*proceedings*

*Abstract*

# Proposal for a Compact Reflective Measurement System for Corrosion Detection Using Sub-Terahertz Waves †

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**Abstract:** Many of Japan's infrastructures are more than 50 years old after construction, and their aging is expected to accelerate in the future. Therefore, the challenge is to inspect the deteriorated condition of those infrastructures. This study focuses on the use of electromagnetic waves in NDT as an inspection method for infrastructure. One issue with this method is that the device is not suitable for actual infrastructure inspections. We constructed a portable reflection measurement system that utilizes sub-terahertz waves among electromagnetic waves. Reflection measurements were conducted on corroded and uncorroded steel plates using this compact system. It may be possible to identify samples using peak shift with a horn antenna. With a probe antenna, identification is based on reflectance.

**Keywords:** sub-terahertz waves; corrosion detection; compact system; NDT

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## 1. Introduction

In the future, much of Japan's infrastructure is more than 50 years old after construction. For example, there are approximately 730,000 road bridges in Japan, and by March 2040, about 75% of them are expected to be 50 years old [1]. Thus, an efficient assessment of the deteriorating condition of aging infrastructure is a challenge. The study focused on steel bridges among the infrastructure. In Japan, steel bridges account for about 38% of all bridges over 15 m in length. The establishment of an efficient and low-cost deterioration diagnosis method for steel bridges is important from the perspective of infrastructure management.

There are various NDT methods such as visual inspection, ultrasonic testing, magnetic particle testing, and radiography testing[2]. We focused on a method that utilizes electromagnetic waves. Microwaves can easily transmit dielectric materials, and terahertz waves can easily identify the material being measured. In the microwave band, there are studies such as mapping corrosion under coatings using probes, detecting defects in steel under coatings using waveguides, and evaluating corrosion of steel in concrete[3-5]. In the terahertz waveband, there are studies on the evaluation of corrosion products using THz-TDS, measurement of corrosion thickness, and changes in response depending on the grade of corrosion[6-8]. However, these methods have not yet been established as measurements that can be applied to infrastructure inspections, and there are issues with the portability of the device when applying them in the field.

Sub-terahertz waves are in the frequency band between microwaves and terahertz waves and are thought to have the advantages of both. In addition, small, low-cost sub-terahertz wave oscillators have already been developed. For in situ measurement applications, we aimed to build a portable optical system by performing only reflection measurements and reducing the amount of data collected.

## 2. Materials and Methods

### *2.1. Testing Sample*

Table 1 summarizes the sample. There are three types of steel plates: steel plates without surface processing, steel plates with sandblasted surfaces, and steel plates with sandblasted and corroded surfaces. Corrosion was produced by 6 cycles of 4 hours in a wet environment at 50°C and 98% humidity and 4 hours in a dry environment at 50°C and 0% humidity. In the wet environment, corrosion was accelerated by spraying salt water with a NaCl concentration of 5 wt%. This simulates a coastal environment that is constantly exposed to salt water.

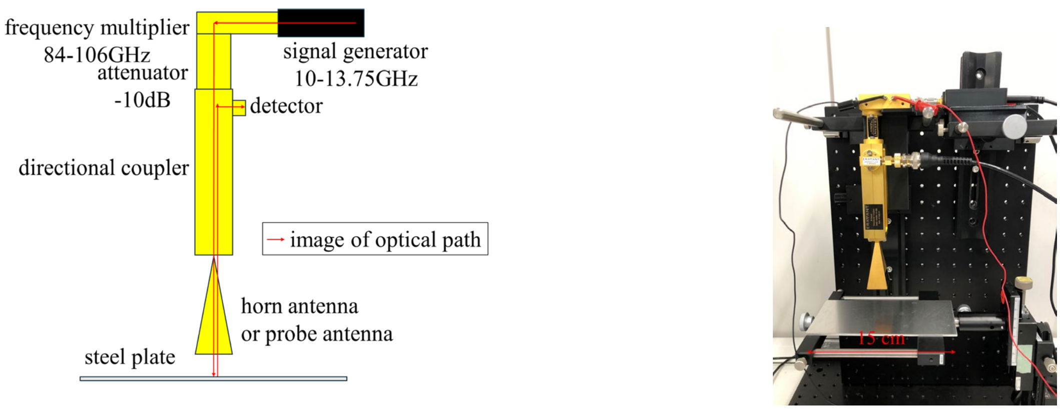
**Table 1.** Three types of steel plates sample are as follows.

| | **Sample 1 (Steel)** [1] | **Sample 2 (Sandblast)** | **Sample 3 (Corrosion)** |
|---|---|---|---|
| Surface | - | sandblast | sandblast |
| Corrosion | no | no | yes |
| Images |  |  |  |

[1] In this study, sample 1 is referred to as steel, sample 2 as sandblast, and sample 3 as corrosion.

### *2.2. Measurment System*

Figure 1(a) shows a schematic diagram of the measurement system, and (b) shows an image of the actual system. The signal generated from the signal generator is multiplied by a multiplier by 8. The signal passes through a directional coupler and is radiated from the antenna into free space. The radiated signal is reflected on the surface of the steel plate, returned to the coupler, and detected by the detector. Collect only the voltage obtained by the detector. An attenuator is used to increase measurement stability. In the field of signal processing, directional couplers are used to measure reflected power. We considered that it could be applied to material evaluation.




(**a**) (**b**)

**Figure 1.** (a) Schematic diagram of measurement system.;(b) photography of real systems.

### 2.3. Experiments

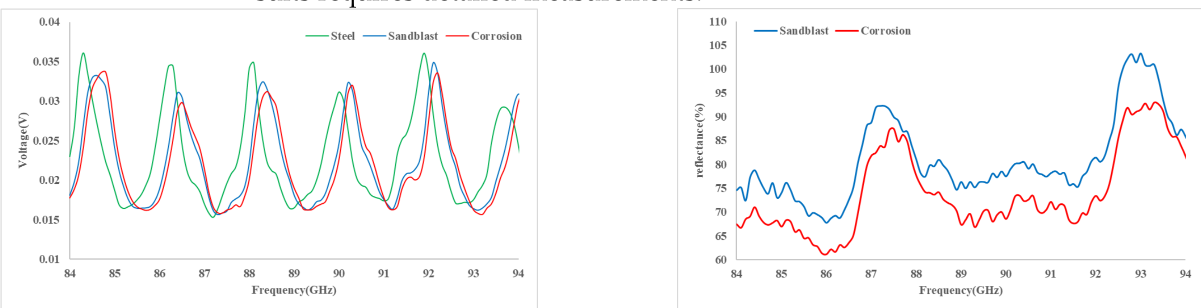
Reflection measurements were conducted on three types of steel plates. The measurement frequency range is 84-106 GHz in 0.1 GHz steps. A horn antenna was used to inspect large areas, and a probe antenna was used to see if corrosion could be identified. When a horn antenna is used, the distance from the antenna to the sample was 30 mm. When a probe antenna is used, the distance from the antenna to the sample was 3 mm. Measurements were conducted in the order of sandblast, steel, and corrosion. To ensure reproducibility, each experiment was conducted three times.

## 3. Results and Discussion

Figure 2(a) shows the three times average raw data measured with a horn antenna. The vertical axis represents voltage, and the horizontal axis represents frequency in the range of 84-94 GHz. We omitted frequencies above 94 GHz because the voltage decreased at those frequencies. Compared to sandblast and corrosion, steel shifts the local maximum. This is an interference peak, and it is related to changes in the optical path length because of sandblast processing. The peaks at the lowest frequencies in the measurement range are 84.3 GHz for steel and 84.6 GHz for sandblast. The peak of corrosion is almost 0.1 GHz (1 step) offset compared to sandblast. The results suggest that the surface properties of the steel plate have a major influence more than corrosion.

Figure 2(b) shows the reflectance of sandblast and corrosion with reference to the steel data. Frequency range is 84-94 GHz. In this frequency range, the reflectance of corrosion is approximately 6.9% lower than sandblast. Probe antennas are better than horn antennas at detecting differences between three types of samples.

Both measurement results are summarized in Table 2. In the horn antenna measurement, we confirmed a peak shift between sandblast and corrosion compared to steel. Since the measurement step is 0.1 GHz, it is unclear whether there is a significant difference between sandblast and corrosion. Measurements with the probe antenna detected differences in reflectance between sandblast and corrosion. Verification of the results requires detailed measurements.




(**a**) (**b**)

**Figure 2.** (**a**) Average of three raw data when using a horn antenna at 84-94 GHz; (**b**) Reflectance averaged from three measurements when using a probe antenna at 84-94 GHz.

**Table 2.** Summary of measurement results.

| Sample | Average Peak Shift (Measured by a horn antenna) [1] | Average Reflectance (Measured by a probe antenna) [2] |
|---|---|---|
| Sandblast | 0.21 GHz | 81.0% |
| Corrosion | 0.32 GHz | 74.1% |

[1] Average deviation of major local maxima compared to steel. Only those considered to be caused by interference. Corresponding to Figure 2(a). Frequency range is 84-94 GHz.

[2] Average reflectance at 84-94 GHz. Corresponding to Figure 2(b).

## 4. Conclusions

The conclusions in this study are as follows:

- A reflection measurement system using sub-terahertz waves was constructed. Reflected waves can be measured with this measurement system.
- The results of the horn antenna suggest that they may be more sensitive to surface conditions than corrosion. The probe antenna may be effective at detecting corrosion, but verification of the results is insufficient.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| NDT | Nondestructive testing |

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