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The Effect of a Proposed 94.5 GHz Space Based, Cloud-Profiling Radar on Millimeter-Wave Radio Astronomy

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An allocation for a downward-looking, satellite-borne radar at a frequency of approximately 94.5 GHz is being sought for studies of the albedo and radiation balance of the Earth, as determined by clouds. Radio astronomers are interested in possible effects on radio telescopes operating in nearby bands, in particular the bands 86-92 GHz, 97.88-98.08 GHz, and 105-116 GHz. Radio astronomy receivers in these bands commonly use SIS (superconductor-insulator-superconductor) mixers cooled to 4K as the input stages, and to avoid noise resulting from lossy elements there is usually no filtering to restrict the input bandwidth.

The satellite would operate in a polar orbit of nominal height 450 km and period approximately 95 min. The radar beam would point towards the nadir and the width of the beam footprint at the ground would be approximately 1 km. Three levels of interaction between the radar and the radio telescope must be considered: coupling between the main beams of both systems, coupling between the main beam of one system and the sidelobes of the other, and coupling between the sidelobes of both systems. If coupling involving a main beams occurs, it persists for a few tenths of a second only, because of the high directivity of the beams and the speed of the satellite. However, the power level of the radar required to measure Rayleigh scattering from cloud particles would, with coupling between both main beams, produce a peak level of approximately 0.7 W at the radio astronomy receiver, and damage to an SIS mixer would result. The probability of occurrence of such coupling is low and there are several practical ways to guard against it. Coupling between a main beam and sidelobes could cause overloading of the receiver and loss of data for a period of about one second during a satellite pass. In the case of coupling between sidelobes at the 0 dBi level, there would be no overloading and interference would occur only if the radio astronomy receiver were tuned to cover the frequency of the radar transmission. With some care in the design and operation of both systems, it should be possible for the two scientific activities to work simultaneously.

Cloud Profiling Radar at Approx. 95 GHz

Administrations/Agencies involved: US, ESA, Japan

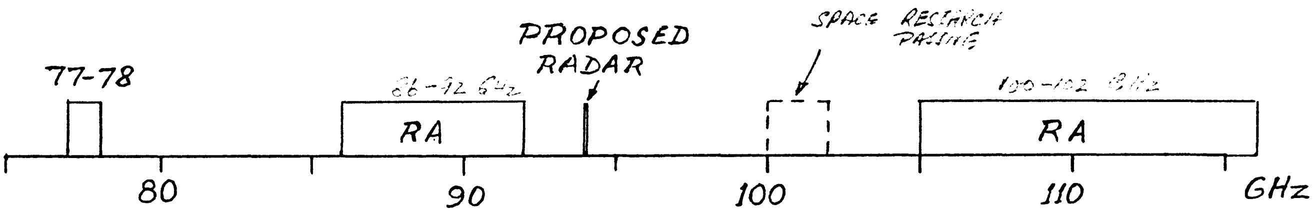
Purpose: Albedo and radiation balance of Earth — *Global warming*

Original allocation for project (Space Res., space-to-Earth): 77-78 GHz

95 GHz preferred for radar because:

(1) Doubles sensitivity (Rayleigh Scattering)
(2) Existing data base from aircraft radar at 94 GHz
(3) Radar hardware components available near 95 GHz

Possible interference to Radio Astronomy Bands: 86-92 GHz, 105-116 GHz
(100-102 also GHz usable for RA)
Note: importance of red-shifted CO



Radar Parameters:

Transmitter peak power, approx 1 kW
Transmitter mean power, 10-20 W
Gain of Radar Antenna, 63 dBi (2-meter dish)
Pointing direction, nadir — *mean power = peak power/100*
Pulse length 3.3 μs ← *3.3 μS, & 3kHz p.r.f.*

Orbital Parameters:

~15.6 orbits/day

Fraction of Earth surface covered in 1 day = 1/700 (between lat ±55°)

Height, 450 km (nominal)
Period, 94 min — *15.6 orbits/day*
Inclination, 50° - 60° → *CORRECTION TO ABSTRACT*
Horizon distance at 450 km (ignoring refraction), 2400 km
Footprint diam., 0.8 km
Footprint velocity, approx. 7 km/sec

Consider R. A . antenna: 30 m, gain at 95 GHz ~88 dB – WORST CASE

(1) Coupling between main beams

Peak power into RA antenna approx 1 W ← Point that catches one's attention 10 mW mean
SIS mixer damage level, -30 dBW to -36 dBW 1 mW per square micrometer of junction

Footprint: 1/700 of Earth ... Duration

Avoidance of Damage:
(1) Avoid pointing at zenith
(2) Computer at observatory predicts satellite position
(3) Radar turn-off over observatory location

(2) Main beam-to-sidelobe coupling

Radar main beam to RA sidelobe, 60-90 dB below 1 W (peak)
RA main beam to radar sidelobe, ~60 dB below 1 W
(levels may cause overloading of mixer for about one sec.)

(3) Sidelobe-to-Sidelobe coupling
Received power about -145 dBW (peak), assuming 0 dBi sidelobes –165
(Note: thermal noise into mixer, say, 10 K and bandwidth 5 GHz, -122 dBW)
Threshold of interference for spectral line observations is nominally -185 dBW

INT. IF RA ...

Duration of Sidelobe-to-Sidelobe Interference:
Duration of horizon-to-horizon pass through zenith, approx 10 min.
15 orbits per day, no more than 2 consecutive passed above horizon for a low latitude observatory, total 4 per day. (More at higher latitudes.)

Total time per day when satellite is above horizon is 0.5 to 1 hours.

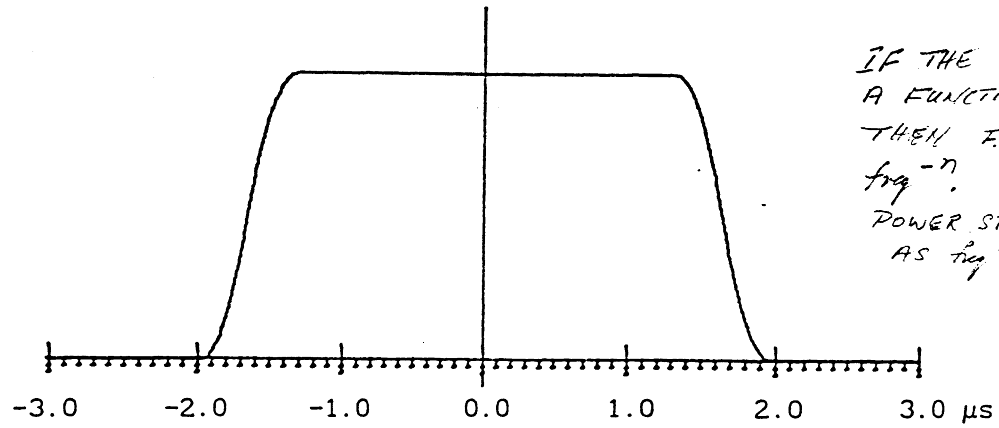
Proposed Solution:

Limit bandwidth allocated for cloud radar satellite to 100 MHz, and stipulate for cloud radar only.

Take precautions to avoid damage, as listed above.

POLAR ...

Difficult to object to: planetary astronomy / global warming.



IF THE n^{th} DERIVATIVE [illegible] A FUNCTION BECOMES [illegible] THEN F.T. [illegible] AS frq^{-n}.
POWER SPECTRUM [illegible] AS frq^{-2n}

Fig 3. Proposed pulse shape. The amplitude is described by

$$v(t) = \Pi(t/T)*\Pi(10t/T)*\Pi(10t/T) \text{ where t is in } \mu s \text{ and } T=3.3\mu s.$$

It has total duration 3.96μs and is discontinuous only in its 2nd derivative. (* denotes convolution.)

Impulsive in 3rd derivative Spectrum falls off as [illegible] f^{-6} in power 18[illegible]

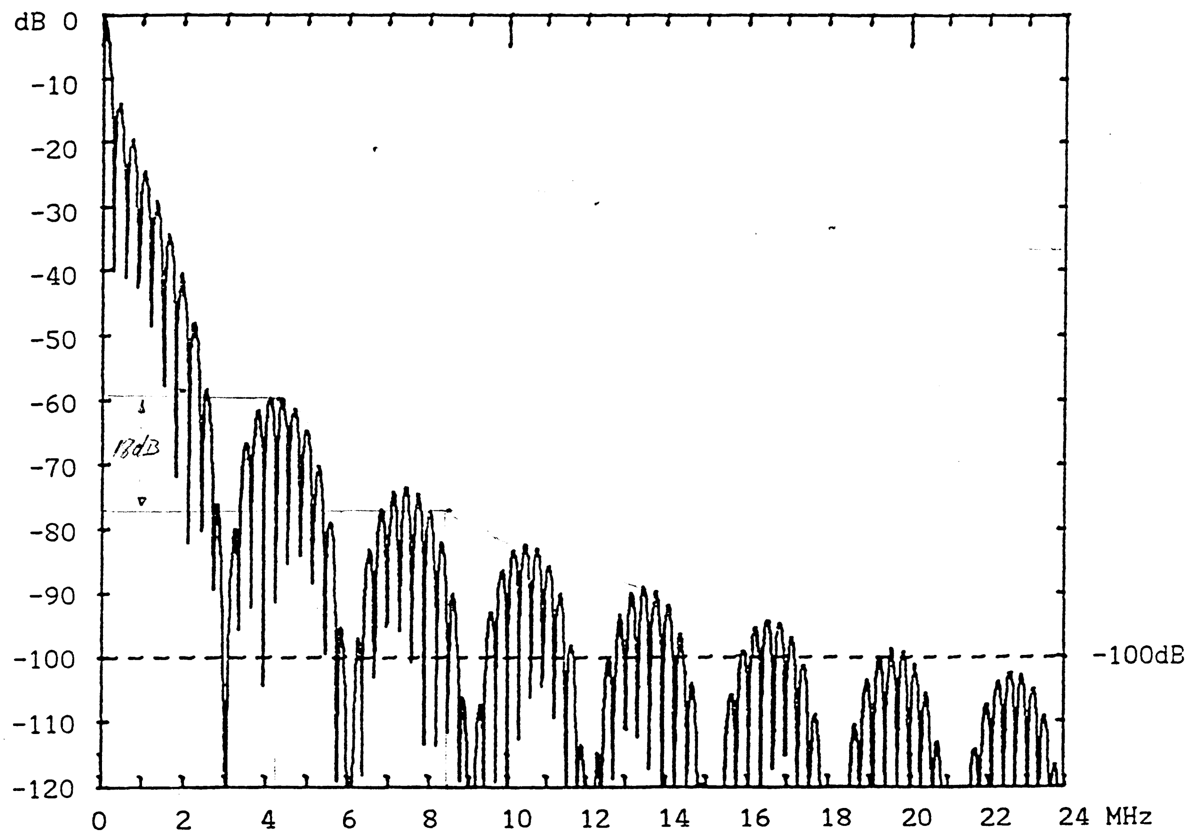


Fig 4. Spectral Power Density (SPD) in dB versus MHz, of the pulse proposed in Fig 3.
The fine "lobes" have width 300kHz and the coarse 3.0MHz.
The level has fallen to -100dB at 20MHz from the carrier.
The line structure at multiples of the PRF are not shown.