MW WPT for HAPS and SPS: Concepts, EMI and Biological Hazards Issues

J Gavan, S Tapuchi.

Sami Shamoon College of Engineering. Ashdod Israel
Faculty of Engineering EEC Department
E mail jacobg@sce.ac.il

Abstract

The long distances Microwave (MW) Wireless Power Transmission (WPT) concepts are followed by the presentation of high Altitude Platforms (HAPS) principles. Stratospheric HAPS operation requiring up to a few hundreds kW of electrical power is limited by long sun eclipses. The realization of terrestrial MW WPT systems feeding HAPS could be useful for their long duration operation and for the preliminary tests of more complex and power demanding Solar Power Satellites (SPS) systems. Electro Magnetic Interference (EMI) and biological hazards issues will be discussed for selected frequencies and compared for terrestrial, HAPS and SPS long range MW WPT systems.

1. Long Distances Microwave Wireless Power transmission Concepts

Significant advancements in Microwave (MW) power tubes, antennas, control tracking systems, PV solar cells and especially the development of efficient RECTENNA enabled the development of long distance WPT systems[1,2]. The main categories of long distance MW WPT systems are: Terrestrial to terrestrial, .terrestrial based to atmospheric platforms including High Altitude Platforms (HAPS), which is the main subject of this paper, and satellites based to terrestrial called Solar Power Satellites(SPS) to supply clean electrical energy[3,4] . G. Goubau and W.C Brown have derived the relations of the WPT efficiency as functions of the distance d, the frequency f and the surfaces of the transmitter (Tx) array and of the RECTENNA [5]. The MW WPT transmitter antenna has to be in Line Of Site (LOS) conditions with the receiver (Rx) RECTENNA.A simple block diagram of a typical MW WPT system is presented in figure1. HAPS has a potential to become a low cost and useful alternative or complement to Geostationary Earth Orbit (GEO) and Low Earth Orbit (LEO) radio relay satellites. The HAPS optimal altitudes are from 17 to 24 km above the jet stream due to minimum velocity of wind, drag and temperature. However HAPS main disadvantage is their long eclipse time [6,7]. Therefore HAPS need significantly bigger and heavier energy production and storage systems than satellites. The electrical power required by HAPS is usually in the range of 10 to 300 kW for payload, stabilization and fixed positioning [3,7]. WPT would be an attractive solution for HAPS to operate continuity for months or years such as depicted in figure 2.Several tests were successful for low altitude airborne platforms but not yet for a HAPS at an altitude of around 20 km [3,5]. The realization of MW WPT systems for HAPS could contribute to more complex and power demanding future SPS for distances of hundreds of km for LEO and up to 38000 km for GEO satellites.

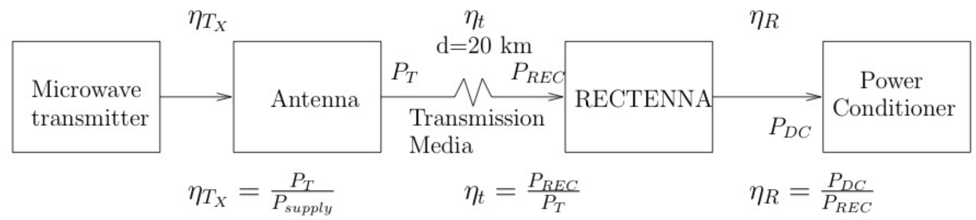

Figure 1: Simple block diagram of a typical MW WPT system

978-1-4244-5118-0/11/$26.00 ©2011 IEEE

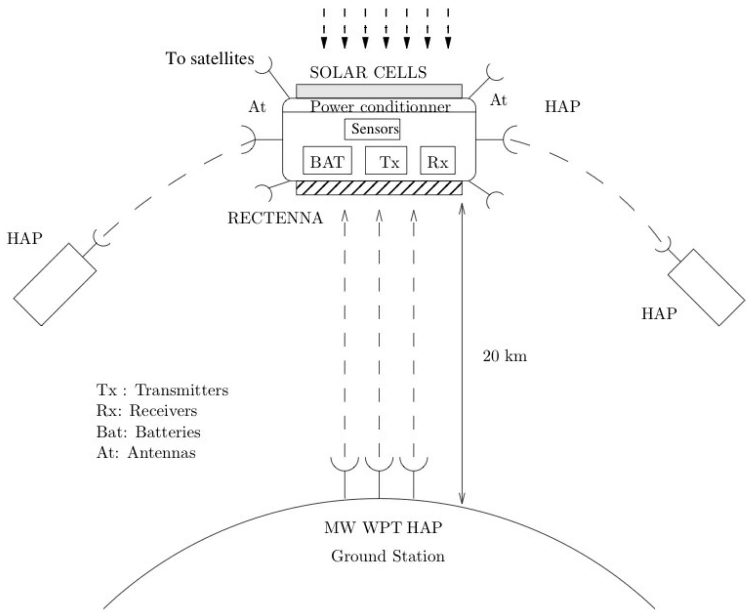

Figure 2: The MW WPT system for a terrestrial base TX to a HAP

2. Long Distances MW WPT EMI and Bio-Hazards Considerations

Considering ITU recommendations only the Industrial, Scientific and Medical (ISM) frequency bands from (2.4-2.5) or (5.725-5.875) GHz can be chosen for MW WPT systems. The use of higher frequencies are preferable to achieve compactness and smaller physical dimensions [2,3]. However MW atmospheric and dispersion losses increase with frequency. The main requirements for the MW TX are: linearity efficiency reliability low cost and compactness. Selective (sharp) output filters can be applied for reducing spurious as the transmitted CW power is not modulated [2,5]. HAPS Terrestrially located TX power conversion efficiency, reliability and compactness are less important than for SPS as power supply and heat dissipation possibilities are available as well as permanent maintenance on the spot and no launch requirement[3]. A 10dB amplitude Gaussian taper distribution can reduce the TX antenna array grating and side-lobes and concentrate the power density in the center of the transmitted beam both at the TX antenna and at the RECTENNA. [2,5]. Thus the external environmental threats of EMI and biological effects are significantly reduced. Retro-directive guiding systems with phase conjugate circuits using a Direct Sequence Spread Spectrum multiple access signal pilot operating at the half of the MW WPT frequency avoid interference threats from the much higher power level MW TX beam [9,10].

The WPT HAPS realization is significantly less complex than SPS due to a maximum required 300 kW instead of GW for SPS, and the reduced non linear effects decreasing harmonics, spurious and inter-modulation products [2,3] . The MW beam length is only around 20 km instead of 36000 km, which require much smaller surfaces of the beam, antenna phased array and RECTENNA and no interaction with the Ionosphere layers and Van Allen belts for the HAPS [2,7]. Frequency selective surfaces can be installed in front of the RECTENNA to attenuate the harmonics without affecting the beam fundamental frequency. Also absorbers could be positioned around the perimeter of the RECTENNA to reduce interference to other radio systems [3,11].The choice of higher frequency bands reduce the probability of RFI. The lower 2.45 GHz ISM frequency band can interfere with numerous

terrestrial and satellite radio systems and for instance the second harmonic may disturb the protected (4.9-5.0) GHz radio astronomy band. Therefore the 5.8GHz band is preferred for HAPS in spite of the bigger atmospheric losses in case of rain as shown in figure3. For dry climate and elevated locations even the 35 and 94 GHz atmospheric radio Mm bands can be advantageous due to the significant reduction of the antenna and RECTENNA arrays physical dimensions as well as the MW transmitted beam cross section and EMI effects [3,8]. However the power density in the center of the MW WPT beam from the TX to the RECTENNA is bigger than the standardized Maximum Permissible Exposure (MPE) especially for the mm waves choice. The main MPE standards are the ANSI/IEEE. The time averaging of exposure is also important [3,12].
The average MPE for HAPS WPT systems is around 100 W/m^2 [14,15]. However the extreme HAP MW WPT power density magnitude do not approach the damage values and the 1500 W/m^2 of the sun light power at the ground, even in the center of the MW beam[13,14]. However the TX antenna phased array and MW beam areas including a buffer zone have to be controlled and restricted only to authorized and protected maintenance staff[1,2] .The air traffic should be forbidden in a suitable security zone around the TX MW beam. In addition the TX has to be switched off or the MW beam power has to be significantly reduced when aircrafts, big birds or other obstacles penetrate the MW WPT beam perimeter or in case of rain [13] .This can be achieved by installing close to the TX site an acquisition RADAR and a monitoring video camera connected to the TX power control loop[3,15].

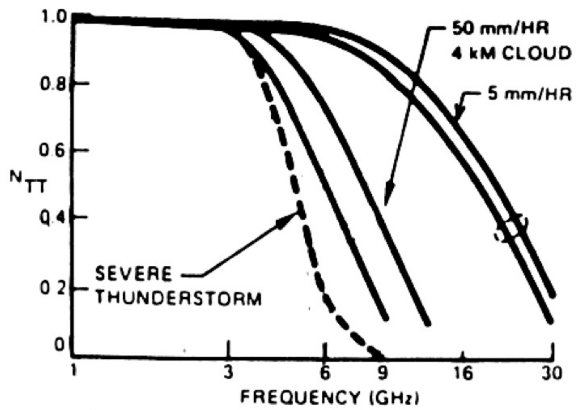

Figure 3: Atmospheric weather losses as function of the frequency

3. Conclusions

In the presentation of MW WPT from terrestrial bases to HAPS future projects we have used several R&D developments results obtained in the evaluation steps of the SPS projects especially by Japanese and USA scientists. The results show that the cost, technology efforts and environmental EMI and bio-hazard threats are significantly less for HAPS. Thus, the SPS evaluation results are very useful for the future design and realization of MW WPT systems for HAPS which are much easier to realize than from SPS.

References

1. M. Shigehara editor, "Space Solar Power Program," International Space University, 1992

2. N. Shinohara, "Wireless Power Transmission for Solar Power Satellites," Supporting Documents for the URSI White Paper on SPS, 2007, pp. 1-43.

3. J. Gavan and S. Tapuchi "Microwave Wireless-Power Transmission to High-Altitude-Platforms Systems," The Radio Science Bulletin, 334, September 2010, pp.25-42.

4.. URSI Working Group on SPS "URSI white paper on Solar Power Satellite (SPS) Systems," The Radio Science Bulletin, 321, June 2007, pp. 13-27.

5. W. C. Brown and E. E. Eves, "Beamed Microwave Power Transmission and its Application to Space," IEEE Transactions on Microwave Theory and Techniques, June 1992, pp. 1239-1250.

6. T. C. Tozer and D. Grace, "High Altitude Platforms for Wireless Communication," Electronics & Communication Engineering Journal, June 2001, pp. 127-137.

7. J. Gavan, S. Tapuchi and D. Grace, "Concepts and Main Applications of High-Altitude-Platforms Radio Relays," The Radio Science Bulletin, 330, September 2009, pp. 20-31.

8. P. Koert, J. T. Cha, "Millimeter Wave Technology for Space Power Beaming," IEEE Transactions on Microwave Theory and Techniques, June 1992, pp. 1251-1258.

9. H. Matsumoto, “Research on Solar Power Station and Microwave Power Transmission in Japan: Review and Perspectives,” IEEE Microwave Magazine, December 2002, pp. 36-45.

10. K. Hashimoto, K. Tsutsumi, H. Matsumoto and N. Shinohara, "Space Solar Power System Beam control with Spread Spectrum Pilot Signals,” Radio Science Bulletin, December 2004, pp. 31-37.

11. McSpadden, J. O. and J. C. Mankins, “Space Solar Power Programs and Microwave Wireless Power Transmission Technology,” IEEE Microwave Magazine, December 2002, pp. 44-57.

12 ANSI\IEEE, "Standard for Safety Levels with Respect to Human Exposure Radio Frequency Electromagnetic Fields 3 kHz to 300 GHz,” New York IEEE, 1999.

13. J. C. Lin, "Wireless Transmission of Space Solar Power and its Biological Implications,” Radio Science Bulletin, 301, June 2002, pp. 31-34.

14. J. M. Osepchuk, "Microwave Power Applications,” IEEE Transactions On Microwave Technology Theory, 50, March 2002, pp. 975-985.

15. C. Malcolm and H. W. Friedman, "System Using a Megawatt Class Millimeter Wave Source and a High-Power RECTENNA to Beam Power to a Suspended Platform,” US Patent 6919847, July 2005.