A PROPOSAL FOR RADAR DETECTION OF CENTIMETRIC SPACE DEBRIS IN GEOSTATIONARY RING

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ABSTRACT

Near-Earth asteroid 1998 WT24 will have a very close approach to Earth at a distance of 0.012 AU on 16 December 2001. We are planning the radar observation of this asteroid at 6 cm wavelength using a bistatic system: Evpatoria, Crimea, 70-m dish and power transmitter → Medicina, near Bologna, Italy, 32-m dish and two-channel receiver. The essence of this proposal is to use the two antennas also to carry out the first attempt of centimetric space debris (SD) radar detection in geostationary ring, on October-November 2001, the scheduled period for the Evpatoria → Medicina system testing.

1. GEO SCAN EXPERIMENT

Unlike the LEO space debris, the GEO region cannot be scanned to take advantage of the Earth's rotation. Moreover, the GEO region represents a relatively narrow layer with more definite coordinates, where the dominant orbital period of GEO objects is near 24 hour, so in beam park case the event frequency will be very small. Therefore, in order to detect by radar any uncatalogued GEO objects, the better way is to survey along investigated track or GEO scan experiment (GSE).

Let θ is the time interval, which is needed to stationary target to cross the antenna beam during its scanning along GEO. The scan rate V_s depends on beam width of major antenna $B_m = 1.25\lambda/D_m$, distance radar-target r and θ:

$$V_s = 1.25\lambda r/D_m\theta \qquad (1)$$

For r = 38000 km, D_m = 70 m and θ = 10 sec, the V_s is about 4 km/sec, and one scan along arc φ will take

$$\Delta T = 0.8\varphi D_m\theta/\lambda, \qquad (2)$$

or about 5.4 hours for arc 2π/3 radians.

The classic beam park mode in the GEO case is also reasonable, but not for search for new objects, but for detailed radar visualization of given interesting targets.

2. BISTATIC RADAR SYSTEM EVPATORIA → MEDICINA

The Evpatoria 70-m Gregory fully steerable antenna and C-band transmitter have the following parameters:

Wavelength λ	6 cm
Central frequency	5.01 GHz
Effective aperture S_t	2500 m^2
Continuous power P_t	150 kW in 2-klystron mode
	90 kW in 1-klystron mode

The Medicina antenna and receiver have the effective aperture S_r = 500 m^2 and system noise temperature T_s about 50 K. The size of investigated volume, which formed at a distance of 38000 km by intersection of two conical, Evpatoria and Medicina, antenna beams, is about 41 km by 88 km.

The minimal radar cross section σ_{min}, which could be detectable with this Evpatoria → Medicina system in GEO orbit, can be estimated with Eq. 3:

$$\sigma_{min} = 4\pi r_1^2 r_2^2\lambda^2 kT_s(S/N)_{min}/P_tS_tS_r\theta \qquad (3).$$

Here r_1 and r_2 – transmitter-target and target-receiver distances, $(S/N)_{min}$ – minimal detectable signal-to-noise ratio, k = $1.38\cdot10^{-23}$ Ws/°K, and θ – coherent integration interval. For $r_1 = r_2$ = 38000 km, $(S/N)_{min}$ = 10 and θ = 10 sec, we get, that σ_{min} = 290 mm^2 and 480 mm^2 for two and one-klystron mode, respectively.

The calculated radar cross section σ_{min} can be converted into diameter of conducting sphere with the Rayleigh formula:

$$d_{min} = (\sigma_{min}\lambda^4/\pi^5)^{1/6} \qquad (4)$$

This conversion indicates that detection of 1.5-2.0 cm objects in GEO with (S/N) ~ 10 dB may be possible.

However, it should be noted that the size of receiving antenna D_r has not too decisive significance on d_{min}:

D_r, m	100	70	64	32	25	16
d_{min}, mm	11	12	13	16	17	20

Considering that the 6-cm radio astronomical band is a widely used one in European VLBI network, this fact would allow to use also various European antennas for

Proceedings of the 3rd European Conference on Space Debris, ESOC, Darmstadt, Germany, 19 - 21 March 2001
(ESA SP-473, August 2001)

such a project. A total of 20 antennas in Europe and Asia exist in this network.

3. ALGORITHM OF BOTH DELAY, DOPPLER AND DOPPLER DRIFT MEASUREMENTS

There are two kinds of sounding radar signals at Evpatoria transmitter – continuous monochromatic wave (CW) and continuous wave with periodic linear frequency modulation (LPM). The CW signals would be used for space debris detection and estimations of SD's radar cross section (size), as well radar echo's Doppler shift (radial velocity) and drift (radial acceleration). And the periodic LFM signals will allow also both above and delay measurements, that is the estimations of SD particle range.

As it was noted in Section 2, for GEO radar research the most appropriate experiments are the slow coordinated scanning with both transmitting and receiving antennas along investigated track. Therefore, regular GEO particle time to time will pass through the volume of conical beam intersection. Let choose the speed of scanning so that it will take θ seconds for a target to cross this volume.

Furthermore, the typical GEO object has a small quasi-sinusoidal diurnal variation of radial velocity caused by its non-exact geosynchronous orbit. For example, non-operational satellite TVSAT-1 has the amplitude of range rate oscillation of V_r = +/- 20 m/sec during an hour [1], or the band of radar Doppler shift at 6 cm $4V_r/\lambda$ = 1333 Hz. So, we can estimate the frequency drift D_f as equal of 370 mHz/sec.

On the other hand, if we intend to realise the θ second coherent interval, or spectral resolution $\delta f = 1/\theta$ Hz, the frequency drift must not exceed $d_f = 1/\theta^2$, or 10 mHz/sec, if θ = 10 sec. You see, $D_f \sim 37\ d_f$ Therefore, we must use the set of de-chirping the data before FFT [2]. A similar algorithm was implemented in 1999 for digital signal processing in SETI@home algorithm [3].

Fig. 1 is the schematic diagram of the digital processing of radar echo signals. Echo signals are converted into digital form and fed to the convolution with complex-conjugate model of sounding CW or LPM signal. The periodic LPM signal has an important advantage before any other wideband signals because of its "one-channel" property – to determine the delay/Doppler parameters of echo we may use not multi-channel correlator, but more simple one channel device or program. To de-chirp the data – that is to remove the effect of Doppler drift. At the finest resolution we have to do it a total of $D_f\ \theta^2$ times in step of $1/\theta^2$ Hz/sec. At each chip rate, echo searching have to be implemented by computing fast Fourier transform and power spectrum at spectral resolution $1/\theta$ Hz in $2V_{max}/\lambda$ bandwidth, where V_{max} is an amplitude of GEO space debris radial velocity. The reduction of the frequency resolution by $1/2^n$, n = 1, 2, …, allows to get both more detail time resolution $\theta/2^n$ and non-coherent integration, if it will be necessary. Post-processing selects real echo and rejects RF interference. Only if the power rises and then falls over θ second period (the time it takes the beam to pass a quasi-fixed target in GEO) such signal would be considered as a candidate of real radar echo. Apparently, if we want the real-time GEO scanning with on-line processing in according with this algorithm, specific and high-productive hard and soft wares would be required.

Analog-to-Digital Conversion
↓
Convolution with Sounding Signal
↓
De-chirping of Doppler Drift
↓
Fast Fourier Transform
↓
Frequency-Time-Power Graphical Representation
↓
Post Processing

Fig. 1. A schematic diagram of the algorithm of coherent integration.

In future also, there are two cardinal reasons to implement two-antenna receiving system, by adding, for example, the similar 32-m antenna in Noto, Sicily. Firstly, such interferometric receiver allows to confirm definitely the fact of particle detection, if echo was recorded together both in Medicina and Noto. Secondly, interferometric receiver hardly increases the accuracy of angle measurements.

4. ADVANTAGES OF EVPATORIA STATION

Unlike the Goldstone radar station, where the use of facilities for debris monitoring is very limited [4], the Evpatoria one practically is always accessible for long-term continual GEO scanning, because of low count of any systematic program of deep space exploration in former SU now. Besides, the leasing of Evpatoria 70-m antenna and power transmitter is not too expensive. Also, Evpatoria C-band transmitter central frequency sites not far from VLBI band, so we may easily adopt, if necessary, any Eurasian radio astronomical observatory for reception of radar echo.

The purposes of this presentation also are to select the most interesting targets and GEO ring regions of forthcoming investigation. As well as, to discuss the expediency and possible directions of future European radar research of space debris, meteoroids, near-Earth asteroids and comets, in other words, the world of near-Earth space on the whole, based on using of Evpatoria C-band radar station and European radio telescopes.

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