Impacts of Mobile Radar and Telecommunications Systems on Earth Remote Sensing in the 22-27 GHz Range

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Abstract- **The IEEE Geoscience and Remote Sensing Society (GRSS) Technical Committee on Frequency Allocation in Remote Sensing (FARS) is charged with providing recommendations and responses to queries on interference and frequency allocation issues in passive and active microwave remote sensing. In response to questions stemming from proposals to develop ultra-wideband (UWB) vehicular radar systems operating in the 22-27 GHz frequency range a technical assessment on the potential for radio frequency interference to passive Earth remote sensing activities was prepared. The study suggests that interference to the passive services at power levels several orders of magnitude above threshold levels is likely from commercial deployment of vehicular UWB radar and telecommunications systems.**

I. Background

Recent proposals for commercial development of vehicular-mounted radar systems for collision avoidance operating in the ~22-27 GHz frequency range have prompted concern about possible interference to passive Earth remote sensing activities. The activities include both ground-based and satellite-based passive microwave remote sensing of water vapor for a variety of national and international weather and climate needs. In response to queries about the likliehood of such interference, the GRSS Technical Subcommittee on Frequency Allocations in Remote Sensing (FARS) has drafted a technical position statement on this problem. This statement (the essentials of which are contained herein) provides a technical basis for the allowable density of transmitters and power levels necessary to permit frequency sharing with passive services in this band.

Frequency allocation and interference issues are not IEEE Standards issues, but rather are matters of regulation by international treaty. The FARS assessment thus fills a critical gap between IEEE Standards and International Telecommunications Union (ITU) regulations.

II. Satellite Based Remote Sensing

The water vapor line at 22.235 GHz is the only practical resonance for radiometric measurements of integrated tropospheric water vapor in equatorial to sub-arctic regions. The bands 22.21 - 22.50 GHz (290 MHz) and 23.6 - 24.0 GHz (400 MHz) are either currently used or potentially valuable for climatological water vapor measurements. The brightness sensitivity to vapor variations over water backgrounds is ~0.5 (K/%RH), and radiatively significant changes in RH are of order 0.1%. Thus, all these bands should have interference sensitivity thresholds of 0.05 K, and possibly lower (~0.01 K) for development of climatologically significant long-term records of RH.

The band 22.21 - 22.50 GHz is allocated by the ITU as co-primary for the Earth Exploration Satellite Service (EESS), and is currently used by the U.S. Geosat Follow-On (GFO) water vapor radiometer and Defense Meteorological Satellite Program (DMSP) SSM/I and SSMIS sensors. This band spans the 22.235 GHz line peak, but is asymmetrically located, with a center frequency 100 MHz higher than the actual line center frequency. Its application to integrated water vapor retrieval along with its current co-primary allocation and use within radio astronomy suggest that it should not be used for the proposed vehicular radar systems, and that a guard band of at least 50 MHz remain on its upper side.

The band 23.6 - 24.0 GHz is allocated to the EESS by the ITU on a primary basis, and will be used by the U.S.-Japanese EOS AMSR-E sensor and the U.S. National Polar Orbiting Environmental Satellite System (NPOESS) Conical Microwave Imager and Sounder (CMIS) for maritime moisture sensing. It is also currently used by the U.S. NASA Jason Microwave Radiometer (JMR) and NOAA Advanced Microwave Sounding Unit (AMSU-A). Along with the band from 21.2 - 21.4 GHz (200 MHz), the 23.6-24.0 GHz band is at one of two critical remote sensing "hinge points" of the 22.235 GHz water vapor line. The significance of the hinge point is that at this frequency the absorption caused by a fixed column amount of water vapor is largely independent of pressure, and so measurements of integrated water vapor over the ocean can often be done more accurately than at frequencies where the absorption is more pressure dependent. In spite of there being two such hinge points, the 23.6-24.0 GHz band is preferred over the 21.2 - 21.4 GHz

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band for vapor measurement due to its primary allocation status. While measurements in the 22.21 - 22.50 GHz band are more sensitive (by approximately a factor of two) to water vapor content, they are also more sensitive to the altitude distribution of water vapor than for the 23.6-24.0 GHz band.

III. Ground Based Remote Sensing

Studies have shown that ground-based radiometric profiling of water vapor for a variety of meteorological application can also be performed in the ~22 - 27 GHz spectral range. For example, skill levels for 1 - 12 hour forecasts based on traditional twice-daily radiosondes can be improved using radiometric profiling. Although traditional 1-hour forecasts are reasonably accurate, forecast skill rapidly degrades until new radiosonde observations are obtained 12 hours later. Radiometric profiling applications include short-term precipitation, visibility, fog and icing forecasting; direct measurement of supercooled liquid water for detection of aircraft icing conditions, and detection of refractivity profiles associated with radar ducting. Newly available portable radiometric and wind profilers can be also used in chemical, biological, and nuclear dispersion modeling and for improved artillery targeting. In the U.S., simulations have shown that slant GPS with radiometric and wind profiler observations can provide high resolution three dimensional wind and moisture analysis.

While ground-based profiling of water vapor has many applications, the benefits can be precluded by radio frequency interference. The optimum frequencies (as determined using eigenanalysis) for water vapor profiling are: 22.235 GHz, 23.2 GHz, 23.8 GHz, 26.0 GHz, and 31.4 GHz, with minimum bandwidths of ~200 MHz. The frequencies closest to the 22.235 GHz line center are most important. The required interference thresholds, however, are on the order of 0.2 K since the ground-based technique is more sensitive than the satellite technique. The required interference thresholds, however, are on the order of 0.2 K since the ground-based technique is more sensitive than the satellite technique. Degradation or defeat of these passive remote sensing capabilities by allowing widespread active use of the spectrum in wavebands close to those listed above would have a severe impact on beneficial remote sensing technologies, for which no cost-effective substitute is currently available.

IV. Allowable Power Density

The averaged transmitted power density corresponding to a specified radiometric interference threshold temperature is given by equation (1). This expression gives the maximum allowable average power for a transmitter within a satellite footprint or ground-based radiometer's approximate range of sensitivity (see appendix for derivation).

$$P_{Tav} \cdot s_{vh}^2 < 4\pi \cdot \frac{kT_{th}B}{\lambda^2} \qquad (1)$$

P_{Tav} = average radiated power density (W/m^2)
k = Boltzmann's constant (1.38E-23 J/K)
T_{th} = allowable interference threshold (K)
B = radiometric bandwidth (Hz)
λ = wavelength (m)
s^2_{vh} = effective scattering and coupling coefficient

In general, direct reception of transmitted energy via side-lobes of the transmitters and radiometer is not necessarily the strongest means of coupling. Instead, power transmitted from radars or communication devices can be received via non-line-of-sight paths by the scattering of the transmitted power from objects illuminated by these devices. The parameter s^2_{vh} accounts for the aggregate coupling from horizontal transmission (preferred for vehicular radar) to the vertically-pointing radiometer, and can be assumed to be between -6 dB to –30 dB. The polarization properties of the scattered fields can be assumed to be random and hence disregarded in the calculation. It should be noted that s^2_{vh} also incorporates path loss due to atmospheric attenuation and scattering, although these effects are typically less than ~3 dB in magnitude and thus not dominant at 22-27 GHz except for long horizontal paths.

Example: The allowable power densities for satellite and ground-based radiometric remote sensing are illustrated by the following example. Given:

B = 200 MHz (radiometer bandwidth)
λ = 1.25 cm (wavelength for 24 GHz)
s^2_{vh} = -10 dB
T_{th} = 0.05 K (threshold temperature)

The allowable aggregate transmitted power density within the satellite footprint becomes $P_{Tav} = 110.9\ pW/m^2$.

In Figure 1 the maximum allowable power density referenced to a 1-square kilometer area is plotted as a function of radiometer bandwidth. The figure can be used for a quick assessment of interference likliehood. In this calculation only that part of the interferers' time averaged spectral power density within the bandwidth of the radiometer is considered.

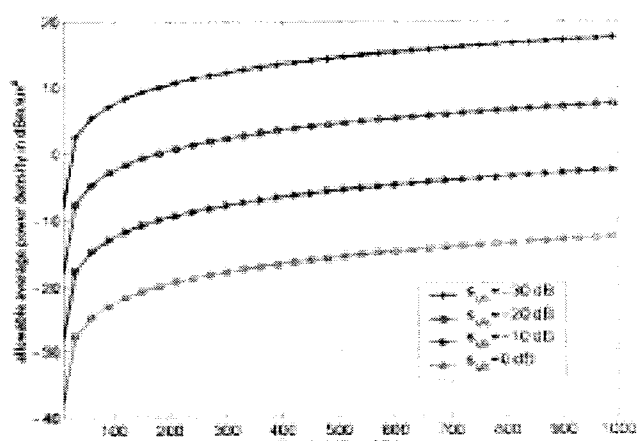

Figure 1: Allowable average aggregate radiated power P_{Tav} from interferers for various scattering coeffi-

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cients as a function of radiometric bandwidth B. The figure assumes f_o = 24 GHz and T_{th} = 0.05 K and 1 km^2 area.

V. ALLOWABLE TRANSMITTER DENSITY

From the above the permissible density of transmitters of a given power level can be directly calculated. As it is assumed that the integration time of the radiometers is much longer than the pulse repetition period of the transmitter, the average transmitted power is the relevant number for a radar system. Given n interferers per unit area and an average power P_{STav} for a single transmitter, then $nP_{STav} = P_{Tav}$ and (1) can be solved for the allowable density n:

$$n < \frac{4\pi}{P_{STav} s^2} \cdot \frac{kT_{th}B}{\lambda^2} \qquad (2)$$

In area density calculations the linear distribution of vehicular traffic needs to be considered. It can be assumed that a ~0.1 m^{-1} maximum linear density of vehicles exists on a typical roadway, but such roadways occupy only a fraction of the total area of an urban region. Given that a typical satellite footprint is approximately 25 km in diameter, and the roadways running across this footprint may consist of several lanes of traffic, the effective area density of traffic is computed according to the total length of roadways within the footprint multiplied by the linear density of traffic and divided by the total area of the footprint. As an example, assume 10 total lanes of traffic at maximum density across the above footprint, in which case the actual average density becomes ~51 transmitters per km^2. Assuming that P_{STav} =0.1 W per vehicle (20 dBm) this density is almost five orders of magnitude greater than that allowed for the spaceborne radiometer in the previous example.

VI. SUMMARY

A simple procedure to estimate the maximum permissible transmitter power and density is provided. Using this procedure it is concluded that vehicular radar sensors and communication systems can impart serious interference to passive microwave Earth remote sensing applications in the bands 22.21 - 22.50 GHz, 23.1 - 23.3 GHZ, 23.6 - 24.0 GHz and 25.9 - 26.1 GHz. It is also shown that the radiometer's specific antenna system parameters need not be regarded since these factors are common to the received radiometric thermal power and interfering power.

APPENDIX

In the following Eq. (1) is derived.

A. Radiometric Power. The radiometric noise power is described through the brightness spectrum. At radiofrequencies the spectral brightness B_f is given by the Rayleigh-Jeans law [1]:

$$B_f(\theta,\psi) = \frac{2kT_{th}(\theta,\psi)}{\lambda^2} \qquad (3)$$

where B_f is the spectral brightness in Watt m^2 sr^{-1} Hz^{-1}, T_{th} the allowable interfering brightness temperature and k is Bolzmann's constant.

The available power at the antenna terminals P_{Tav} is calculated by summing up all contributions weighted by the radiation pattern C of the antenna, giving

$$P_R = A_w \int_{f_o - B_R/2}^{f_o + B_R/2} \frac{1}{2} \iint_{4\pi} B_f(\theta,\psi) \cdot C^2(\theta,\psi) d\Omega \, df \qquad (4)$$

where A_w is the effective area of the radiometer's antenna and B_R is the bandwidth of the radiometer.

Assuming a small fractional bandwidth and the brightness temperature to be constant within the antenna's footprint, yields the following expression for the available power:

$$P_R = A_w B_R \frac{k}{\lambda^2} T_{th} \iint_{4\pi} C^2(\theta,\psi) d\Omega \qquad (5)$$

B. Interfering Power. The received power at the antenna due to an interferer having a time-averaged spectral power density p_I is given by:

$$P_I = A_w \frac{1}{4\pi R^2} \int_{f_o - B_I/2}^{f_o + B_I/2} \iint_{area} p_I(\theta,\psi) s^2 vh \cdot C^2(\theta,\psi) dA \, df \qquad (6)$$

where R is the distance to the interferer and B_I is the bandwidth occupied by the interferer. For a constant spectral density of the interferers, the above expression simplifies to:

$$P_I = A_w B_I p_I \frac{s^2 vh}{4\pi} \iint_{4\pi} C^2(\theta,\psi) d\Omega \qquad (7)$$

C. Comparison. Requiring that $P_I < P_R$ and by comparing (5) to (7) results in

$$p_I < 4\pi \frac{kT_{th}B_R}{s^2 vh \lambda^2 B_R} \qquad (8)$$

The time averaged interferer power within the bandwidth of the radiometer B_R is:

$$P_{Tav} = p_I B_I \qquad (9)$$

which yields the results of equation (1) wherein the specifics of the antenna pattern cancel.

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