

KaBOOM- Ka Band Objects: Observation and Monitoring

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ABSTRACT

With the successful completion (Sept 2010) of a field demonstration of uplink arraying at 8 GHz (X-band) using real-time atmospheric compensation enabled by phase transfer rather than time transfer techniques, NASA is pursuing a similar demonstration of the capability at 30-31 GHz (Ka band). Such a demonstration would then enable NASA to establish [a] a high power, high resolution, 24/7 availability radar system for characterizing observations of Near Earth Objects, determining the statistics of small [$\leq 10\text{cm}$] orbital debris, [b] to incorporate the capability into its space communication and navigation tracking stations for emergency spacecraft commanding in the Ka band era which NASA is entering, and [c] to field capabilities of interest to other US government agencies. We describe a project of Evolutionary Steps Leading to Revolutionary Increases in Capability and Capacity.

1.0 INTRODUCTION

NASA has embarked on a path to implement a high power, higher resolution radar system to better track and characterize near Earth objects [NEO's] and orbital debris. We are advancing an X/Ka band system to supplement the S-band radar at Arecibo, Puerto Rico and the X-band radar at NASA's Goldstone tracking complex in California. The three facilities will complement each other in that different wavelengths have different resolutions and penetration depths. The X/Ka band radar system also has applications for cost effective space situational awareness. This work describes our path toward demonstrating Ka band coherent uplink arraying with real-time atmospheric compensation using three 12m diameter antennas at the Kennedy Space Center. Coherent uplink arraying has been successfully demonstrated by three NASA groups: at X band Ku bands, with and without atmospheric compensation, and by sending commands to and receiving telemetry from GEO and deep space satellites.

KaBOOM is a Ka band coherent uplink arraying proof of concept demonstration being undertaken to allow decision to be made for implementing a National Radar Facility [large scale arrays(s)]:

- High power, high resolution radar system
- Space Situational Awareness
- 24/7 availability for NEO and orbital debris tracking and characterization
- High resolution mapping of water in discrete locations on the moon
- Map out radar stealth zones on Mars- help define "no drive" zones for future rovers to avoid the Spirit problem
- Solar sailing propulsion capability

2.0 THE NEED FOR UPLINK ARRAYING

NASA has several major needs for uplink arraying: (1) planetary defense- tracking and characterization (size, shape, spin, porosity) of near Earth objects (NEOs), (2) Improved detection/tracking of small ($\leq 10\text{cm}$) orbital debris particles, (3) rapidly available high power emergency uplink capability for spacecraft emergencies, (4) radio science experiments (tomography of planetary atmospheres, general relativity tests, mass determinations, occultations, surface scattering, etc). The NASA Authorization Act of 2008 directs NASA to catalog 90% of NEOs $> 140\text{m}$ in size. The Goldstone radar on the 70m antenna is available only 2-3% of the time due to spacecraft tracking obligations and is further limited by the high power density of the beam since the transmitter is 450 kW.

Tracking of orbital debris particles less than 10cm in size is difficult. Where high resolution is possible, the antenna beam is too small for accurate tracking; statistics of small particles are obtained, however. In those facilities where particle tracking is possible, the resolution is lacking.

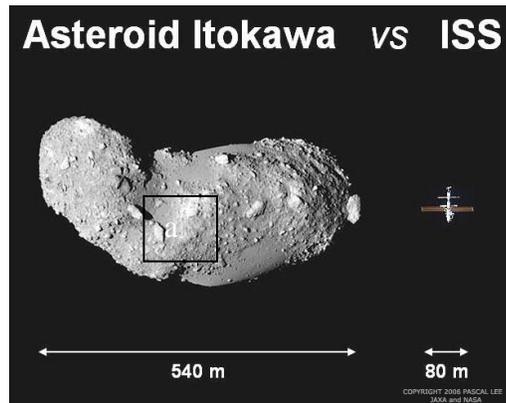


Fig 1. Relative sizes of asteroid Itokawa and the International Space Station. Note the boulders on the asteroid. For robotic and crewed missions to asteroids, NASA will need to know the surface structure - such as the boulders in the box - so as to ensure the safety of the landing spacecraft and its inhabitants.

It is interesting to note that uplink arraying offers an opportunity to get high EIRP (effective isotropic radiated power) from relatively lower power transmitters because the uplink power, for identical transmitters and antennas, is proportional to N^2 , where N is the number of antennas in the array. Figure 2 demonstrates this effect for data taken of the planet Venus with two of the 34m antennas at Goldstone. Figure 2a shows the radar image for a single 34m antenna. Figure 2b shows the radar image, with a 6 dB gain (factor of 4) when two 34m dishes were coherently linked.

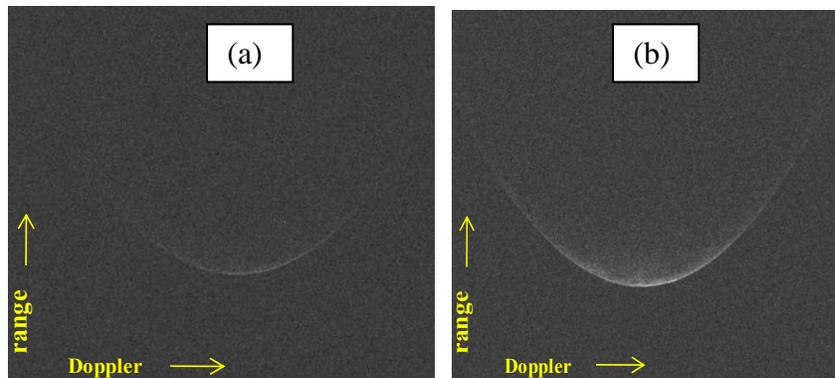


Fig 2. Doppler-delay images of Venus, taken on 2010 DOY-297, Goldstone Solar System Radar processing: a) single 34m antenna illumination; b) 2-34m antenna phased-array illumination, showing greatly improved image quality.

3.0 ADVANTAGES OF A MULTIPURPOSE FACILITY EMPLOYING UPLINK ARRAYING TECHNIQUES

- The **array is a more reliable** resource than a single dish. If the 70m is down for any reason, so too is the radar facility. The same is true for the high power klystron tubes used for the radar. However, with an array, if any given antenna is taken out for maintenance or is in an anomalous condition, little performance is lost. For example, losing a single antenna out of 25 would be a loss of only 2% of the array downlink capability and only 1% of the uplink capability. Hence, availability of the array is more assured and robust to operational “down time” or element failures.
- **Virtually 24/7 availability.** Whereas radar observations on the DSN 70m antenna comprise < 3% of the available antenna time, on a NEO-focused purpose array, some 25-30 times more antenna time could be available and thus 25-30 times the number of sources can be observed in a given year. This will dramatically help NASA reach the goal of tracking and characterizing 90% of NEOs $\geq 140\text{m}$ by 2020.
- **Spectrum management is not an issue** with the array. Since the high power, coherently combined beam forms ~ 200 km above the earth, the FAA EIRP limit will not be violated obviating the need for a time-consuming coordination among a large number of Agencies.
- The **angular resolution** of the proposed array is 4 times better than that of the 70m antenna at Goldstone. With antenna spacings of 60m, an effective diameter of $\sim 300\text{m}$ can be achieved- imagine a 5x5 antenna array. Increased angular resolution can help characterize NEOs in unprecedented detail. Bistatic and multistatic modes offer even finer resolution.
- **Scalability.** If still higher resolution or greater sensitivity is desired, additional antenna elements can be added. At roughly \$1M per antenna element, increased capability can be added at a low cost.
- **Extensibility** to Ka band. This would be unique to NASA and provide 16 times the angular resolution of the 70m radar system as well as significantly improved range and range-rate measurement.
- **Radio science experiments** are usually conducted by transmitting signals from the spacecraft past/through the target of interest to the ground. However, spacecraft transmitters, $\sim 20\text{W}$, limit the signal to noise ratio and hence the science results. Using a high power uplink from the ground to the target to the spacecraft and then downlinking the data via telemetry (ala New Horizons) can increase the S/N by ≥ 1000 . Science using traditional “downlink” measurement techniques will also be improved due to the higher sensitivity of the array.

4.0 UPLINK ARRAYING WITH REAL-TIME ATMOSPHERIC COMPENSATION DEMONSTRATED

NASA and the Martin/Minear: local closed-loop phase control calibration method. This demo was done at X-band using 3 low cost 12m antennas. Modulated (2MHz bandwidth BPSK, and QPSK, 2Mbps rate $\frac{1}{2}$ Viterbi) signals were sent to geostationary satellites. G. Patrick Martin and Kathy Minear demonstrated conclusively that coherently combined uplink array signals can be achieved using a model-based uplink arraying method that does not require external calibration targets due to a continually self-calibrating circuit control thereby yielding instant availability of the system. Furthermore, they demonstrated that if there is a reference source such as a beacon on the uplink target satellite or a background celestial source (e.g.- a quasar), then the system can compensate in real time for atmospheric fluctuations- providing that both the target source and reference source are in the primary beam of each antenna of the array: the radio frequency analog of adaptive optics.. This group too demonstrated the theoretical benefits in EIRP for uplink combining, namely, a 6 dB power enhancement for a two antenna element system and a 9.6 dB for an array of 3 antennas. Also, demonstrated were the theoretical benefits in G/T for downlink combining. The major downside to this demonstration is that NASA was not given access to the algorithms so we have not been able to verify whether the techniques demonstrated represent simply a point solution or whether they are applicable in general.



Fig 3. Array of Three 12m Reflector Antennas on a Scalene Lattice

5.0 METHODOLOGY

5a. Mitigation of the Principal Error Contributors

1. Accommodation of circuitry, transmission line, and antenna shape variation
2. Differential beam steer phase due to dish to target line-of-sight variation
3. Mitigation of propagation phase variation due to tropospheric effects

5b. Solution to Error Contributors

1. Continuous Closed-Loop Carrier Phase Control using Tx signal itself
Complex Envelope realization mitigates need for high precision time delay
2. Continuous Model-Based Adaptive Combining of antennas
Initial estimate of Antenna Reference Points (ARP) can be refined using Instant Return
3. Transmit using a received signal

Expected to compensate for phase due to the atmosphere

In the next Figure, we show the method employed on 12m antennas to detect, measure, and compensate for circuit phase errors. Similar methodologies have been employed by NASA at the Jet Propulsion Lab.

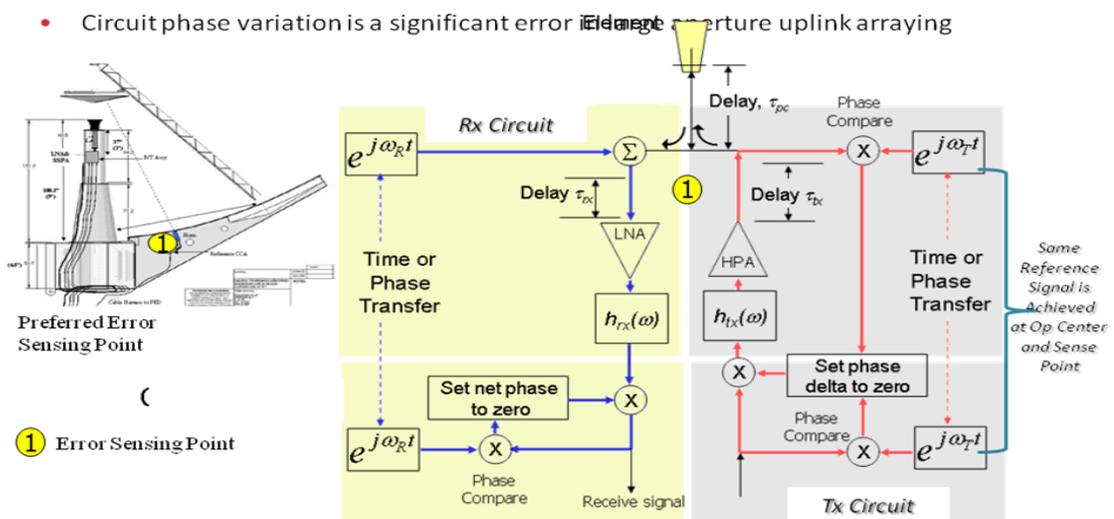


Fig. 4. Continuous Closed-Loop Phase Control using the Tx Signal Itself Mitigates Phase Errors due to: Transmission Lines, Circuitry, and Antenna Deformation

6.0 RESULTS: CLOSED LOOP CIRCUIT CONTROL EXPERIMENT

In order to achieve a coherent beam for uplink, the phase errors around the circuit should be as small as possible. In the case of the demonstration in Florida, our goal was to achieve a peak-to-peak phase variation of no more than 10° and an rms phase variation of no more than 3° . After accounting for some less than optimum hardware, both goals were achieved and indeed surpassed. Figure 4 shows the phase stability of the closed loop system over an 83+ hour run.

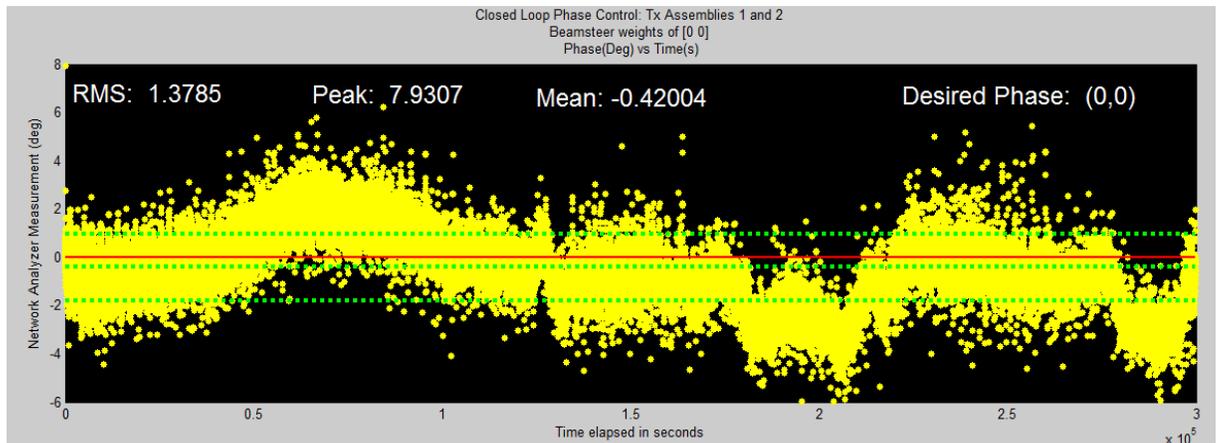


Fig. 5. Results for Closed Loop Circuit Control using Transmit Error Detection Assemblies.

7.0 ATMOSPHERIC FLUCTUATION PHASE ERROR CORRECTION: RF ADAPTIVE OPTICS

The tropospheric contribution to phase errors can be significant and are certainly unpredictable as evidenced by water vapor radiometer measurements. However, there is no apparent linkage between meteorological data and the observed phase fluctuations. Thus, ground-level measurements are not accurate indicators of what is occurring higher in the atmosphere. Developing an all encompassing, universal model to predict the phase stability of a particular site would be extremely difficult. Furthermore, if the longest baseline of the array is even a few kilometers in extent, different weather conditions above individual array elements would make precise modeling of atmospheric phase fluctuations of the array as a whole an extraordinary challenge.

A simpler solution is to develop a real-time atmospheric compensation algorithm just as the optical astronomers do using a sodium laser to get an artificial "star" in the telescope field of view simultaneously with the object of interest. The algorithm developed for the closed loop uplink arraying demo, the RF analog of the well known adaptive optics methodology, was successfully used to mitigate in real-time the varying atmospheric fluctuations. The algorithm handles the general case where each dish-to-target path may be looking at different columns of atmosphere due to the wide spacing of the elements.

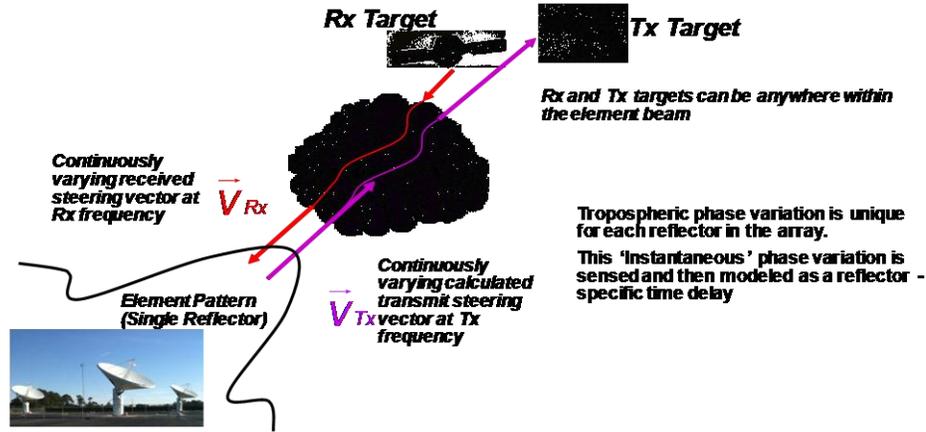


Fig. 6. Pictorial Representation of Tropospheric Fluctuation Phase Error Correction via RF Adaptive Optics

Real time propagation variations were mitigated by using a signal from a source of known angular position preferably within the primary beam is received through the atmospheric variation. Since the closed loop receive circuit control was in operation, variations in the received steering vector from the modeled vector measure the magnitude of the tropospheric phase contribution in the direction of the received signal. If the antenna beam width is small, then tropospheric variation toward the Tx target will be essentially the same as to the receive target. Since the effect due to atmospheric variation, mainly due to water vapor and turbulence, is one of frequency independent time delay, then the total differential delay obtained from model and measured receive variation was able to be applied to calculations of the steering vector for the transmit direction. Any known astrometric source may be used for this purpose, such as another satellite, quasar or supernova remnant. For Ka band, the planets are excellent calibration and reference sources.

8.0 MEASURED RESULTS OF REAL TIME ATMOSPHERIC COMPENSATION

Since the proof resides in measured data, first we show the results of the expected EIRP gain from a coherently phased uplink array.

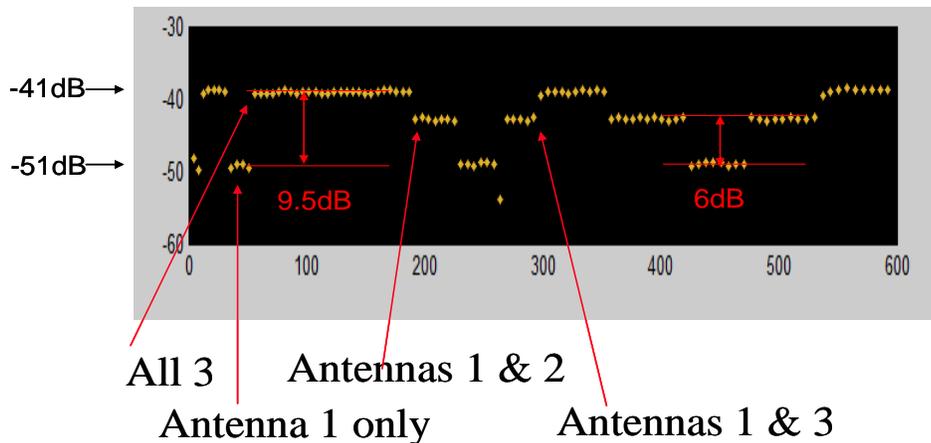


Fig. 7. Measured EIRP increase for three arrayed 12m antennas through target satellite

We were not satisfied testing the algorithms and demonstrating coherent uplink arraying in clear, relatively dry (for Florida!) air. Fortunately, Tropical Depression 16, later upgraded to Tropical Storm Nicole, provided a marvelous opportunity to excel.

- Environmental conditions at the time of Exp 5 Real-Time Atmospheric Fluctuation Compensation
- Tropical Depression 16, Sept 29, 2010, 04:45UTC (12:45AM)
 - Light rain and substantial irregular water vapor content along pathway

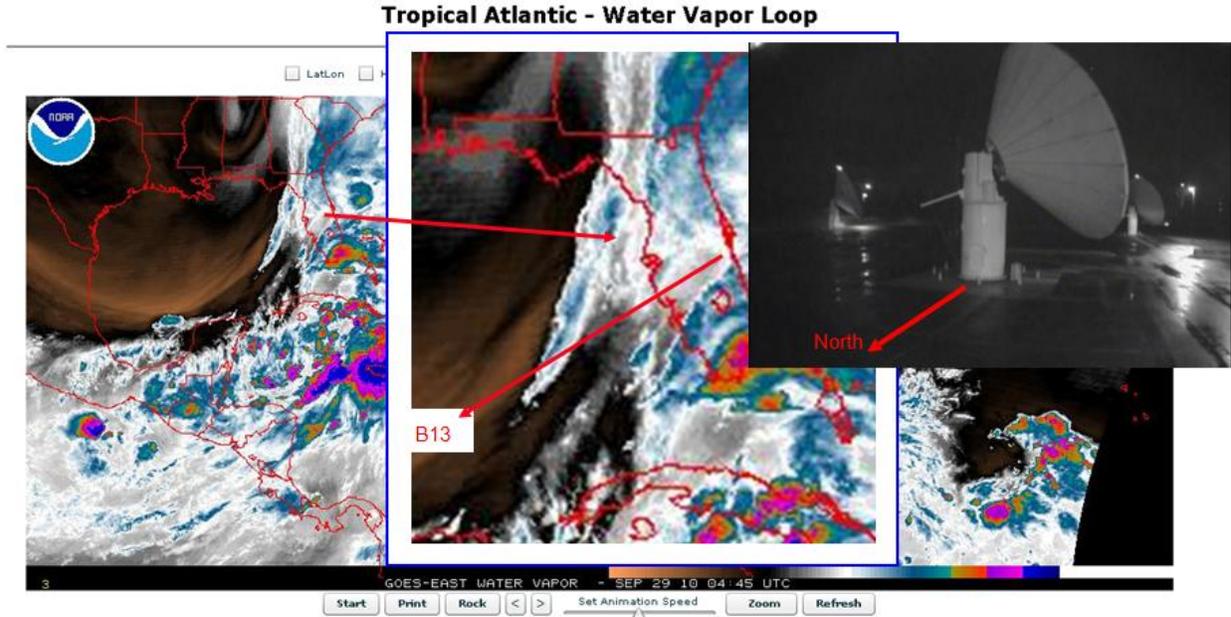


Fig. 8. Conditions of a robust test of real-time atmospheric fluctuation compensation coherent uplink arraying

Under these conditions, Fig. 9 shows the phase fluctuations with and without the real-time atmospheric fluctuation algorithm noted in the figure as “instant return.” Note that the peak to peak variations are almost an order of magnitude *less* using the correction algorithm than without. Even on a “good” day in coastal central Florida, the algorithm increased the coherent signal by 0.5 dB on the single, limited test we carried out.

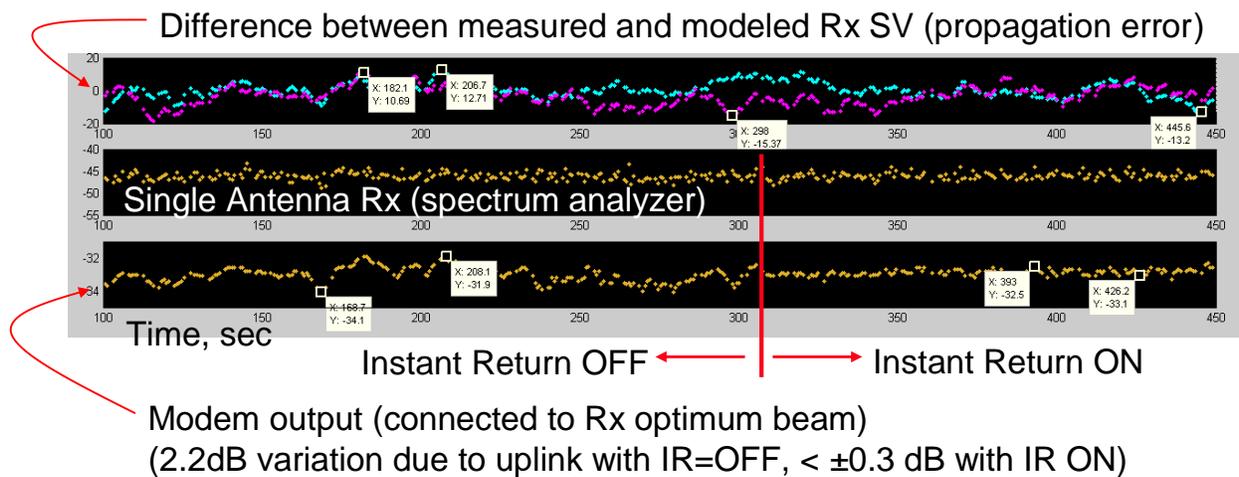


Fig. 9. Demonstration of ~ order of magnitude decrease in phase fluctuations using RF using the compensation algorithm

With the demonstration of real-time atmospheric fluctuation compensation, we have almost closed the chapter on uplink arraying demos at X-band.

9.0 NEXT STEP: KaBOOM: Ka BAND OBJECTS OBSERVATION AND MONITORING

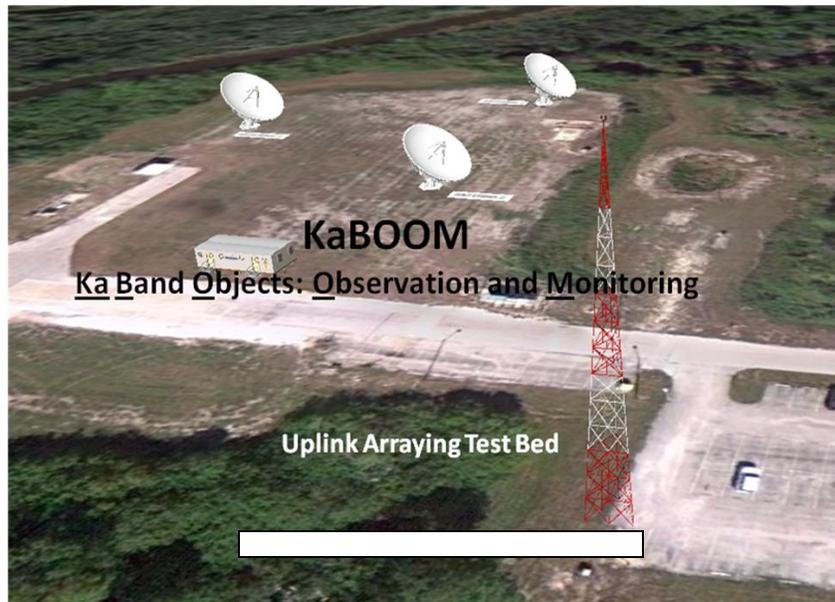


Fig. 10. KaBOOM Test Bed Setup at Kennedy Space Center

Going beyond X-band for NASA involves Ka band tracking capabilities. Although the demonstration of coherent uplink arraying at Ku band has been successful and gives us encouragement that such techniques will be successful at Ka band, we have no data to bear out that hypothesis. Furthermore, we have not yet shown how to make uplink arraying reliable in an operational sense because we have not previously had the resources to undertake that aspect.

In Phase 1, building on the previous three-antenna element interferometer testbed to demonstrate the N^2 , where N is the number of antennas in the array, the antennas have been moved to a government facility: NASA's Kennedy Space Center to ensure security and lower life cycle costs. The new three-antenna element interferometer testbed will re-validate previously obtained data, reestablishing the testbed overall baseline performance incorporating lessons learned from the initial instantiation. Thereafter, we intend to demonstrate coherent uplink arraying with real-time atmospheric fluctuation correction at Ka band 30-31 GHz.

In Phase 2, given successful performance and passing of NASA and our partner's funding decision gates, we shall construct a larger, multi-element array to increase capability. The Table below shows the potential advantages. It is evident that even with a modest number of antennas (15), there is the possibility of a 100% increase in maximum imaging distance over the current 70m capability and the ability to track objects over a volume more than 8.6 times larger than is current possible. Even a modest system of antennas can provide a substantially greater uplink power than is current available at Ka band. However, this assumes coherent uplink arraying at Ka-band can be accomplished. Phase 1 is designed to demonstrate this capability and its limitations; i.e.- where does Ka band uplink arraying break down or become ineffective.

The advantages of operations at Ka band are enormous:

- For radar applications, an increased spectral bandwidth allocation of 2.6 GHz (vs. 100 MHz at X-band-Goldstone radar) thereby leading to a dramatic increase in spatial and range resolutions as well as more power

on target (Table I). This is enabled by the newly developed 30 kW Ka band klystrons having a bandwidth of 4 GHz [33-37 GHz].

- For NEO, Space Situational Awareness, and orbital debris cases, the increased power afforded by uplink arraying radars can help to better characterize objects and can track and characterize objects farther out than current radars (Table I).
- For geolocation applications, measurement of atmospheric fluctuations coupled with other sensor data has the potential to increase the accuracy and precision of ground-based target location.
- For space communication purposes, the wider spectrum allocation (10X wider than at X-band) will allow for more data to be sent at a given time.
- For radio science, the 100-1000x increase in possible uplink power will allow for more precise determination of planetary properties.

Table I. Comparison of Current and Proposed Systems

	# Antennas	EIRP (TW) *	EIRP (Array/ MMW)	EIRP (Array / 70m)	Max Distance (au)	Spatial Resolution at GEO (m) **	Range Resolution (cm) ***	Search Volume wrt 70m
MMW Ka 14m; 50% efficiency	1	0.2	n/a	0.02	n/a	n/a	2	n/a
70m; X-band, 460kW	1	11	n/a	1	0.1	5	1800 no chirp; 400 in chirp mode	1
12m; Ka 100kW; 50% efficiency	1	0.86	1	0.05	0.05	n/a	5	0.07
	15	194	970	18	0.20	1.5	5	8.61
	25	538	2690	49	0.26	1.5	5	18.49
	50	2153	10765	196	0.37	1.5	5	52.33
	100	8610	43050	783	0.53	1.5	5	147.98

* Theoretical value. Losses due to weather, system inefficiencies have not been measured and so are neglected here

** Assumes US-Australia baseline [multistatic radar]

*** Signal/Noise dependent; calculation neglects rotation etc so might be small by a factor of 2, but not an order of magnitude

The target satellite chosen for the Phase 1 Ka band demonstration has an elevation as seen from KSC of only 10 degrees- meaning an air mass 5.6X greater than that toward the zenith. This constraint of increased attenuation and scintillation coupled with the non-ideal Ka band weather provides a highly challenging environment. Since this is a demonstration for NASA as well as for other partners who may deploy larger systems using these techniques in non-Ka band-pristine locations, we have deliberately chosen a difficult challenge.

10.0 APPLICABILITY TO NASA HUMAN SPACEFLIGHT AND SCIENCE ENDEAVORS

Part of the “flexible path” NASA is embarking on calls for exploration- robotic and crewed- to asteroids. Before a crew is sent to an asteroid, it is most likely, based on past exploration NASA practices, that a robotic precursor will be sent to investigate. However, which asteroid will be chosen? If the “wrong” asteroid is chosen, we shall have lost or wasted a decade of time and funding. Hence it is incumbent upon us to select the best target.

It is well known that radar is an ideal technique to characterize (size, shape, spin, porosity) near earth objects and precisely determine their orbits (up to 5 orders of magnitude more precise than optical determinations). Radar measurements can prevent potential mission targets from being “lost.” Many NEO’s are lost shortly after discovery using optical techniques. However, radar observations can anchor the orbit of an object for decades or in some cases

centuries. Furthermore, higher powers and thus farther distances can be achieved with an arrayed system thereby (a) expanding the search volume for NEO's (a factor of ~150 for an array of 100 antennas), and (b) through characterization, narrow the potential target list thereby reducing the risk of sending a robotic precursor mission to the "wrong" asteroid.

Large arrays with high power transmitters on each antenna could lead to an NEO Early Warning System. In the next figure, we show the current capability, and what is possible with a large array: extending the area of tracking from 0.1 AU (1 Astronomical Unit is the average Earth-Sun distance, ~ 150M km).

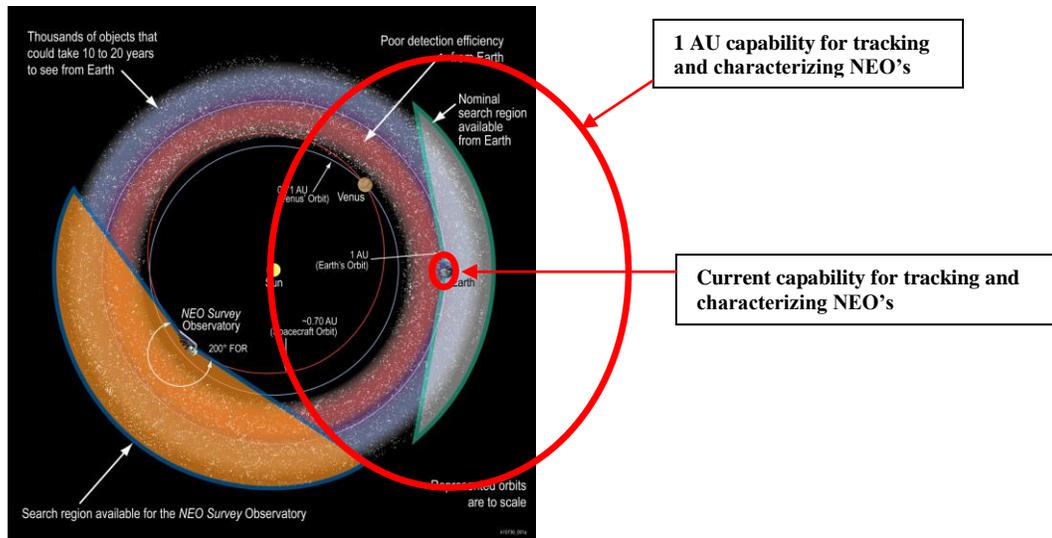


Fig 11: Possibility for a NEO Early Warning System

11.0 APPLICABILITY TO ORBITAL DEBRIS AND SPACE SITUATIONAL AWARENESS (SSA)

As time goes on, orbital debris has become and will continue to become an ever increasing source of risk to rocket launches, to the International Space Station, and to government and commercial space assets. Tracking of orbital debris on cm (or even mm) size scales and larger has become concomitantly more imperative. (Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's meteoroid and Orbital Debris Programs," National Research Council report: The National Academies Press at http://www.nap.edu/catalog.php?record_id=13244). Here again, Goldstone has made a contribution- the statistics of the numbers of small particles, but the beam size is far too small to track these particles. The proposed array, with broad primary beam antennas, has the advantage. This type of system can complement and supplement the activities of the Space Fence.

For SSA, the recent GAO report : "SPACE ACQUISITIONS : Development and Oversight Challenges in Delivering Improved Space Situational Awareness Capabilities" (GAO-11-545 May 2011: <http://www.gao.gov/new.items/d11545.pdf>) summed up the current status: "The United States' growing dependence on space systems for its security and well-being—such as for missile warning; intelligence, surveillance, and reconnaissance; communications; scientific research; weather and climate monitoring; and positioning, navigation, and timing—makes these systems vulnerable to a range of intentional and unintentional threats. These threats range from adversary attacks such as anti-satellite weapons, signal jamming, and cyber attacks, to environmental threats such as harsh temperatures, radiation, and collisions with debris and other man-made or natural objects, which have been increasing rapidly over the past several years."

A Ka band system using coherent uplink arraying techniques and bistatic and multistatic radars can meet and probably exceed the goals or, at the very least, compliment a 90 GHz system. Specifically, at Ka-band range resolution of 5 cm and a spatial resolution (using a US-Australia baseline) of ~ 7 cm can be achieved.

The first demonstration of using coherent uplink arraying has been undertaken at the Jet Propulsion Lab (Vilrotter and Tsao) using two 34m beam wave guide antennas at X-band. Precise calibration of Array Radar antenna phase required, and the phase calibration can be accomplished via the “Moon-Bounce” method. In addition, closed-loop phase control is required to maintain phase calibration since temperature variations and equipment instabilities degrade coherence. The proposed array radar approach provides simultaneous projection of OD velocity vectors onto three independent baselines, thus enabling trajectory determination from a single Array Radar observation!

In brief, three 34m BWG antennas with 20 kW transmitters at 7.18 GHz are available. The array spans ~ 500 meters with antenna null-to-null beamwidths ~ 170 mdegs and spacings: DSS-24 – DSS-25 baseline ~ 23 mdegs and DSS-24 – DSS-26 baseline ~ 15 mdegs. For a single antenna: EIRP of 34m antenna, 20 kW transmitter; two antenna array: peak EIRP of 34m antenna, 80 kW transmitter; three antenna array: peak EIRP of 34m antenna, 180 kW transmitter. CAVEAT: Simultaneous multi-frequency/multi-baseline operation remains to be shown. This would enable processing of simultaneous echoes from different baselines.

The receiver operates at 1 MS/S complex samples with 8 bits quantization. For the array radar signal processing, we developed algorithms to process received samples, display data . Event frequency and amplitude, spectrograph displays were generated.

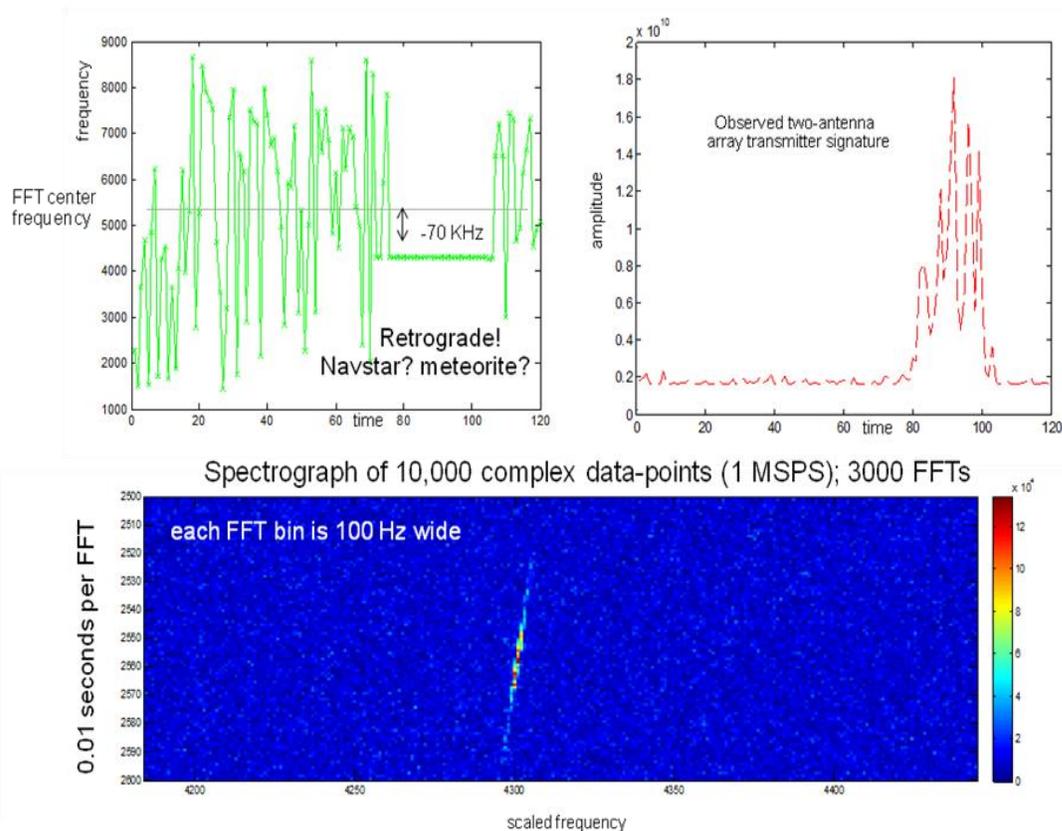


Fig 12. Preliminary Experimental Results of a twp antenna radar array

12.0 APPLICABILITY TO MAPPING OUT “NO DRIVE” ZONES ON MARS

A radar stealth region 2000 x ~ 300 km was discovered on Mars (Muhleman et al. 1993). It was dubbed a stealth region because there were virtually no radar reflections from the area. The best postulate for the stealth property is that the soil has a density of 0.5 gm/cc thus inhibiting reflections. It is believed that the Mars rover Spirit got stuck in such a “sandy” constituency- away from the stealth region (McCustion, private communication 2012). If could map the entire planet and the locations of such regions- e.g., “no drive” zones, we might save or increase the useful lifetimes of multibillion dollar assets.

Once we have established that Ka band uplink arraying is possible, the next step is to establish a large array with high power Ka band transmitters. Using arrays with radio *astronomy* resolution techniques on a US-Australia baseline at Ka band would provide a ground resolution of 50 km. Useless for attaining our goal. Using radio *astrometry* techniques where we can measure to 1/100 of a beam or better, we might expect to get resolutions of 0.5 km. Interesting, but the fundamental limitation is the diameter of the Earth. With 2- 50kW transmitters on a feasible number of antennas, we can use the array in a SAR mode and let baseline be determined by the motion of the planets. Preliminary calculations show that at Mars closest approach to Earth, about $9 * 10^7$ km, a ground resolution of 10m can be obtained! The problem of $1/r^4$ losses from radar observations still exists, though. If, however, NASA puts an orbiter around Mars with Ka band capability, a high power signal from Earth could reflect off the planet and be captured on the spacecraft thereby changing a $1/r^4$ diminution to merely a $1/r^2$ effect.

13.0 APPLICATION TO SOLAR SAILING

Here, a microwave beam will strike a solar sail delivering electromagnetic pressure. This is a natural extension of solar sailing in that the microwave beam assists the sun (Benford and Benford 2003). A qualitative study of how much mass could be delivered to Mars at closest approach was undertaken in 2004, and provided intriguing results (Benford and Benford 2004). NASA is exploring a proof of concept demonstration as a prelude to a large scale, high power uplink array as one of the tools in the human space exploration tool kit

14.0 RISKS

There are some risks in the development of a Ka band coherent uplink arraying system. Below is a list of the listing of these risks, their probabilities and consequences and mitigation plans. As with any R&D program, there are surely some unknown unknowns. We experienced this situation during the R&D effort for coherent uplink arraying with atmospheric compensation at X-band yet in each case, these challenges were successfully overcome. In fact, we have *used* the knowledge to help design the Ka band system under consideration.

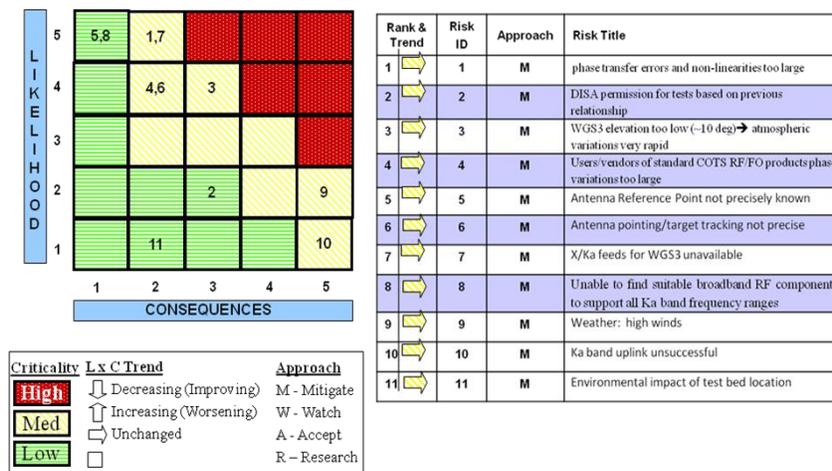


Fig. 13. KaBOOM initial risk matrix

15.0 CONCLUSIONS

We have the funding in place for a demonstration of uplink arraying at Ka band with real-time compensation for atmospheric fluctuations. We shall start in a space communications mode and then demonstrate Ka band radar capabilities. We expect to begin the implementation in summer of 2012. Additionally, a skunk works project team has been established: (1) minimal formal management- all team members will manage the project together; (2) a top-drawer technical team. Finally, it is gratifying that all the hard work and accomplishments over the last decade on various aspects of uplink arraying has garnered broad support with NASA and with our mission partners.

16.0 ACKNOWLEDGEMENTS

It is a pleasure to thank Pete Aragona, Jason Crusan, Lindley Johnson, Richard McGinnis, Bill Marinelli, G. Patrick Martin, Michael Miller, Kathleen Minear, Wade Minear, Chris Moore, and Marc Seibert, for their guidance and encouragement regarding the demos. The author also is appreciative of NASA management at Headquarters at the Division, Directorate, and Agency levels for allowing these demonstrations to be undertaken.

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