



A Feasibility Study of Techniques for Interplanetary Microspacecraft Communications

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Microsatellites to Microspacecraft

- Numerous successful microsatellite missions
- Dynacon, UTIAS/SFL, & UBC successfully launched MOST on June 30th
- Microsatellites limited primarily to Low-Earth Orbit (LEO)
- Many difficulties must be overcome to expand the role of microsatellites to become *microspacecraft*, capable of performing interplanetary missions

Microspacecraft Issues

- Launch availability
- Propulsion
- Radiation
- Power (for very long distances away from Sun)
- **Communications**

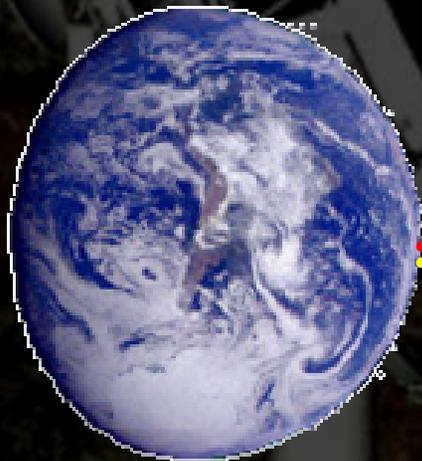
	Magellan	Mars Global Surveyor	Galileo	Cassini
Downlink	1k2 & 268k8	2k & 21k33	134k *	40 bps & 17k

* due to high gain antenna failure, actual data rate 10 bps with no arraying, 1000 bps with arraying

- Can improve the communications system either on the spacecraft and/or on the ground

Spacecraft Radio/Antenna Improvements

- Need to increase effective isotropic radiated power (EIRP)



900 km
(LEO)

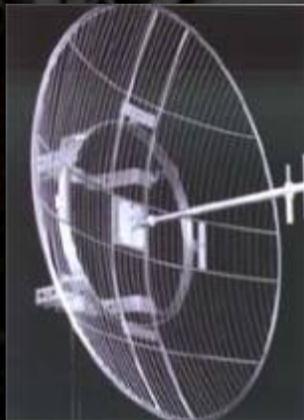
385 000 km
(Lunar Orbit)



Over 40 dB path loss introduced
between LEO and Lunar orbit!

Spacecraft Radio/Antenna Improvements

- Better way to improve the EIRP – directional spacecraft antennas
- Eg. 30 cm parabolic dish (assume 70% eff.)



20 dBi gain at S-Band (2 GHz)

40 dBi gain at K-Band (20-30 GHz)

- Where can a dish antenna fit on the microspacecraft bus?

Earth Ground Station Solutions

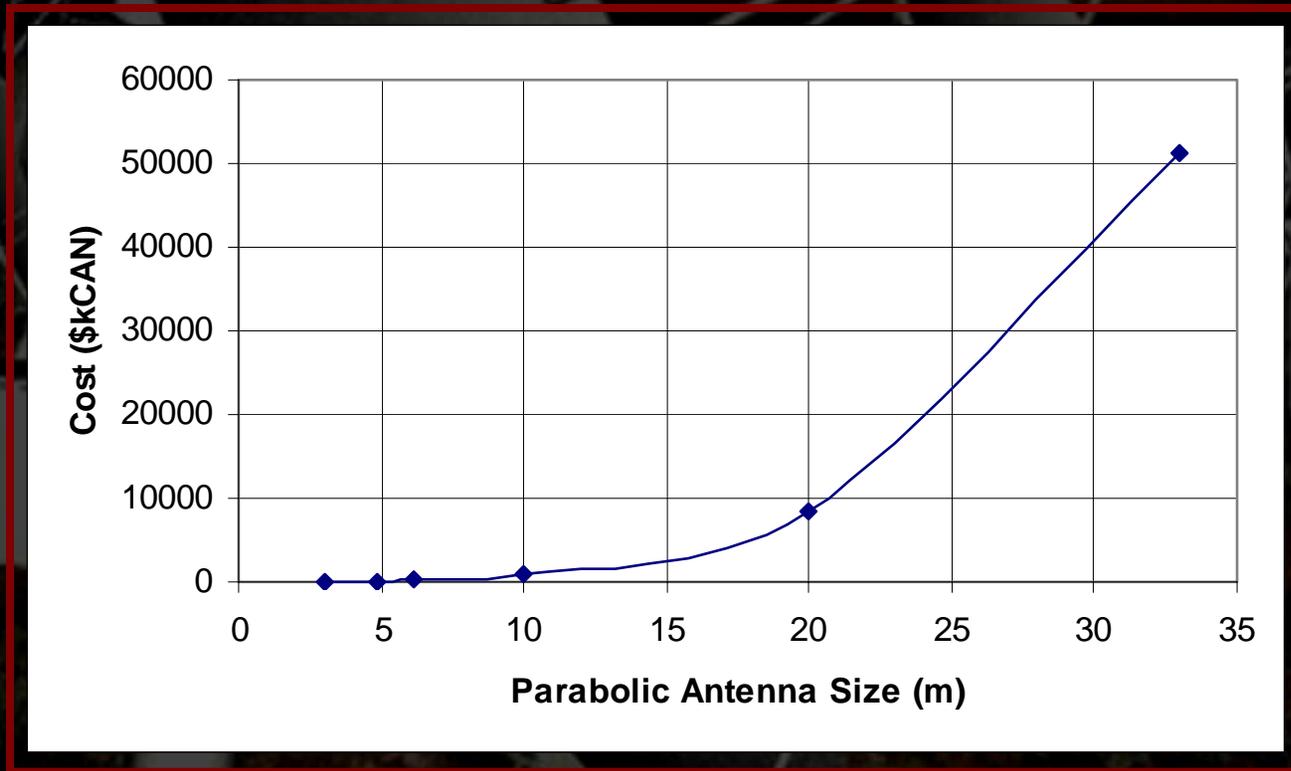
- Easier to implement (power and available space are not as limiting)
- Parabolic antennas can range anywhere from 2 m to 70 m in dia. (NASA Deep Space Network)



Everyone should have one of these!

Earth Ground Station Solutions

- Problem: Ground station costs increase dramatically as the size of the antenna increases

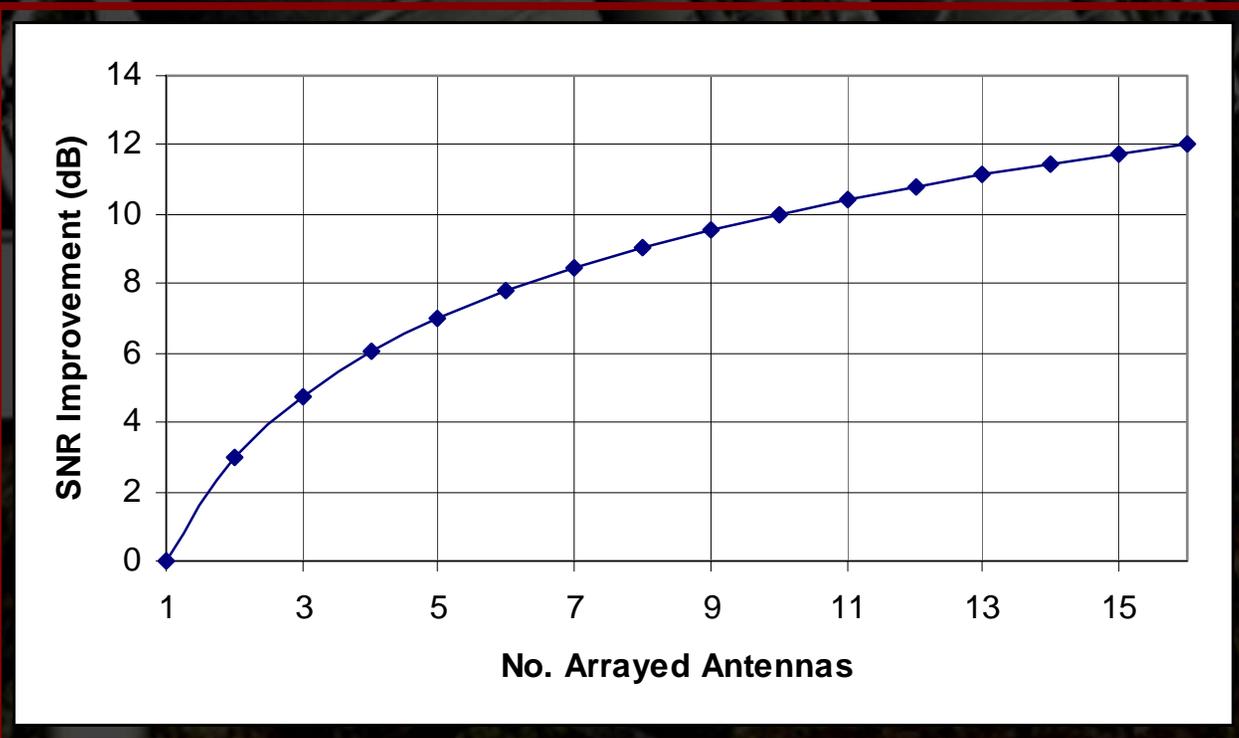


Eg. Upwards of CAN\$500 000 for a 5 m antenna ground station

Solution: Antenna Arraying

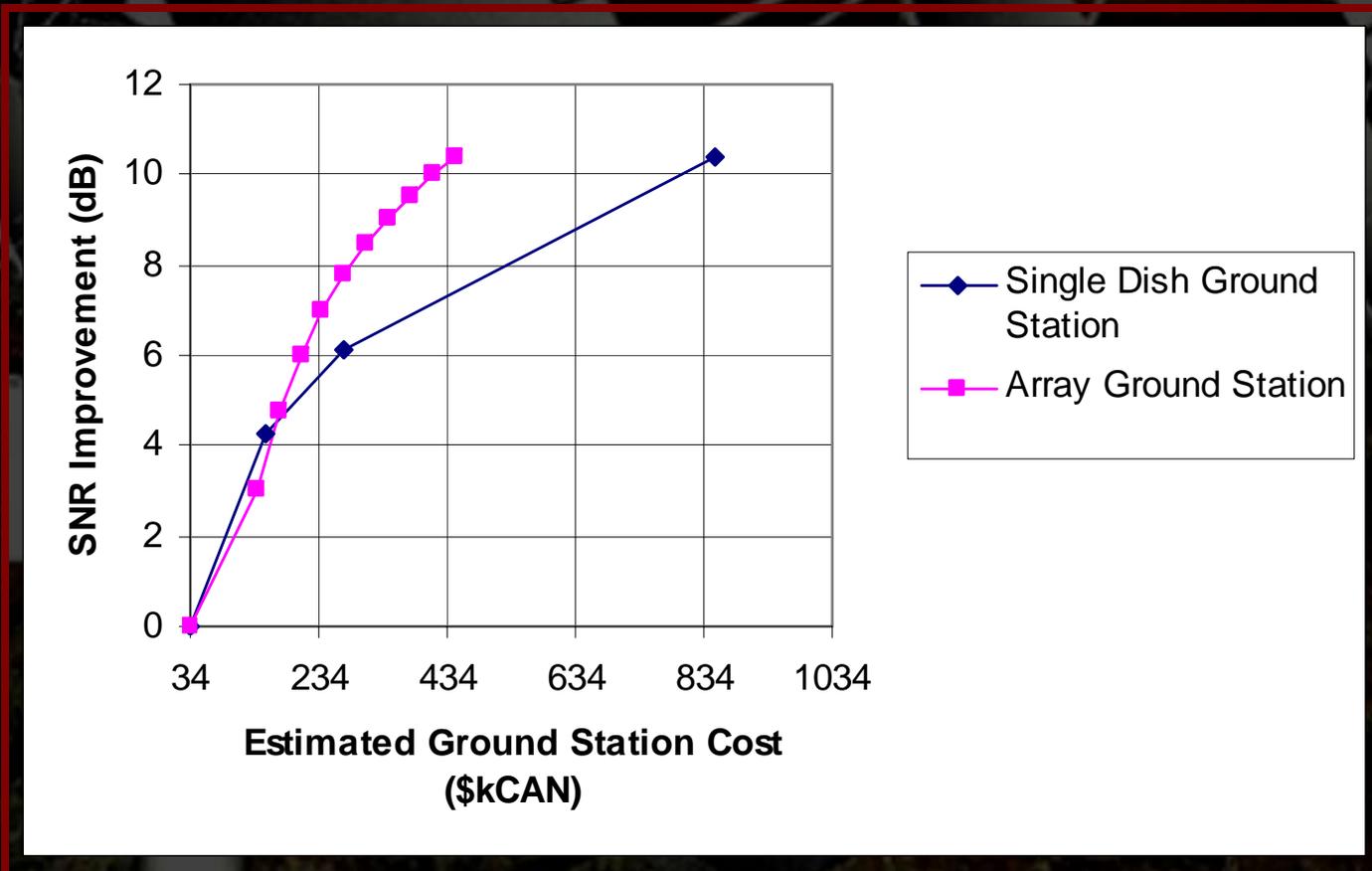
- Done by the DSN for Galileo and Voyager
- Costs scale linearly for increasing effective aperture

Ideal SNR improvement of 3 dB for every doubling of the number of identical antennas in an array



Solution: Antenna Arraying

- Cost Comparison: Array is made up of 3 m dish antennas – includes central site cost



Many Different Ways to Array Antennas

- Connect the antennas up via equal length segments of cable and combine at RF/IF (all the antennas share the same local oscillator (LO))
 - Better to combine at baseband (modem frequencies) - tolerance requirements for timing and phase errors are directly proportional to the frequency of the signal being combined
- Requirement to share LO limits the sky coverage and design flexibility of the array



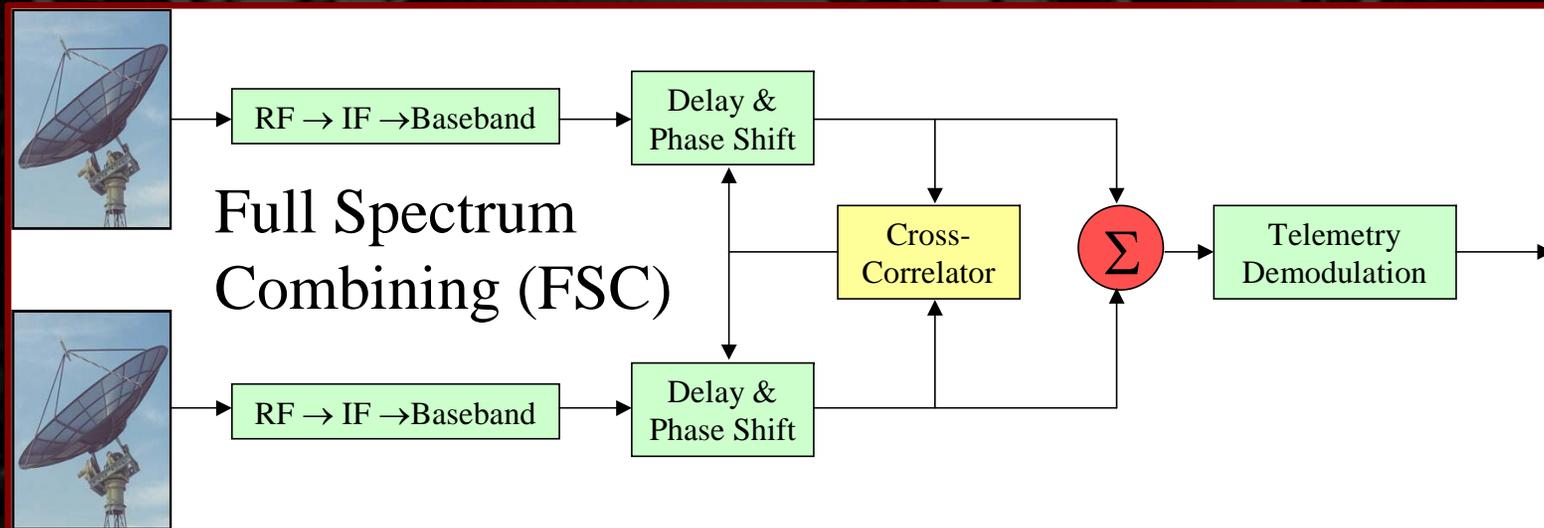
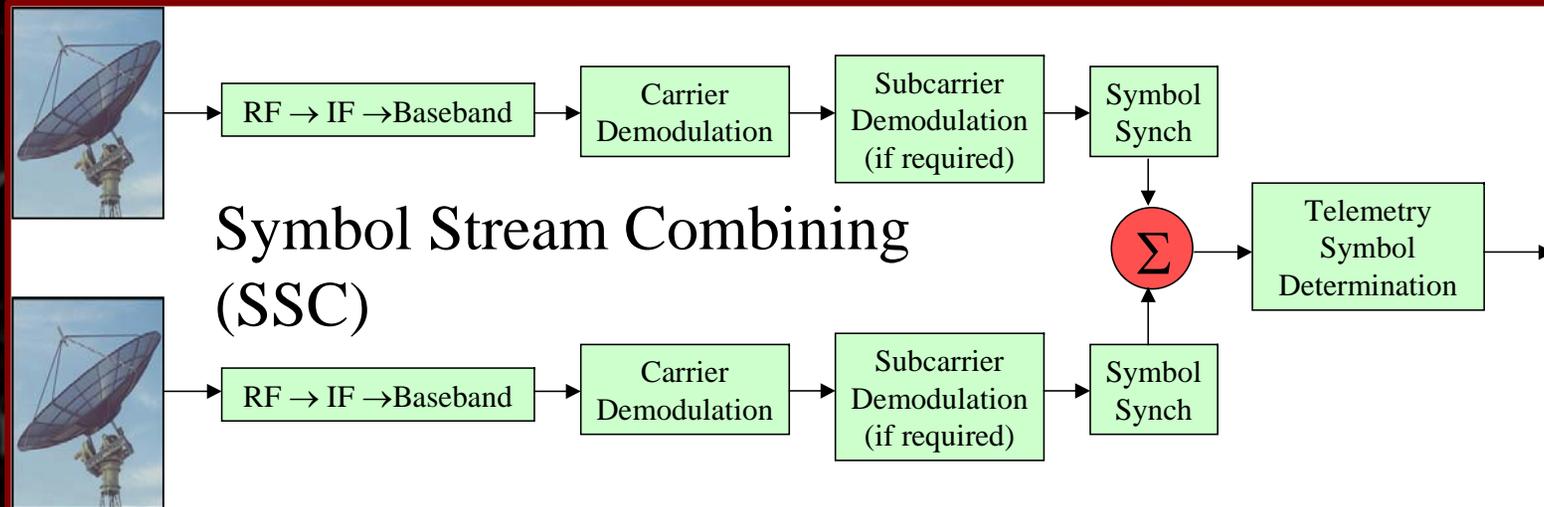
Many Different Ways to Array Antennas

- A more flexible array design would allow the users to locate the antennas, each with its own LO, wherever they wish
- This design would allow for the construction of a ground station array using existing ground stations located across a large surface area, increasing the sky coverage of the ground station

Very Long Baseline Interferometry (VLBI)

- Radio astronomy (1960's): data collected at each site in an array recorded on magnetic tape. Tapes are then combined at a central correlator site to extract signals out of the noise
- Similar techniques can be used to combine, in real time over a high speed data link, microspacecraft communication signals received by an array. VLBI can also be used to calculate cross-track information on the microspacecraft

Array Signal Combination Techniques



Sources of Error in a Commercial FSC Array

- Must compensate time and frequency phase errors introduced by such sources as:
 - the fact that each antenna receives the signal at a different time due to their different geographic locations
 - frequency and phase shifts between the various commercial grade LOs
 - timing accuracy problems when combining high data rate signals using commercial grade radio equipment
- Array decorrelation will occur unless these errors can be detected and corrected

Array Simulations & Experiments

- Currently, simulations are being done to test the capabilities of a FSC-VLBI ground station array using commercial radio equipment. To improve its performance, the following is being done:
 - Several spread-spectrum techniques are in the process of being researched and simulated
 - A method of performing frequency-domain correlation is being developed
 - Several digital sampling and filtering techniques are also the subject of current research

Array Simulations & Experiments

- Simulations will involve communications with a microspacecraft with a low powered radio with an omni-directional antenna in LEO, Lunar orbit, and Mars orbit
- The advantages of using an array to uplink signals to a microspacecraft are also under study.
- The next step after the simulations will be to develop laboratory hardware experiments using equipment that can simulate noise, array time differences, and LO frequency drift

Conclusions

- The flexibility of the FSC-VLBI design would allow for the creation of an array that can communicate with microspacecraft using small, existing ground stations located over a large area
- Though interplanetary microspacecraft missions might be years away, if hardware experiments are successful, the techniques developed can also be used to increase the data bandwidth of LEO microsattellites to 1 Mbps and beyond



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