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Remote Sensing Through Millimeter Wave Radiometer Sensor

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Abstract

The extension of imaging techniques from shorter wave length of IR and visible to longer wave length of mm wave invites substantial penalties to be paid in terms of size and spatial resolution. In spite of the above cited limitations, passive imaging sensors have gained popularity due to its superior performance under adverse weather conditions i.e. fog, dust &battle field smoke. Besides operating under stealth conditions the images generated have a high contrast, stable signature and provide easy interpretation of images. Millimeter wave imaging through passive radiometric sensor is proving to be a great boon for the covert surveillance of battlefield by sensing the manmade objects, and armored vehicles from a remote platform. The all-weather capability of mm wave imaging sensor provides the necessary edge over the other technologies as part of sensor suit for imaging. Passive mm wave imaging system develops a picture by detecting non-coherent noise i.e. Radiant electromagnetic energy. In this band, emissivity varies greatly from near zero for metallic objects to nearly one for natural objects like vegetation. Metallic objects appear very cold to a passive MM wave sensor due to their low emissivity (high reflectivity) relative to terrain and other non-metallic objects in the image. Because, these metallic objects are almost totally reflective, so any type of counter measure will have little effect on their detection. The key to passive MM wave imaging is the large temperature contrast in the MM wave spectral band due to large variation in emissivity value for the various target materials and terrain in an imaged scene. Temperature contrast of greater than 100 times the contrast of IR systems are common for the systems operating in the MM wave spectral band as any material at a temperature above absolute zero radiates in microwave, Millimeter wave and other spectral regions. All objects in a given scene of interest are either reflecting or radiating electromagnetic energy in a given spectral band. Present paper discusses the usage of 94GHz imaging sensors with single receiving elements for the purpose of surveillance, its detection capabilities and image data of the metallic targets in the background of ocean, land and hilly terrain.

Keywords- Radiometer, Passive-Imaging, Millimeter Wave and Remote Sensing.

1. Introduction

It is well known that objects above absolute zero temperature radiate in the complete RF spectrum. From Planck’s blackbody radiation, it is also understood that at 300K the maximum of radiation is in the infrared (IR) range of spectrum. With the lowering of the temperature, peak of radiation moves towards larger values of wavelength i.e. towards microwave /mm wave frequencies. At mm wave frequencies though the radiated noise is 10^{-5} times less than IR, but contrast is increased by 100 times (Brown et al., 1998), showing the

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potential of using mm wave frequencies band for sensing the terrain, metallic objects and other gray bodies of interest.

W-band frequencies around 94 GHz have been selected for the realization of passive imaging sensor optimizing the thermal and spatial resolution for a reasonable size of sensor hardware (William et al., 1986). Recent progress made to achieve better performance components in this frequency band have permitted to realize sensor with required noise temperature and thermal resolution. The scanning radiometer sensor with single and dual receiving elements (Huguenin, 1997) have been utilized, to collect the image data of metallic targets in the hilly & flat terrain and ships in the water background. The image data taken with the developed prototype radiometer sensor shows a great potential for using it as a tool for remote sensing. The achieved thermal sensitivity of radiometer is sufficient to detect extended metallic targets in the background of underlying surface at large ranges. The low attenuation of mm wave compared to IR in the adverse weather conditions makes this sensor to complement, an integrated sensor suit, for all weather surveillance of secure military zones. In the hilly terrains, metallic roof tops have been detected upto 7 km of range at grazing look down angle.

2. Brightness Temperature of Metallic Objects

Basic principal of mm wave passive imaging is to measure the brightness temperature of metallic objects in the viewed area. This brightness temperature is a function of material size, shape and aspect angle of the target reflecting surface. It also depends on the properties of the intervening atmosphere between sensor and the target, ambient temperature and the emissivity of the background in which the target is immersed (Appleby and Lettington, 1991). The radio brightness temperature of sky at this frequency band is approximately 100K which is lower than the background noise temperature. This radio brightness radiation flux gets reflected from the metallic targets which make them stand out in the background of vegetation and other terrain of higher emissivity.

The flux density received by the sensor can be related to the object by

$$R_{\Sigma} = K\left(T_{object} + T_{reflected\ sky} + T_{background}\right)B_n \tag{1}$$

Where, T_{object} : Emission from the object in the main beam of the antenna
$T_{reflected\ sky}$: Reflected cosmic noise from the metallic targets
$T_{background}$: Emission of the background in which metallic target is immersed
K : Boltzmann's constant
B : Bandwidth

The received radiation flux from an object in the antenna main beam is sum of

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(i) Product of objects temperature with its emissivity multiplied by beam fill factor and reduced by atmospheric attenuation
(ii) Product of radiometric cosmic noise temperature with reflectivity of the object and antenna beam fill factor and reduced by atmospheric attenuation.
(iii) The flux received from the background, which corrupts the useful signal from the object, is the sum of physical temperature multiplied by emissivity of background and cosmic temperature multiplied by its reflectivity. This whole is multiplied by area of ground foot print of beam excluding area occupied by the target. This value is again reduced by the atmospheric attenuation while reaching to the optics of the sensor (Smith et al., 1996).

The received flux from the scene in the main antenna beam is again corrupted by the flux received from the side lobe. Antennas required for the radiometry purpose should therefore have very high beam efficiency, more than 90%, so that the signal received from the side lobe should not enhance or decrease the level of the received signal from the main beam. The flux received by the antenna is given by (Smith et al., 1998)

$$R_{\sum} = K[\eta T_{\text{main lobe}} + (1-\eta)T_{\text{side lobes}}]B_n \quad (2)$$

where, η is the antenna beam efficiency.
The metallic target signatures are generally stable with respect to time (day and night) in mm wave imaging because reflected flux from metallic targets is predominated by the cosmic noise reflection. The flux emitted by the metallic objects which is a function of temperature is very low and has secondary effect on the total flux received from the metal targets. In IR band temperature inversion makes metallic signature unstable and may lead to false information.

3. System Details
Radio contrast is the basic phenomena of passive mm wave imaging which has been explored to detect the objects in the background having different emission characteristics. The received power from viewed area has large variation as antenna beam crosses the metallic, non-metallic, vegetation and water bodies. The radiometer thermal sensitivity is responsible to detect the contrast between two sequential dwells while scanning the area in raster mode. The scanning speed is such that it dwells at half beam width angle for the time equal to the integration of radiometer (30 msecs) and overhead for data acquisition and display before moving to the next points (Kemppinen and Hallikainen, 1992). A dual polarization Dicke radiometer with noise temperature of 880K with thermal resolution of 0.5K @30 msec has been utilized for collecting the image data. Two super heterodyne receivers with double side band frequency down conversion having common local oscillator are being used to down convert both the polarization of the received signals. The radiation collected by the radiometers is determined by the radiation pattern of the antenna having pencil beam of 7

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milli radians. The antenna selected is an offset reflector for the purpose of higher beam efficiency. Complete hardware is mounted on a two –axis scanning system which is controlled via RS-232. The image data is acquired with the following operating features.

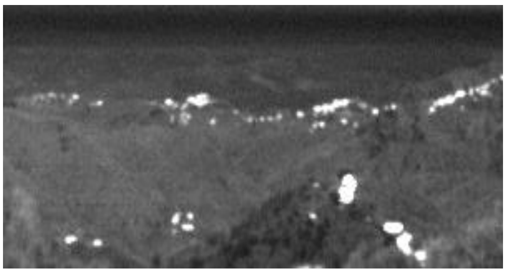
1) Field of view is selectable through software. It may be selected +/-90 degree from the mean position in the azimuth and -60 to +90 in the elevation plane. The scan pattern is generally raster type.
2) The frame time depends on the time dwelled on single pixel, which is integration time and overhead for the data acquisition and display.
3) To extract the highest scene frequency of spatial domain minimum two samples per beam width in both planes have been optimized, which is as per Nyquist sampling theorem (Wei and Zhang, 1999).

4. Experimental Installation

In two of the experiments conducted to evaluate the performance of the imaging sensor the system was installed on an elevated platform (Rooftop) so that clear line of sight is established between the scene and sensor. The radiometer is stabilized and programmed in raster mode scanning for both the planes. The image data is displayed pixel by pixel in synchronous manner with the raster mode scanning. The acquired image data is stretched to the complete dynamic range of the ADC. The image data is corrected for the removal of fix pattern noise for the purpose of flat fielding. Standard Image processing techniques are applied for enhancing contrast and intensity for the purpose of extracting information as per requirement without adding artifacts. Some of the image data acquired during these tests is as shown in Figure 1, 2, 3 and 4.

5. Experimental Results

There is clear indication of the metallic and non-metallic objects in the hilly and water background with high contrast up to the range of 7 km in the near horizontal mode. This dictates the much higher potential of using mm wave passive imaging in the look down mode for remote sensing for even higher ranges in all weather conditions.



(a)

(b)

Figure 1. Images acquired at mid night (a) MM Wave image (b) Visible image

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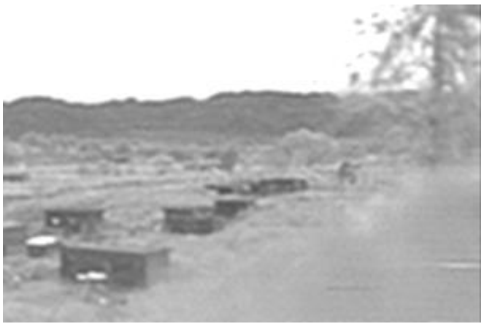
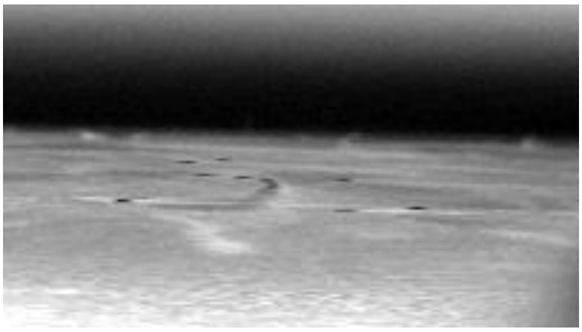


(a) **(b)**

Figure 2. Surveillance of an area with periodic update for change detection using mm wave passive imaging

(a)Scene without Target **(b) Scene with Target**



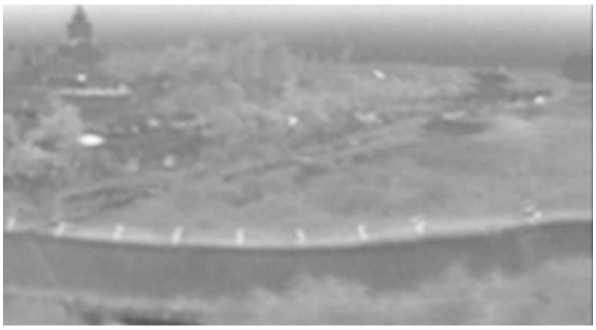


Figure 3. Wakes and cutters in water back ground

Figure 4. Urban area as seen through mm wave sensor

This sensor is best suited to be a complementary/supplementary to a sensor suite on a terrestrial/airborne platform for all weather remote sensing for commercial and military use with covert mode as the added advantage for tactical surveillance.

6. Conclusion

Image data of metallic targets taken with 94 GHz imaging sensors reveals that contrast between metallic objects embedded in various kinds of backgrounds helps detection under all weather conditions. Moderate resolution image data can be utilized for precision delivery of warheads in radio silence zones and covert surveillance of security sensitive installations during all seasons including nights.

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