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A new class of orbiting very large ultra-light orientable MW antennas

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Abstract

The possibility of orienting very large ultra-light balloon-like MW antennas, orbiting in the Earth magnetic field, through electric currents flowing in Cu wires embedded in the antennas walls, are examined. It is shown that such currents may easily provide the needed forces without the necessity of mechanically orienting the antenna itself.

Keywords: Microwave Antennas inflatable ultra-light

Introduction

In the early '60 two large diameter balloons, named Echo 1 and Echo 2, have been put in orbit by the US. The detailed characteristics of such light passive satellites can be easily found in the scientific literature; here it is enough to remember their main approximate technical properties:

- orbit height 1700 Km; weight 60 Kg; diameter 2 R equal to 30 m; a sphere of Mylar covered with one layer of Al (Echo 1) and, respectively, two layers of Al each 9,1 x 10 (-3) mm tick (Echo 2).

Since the two objects were spherical and only used as passive repeaters, there was no need of orienting them in any way.

From that time many others studies have been made and published concerning the possible deployment ol large balloons antennas.

In the ’80, ESA promoted a Phase A study concerning the deployment of a 15 m diameter antenna, using the inflatable Space Rigidized thecnology. The reflecting antenna was supposed to be attached to a radioastronomy satellite named QUASAT, orbiting the earth on an elliptical orbit and to be used with the VLBI network in Europe and the US. The satellite was intended to operate at different wavelength:1.35 cm, 6 cm, 18 cm and 92 cm (see, e.g., Maccone C, 1988).

More recently, a scientific radio telescope satellite, named Spectr-R, with a 10 m antenna, has been launched in a highly elliptical orbit on 18 July 2011. However the antenna was a "traditional" antenna consisting of a solid central mirror of 3 m diameter surrounded by 27 solid petals made of carbon fiber (see, e.g., "Radio Astronomy User Handbook", Radio Astronomy Science and Technical Operations Group, 29 July 2015).

Following previous studies, JPL in the ’90 and at the beginning of this century produced a large number of documents concerning inflatable structures. In particular in December 1998 (JPL Document n. 16330), the Arise team prepared a very detailed study concerning the possibility of putting in orbit a satellite named ARISE. Such a satellite was supposed to have a 30 m antenna and to be placed in an elliptical orbit with a 5000 Km perigee and a 40000 Km apogee. Other studies on inflatable structures have been produced in more recent years by L-Garde Inc. It has to be noted that the reflector antennas was mechanically oriented by the satellite itself acting through very long booms.

In the present paper a different approach is adopted. The antenna itself is assumed to have within its own walls, notwithstanding their extremely small tichness, the possibility of generating forces, distributed on its surface, sufficient to rotate itself in the desired direction without any need of actions from the accompanying satellite.

The new antenna system.

Let us imagine to metallize with a metallic coating just part of a sphere: in this way a large reflecting surface will be realized. It would be even possible today to put in orbit balloons much bigger than the Echo ones or with a shape, for the coated portion, nearer to a parabola than to a sphere, as assumed in the studies concerning the QUASAT and the ARISE satellites. However the main problem to be faced is how to orient the object itself if it has to behave like an antenna. Indeed the extreme smallness of the walls together with their extremely large dimensions imposes to exercise a diffuse, weak but regular force to slowly turn the antenna in the right direction in order not to introduce deformations and to induce instabilities in the envelope itself.

In what follows a way of re-orienting the balloon in a chosen direction will be suggested although nothing will be said concerning the sensors to control the process: at the present time the control system is not the main concern.

Let us assume to put a spherical balloon in orbit at 2000 Km above the earth's surface at the equator, where the earth's magnetic field B is approximately 1.375 x 10 (-5) T.

If, for the time being , we assume a 1 A electric current "i" flowing in a conducting wire embedded in the balloon walls on a maximum radius circle, an electric coil is formed, interacting with the earth's magnetic field. The mechanic momentum M acting on the coil due to the presence of the magnetic field B, is in turn equal to the product of the time derivative of the angular velocity, dW/dt (where W equals dTeta/dt and Teta is the angle between B and the plane of the ring) , for the momentum of inertia of the body, I , that is M = I dW/dt.

M equals the product of the current i (1 A) for the area of the ring, 3,14 x 15 (+2) square meters, for the cosine of the angle Teta between the earth's magnetic field and the plane identified by the ring itself, multiplied by B= 1.375 x 10 (-5) T . For the time being let us assume to be interested only in evaluating the rotation for small angles between the magnetic field and the plane of the ring assumed co-planar at the beginning; in such a case , the cosine of the angle Teta can be assumed constant and approximately equal to 1.

Assuming a mass of 50 Kg for the entire balloon, mass entirely distributed for simplicity (only order of magnitudes are of interest at this point) along a ring of 15 m radius, I equals 11250 Kg m(+2).

Consequently the above equation M = I dW/dt becomes :

M=1 x 3,14 x 15 (+2) x 1.375 x 10 (-5) = 11250 x dW/dt.

Integrating twice, Teta = 0,043 x 10 (-5) x t (+2) and if the rotation of interest equals 30 °, putting Teta=30° in the above equation and solving for t, it comes out that t equals approximately 18 minutes.

The above order of magnitude estimates show that significant rotations can be induced by the interaction of the earth's magnetic field with a current impressed in a conductor embedded in the balloon; in the computation presented, it has been assumed to excite a 1 A current but very different values of current, even significantly larger, may easily be excited, and, consequently, larger rotation velocity may be reached.

However, various other problems need to be addressed before even just justify reasonably a more detailed study of the hypothesis suggested in the introduction.

Further problems and suggested solutions

In order to orient the balloon in any desired direction, it should be necessary to dispose of 3 electric currents flowing in 3 rings at 90° one respect to the others. Of course this is possible without increasing too much the weight of the balloon (the total weight of 3 Cu wires with a 1 mm(+2) cross section is approximately 6 Kg.). Furthermore, it will be necessary to activate the currents (and possibly modulate or even inverting them) in order to exactly orient the balloon in the desired direction; however, as we have stated, we are not considering these aspects now, requiring anyhow very simple electronic controls.

More important is to evaluate the energy needed to actuate the rotation. Let us assume to use 1 mm(+2) Cu conductor . Each circle having a length of 94 m presents a total resistance of 1.6 Ohm, consequently the power dissipated in heath to induce a 1 A current in the wire, is extremely small (less than 2 W). The mechanical energy to be provided for putting in rotation the balloon is easily evaluated. Let us assume that, at the end of the 30° rotation, the total kinetic energy is concentrated in a 50 Kg mass at 15 m from the center of rotation having a velocity of dTeta/dt x 15 (m/s); therefore the final total kinetic energy is 0.5 x 50 (dTeta/dt x 15)(+2) where dTeta/dt, when Teta=30°, equals 95 x 10(-5) rad/s, as can be immediately deduced from the preceding computations; this quantity divided for the approximately1000 s necessary to reach the 30° rotation, gives the needed average power, even significantly less than the ohmic losses.

In conclusion, the total electric power needed is not larger than a few watts for each ring to be activated, and can be easily provided by a few photovoltaic cells without significantly increasing the total weight of the balloon.

Another point to be addressed is the interaction of the metallic conductors with the walls of the balloon. As already stated, the interaction should be quite "delicate" in order not to deform the light structure of the balloon itself: the balloon should behave like a rigid body when put in rotation . Of course, this point should be carefully analyzed, however, some order of magnitude estimates can be performed. In order to put in rotation the structure, each 1 m of electric wire exercises a force f equal to   i x B. At the same time, the residual atmosphere within the balloon exerts a pressure p that in turn causes a force F at the interface between the balloon walls and the wire for each meter of the wire itself, of F = 3.14 x R(+2) x p / 2 x 3.14 R: f should be much smaller than F, consequently the pressure i x B x 2 / R= 0,55 x 10(-5) Pa should be much less than p.

Furthermore, in order to be a good electromagnetic reflector, the metallic coating should be thicker than the skin depth: this is the case for the Echo 2 Al coating even at 1 GHz .

Finally, an elliptical orbit may be used (as for the proposed ARISE satellite) with a few thousands Km perigee and a 40000 Km apogee: the large angular orientation of the antenna/balloon may be implemented when the balloon is at the perigee where the earth magnetic field is bigger while small angular adjustments may be implemented around the apogee where the earth magnetic field is much smaller.

Conclusions

The order of magnitude estimate presented above, are proving the possibility of putting in orbit ultra-light extremely-large orientable antennas, having the mechanism of rotation embedded in their own walls, significantly simplifying the entire system. Furthermore many of the functions needed on board an operative satellite may even be implemented on the balloons walls.

References

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