Long Distances Microwave Wireless Power Transportation: EMI and Biological Hazards Issues

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Abstract

The long distances Microwave (MW) Wireless Power Transmission (WPT) concepts are presented for two promising cases: the High Altitude Platforms (HAPS) and the Solar Power Satellites (SPS) systems.

Long operation of Stratospheric HAPS at altitude of 17 to 24km operating from solar cells which require up to 250 kW of electrical power in case of maximum wind conditions 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 at operation distances of more than 36000 km. However techniques to mitigate Electro Magnetic Interference (EMI) and biological hazards effects are required in order to enable the operation of these future systems. Several mitigation techniques will be discussed in this presentation for selected frequencies and compared for HAPS and much more complex SPS long range MW WPT systems.

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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 receivers rectifying Antennas (RECTENNAs) converting the MW energy to direct Current (DC) 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 big amount of clean electrical energy[3,4].

G. Goubau and W.C Brown have derived the relations of the WPT system 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 have a potential to become a low cost and useful alternative or complement to Geostationary Earth Orbit (GEO) and Low Earth Orbit (LEO) satellites. The HAPS optimal altitudes are from 17 to 24 km, located at the lower troposphere layers above the jet stream due to minimum velocity of wind, drag and temperature. However HAPS main disadvantage is their long eclipse time [6,7]. For instance, a HAP above north Europe will receive in the winter time only a few hours of sun per day because of the earth shadow. 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 250 kW for payload, stabilization and fixed positioning [3,7]. WPT would be an attractive solution for HAPS to operate 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 supplying to terrestrial grid huge amount of energy for operation distances of hundreds of km in case of LEO and up to 38000 km in case of GEO satellites as depicted in figure3 [2].

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

Considering ITU recommendations 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 [2,8]. However atmospheric and dispersion losses increase with frequency.

The main requirements for the MW WPT TX are: linearity efficiency reliability low cost and compactness. Selective (sharp) output filters can be applied for reducing spurious as the transmitted CW power has a very narrow bandwidth [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. [2,9]. Thus the external environmental threats of EMI and biological effects are significantly reduced. Recently a Raleigh tapper distribution was suggested which enhance the accuracy of RECTENNA tracking and the permitted MW power transmission [10]. A TX retro-directive guiding systems with phase conjugate circuits using a Direct Sequence Spread Spectrum multiple access low power signal pilot operating at the half of the

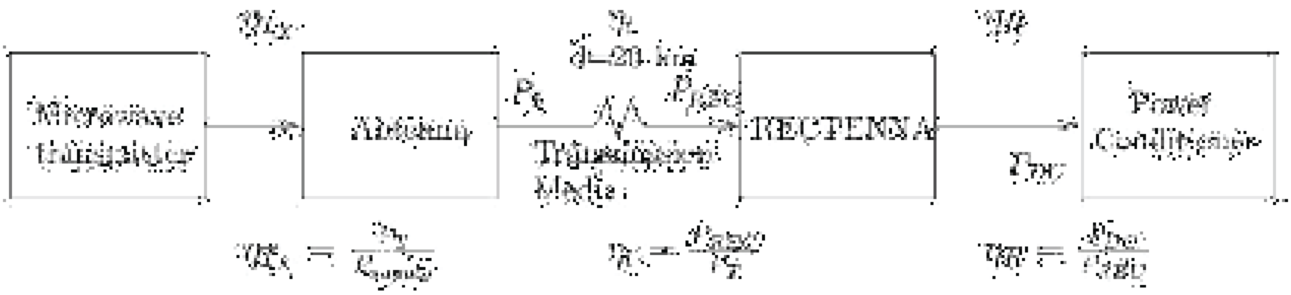

Figure 1: Simple block diagram of a typical long distance MW WPT system

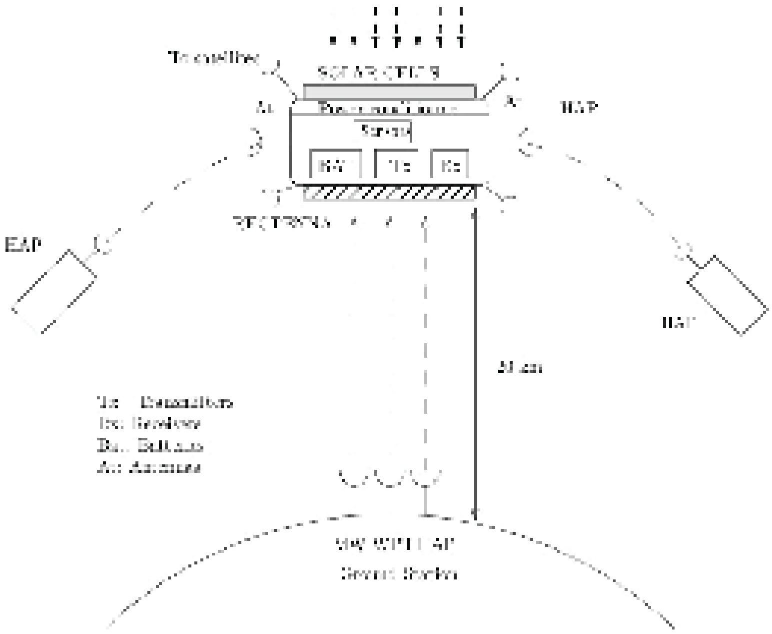

Figure 2: The MW WPT system for a terrestrial base TX to a HAP

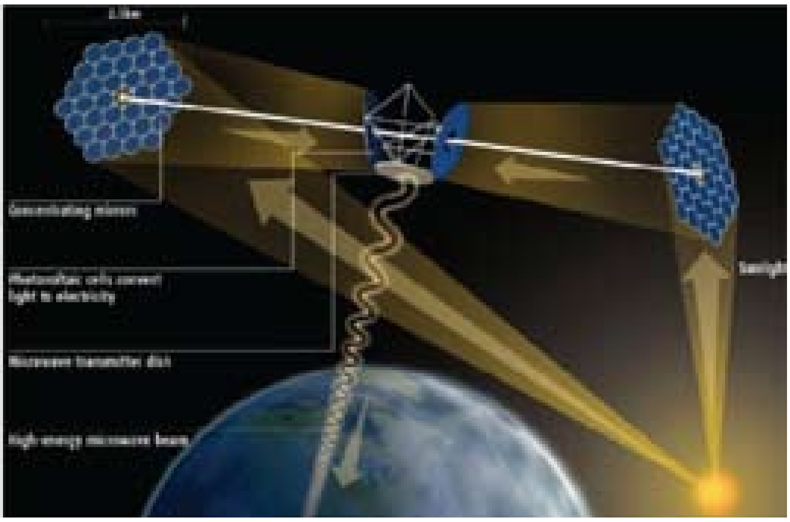

Figure 3 : An artistic picture of the SPS NASA concept

MW WPT frequency avoid interference threats from the much higher power level MW TX beam [9,11].

The WPT HAPS realization is significantly less complex than SPS due to a maximum required power of 250 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 in comparison with the SPS [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 [3,12].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 figure4. For dry climate operation 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 of the EMI effects [3,8]. However the power density in the center of the MW WPT beam from the TX to the RECTENNA increases significantly for these higher Mm waves and in case of high power transmission can exceed the standardized Maximum Permissible Exposure (MPE). The main MPE limit standards are the ANSI/IEEE and the time averaging of exposure is also important [3,13].

The average MPE for HAPS WPT systems at 5.8 GHz 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 heavy rain [14] .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[3,16].

3. Conclusions

In the presentation of a suggested MW WPT system from a terrestrial base 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 paper results show that the cost, technology efforts and environmental EMI and bio-hazard threats are significantly less for HAPS. Thus, the HAPS evaluation results and implementation may be useful for the future design and realization of MW WPT systems for SPS which are much more costly and complex to realize.

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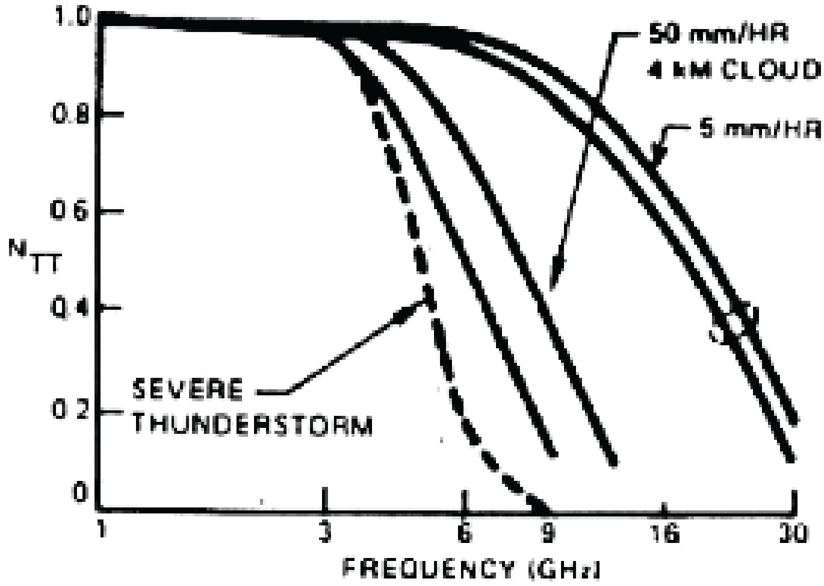

Figure 4: Atmospheric weather losses as function of the frequency and the rain intensity

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Jacob Gavan earned the B.Sc. degree from the Haifa Technion in Israel 1961, the MEE degree from Eindhowen Technological University in the Nederland in 1969 through a Philips Company scholarship, both, with distinction, and the Ph.D. degree in radio communication in 1979 in ENSERG Grenoble (France) **with congratulations of the Jury.**

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Jacob Gavan was elected as IEEE fellow in 1995 and founded a department of Communication Engineering at the Holon Institute of Technology (HIT). He was elected to Dean of the HIT new Engineering school and nominated as Full Professor from December 2001 till 2006. Prof. Jacob Gavan leaded the establishment of a MSc program in Electronic and Communication Engineering.

Jacob consulted several Israeli and international companies. He has published over 150 papers shown in his CV "Jacob Gavan" or in Google for Jacob (Jacques) Gavan.

Professor Jacob Gavan is active in URSI Commission E, past Chairman of E9 working group on "Interference in Radio Systems above 30 MHz" and new Cochairman of E8 working group on "Electromagnetic Compatibility in Wire and Wireless Communication Systems". Recently he was nominated co-chair commission E for the inter-commission working group on solar power satellites and as guest editor for the Radio Science Bulletin special issue on High Altitude Platforms. Jacob was also associated editor of the IEEE Transactions on EMC for several years. From fall 2005 Professor Jacob Gavan was elected and reelected till 2010 as distinguished lecturer by the IEEE Communication society and as chairman of the student activities in IEEE Israel .From 2008 Jacob founded a new track of communication engineering in Sami-Shamoon college of engineering in the Negev, consult there and teach space communications His biography is listed in the International Directory of Distinguished Leadership.

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Saad Tapuchi earned the B.Sc. degree from the Ben-Gurion University of the Negev, Beer-Sheva 1973, the M.Sc from the Hebrew University of Jerusalem – School of Applied Science and Technology 1982 and Ph.D. from Ben-Gurion University of the Negev, Beer-Sheva 1988.

Dr. Saad Tapuchi served as the Head of the Telecommunication department in the Telecommunication school for practical engineering of the Bezek Corporation in Jerusalem from 1973 to 1986. In 1986 he was nominated as director of the Telecommunication School till 1998. From 1998 Dr. Saad Tapuchi begin working at Sami Shamoon College of engineering at two campuses in Beer-Sheva & Ashdod. Since 2002 he was elected as Dean of the EEC Faculty of the Sami Shamoon College of engineering.