ABSTRACT

Active Microwave and Millimeter Wave SAR Remote Sensing

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Active Microwave and Millimeter Wave SAR Remote Sensing

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ABSTRACT

Spaceborne active sensors operate in frequency bands allocated to the Earth Exploration-Satellite (EES) (active) and Space Research (SR) (active) Services. The synthetic aperture radar (SAR) is one type of spaceborne active sensor, which produces a radar image or interferometric topographical map of the Earth's or planet's surface. There are some thirteen frequency bands presently allocated to EESS (active) and SRS (active), ranging from 1.215 GHz to 195 GHz, going from microwave frequencies to millimeter wave frequencies. This paper presents the performance and interference criteria for spaceborne active sensors, interference mitigation techniques, and allocation considerations for certain frequency bands for the upcoming WRC 2003.

INTRODUCTION

Spaceborne active sensors operate in frequency bands allocated to the Earth Exploration-Satellite (EES) (active) and Space Research (SR) (active) Services. The synthetic aperture radar (SAR) is one type of spaceborne active sensor. The spaceborne SAR is an active sensor looking to one side of the spacecraft nadir track, collecting a phase and time history of the coherent radar echo from which typically can be produced a radar image or interferometric topographical map of the Earth's or planet's surface. The SAR can be operated as a bistatic SAR in that the transmitter is on a different platform from the receiver platform, which is often at a much lower orbit altitude, or more typically, a monostatic SAR in that the transmitter and receiver are collocated on the same platform. The SAR characteristics are shown in Table 1. The typical SAR looks off to one side, with the angle from nadir to antenna boresight of 20 deg to 55 deg. The 3 dB antenna footprint on the Earth's surface is typically fixed to one side at broadside or at a squinted angle or can be scanned in elevation across-track to increase the swath width by scanning several beams over scan cycles during the azimuth integration time. The footprint can also be scanned in azimuth along-track to spotlight a particular location on the Earth's surface in order to increase the azimuth resolution. The SAR antenna length along the velocity vector is nominally several times the width in elevation to give the antenna pattern a fan beam shape and the resulting footprint on the Earth's surface is elongated in elevation many tens of kilometers and shortened in azimuth to a few kilometers. Thus at typical orbit altitudes of 225 km to 800 km, the footprint flies past a given point on the Earth in a second or less, so that the interference in the antenna mainbeam is very fleeting. The average radiated power is the product of the peak radiated power and the duty factor, which for the pulsed system is the pulse width times the pulse repetition frequency (PRF). So if the radiated peak power ranges from 1.5 kW to 8 kW and the duty factor ranges from 1% to 5 %, then the average radiated power ranges from 15 Watts to 400 Watts. The spectrum width in range, which determines the resolution in range for linear FM pulses or similarly coded pulses, is typically 20 MHz to 300 MHz. The SAR service area depends on the application, and includes land, coastal, and ocean areas.

FREQUENCY BANDS WITH COMPATIBILITY STUDIES- 420 MHZ TO 195 GHZ

There are some thirteen frequency bands presently allocated to EESS (active) and SRS (active), ranging from 1.215 GHz to 195 GHz, as shown in Table 2. In addition, the 420-470 MHz band is under consideration in the WRC-2003 resolution 727, with a resolves to consider provision of up to 6 MHz of frequency spectrum to the EESS (active). Also, the 5460-5570 MHz band is under consideration in the WRC-2003 resolution 736 resolves to consider additional

Table 1 - Spaceborne SAR Characteristics

Parameters	Typical SAR Characteristics
Viewing Geometry	Side-looking @20-55 deg off nadir
Footprint/ Dynamics	(1) Fixed to one side at broadside or at a squinted angle (2) ScanSAR (3) Spotlight
Antenna Beam	Fan beam
Radiated Peak Power	1500-8000 W
Waveform	Linear FM pulses
Spectrum Width	20-300 MHz
Duty Factor	1-5 %
Service Area	Land/ coastal/ Ocean

primary allocation for the EESS (active) and SRS (active). The microwave bands include the ten bands in Table 2 from 420-470 MHz to 24.05-24.25 GHz. The millimeter wave bands include the five bands in Table 2 from 35.5-35.6 GHz to 192.0-195.0 GHz.

FREQUENCY ALLOCATIONS – REQUESTED AND ALREADY ALLOCATED BASED ON SHARING STUDIES AND EXPERIMENTS

Out of the thirteen allocated frequency bands, the 3.1-3.3 GHz and 24.05-24.25 GHz bands are secondary allocations, the 78-79 GHz band is allocated by footnote S5.560, and the 94.0-94.1 GHz band is limited to spaceborne cloud radars by footnote S5.562. Prior to the WRC-1997, JWP 7-8R performed, in some thirteen bands, compatibility studies between the spaceborne active sensors and the radiolocation/ radionavigation services to support the various frequency allocation upgrades from secondary by footnote, to primary allocation. In addition, several experiments were performed to investigate sharing with the radiolocation/ radionavigation services, in the band 1215-1300 MHz. GPS/SAR compatibility was tested during reception of actual GPS satellite signals into the GPS receiver while at the same time injecting SAR interference signals; the GPS experienced only a few tenths of a dB degradation in the tracking loop SNR, which was deemed acceptable. Also, ARSR-4/SAR compatibility was tested at the Washington/Baltimore airport ARSR-4 facility by simulating the tracking of ARSR-4 targets as the antenna rotated, and at the same time injecting SAR-like signals into the front end of the ARSR-4; the ARSR-4 performed nominally even as the I/N was increased to +20 dB, revealing some 30 dB of processing gain for the ARSR-4 system.

INTERFERENCE CRITERIA- ITU-R RECOMMENDATION

The performance and interference criteria for active spaceborne sensors are given in Rec. ITU-R SA.1166. The performance criteria allows a degradation of the normalized standard deviation of power received from a pixel by less than 10%. The interference criteria allows an aggregate interference power to noise power ratio (I/N) of –6 dB and the maximum allowable interference level should not be exceeded for more than 1% of the images in the sensor service area.

INTERFERENCE MITIGATION- NEσ_0 EQUATION, PARAMETERS VARIED TO REDUCE PEAK AND AVERAGE INTERFERENCE

Interference mitigation techniques are provided in the Rec. ITU-R SA.1280 and addresses the selection of active spaceborne sensor emission characteristics to mitigate the interference potential to terrestrial radars. The equation for the on-tune rejection (OTR) is given whereby the interference level into the terrestrial radar receiver is mitigated for large SAR bandwidths or chirp rates. One important performance parameter for SARs is the noise equivalent

Table 2 - Compatibility Studies by Frequency Band

Frequency Band (MHz)	Allocation Status	Typical SARs Studied	EESS (active)/SR (active)	Other Services in Band Included in Compatibility Studies
420-470	No allocation, 6 MHz bandwidth under consideration in WRC'03 Res. 727	(F)	EESS(active), SR(active)	RADIOLOCATION,RNSS, AMATEUR, FIXED, MOBILE
1215-1300	Primary (WRC'97)	SIR-C, JERS-1	EESS(active), SR(active)	RADIOLOCATION,RNSS, Amateur (secondary)
3100-3300	Secondary (WRC'97)	ALMAZ	EESS(active), SR(active)	RADIOLOCATION
5250-5460	Primary (WRC'97)	RADARSAT, ASAR, ERS1/2, ENVISAT ASAR(F), RADARSAT-2	EESS(active), SR(active)	RADIOLOCATION (active and secondary), AERONAUTICAL RNSS
5460-5570	No allocation, under consideration in WRC'03 Res. 736	(F)	EESS(active), SR(active)	RADIOLOCATION
8550-8650	Primary (WRC'97)	(P)	EESS(active), SR(active)	RADIOLOCATION
9500-9800	Primary (WRC'97)	X-SAR	EESS(active), SR(active)	RADIOLOCATION, RADIONAVIGATION
13250-13750	Primary (WRC'97)		EESS(active), SR(active)	AERONAUTICAL RNSS, RADIOLOCATION
17200-17300	Primary (WRC'97)		EESS(active), SR(active)	RADIOLOCATION
24050-24250	Secondary (WRC'97)		EESS(active)	RADIOLOCATION, Amateur (secondary)
35500-35600	Primary (WRC'97)		EESS(active), SR(active)	RADIOLOCATION,METEOLOGICAL AIDS
78000-79000	Primary by RR footmote S5.560 (WRC'97)		EESS(active), SR(active)	
94000-94100	Primary by RR footmote S5.562 for spaceborn cloud radars only (WRC'97)		EESS(active), SR(active)	RADIOLOCATION
130000-131000	Primary (WRC'2000)		EESS(active), SR(active)	RADIOLOCATION
192000-195000	Primary (WRC'2000)		EESS(active), SR(active)	RADIOLOCATION

backscatter cross section (NE σ_0), which is that backscatter cross section for which the signal-to-noise ratio is 0 dB. By optimally selecting SAR parameters, the NE σ_0 can be minimized and at the same time, the SAR interference peak or average power into other services can be minimized.

CURRENT WRC '03 STUDIES- 420-470 MHZ AND 5460-5570 MHZ BANDS

The WRC-2003 resolution 727 resolves to consider provision of up to 6 MHz of frequency spectrum to the EESS (active) in the band 420-470 MHz. Several studies from the spaceborne active sensor community has analyzed the interference from spaceborne SARs in the band 420-470 MHz into Earth stations, the radio amateur service, fixed service, and ISM equipment, concluding that although there may be occasional interference to the various other services, that the interference will be short in time and will have a very long interval of six months or longer and thus the affected service will not be rendered incapable of operating effectively; the study would need to be extended with a sharing analysis with terrestrial space object tracking radars. Another study by the from the spaceborne active sensor community analyzes the interference levels of a very low power, low sidelobe spaceborne SAR into the amateur and amateur satellite services, offering that the SAR parameters can be chosen for certain SAR modes to reduce the interference level to acceptable levels. Mitigation techniques include lowering the antenna sidelobes in both azimuth and range, and lowering the average power for certain modes with reduced backscatter sensitivity.

The WRC-2003 resolution 736 resolves to consider additional primary allocation for the EESS (active) and SRS (active) in the band 5460-5570 MHz. For the 5460-5570 MHz band, the previous studies in the 5250-5460 MHz band showing compatibility between spaceborne active sensors and the radiolocation/ radionavigation services, have been extended to the band 5460-5570 MHz. In addition, several studies from the spaceborne active sensor community has analyzed the compatibility between spaceborne SARs in the band 5470-5570 and wireless access systems including RLANs in the mobile service. In the interference mitigation techniques as provided in the Rec. ITU-R SA.1280, the selection of active spaceborne sensor emission characteristics can help to mitigate the interference potential to terrestrial radars. One consideration for this 5460-5570 MHz band is to use it for the wideband SARs with high time- bandwidth products, which tend to give high on-tune rejection factors and thereby lower the interference levels into terrestrial radars. The wider SAR bandwidths also give higher kTB system noise temperatures, allowing greater acceptable interference levels from other services, and further improves the sharing situation.