high directivity with half power beamwidth (HPBW) smaller than 30 degree.

Chapter 3 analyzes the direct coupling which is the major issue in the array of 1mm-thick bulk LTSAs formed to realize quick acquisition in imaging. Two array configurations, coplanar and stacked, are considered. Our analysis shows that the direct coupling in both models is very low, less than -20 dB in stacked and less than -30 dB in coplanar, due to the high directivity of antenna pattern. We also measure the detected power in array environment. The experimental results show that there is less influence of coupling on the detected power in coplanar array even for an element spacing of 1 mm. This fact suggests that we can configure low coupling coplanar array of bulk LTSAs to realize high-density acquisition.

Chapter 4 focuses on the performance of our active MMW imaging system. To solve glaring and speckle noise in an active MMW imaging, we propose complex-valued self-organizing map (CSOM) using complex inner product to classify the object from the surroundings. We test this classification scheme on Polyethylene (PET) bottle filled with water which is assumed as liquid bomb in two situations, mechanical scanning with single Tx/Rx and quick acquisition with array of bulk LTSAs. In the first case, after processing by CSOM, the target object is represented with single cluster instead of three as in conventional Eucledian metric. Furthermore, the target object is clearly distinguished from the surroundings with low glaring and speckle noise. CSOM using complex inner product is proved to be more effective to identify the object than the conventional CSOM. As for the second case, we replace single Rx with the array of eight MMW EPD front-ends. We illuminate the target with AM wave and extract the envelope of the scattering wave simultaneously. By using the array of the front-ends, we can extremely shorten scanning time.

Chapter 5 proposes the microstrip-to-slot transition with two via holes for feeding the bulk LTSA. This balun structure enables the bulk LTSA to work as the ultra-wideband transmitter with a fractional bandwidth (FB) of 0.4. We demonstrate that the structure with two suitable via-hole positions can improve FB as compared to the structures with one via-hole. We optimize its reflection characteristic by adjusting the microstrip-line width. We find that a structure with the line width larger than 2.8 mm has ultra-wideband characteristic.

Chapter 6 summarizes all the details concerning to the proposed bulk LTSA for an active MMW imaging. Achievement of this dissertation will provide benefit as a guideline for the design of the antenna applied for active MMW imaging systems.