WILTSHIRE & GRANNIS LLP

April 7, 2014

Ex Parte

Marlene H. Dortch
Secretary, Federal Communications Commission
445 12th Street SW
Washington, DC 20554

Re: *Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, ET Docket No. 13-49*

Dear Ms. Dortch:

On April 3, 2014, Alan Norman of Google Inc., Andy Scott of the National Cable & Telecommunications Association, Mary Brown of Cisco Systems, Inc. and I met with Julius Knapp, Mark Settle, Karen Rackley, and Aole Wilkins of the Office of Engineering and Technology, regarding the above-captioned proceeding. Specifically, we discussed the attached paper that analyzes the potential for interference to incumbent systems in the U-NII-2B band and identifies methods of protecting incumbent systems.

Pursuant to the Commission's rules, this letter is being submitted for inclusion in the public record of the above-captioned proceeding.

Sincerely,

/s/ Paul Margie

Paul Margie
Counsel to Google Inc.

cc: Meeting participants

Enclosure

Databases Allow RLANs to Protect Incumbent Services in the 5350 – 5470 MHz Band

The incumbent services in the 5350 – 5470 MHz band are Earth Exploration-Satellite Service (active), Radiolocation Service, Aeronautical Radionavigation Service, and Space Research Service (active). Recent studies have suggested that even with Dynamic Frequency Selection (DFS) and significant restrictions on usage and power, RLAN devices may not be able to protect these incumbent services. This paper shows that RLANs can protect incumbent services in the 5350 – 5470 MHz band by operating with location aware Access Points (AP's) capable of querying a centralized database. The database provides each AP with an authorization ticket indicating under what conditions it can operate in the band at its location, and with what transmit power restrictions. Tickets have a three-hour life. Only RLAN devices connected to an AP with a valid ticket can operate in the 5350 – 5470 MHz band, and only to the extent authorized by the ticket. The ticket specifies the maximum RLAN transmit power (dBm), as a function of time, under two conditions: 1) when the RLAN operates with an AP having a real-time connection to a Dedicated Listening Device (DLD) monitoring its area, and 2) when the RLAN operates with an AP that is not connected to a DLD.

The database is updated with protection zone schedules provided by government agencies and with orbital information for satellites operating in the EESS (active). The protection zone schedules define a geographic area and the RLAN transmit power limits under the two conditions as a function of time. As the tickets have limited, three hour life, changes to protection zones are fully implemented within three hours. Orbit information for EESS (active) satellites is either provided by the satellite operator, or obtained from publicly available databases. The database propagates the orbital information and combines it with an elevation/azimuth map for that particular satellite's antenna to determine areas, as a function of time, where RLAN transmit powers are limited to +17 dBm [TBR] in the 5350 – 5470 MHz band.

Using databases, RLAN operations completely protect incumbent services. Just as TV White Space databases operate today, database providers would not charge protected entities (government agencies and EESS (active) operators) for registration. Rather, unlicensed device makers/operators would pay for access to the database. Also, as with TV White Space databases, all interfaces would be standardized by industry. The interfaces described in this document are intended as a starting point for that process.

1 Incumbent Services

The ITU-R allocations for the 5350 – 5470 MHz band are shown in Table 1. The 5350 – 5460 MHz segment is allocated to the Earth Exploration-Satellite Service (active), the Radiolocation Service, the Aeronautical Radionavigation Service, and the Space Research Service (active) on a co-primary basis. The 5460 – 5470 MHz segment is allocated to the Earth Exploration-Satellite Service (active), the Radiolocation Service, the Radionavigation Service, and the Space Research Service (active) on a co-primary basis.

Table 1 – ITU-R Table of Frequency Allocations (5350 – 5470 MHz)

5 350-5 460 MHz	EARTH EXPLORATION-SATELLITE (active) 5.448B RADIOLOCATION 5.448D AERONAUTICAL RADIONAVIGATION 5.449 SPACE RESEARCH (active) 5.448C
5 460-5 470 MHz	EARTH EXPLORATION-SATELLITE (active) RADIOLOCATION 5.448D RADIONAVIGATION 5.449 SPACE RESEARCH

5.448B The Earth exploration-satellite service (active) operating in the band 5350 - 5570 MHz and space research service (active) operating in the band 5460 - 5570 MHz shall not cause harmful interference to the aeronautical radionavigation service in the band 5350 - 5460 MHz, the radionavigation service in the band 5460 - 5470 MHz and the maritime radionavigation service in the band 5470 - 5570 MHz. (WRC-03)

5.448C The space research service (active) operating in the band 5350 - 5460 MHz shall not cause harmful interference to nor claim protection from other services to which this band is allocated. (WRC-03)

5.448D In the frequency band 5350 - 5470 MHz, stations in the radiolocation service shall not cause harmful interference to, nor claim protection from, radar systems in the aeronautical radionavigation service operating in accordance with No. **5.449**. (WRC-03)

5.449 The use of the band 5350 - 5470 MHz by the aeronautical radionavigation service is limited to airborne radars and associated airborne beacons.

1.1 Earth Exploration Satellite Service (EESS) (active)

The technical characteristics of the EESS satellites operating in the 5350 – 5470 MHz band are provided in Appendix A[1]. The non-geostationary orbit (NGSO) satellite systems operating in the 5350 – 5470 MHz band are listed in Table 2. All of these satellites are in the EESS. The notified systems are: RADARSAT-2C, -2D, and -3B from Canada; HY-2 from China; JASON2 and 3 from France; SENTINEL-1 and -3 from France/ESA; and SMOTR from Russia. The aggregate number of notified satellites (having completed coordination) from all administrations in this band is 18. An additional 30 satellites have been advanced published (starting coordination).

[1] Extracted from Document 4-5-6-7/123-E (a liaison statement from WP7C)

Table 2 – NGSO Satellites Operating in the 5350 – 5470 MHz Frequency Range (ITU-R Space Network List)

Administration	Satellite	Status	# Satellites	Apogee/Perigee (km/km)	Inclination (°)	Period (HH:MM)	Class
Canada	RADARSAT-2C	Notified	1	789	98.6	1:41	EW
	RADARSAT-2D	Notified	1				
	RADARSAT-3B	Notified	6	617/586	97.7	1:36	E3
China	HY-2	Notified	1	963	99.34	1:44	E3
	FY-3-A	API	4	854/818	98.75	1:40	E3
France	JASON2	Notified	1	685	98.1	1:38	E3
	JASON3	Notified	1	1336	66	1:52	E3
France/ESA	SENTINEL-1	Notified	3	701.2/684.5	98.183	1:39	E3
	SENTINEL-3	Notified	3	808.1/791.5	98.6	1:41	E3
Indonesia	RISAT	API	1	536.38	97.6	1:35	E3
Luxemburg	LUX-NGSO-1	API	6	500	98	1:35	EW
	LUX-NGSO-2	API	6	500	105	1:35	EW
	LUX-NGSO-3	API	6	500	120	1:35	EW
Russia	SMOTR	Notified	1	650	97.37	1:35	E3
	GEO-IK-2	API	3	1000	99.4	1:45	E3
USA	OSTM	API	2	1336	66	1:52	E3
	USOCEAN	API	2	1336	66	1:52	E3

E3 - Space station in the Earth exploration-satellite service (active sensor)
EW - Space station in the earth exploration-satellite service

1.2 Radionavigation and Radiolocation Services

The technical characteristics of the radionavigation and radiolocation services operating in the 5350 – 5470 MHz band are provided in Appendix B[2].

[2] Extracted from Rec. ITU-R M.1638 Characteristics of and protection criteria for sharing studies for radiolocation, aeronautical radionavigation and meteorological radars operating in the frequency bands between 5250 and 5850 MHz.

2 System Architecture

The database based system architecture is shown in Figure 1. The database is updated with restrictions from government agencies and with EESS (active) satellite orbital information and antenna masks provided by operators. Location aware AP's query the database via the Internet to obtain an authorization ticket indicating under what conditions they can operate in the band at their locations, and with what transmit power restrictions. Tickets have a three-hour life. Only RLAN devices connected to an AP with a valid ticket can operate in the 5350 – 5470 MHz band, and only to the extent authorized by the ticket. The ticket specifies the maximum RLAN transmit power (dBm), as a function of time, under two conditions: 1) when the AP has a real-time connection to a Dedicated Listening Device (DLD) network monitoring its area, and 2) when the AP is not connected to a DLD network. These power limits can be set to a large negative number of dBm, effectively preventing the RLAN from operating during such a restriction.

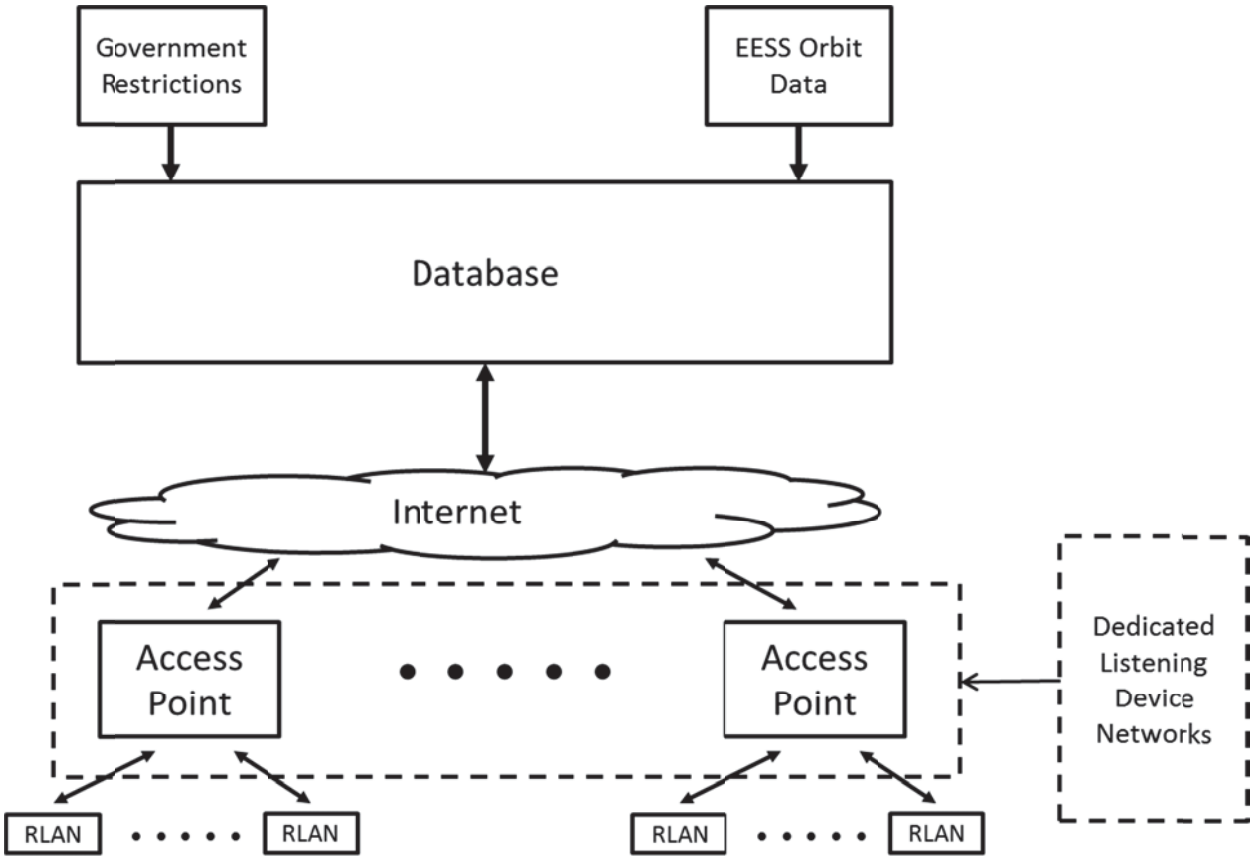


Figure 1 – Database Architecture

The database query consists of the AP identifier and AP location, as shown in Table 3. A secure HTTPS interface is used for all database queries and responses.

Table 3 – Database Query

AP Identifier	MAC Address
AP Location	Latitude (°N)
	Longitude (°E)

	Altitude (km)

The database response, the authorization ticket, is shown in Table 4. It contains a Ticket Identifier, the issue time, the AP Identifier, the AP location, and one, or more, Windows. Each Window contains a Window end time, the max authorized RLAN transmit power with a DLD network, and the max authorized RLAN transmit power without a DLD network. The power limits for each Window apply from the end time of the previous Window to the end time of the current window, expect for Window 1, which applies from the Issue Time of the ticket to the Window 1 end time.

Table 4 – Authorization Ticket

Ticket Identifier		XXXXXXXXXXXXXXXX
Issue Time		YYYYMMDD HH:MM:SS
AP Identifier		MAC Address
AP Location		Latitude (°N)
		Longitude (°E)
		Altitude (km)
Window 1	Window End Time	YYYYMMDD HH:MM:SS
	With DLD Tx Power Limit	Max RLAN Tx Power (dBm)
	Without DLD Tx Power Limit	Max RLAN Tx Power (dBm)
⋮	⋮	⋮
Window N	Window End Time	YYYYMMDD HH:MM:SS
	With DLD Tx Power Limit	Max RLAN Tx Power (dBm)
	Without DLD Tx Power Limit	Max RLAN Tx Power (dBm)

If there are no government restrictions in effect at the AP location, and if it is outside of all EESS (active) coverage's, then the database sets the power limits to +30 dBm (TBR). With this architecture, the transmit power at which an RLAN devices can operate in the 5350 – 5470 MHz band at a given time is limited based on the location of its associated AP to fully protect incumbent services.

2.1 Government Restrictions

Government restrictions are input to the database as shown in Table 5. Each restriction consists of ordered pairs of latitude and longitude defining a closed region, associated start and stop times for the restriction, and maximum RLAN transmit powers for operation with, and without, real-time connection to a DLD Network. Tickets issued by the database will immediately [TBR] reflect government restrictions as they are input. As the database tickets have limited, three hour, life, changes to protection zones are fully implemented within three hours of a restriction being entered into a database.

The Restriction Identifier allows the government entity to modify or cancel previously input restrictions.

Table 5 – Government Restriction

Government Entity Identifier	XXXXXXXXXXXXXXXX
Restriction Identifier	XXXXXXXXXXXXXXXX
Input Time	YYYYMMDD HH:MM:SS
Region	Latitude 1 (°N)
	Longitude 1 (°E)
	Latitude 2 (°N)
	Longitude 2 (°E)
	• • •
	Latitude N (°N)
	Longitude N (°E)
Start Time	YYYYMMDD HH:MM:SS
End Time	YYYYMMDD HH:MM:SS
With DLD Tx Power Limit	Max RLAN Tx Power (dBm)
Without DLD Tx Power Limit	Max RLAN Tx Power (dBm)

2.2 EESS (active) Satellites

The Joint Space Operations Center (JSpOC), detects, tracks, and identifies all artificial objects in Earth orbit, including all EESS satellites. Currently, the JSpOC tracks more than 16,000 objects orbiting Earth. About 5 percent of those being tracked are functioning payloads or satellites, 8 percent are rocket bodies, and about 87 percent are debris and/or inactive satellites. The Space Surveillance Network (SSN), a worldwide network of 30 space surveillance sensors (radar and optical telescopes, both military and civilian) takes approximately 400,000 observations per day to update the catalog of objects. Two-Line Element (TLE) parameter sets extracted from this data are available at www.space-track.org. Another source of TLE parameter sets is http://eostation.scanex.ru/schedule/tle/new.tle. The TLE sets allow for precise calculation of the satellite orbits.

Example TLE sets for the RADARSAT-2 satellite and for the JASON2 satellite follow:

```
0 RADARSAT 2
1 32382U 07061A 14026.88740895 .00000214 00000-0 10000-3 0 7207
2 32382 098.5775 036.4451 0001250 091.1167 025.3181 14.29985420319464

0 JASON 2
1 33105U 08032A 14026.53311414 -.00000043 00000-0 79234-4 0 8345
2 33105 066.0412 172.4118 0007624 275.7028 209.8476 12.80929882262079
```

The TLE format is described in Appendix C.

Orbit information for EESS (active) satellites is provided by the satellite operator. Operators can choose to provide orbital information either as a TLE set or as a reference to a web service, such as that provided by Space Track or EOStation.ScanEx.ru. If a web service reference is provided, the database will automatically obtain TLE sets from that source at one hour intervals. The database propagates the orbital information and combines it with an elevation/azimuth map for that particular satellite's antenna

to determine areas, as a function of time, where RLAN transmit powers are limited to +17 dBm [TBR] in the 5350 – 5470 MHz band. The input format is shown in Table 6.

The database propagates the TLE sets for the EESS (active) satellites using the SGP4 simplified perturbations model. The availability of frequent TLE updates allows this process to predicted satellite positions with better than 1-km [TBR] accuracy. This error is taken into account when identifying the RLAN exclusion zones.

Table 6 – EESS (active) Operator Input

EESS (active) Operator Identifier		XXXXXXXXXXXXXXXX
Input Time		YYYYMMDD HH:MM:SS
Two Line Element Set Or Web Service Reference		TLE (see Appendix C) Or Web Service Reference
Window A	Start Sub Satellite Point	Latitude A (°)
	End Sub Satellite Point	Latitude A (°)
	Satellite Antenna Azimuth-Elevation Mask	Az 1 (°)
		El 1 (°)
		Az 2 (°)
		El 2 (°)
		⋮
		Az N (°)
		El N (°)
⋮	⋮	⋮
Window X	Start Sub Satellite Point	Latitude X (°)
	End Sub Satellite Point	Latitude X (°)
	Satellite Antenna Azimuth-Elevation Mask	Az 1 (°)
		El 1 (°)
		Az 2 (°)
		El 2 (°)
		⋮
		Az N (°)
		El N (°)

2.3 Dedicated Listening Device (DLD) Networks

Each Dedicated Listening Device (DLD) network consists of one, or more, DLD's with low latency connections to AP's in their areas of coverage. The DLD's are location aware high sensitivity receivers installed at locations with views of the sky and surrounding terrain. DLD Networks contain a sufficient number of DLD's to provide unobstructed views of the sky and surrounding terrain, and hence eliminate the "hidden node" problem. They report the presence of radiolocation or radionavigation emissions to the AP's. An AP connected to a DLD Network, and its associated RLAN devices, must reduce all

transmissions within the 5350 to 5470 MHz band to the level specified in that AP's authorization ticket within 500 milliseconds [TBR] of that DLD Network detecting a radiolocation or radionavigation emission in the band. This reduction remains in effect for a minimum of 5 seconds after the last radiolocation or radionavigation emission detection.

Each AP that relies on a DLD Network pings that network every 30 seconds [TBR] and if it does not receive a response within 5 seconds [TBR] it reverts to the Without DLD Network power limit contained in its authorization ticket until such time as the connection is re-established. The purpose of this ping is to confirm that the AP continues to be connected to an operating DLD Network.

DLD's operate by detecting signatures of known radar types. Unknown radars can cause the DLD to detect them by transmitting a short signature of a known radar type. This provides a mechanism for new radars and radars whose signatures are not public to obtain protection.

DLD Networks must meet minimum performance requirements and are certified to industry standards.

3 European Concerns

France recently raised concerns with an avoidance approach in a European forum[3]. The approach considered is flawed in several respects. It assumes that individual RLAN devices would perform orbital calculations, and France rightly identifies concerns with this approach requiring dissemination of orbital data to individual RLAN devices and orbital propagation calculations in each device. The architecture presented in this paper avoids these issues by limiting orbital data and orbital propagation calculations to centralized databases; and only requiring Access Points that wish to operate in the 5350 - 5470 MHz band to query these databases.

[3] CPG-PTD(14)017.

APPENDIX A – Excerpt from Document 4-5-6-7/123-E

1 Technical characteristics of EESS (active) sensors in the 5 350-5 470 MHz band

The EESS (active) sensors performance and interference criteria are given in Recommendation ITU-R RS.1166-4. The band 5 350-5 470 MHz is expected to be used only by SAR and altimeters and the relevant interference criteria are given in Table 1.

Table 1

Sensor type	Interference criteria		Data availability criteria (%)	
	Performance degradation	I/N (dB)	Systematic	Random
Synthetic aperture radar	10% degradation of standard deviation of pixel power	–6	99	95
Altimeter	4% degradation in height noise	–3	99	95

Interference from RLAN being likely produced by an aggregation of interferer, they would hence be related to population densities and would hence more than likely be systematic. The percentage of data availability to be used in the RLAN case would therefore be 99%.

Table 2 provides relevant parameters to be used in any compatibility studies between RLAN and EESS (active) sensors.

Table 2

Parameter	Radarsat-1	Radarsat-2	Radarsat-3 (RCM)	Radarsat Next Generation (RNG)	Sentinel-1 CSAR	Sentinel 3 SRAL
Sensor type	SAR	SAR	SAR	SAR	SAR	ALTIMETER
Altitude (km)	792-813	792-813	586.9-615.2	586.9-615.2	653	800
Inclination (°)	98.6	98.6	97.74	97.74	98.18	98.65
Frequency (MHz)	5 300	5 405	5 405	5 405	5 405	5 410
Peak radiated power (W)	4 350	2 400 or 3 700	1 490	1 990	4140 (at ant input)	32 (at ant input)
Polarization	HH	HH, VV, HV,VH	HH, VV, HV,VH, compact (circular on Tx, linear on Rx)	HH, VV, HV,VH, compact (circular on Tx, linear on Rx)	V and H	Linear
Antenna type	Rectangular slotted waveguide	Phase array	Phase array	Phase array	Phase array	Parabolic reflector 1.2m
Antenna gain (dBi)	38-41	43	40-45	40-45	43.5 to 45.1	34.5
Antenna pattern steering	Steerable in elevation from 9 to 50°	Steerable in elevation from 9 to 50°	Steerable in elevation from 16 to 51°	Steerable in elevation from 16 to 53°	Steerable in elevation 18 to 40°	No (TBC)
Antenna pattern			**See Below**		**See Below (TBC)**	Based on F.699 (TBC)
Antenna orientation (° from nadir)	30^0 (right-looking)	$\pm 29.8^0$ (right- or left-looking)	33^0 (right-looking)	33^0 (right-looking)	20 to 47 deg	Nadir (altimeter)
Noise figure (dB)	5 (system)	6 (system)	6 (system)	6 (system)	3.2	3.8
Pulse/Receiver bandwidth (MHz)	11.6, 17.3 or 30.0	11.6, 17.3, 30, 50, 100	14-100 (selectable)	14-300 (selectable)	Up to 100 MHz	320
Noise power (dBW)	–130 to –126	–129 to –120	–128 to –119	–128 to –114	-121	-115
Service area	Global	Global	Global	Global	Global	Global
Footprint (km^2)	300 (avg)	300 (avg)	225 (avg)	225 (avg)	80 to 400 km continuous swath	48.4 km (diameter)
Image swath width (km)	45-500	18-500	20-500	20- 500	20 - 250	

2 Radarsat-3 (RCM) antenna patterns

Radarsat Constellation Mission (RCM) is the Earth observation satellite network which Canada is currently implementing with the characteristics given above. The antenna characteristics of RCM are described below.

There is a very large amount of beams for RCM, with different shapes, maximum gains, side lobes levels, elevation pointing angles, etc. The beams are very complex and the antenna patterns away from the main lobe are difficult to predict and may differ significantly from the predicted value in practice due to distortions, imperfections, etc.

For the sake of performing the interference analysis, a simplified model capturing the main characteristics of the beam, is given below (in dB):

$$D(\theta_{el}) = (0.12\theta_0 + 39.2) + 10log_{10}\left[sinc^2\left(\frac{40\sqrt{2}}{cos^2\theta_0}sin(\theta_{el} - \theta_0)\right)\right], \quad (1)$$

where θ_0 is the elevation pointing angle in degree and sincx=sinx/x. The sinc antenna pattern is the directivity of a uniformly fed phased array and is a good approximation of the pattern in the main lobe region. The (0.12 θ_0+39.2) factor captures the variation of the maximum directivity with the scan angle and is representative of the RCM performance. The geometrical factors in the sinc() function capture the variation of the beamwidth to provide about constant swath over the span of elevation angles.

Away from the boresight, this model must be used with care. The directivity computed from Eq. 1, should be limited to –60 dB below the maximum directivity. For example, for the pattern with the lowest directivity shown in Figure 1, the maximum directivity is 41.5 dBi and the minimum used in the study should be (41.5 – 60) = –18.5 dBi. An example is shown in Figure 2. It should be noted that in reality side lobes level varies significantly from one beam to another and this model is a simplification.

In azimuth (direction of satellite propagation), the pattern is simpler and can be approximated by a sinc function (uniform illumination) pointing at zero degree, with a 3 dB width in radian given by: $\theta_{3\,dB} \approx 0.886\lambda/L$, where L=6.75 m. The simplified directivity pattern in azimuth is given by

$$D(\theta_{az}) = 10log_{10}\left[sinc^2\left(\left(\frac{\pi L}{\lambda}sin\theta_{az}\right)\right)\right], \quad (2)$$

where θ_{az} is the azimuth angle.

The overall gain is the product (sum in dB) of the elevation and azimuth antenna beam patterns, with a floor at –60 dB below the peak value.

Figure 1 Example of antenna patterns for three different beams over the accessible swath

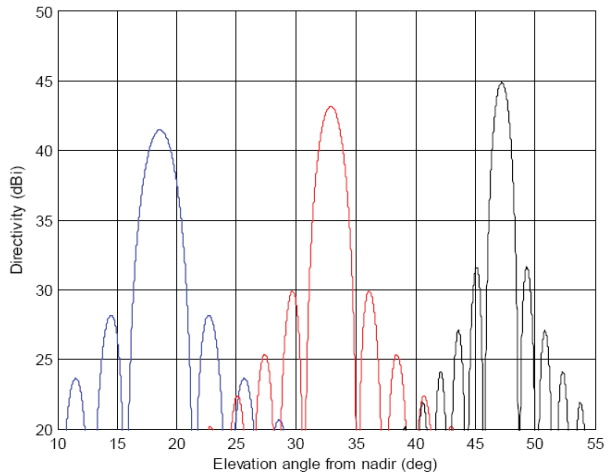
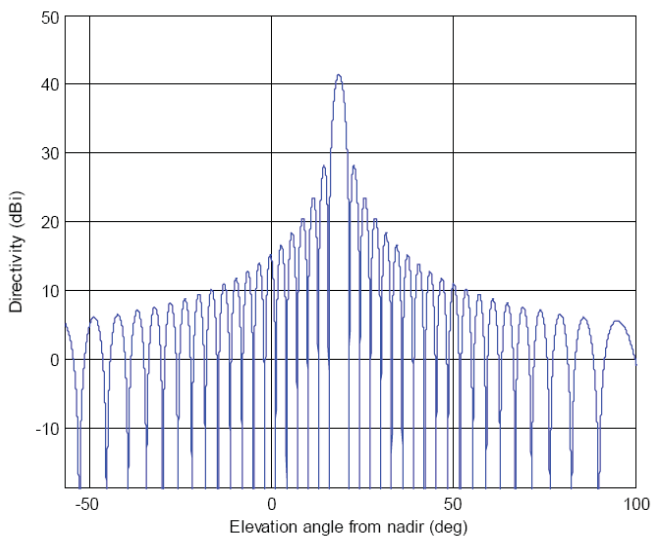


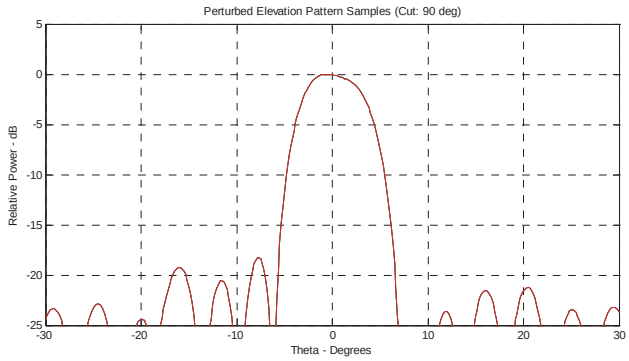
Figure 2 Antenna pattern of Figure 1 given on a larger angular extend to show sidelobe performance



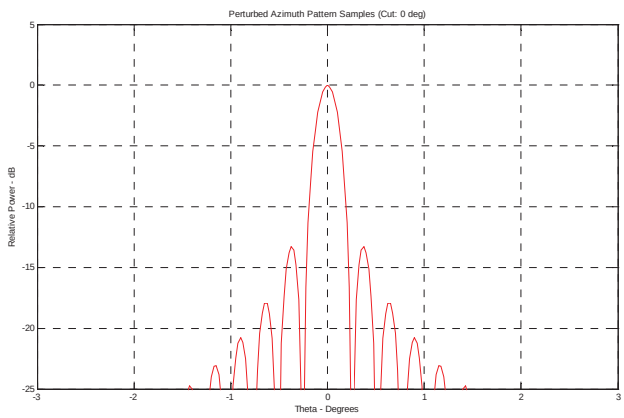
3.1 Sentinel-1 antenna patterns

Below is given an example of antenna pattern for one the sentinel-1 emission mode.

3.2 Elevation (Directivity: 43.53 dBi)



3.3 Azimuth



APPENDIX B – Excerpt from M.1638

Characteristics	Radar A	Radar B	Radar C	Radar D	Radar E	Radar F	Radar G	Radar H	Radar I	Radar J
Function	Meteorological	Meteorological	Meteorological	Aeronautical radionavigation	Meteorological	Meteorological	Meteorological	Meteorological	Meteorological	Meteorological
Platform type (airborne, shipborne, ground)	Ground/ship	Airborne	Ground	Airborne	Ground	Ground	Ground	Ground	Ground	Ground
Tuning range (MHz)	5 300-5 700	5 370	5 600-5 650	5 440	5 600-5 650	5 300-5 700	5 600-5 650	5 600-5 650	5 600-5 650	5 250-5 725
Modulation	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Conventional	With Doppler capability	With Doppler capability
Tx power into antenna	250 kW peak 125 W avg.	70 kW peak	250 kW peak 1 500 W avg.	200 W peak	250 kW peak	250 kW peak	250 kW peak	250 kW peak 150 W avg.	250 kW peak 150 W avg.	2.25 kW peak
Pulse width (µs)	2.0	6.0	0.05-18	1-20	1.1	0.8-2.0	3.0	0.8-5	0.8-5	0.1
Pulse rise/fall time (µs)	0.2	0.6	0.005	0.1	0.11	0.08	0.3	0.2-2	0.2-2	0.005
Pulse repetition rate (pps)	50, 250 and 1 200	200	0-4 000	180-1 440	2 000	250-1 180	259	250-1 200	50-1 200	100 000
Output device	Coaxial magnetron	Coaxial magnetron	Klystron	Magnetron	Klystron	Tunable magnetron	Coaxial magnetron	Coaxial magnetron or Klystron	Coaxial magnetron	Coaxial magnetron
Antenna pattern type (pencil, fan, cosecant-squared, etc.)	Conical	Fan	Pencil	Pencil	Pencil	Pencil	Pencil	Pencil	Pencil	Pencil
Antenna type (reflector, phased array, slotted array, etc.)	Solid metal parabolic	Parabolic	Parabolic	Slotted array	Parabolic	Parabolic	Solid parabolic	Solid parabolic	Solid parabolic	Solid parabolic
Antenna polarization	Vertical	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal	Horizontal and/or vertical	Horizontal or vertical	Horizontal or vertical
Antenna main beam gain (dBi)	39	37.5	44	34	50	40	40	40-50	40-50	35-45

Characteristics	Radar A	Radar B	Radar C	Radar D	Radar E	Radar F	Radar G	Radar H	Radar I	Radar J
Antenna elevation beamwidth (degrees)	4.8	4.1	0.95	3.5	< 0.55	< 1.0	1.65	0.5-2	0.5-2	2.4-12
Antenna azimuthal beamwidth (degrees)	0.65	1.1	0.95	3.5	< 0.55	< 1.0	1.65	0.5-2	0.5-2	1.5-12
Antenna horizontal scan rate (degrees/s)	0.65	24	0-36 (0-6 rpm)	20	21-24	30-48	30-48	6-18 (1-3 rpm)	6-18 (1-3 rpm)	1.2
Antenna horizontal scan type (continuous, random, 360°, sector, etc.) (degrees)	360	180 Sector	360	Continuous	Continuous 360 Sector	360	360	360	360	360
Antenna vertical scan rate (degrees/s)	N/A	N/A	N/A	45	15	15	15	1-10	1-14	N/A
Antenna vertical scan type (continuous, random, 360°, sector, etc.) (degrees)	N/A	N/A	N/A	Sector	Stepwise, 0.5-60	Stepwise, −2 to +60	−1 to +60	−1 to +90	−5 to +90	N/A
Antenna side-lobe (SL) levels (1st SLs and remote SLs) (dB)	−26	−20	−35	−31	−27	−25	−25	−25 to −35	−25 to −35	−20
Antenna height (m)	30	Aircraft altitude	10	Aircraft altitude	30	30	30	6-30	6-30	10
Receiver IF 3 dB bandwidth (MHz)	0.5	0.6	20	1.0	0.91	0.6	0.25 to 0.5	0.7 to 4	0.1 to 3.0	10
Receiver noise figure (dB)	7	6	4	5	2.3	3	3	3.5-8	1.5-8	3
Minimum discernable signal (dBm)	−110	−106	−97	−109	−109	−109 to −112	−114	−113 to −120	−113 to −120	−113 to −118

Characteristics	Radar K	Radar L	Radar M	Radar N	Radar O	Radar P	Radar Q	Radar R	Radar S
Function	Instrumentation	Instrumentation	Instrumentation	Instrumentation	Instrumentation	Surface and air search	Surface and air search	Research and Earth imaging	Search
Platform type (airborne, shipborne, ground)	Ground	Ground	Ground	Ground	Ground	Ship	Ship	Airborne	Airborne
Tuning range (MHz)	5 300	5 350-5 850	5 350-5 850	5 400-5 900	5 400-5 900	5 300	5 450-5 825	5 300	5 250-5 725
Modulation	N/A	None	None	Pulse/chirp pulse	Chirp pulse	Linear FM	None	Non-linear/ linear FM	CW pulse
Tx power into antenna	250 kW	2.8 MW	1.2 MW	1.0 MW	165 kW	360 kW	285 kW	1 or 16 kW	100-400 W
Pulse width (µs)	1.0	0.25, 1.0, 5.0	0.25, 0.5, 1.0	0.25-1 (plain) 3.1-50 (chirp)	100	20.0	0.1/0.25/1.0	7 or 8	1.0
Pulse rise/fall time (µs)	0.1/0.2	0.02-0.5	0.02-0.05	0.02-0.1	0.5	0.5	0.03/0.05/0.1	0.5	0.05
Pulse repetition rate (pps)	3 000	160, 640	160, 640	20-1 280	320	500	2 400/1 200/ 750	1 000-4 000	200-1 500
Chirp bandwidth (MHz)	N/A	N/A	N/A	4.0	8.33	1.5	N/A	62, 124	N/A
RF emission bandwidth –3 dB –20 dB (MHz)	4.0 10.0	0.5-5	0.9-3.6 6.4-18	0.9-3.6 6.4-18	8.33 9.9	1.5 1.8	5.0/4.0/1.2 16.5/12.5/7.0	62, 124 65, 130	4.0 10.0
Antenna pattern type (pencil, fan, cosecant-squared, etc.)	Pencil	Pencil	Pencil	Pencil	Pencil	Cosecant-squared	Fan	Fan	Pencil
Antenna type (reflector, phased array, slotted array, etc.)	Parabolic reflector	Parabolic	Parabolic	Phased array	Phased array	Parabolic	Travelling wave feed horn array	Two dual polarized horns on single pedestal	Slotted array

Characteristics	Radar K	Radar L	Radar M	Radar N	Radar O	Radar P	Radar Q	Radar R	Radar S
Antenna polarization	Vertical/left-hand circular	Vertical/left-hand circular	Vertical/left-hand circular	Vertical/left-hand circular	Vertical/left-hand circular	Horizontal	Horizontal	Horizontal and vertical	Circular
Antenna main beam gain (dBi)	38.3	54	47	45.9	42	28.0	30.0	26	30-40
Antenna elevation beamwidth (degrees)	2.5	0.4	0.8	1.0	1.0	24.8	28.0	28.0	2-4
Antenna azimuthal beamwidth (degrees)	2.5	0.4	0.8	1.0	1.0	2.6	1.6	3.0	2-4
Antenna horizontal scan rate (degrees/s)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	36, 72	90	N/A	20
Antenna horizontal scan type (continuous, random, 360°, sector, etc.) (degrees)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	Continuous 360	30-270 Sector	Fixed to left or right of flight path	Continuous
Antenna vertical scan rate (degrees/s)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A	N/A	N/A	N/A
Antenna vertical scan type (continuous, random, 360°, sector, etc.) (degrees)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A (Tracking)	N/A	Fixed	Fixed in elevation (–20 to –70)	N/A
Antenna side-lobe (SL) levels (1st SLs and remote SLs) (dB)	–20	–20	–20	–22	–22	–20	–25	–22	–25
Antenna height (m)	20	20	8-20	20	20	40	40	To 8 000	9 000
Receiver IF 3 dB bandwidth (MHz)	1	4.8, 2.4, 0.25	4, 2, 1	2-8	8	1.5	1.2, 10	90, 147	1
Receiver noise figure (dB)	6	5	5	11	5	5	10	4.9	3.5
Minimum discernable signal (dBm)	–105	–107	–100	–107, –117	–100	–107	–94 (short/medium pulse) –102 (wide pulse)	–90, –87	–110

APPENDIX C – Two-Line Element Description

Line	Columns	Description
1	1	Line Number
	2-24	The common name for the object based on information from the Satellite Catalog.
2	1	Line Number
	3-7	Satellite Catalog Number
	8	Elset Classification
	10-17	International Designator
	19-32	Element Set Epoch (UTC)
	34-43	1st Derivative of the Mean Motion with respect to Time
	45-52	2nd Derivative of the Mean Motion with respect to Time (decimal point assumed)
	54-61	B* Drag Term
	63	Element Set Type
	65-68	Element Number
	69	Checksum
3	1	Line Number
	3-7	Satellite Catalog Number
	9-16	Orbit Inclination (degrees)
	18-25	Right Ascension of Ascending Node (degrees)
	27-33	Eccentricity (decimal point assumed)
	35-42	Argument of Perigee (degrees)
	44-51	Mean Anomaly (degrees)
	53-63	Mean Motion (revolutions/day)
	64-68	Revolution Number at Epoch
	69	Checksum