Microwave Long Distances Wireless Power Transmission : Concepts, EMI and Biological Hazards Considerations

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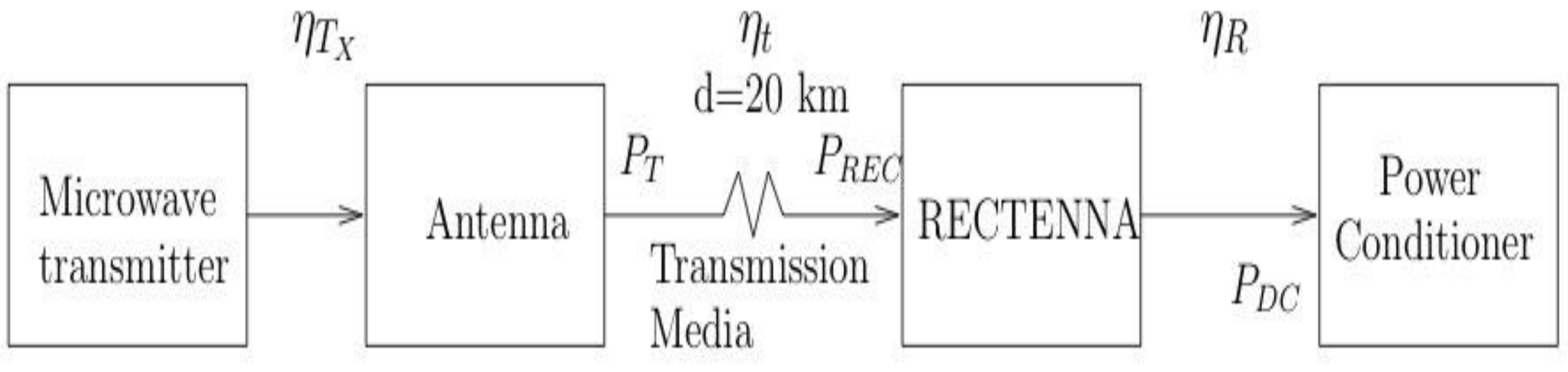
MW WPT :Concepts, EMI and Biological Hazards Considerations. (Headlines)

- Introduction
- Microwave(MW) Wireless Power Transmission (WPT) Concepts
- Terrestrial, High Altitude Platforms (HAPs)
- Solar Power Satellites (SPSs)
- Electro Magnetic Interference (EMI) Effects
- Biological Hazards Considerations
- Conclusions

Introduction

- Wireless communication
  - Marconi , Popov, etc
  - Terrestrial , RADAR and Satellite Systems
  - High Altitude Platforms Station (HAPS)
- Wireless Power Transmission (WPT)
  - Tesla, W.C Brown ,P.Glaser, et
  - Terrestrial and HAPs
  - Solar Power Satellite (SPS)
  - R.M. Dickinson, J.C. Mankins, H.Hashimoto

Block Diagram of a Typical MW WPT System

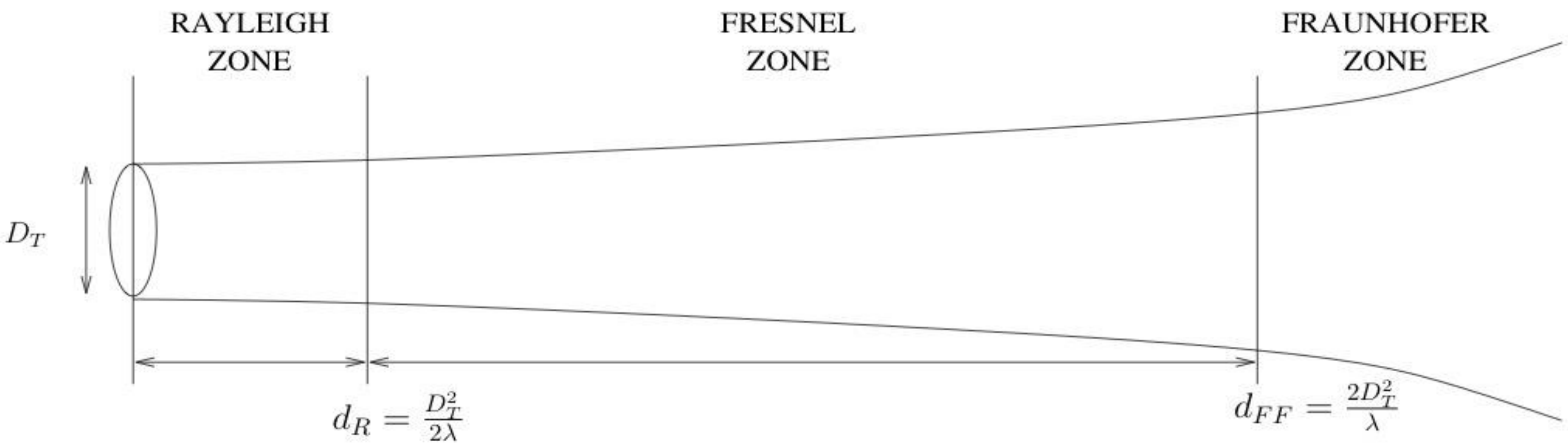


$$\eta_{T_X} = \frac{P_T}{P_{supply}} \qquad \eta_t = \frac{P_{REC}}{P_T} \qquad \eta_R = \frac{P_{DC}}{P_{REC}}$$

WPT Systems

- RFID Systems-Resonance effects
- Short ranges WPT (0.1-100)m
- Long Ranges WPT (0.1-38000) km
- Microwave (MW) or LASER
- Terrestrial operating MW WPT Systems
- JPL: 2.4 GHz,30kW DC,82%,1.6 km, 1975
- Reunion:2.45 GHz,10kW DC,07 km, 1992
- SHARP:2.45 GHz,10kWDC, 0.1km, 1987
- Kyoto U. Aircraft to Ground 5.8GHz 1993

Effects of the MW beam transmitted by an aperture antenna of diameter D_T

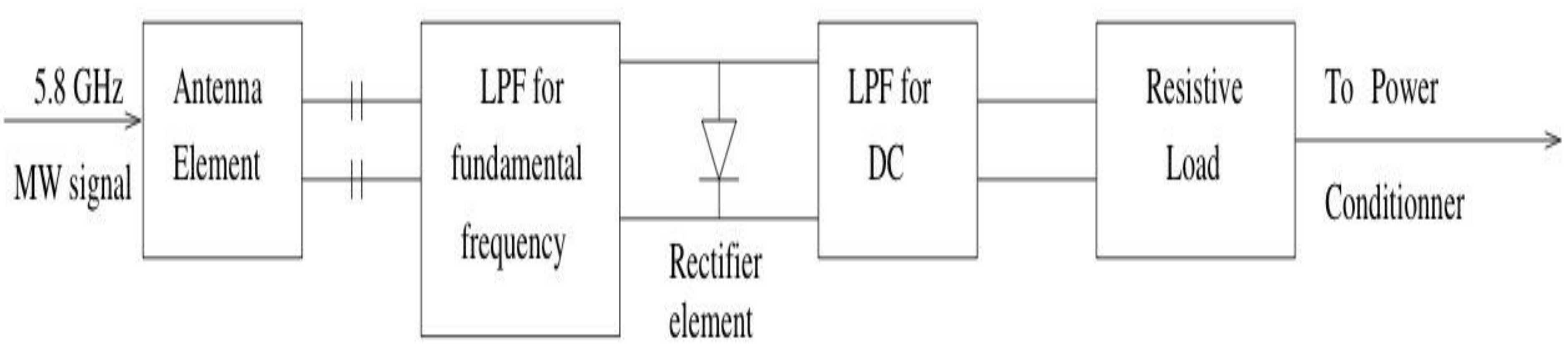


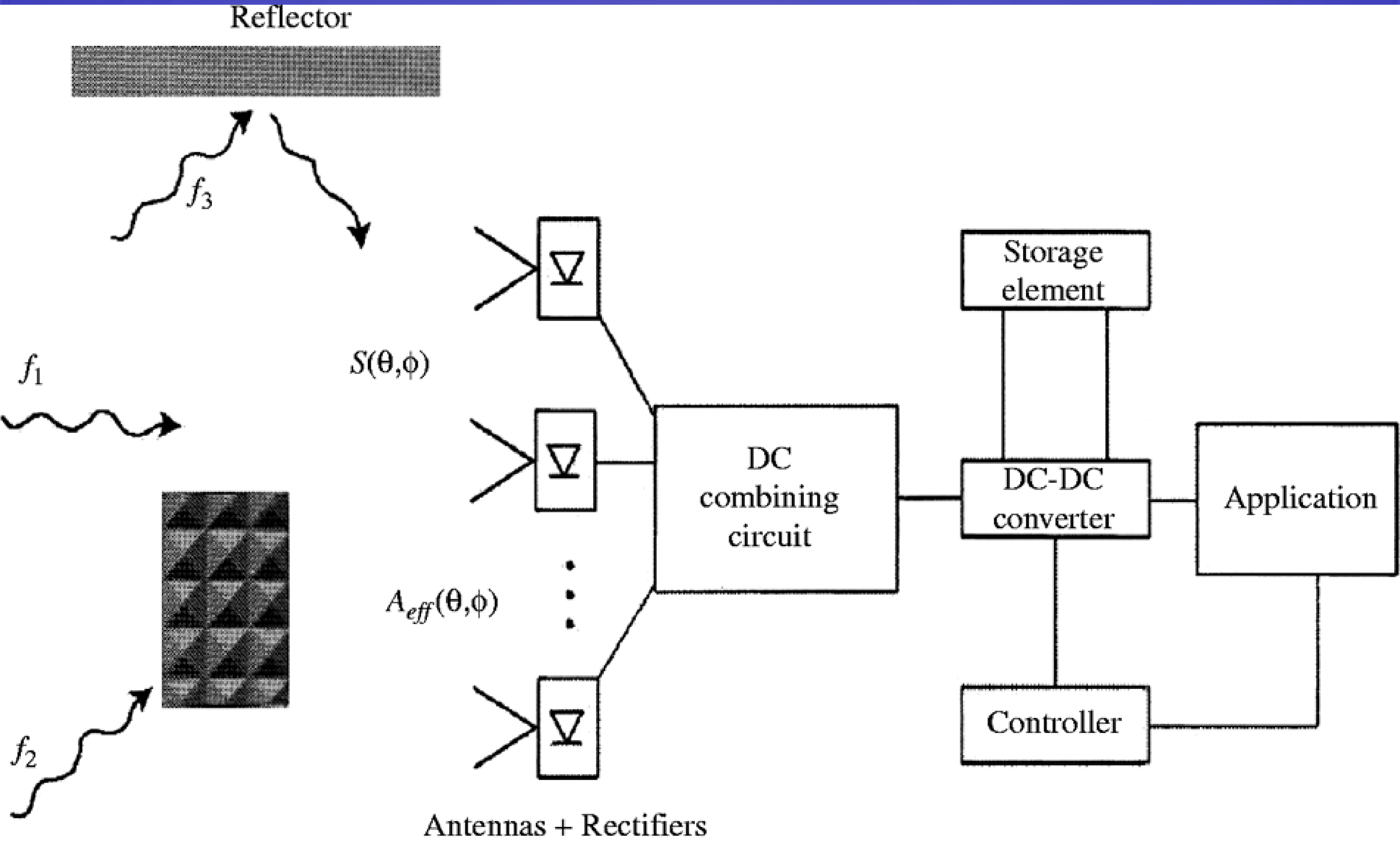
Dt (m)=(dr(m)×0.6/f(GHz))$^{0.5}$
Dt (with HAPs dr=20000m and F=5.8GHz.
Therefore Dt=45m
For maximal power transfer efficiency

At (m2)≈dr(m)/2f(GHz)

Hawaii J. Mankins experiment 148 Km Pt=20W eff. very low at 2.45 GHz

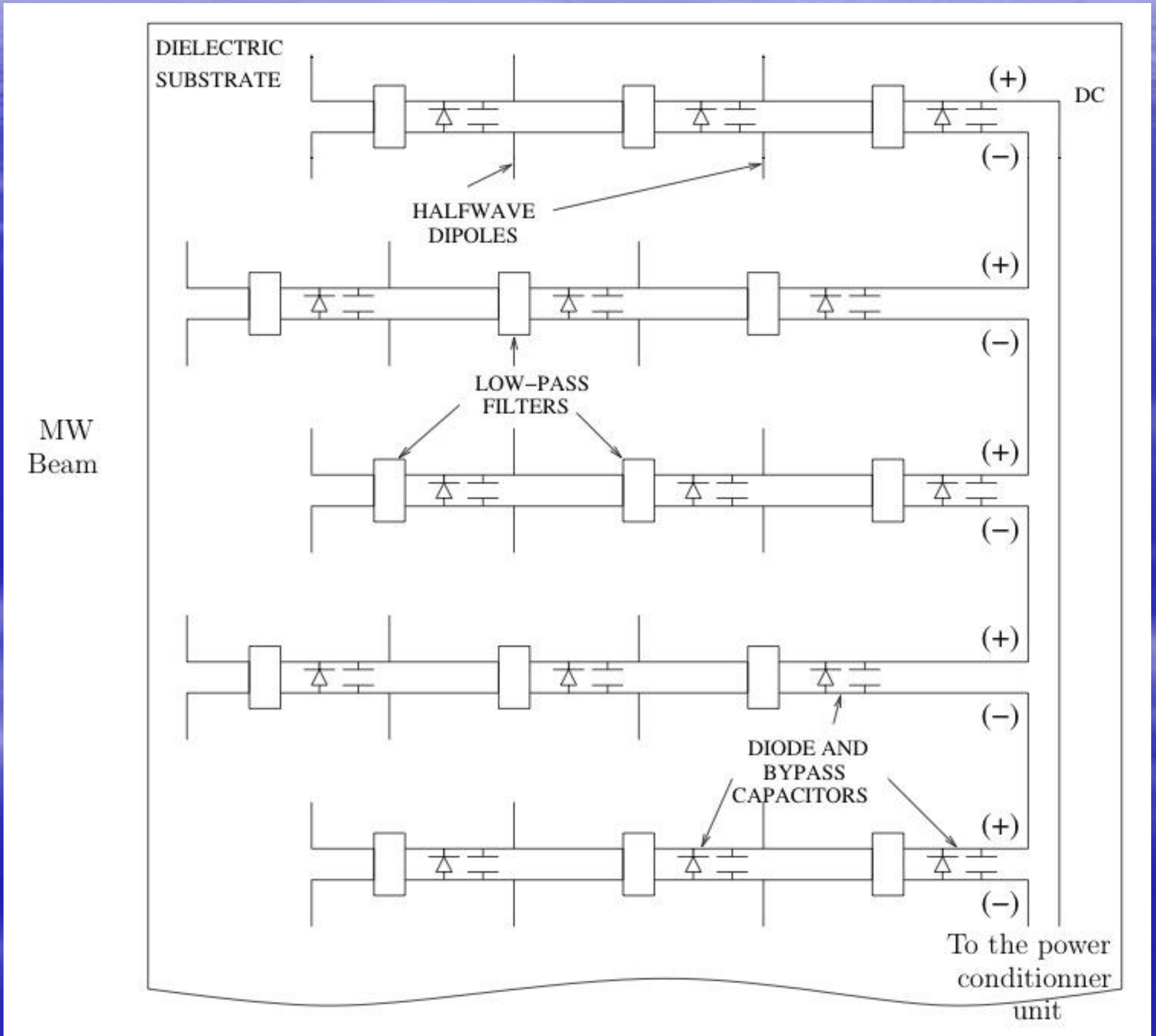
Typical RECTENNA Element for a WPT System. Pioneer W.C Brown



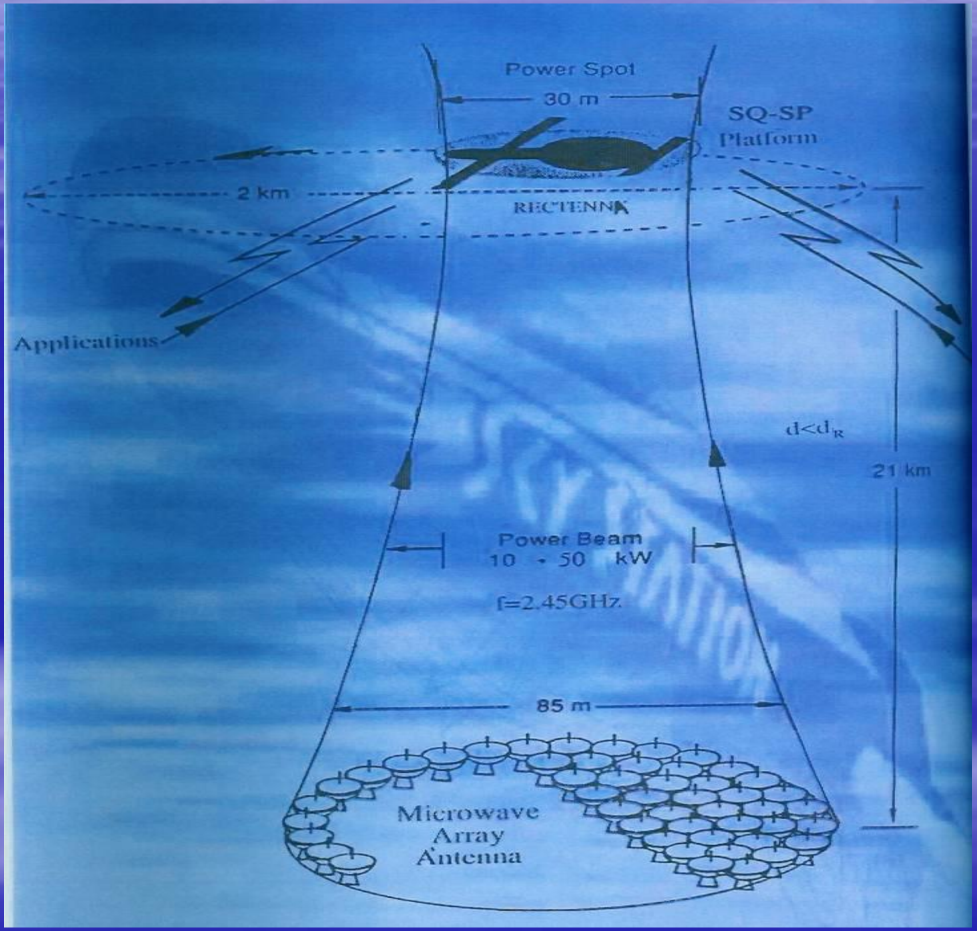


Source: Hagerty *et al.* (2004:1015)

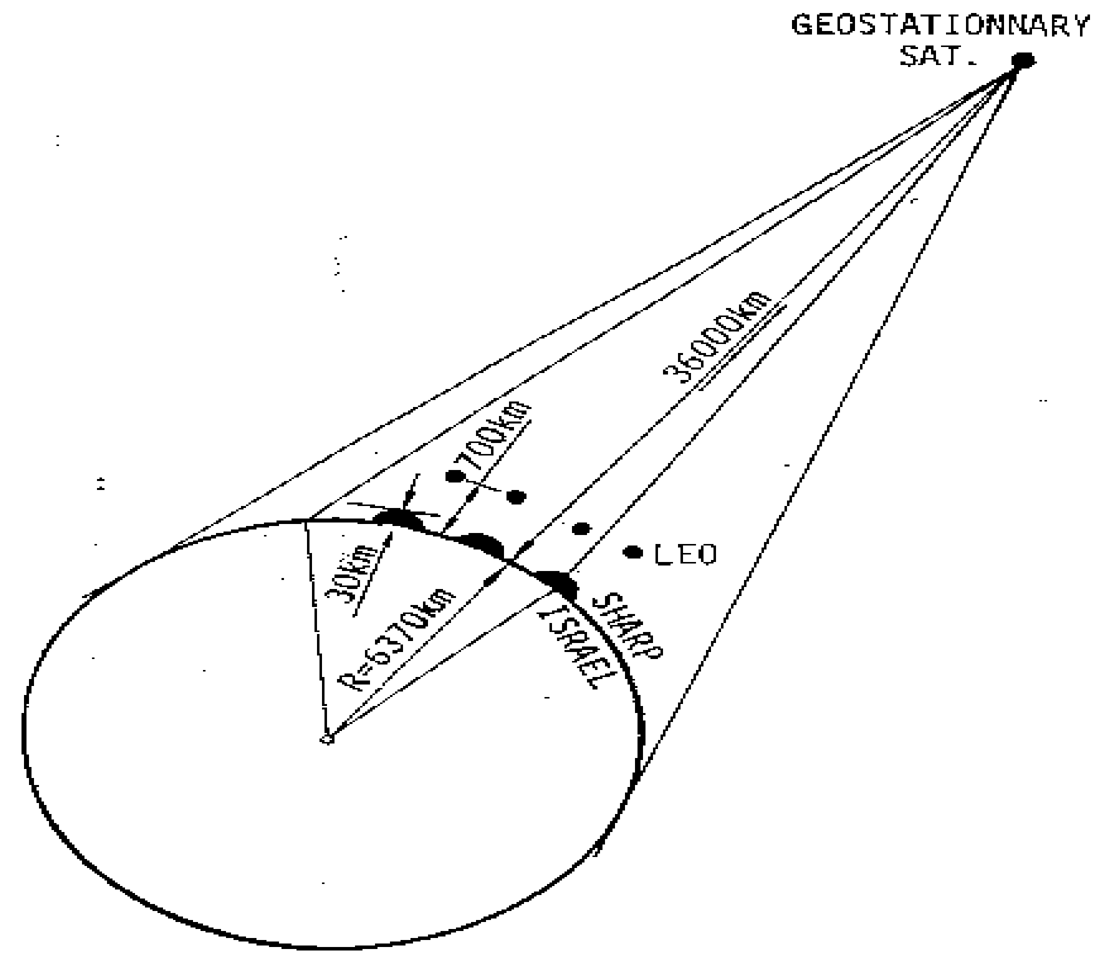
Thin film RECTENNA array



Artistic Pictures of WPT Systems for HAPS



GEO, LEO,MEO Sat. and HAPS.



Comparison between the Geostationnary and
the proposed Radio-Communication Systems

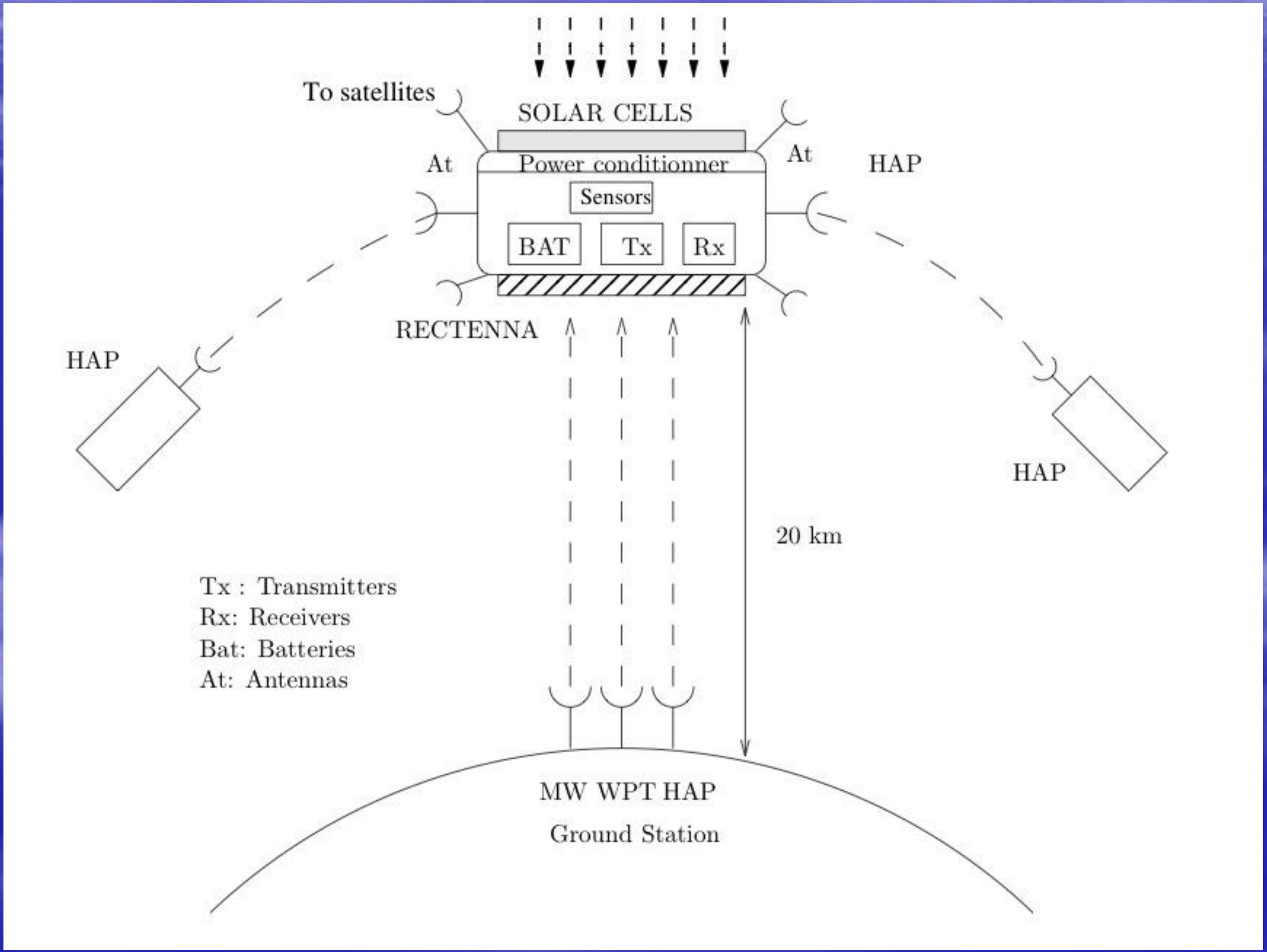
HAPS Main Advantages

- Low Cost of the platform and launching
- Low maintenance Cost. Rapid deployment
- Low Free Space Dispersion Losses
- Low power Consumption (Tx , Rx)
- High Reception Sensitivity
- Large coverage zone relative to ground communication
- Good LOS (line of sight) Conditions
- Short time delay enable high capacity

HAPS Disadvantages

- Limitations in Solar Energy
- Vulnerable to enemy attack and Jamming
- Not yet Proved (Mature)Technology

The sandwich MW WPT system for a terrestrial base Tx to a HAP

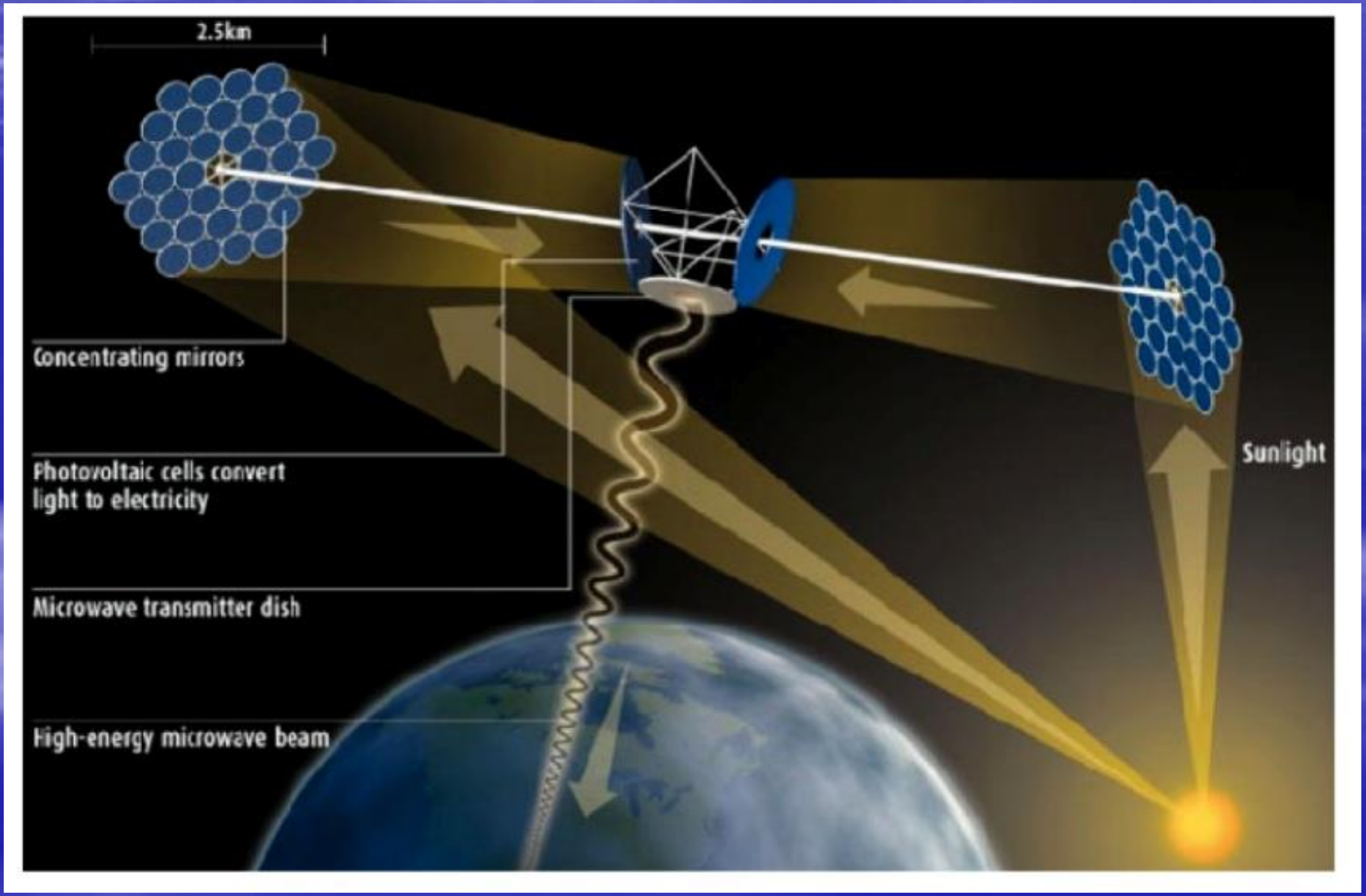


HAPS Spectrum and Bandwidth

- Frequency Ranges
- 2.1GHz S Band, B= 60MHz, (9.6-384)kbps.
- (28- 31) GHz Ka Band, B=300MHz
- (47-48) GHz, B=300MHz for fast internet

ITU Allocations

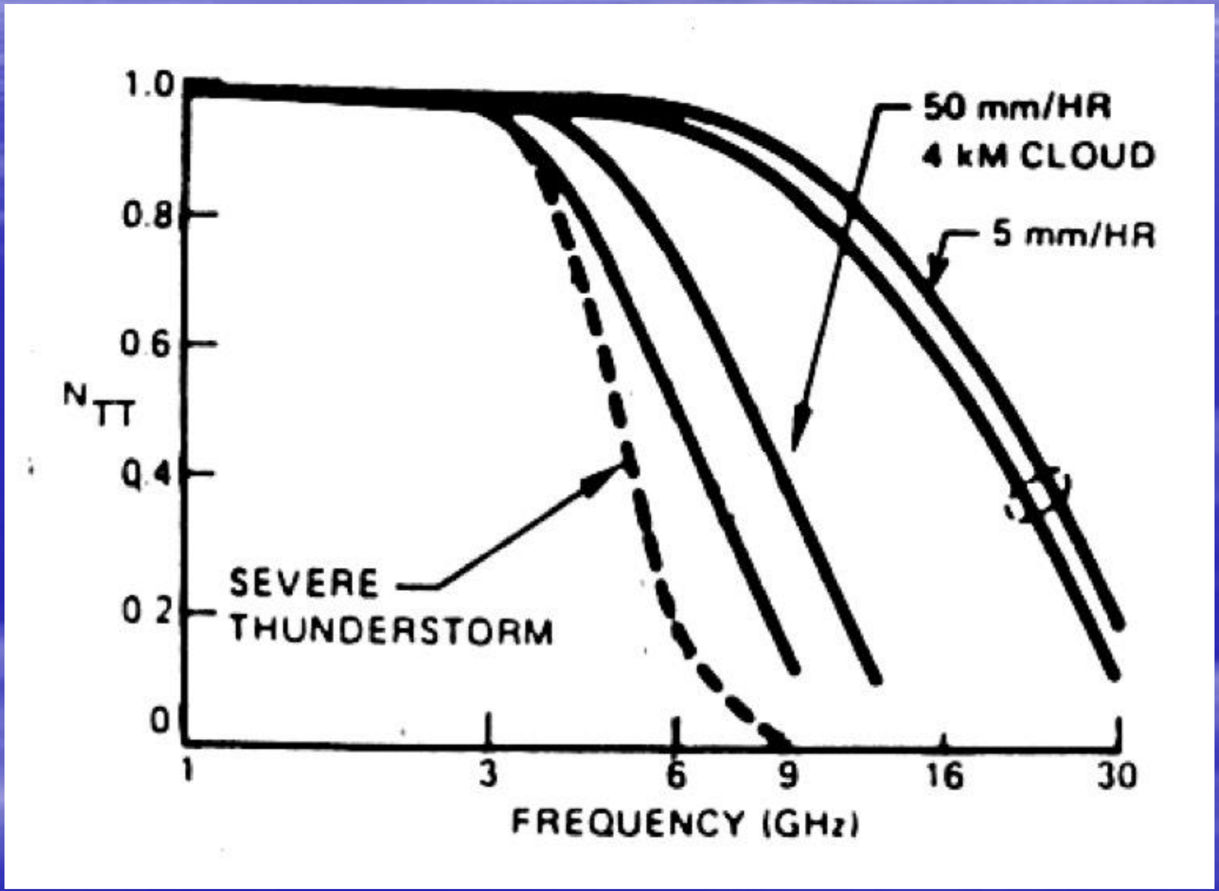
An artistic picture of GEO SPS NASA,. concept Pioneers: P. Glaser, J.Mankins, H. Matsumoto. NASA and Japanese Aerospace



MW WPT Systems Parameters

- MW WPT Systems Frequencies:
- ISM (2.45, 5.8 and 24.5) GHz
- Atmospheric Windows (35,94 and 140) GHz
- Precise Tracking and Control Require:
- Phased Conjugated Retro-directive Antenna Array.
- Pilot Signal at half Tx frequency or DSSS multiplexing.

Atmospheric weather losses as function of the frequency



L.atm .(db) for f=5.8 GHz and Rain path length of 4km and clouds; weather at T=(0^0C) and Rain: 5mm/h (0.05),10mm/h(0.16), 50mm/h(1.2), 100mm/h(2.8), and Severe thunderstorm (9)

Total Zenith Attenuation (in dB) as function of frequency at clear weather conditions

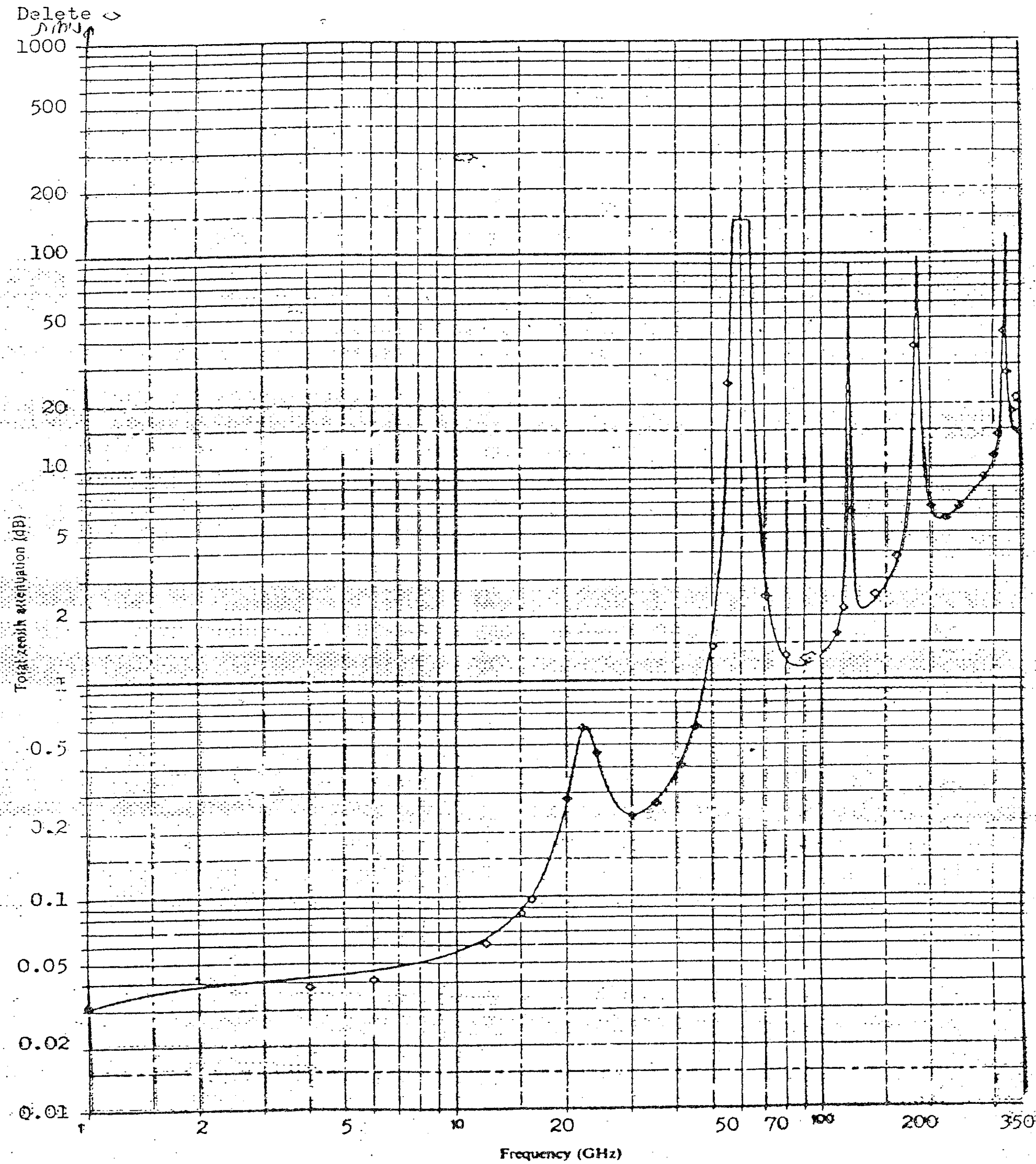
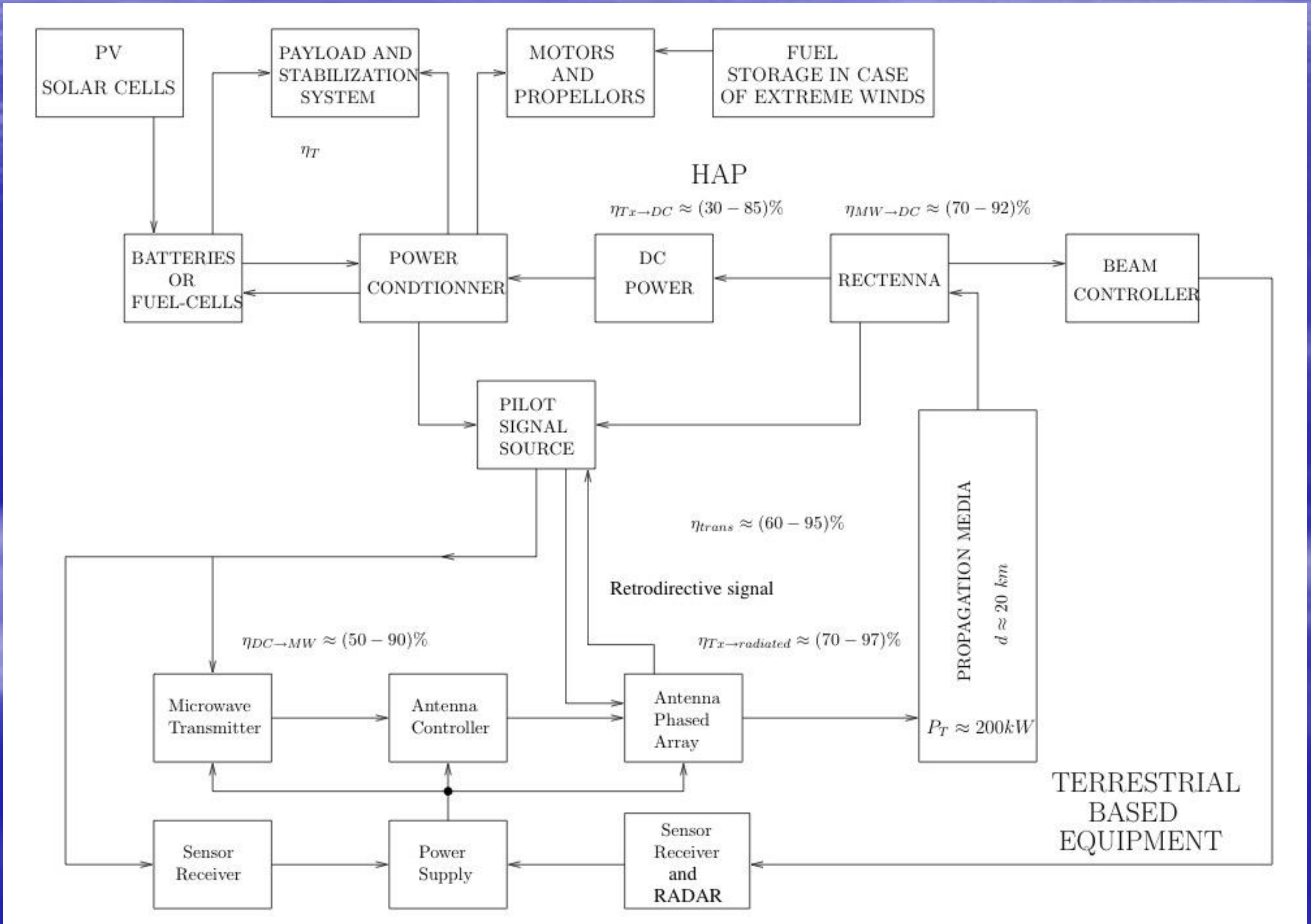


FIGURE 4 – *Total zenith attenuation*

Pressure : 1 atm
Temperature : 20° C
Water vapour : 7.5 g/m³
} at ground level

Detailed block diagram of a typical MW WPT system feeding a HAP



HAPMW WPT Systems Electromagnetic Interference (EMI) Considerations

- Main EMI mitigation measures required to protect radio systems from WPT systems:

MW WPT Tx Stability and linearity more important than power efficiency.

- Sharp filters at the WPT CW Tx output
- To reduce harmonics ,active and passive Inter-Modulation and Desensitization Mitigation techniques for HAPs communication Rxs.
- The interference effects depend more on the distance from the interference source than the interfering power.

MW WPT Systems Electromagnetic Interference (EMI) Considerations (2)

- Tx antenna array control to reduce grating and side lobes protection from RFI
- Gaussian or Raleigh Tapers to concentrate Tx power density at the array center .
- RECTENNA frequency selective surfaces and absorbers for HAPS to reduce EMI.
- The EMI effects decrease for higher frequencies but the atmospheric losses increase.

Bio-Hazard Consideration

- The radiation Maximum Permissible Exposure (MPE) main standards are the ANSI/ IEEE and the IRPA/ WHO .The time averaging of exposure is also important and a factor of security of 5 is added to distinguish between the general public and the controlled locations occupational radiation exposure conditions of 10 W/m^2

Bio-Hazard Consideration (2)

- Above 300 MHz the MPE is increased with frequency due to MW radiation skin depth instead of resonance effects.
- The Transmitter and RECTENNA phased array perimeter has to be forbidden for the general public. For the professional staff the MPE is 250W/m^2 for frequencies exceeding 3 GHz.The damage value is 1500W/m^2 the sun light power density S on the ground.

Table: The HAPS MW WPT antenna aperture: D_T, A_T and S_T for 200kW transmitted power as function of f in case of maximum power transmission efficiency (fig.6).

f (GHz)	2. 45	5. 8	24. 5	35	94
D_T (m)	70	45. 5	22. 1	18. 5	11. 3
A_T (m^2)	3850	1625	385	270	100
S_T (W/ m^2)	52	123	520	740	2000

Dt (m)=$(dr(m)\times 0.6/f(GHz))^{0.5}$
Dt (with HAPs dr=20000m and F=5.8GHz.
Therefore Dt=45m

RECTENNA plane Diffraction field in a WPT system

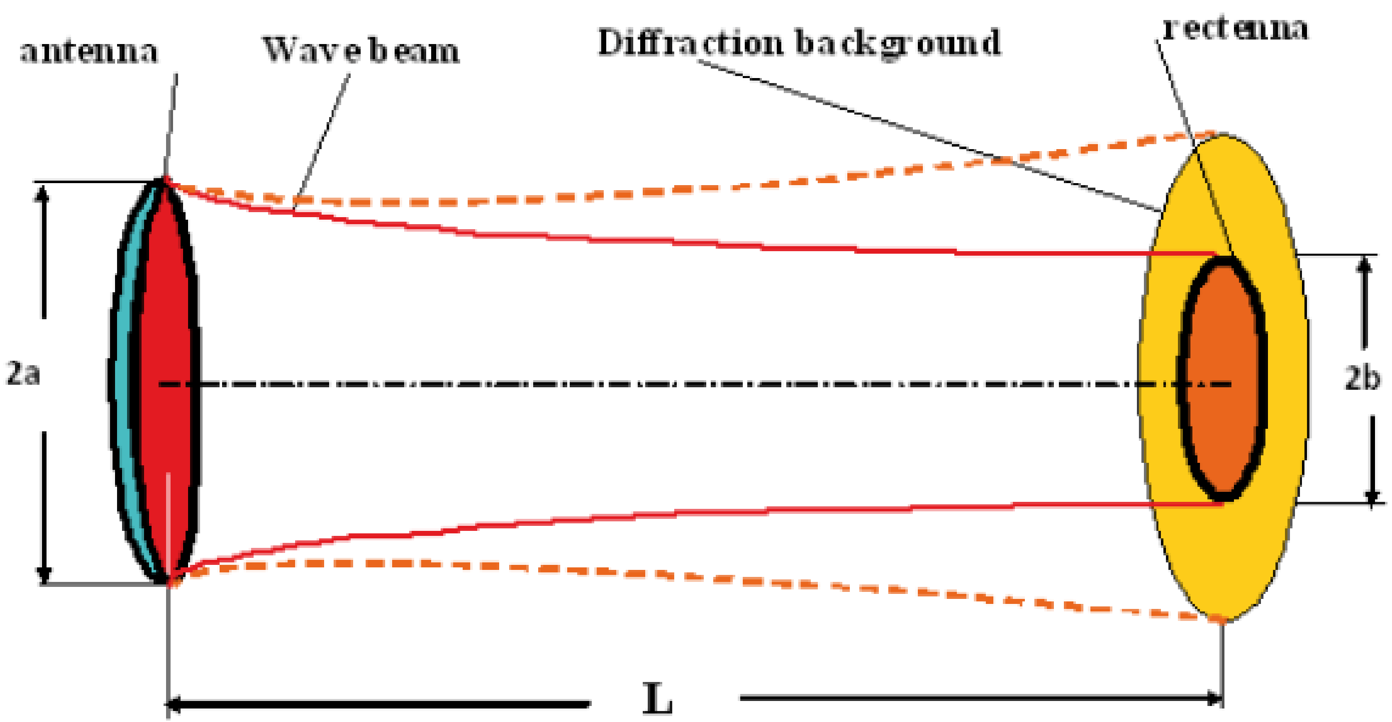


Figure 1. A diagram of the formation of a microwave beam in the wireless power transmission-system.

The Radio Science Bulletin 338; 2011 p26.

Comparison between Gaussian and Rayleigh Tappers

Figure 2a. The three-dimensional field-intensity distributions on the rectenna for the Gaussian beam.

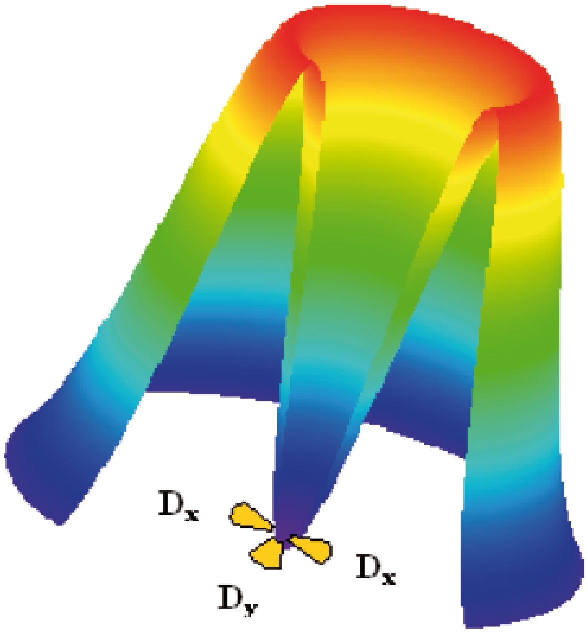
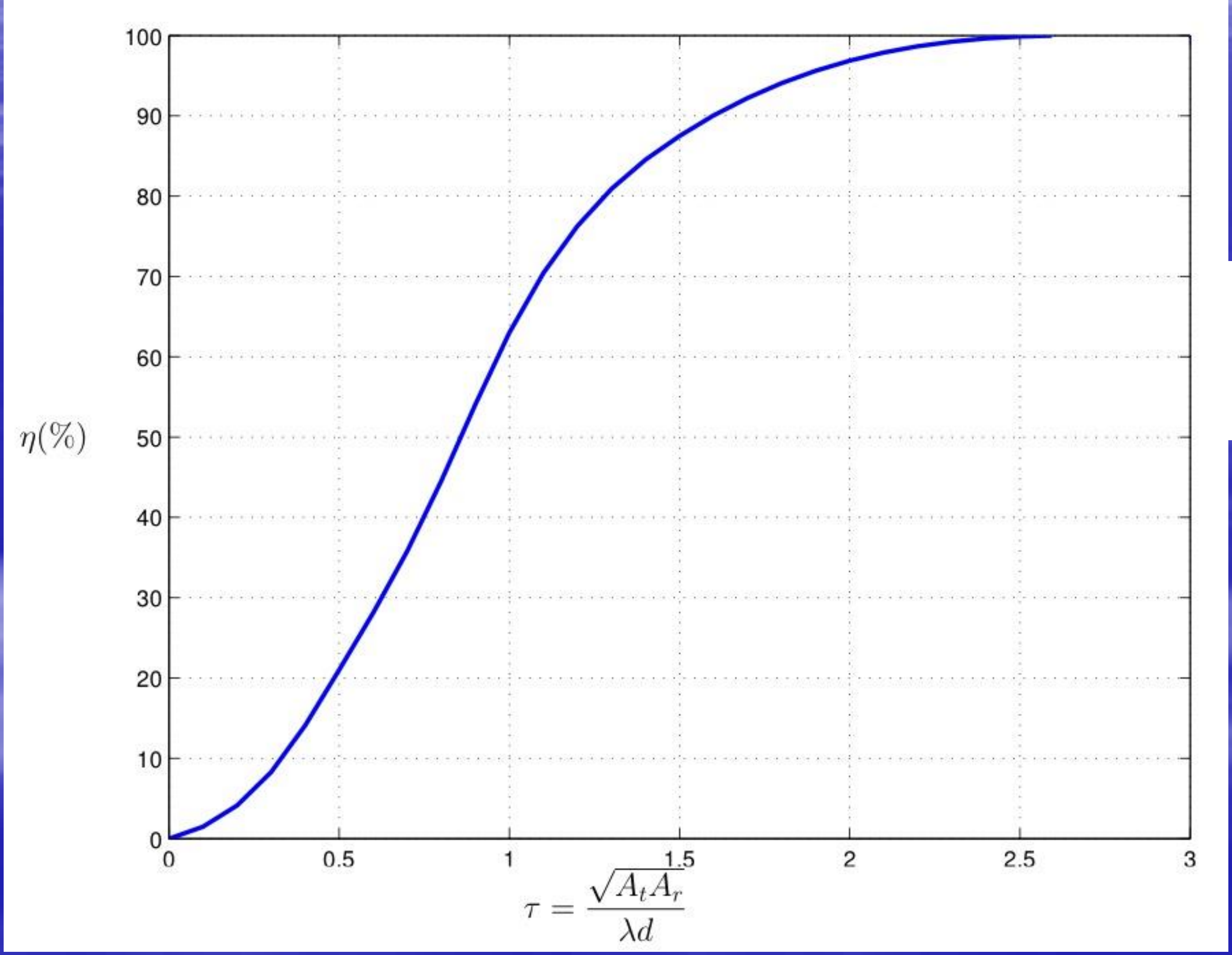


Figure 2b. The three-dimensional field-intensity distributions on the rectenna for the Rayleigh beam: D_x *and* D_y *are the quadrupole sensors.*

The Radio Science Bulletin 338; 2011 p 27.

Empirical Power Transmission Efficiency as function of tau (Goubau and W.C.Brown)



$$\tau = \frac{10f(\mathrm{GHz})\sqrt{A_t A_r}}{3d}$$

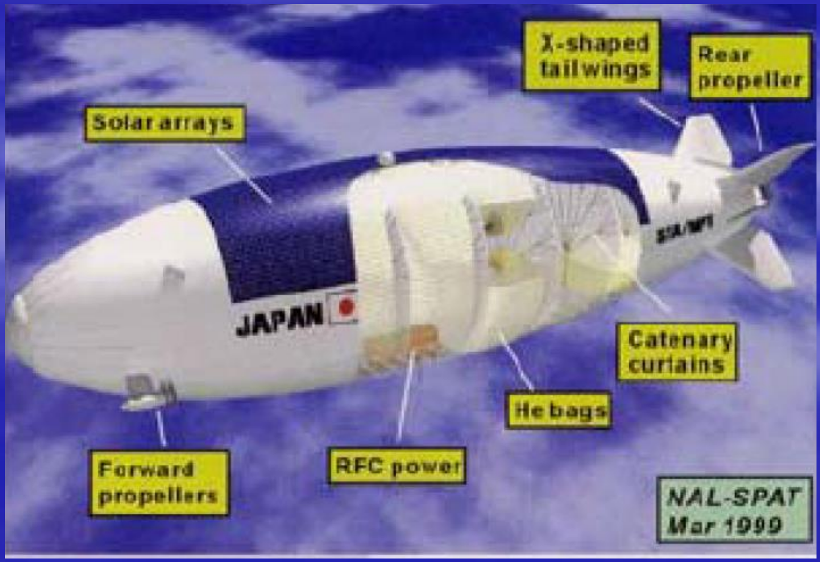
Numerical values of the required aperture antennas, MW beam and HAP RECTENNAS areas as function of power transmission efficiency ,aperture and frequency.

MW WPT Areas		Terrestrial d=10,000m		HAPS d=20,000m		SPS d=36000000m	
Frequency band		η_T= 60%	η_T= 95%	η_T= 60%	η_T= 95%	η_T= 60%	η_T= 95%
2.45 GHz	$A_r = A_t$ (m^2)	1224	2203	2448	4406	4.4×10^6	7.9×10^6
	$D_r = D_t$ (m)	44.1	59.2	62.4	83.7	2650	3550
5.8 GHz	$A_r = A_t$ (m^2)	517	931	1034	1862	1.9×10^6	3.4×10^6
	$D_r = D_t$ (m)	28.7	38.5	40.6	55.1	1750	2350
35 GHz	$A_r = A_t$ (m^2)	86	155	172	310	0.31×10^6	0.56×10^6
	$D_r = D_t$ (m)	11.7	15.3	16.5	22.2	705	950
94 GHz	$A_r = A_t$ (m^2)	32	58	64	116	0.11×10^6	0.2×10^6
	$D_r = D_t$ (m)	7.2	9.7	10.1	13.6	470	570

HAP airship dimensions

	L (m)	D (m)	M (Kg)
Stratellite Sanswire	75	45	3000
Dickinson Patent	300	45	18000*
Japan HAP Project 2002	245	60	22400

* Including solar cells and RECTENNA



Wireless power Transmission (WPT) Evolution

Progress and Development in:

- MW Power Devices and Transmitters (Klystrons, Magnetrons (SPORTS), TWT, Gyratrons, Ga N, Si C)
- Rectifier-Antenna (RECTENNA) Systems
- Smart Phased Array Antennas
- Precise Tracking and Control
- Robotic operation and 3D printers
- Smart Electrical grid

Conclusions(1)

- MW WPT systems can be useful for supplying HAPs with the required payloads, stabilization power and energy for long operation of radio relays, communication, broadcasting, remote sensing and many other applications.
- The considerable R&D achievements in the field of SPS development especially by Japanese and US scientists are very important in the future implementation of MW WPT to HAPs and other long range WPT projects.

Conclusions (2)

- The challenges for HAPs MW WPT systems are significantly lower cost and easier to implement than for SPS.
- The MW WPT systems optimal frequency range for HAPs and SPS is the 5.8 GHz ISM band.
- The EMI regulation restrictions are important and bio-hazards threats are significantly less for HAPs than for SPS systems but the basic .problems are similar.

Conclusions (3)

- Implementation of MW WPT systems for HAPs may be useful for the EMI and bio-hazard threats evaluations and development of more challenging future SPS systems.
- The crucial EMI and bio-hazard issues requires a good collaboration with the ITU, WHO, IEEE and URSI and national standard organizations

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Thank
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