25PD2

Theory of lidar using Modulation Interference Radar (MIR) and its fundamental experiments using super sonic waves.

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Abstract

Volcanic disasters caused by some injurious volcanic gases or aviation accidents caused by very fine ash cloud are important problems which one should not ignore. In order to solve such volcanic disasters, it is very important to estimate the components and the flow rates of eruptional materials. Furthermore, for the application of volcanic steam to power generation, it is also very important to estimate the flow rates and components of volcanic gases. However, it is very difficult to measure directly the total output of volcanic gases. So, the measurement techniques for the volcanic gas are demanded. If we can do it by the remote sensing method, we can contribute to such problems very much. The lidar (Light Detection And Ranging) technique is considered to be one of the effective methods for these purposes. Lidar is a kind of the radar system using laser as the carrier wave, of where which wave length is very short. Then it can detect very fine particles in the volcanic ash cloud and also can measure density of volcanic gas using the spectrum.

Such lidar has been used for observation of the atmosphere in environment. If we use it for the volcanic gas observation, however, some kinds of problems will be caused. The volcanic gas or ash is discharged from the narrow volcanic centers, so the density and the opacity of volcanic gases are very large. So the lidar needs very high distance resolution and wide dynamic range to apply volcanic gas observation. Furthermore, for the ash cloud detection, the lidar will need higher S/N ratio and resolution to detect it with enough accuracy. To solve these problems, we suppose the MIR method and analyzed basic characteristics of it and conducted fundamental experiments using super sonic waves. As a result, we obtained an interference wave with the expected frequency.

Principle of the MIR method

The principle of the MIR method is similar to the Fourier spectrometer using the Michelson interference meter. The Fourier spectrometer changes its phase. However, the MIR changes its modulation frequency. The relation of principle between MIR and the Fourier spectrometer is opposite on equations. So, the MIR method can be called the Fourier phase separate meter. The MIR system is shown in Fig.1..

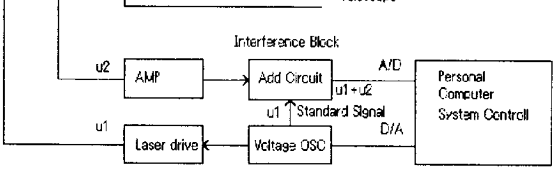

Fig.1 MIR system

MIR uses phase differences between a standard signal and reflection signals from targets. In Fig.1, we set the modulation frequency to f and the amplitude of standard signal to a_1. Standard signal u_1 is shown as equation (1).

$$u_1=a_1\cos(2\pi ft). \tag{1}$$

Here, we treat one reflection wave to simplify the treatment. The reflection signal u_2 is shown as equation (2).

$$u_2=a_2\cos\{2\pi f(t-\frac{2x}{c})\}. \tag{2}$$

In equation (2), a_2 is the amplitude of reflection signal and c is the velocity of light. Reflection and standard signals are mixed at the mixer and the power of the interference wave $P(f)$ is obtained as equation (3).

$$P(f)=a_1^2+a_2^2+2a_1a_2\cos\{2\pi f\frac{2x}{c}\}. \tag{3}$$

The DC components of equation (3) are not necessary here, so they are removed and the following MIR basic equation as equation (4) is obtained.

$$P(f)=a_1a_2\cos(2\pi f\frac{2x}{c}). \tag{4}$$

Equation (4) is supposed for a reflection wave. Real reflection consists of many reflection waves. Then we introduced the distribution of the reflected waves as $R(2x)$. Accordingly $P(f)$ is shown as equation (5).

$$P(f)=\int_0^{\infty}a_1R(2x)\cos(4\pi f\frac{x}{c})dx. \tag{5}$$

The distribution of reflection $R(2x)$ is obtained by Fourier transformation of equation (5) and is shown as equation (6).

$$R(2x)=\int_0^{\infty}P(f)\cos(4\pi f\frac{x}{c})df. \tag{6}$$

Here, to simplify the equation, we set a_1 to unity.

Laboratory measurement is started from the modulation frequency F_1 to the end of the modulation frequency F_2. So, the measurement reflection $R'(2x)$ is shown as equations (7) and (8).

$$R'(2x)=\int_{-\infty}^{\infty}R(2x)\,sinc4\pi F(\frac{x-\xi}{c})d\xi. \tag{7}$$

Here, the band width of the modulation frequency is defined as $F(=F_2-F_1)$.

$$R'(2x)=\int_{F_1}^{F_2} P(f)\cos(4\pi f\frac{x}{c})df. \tag{8}$$

From equation (8), the measured reflection *R'(2x)* consists of convolution relationship between the real reflection *R(2x)* and sinc function with band width *F*. So, the distance resolution *RES* of the measured reflection *R'(2x)* is shown as equation(9).

$$RES=\frac{c}{2F}. \tag{9}$$

And the measurement distance *DIS* of MIR is defined as equation (10), where its modulation frequency is *STEP*.

$$DIS=\frac{c}{2STEP}. \tag{10}$$

Characteristics of MIR

MIR has some useful characteristics comparing with the conventional pulse radar system. Such characteristics can be shown as bellow.

1. High distance resolution and high S/N ratio.
2. High accuracy.
3. Large output power of radar signal and small-sized system.
4. Frequency uniformity and good feed-back control.
5. Stacking advantage.

These characteristics of MIR mainly come from its free feature of response time. The conventional pulse radar can be called as the time domain radar and it measures its transient response. The MIR system, however, can be called as the frequency domain radar and it is free from response time. The relation of the MIR method and to the conventional pulse radar method are similar to the relationship the prism spectrometer and the Fourier spectrometer.

MIR fundamental experiment using super sonic wave

In order to confirm the effectiveness of this theory, we conducted fundamental experiments using super sonic wave. The reason why we chose super sonic waves is that the velocity of sonic wave is much slower than that of light. So, it is easier for laboratory experiments. The experiment system is shown in Fig.2..

In the system, the super sonic wave of 40kHz is modulated by the standard signal which is offered by the local oscillator. The transmitted wave is reflected by a target and is detected by the super sonic

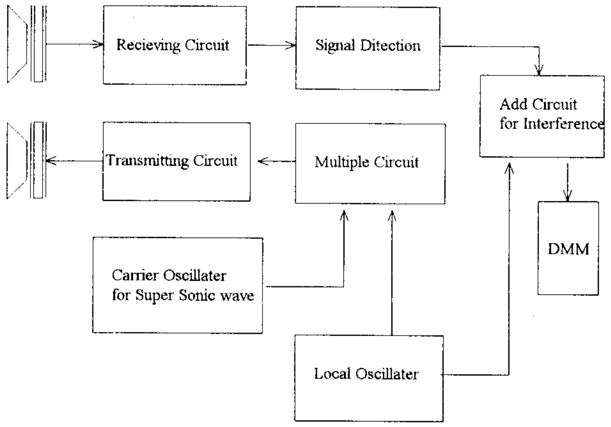

Fig.2 MIR Experiment System

sensor. The reflected signal is amplified and is sent to the add circuit and mixed with the standard signal from the local oscillator. Interference power is measured and each modulation frequency is memorized.

The target is set at 60cm apart. Modulation frequencies are changed from 100Hz to 1000Hz with 20Hz steps. So, the band width of modulation frequency is 1kHz. From equation (9) and (10), the resolution and measurement distance of this MIR radar are 0.17m and 8.5m, respectively. So, the interference frequency will be appeared at 283Hz. The measured interference pattern is shown in Fig.3. The frequency from this experiment is about 260Hz which is nearly equal to the expected one.

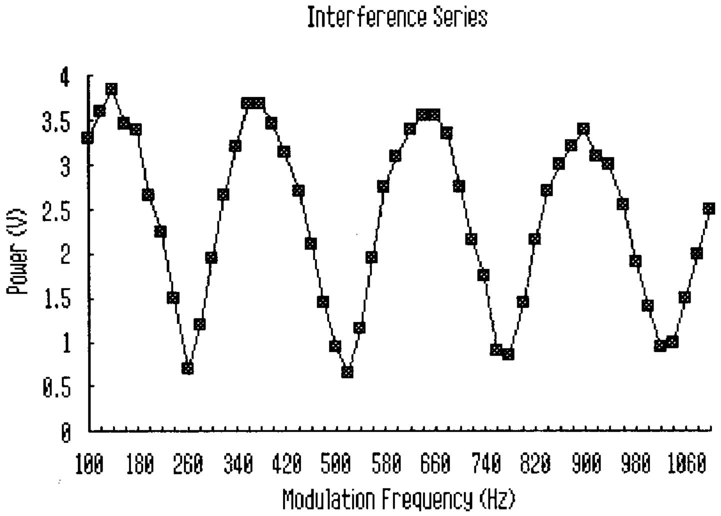

Fig.3 Interference pattern of fundamental experiment

Conclusion.

To apply volcanic gas observation, we supposed the MIR method and conducted fundamental experiments using super sonic wave. From the theoretical aspects, MIR can be defined as the frequency domain radar and it has different characteristics from the conventional pulse radar system. From the experiment, we obtained an interference wave of reflection with the expected frequency. The result shows the effectiveness of the newly supposed radar system.