Progress of A New Microwave Location Monitoring System Using Addressable Active Reflectors

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Abstract — **In this paper, the developmental progress of a new microwave location monitoring system with principles of the system operation is described. The system basically utilizes the principles of an FM radar and a microwave interferometer, but the targets of this radar are active and provide amplification of the incoming signal and change the signal frequencies. Also, each target possesses a switch which can be turned on if a certain target is called by the base unit. This microwave location monitoring system is planned to operate for monitoring land slides reliably even in bad weather conditions and in dusty environments, and can be implemented with low cost.**
Index Terms — **Location monitoring, microwave, FM radar, digital complex demodulation.**

I. INTRODUCTION

In order to protect from potential dangers of land slides in slope regions of a mountain or in construction sites, it is necessary to have a location monitoring system that can be operated reliably even in bad weather conditions or dusty environments. Currently, several location monitoring systems are commercially available in the market by utilizing relative movement of strings, by using laser distance meters or by using GPS receivers. However, currently, none of the available systems meet the requirements of reliability in bad weather conditions and low-cost for applications of actual location monitoring systems in the field.

A laser-based distance meter provides the target distance accuracy of several mm's, but will have difficulties in measuring distances in rainy days, in a dusty environment, or in the presence of minor obstacles − such as bushes, grasses, or artificial structures − in font of the targets. Also, some contaminations of the laser window or a slight dislocation of the target faces will reduce the reliability and accuracy of the system.

Previously, microwave radars were used to measure the distance and speed of the vehicles, which are now mostly replaced with Ladars. These systems are a type of pulse-Doppler radars, which use the time-delay and frequency shift to determine the target distance and speed. In this paper, we propose a new location monitoring system using the principles of a microwave FM radar and interferometer with addressable active reflectors [1]. An FM (frequency-modulated) radar can be used to measure the target distance, where the frequency of the transmitted EM wave is swept and mixed with the reflected wave from the target to generate a beat signal, which is proportional to the target distance. In order to increase the accuracy of the distance measurements, a DSP algorithm called the *digital complex demodulation* technique [2]-[4] is utilized to accurately determine the phase delay of the reflected signal. Also, the system utilizes the interferometer principles to measure accurately the relative movement of the target in mm accuracy.

The characteristics of the proposed location monitoring system is the following: a) addressable multiple targets using active circuit components, b) distance measurement with accuracy of several cm's using the FM radar principle at the ISM band, c) target movement monitoring with accuracy of several mm's using interferometer principles, and d) operating ranges up to a few km's.

In this paper, the configuration of a new microwave location monitoring system utilizing FM radar and microwave interferometer principles is proposed, and the system implementation method is described.

II. THE MICROWAVE LOCATION MONITORING SYSTEM

Figure 1 shows a basic configuration of the microwave location monitoring system in a slope of a mountain, where several targets are planted in order to monitor the movement of the land. The system consists of a *base unit*, which provides the reference location and contains an RF module and a control module, and *addressable active reflectors*, which are located at the target locations for distance monitoring. The base unit emits the frequency-modulated EM signals, and should be able to measure the distance of the each individual target. This can be done by radiating an address code that is modulated on a carrier to the targets before sending the FM radar or interferometer signals, and the reflector corresponding to that address will interact with the base unit.

A. Basic Principles of An FM Radar

The schematic of an FM radar is shown in Fig. 2(a). As shown in the figure, the FM radar sweeps the frequency of the transmitting signal and radiates EM energy toward the target. The target reflects the incident EM wave, and the reflected wave is time-delayed as compared with the reference signal and is collected by the receive antenna. The received signal is then mixed with the reference LO signal at the mixer to produce an IF signal (beat signal), which is proportional to the target distance. This is shown in Fig. 2(b). As the picture shows, the reflected signal from Target 2, which is farther than Target 1, is more time-delayed and produces a higher beat frequency. If the frequency sweep is linear, a simple way of measuring distance is to relate the beat frequency (f_{IF}) to the target distance (R) as

$$f_{IF} = \frac{2R}{c} \cdot \frac{\Delta f}{\Delta t}$$

where Δf is the bandwidth of the swept frequency and Δt is the sweep time. In this case, the beat frequency is higher if the bandwidth of the frequency sweep is broader and/or if the sweep time is shorter. However, if the frequency sweep is not linear, the frequency of the beat signal would vary with time.

In order to determine the beat frequency, a simple method using zero-crossing or FFT can be used. However, to accurately account for the target distance, the beat signal can be digitized and a DSP process called *digital complex demodulation* method can be applied to relate the phase shift of the reflected wave and the target distance. Using the digital complex demodulation, the phase shift can be retrieved accurately within π/10 uncertainty [4].

B. Movement Measurement Using Interferometer Principles

An EM wave at a fixed frequency launched from the base unit will be reflected by a target and radiated back to the base unit. As shown in Fig. 3, there is a phase difference between the reference wave and the reflected wave, which is detected with a phase detector (mixer). By monitoring the phase difference, the relative target movement can be determined with mm accuracy. If the phase difference of 5° can be detected, target movement variations more than ~ 2 mm can be monitored at 2.4 GHz. Since the wavelength of the EM wave at 2.4 GHz is 15.8 cm, the movement more than this wavelength may cause distance ambiguity. However, in combination with the FM radar, the target distance can be accurately determined and monitored.

C. Configuration of the Base Unit

The schematic of the base unit, which is to be installed at the reference point, is shown in Fig. 4. For transmission, the ISM frequency band of 5.725 to 5.850 GHz is used. The transmitted wave from the base unit will be received by the active reflector and re-transmitted after amplifying the received signal and changing the frequency to 2.4 GHz ISM band. In order to measure the distance of a certain target, first, an address code, which is amplitude-modulated at 5.8 GHz, is radiated to the targets. Although all the active targets receive the address data, the target corresponding to the address code will turn on and respond to the transmitted frequency-modulated signal for distance measurements. The received signal at the base unit is mixed with the reference LO signal to produce a beat signal of which the frequency is proportional to the target distance. The IF signal is connected to a digitizer and processed with the digital complex demodulation algorithm to accurately account for the phase delay.

D. Configuration of the Active Reflector

An active reflector is *a transponder with a digital switch*. In order to measure the distance of a certain target, when an EM wave is radiated from the base unit, only one of the targets that matches with the address code should respond. This can be accomplished, in active reflectors, by first detecting a digitally-modulated address and by turning on the amplifier(s) if the address code matches with that of the reflector. The schematic of the active reflector, which can be addressable, is shown in Fig. 5. Also, to maximize the sweep frequency band in order to increase the accuracy of the FM radar and to reduce interactions between the transmit and receive frequencies, the received frequency of the 5.8 GHz band at the active reflector is changed into the 2.4 GHz band. Also, due to the maximum limit of the transmitted power at the base unit for the ISM band (≤ 10 dBm), the received power at the reflector located at 500 m away from the base unit is only about -90 dBm. Since the received power at the reflector is very small, the signal is amplified with ~100 dB of gain before retransmitted.

E. The Operation of the Location Monitoring System

In order to determine the absolute location in the 3-D space (x, y, z), three base units, whose locations are accurately known, are required. The arrangement of the measurement system is shown in Fig. 6. If the distances between the three base units and a reflector are known, the accurate location of the target in (x, y, z) can be calculated.

The base units are required to measure distances of the targets, one by one. This can be performed by first sending a sequential address code to choose a reflector. When a reflector corresponds to the requested address code, the reflector amplifies the received signal and emits back the received power to the base unit. The received power at the base unit is to be mixed with the reference signal producing a beat signal, which is then digitized.

Let's assume that the target is 150 m away from the base unit and the full ISM band of 2.4 to 2.484 MHz is swept in 1 ms. Then the frequency of the beat signal is obtained by the following equation.

$$f_{IF} = \frac{2 \cdot R}{c} \cdot \frac{\Delta f}{\Delta t} = \frac{2 \times 150 \text{ m}}{3 \times 10^8 \text{ m/s}} \cdot \frac{84 \times 10^6 \text{ /s}}{1 \times 10^{-3} \text{ s}} = 84 \text{ kHz}$$

Also, the phase delay can be calculated as

$$\Phi_R = \frac{4\pi \cdot R \cdot \Delta f}{c} = \frac{4\pi \times 150 \text{ m} \cdot 84 \times 10^6 \text{ /s}}{3 \times 10^8 \text{ m/s}} \approx 528 \text{ rad}$$

Therefore, since one fringe corresponds to 2π of phase shift, about 84 fringes occur during 1 ms sweep. In order to have the 5 cm accuracy, the accuracy of phase measurement should be less than $10°$, which can be achievable by applying the digital complex demodulation algorithm.

F. Implementation

Currently, this microwave location monitoring system including the base unit, the active reflector unit, and the control unit is being developed. Figure 7 shows the implemented RF module of the base unit. The microwave components such as a VCO, amplifiers, mixers, and directional couplers are chosen from the commercially available packaged ICs. For the antennas, planar Yagi-Uda antennas are used [5]. Other modules are being assembled, and system tests will be performed to verify the performance of this location monitoring system.

III. CONCLUSION

In this paper, the principles of operation for the new microwave location monitoring system are described. The system utilizes two ISM bands at 2.4 and 5.8 GHz. To determine the distance to a target among multiple targets, an addressable switch is integrated with the active reflector. The target distance can be measured with mm-accuracy by operating the system in combination of an FM radar and a microwave interferometer. Using three base units, the absolute location can be determined. Currently, this system is being developed, and some modules are already assembled and tested. In near future, the complete system performance will be tested.

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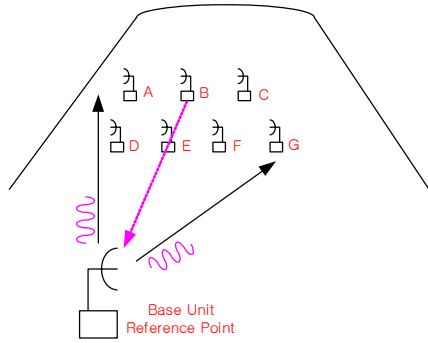
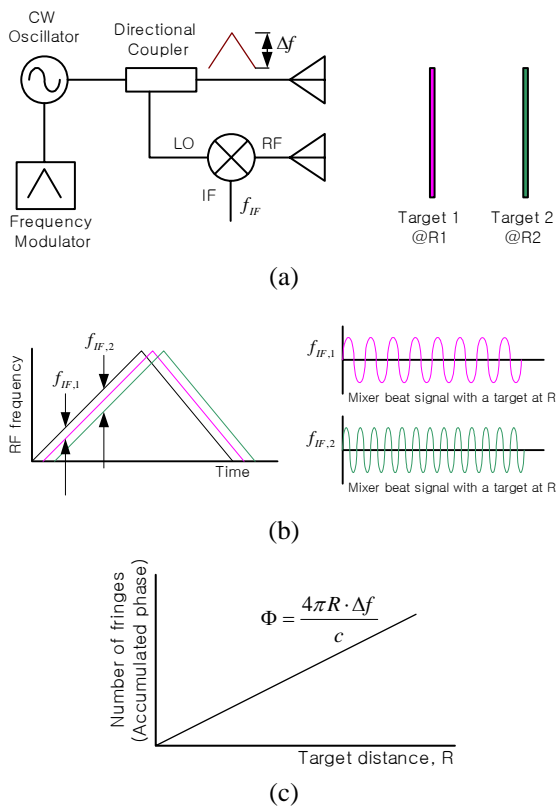Fig. 1. Location monitoring system for targets in a slope of a mountain.

Fig. 4. Schematic of the base unit to be installed at the reference location.

(a)

(b)

$$\Phi = \frac{4\pi R \cdot \Delta f}{c}$$

(c)

Fig. 2. (a) Schematic of an FM radar, (b) the beat signal of the FM radar, and (c) phase shift vs. target distance.

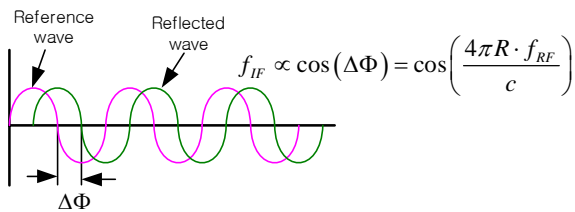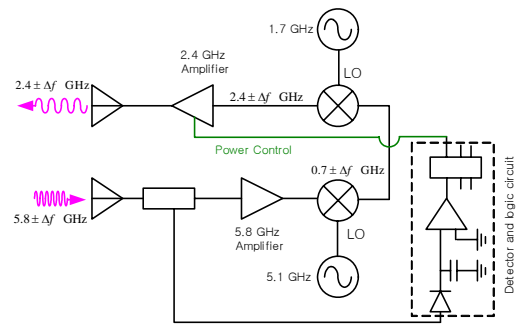Fig. 5. Schematic of the addressable active reflector unit.
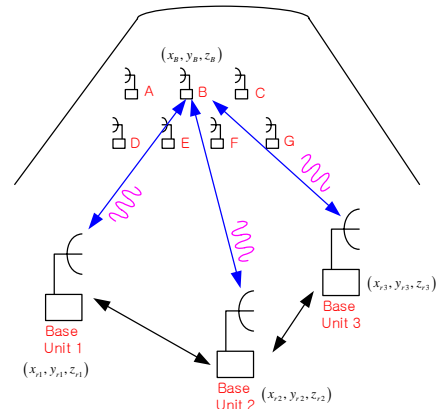
Fig. 6. Schematic for the absolute location measurement.

$$f_{IF} \propto \cos(\Delta\Phi) = \cos\left(\frac{4\pi R \cdot f_{RF}}{c}\right)$$

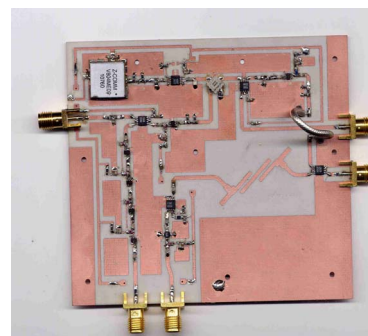Fig. 3. The phase shift generated by the reference wave at the base unit and the reflected wave from the target.

Fig. 7. Prototype of the base unit.