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AN ALL ELECTRONIC TRANSPORTATION SYSTEM FROM LEO TO GEO AND BEYOND

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System description and moon mission interface. The all electronic LEO to GEO transportation system (1) now being studied by NASA as part of the space transportation infrastructure and that combines the high specific impulse of the ion thruster with beamed microwave power may have application to a moon or Mars mission. The range of the system can probably be extended to twice GEO distance where 80% of the delta V required for the moon mission will have occurred. In principle the electronic OTV (orbital transfer vehicle) transports the moon mission to twice GEO, comes back to perform its routine LEO to GEO function, and then later retrieves the mission when it returns from the moon. The system schematic and a diagram of the complete, four beam system are shown in Figure 1. All elements of the system must be located in the equatorial plane to allow beam contact with the OTV each time it orbits the earth. This location is consistent with minimum launch costs to LEO and GEO and a joint use of the ground-based installation to beam low cost power to "orbiting industrial parks".

LEO to GEO flight times. The low combined mass of the ion thruster and the microwave receiver relative to the thrust generated allows large, unanticipated accelerations of an electric OTV. LEO to GEO flight times of about 10 days can be projected for an express (small payload) mission, after making allowances for initial intermittent contact with the microwave beam. Figure 2 shows the transport times for single and four beam systems for a 51% payload.(2)

Technology readiness and modular construction. The technologies of both the space portion (ion thrusters and "rectenna") are well developed but their interfacing needs experimental study. Modular construction allows easy expansion of both space and ground systems. Many low-cost microwave components are available.

System capacity and costs. A full scale system (4 beams and 4 OTVs) could handle up to 60,000,000 kg/yr of payload to GEO. Costs for 60 cycle earth power and 10 yr. system amortization cost, on basis of $/kg of payload, are each estimated to be $15/kg for a full scale system. Smaller systems will cost more but are still very attractive.

Reduction of propellant mass. The amount of ion thruster propellant needed in LEO for a typical round trip to GEO with payload is typically less than 10% that of propellant for conventional chemical rockets. Argon or xenon may be used.

(1) W. C. Brown. AIAA-85-2045 paper. Int'l Electric Propulsion Conf. Oct. 1985
(2) W. C. Brown. Science Technology Series, Vol 67, 1987 Amer. Astro. Soc.

Abstract for the Symposium
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UNIQUE PROPERTIES OF MICROWAVE POWER TRANSMISSION TO TRANSFER ENERGY

- NO MASS REQUIRED BETWEEN SOURCE OF ENERGY AND POINT OF CONSUMPTION
  - NO WIRES
  - NO FERRYING VEHICLES
- ENERGY CAN BE TRANSFERRED AT VELOCITY OF LIGHT
- DIRECTION OF ENERGY TRANSFER CAN BE RAPIDLY CHANGED

CHARACTERISTICS COMMON TO ALL APPLICATIONS

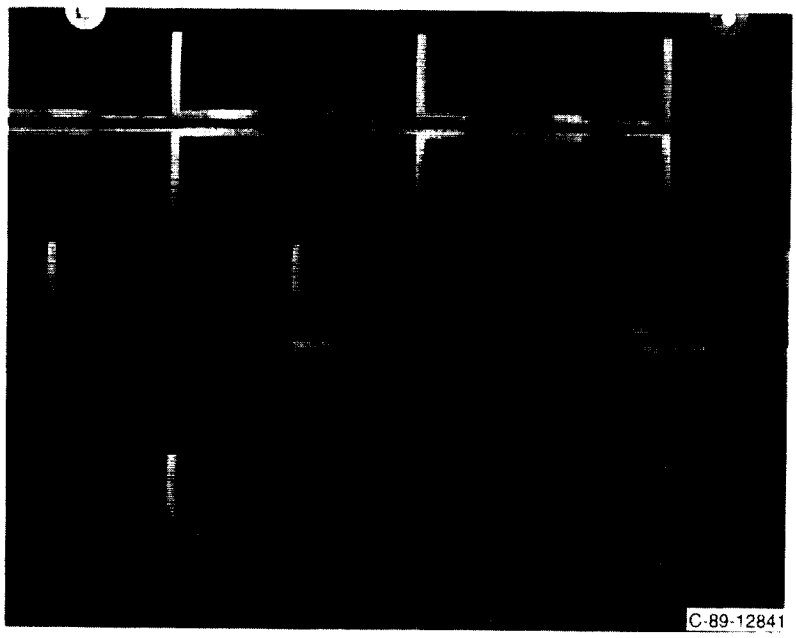
EQUATORIAL PLANE
- BOTH UPLINK APPLICATIONS COMPLETELY IN PLANE
- DOWNLINK TRANSMITTER IN PLANE

FREQUENCY --- 2.45 GIGAHERTZ (12 CM) OR CLOSE TO IT

ELECTRONICALLY STEERABLE PHASED ARRAY TRANSMITTERS COMPOSED OF MODULES

DEVICE THAT SIMULTANEOUSLY ABSORBS MICROWAVE POWER AND RECTIFIES IT TO DC POWER AT 80+% EFFICIENCY

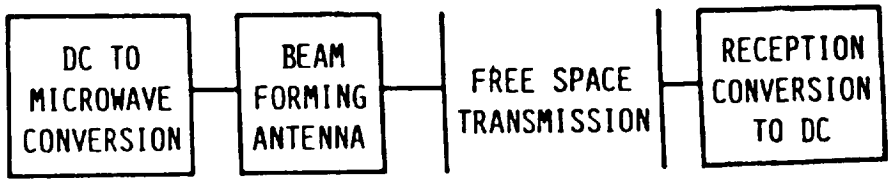
LARGE AND VERY HIGH POWER SYSTEMS



UNIQUE PROPERTIES OF MICROWAVE POWER TRANSMISSION TO TRANSFER ENERGY

- NO LOSS OF ENERGY TRANSFER IN VACUUM OF SPACE
  LITTLE LOSS IN EARTH'S ATMOSPHERE AT THE LONGER MICROWAVE WAVELENGTHS
- THE MASS OF THE POWER CONVERTERS AT THE TERMINALS CAN BE SMALL
- ENERGY TRANSFER BETWEEN POINTS IS INDEPENDENT OF GRAVITATIONAL POTENTIAL

BEAMED MICROWAVE POWER TRANSMISSION SYSTEM



70 - 90 % 70 - 97 % 5 - 95 % 85 - 92%

MAXIMUM POSSIBLE DC TO DC EFFICIENCY --- 76%

EXPERIMENTAL DC TO DC EFFICIENCY --- 54%

SOLAR POWER SATELLITE EFFICIENCY --- 58-72%

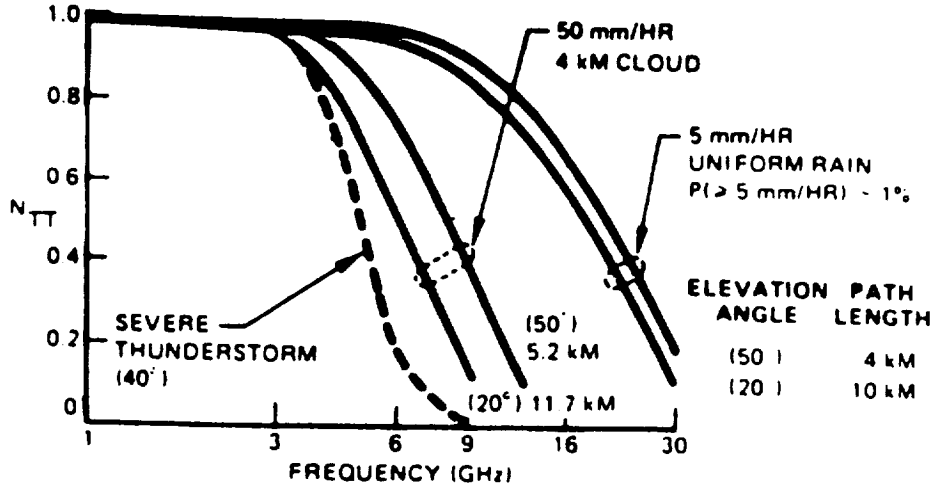
BEAMED MICROWAVE POWER TRANSMISSION SYSTEMS INTERRCONNECTING EARTH AND SPACE

UPLINKS

- o ALL ELECTRONIC TRANSPORTATION SYSTEM FROM LOW EARTH ORBIT TO GEOSYNCHRONOUS ORBIT
- o ELECTRIC POWER BEAMED TO "ORBITING INDUSTRIAL PARKS"

DOWNLINK

- o TRANSFER OF POWER DERIVED FROM THE SUN IN GEOSYNCHRONOUS ORBIT TO THE EARTH.- THE SOLAR POWER SATELLITE CONCEPT



TRANSMISSION EFFICIENCY
MOLECULAR ABSORPTION AND RAIN

FOCUS ON ALL ELECTRONIC TRANSPORATION SYSTEM FROM LEO TO GEO

- SAFE, RELIABLE, AND "LOW G"
  BUT, SHORT, UNANTICIPATED TRANSPORT TIMES FOR AN ELECTRIC PROPELLED VEHICLE
- LOW COST IN COMPARISON WITH OTHER TECHNOLOGIES
- MODULAR APPROACH ALLOWS EASY EXPANSION OF MICRO-WAVE SYSTEM AND TRANSPORT TONNAGE
- COMPONENTS OF SYSTEM IN ADVANCED STATE OF DEVEL-OPMENT

HYPOTHETICAL MISSION TO MARS
100,000 KG FROM GEO TO MARS; 25,000 KG FROM MARS TO LEO

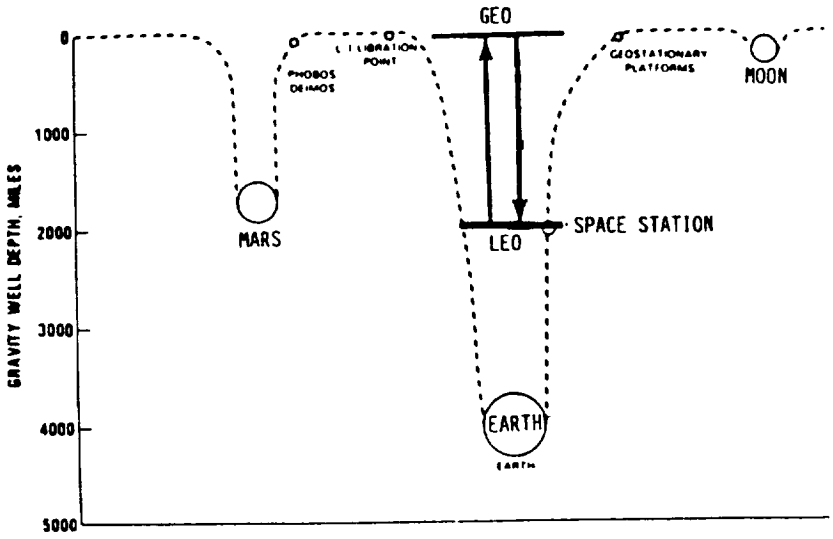
	Chemical Rockets	Ion Thrusters
Mass of Propellant From Earth to LEO for OTV*	1,150,000 KG	27,500 KG
No. of Shuttle Payloads at 30,000 KG	38	1
Cost of Transportation at $2,000/KG	$2,300,000,000	$55,000,000

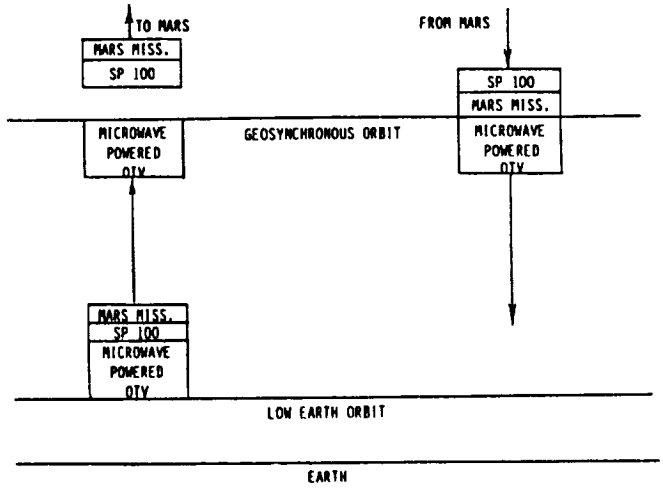
* OTV transports 100,000 kg to GEO and then later picks up 25,000 kg return mission at GEO and returns to LEO.

LARGE AND VERY HIGH POWER SYSTEMS

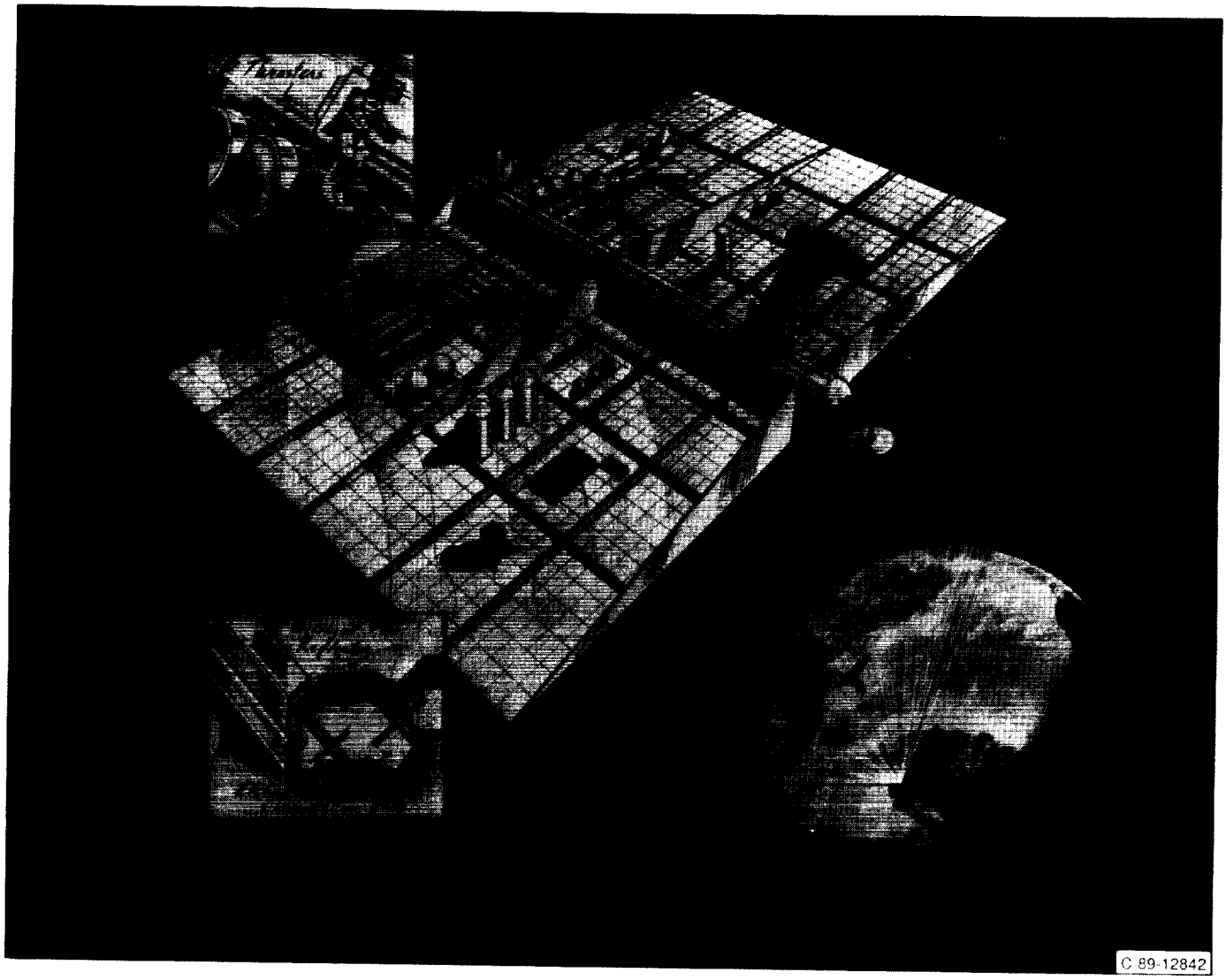
APPLICATION	TRANSMISSION DISTANCE KILOMETERS	APERTURE RADIUS METERS	POWER MEGAWATTS
SOLAR POWER SATELLITE	36,000	1280	6000
LEO TO GEO ORBITAL TRANSFER VEHICLE	36,000	750	400
ORBITING INDUSTRIAL PARK	400	124	20
STRATOSPHERIC AIRCRAFT PLATFORM	20	28	1

INNER SOLAR SYSTEM GRAVITY WELLS





A HYPOTHETICAL MARS MISSION WITH HYBRID POWER SOURCES FOR ELECTRIC PROPULSION



PHYSICAL SHAPE AND ORBITAL ATTITUDE OF ORBITAL TRANSFER VEHICLE

- IN APPEARANCE THEY ARE LARGE, PLANAR , MONOLITHIC STRUCTURES
- RECTENNA IS LARGE IN AREA TO (1) SUPPLY LARGE AMOUNTS OF POWER NEEDED FOR PROPULSION, AND (2) TO INTERACT EFFICIENTLY WITH MICROWAVE BEAM
- IN ATTITUDE, THE FLAT FACE OF THE VEHICLE ALWAYS REMAINS PARALLEL TO THE EARTH'S SURFACE.

THE SYSTEM IS BASED IN THE EQUATORIAL PLANE

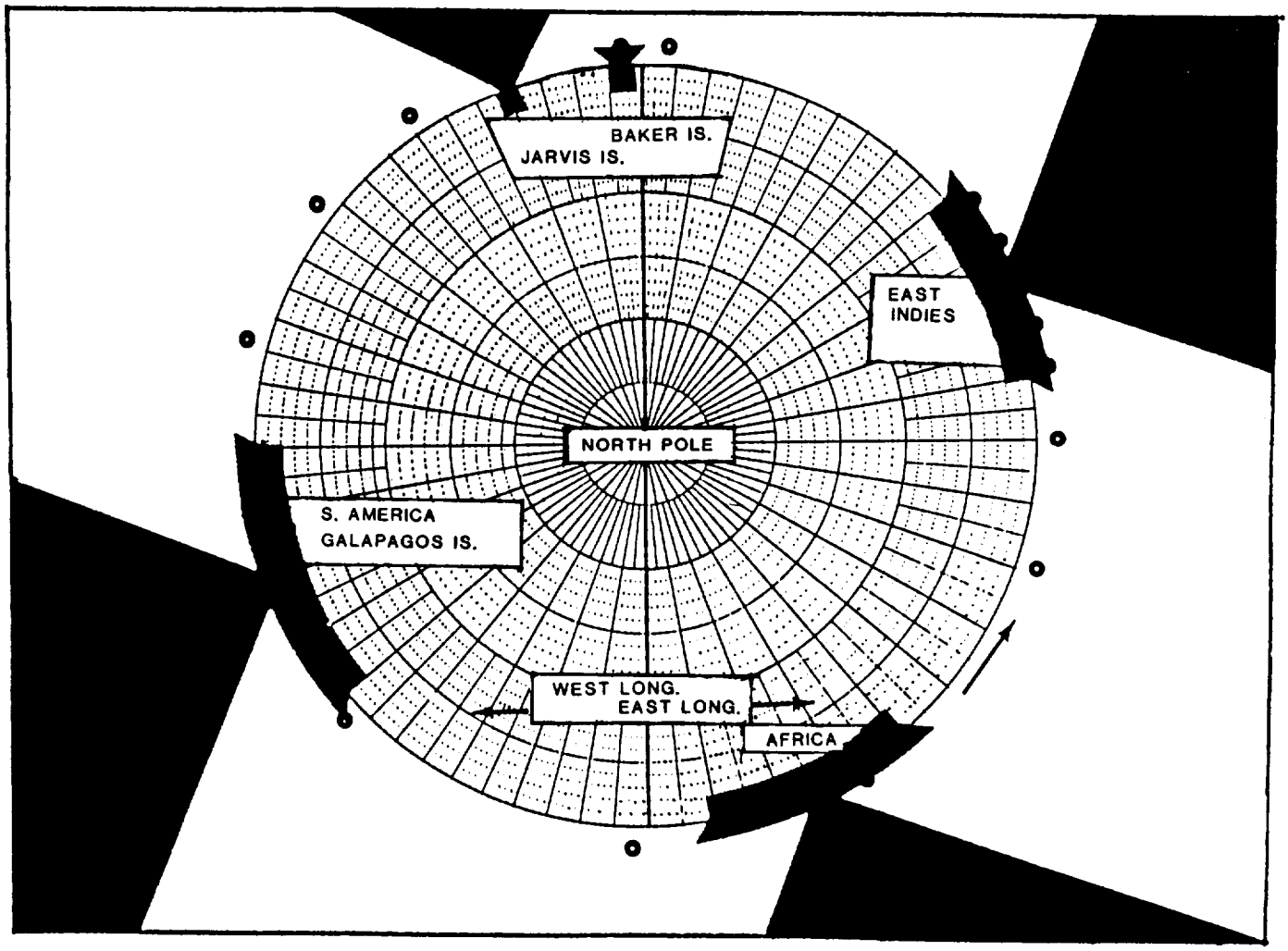
WHY?

- ONLY IN THE EQUATORIAL PLANE DO THE SATELLITES PASS OVER THE MICROWAVE TRANSMITTERS EACH TIME THEY ENCIRCLE THE EARTH.
- COST OF TRANSMITTERS TO SWING BEAM THROUGH ONE PLANE ONLY IS SMALL FRACTION OF COST OF TRANSMITTERS THAT HAVE NO SUCH RESTERICTION.

IMPLICATIONS OF THE EQUATORIAL PLANE

- THE FULLY OPERATIONAL SYSTEM IS INTERNATIONAL IN CHARACTER
- SYSTEM IS CONSISTENT WITH LOWER LAUNCH COSTS AT THE EQUATOR
- THERE ARE ENOUGH LAND SITES TO PROVIDE A 25% DUTY CYCLE IN LOW LEO
- THERE ARE ENOUGH LAND SITES TO LOCATE FOUR LARGE TRANSMITTERS TO PROVE 100% DUTY CYCLE FOR ORBITS 10,000 KM ABOVE EARTH'S SURFACE
- SYSTEM CAN SUPPLY PRIME OR AUXILLIARY POWER TO "ORBITING INDUSTRIAL PARKS" IN LOW EARTH ORBIT.

PAGE 20-REPORT OF THE NAT'L COMMISSION ON SPACE



LAND MASS AVAILABILITY FOR MICROWAVE TRANSMITTERS

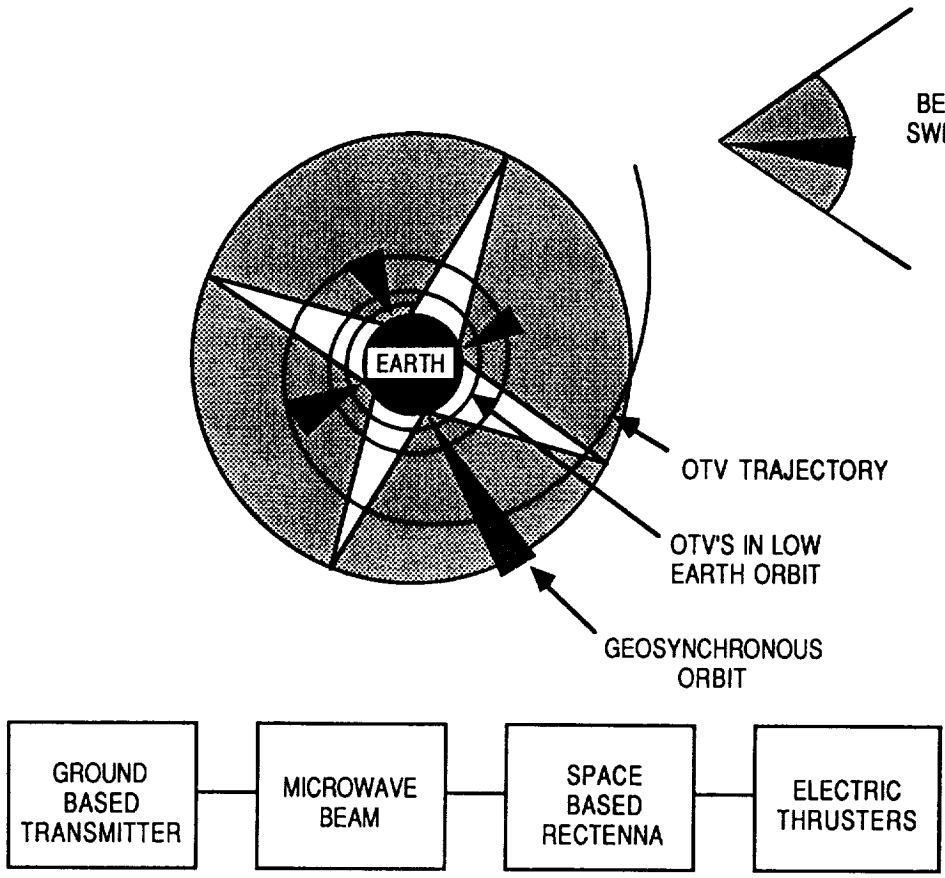
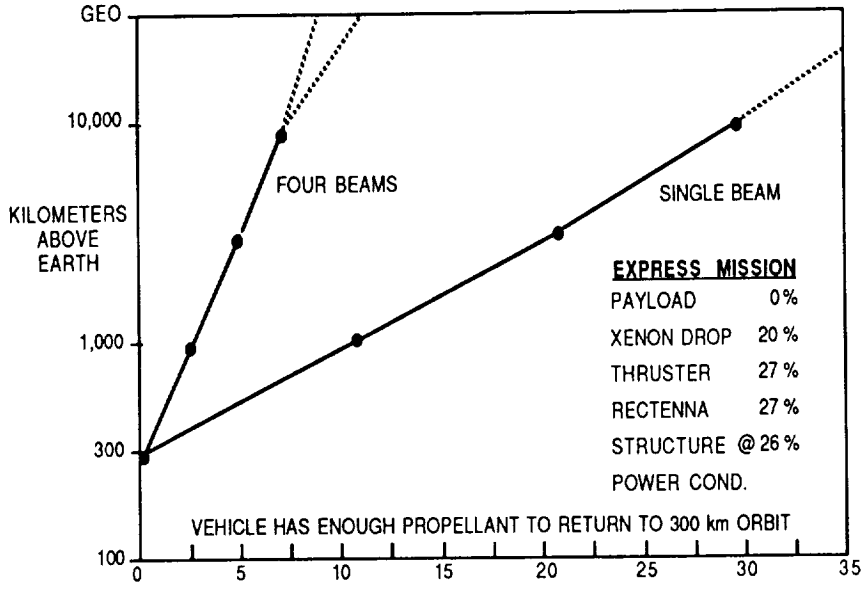


Fig. 1. LEO to GEO Electronic Transportation System

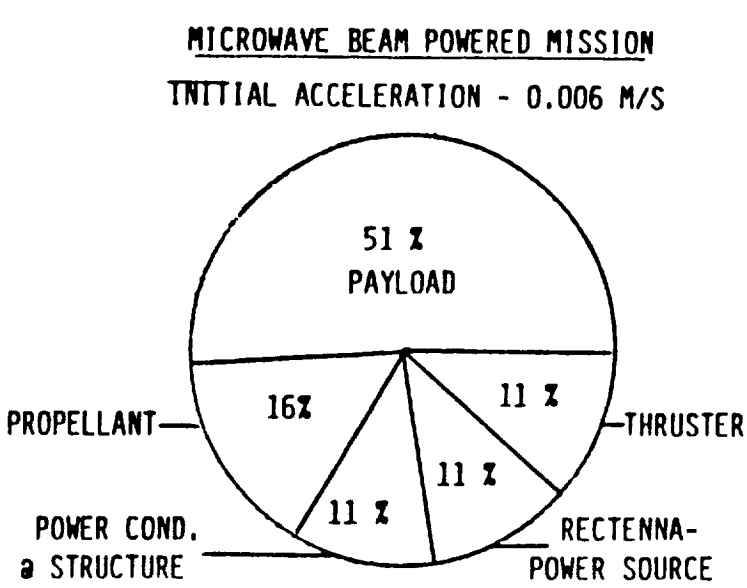
FIGURE ABOVE SHOWS ESSENTIAL FEATURES OF LEO TO GEO TRANSPORTATION SYSTEM. THE TRAJECTORY OF THE ORBITAL TRANSFER VEHICLE IS A SPIRAL. AN ELECTRONICALLY SWEPT MICROWAVE BEAM ENGAGES THE SATELLITE AS IT PASSES OVER THE TRANSMITTER. THE ENGAGEMENT TIME IS SHORT IN LEO BUT RAPIDLY INCREASES AS THE OTV GAINS ALTITUDE. THE FULLY DEPLOYED SYSTEM WOULD USE FOUR TRANSMITTERS SPACED ABOUT EQUALLY AROUND THE EARTH.

THE MICROWAVE BEAM POWERED ELECTRIC TRANSPORTATION SYSTEM FROM LEO TO GEO CONSISTS OF AN ELECTRONICALLY STEERED MICROWAVE BEAM ORIGINATING AT THE EARTH'S SURFACE THAT AUTOMATICALLY TRACKS THE ORBITAL TRANSFER VEHICLE THAT IS EQUIPPED WITH A RECTENNA TO CAPTURE THE MICROWAVE BEAM AND TO CONVERT IT INTO DC POWER FOR THE ELECTRIC THRUSTERS.

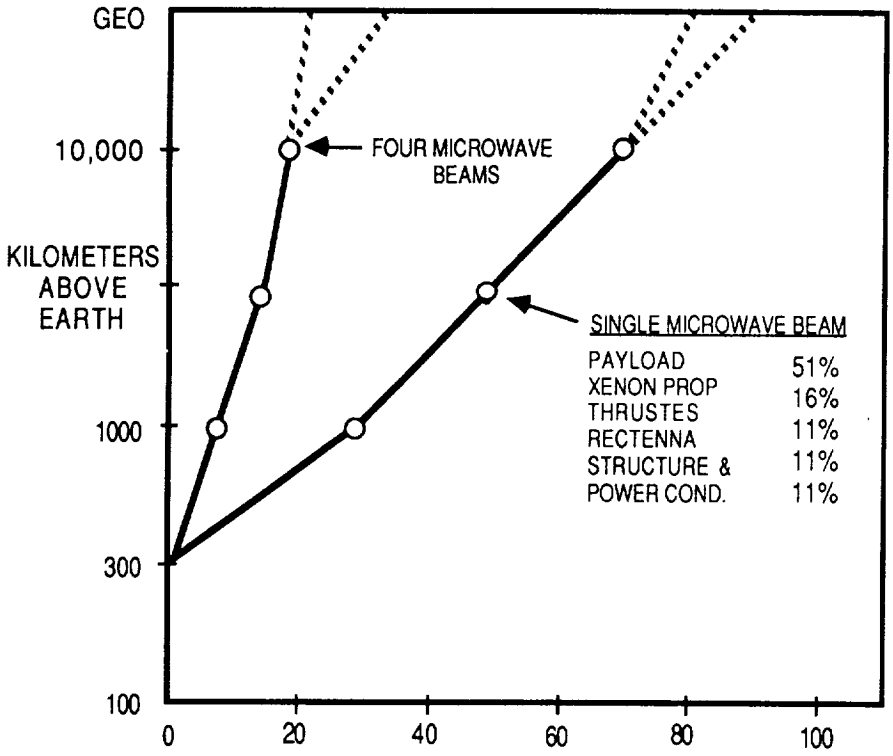


FEATURES OF ALL ELECTRONIC LEO TO GEO TRANSPORTATION SYSTEM

- MASSES OF ION THRUSTER AND RECTENNA ARE BOTH A LOW 1 kg/kW (OR LESS) MAKING POSSIBLE EXPRESS MISSIONS TO GEO OF TWO WEEKS OR LESS
- VEHICLE CAN START AT 300 KILOMETER ORBIT
- COMPLEXITY AND COST OF POWER CONDITIONING ARE LOW
- RECTENNA AS POWER SOURCE HAS MANY GOOD FEATURES:
  - IT IS IN AN ADVANCED STATE OF DEVELOPMENT
  - SIMPLE TO MANUFACTURE WITH EXISTING FACILITIES
  - NO AUXILIARY COOLING NECESSARY
  - POTENTIAL FOR VERY LONG LIFE (DECADES)
  - HIGHLY RELIABLE BECAUSE OF SIMPLICITY
  - AREA AND POWER EXPANSION EASY (MODULARITY)
  - NO IONIZING RADIATION
  - MODULES CAN BE CONNECTED IN SERIES OR PARALLEL TO MATCH COMPONENT REQUIREMENTS

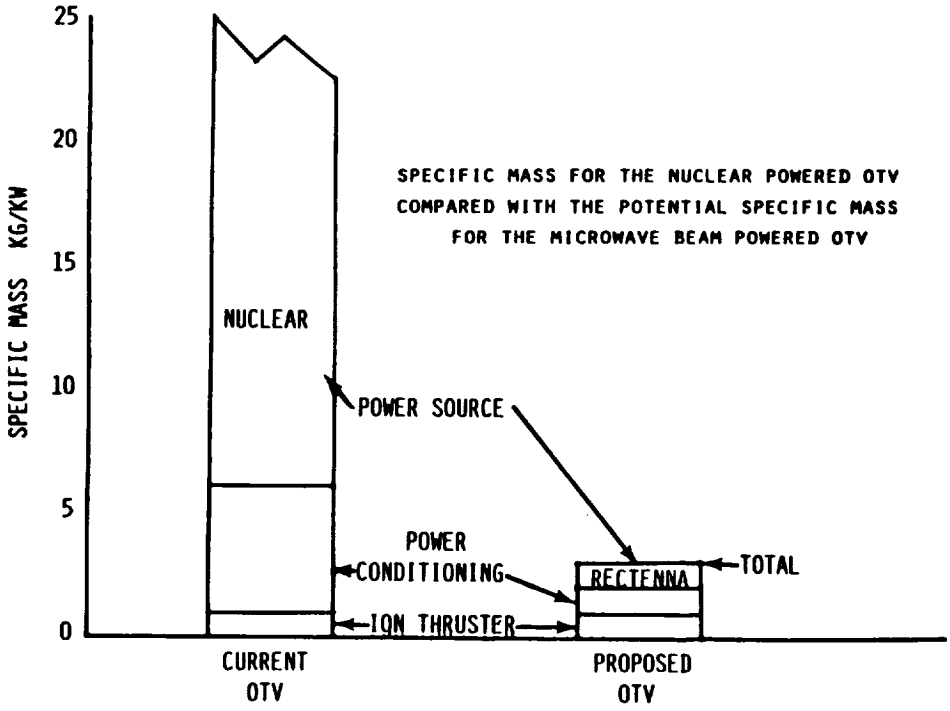


BREAKDOWN OF SPACECRAFT MASSES FOR XE; I_{SP} OF 4200
INITIAL CONDITION: 300 KILOMETER CIRCULAR ORBIT
MISSION: OTV DELIVERS PAYLOAD TO GEO AND RETURNS TO LEO



DAYS OF TOTAL ELAPSED TIME AFTER START AT 300 KILOMETER ORBIT

FIG. 2. Orbit Altitude as a Function of Elapsed Time



THE SPECIFIC MASS OF THE DRY VEHICLE CAN POTENTIALLY BE REDUCED BY A FACTOR OF 10 BY THE MICROWAVE BEAMED POWER SOURCE. THIS REPRESENTS A MAJOR PERTURBATION IN THE APPLICATION OF ELECTRIC PROPULSION.