New MI Compact Range Facility Measures Innovative Panasonic Airborne Antenna

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Abstract— **Panasonic Avionics Corporation has developed an innovative antenna design that provides Ku-band connectivity for its In Flight Entertainment and Communications (IFEC) systems. Traditional approaches suffer outages when crossing the equator due to Adjacent Satellite Interference (ASI). Through the addition of a second antenna panel, Panasonic has both increased the overall performance and eliminated the ASI problem by cutting the elevation beam width by 50% when operating in the tropics and when crossing the equator. Due to the great success of its IFEC systems, Panasonic had a need to dramatically increase the production and test capacity for its antenna all while transitioning the manufacturing to a new facility in Lake Forest California.**

MI Technologies has delivered two new state of the art compact range measurement systems and has worked with Panasonic to develop automated test systems that have reduced the test time by more than a factor of 4. The range design includes significant automation, integration with the antenna's built in up and down converters, and the ranges are reversible.

I. The In Flight Entertainment Application

In-flight entertainment (IFE) refers to the entertainment available to aircraft passengers during a flight. In 1936, the airships and dirigibles offered passengers a piano, lounge, dining room, smoking room, and bar during the 2½ day flight between Europe and America. After the Second World War, IFE was delivered in the form of food and drink services, along with an occasional projector movie during lengthy flights. Before then, the most a passenger could expect was a movie projected on a screen at the front of a cabin, which could be heard via a headphone socket at his or her seat. In recent years, IFE has been expanded to include in-flight connectivity—services such as Internet browsing, text messaging, cell phone usage (where permitted) and emailing. In fact, some in the airline industry have begun referring to the entire in-flight-entertainment category as "IFEC" (In-Flight Entertainment and Connectivity or In-Flight Entertainment and Communication).

Modern IFE systems trace their lineage to the 1960s when they first began to become mainstream and popular. In 1961, 16mm film system for a wide variety of commercial aircraft became available. In 1963, the first pneumatic headset was used on board commercial aircraft. These early systems consisted of in-seat audio that could be heard with hollow tube headphones. In 1979 pneumatic headsets were replaced by electronic headsets. In 1971, the 8mm film cassette was developed. Flight attendants could now change movies in-flight and add short subject programming. In 1975, video games that could be played on-board flights were introduced. In the late 1970s and early 1980s, CRT-based projectors began to appear on newer aircraft. These used LaserDiscs or video cassettes for playback. In 1985 the first personal audio player was offered to passengers, along with noise cancelling headphones. During the 1990s the demand for better IFE became a major factor in the design of aircraft cabins. In 1988, the first in-seat audio/video on-demand systems were introduced using 2.7 inch LCD technology. The LCD technology received an overwhelmingly positive passenger reaction.

Today, in-flight entertainment is offered as an option on almost all aircraft, although some older narrow body aircraft are still not equipped with any form of In-flight entertainment at all. This is mainly due to the aircraft space and weight limitations.

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A modern typical IFEC network architecture is dependent on satellite communications as shown below in Figure 1.

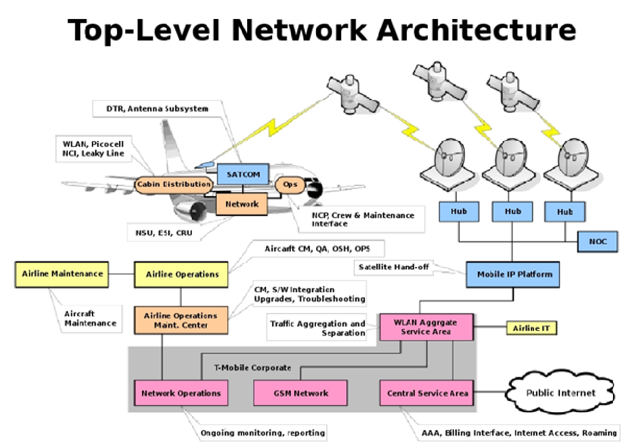

Figure 1 – Typical IFEC Network Architecture [2]

II. The Trans-Equatorial Challenge

There are many airlines whose operating regions are such that trans-equatorial performance for their IFEC system is critical. First, a couple things about the technical challenges of operating a satellite connected aircraft when flying near the equator. With parabolic antennas (which sport a curved surface with the cross-sectional shape of a parabola) there is no issue. But these days commercial aircraft are fitted with low profile, fuselage mounted antennas, and the technical solution for solving polarization of signals is found in dual panel configurations. When you take a typical 1.2-meter VSAT antenna and squish it down to fit on top of a plane you end up with an elliptical beam shape where the azimuth beam width is relatively narrow but the elevation beam width is quite large. The large part of the beam can cause Adjacent Satellite Interference (ASI) when the skew angle approaches 90 degrees. Antenna can adjust horizontal and vertical polarity as the skew varies but cannot adjust the beam shape. At a skew angle of zero the narrow part of the beam is lined up correctly and there is minimal ASI. At a skew angle approaching 90 degrees the wide part of the beam is hitting the adjacent satellites increasing ASI.

Typically operators limit skew angle to something less than 90 degrees so they can operate legally and economically but to cross the equator without outages you must operate at a 90 degree skew. This is why the Panasonic antenna has a second panel. In additional to increasing overall performance the second panel cuts the elevation beam width by 50% when operating in the tropics and allows full functionality crossing the equator. This issue applies to all noncircular antennas for all frequencies such as Ku, Ka, C, L, X and S band. The beam skew issue becomes more of an issue the closer you get to the equator. [3]

III. The Panasonic Antenna Solution

Panasonic currently has systems fielded on several aircraft types that are now using its dual panel antenna to deliver a broadband connection to the aircraft, and they expect that number to increase significantly in the short term as they aggressively work to outfit customers' aircraft with Panasonic's Global Communications Suite.

In addition, Panasonic has hundreds and hundreds of hours of flight test data that clearly demonstrates the capabilities and performance of their antenna operating near and crossing over the equator. The performance capabilities of the antenna are a clear differentiator for them when they engage customers, and they have, in fact, won programs in large part due to the performance of the dual panel antenna.

A. Architectural overview

Panasonic selected Ku-band because it is less vulnerable to rain fade and there is optimum satellite coverage. Additionally, in the Ku-band world, there are multiple satellite operators. Should something go wrong, finding a backup satellite is not normally a problem.

The antenna system consists of two Ku-Band aperture panels which are coherently combined at an L-Band IF. Each aperture is an array of waveguide elements, combined with a low-loss corporate feed network. The H and V aperture ports connect directly to a waveguide diplexer and then to the LNB and HPA/BUC and converted to IF. The polarization state is determined by the polarization synthesizer, operating at the L-Band IF. Supported polarizations include dual orthogonal (arbitrarily oriented) linear or dual orthogonal circular for receive and arbitrarily oriented linear for transmit.

The two apertures are then coherently combined using a "mini-network analyzer" system that can keep all signals tightly aligned in amplitude and phase. This system, however, has no way to detect the amplitude and phase variations associated with the aperture arrays themselves. This can only be evaluated on the antenna range. A correction vector is determined and stored in the system to ensure optimum pattern formation. A calibration process to ensure that the polarization angles of the two panels are closely aligned is also required. Determining the correction vector and performing the calibration are long and tedious processes if performed manually, but fertile ground for an automated solution.

B. High level of functional integration:

This antenna system incorporates many functions that are often contained in external LRUs. These include high-power amplifiers (HPAs), low-noise amplifiers, diplexers, frequency up and down converters (BUCs and LNBs), polarization synthesizers and an overall system management processor, all mounted on a low-profile elevation over azimuth positioner. The antenna control unit (ACU) is located on board. There is also a subsystem to maintain coherence between the plates under changing conditions and aircraft orientations. Electrical interfaces to the system include transmit and receive IF ports, Ethernet control, ARINC navigation data and DC prime power.

C. Dense integration leads to testing challenges

Arranging the aperture, diplexer, LNB, BUC and polarization synthesizer in a tight module stack leads to optimum performance in terms of maximizing G/T and minimizing the power required for a given EIRP. It also makes testing a challenge. For instance, traditional antenna performance testing (patterns, crosspol, EIRP, G/T, etc.) must be done "cross-band" with the plane wave excitation at Ku-Band, but the test equipment receives an L-Band IF return signal (receive mode). The opposite situation is the case for transmit mode; L-Band excitation returns a Ku-Band plane wave output. Any receive system measurements at microwave frequencies are meaningless, since the polarization synthesizer operates at IF.

The antenna test range instrumentation must accommodate both transmit and receive modes as well as a passive Ku/Ku mode for acceptance testing of the bare aperture arrays prior to their integration into a system. The range must also require a minimum amount of manual reconfiguration when changing between modes in order to support the highest level of automation and throughput possible in a production environment.

D. Summary of the test problem

Due to the great success of its IFEC systems and the need to ramp up system production quickly, Panasonic had a need to dramatically increase the production and test capacity for its antenna all while transitioning the manufacturing to a new facility in Lake Forest California.

The antenna presented a high level of functional integration, dense packaging into a compact assembly, and a complex array of various transmit and receive modes. Adding the requirement of no manual reconfiguration of the range instrumentation during testing, and minimization of operator skill requirements, the test automation effort represented a serious challenge.

IV. The Test and Measurement Solution

MI Technologies delivered two new state of the art compact range measurement systems and has worked with Panasonic to develop automated test systems that have reduced the test time by more than a factor of 4 allowing Panasonic to keep up with the significant ramp up in production that was required. The range design includes significant automation, integration with the antenna's built in up and down converters, and the ranges are reversible.

The objectives for the new facilities were to:

- Provide the automated ability to measure radiation patterns, gain and polarization state of airborne Ku - Band antennas.
- Allow transmit and receive testing with frequency conversion.
- Provide the automated ability to determine the correction vectors needed to address the amplitude and phase variations associated with the aperture arrays themselves.
- Provide the automated ability to perform a calibration process to ensure that the polarization angles of the two panels are closely aligned.
- Provide pass/fail acceptance testing for production and repaired antennas.
- Maximize measurement repeatability while minimizing the skill level required of the test technician.
- Eliminate the need to test outdoors.

A. *Test facility overview*

Each facility is based around an MI-504C Compact Range that provides a 4 foot diameter, 4 foot long cylindrical quiet zone. The MI-504C Compact Range reflector is a mature and proven design that features a support structure optimized for stability and a highly uniform surface that is machined and laser verified to provide excellent test zone quality. The compact range subsystem includes a precision reflector mounted on a pedestal assembly to achieve proper height in the chamber. A feed stand with a motorized polarization rotator with an interface that allows the mounting of a series of MI-233 Compact Range Feeds is included. The MI-233 feeds are banded corrugated compact range feeds that provide a broad beamwidth to properly illuminate the compact range reflector. This performance successfully limits the amplitude taper across the compact range test zone which enhances the accuracy of the measurement. A 10 - 15 GHz feed was developed for the system to eliminate the need to switch between an X-band (8-12 GHz) and Ku-band (12-18 GHz) feed horns while providing the needed frequency coverage. A field probe measurement program to verify quiet zone performance in the compact range was performed. The following Quiet Zone performance was achieved:

Quiet zone shape: Circular cylinder

Amplitude Taper: <0.46 dB

Amplitude Ripple: +/ - 0.4 dB

Phase Variation: <8.16 degrees ·

MI provided its MI-350 Advanced Microwave Measurement system that includes the following products:

- MI-3001 Data Acquisition and Analysis Workstation with MI-3000 Arena™ Software provides capabilities for ease of operation for routine product tests, as well as flexibility for implementation of unique test cases
- MI-750 Microwave Receiver a high performance receiver that offers a combination of both very fast measurement speed and high dynamic range simultaneously, and that is also based on a modular digital architecture that provides high reliability and availability
- The MI-3121 Signal Source, a synthesized RF signal source that provides high output power with fast frequency switching speed
- MI-710 Position Controller provides for optimum tuning of each axis to assure smooth operation with high resolution position feedback

MI provided a roll over azimuth positioning system with a floor slide. The positioners included in the system are based on MI Technologies standard products and provide high accuracy and long term reliability. The positioners are DC servo based units equipped with standard synchro transducers capable of achieving an accuracy of better than 0.05 degrees. The mast supporting the roll axis is mounted on a manual slide assembly that allows the antenna under test to be centered over the azimuth axis. The minimum load capacity of the positioning subsystem is 200 lbs. The floor slide is capable of 4 feet of travel. The MI-710 Position Controller is a digital servo based controller capable of providing individual axis control for all motorized axes.

The RF subsystem is capable of operation from 1 - 20 GHz (easily extendable through W-Band at a later date). The RF subsystem is capable of measuring antenna systems with internal up and down frequency conversion, e.g. a 12.45 GHz received signal is output from the antenna at 1.2 GHz. Similarly, a 1.2 GHz IF input to the antenna results in a 14.25 GHz transmit signal radiated from the antenna. The RF subsystem is also able to operate in either transmit (signal flow from the AUT aperture to the range) or receive (signal flow from the range to the AUT aperture) mode. The RF subsystem also provides a noise floor of better than -50 dBi up to 18 GHz.

The MI-3001 Data Acquisition and Analysis Workstation with MI-3000 Arena™ Software provides full software control of the instruments and positioners allowing the test and calibration process to be fully automated.

The overall physical layout of the compact range facility is shown in Figure 2.

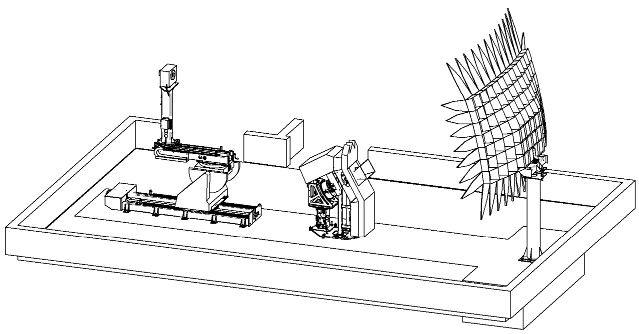

Figure 2 – Compact Range Physical Layout

A block diagram of the overall system is shown in Figure 3 (shown at end of paper).

B. Automated range switching

Unique RF aspects of this system are driven by the requirements for range reversal, and for test of an AUT with up and down conversion. These requirements had been implemented by MI in similar systems in the past and the solution is based on proven hardware approaches that are low risk. The system can perform the following with almost no re-cabling via the Custom Range Switching Assembly:

- Drive an antenna with internal up conversion with an IF signal from 0.1 to 2 GHz and measure the transmitted RF from 2 – 20 GHz.
- Transmit RF from 2 – 20 GHz and receive the fixed IF frequency from 0.1 to 2 GHz
- Measure passive antennas from 2 – 20 GHz while transmitting from the compact range feed

The block diagram in Figure 4 (shown at end of paper) shows the internal details of the Range Switching Assembly (RSA) and the AUT Mixer Assembly (AMA) as they relate to the rest of the RF instrumentation. The switches and mixers in these assemblies provide the ability for the range to be automatically configured to support the two unique aspects of this facility: Transmit/Receive reversibility and the selection of either IF/RF frequency translation (active mode) for testing systems or no translation (passive mode) for testing passive panels.

C. Transmit/Receive Reversability

In the frequency translation (Active) mode, the test path is not reciprocal because the AUT up-converts for transmit and down-converts for receive. For transmit, an L-Band IF signal is sent to the AUT, but a Ku-Band signal is returned to the range feed. For receive, a Ku-Band signal is sent to the range feed, but an L-Band IF signal is returned by the AUT. Additionally, the transmit and receive interfaces to the AUT are on two different ports. In order to accommodate both transmit and receive modes without cable changes, the switches in the RSA (1S1, 1S2, 1S4 and 1S5) and AMA (2S3) provide AUT port selection and the required signal routing between the source/receiver and the AUT/range feed.

D. Frequency translation

To compensate for the AUT frequency conversion in the Active mode, two of the mixers in the RSA provide complementary frequency conversions to keep the range receiver interface at a constant frequency. The third mixer in the RSA is used for the reference channel.

An additional requirement is to measure passive aperture panels at Ku-Band to verify gain and cross-polarization rejection prior to their integration into an antenna system. This capability is provided by bypassing the two mixers in the RSA and switching the mixer in the AMA in-line. This is the traditional configuration found in "normal" ranges that only need to work with passive antennas.

V. PRODUCTION TESTING RESULTS

The automation effort included control of the range instrumentation as well as remote configuration of the antenna under test into its various modes via an Ethernet connection. Following processes and tests were automated:

- Inter-panel coherence calibration
- Polarization calibration
- Passive panel gain and cross-polarization rejection
- Transmit and receive radiation patterns
- System-level cross-polarization rejection
- Linear polarization angular accuracy
- Transmit drive level/P1dB/EIRP
- Transmit and receive spurious levels
- Prime power consumption
- Built-in test functionality

Calibration of the inter-panel coherence and polarization take the most time to complete by a wide margin compared to the other performance verification tests. Performing these processes manually took a total of 18 hours of skilled technician labor per antenna. The process was tedious and prone to human error. After this was automated, the technician time required was reduced to 4 hours and the quality and consistency of the result improved.

Performance verification testing took a total of 6 hours of skilled technician labor when performed manually. After automation, the labor time was reduced to 2 hours and the skill required to perform the testing was also reduced. Reducing the skill level requirement allowed additional staff with less antenna test experience to be cross-trained to perform this testing.

These improvements increased the facility throughput from about 7 systems per month when performed manually (on a single range) to about 60 systems per month with the benefit of automation and two ranges. These rates are for a single workday shift. The reduced skill requirement makes the addition of a second shift much more practical, so the production test rate could be effectively doubled in this way.

Keywords: Compact Range, Automation, Test Time

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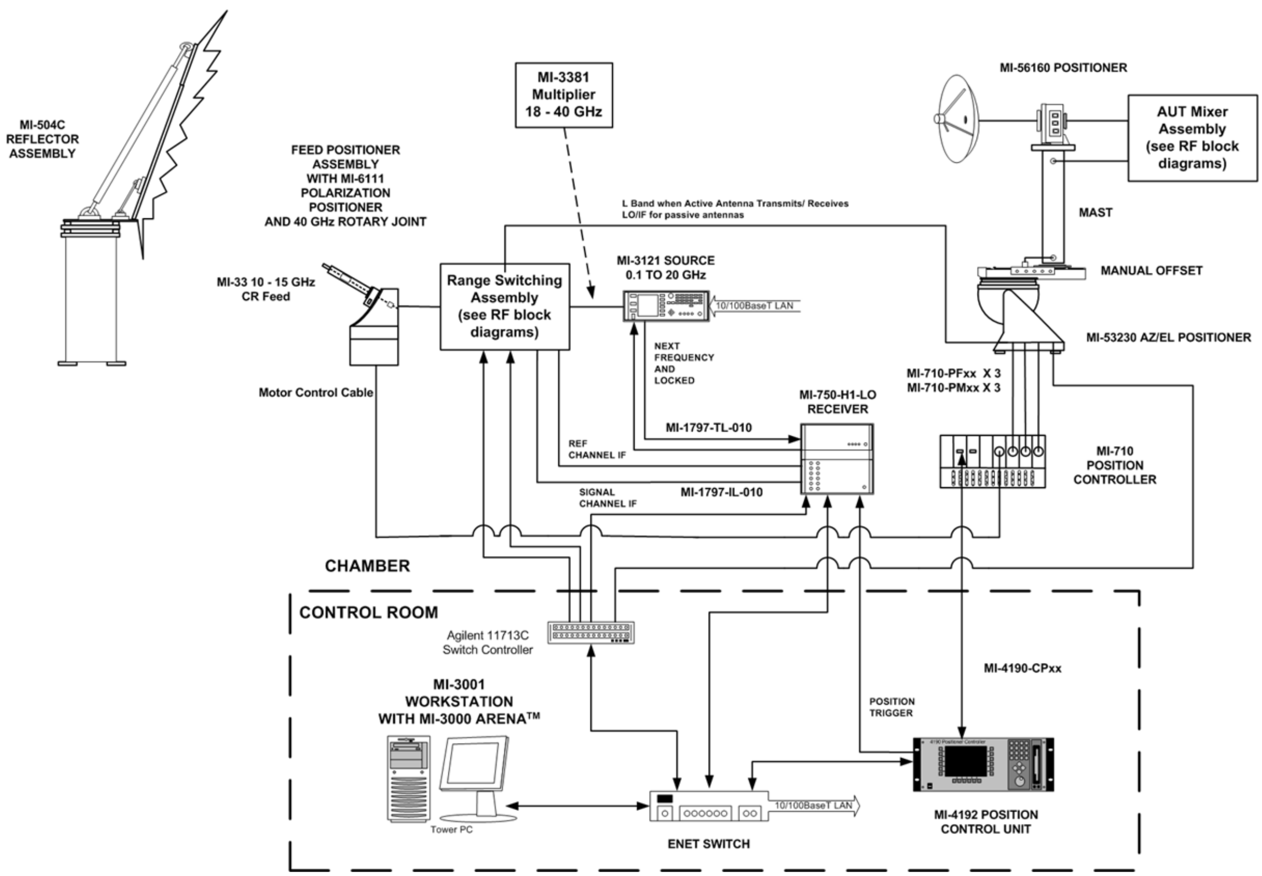

Figure 3 – Overall System Block Diagram

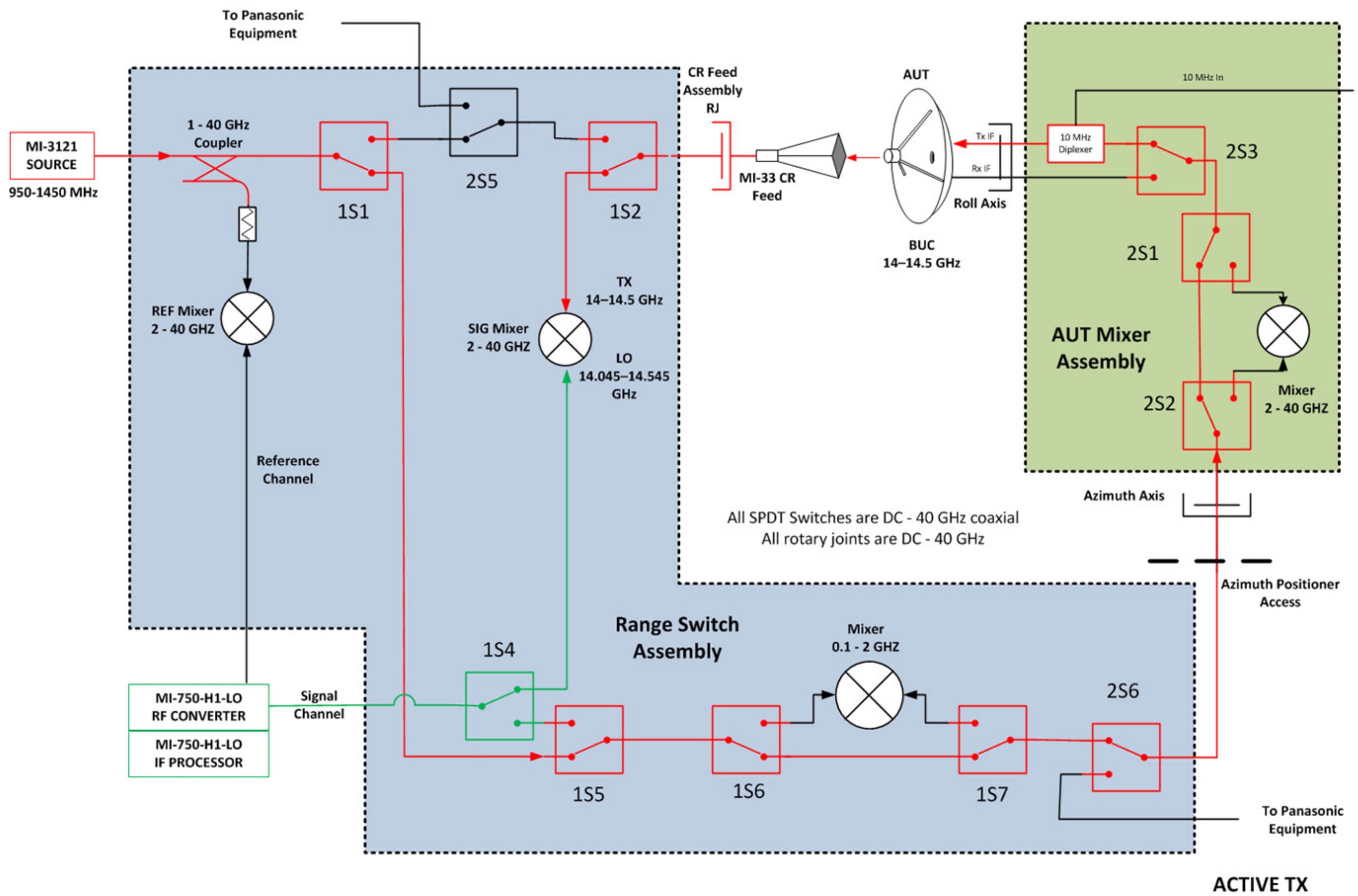

Figure 4 – Range Switching Assembly (Active Tx Mode Shown)