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MILLIMETER WAVE RADAR FOR DETECTING THE SPEECH SIGNAL APPLICATIONS*

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ABSTRACT

MilliMeter Wave (MMW) Doppler Radar with grating structures for the applications of detecting speech signals has been discovered in our laboratory. The operating principle of detection the acoustic wave signals based on the Wave Propagation Theory and Wave Equations of The ElectroMagnetic Wave (EMW) and Acoustic Wave (AW) propagating, scattering, reflecting and interacting has been investigated. The experimental and observation results have been provided to verify that MMW CW 40GHz dielectric integrated radar can detect and identify out exactly the existential speech signals in free space from a person speaking. The received sound signal have been reproduced by the DSP and the reproducer.

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Due to the interation between the EMW and the AW on the large numbers of particles and particle clouds in air supporting and on the interface of two mediums, such as window glass, rough surface, etc, the speech signals can be received without any monitor mounted in THE ANY NEEDED MONITORIAL PLACE. It is able as another way that the acoustic waves can be excited and propagated also on the MMW surface wave dielectric grating waveguide to mix with MMW in mixer, if the design is reasonable and the acoustic wave field can exist at radar position. A 60GHz or 90GHz Radar will be better than that of 40GHz Rodar on the performances for this new application.

INTRODUCTION

For detecting the speech signals from a person, there are many techniques to be published in the world. The light wave radars, laser radars, for this kind of the security application; maybe, have been reported in the special conferences and Journals. However the materials in detail are usually difficult to obtain. It is well known that the laser radar can identify and detect out the existential speech signals in free space. The laser radar with high sensibility had been utilized successfully in the security application. Its theory and operating principle are based on the Electromagnetic wave propagation Equations to observe the acoustic wave signals. Up to now, for same application little millimeter wave radar has been reported in the world. So that people know little information about millimeter wave Doppler radar detecting the speech sound signal application. Light radar, laser radar, and MMW radar are same on theoretical principle to detect the acoustic wave signal through the electromagnetic wave fields. The difference between laser radar and MMW radar is only from various frequency. The MMW spectrum is to be located in low frequency band of light wave spectrum.

However the weather radar with lower electromagnetic wave frequency than millimeter wave frequency has been applied succescully, according to the motions of the particles and particle clouds in free space. The motions of the particles and particle clouds have to be borne in numerous human applications at recent years.

Therefore MMW radar is able to have new application on the theory. The new application principle and three possible receivable ways for speech sound signal are discussed and provided.

The main differences between the Electromagnetic wave and Acoustic wave are due to the vector character of the electromagnetic field and the scalar nature of sound wave. Sometimes these differences are significant because of boundary conditions or polarization effects but often the analysis is very similar especially in those cases when the model in electromagnetics leads to a discussion of scalar fields.

PRINCIPLE

The sound field in air medium is described by the potential U. which is defined by the wave equation[1]

$$\nabla^2 U - \frac{1}{S^2}\frac{\partial^2 U}{\partial t^2} = -4\pi Q(\vec{R}, t) \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

where $\vec{R}$ is the rdius vector with components $\{x, y, z\}$; t is the time; S is the sound velocity; $4\pi Q$ is the source density distribution. The velocity $\vec{V}$ of the particles in medium and the sound pressure P are related to the potential U and the density ρ of medium by the following relations:

$$\vec{V} = -\nabla U; \qquad P = \rho\frac{\partial U}{\partial t} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

Equition (2) is also equivalent in force of sound field.

$$U(\vec{R}, t) = U(\vec{R})e^{-i\omega t};$$

$$Q(\vec{R}, t) = Q(\vec{R})e^{-i\omega t}$$

$$(\nabla^2 + k^2)U = -4\pi Q(\vec{R}) \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (3)$$

where $k = \omega/s = 2\pi/\lambda$ and λ is sound wavelength.

Equation (3) is known as a Helmholtz Equaiton.

If the source is a point source in a volume and is located at point $\vec{R}'$. The radiated field $U(\vec{R})$ of sound waves propagation in infinite space and on the surface can be derived by Green's function as following form:

$$U_v(\vec{R}) = \int_v Q(\vec{R}') \frac{e^{jk|\vec{R}-\vec{R}'|)}}{|\vec{R} - \vec{R}'|)} d\vec{R}' \quad \cdots\cdots\cdots\cdots\cdots \quad (4)$$

$$U_s(\vec{R}) = \frac{1}{2\pi} \frac{e^{ikR}}{R} \int_\Sigma \frac{\partial U(\vec{r})}{\partial z} e^{-i\vec{k}\cdot\vec{r}} d\vec{r} \quad \cdots\cdots\cdots\cdots\cdots \quad (5)$$

According to the definition of a Green's function in the Fraunhofer Zone, the sound radiation field $U_v(\vec{R})$ at distance R is written for the sound potential in the volume v. as:

$$U_v(\vec{R}) = d_v(\vec{k}) \frac{e^{ikR}}{R} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (6)$$

where $$d_v(\vec{k}) = \int_v Q(\vec{R}') e^{i\vec{k}\cdot\vec{R}'} d\vec{R}',$$

$$\vec{k} = \vec{\upsilon} k; \ \vec{\upsilon} = \vec{R}/R$$

From Formulas (6) and (2) after the sound pressure $P(\vec{r},t)$ to be computed, an external force $f(\vec{k},t)$ exerted normal to the unperturbed surface and the numerours particles and particle clouds in air supporting[2] can be obtained as follows:

$$f(\vec{k},t) = \frac{k}{\rho} \tanh(kd) \int_{-\infty}^{\infty} P(\vec{r},t) e^{-i\vec{k}\cdot\vec{r}} d\vec{r} \cdots\cdots\cdots\cdots \quad (7)$$

Then the equation $\xi(\vec{k},t)$ of oscillating motion for the surface perturbed by the force is derived as:

$$\frac{d^2\xi(\vec{k},t)}{dt^2} + 2r \frac{d\xi(\vec{k},t)}{dt} + \Omega^2 \xi(\vec{k},t) = f(\vec{k},t) \quad \cdots\cdots\cdots \quad (8)$$

where r is the attenuation coefficient. If neglect small r:

$$\frac{\partial \xi(\vec{k},t)}{\partial t} = \int_{-\infty}^{t} f(\vec{k},t) \cos[\Omega(\vec{k})(t - t')] dt' \quad \cdots\cdots\cdots \quad (9)$$

$$\xi(\vec{k},t)=\sum_{n}\xi(\vec{k})e^{i\Omega_n(\vec{k})t}$$

The surface perturbations can be represented by monochromatic plane waves propagating with various wave vectors $\vec{k}$ and frequecies Ω:

$$\xi(\vec{r},t) = \mathrm{Re}\iint_{-\infty}^{\infty} d^2\vec{k}\,\xi(\vec{k})e^{i[\vec{k}\cdot\vec{r}-\Omega(\vec{k})t]} \quad \cdots\cdots\cdots\cdots (10)$$

The electromagnetic wave scattering or reflecting field $E_{\vec{p}}$ from the surface perturbed by the sound pressure $P(\vec{r},t)$ or force f $(\vec{k},t)$ at the radar position has been expressed

$$E_{\vec{p}} = \frac{k^2}{\pi}\int_s \frac{\exp[jk(R_1+R_2]}{R_1R_1}F_{\vec{p}}^{\vec{p}_0}(\vec{\alpha},\vec{\beta})\xi(\vec{r})d\vec{r} \quad \cdots\cdots (11)$$

where: $F_{\vec{p}}^{\vec{p}_0}(\vec{\alpha},\vec{\beta})=\alpha_zP_z[\vec{p}_0\cdot(\vec{\beta}-\vec{\alpha})]+\beta_zP_{oz}[\vec{P}\cdot(\vec{\alpha}-\vec{\beta})]+P_zP_{oz}(1-\vec{\alpha}\cdot\vec{\beta})+\alpha_z\beta_z\{\vec{P}_0\cdot\vec{\alpha})(\vec{P}\cdot\vec{\beta})-(\vec{P}\cdot\vec{P}_0\}$ for $|\varepsilon|\to\infty$

$\vec{P}_0$ is the dipole moment of transmitting antenna.
$\vec{P}$ is the dipole moment of receiving antenna.
$\vec{\alpha}$ and $\vec{\beta}$ are incident and reflect wave vectors respectively.

In practical circumstance exist the surfaces to be able to be perturbed, such as window glass, etc,. They can be perturbed by sound pressure to cause a weak oscillating motion. From which the reflecting signal $E_{\vec{p}}$ of the electromagnetic waves is with the amplitude and phase fluctuation related to the acoustic wave source. By Doppler radar the speech sound signals can be received.

As mentioned above, it is first way to receive the acoustic wave signal. Second way is that MMW radar transmits the electromagnetic wave in free space. If the particles and particle clouds at rest in uniform air medium, The EM field wave equations are listed below:[3]

$$\nabla^2\vec{A}-\frac{1}{C^2}\frac{\partial^2\vec{A}}{\partial t^2}=-\mu\vec{J} \quad \cdots\cdots\cdots\cdots\cdots\cdots (12)$$

$$\nabla^2 V - \frac{1}{C^2}\frac{\partial^2 V}{\partial t^2} = -\rho/\varepsilon$$

$$\vec{D} = \varepsilon\varepsilon_D\vec{E}, \qquad \vec{B} = \mu\mu_0\vec{H}, \qquad \vec{J} = \sigma\vec{E}. \quad \cdots\cdots\cdots (13)$$

and all field components have a variation

$$\exp[i\omega\{t-(lx+my+nz)\}] \quad \cdots\cdots\cdots\cdots\cdots (14)$$

If a particle or particle cloud moving in the EM field at velocity $\vec{V}$ caused from the sound potential gradient $\vec{V} = -\nabla U(\vec{R}, t)$, then the EM field is perturbed. At the particle position, the Electromagnetic fields are become as:

$$\vec{E}' = \beta\vec{E} + (1-\beta)(\vec{E}\cdot\vec{V}/V^2 + \beta\vec{V}\times\vec{B} \quad \cdots\cdots\cdots\cdots (15)$$
$$\vec{B}' = \beta\vec{B} + (1-\beta)(\vec{B}\cdot\vec{V}/V^2 - \beta\vec{V}\times\vec{E}/C^2$$
$$\vec{D}' = \beta\vec{D} + (1-\beta)(\vec{D}\cdot\vec{V}/V^2 + \beta\vec{V}\times\vec{H}/C^2$$
$$\vec{H}' = \beta\vec{H} + (1-\beta)(\vec{H}\cdot\vec{V}/V^2 - \beta\vec{V}\times\vec{D}$$

and all field components vary according to the factor:

$$\exp[i\omega'\{t'-(l'x'+m'y'+n'z')\}] \cdots\cdots\cdots\cdots\cdots (16)$$

After insertion of $t' = \beta(t - vx/c^2)$ and $x' = \beta(x - vt)$, $z' = z$, $y' = y'$, the expression (16) becomes:

$$\exp[i\omega'\{\beta(1+vl'/c)t + x'(l' + \frac{v}{c})\beta/c - (m'y+n'z)/c\}]$$

Therefore

$$\omega = \omega'\beta(1+vl'/c) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (17)$$

where $\beta = (1-v^2/c^2)^{-\frac{1}{2}}$.

$$v/c << 1;$$

The formula (17) gives the change in frequency received by radar. It is called as Doppler Effect and depends upon both the speed and direction of a particle.

$$\omega=\omega'\beta(1+\vec{V}\cdot\vec{n}/c) \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (18)$$

where $\vec{n}'$ is a unit vector in the direction of EMW propagation.

In practice, the scattering or reflecting may be produced from large numbers of solid or liquid particles or particle clouds in air supporting, such as dusts, grains, fog, powders etc. Due to the particles and particle clouds moving caused by acoustic source, there are a resultant fluctuation in the electromagnetic field strength and a change in frequency. They depend upon the acoustic potential and the particle size, density and concentration[4]. So that speech sound signal can be received in air medium by radar.

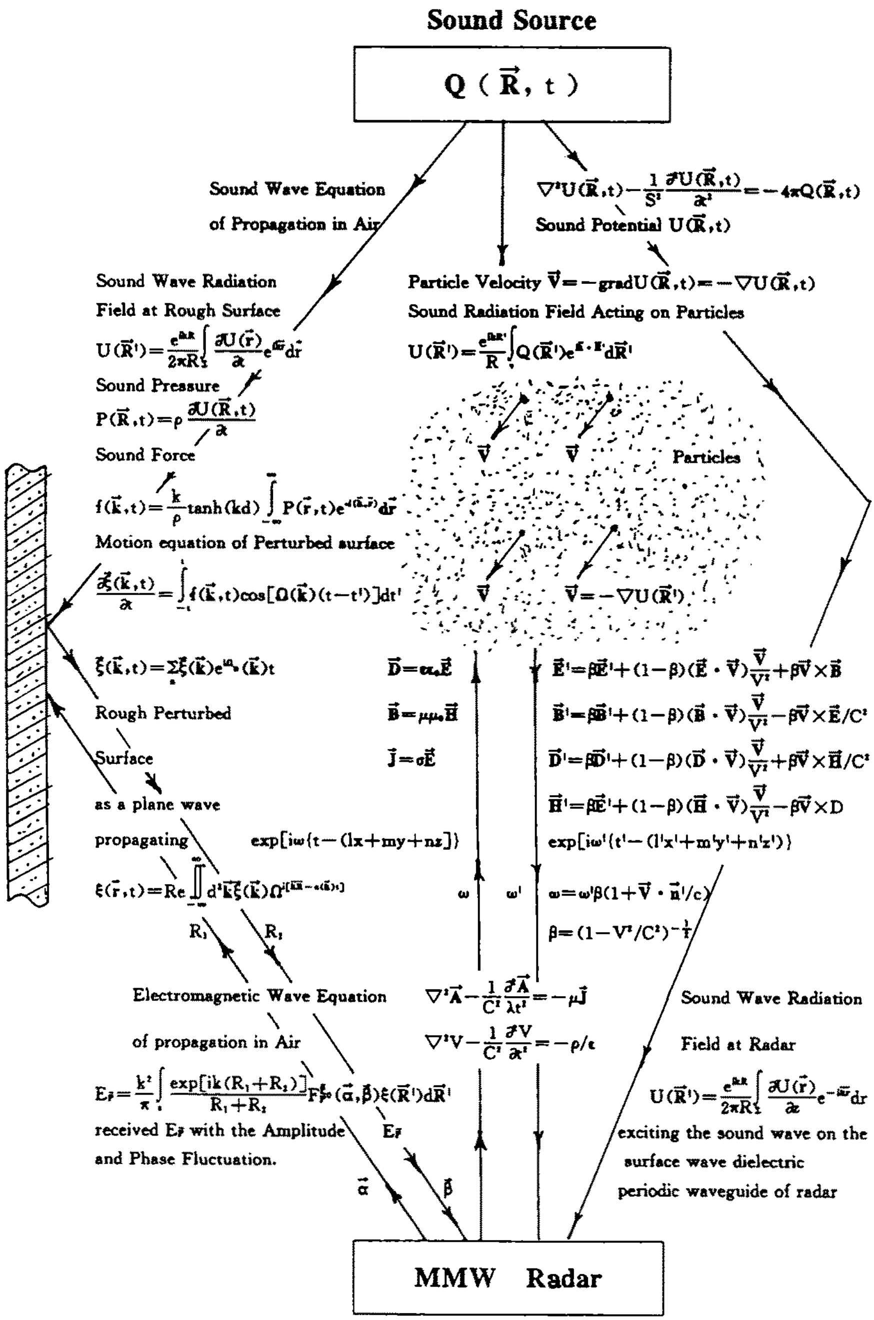
When MMW radar is radiated by the acoustic wave field from the formula (5), the acoustic wave may be excited on MMW planar periodic dielectric antenna and propagated along the surface wave dielectric waveguide of radar to mix with millimeter wave in the mixer[3]. This is third possible receivable way.

What is the main receivable way among the three possible ways needs to be researched at next step further.

EXPERIMENTAL RESULTS

MMW Doppler CW radar at 40GHz for detecting the speech signals has been observed already in our laboratory by the osilloscope. The received speech sound wave signals have been reproduced by the DSP and the reproducer. The experimental results have been provided to verify that A 40GHz Doppler radar with the new application can detect and identify out the speech sound wave signals in air medium space from a outdoor/indoor person or radio receiver speaking without any monitor to be mounted in THE ANY NEEDED MONITORIAL PLACE.

The MMW radar sensibility has to be increased for new application. The DBR Gunn Oscillator, Mixer and leaky-wave antenna with planar dielectric grating structures have to be designed further according to optimal criteria for both the millimeter wave band and the speech sound wave band. The DSP shall be better to do.



MMW Radar New Application Principle and three possible receivable ways.

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