Is it Possible to Detect the Stealth Flying Objects by the Millimetre Wave Radiometer?

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Keywords: Microwave radiometer, Passive millimetre wave imaging system, Remote sensing control, Antiradar coating

Abstract: This work evaluates the possibility of using the passive millimeter waves (PMMW) radiometric discriminator for the remote control and the detection of stealth aircrafts.

1 INTRODUCTION

Microwave radiometry is concerned with measurements of natural electromagnetic radiation of an object of physical temperature above 0° K.

A large literature describes the main working principles of microwave radiometry (Reinwater, 1978; Moffa et al, 2001; Goldsmith et al,1993; Appleby and Lettington, 1991; Piechl, 2004; Poradish and Habbe, 1982; Esepkina et al, 1973; Skou, 1989; Shuchardt et al, 1981). With respect to special application fields, it is interesting also to read old publications and patents regarding military designs and applications based on the deployment of millimeter wave bands during the Cold War (Shuchardt,1978; Moore et al., 1976; Parnell, 1988; Seashore, Miley and Kearns, 1979; Corrado, 1988; www.giws.de). After, due to the large potential market, there has been a large diffusion of modern microwave firms for the equipment of the airport security systems and the detection of the concealed objects.

Based on the growing problem of the terrorism, especially after 11 September 2001, a large amount of money has been devoted to special programs for the design of special passive millimeter wave imaging systems (PMMW) (Proc..of SPIE a lot of, Huguenin,2006; Appleby,2007; Internet,Dill et al. 2009).

The focus of the present work is on the possibility offered by PMMW radiometric systems in order to detect remote aircraft with antiradar surfaces coverage (Figure 1).

A relevant statement about the use of an anti-radar surfaces adapted to the stealth ship is provided just below. (wikipedia.org/wiki/Stealth ship). “In designing a ship with reduced radar signature, the main concerns are radar beams originating near or slightly above the horizon (as seen from the ship) coming from distant patrol aircraft, other ships or sea-skimming anti-ship missiles with active radar seekers. Therefore, the shape of the ship avoids vertical surfaces, which would perfectly reflect any such beams directly back to the emitter. Retro-reflective right angles are eliminated to avoid causing the cat’s eye effect. A stealthy ship shape can be achieved by constructing the hull and superstructure with a series of slightly protruding and detruding surfaces”.

Anyway, it is sufficient to change the word from “ship” to “aircraft”.

The stealth coating it is very suitable to avoid the specular reflection for active systems, but at the same time is practically useless for radiometric systems, because nature produces radiations, which re-reflect from this surfaces to antenna of radiometer from the every directions (Figure 2 and 3)

Qiu J., Lan S., Liu H., Yin X., Denisov A., Qing X., Man Z. and Soldovieri F.
Is it Possible to Detect the Stealth Flying Objects by the.
DOI: 10.5220/0006227200610068
In *Proceedings of the Fifth International Conference on Telecommunications and Remote Sensing (ICTRS 2016)*, pages 61-68
ISBN: 978-989-758-200-4

Figure 1: Photos of various modern famous special aircrafts with antiradar surfaces.

Objects reflect and emit radiation in the millimeter wave range as they do it in the infrared and visible ranges. The degree to which the object reflects or emits is characterized by emissivity ***ε***. A perfect radiator (absorber) has ***ε*** = 1 and is known as a blackbody (Esepkina, 1973). A perfect reflector (non-absorber) has ***ε*** = 0. The earth and the sky can be approximated as blackbody, whereas the metal object is a reflector. Intermediate values of the emissivity ***ε*** depends on several parameters as, dielectric properties of the objects, angle of observation (for example, for the water surface), the polarization parameters, the surface roughness or coatings, the wavelength and other factors.

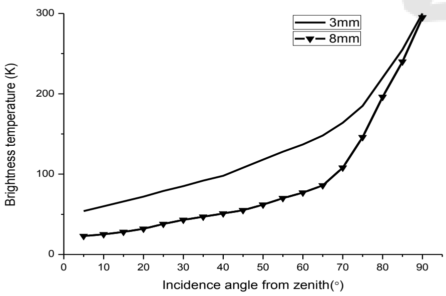

Figure 2: Brightness temperature of sky at the various angles of relatively zenith.

The measurement of such a radiation is more correct and understandable in terms of radio brightness (simply brightness*) temperature*, which is expressed in temperature ***T.***

According to the usual definition (Esepkina, 1973), a radiometer (Figure 4) is a receiving device designed for the measurements of the level of noise radiation in an assigned band of the frequencies ***Δf.***

The main functionality of the receiver in a radiometer is to provide a measure of the input noise power, expressed as an antenna temperature, in equivalent black body temperature units. The sensitivity of the radiometer $\boldsymbol{\Delta T_{sens}}$, is defined as the minimum detectable signal and is determined by amplitude of the fluctuations presented at the output indicator in the absence of the signal.

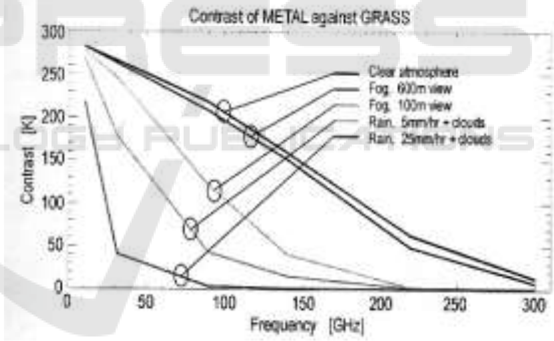

Figure 3: Possible radio-brightness radiometric contrast between metal and grass at the zenith angle for the case of the observing an obects on the earth surface

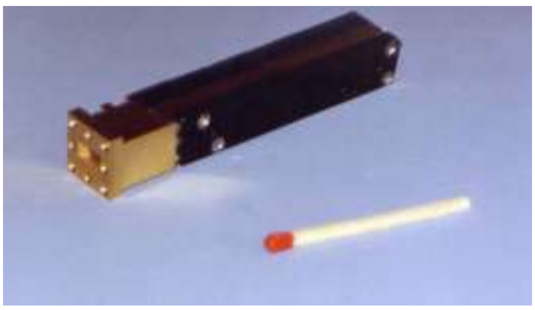

Figure 4: Picture of the 8 mm radiometer (Gorishnyak et al, 2004).

Usually, the temperature sensitivity of radiometer is evaluated for post-detection time 1 sec. More details about various situations concerning $\boldsymbol{\Delta T_{sens}}$ (calculated and measured) can be found in (Esepkina, 1973; Skou 1989).

The bottom of the aircrafts will reflect the radiation of the hot Earth and accordingly it will be seen by the radiometer as an hot object with respect to the background of the cold sky (space).

Even in case of the coating of all surfaces by special absorption (small probability) material ("painting"), such a "blackbody" will have surface brightness temperature as from outside of the aircraft. Remember standard information at the board during the air flight: "Temperature of air overboard makes minus 56 degrees.

In this paper, we evaluate the possibility of using PMMW radiometric system for the remote control and the finding of stealth aircrafts. The choice of the real working frequency depends on the real size of antenna and the microwave losses in atmosphere on path radiometer – aircraft (Figure.5 and Table 1).

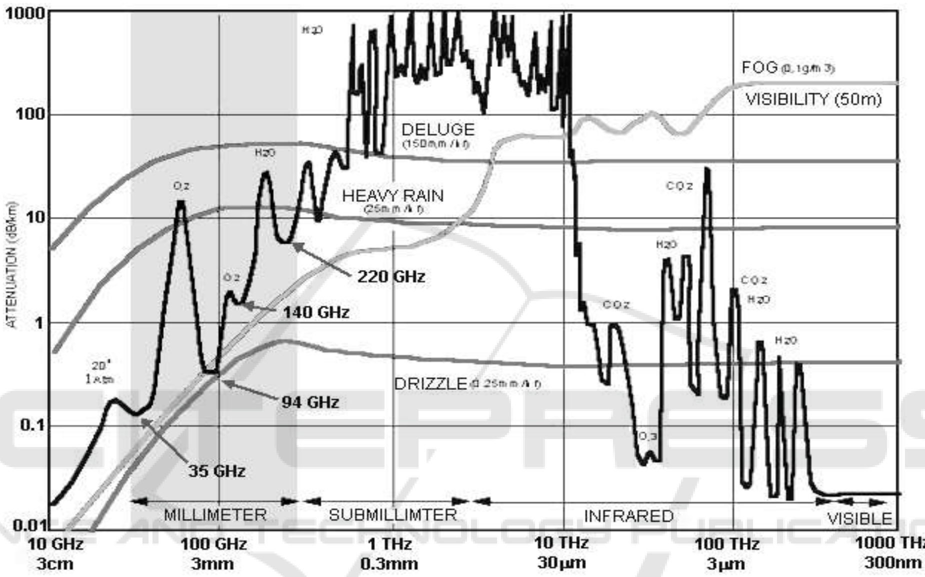

Figure 5: Absorption of the electromagnetic waves in the atmosphere

Table 1: Absorption in atmosphere for Three Window Frequencies (Seashore et al, 1979)

CHARACTERISTIC	FREQUENCY		
	35GHz	94GHz	140GHz
Wavelength	8.6mm	3.2mm	2.2mm
Clear Air Attenuation	0.12dB/km	0.4 dB/km	1.6 dB/km
Rain Attenuation			
0.25mm/hr	0.07 dB/km	0.17 dB/km	0.2 dB/km
1.0 mm/hr	0.25	0.6	0.7
4.0 mm/hr	1.0	3.0	3.2
16.0 mm/hr	4.0	8.0	9.0
Fog Attenuation			
Light 0.01g/m^3	0.006 dB/km	0.035 dB/km	0.07 dB/km
Thick 0.1 g/m^3	0.06	0.35	0.7
Dense 1.0 g/m^3	0.6	3.5	7.0
Apparent Sky Temperature			
Clear	23°K	50°K	81°K
Moderate Overcast	65	120	200
Rain	110	220	250

2 TECHNICAL DETAILS

2.1 Passive Millimeter Wave Imaging

A very increasing interest towards the design and production various PMMW imaging system is due to the real possibility to have fourth type of the remote control system in addition to the existing optical, radar and infrared (IR) systems. Attractive feature of PMMW imaging systems is the capability to operate under adverse weather conditions and to be sensitive to non-metallic targets. In addition, since PMMW sensor is passive, it can be operated in all locations including friendly and hostile ports where RF emissions may be disruptive to local systems. (Moffa et al, 2001).

Figure 6 presents images produced by the 32 sensors 8 mm PMMW system with antenna diameter 90 cm (Gorishnyak et al, 2004; Denisov et al, 2009). For this system, sensor sensitivity is 0,01 K for post detecting time 1 sec and the sensor works without any modulation-calibration at the entrance. This system according to the theory works with full power radiometers. In figure 6, it is worth noting that the black spots on the image of city, at the top of building, represent the mobile phone transmission stations, producing harmonics in 8 mm band. Radio-images in 90 GHz (3mm wavelength) frequency band presented on Figure 7.

PMMW system are now gaining of deep cooling based on superconductors for the space tasks (Proc.of SPIE,2014) and the improvement of the passive images, with the help of advanced data processing, for the super resolution (Luxin et al. 2006). In the near future, it is expected the modern application of the processed radio-images in the various spectral bands with the help of a correlation analysis.

2.2 Technical Peculiarities of the Radiometric Discriminator

Good performance of radio-image systems is based on the necessity to have identical sensors; this is not challenging in case of a direct amplifier based on the Monolithic Microwave Integrated Circuits (MMIC) with enough high dynamic range. Instead, various issues arises in the data processing, when we have to turn from the measurements with a large number of sensors in an image in a digital form or in optical up-converting "looks". Issuers regard also special cooling (Moffa, 2001) and temperature stabilization, which really increases the cost of PMMW system. For example, prime cost of 8 mm sensor in Figure 4 has value around 700 $, and for modern European direct amplifiers on 3 and 2,2 mm the cost is 5-20 times more expensive.

Figure 6: Radio-images in 8 mm wave band in comparing with the optical images of the same scenes.

Figure 7: Radio-images in 3 mm wave band

sensors, because the relevant angle of view is enough small in this case.

Here, we focus on the differential modulation radiometer, which is also named by discriminator.

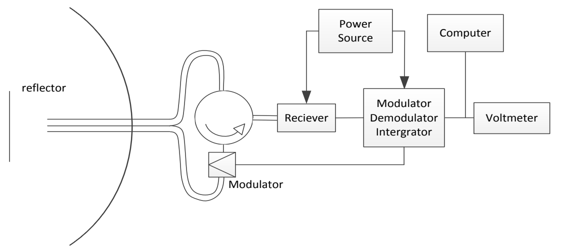

Figure 8: Block-scheme of the simplest 8 mm microwave discriminator.

The discriminator (see Figure 8) exploits two feeders combined with the one antennas surface. The special antenna system forms two space beams directed on the two neighboring directions of the space in the horizontal plane (the same device can be done for the vertical plane). The angle between the two beams depend on the technical specification. The incoming signals from these two directions are at the input of the switch and later to the radiometer (Figure 8). Usually, it is convenient to deploy a circulator in replacement of the switch where radiometer is connected to the third gate of the circulator. In this configuration, at the input of the radiometer there are two microwave signals at the modulation frequency (for example, 10 kHz). After amplification (around 56 dB), the signal are detected and are going as the meander with modulation frequency. Afterward, the resulting signal can be demodulated by the synchronous detector with time constant around $\tau = 0.01$sec. Finally, at the output of the integrator (discriminator), there is a signal proportional to the difference of the power in the measured beams. This signal difference arises only in case of observation of different observed scenes. Therefore, as the result of the scanning, there is a picture that resembles the two neighboring angles of the space and accounts for the contour of the observed object.

2.3 The Job of the Discriminator

For a simple explanation of the working principle of the discriminator, we can refer to Figure 9.

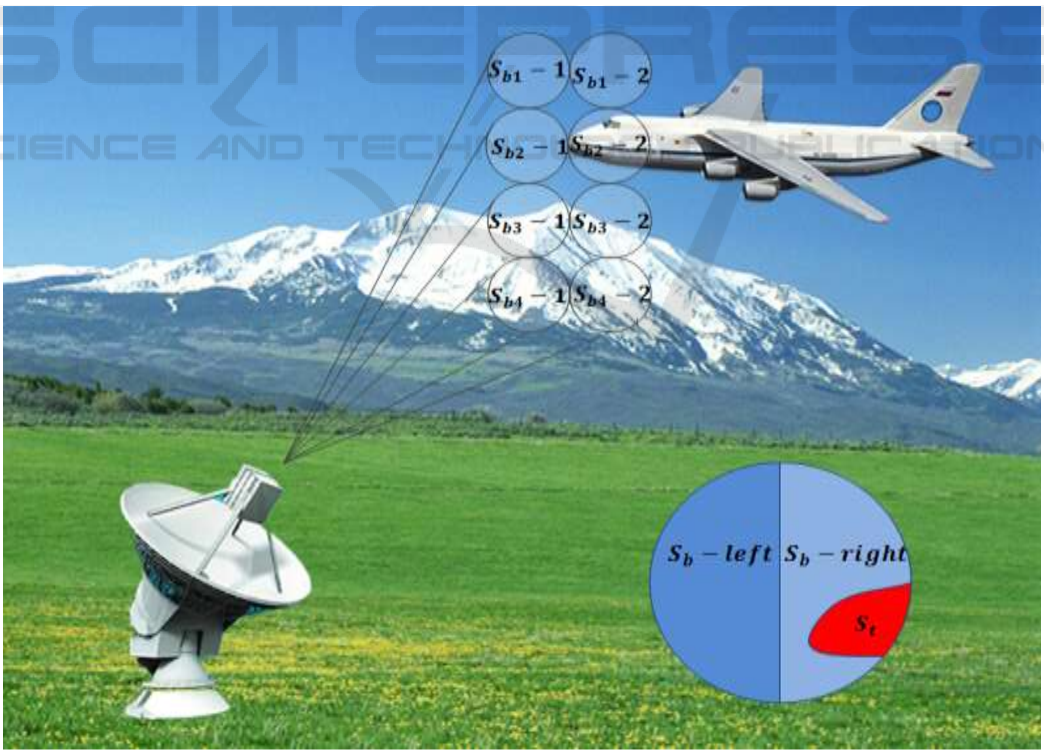

Figure 9: Pictorial description of the working principle of a discriminator.

There the four channels PMMW discriminator system produces the scanning of scene. The first spot of the antenna beam $\mathbf{S_{b\text{-}left}}$, does not intercept any part of the observing object whereas the object

There the four channels PMMW discriminator system produces the scanning of scene. The first spot of the antenna beam $\mathbf{S_{b\text{-}left}}$, does not intercept any part of the observing object whereas the object is imaged in the second right spot $\mathbf{S_{b\text{-}right}}$,.

For an evaluation of these two following observing spots, the brightness temperatures T of the object is used. The brightness temperature can be evaluated according to the expression concerning the microwave power $P = kT\Delta f$, where k –Boltzmann's constant, T–brightness temperature, Δf- the band of the receiving frequencies, which income to the radiometer from the two antenna's spots. Of course, this task requires a critical technology (Huguenin,2006, Dill et al,2009). In Eq.1 there is $\mathbf{S_{back}} = \pi \mathbf{A}^2$, where **A** is the area of the aperture antenna beam spot at the distance **L** till the aircraft. Other main parameters are: the brightness temperature of background (cold sky) is $\mathbf{T_{back}}$, (concerned with $\mathbf{S_{b2}}$**-1,** $\mathbf{S_{b1}}$ **-1,** $\mathbf{S_{b1}}$ **-2** on fig.9), this value is dependent on the atmosphere conditions and in particular on the absorption in atmosphere, which increases the brightness temperature of sky compared to the case of clear air. The diameter of the antenna's beam spot is $A = 1{,}22\ L \sin \lambda/D$. $\mathbf{S_t}$ – area of the aircraft surface inside of the beam spot $\mathbf{Sb_2}$**-2** with the brightness temperature of the aircraft depending on the reflection from the earth or water $\mathbf{T_t}$.

In the inset of Figure.9, we schematically present two parts of the antenna beam spots $\mathbf{S_{b\text{-}left}}$ and $\mathbf{S_{b\text{-}right}}$. Both $\mathbf{S_{b\text{-}left}}$ and $\mathbf{S_{b\text{-}right}}$ are two half of the full surface of $\mathbf{S_b}$. Discriminator compares the received signals from these two beam spots; the difference between the received microwave power in terms of the brightness temperatures of these two spots can be evaluated in the simplest approximation as :

$$\left| T_{back} - \frac{T_{back}\,(S_{b\text{-}right} - S_t) + T_t \cdot S_t}{S_{b\text{-}right}} \right| = \left| T_{back} - T_t \right| \cdot \frac{S_t}{S_{b\text{-}right}} \qquad (1)$$

So, if the receiver of discriminator has a sensitivity better that the result of eq. (1), it is possible to detect the distinction inside of this direction and the objects can be found by PMMW discriminator system.

Every antenna has the efficiency η (for example, in percents). On the track object – radiometer, attenuation in atmosphere and losses from the antenna to the input of the radiometer can be accounted by the parameter α (expressed in dB or times). Every measuring system must have a reserve in the probability of detection of κ (signal/noise).

If we consider $\Delta T_{Contrast} = T_{back} - T_{sky}$, it is possible to recognize an aircraft, under a simple approximation in case of :

$$\Delta T_{Contrast} \geq \kappa\ \alpha\ \Delta T_{sens}\ S_{b\text{-}right} / S_t\ \eta\ \sigma \qquad (2)$$

Obviously, it is desirable to have a large contrast $\Delta T_{Contrast,}$ which depends on the environmental conditions, the brightness temperature of sky (Figure 2), the polarization effects, the working frequency, the material and geometry of the reflecting surfaces of the observed flying objects and position of observing object of relatively horizon, zenith and sun. Right part of Eq.2 depends on the sensitivity ΔT_{sens}, microwave losses in atmosphere α and $(S_{b\text{-}right}/S_t)$. If we consider the sensitivity of radiometer for post-detection time 1 sec, real value is 0,01 K for 8 mm and in 3 mm practically too. There are no big problems to do the radiometric system at the base of modern MMIC with good thermal stabilization, which is the key factor to filter out possible amplification drift between the multitude of sensors. In principle by using MMIC with more small noise factor or special cooling, it is possible to reach best sensitivity, as for example, for the space investigation (Proc. of 22th ISSTT), but this is not of interest in the application considered in this paper. By turning to the value $S_t / S_{b\text{-}right}$ which defines the percent of the filling an aperture antenna 's beam spot by the surface of aircraft, which according to aerodynamics must have enough big figure in comparing with an armor objects, for example, on the earth (www.giws.de). Table 2 presents the diameter of the antenna's beam spot at the various distances from an antenna as the function of its diameter. According to the picture in fig.5 and Table 2, it is possible in good approximation to evaluate the real microwave losses on path between radiometric discriminator and the aircraft to be observed.

Table 2: Diameter of antenna bean spot versus the distance from the antenna for the 8 mm wavelenght

Distance (km) / Diameter of antenna (m)	2	4	5	10	15	20
0.9	22	43	57	108	162	216
1.0	19	39	49	97	146	194
1.2	16	32	40	81	121	162
1.5	13	26	32	65	97	130
2.0	10	19	24	49	73	97

2.4 Simplest Calculation of the Possible Distance

Let's try to use Eq.2 in two real cases, concerning possible contrast levels $\Delta T_{Contrast}$ as 250 K and 100 K (fig.9).

Range of radio brightness contrast $\Delta T_{Contrast}$ for the situation presented in Figures 2,3,9 and Table 1 can be from 23 till 270 K.

Real parameters of the discriminator:

- Radiometer sensitivity is 0.01 K for post detection time 1 sec, at the real time for the analysis (doing pixel) as τ = 10 msec, ΔT_{sens} for this scanning rate will be 0.1 K.

- Wavelength λ = 8 mm

- The diameter antenna discriminator ***D,*** for example - 200 cm (not so big problem to do it for 8 mm, if the accuracy of the surface must be worse that ***λ/10)***. Diameter of an antenna spot at the distance ***L*** is

$A = 1.22L(\lambda/D)$ and accordingly S_b is $\pi A^2/= \pi[1.22L(\lambda/D)]^2/4$. $S_{b\text{-}left} = S_{b\text{-}right} = 0{,}5\pi A^2/4$, according to inset on fig.4.

- The antenna efficiency, for example, η = 0,8.

- The factor of the object position σ (σ = 0,8)

- The size of the appearing object inside of the antenna beam spot S_t is 5 x 10 m^2 (middle size ship).

- The probability of detection of κ (S/N) = 3-10 times. (Accept κ = 5)

- The attenuation or microwave losses between discriminator and observed ship α (3….10 dB). (Accept α =6 times).

In this case it will be Eq.3:

$$\Delta T_{sens} < \frac{S_t\ \eta\ \sigma\ \Delta T_{Contrast}}{\kappa\ \alpha\ 0{,}5\ \pi\ (L\ 1{,}22\ \lambda/D)^2/4} \tag{3}$$

Arithmetical calculations will provide

$$0{,}1\ K < \frac{50 \times 10^4\ cm^2 \times 0{,}8 \times 0{,}8 \times (100\ldots250\ K) \times (200\ cm)^2 \times 4}{5 \times 6 \times 0{,}5 \times 3{,}14 \times \mathbf{L^2} \times (1{,}22)^2 \times 0{,}64\ cm^2} \tag{3.1}$$

$$\mathbf{L^2} < (100\ldots250) \times 50 \times 0{,}64 \times 16 \times 10^8 / 15 \times 0{,}64 \times 4{,}68 \times 0{,}1 \tag{3.2}$$

..

According to (3-1) the value ***L*** for the best case (**contrast equal to 250 K**) will be **16,87 km**. For $\Delta T_{Contrast}$ of 100 K, the distance decrease at about 10,67 km. These evaluations have been made under the assumptions of $S_t = 50\ m^2$, but according to Internet the real wing surface of the left aircraft on the Figure 1 is 73 m^2, and the right one has surface 478 m^2 !

It is worth noting that for the evaluations in the case of a UAV, if we use the reflecting surface of about 1 m^2 (really it is more smaller for the observing UAV), the value L will be around 2,4 Km for the same discriminator antenna size.

3 CONCLUSIONS

For the cases where the PMMW kvazi image is not so principle it can be used simple microwave discriminator which is variety of the differential modulation radiometer for the detection of an objects. In this case, the receipted results can repeat the contour of the observing objects.

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