Antenna coupled bolometer simulation for terahertz radiation detection diffracted by a small metal object

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Abstract. Terahertz (THz) wave technologies are becoming near future wireless technologies because of its advantages of considerable bandwidth and still unlicensed spectrum. Its small bandwidth offers a more compact wireless device on a scale of micrometers. Detection is a challenge for applying these potential technologies. An antenna coupled with a bolometer device is a candidate to capture emitted THz wave radiation. Another consideration can be any possible obstacles. This paper presents a simulation of Terahertz wave radiation detected with a dipole antenna connected to a bolometer. This research uses a 3D simulation software of CST Microwave Studio to simulate linearly THz plane waves radiation passing through a small metal object. Some dipole antennas coupled bolometer detect the power of the plane wave radiation in location after the emitted plane waves hit the object. The result shows that the highest detected power can be detected. Even the detector is located at the center of the area blocked by the metal object. This condition indicates that diffraction is high enough, affected by the comparable size, the metal, wavelength, and observation distances. More studies to characterize this diffraction effect are becoming useful, especially for THz imaging applications, such as metal detection for an airport security system.

1. Introduction
Terahertz (THz) wave technologies are becoming near future wireless technologies because of its advantages of considerable bandwidth and still unlicensed spectrum. The THz wave is a spectrum of electromagnetic waves within a frequency range of 0.1 – 10 THz [1]. In the past, the development of THz technologies was not as quite updated as it is today due to lack of sources and detectors that work either effectively and sensitively within the frequency spectrum [2] [3]. Nowadays, research and development of THz wave technologies have been in various applications, such as security [4] [5] [6], pharmacy [7], nondestructive testing (NDT) [8] [9], and the health industry [10]. Generally speaking of security, it is obviously an important matter that needs to be considered, especially in the aviation world [4]. It has been becoming more popular that people choose air transportation as one of the options for traveling, doing business, in and outside the country. During the development of air transportation, events and tragedies over past decades have demonstrated the need for more effective security screening and contraband detection against an increasing number of threats and substances [4].

Various technologies have been available to do security screening. The main purpose is detecting and imaging the presence of any threats, such as weapons, explosives, drugs and any other illegal items. The two most likely common to be applied in airports as security systems are X-ray backscatter technology and millimeter-wave technology.
X-ray backscatter technology for the airport security system is different from the medical x-ray imaging system. To be exact, it generates a wave with a length of approximately 100 picometers and radiation of 0.02 – 0.03 microsieverts. Although the number of radiation is small enough, the type of radiation is ionizing, which can threaten human healthcare, especially for frequent flyers, such as pilot and flight attendant [11][12]. The imaging result of this technology happens to be very accurate because it uses high frequency, very accurate as it can image the naked human body in the system that might bring up some privacy issues to the society [4].

Millimeter-wave technology generates electromagnetic waves in a range of 0.1 – 1 millimeter. These wavelengths are longer than the X-ray backscatter system. This technology is safer comparing from X-ray backscatter system because this technology produces non ionized radiation. In other aspects, by radiating lower frequency, this technology produces images that are not as accurate as previous technology. As large wavelength diminishes the achievable spatial resolution, this technology requires a small working distance [1].

THz waves technology offers an alternative option to the problems. It generates electromagnetic waves that are longer than the X-ray backscatter system, long enough to penetrate clothing, yet short enough to provide high resolution with modest apertures with very low power [4]. Moreover, the THz frequencies are not affected by dust, fog, and rain [13]. The radiation produced is nonionizing, which is safe for human tissues [14].

In a THz screening system, Figure 1 shows two methods, which are transmission mode and reflection mode, respectively. The main difference between the two methods is the position of the object in the system. On the first method of transmission mode, the object is in between the THz sources and sensors. The system works by generating THz waves in the source and simply propagate the wave into the object. Then the sensor will detect the waves after propagating along within the object. Meanwhile, on another method, reflection mode, the source and the sensors are in the same field with a difference in position and height. This method works by generating THz waves in the source, and then the waves will be radiated to the object. By the reflective effect of the object, the waves will travel backward and be received by the sensor for further processes in the system.

![Figure 1. Illustration of THz Imaging System Implementation with (a) Transmission Mode and (b) Reflection Mode. [6]](image)

This paper discusses a study of THz imaging simulations to image the metal object by the first method. Beside it is simpler to design and observe, this method offers effectiveness for imaging metal with small quantities as the metal dimension used in the simulation [6]. The metal object to be imaged will be in between the source and the detector. Simulations are performed with variations in the type of metal objects, detectors, polarization, and radiated frequency.
2. Diffraction and Simulation Model

2.1. Diffraction

Diffraction is the concept that can be explained by Huygens’s Principle, as the bending of a wave around the edges of an opening or an obstacle. The diffraction that is likely to happen in this THz imaging system is knife-edge diffraction. Knife-edge diffraction is a common problem when there is an object in the propagation path of wave, located in between the transmitter (source) and receiver (detector), where the tip of the object becomes the second source of the wave propagation [15].

![Figure 2. Illustration and Parameter of Knife Edge Diffraction. [15]](image)

Figure 2 shows an illustration of knife-edge diffraction. There are several parameters in knife-edge diffraction that needs consideration. Parameters contained in the knife-edge diffraction model include $x$ (length of the Line of Sight (LOS) Path between Tx and Rx), $\alpha$ (angle between Tx and Rx (in radians)), $h$ (height of measured from the intersection of $x$ with the object to the top of the object), $d_1$ (distance between Tx and object), $d_2$ (distance between an object and Rx), $\theta$ (diffraction angle (in radians)). Values of the received power at Rx when knife-edge diffraction can be calculated by equation (1) – (4). If the value of $v$ is greater than 0.78, we use equation (5) to calculate the value of $J(v)$. Equation (6) is the equation to calculate the received power value in the detector in the shadow region. [16]

\[
x = \sqrt{d_1^2 + d_2^2 - 2d_1d_2\cos(\pi - \theta)} \quad (1)
\]

\[
\alpha = \cos^{-1}\left(\frac{d_1^2 + x^2 - d_2^2}{2xd_1}\right) \quad (2)
\]

\[
h = d_1 \tan \alpha \quad (3)
\]

\[
v = h \sqrt{\frac{2}{\lambda} \left(\frac{1}{d_1} + \frac{1}{d_2}\right)} \quad (4)
\]

\[
J(v) = 6,9 + 20 \log(\sqrt{v - 0,1}^2 + 1 + v - 0,1) \quad dB \quad (5)
\]

\[
\text{Received Power (dB)} = -25,9176 - J(v) \quad (dB) \quad (6)
\]
This research is doing simulations of some conditions by using Computer Simulation Technology (CST) Studio Suite software. Those simulations consider a plane wave port to generate plane wave radiation as the source of THz waves radiation. The plane wave amplitude is 1 V/m. The detector is using antenna coupled bolometer. Antenna coupled bolometer has been proven by research to have an advantage in absorbing THz power [17].

2.2. Simulation Model
Figure 3 shows a simulation scenario that consists of 4 sections, which are a simulation of a circular metal object with only bolometers, a simulation of a circular metal object with an antenna coupled bolometer, a simulation of a rectangular metal object with the only bolometer, and simulation of a rectangular metal object with antenna coupled bolometer. The choice of metal used in the simulation is considered to represent metal coin and block, and also for comparison for the resulting images obtained at the simulations.

Plane-wave as the source of radiated frequency located on the left side in the image, marked by green point. A detector is on the right side in the image, marked as five dots in the picture. The metal object is in between the plane wave and detector, marked in yellow.

Each scenario considers a variety of plane wave polarization and radiated frequency. The plane wave polarization are varied into Ex-polarization (Co-Polarization) and Ey-Polarization (Cross Polarization). Meanwhile, the radiated frequency are varied into 0.5 THz, 0.75 THz, and 1 THz. The objective of the following simulations is to observe the correlation in THz imaging between metal shapes and detector type affected by polarization type and radiated frequency.

![Figure 3. Side view of the THz imaging simulation.](image)

Figure 4 shows the structure of an antenna coupled bolometer. The considered antenna in this research is a bowtie type antenna due to its simplicity and wide bandwidth [18] [19]. The material of the antenna is gold, which has good conductivity. A bolometer is in a gap between two parts of the bowtie antenna. This bolometer has a function to observe energy captured and transferred from the antenna. The considered bolometer material is a lossy metal with a resistivity of $8.75 \times 10^{-6} \, \Omega\text{m}$. One element of the antenna coupled bolometer has dimensions of length, width, and thickness of 99 μm, 26.5 μm, and 1 μm, respectively. The antenna has linear horizontal polarization.

The antenna coupled bolometer as a detector is multiplied into 25 elements independently and organized into a configuration of 5x5 elements, as shown in Figure 5. The detector is at a distance of 4000 μm from the metal object. Every element of this configuration means every detected point or pixel of an imaging sensor.
2.2.1. Circular Metal Object with Only Bolometers Detector.

There is a targeted object of a copper-annealed metal placed between the plane wave and detector. The metal object has 50 μm thickness varied into a rectangular shape and circular shape. The shadow of the metal object is the basis to produce the image.

Figure 6 shows a simulation scenario using a circular shape metal object with radius and thickness are 150 μm and 50 μm, respectively. The detector is using 25 elements of bolometers, organized into a 5x5 array configuration. By only considering the bolometer structure without connected to the antenna, this simulation scenario will be useful for basic comparison for the next scenarios after considering the antenna coupled bolometer structure for detecting the incoming radiation. Figure 6 (b) shows the front view simulation with only a bolometer detector organized into a 5x5 array configuration, a plane wave, and a circular metal object placed between the plane wave and detector.

2.2.2. Circular Metal Object with Antenna Coupled Bolometer Detector.

Figure 7 shows a side view and front view simulation scenario of a circular metal object with antenna coupled bolometer detectors. This simulation is using a circular metal object and an antenna coupled bolometer as a detector. The detector has 25 elements of the antenna coupled bolometer, organized into a 5x5 array configuration. Figure 7 (a) shows the side view of the simulation with an antenna coupled bolometer. A circular metal object is placed in between the plane wave and detector with a distance of 4000 μm from the detector.
Figure 7. (a) Side view and (b) front view simulation scenario of a circular metal object with antenna coupled bolometer detector

2.2.3. Rectangular Metal object with Only Bolometers Detector.
Figure 8 shows the side view and front view of the simulation scenario of a rectangular metal object with only bolometers. The rectangular metal object has dimensions of length, width, and thickness of 300 μm, 300 μm, and 50 μm, respectively. The detector is using 25 elements of the bolometer, organized into a 5x5 configuration. Figure 8 (a) shows a side view of a simulation with only a bolometer detector. A rectangular metal object is marked as yellow square placed 4000 μm away from the bolometers as a detector.

Figure 8. (a) Side view and (b) front view of simulation scenario of a rectangular metal object with only bolometer detector.

2.2.4. Rectangular Metal Object with Antenna Coupled Bolometer Detector.
Figure 9 shows the side view, and front view simulation scenario of a rectangular metal object with antenna coupled bolometer detectors. The targeted object is a rectangular metal object and antenna coupled bolometer as a detector. As previous simulations, the antenna coupled bolometer is in a 5x5 configuration. Figure 9 (b) shows a front view of the simulation with an antenna coupled bolometer. A rectangular metal object is placed 4000 μm away from the detector and in the center position as the previous simulation.
3. Results and Discussion

Figure 10 shows the simulation result for the first two scenarios of a circular metal object, detector with only bolometer and detector with antenna coupled bolometer. The images are coming from the intensity of absorbed power by every bolometer. Figure 10 (a) shows the Ex-polarization is likely more representing the circular metal as the object. Simulations with radiated frequency variation show as the radiated frequency increases, clearer image will be produced in this THz imaging system. This condition can occur because the greater the radiated frequency used, the system will have a higher spatial resolution, which will produce clearer images [1] [6].

Figure 10 (b) shows Ex polarization has more representing results to object comparing with Ey polarization. Increasing radiated frequency also results in the production of clearer images in these simulations. Compared to Figure 10 (a), the imaging results in Figure 10 (b) are more likely to represent the circular metal object imaged in the system both in Ex polarization and Ey polarization. This situation likely happened because of the ability of the antenna to absorb THz wave and transfer to the bolometer [17]. This antenna ability affects the system to produce more representing images to the circular metal object.
Table 10. Images simulation results of a circular metal object (a) only bolometer without antenna and (b) bolometer connected to the antenna.

Figure 10. Images simulation results of a circular metal object (a) only bolometer without antenna and (b) bolometer connected to the antenna.

Figure 11 shows simulation results for the last two scenarios of a rectangular metal object, detector with only bolometer and detector with antenna coupled bolometer. The images are also coming from the intensity of absorbed power by every bolometer. Figure 11 (a) with Ex polarization tends to be more representing the rectangular metal object compared to Ey polarization.

In Ex polarization, the electric field movement direction is parallel to the antenna coupled bolometer electric field movement direction (Co-Polarization). Ey polarization has an orthogonal direction of electric field movement towards the antenna coupled bolometer electric field movement (Cross Polarization) direction. In other words, simulations using Ex polarization will produce more representing images of the metal object due to the parallel electric field movement direction of the source and detector makes the detector can absorb the maximum value of power [20].

Table 11. Images simulation results for the last two scenarios of a rectangular metal object, detector with only bolometer and detector with antenna coupled bolometer.
Table 1. Images simulation results of a rectangular metal object (a) only bolometer without antenna and (b) bolometer connected to the antenna.

| THz | Ex | Ey |
|-----|----|----|
| 0.5 | ![Image](Ex_0.5.png) | ![Image](Ey_0.5.png) |
| 0.75 | ![Image](Ex_0.75.png) | ![Image](Ey_0.75.png) |
| 1 | ![Image](Ex_1.png) | ![Image](Ey_1.png) |

**Figure 11.** Images simulation results of a rectangular metal object (a) only bolometer without antenna and (b) bolometer connected to the antenna.

Figure 11 (b) has the results of rectangular metal object simulation with bolometer connected to the antenna. Images are quite representing the rectangular metal object, more representing the object as the radiated frequency increases. Compared to Figure 11 (a), the results in Figure 11 (b) are more representing the rectangular metal objects when viewed from both polarization and radiated frequency variations. As the previous simulation, these results show the ability of the antenna to absorb the THz waves and transfer them to bolometers so the system will produce more representing images to the metal object [17].

Figure 10 and Figure 11 represent a comparison between 4 scenarios. Metal existence in the system is indicated by the intensity of absorbed power of every bolometer, which marked by the yellow color in images. The yellow color in the figures represents the value of absorbed power contained in the bolometer is highest compared to other colors. This condition is not following the concept where the absorbed power value absorbed in the bolometer should indicate the minimum value. When the THz waves irradiated into the target, the metal object should have reflected the wave that hits the object [6]. Consequently, detectors located behind the object should get the minimum value of absorbed power due to the reflection effect carried out by metal. Contrarily, the value of absorbed power located behind the object shows the maximum value. It turned out the THz waves that hit the tip/edge of the object will be deflected and bent to the region behind the object (shadowed region), as the diffraction concept mentioned before [15]. Waves that are deflected and bent into the shadowed region at one point will overlap and strengthen one another. Resulting in bolometers located behind the object absorbs maximum power compared to the other places. Based on equation (4) – (6), absorbed power due to the diffraction effect is influenced by distance parameters. This condition makes distance observation needed for more consideration when practicing the THz imaging system.

**4. Conclusion**

This paper has discussed the simulation results of four scenarios, with variations in metal shape, detector, radiated frequency, and polarization. As result, the diffraction effect occurs in most of the scenarios in the simulation system. The diffraction effect in this THz imaging simulation system can be measured and analyzed with the concept of knife-edge diffraction. However, imaging metal objects in THz waves still applicable with consideration of metal shape, polarization, radiated frequency...
wavelength, and detector observation distance. In this study, the implementation of an antenna coupled bolometer as detector proves the production of clearer images due to its absorbing power ability and sensitivity.

5. References

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