McCormick

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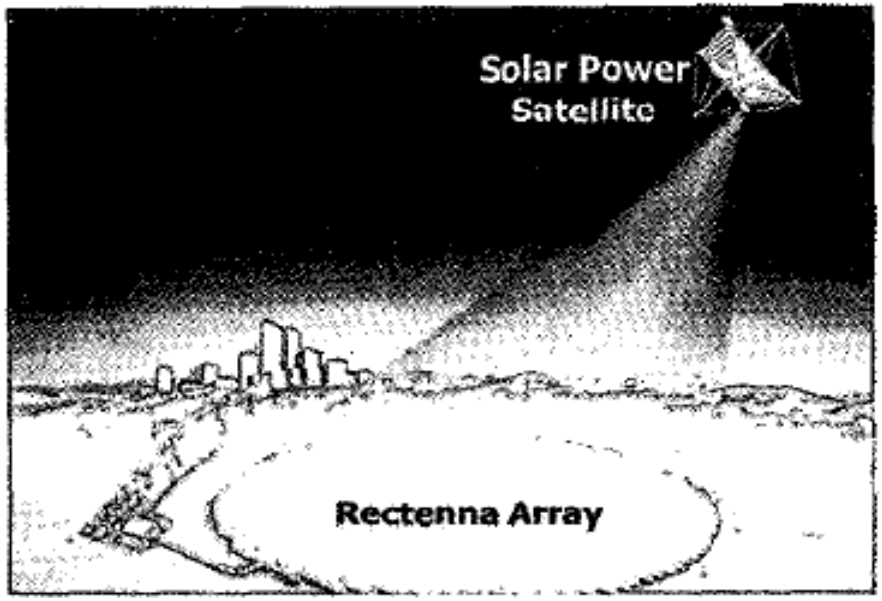
Space-Based Solar Power

Jessica Hoffman

MSE 395

June 3, 2008

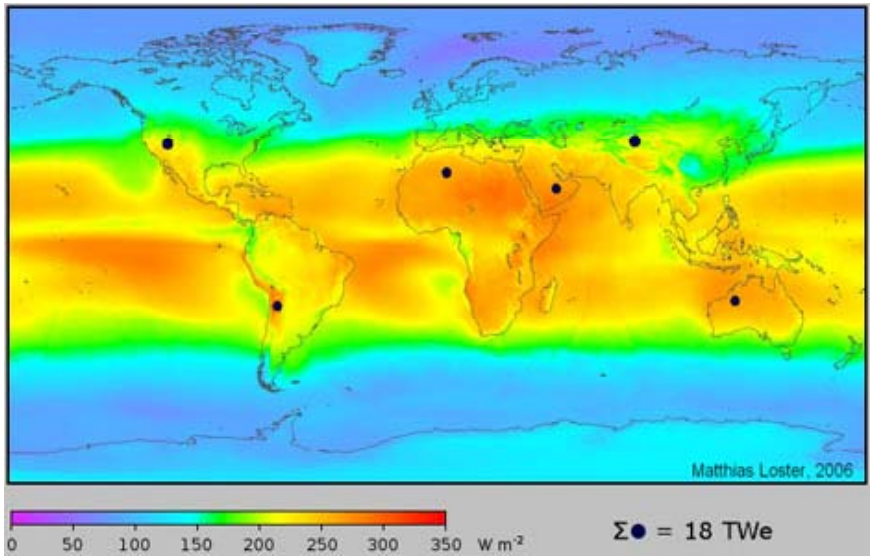
What is Space-Based Solar Power (SSP)?



- Capture solar energy using satellite
- Convert electricity to microwave frequency
- Beam to Earth using transmitter
- Collect and covert back to electricity using rectenna

Rodenbeck, C.T. and K. Chang. IEEE Antennas and Propagation Magazine, 2005. **47**(4): p. 67-72.

Space-Based vs. Terrestrial Solar Power



- Not affected by:
  - Day/Night cycles
  - Clouds
- Usable anywhere on Earth (“sunfuel”)
- Requires less land

Brief History of SSP

technically feasible but still expensive!

"science fiction"

1968: Peter Glasser proposes space solar power

1976-1980: DOE and NASA first consider solar power satellites

NRC says: too expensive; time needed to develop technologies

1995: NASA conducts Fresh Look Study; possible systems and architectures proposed

1998: NASA Concept Definition Study and market assessment

2000: NASA outsources testing and R&D on related concepts and technologies

2000: US government calls for NASA to reduce earth-to-orbit transit costs within 20 years

Mankins, J.C. Acta Astronautica, 1997. **41**(4-10): p. 347-359.

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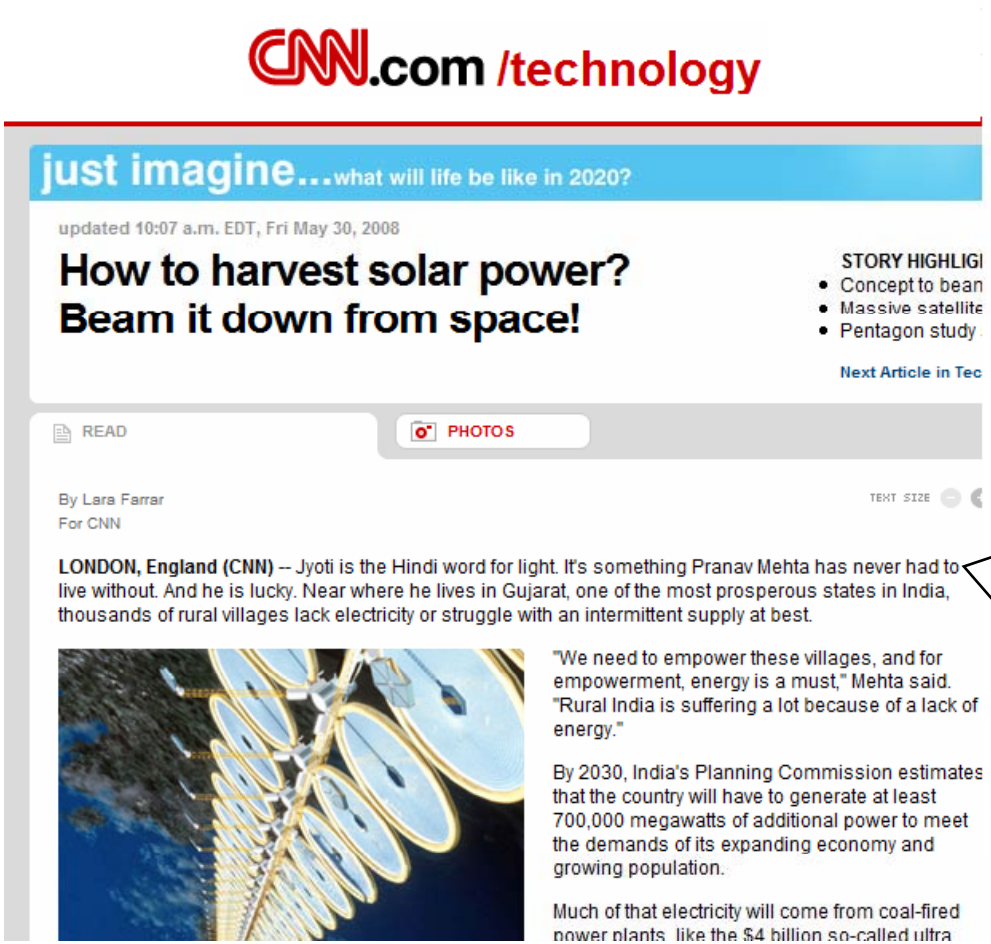


CNN.com /technology

just imagine...what will life be like in 2020?

updated 10:07 a.m. EDT, Fri May 30, 2008

How to harvest solar power? Beam it down from space!

STORY HIGHLIGI
- Concept to bean
- Massive satellite
- Pentagon study

Next Article in Tec

READ PHOTOS

By Lara Farrar
For CNN

TEXT SIZE

LONDON, England (CNN) -- Jyoti is the Hindi word for light. It's something Pranav Mehta has never had to live without. And he is lucky. Near where he lives in Gujarat, one of the most prosperous states in India, thousands of rural villages lack electricity or struggle with an intermittent supply at best.

"A single kilometer-wide band of geosynchronous Earth orbit experiences enough solar flux in one year to nearly equal the amount of energy contained within all known recoverable conventional oil reserves on Earth today"

In 2007, Pentagon's National Security Space Office encourages US government to spearhead this effort

Challenges

- Need for interim markets
- Global acceptance and cooperation
  - Radio frequencies
  - Orbits
- Concern regarding microwaves
- Development of related technologies

Wireless Power Transmitters

- Efficient DC to RF conversion
- Emit at 5.8 GHz
- Total aperture size: diameter = 500 m
- Three converter types:

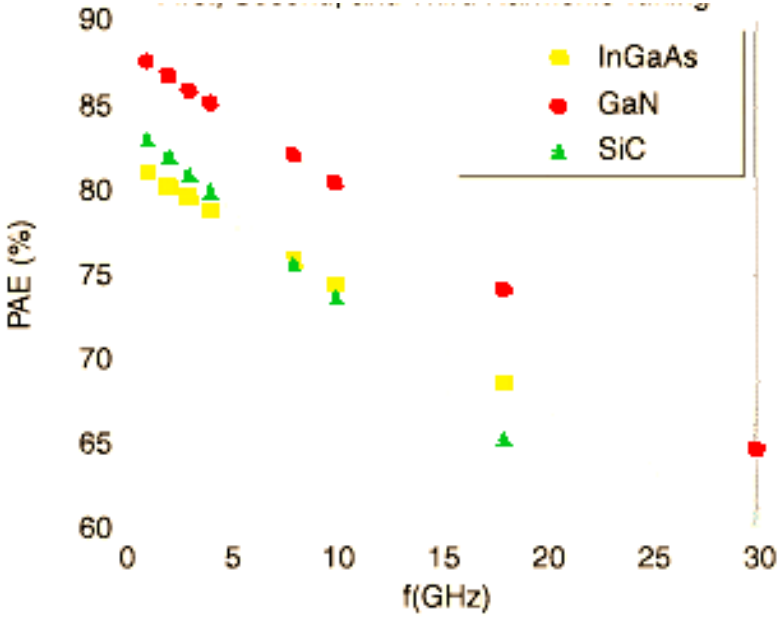
	Klystron	Magnetron	Solid-State Amplifier
# converters	~210,000	~400,000	~84,000,000
Converter mass (kg)	14	1	0.001
Converter operating voltage (V_{dc})	28,000	6,000	80
Overall transmitter specific mass (kg/m^2)	40.4	32.0	33.9

J.C. Mankins. IEEE Microwave Magazine, Dec 2002: p. 46-57.

Transmitters: the Solid State Amplifier

PAE = Power Added Efficiency

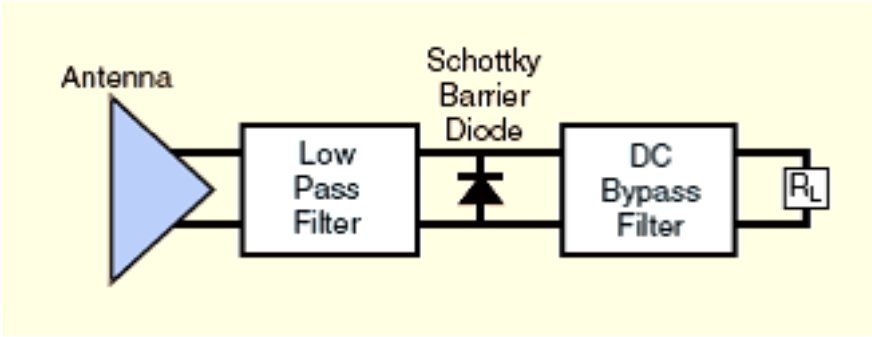
- Measure of amplification abilities
- Varies with frequency
- GaN most promising, but:
  - Expensive
  - Charge and interface effects
  - Resistance at contacts and in channels of device



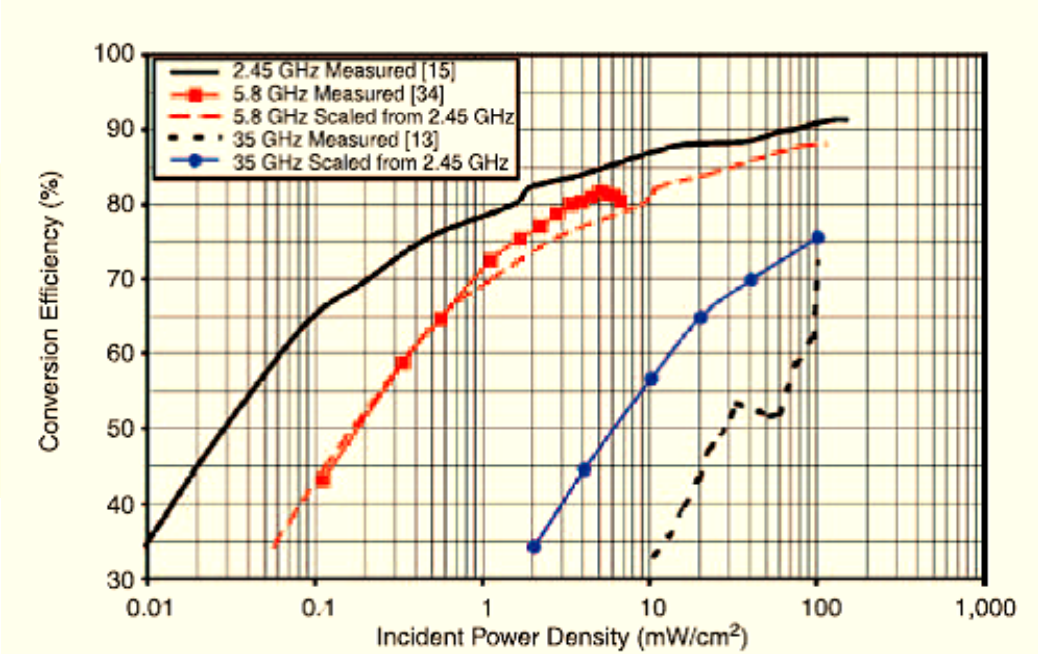
J.C. Mankins. IEEE Microwave Magazine, Dec 2002: p. 46-57.

Rectennas

- Rectifying Receiving Antenna
- Collect microwaves and convert to DC
- Typically found in printed-circuit format
- Optimization by different printing patterns

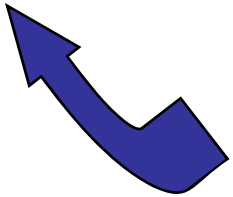


J.C. Mankins. IEEE Microwave Magazine, Dec 2002: p. 46-57.



Sources of Inefficiency	Efficiency	Power (GW)	Notes
Input power (GW dc)		2.672 dc	
RF Circuit Efficiency			
DC-RF converter efficiency	0.860	2.298	Assumes average converter efficiency
RF filter insertion loss (IL)	0.891	2.048	Estimated total IL = 0.5 dB
Transmitting Antenna Efficiency			
Subarray random electronic failures	0.960	1.966	Estimated 2% failures
Meteorite hit element failures	1.000	1.966	100 failures/year
Amplitude error	0.996	1.957	±1 dB amplitude deviation
Phase error	0.978	1.914	±15° phase deviation
Phase quantization	0.997	1.908	5-b phase shifter
Taper quantization	0.989	1.886	10 steps
Antenna aperture efficiency	0.980	1.849	Conductive losses in aperture
Transmitter scan loss	1.000	1.849	Assumes broadside radiation
Mismatch loss	1.000	1.849	Assumes Array VSWR = 1.0
Beam Coupling Efficiency			
Propagation loss	0.979	1.809	Rain rate = 4 mm/hr @ 5.8 GHz
Collection efficiency	0.921	1.666	Gaussian beam taper = 10.14 dB
Polarization loss	1.000	1.666	Assumes near perfect alignment
Rectenna Efficiency			
Rectenna random failures	0.990	1.649	Estimated 1% failures
RF filter insertion loss (IL)	0.891	1.469	Estimated IL = 0.5 dB
Rectenna scan loss	1.000	1.469	Rectenna tilted to avoid loss
Mismatch loss	1.000	1.469	Assumes Array VSWR = 1.0
Rectenna efficiency	0.860	1.263 dc	Projected optimized average efficiency
DC to utility grid efficiency	0.950	1.200 dc	Assumed dc-dc converter efficiency
System dc-dc efficiency	45%		

~45% efficient



J.C. Mankins. IEEE Microwave Magazine, Dec 2002: p. 46-57.

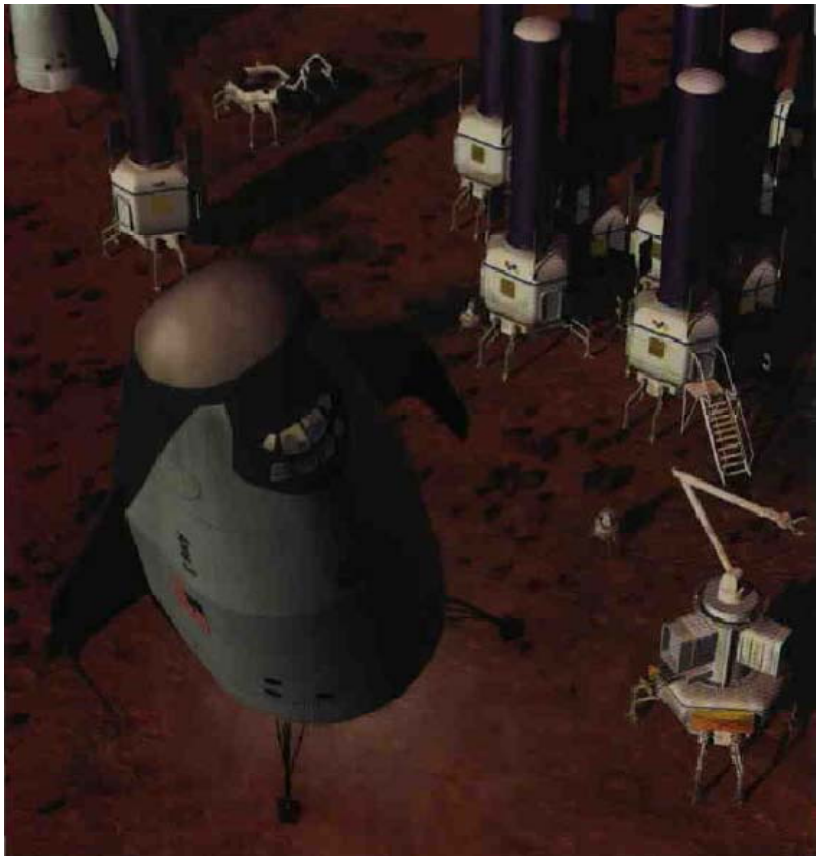
Questions?

Back Up Slides

Lunar Solar Power

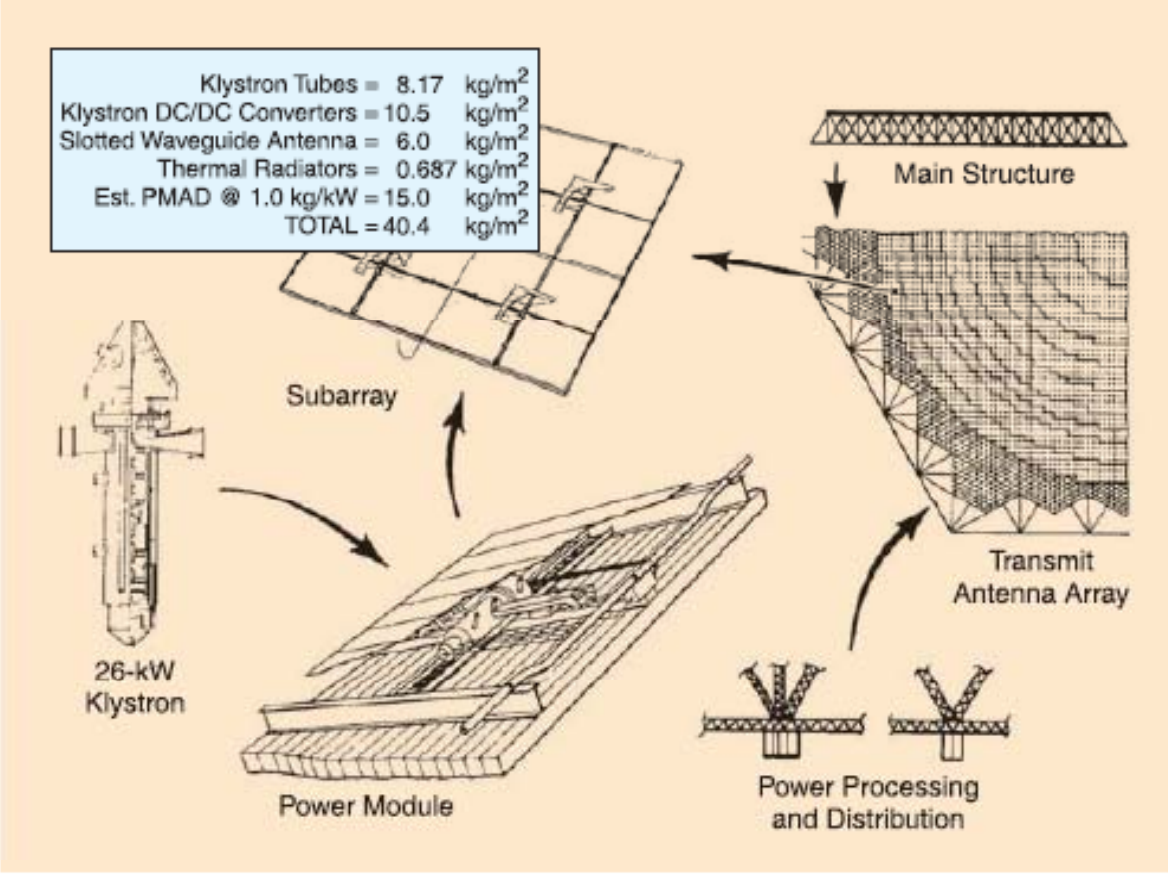
- Modular factories sent to moon to construct solar power units out of lunar soil (silicon, aluminum, etc)

- "Improvement" over SSP:
  - Lower launch cost
  - No orbital debris

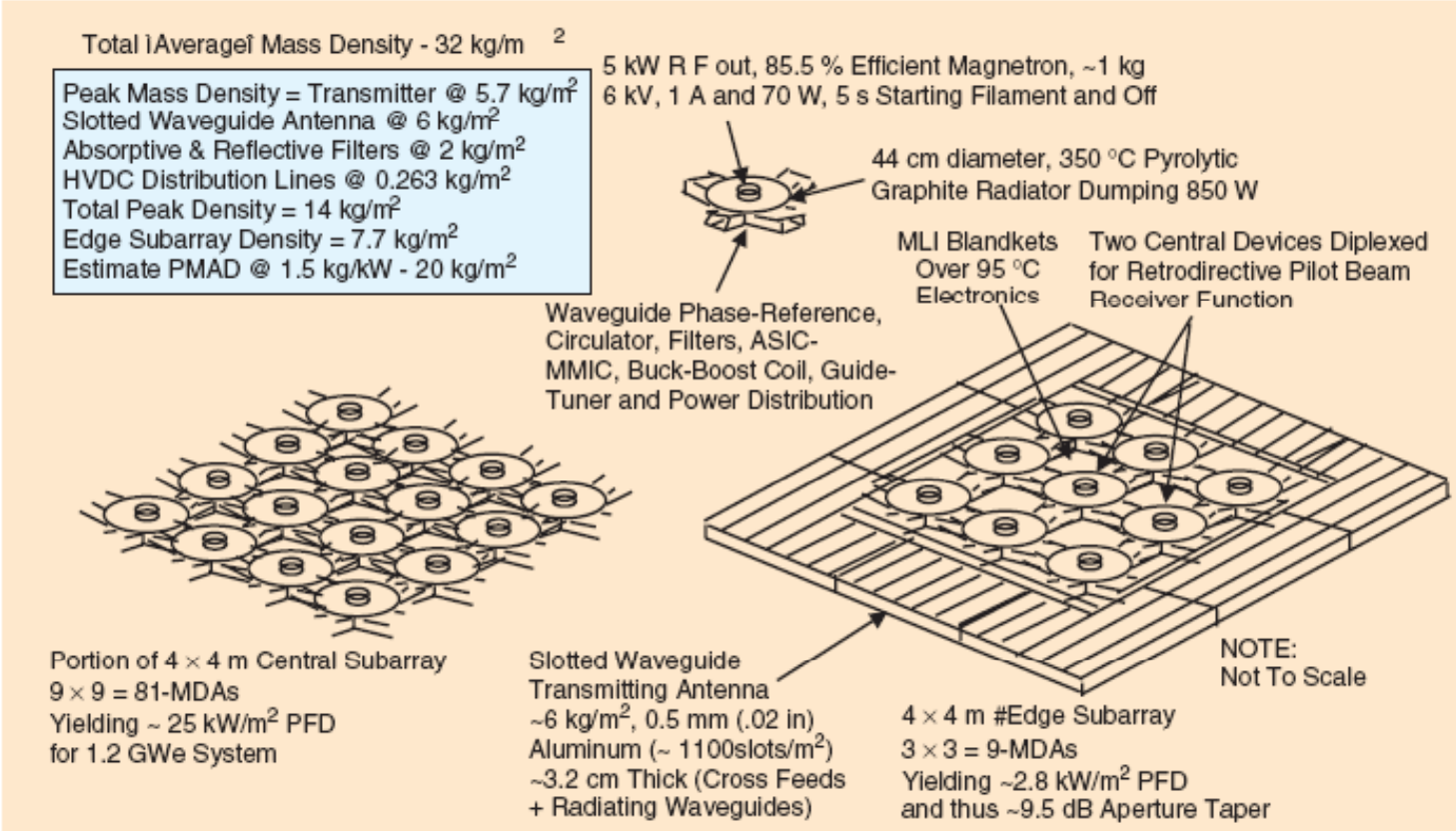


Moore, T. Epri Journal, 2000. **25**(1): p. 6-17.

klystron


Klystron Tubes = 8.17 kg/m²
Klystron DC/DC Converters = 10.5 kg/m²
Slotted Waveguide Antenna = 6.0 kg/m²
Thermal Radiators = 0.687 kg/m²
Est. PMAD @ 1.0 kg/kW = 15.0 kg/m²
TOTAL = 40.4 kg/m²
Main Structure
Subarray
Transmit Antenna Array
26-kW Klystron
Power Module
Power Processing and Distribution

magnetron


Total (Average) Mass Density - 32 kg/m 2
Peak Mass Density = Transmitter @ 5.7 kg/m2
Slotted Waveguide Antenna @ 6 kg/m2
Absorptive & Reflective Filters @ 2 kg/m2
HVDC Distribution Lines @ 0.263 kg/m2
Total Peak Density = 14 kg/m2
Edge Subarray Density = 7.7 kg/m2
Estimate PMAD @ 1.5 kg/kW - 20 kg/m2
5 kW R F out, 85.5 % Efficient Magnetron, ~1 kg
6 kV, 1 A and 70 W, 5 s Starting Filament and Off
44 cm diameter, 350 °C Pyrolytic
Graphite Radiator Dumping 850 W
MLI Blandkets
Over 95 °C
Electronics
Two Central Devices Diplexed
for Retrodirective Pilot Beam
Receiver Function
Waveguide Phase-Reference,
Circulator, Filters, ASIC-
MMIC, Buck-Boost Coil, Guide-
Tuner and Power Distribution
Portion of 4 × 4 m Central Subarray
9 × 9 = 81-MDAs
Yielding ~ 25 kW/m2 PFD
for 1.2 GWe System
Slotted Waveguide
Transmitting Antenna
~6 kg/m2, 0.5 mm (.02 in)
Aluminum (~ 1100slots/m2)
~3.2 cm Thick (Cross Feeds
+ Radiating Waveguides)
4 × 4 m #Edge Subarray
3 × 3 = 9-MDAs
Yielding ~2.8 kW/m2 PFD
and thus ~9.5 dB Aperture Taper
NOTE:
Not To Scale

Solid State Transmitter