Short Range Radar Utilizing Standing Wave of Microwave or Millimeter Wave

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Abstract

In this paper, we propose a new radar using standing wave, and describe the measurement principle. This radar does not use a time delay like a usual radar but uses the information of phase indirectly by using the standing wave. The frequency range of a signal source determines the minimum detection range, and it is several 10cm when the frequency range is several 100MHz. We experimented for the verification of the measurement principle and showed that this radar can measure actually from short range such as several 10cm.

1 Introduction

In order to prevent a collision between a vehicle and the obstruction such as the pedestrian who inhabits near the vehicle, the implement to detect the obstruction and to measure the distance is demanded. Currently, it is expected that millimeter wave radar, laser radar, CCD camera and so, be used for their purposes.

In conventional microwave or millimeter wave radar [1, 2, 3], a long range is measured easily, but the measurement of the short range such as up to about 10m is difficult extremely. It is hard to use a laser radar in rainy weather, very bright daytime and the like because its performance is degraded. With a CCD camera, although detection of an obstruction is possible, it cannot measure the distance. By using two CCD cameras, the distance can be measured but measuring the long range such as several 10m or more is hard at the reason the parallax becomes very small.

In this paper, we propose a new short range radar utilizing a standing wave of microwave or millimeter wave. It can measure the distance of several 10cm and more. As one of the measurement equipments of distance using standing wave, the displacement sensor using the standing wave on a transmission line [4] is mentioned. The principle of this radar is based on it.

2 Measurement Principle

2.1 The Case of a Single Target

The basic structure of a new radar is shown in Fig.1. This radar measures the distance d to the target utilizing the standing wave which is produced by the reflection at the target. Namely, it does not use a time delay like a usual radar but uses the information of phase indirectly by using the standing wave.

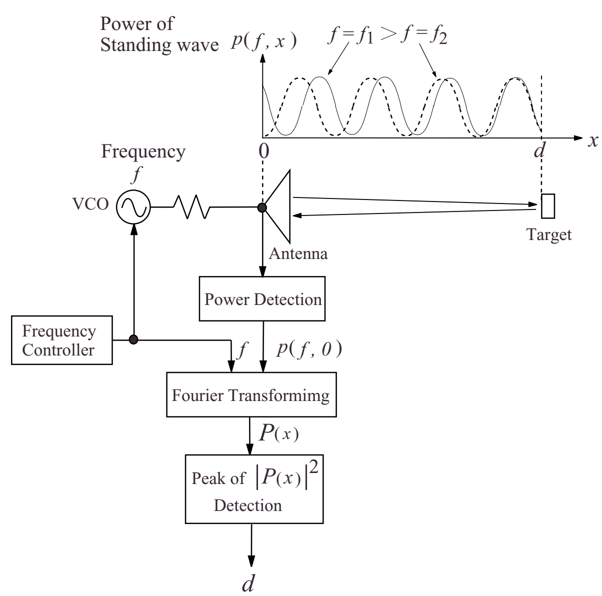

Fig. 1. Short range radar utilizing standing wave

When the transmitted signal by the antenna, i.e., the traveling wave V_T is given by the following,

$$V_T(f,x) = e^{j\frac{2\pi f}{c}x} \tag{1}$$

the wave reflected at the target V_R can be expressed as following.

$$V_R(f,x) = \gamma e^{j\phi} \cdot e^{j\frac{2\pi f}{c}(2d-x)} \tag{2}$$

Where d is the distance to the target, $c = 3 \times 10^8$(m/s), γ and ϕ are the magnitude and the phase of the reflection coefficient at the target. γ includes the propagation loss.

The standing wave is defined by the amplitude of the composite wave of the traveling wave V_T and the reflected wave V_R. Therefore, according to Eq.(1) and Eq.(2), the standing wave $a(f,x)$ is expressed as following.

$$\begin{aligned} a(f,x) &= |V_T(f,x) + V_R(f,x)| \\ &= \left| e^{j\frac{2\pi f}{c}x} \left\{ 1 + \gamma e^{j\left(2\pi\frac{2(d-x)}{c}f+\phi\right)} \right\} \right| \end{aligned} \tag{3}$$

Consequently, the 2nd power of the standing wave, i.e., the power $p(f,x)$ is given by the following expression.

$$\begin{aligned} p(f,x) &= a^2(f,x) \\ &= \left| e^{j\frac{2\pi f}{c}x} \right|^2 \cdot \left| 1 + \gamma e^{j\left(2\pi\frac{2(d-x)}{c}f+\phi\right)} \right|^2 \\ &= 1 + \gamma^2 + 2\gamma\cos\left(2\pi\frac{2(d-x)}{c}f + \phi\right) \end{aligned} \tag{4}$$

$p(f,0)$ is the power of the standing wave in the feeding point of the antenna, and it is shown in Fig.2.

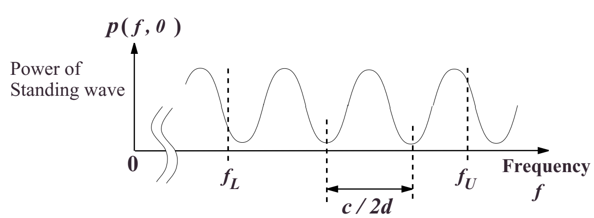

Fig. 2. Power of standing wave in $x = 0$ v.s. frequency f

Eq.(4) and Fig.2 show that $p(f,0)$ is periodic to f, and the period is $c/2d$. Therefore, we can ask for the distance d by Fourier transforming $p(f,0)$ with the formula of Fourier transformation Eq.(5) using $\frac{2x}{c}$ instead of $\frac{\omega}{2\pi}$ and f instead of t.

$$F(\omega) = \int_{-\infty}^{\infty} f(t)e^{-j\omega t}dt \tag{5}$$

Assuming that γ and ϕ are constant, the Fourier transformation of $p(f,0)$, i.e., $P(x)$ is given by the following expression.

$$\begin{aligned} P(x) &= \int_{-\infty}^{+\infty} p(f,0)e^{-j2\pi\frac{2x}{c}f}df \\ &= \frac{c}{2}\Big\{(1+\gamma^2)\delta(x) \\ &\qquad + \gamma e^{j\phi}\delta(x-d) + \gamma e^{-j\phi}\delta(x+d)\Big\} \end{aligned} \tag{6}$$

Eq.(6) shows that the spectrums of $p(f,0)$ exist in $x = 0$, d and $-d$.

Actually, f is restricted to the limited range. Therefore, we use the following expression.

$$P(x) = \int_{f_L}^{f_U} w(f)p(f,0)e^{-j2\pi\frac{2x}{c}f}df \tag{7}$$

Where $w(f)$ is window function.

In order to obtain the period of $p(f,0)$, it is considered that the frequency range equivalent to one or more cycles is required. Thus, the minimum detection range $x_{\min}$ of this radar is determined with $f_U - f_L$, that is,

$$x_{\min} = \frac{c}{2(f_U - f_L)} \tag{8}$$

We consider that the resolution is same or less than $x_{\min}$.

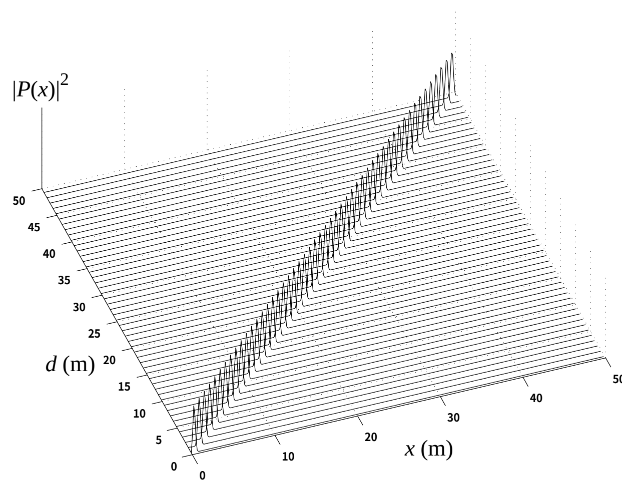

Fig. 3. Calculation of $|P(x)|^2$

In the case of $d = 0.3$m to 50m, the calculating results using Eq.(7) is shown in Fig.3. Where $f_L = 7.5$GHz, $f_U = 8.0$GHz, $\gamma = 0.1$, $\phi = 0$, $w(f)$ is Hamming window, and DC component in $p(f,0)$ is eliminated. Fig.3 shows that the distance d is obtained by detecting x which gives the peak of $|P(x)|^2$.

2.2 The Case of Multiple Targets

The Case of Multiple Targets is shown in Fig.4.

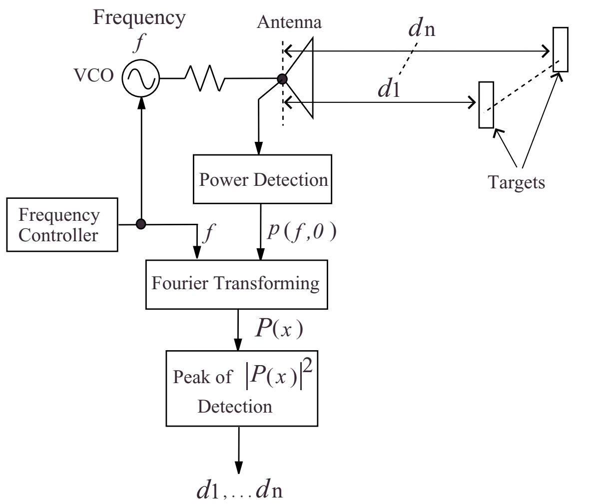

Fig. 4. The Case in which Multiple Targets Exist

When the distance to each target is $d_k (k = 1, 2, \ldots, n)$, each reflected wave V_{Rk} can be expressed as following.

$$V_{Rk}(f,x) = \gamma_k e^{j\phi_k} \cdot e^{j\frac{2\pi f}{c}(2d_k - x)} \tag{9}$$

Where γ_k and ϕ_k are the magnitude and the phase of the reflection coefficient at each target. γ_k includes the propagation loss.

The standing wave $a(f,x)$ is given by the following expression.

$$\begin{aligned} a(f,x) &= \left| V_T(f,x) + \sum_{k=1}^{n} V_{Rk}(f,x) \right| \\ &= \left| e^{j\frac{2\pi f}{c}x} \left\{ 1 + \sum_{k=1}^{n} \gamma_k e^{j\left(2\pi\frac{2(d_k - x)}{c}f + \phi_k\right)} \right\} \right| \end{aligned} \tag{10}$$

$a^2(f,x)$, i.e., $p(f,x)$ is given by the following expression.

$$\begin{aligned} p(f,x) &= \left| e^{j\frac{2\pi f}{c}x} \right|^2 \cdot \left| 1 + \sum_{k=1}^{n} \gamma_k e^{j\left(2\pi\frac{2(d_k - x)}{c}f + \phi_k\right)} \right|^2 \\ &= \left\{ 1 + \sum_{k=1}^{n} \gamma_k \cos\left(2\pi\frac{2(d_k - x)}{c} + \phi_k\right) \right\}^2 \\ &\quad + \left\{ \sum_{k=1}^{n} \gamma_k \sin\left(2\pi\frac{2(d_k - x)}{c} + \phi_k\right) \right\}^2 \end{aligned} \tag{11}$$

In the feeding point of the antenna ($x = 0$), we can assume that $\gamma_k \ll 1$ since it is considered generally that the amplitude of the reflected wave is very small to the traveling wave. Therefore, $p(f,0)$ can be approximated as following.

$$p(f,0) \approx 1 + 2\sum_{k=1}^{n} \gamma_k \cos\left(2\pi\frac{2d_k}{c} + \phi_k\right) \tag{12}$$

The Fourier transformation of $p(f,0)$, i.e., $P(x)$ is

$$\begin{aligned} P(x) &= \int_{-\infty}^{+\infty} p(f,0) e^{-j2\pi\frac{2x}{c}f} df \\ &= \frac{c}{2}\Big\{ \delta(x) + \sum_{k=1}^{n} \gamma_k e^{j\phi_k} \delta(x - d_k) \\ &\quad + \sum_{k=1}^{n} \gamma_k e^{-j\phi_k} \delta(x + d_k) \Big\} \end{aligned} \tag{13}$$

Eq.(13) shows that the spectrums of $p(f)$ exist in $x = 0$, d_k and $-d_k$.

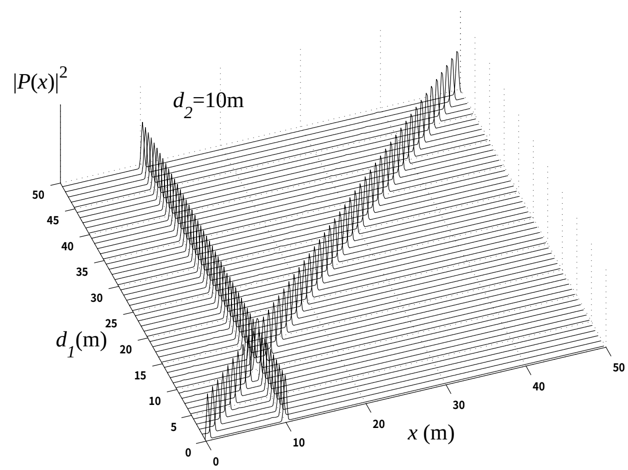

Fig. 5. Calculation of $|P(x)|^2$ in the case where two targets exist

Actually, we use Eq.(7) as the case of a single target. In the case where two targets exist, the results of calculation is shown in Fig.5. Where $d_1 = 0.3$m to 50m and $d_2 = 10$m, $f_L = 7.5$GHz, $f_U = 8.0$GHz, $\gamma_1 = \gamma_2 = 0.1$, $\phi_1 = \phi_2 = 0$, $w(f)$ is Hamming window, and DC component in $p(f,0)$ is eliminated. Fig.5 shows that the distances d_1 and d_2 can be obtained by detecting x which gives the peak of $|P(x)|^2$ as the case of a single target.

3 Experiments

We have experimented indoors for the verification of the measurement principle of this radar. The schematic structure of the experiment system is shown in Fig.6.

The network analyzer has been used for observation of the power of the standing wave $p(f,0)$, and its output has been used as the signal source. The output power is 10mW. The

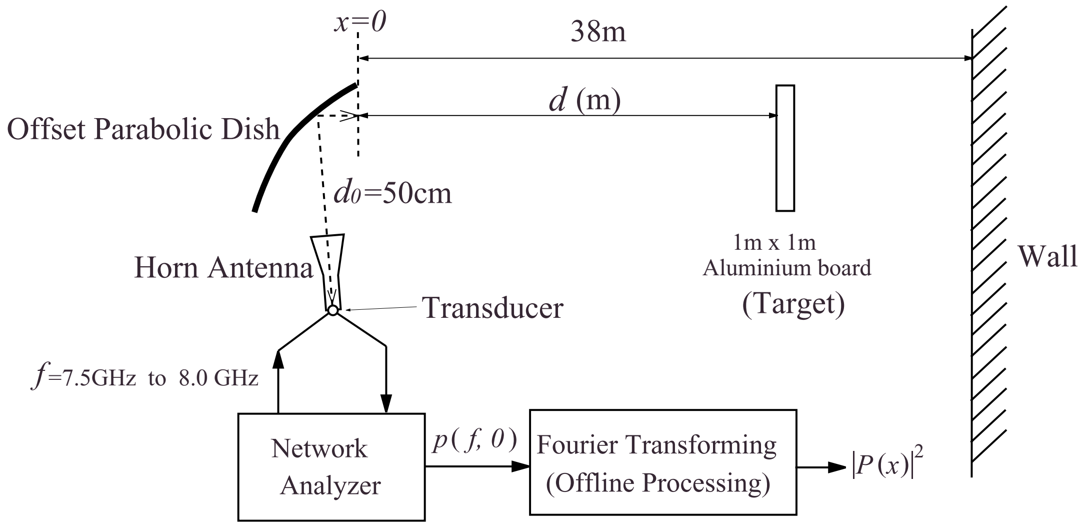

Fig. 6. Schematic structure of the experiment system and the environment

frequency range of the signal source is 7.5GHz to 8.0GHz, and the resolution is about 1.5MHz.

The antenna is an offset parabolic dish using a horn antenna as a radiator, the diameter of the dish is about 80cm.

The target is the aluminum board of 1m×1m. As there is the wall at the side opposite about 38m of the antenna, in our experiments, the distance to the target has been restricted to below this.

The data observed by the network analyzer have been Fourier transformed by off-line processing on a personal computer.

The results of our experiments are shown in Fig.7. Fig.7(a) $\sim$ Fig.7(e) show the results of having asked for $|P(x)|^2$ with the single target placed in d=0.4m, 6.0m, 9.3m, 15.7m and 21.1m. It is confirmed that the position where the spectrum exists corresponds to the distance d.

Fig.7(f) shows the result with multiple(two) targets placed in d=2.8m and 21.4m. Also in this case, the spectrum exists at the position that corresponds to the distance of each target.

It is considered that the spectrum which exists in the position of $x = 38$m originates in the reflected wave at the wall.

4 Conclusions

In this paper, we proposed a new radar using standing wave, and described the measurement principle.

We experimented for the verification of the principle and showed that this radar can measure actually from short range such as several 10cm.

About long distance measurement, it is considered that this radar has the performance equivalent to the conventional radar since the restriction on the principle is not discovered.

In our experiments, Although we used the microwave of 7.5GHz to 8.0GHz by the restriction on the performance of the network analyzer which we used, we consider that the same results can be obtained also by using a millimeter wave. However, when using a millimeter wave, the implementation of the signal source with the stability and the accuracy of its frequency will become a subject.

Future, we will build the radar system shown in this paper, and verify the performance, i.e., the measurement range, accuracy, resolution, response time and so on.

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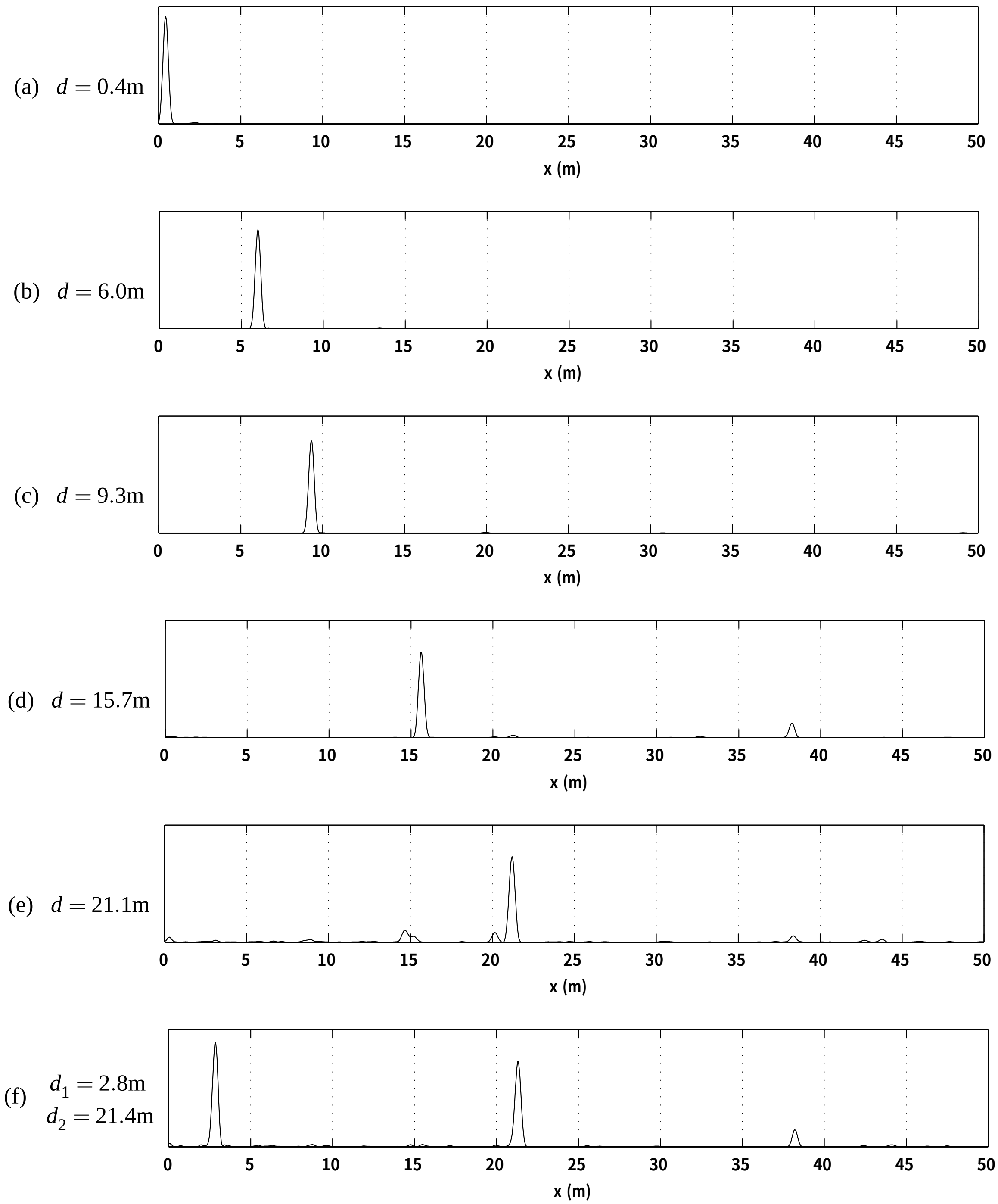

Fig. 7. Experimental results of $|P(x)|^2$, (a) $\sim$ (e) are the case of a single target, and (f) is the case of multiple targets

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