THE MULTIPLE ACCESS TESTBED FOR RESEARCH IN INNOVATIVE COMMUNICATIONS SYSTEMS (MATRICS)

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***Abstract* – NASA is presently in the planning stages for the next generation earth relay architecture which will transition to Ka-band services in a new, potentially commercially-driven architecture, by 2040. To assess the performance of various technologies and architectures, the Multiple Access Testbed for Research in Innovative Communications Systems (The MATRICS), is being developed to offer a flexible emulation platform for system-level architecture and technology assessments of candidate next generation Ka-band relay and user terminal solutions. In this paper, we describe the architecture and setup of the MATRICS, which is presently housed in GRC's 25-ft anechoic chamber.**

I. INTRODUCTION

TDRSS-M was launched in August 2017 and represents the final replenishment satellite of the TDRSS fleet. With a design life of 15 years, it is expected that as of 2040, a new relay satellite architecture will be implemented to replace the TDRSS fleet to provide communications and navigation relay services for future NASA missions. This next generation earth relay capability is presently in the planning stages and is expected to initiate optical communications services and herald NASA's full utilization of the Ka-band spectrum. Over the past several years, NASA has funded studies, including the Space Based Relay (SBR) study, Earth Regimes Network Evolution Study (ERNEST), and the Pathfinder program, to look at how this new architecture could leverage existing and future commercial communications infrastructure to evolve concomitantly with commercial satellite communications (SATCOM) objectives [1-3].

As part of this effort, the Technology Assessment for Next Generation Architectures (TANGA) project was created to, as the name suggests, provide system-level performance assessments of potential technologies which may be implemented, either on the relay or user spacecraft, within the evolving design of the next generation relay system. Some potential RF technologies being investigated include: Multibeam Ka-band phased arrays (for both user and relay spacecraft), wideband or reconfigurable Ka-band systems capable of covering both commercial and government Ka-band frequencies, low cost commercial-off-the-shelf (COTS) phased array technologies, omni-directional Ka-band antennas, commercial spot beam technologies, digital beamforming technologies, and onboard processing technologies. To support this research a testbed, dubbed the Multiple Access Testbed for Research in Innovative Communications Systems (The MATRICS), is being developed in order to assess these proposed technologies for potential insertion into the next generation communications architecture. The MATRICS will provide NASA with the system level evaluation tools that address the knowledge trade space between simulation/component-level characterization and full flight payload demonstration for risk reduction and assessments of novel technologies that could play a role in the future NASA space network.

II. OBJECTIVES/APPROACH OF THE MATRICS

The Multiple Access Testbed for Research in Innovative Communications Systems (MATRICS) was developed with the following goals in mind:

- Provide a flexible, system-level architecture assessment tool for candidate next generation Ka-band relay and user terminal solutions.
  - Develop unique capability within NASA to support the demonstration and testing of proposed technologies, architectures, and CONOPS for an evolving next generation relay platform in realistic link scenarios.
  - Provide an opportunity to develop/demonstrate novel approaches to next generation architecture solutions.
  - Validate NASA/Industry solutions for next generation Ka-band architecture
- Mitigate pre-flight risk via enhanced testing in a realistic emulation environment
- Provide NASA with a high fidelity assessment of user terminal and multiple access technology capabilities for the next generation relay.

The approach of the MATRICS is to create an accurate emulation environment within the confines of a (currently) 25 ft anechoic chamber at NASA Glenn

Research Center. As such, the link requirements need to be effectively scaled from the roughly 40,000 km range distances down to the limited range distance available. Configuration of the MATRICS takes into account Field of Regard (FOR) requirements for LEO-GEO relay links (+/- 13°), EIRP, G/T, and free space loss parameters that need to be scaled to realize commensurate link budgets, as depicted in Figure 1. To start, current TDRSS link performance parameters were used as a baseline configuration, and are summarized for the current Ka forward and return service in Table 1 [4].

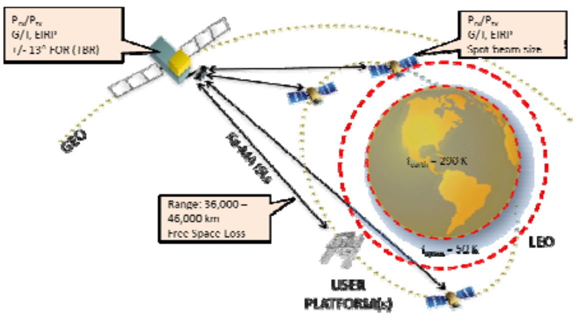

Figure 1: Depiction of user-relay links in the NASA Space Network (TDRSS).

Table 1: Summary of Salient TDRSS Ka Forward/Return Link Parameters

Parameter	*Ka (Forward)*	*Ka (Return)*
EIRP	63 dBW	--
G/T	--	26.5 dB/K
Free Space Loss	~210 dB	~210 dB
Bandwidth	50 MHz	225-650 MHz
Modulation	BPSK/UQPSK	BPSK/UQPSK
Data Rate	300kbps – 25Mbps	300 Mbps

III. THE MATRICS ENVIRONMENT

A depiction of the MATRICS concept is shown in Figure 2. At its core, a dynamic testing platform involves a stationary mock relay positioned at one end of the anechoic chamber while a mobile mock low earth orbit (LEO) user is placed at the opposite end. The LEO user is mounted to an approximately 6 ft boom affixed to a Moog QPT-500 pan and tilt positioner such that the user is physically gimbaled across the full field of regard of the relay. In this way, dynamic link performance, as well as link establishment protocols and concepts of operation can be assessed as a LEO user traverses the relay.

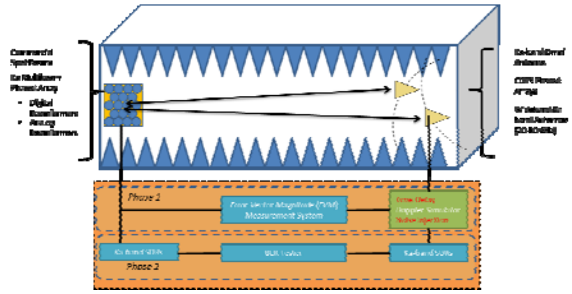

Figure 2: System diagram of the MATRICS setup in NASA GRC's anechoic chamber.

The first phase of the MATRICS development presently allows for direct error vector magnitude (EVM) measurements for return links (user transmitting to relay). A Keysight M8190A Arbitrary Waveform Generator provides the source signal data at 1.2 GHz IF output which is upconverted via a single sideband mixer to the operational Ka-band frequency of interest. The M8190A has the following performance specifications:

- 12-bit resolution up to 12 GSa/s
- Variable sample rate from 125 MSa/s to 12 GSa/s
- Up to 12.25 effective number of bits (ENOB)
- Up to 2 GSa arbitrary waveform memory per channel
- 5 GHz analog bandwidth
- Real-time DSP for digital up conversion to IF and changing waveform parameters on the fly

The M8190A is coherent locked to a Keysight M9703B 12-bit digitizer which is utilized for sampling the receive signal at the 1.2 GHz IF. The M9703B is an 8-channel high speed digitizer capable of simultaneous data captures of up to 3.2 GS/s. In the first phase MATRICS setup, a single channel input is used for sampling the beamformed receive relay array. However, the M9703B can also be configured using the remaining channels to perform element sampling for digital beamforming demonstrations (planned for Phase 2). The combination M8190A/M9703B is used to perform the EVM measurements of the MATRICS. Doppler simulation is then imposed through the hardware by sweeping the up/downcoversion LOs via a Matlab script. Presently, time delay and noise injection parameters are yet to be implemented.

In the follow-on phase, flexible software defined radios will be integrated into the MATRICS to obtain direct bit-error-rate measurements of the various architectures and allow for investigation of DVB-S2 and adaptive coding and modulation schemes. The flexibility of the setup will also allow for replacement of the relay and user antennas to demonstrate a wide variety of architectures and characterization of different user terminals. Of particular interest to NASA is the possibility of using current commercial spot-beam architectures to provide services to LEO spacecraft. Presently, this has been shown to work for airline services in flight, but the challenge of utilizing the same approach for much faster moving LEO satellites is one that still needs to be validated. Also, assessments of various COTS phased arrays which could be implemented for LEO user terminals is of extreme interest for the development of low-cost Ka-band systems for future NASA missions.

A. Mock Relay Hardware Setup

The current setup of the MATRICS was implemented to perform initial validation of the concept. For this setup, a linear array was developed to represent the relay receive system. The linear array consists of an 8-element scalar horn array, whose block diagram is shown in Figure 3. Beamforming of the array occurs at the IF frequency of 1.2 GHz with a bandwidth of 650 MHz to accommodate the maximum channel bandwidth of the current TDRSS return service. Programmable Vaunix Lab Brick digital attenuators and phase shifters are implemented at IF to provide the amplitude and phase control with a resolution of 0.1 dB and 1° phase shift, respectively. An IF beamforming system was chosen to allow for flexibility of the back end beamformer for testing across various channels within the full commercial and government Ka-band spectrum. A photograph of the MATRICS setup in the GRC anechoic chamber, as well as the relay receive array and beamformer electronics rack is shown in Figure 4.

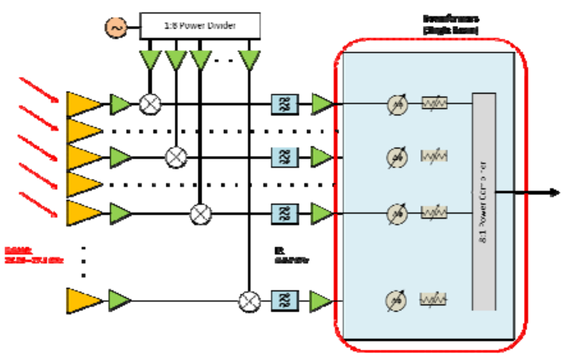

Figure 3: Block diagram of the mock relay receive array.

Preliminary testing of the receive array with the IF beamforming network was performed and indicate good agreement with theory as the relay array is beamsteered across the full field of regard, as shown in Figure 5.

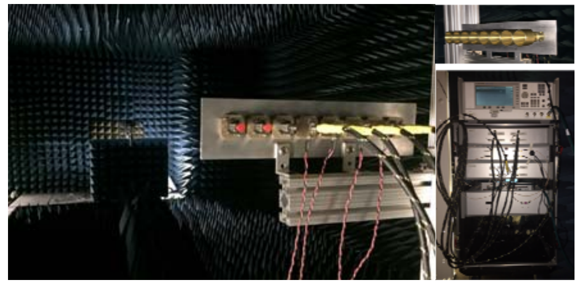

Figure 4: Photograph of the MATRICS setup in NASA GRC's anechoic chamber (left) and the relay receive array and beamforming rack (right).

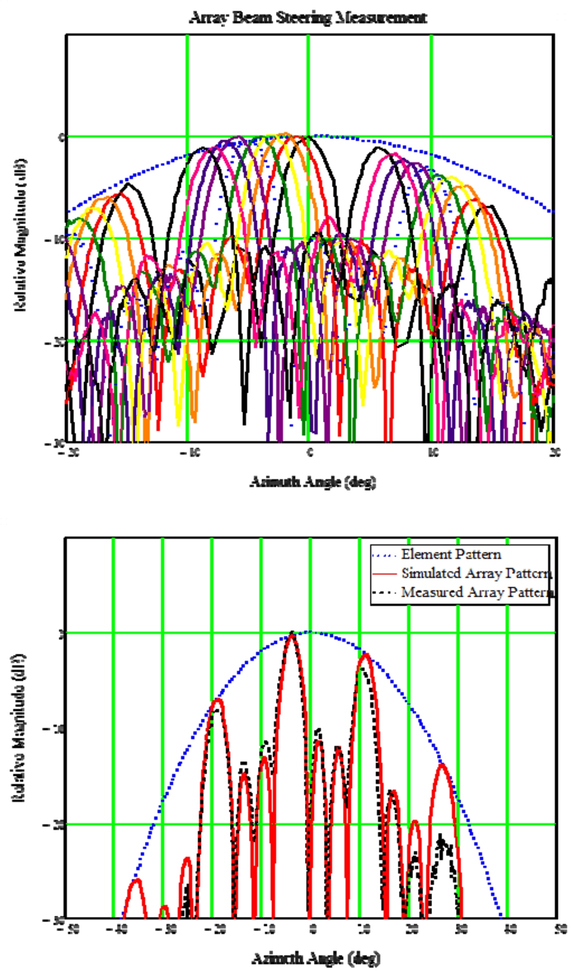

Figure 5: Beamsteering of the relay linear receive array from 0 deg to -9 deg using 4 of the 8 elements (top). Theoretical vs measured array pattern for a beemsteer of 4 deg (bottom).

IV. Initial Testing

First validation tests of the MATRICS were performed using an Anokiwave AWMF-0129 planar active antenna. The operational parameters of the AWMF-0129 are summarized in Table 2, below.

Table 2: Anokiwave AWMF-0129 Phased Array

Parameter	*Performance*
Frequency	27.5-30.0 GHz
Number of Elements	64
EIRP (at P1dB)	50 dBm
G/T	-7 dB/K (at boresight)
Polarization	Vertical Linear
Electronic Beam Scan	+/- 60 deg 2D
Number of Beams	1
Beam Update Rate	13 us
RF Interface	Tx/Rx Half Duplex
Average Power	18 W DC
Size	11cm x 15cm x 4cm
Weight	0.5 kg
Supply Voltage	12 or 18 VDC
Control Interface	LVDS, Ethernet, USB

The Anokiwave AWMF-0129 is a commercial off the shelf (COTS) phased array product intended for 5G wireless applications. NASA's interest, in general, is in identifying if COTS phased arrays like this one could potentially be leveraged for development of low-cost space applications. However, being designed for commercial applications, testing was needed to identify performance limitations in operating outside the specified commercial Ka-band (27.5-30GHz) to NASA's Ka-band allocation (25.5-27.5 GHz). Figure 7 shows the pattern measurements performed at various scan angles out to +/-30 deg at an in band operational frequency of 28 GHz and an out of band frequency of 26.5 GHz. From the plots, it is observed that the Anokiwave phased array does exhibit some efficiency losses operating outside its intended design frequency of approximately 3 dB and a nominally 1 dB scan loss out to 30 deg scan angle.

A. *First Link Test of the MATRICS*

The emulation link budget used was matched to the equivalent relay link parameters indicated in Table 3, which are arbitrarily chosen for this run. The derived equivalent relay link parameters provided in Table 3 were based on calculating the equivalent EIRP needed from a transmitting user terminal to match the same receive carrier-to-noise density (C/N0).

The orbit simulated was that of a Ka-band payload attached to the International Space Station. Orbit propagation simulations were conducted prior to the test to identify the necessary pointing angles (for both the relay and the user antennas) as a function of orbital position. These pointing angles were then coordinated in time with the physical location of the mock LEO user in the MATRICS and program tracked for both ends of the link throughout the emulated orbital pass. Pointing angles were directly sent to the Anokiwave system via the Ethernet interface and the calculated phasing weights were time synchronized for beam steering of the linear array representing the relay.

As indicated in Table 3, a 100 Mbaud data rate was employed using QPSK modulation. A screenshot of the resulting EVM performance characterized during the run is shown in Figure 8, where a maximum EVM of 1.4% was achieved. EVM was tracked throughout the orbital pass, demonstrating, as expected poorer performance at the look angles beyond ~50 deg, which represents the limit to which the Anokiwave phased array could steer with reliable array gain.

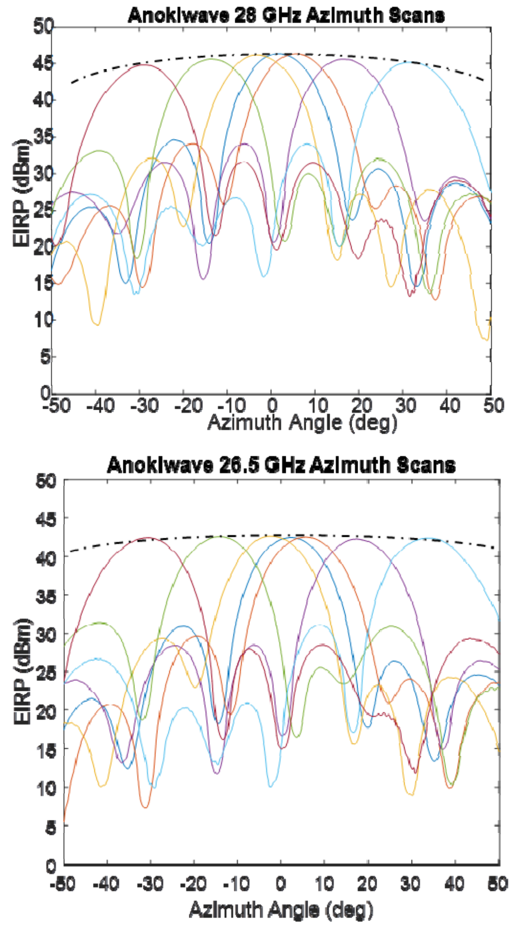

Figure 7. Pattern measurements of the Anokiwave AWMF-0129 at 28 GHz (top) and 26.5 GHz (bottom) operational frequency.

Table 3: MATRICS Test Run Parameters

	MATRICS	*Equivalent Relay*
Transmit Parameters		
Frequency	26 GHz	26 GHz
EIRP	-10 dBW	84 dBW
Channel Loss Parameters		
Free Space Loss	77.64 dB	212.47 dB
Polarization Loss	3 dB	3 dB
Communications Parameters		
Bandwidth	100 MHz	100 MHz
Modulation	QPSK	QPSK
Data Rate	100 Mbaud	100 Mbaud
Receiver Parameters		
Noise Spectral Density	-189.57 dB	-198.59 dB
G/T	-14.49 dB/K	26.01 dB/K
Receive Carrier Power	-66.1 dBW	-75.5 dBW
C/N0	123.5 dBHz	123.5 dBHz

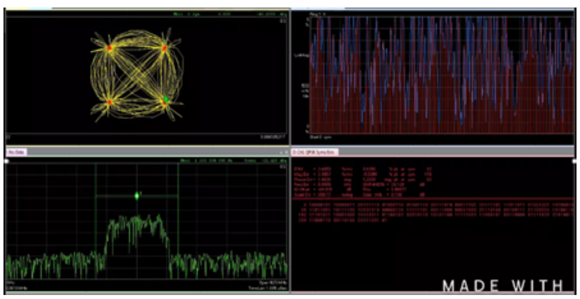

Figure 8. Screenshot of the Keysight M8190A measured EVM performance of the link.

V. FUTURE PLANS

Beyond these initial demonstrations, the MATRICS still has some development effort needed to get the testbed to full functionality. The following list details the planned upgrades to the MATRICS testbed in the coming year:

- Addition of secondary rotation stage to include two user terminals for true multiple access emulation capability
- Redesign of mock relay array from linear to hexagonal close-packed array, as is typical in most satellite configurations
- Second analog beamformer hardware to support two simultaneous users in FDMA
- Implementation of time delay and noise injection for accurate link emulation
- Full utilization of the Keysight M9703B digitizer for digital beamforming demonstrations
- Addition of a small transmit array for bi-directional communications.
- Integration of SDRs into the system for direct bit error rate measurements and ACM and CONOPS demonstrations.

VI. CONCLUSIONS

The MATRICS is presently still in the build-up phase, but is showing to be a useful tool for NASA to assess realistic communications systems performance in a dynamic link environment. As part of the technology assessment needed for NASA's next generation relay architecture, Ka-band user terminal demonstrations will play an important role as NASA tries to entice future users into this underutilized NASA Ka-band spectrum. Furthermore, as the development of NASA next generation relay architecture continues to evolve, the flexibility of the MATRICS will allow for extensibility to changes until a final architecture is identified.

VII. REFERENCES

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