ViaSat's 50 Year Legacy in Range Telemetry:
Its Past, Present and Future

Armando R. Gattoni
ViaSat Inc.
Duluth, GA, USA

ABSTRACT

In April of 2000, ViaSat (Carlsbad, CA) acquired the Communications and Tracking Systems division of Scientific Atlanta (Atlanta, GA). Through that acquisition ViaSat can trace a fifty year heritage of range telemetry product and system development. This paper describes some of ViaSat's key contributions during those years, beginning with CORTS (Conversion of Range Telemetry Systems) and including development of Monoscan Converters for single-channel monopulse tracking, the 410 WA and Series 930 Telemetry Receivers, E-Scan autotracking and numerous tracking antenna systems. This paper includes recent (within ten years) systems and products specifically developed for telemetry applications, and concludes with what ViaSat believes the future holds for telemetry tracking systems.

PAST
Monoscan Converters

By mid-1960s the company now known as ViaSat, Antenna Systems Division (formerly Scientific Atlanta) had greatly expanded its product line and technical expertise. In addition to precision antenna pattern measurement equipment, the company had developed numerous antennas (log-periodic/helix arrays and parabolic reflectors), pedestals, positioning controls and a complete line of telemetry receiver products. These individual products and complete systems were gaining world-wide recognition as robust, reliable and practical. Even NASA recognized the company's technical contributions during various phases of the US Manned Space program. It was in 1967 that the US government released procurement specifications for CORTS: a program to convert telemetry ranges from sub-1 GHz operation (primarily P-band) to L, L/S and S-bands. These specifications challenged systems suppliers to use the latest technology in overcoming practical problems such as tracking RF from spinning missiles or modulated by propellers and rotors, while also covering the wide band from 1435 to 2300 MHz. ViaSat's engineering staff developed a novel approach to the problem, the Monoscan Converter as shown in Figure 1, and successfully incorporated it into meeting CORTS system requirements.

The primary technical advantages of the Monoscan were three-fold. First, it utilized a single-channel "pseudo-monopulse" technique that eliminated phase matching difficulties of traditional monopulse over multiple cable lengths. Second, it overcame problems of conical scan tracking producing "beat notes" with AM modulation on the target signal, as recently described in 2013 ITC Student Paper of the Year, *"Does a Spinning Missile Cause Tracking Error at C-band"* by

Mr. Darren Kartchner. In the first technical description of the Monoscan Converter, *"Scan-coded Single Channel Monopulse Automatic Tracking Systems"* by Mr. P.M. Pifer, the variable switching capability of the unit was considered its most novel feature. Scanning could be up to 1000 Hz (much higher than a mechanical conscan), fixed at a frequency far removed from extraneous AM on the RF signal, swept with a triangle waveform or even a pseudo-random signal. As an added bonus for systems with critical G/T requirements, the sum (or data) channel could be separate from the tracking channel and free of tracking modulation, unlike a conical scan antenna.

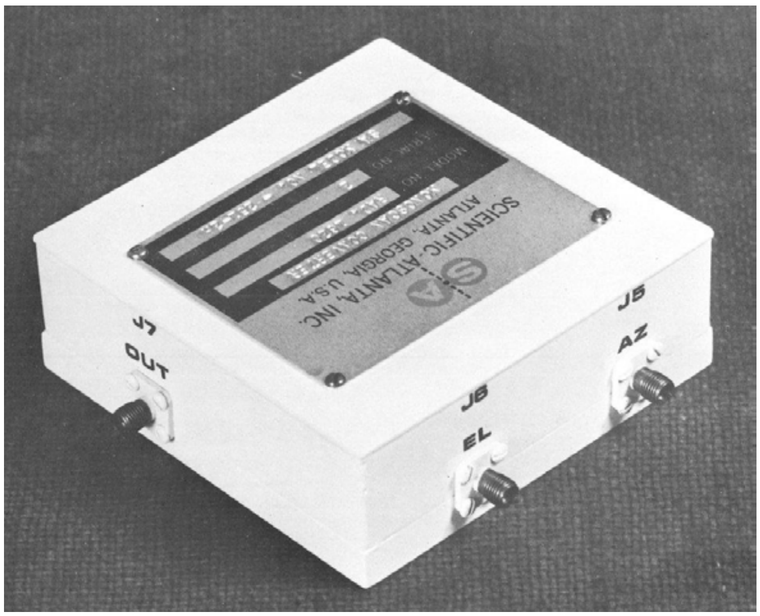

Figure 1. Monoscan Converter

And finally, the Monoscan provided a singular solution for the wide RF band. This third requirement was perhaps the most challenging as there had been numerous other converters built with discrete components over narrow bands. A key construction feature was the flexible pwb material which allowed the 180 degree phase path to literally be a "twist," as shown in the pwb assembly photo, figure 2. During the production life of the product, each Monoscan Converter was hand assembled, trimmed and tested. Today, readily manufactured RF switches, hybrids and similar components can be used to form the same function at less cost. Figure 3 is a schematic of the Monoscan Converter, which by today's standards is incredibly simple! The operation is controlled by four current drivers (located in control room electronics) operating into PIN diodes. As the diodes are forward or reverse biased, the appropriate RF signal paths (Az or El/ 0 or 180 degrees) are established or blocked. The time multiplexed RF signals are added to the RF sum signal via a coupler, thus the axis tracking errors appear as amplitude modulation on the sum reference. Table 1 provides a list of performance parameters of the original Monoscan Converters.

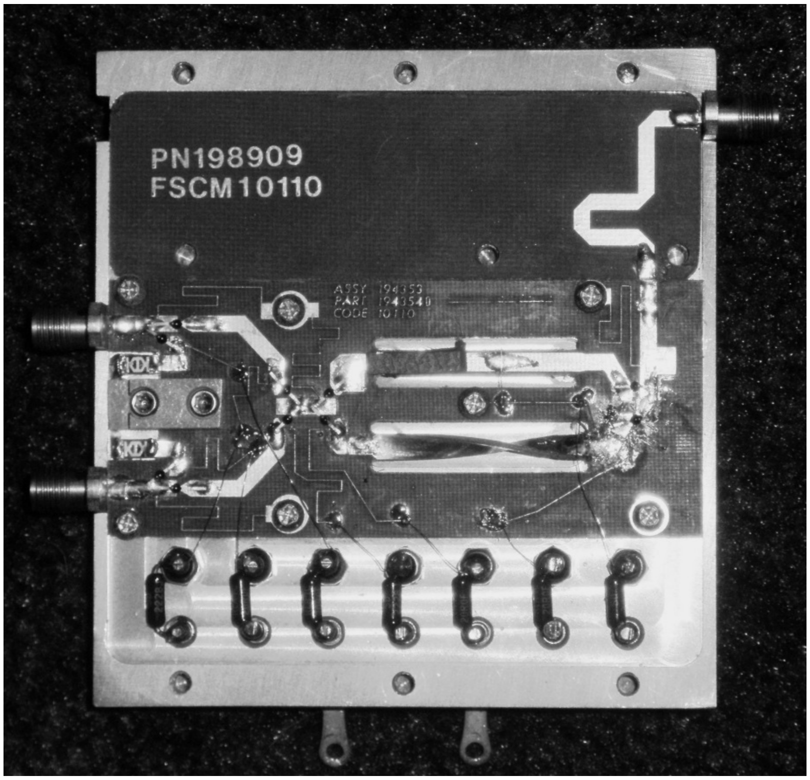

Figure 2. Monoscan Converter PWB Assembly

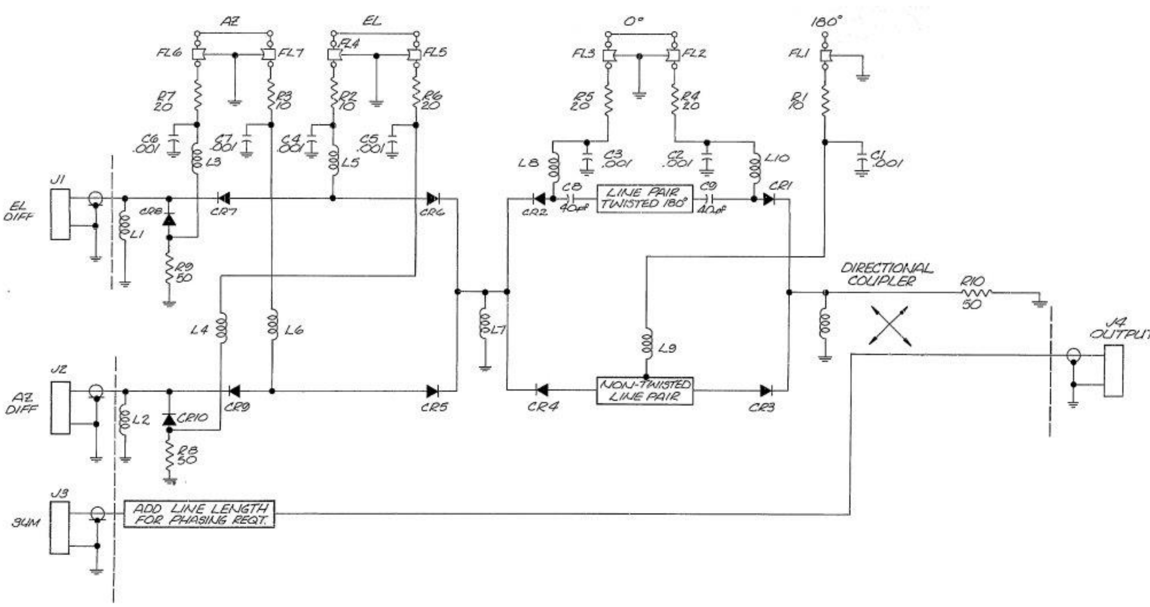

Figure 3. Monoscan Converter Schematic

Table 1. Monoscan Converter Performance

Parameter	Performance Specification
Input Frequency Range	1400 to 2300 MHz (2400 in later versions)
Sum Channel Insertion Loss	0.8 dB maximum, input to coupler output
Difference Channel Insertion Loss	14 ±1 dB, each Δ input to coupler output
Coupler Slope	± 0.4 dB across each of three bands: 1435 to 1540 MHz 1650 to 1750 MHz 2200 to 2300 MHz
Isolation	30 dB minimum
Switching Time	15 μseconds maximum

ViaSat incorporated these Monoscan Converters into an L-L/S-S band feed design (Model 70) that was integrated into one of two reflectors: an 8 ft diameter on a Model 3100 Pedestal or 18 ft diameter on the Model 3200 Pedestal. These antenna systems were known as the Series 3000 UHF Automatic Tracking Antennas, eighteen of which were delivered to various US Test Ranges under the CORTS program.

Telemetry Receivers

Also during the 1960s, ViaSat (aka Scientific Atlanta) acquired design rights to a double conversion, superheterodyne telemetry receiver originally developed by DCE. The author understands this receiver initially used Nuvistor tubes for amplification stages, however, ViaSat reworked the electronics to be completely solid-state for improved life and reliability. The Model 410 WA, shown below in Figure 4, was an analog engineering piece of art! The all-aluminum chassis and plug-in modules were designed to be EMI tight, meeting the requirements of MIL-STD-461. The tuning heads utilized multipole pre-selectors and a state-of-the-art double-balanced, hot carrier diode mixer covering RF input frequencies from 60 to 4200 MHz. Tuning was extremely smooth with a zero-backlash drive and dial mechanism controlling the Variable Frequency 1st LO.

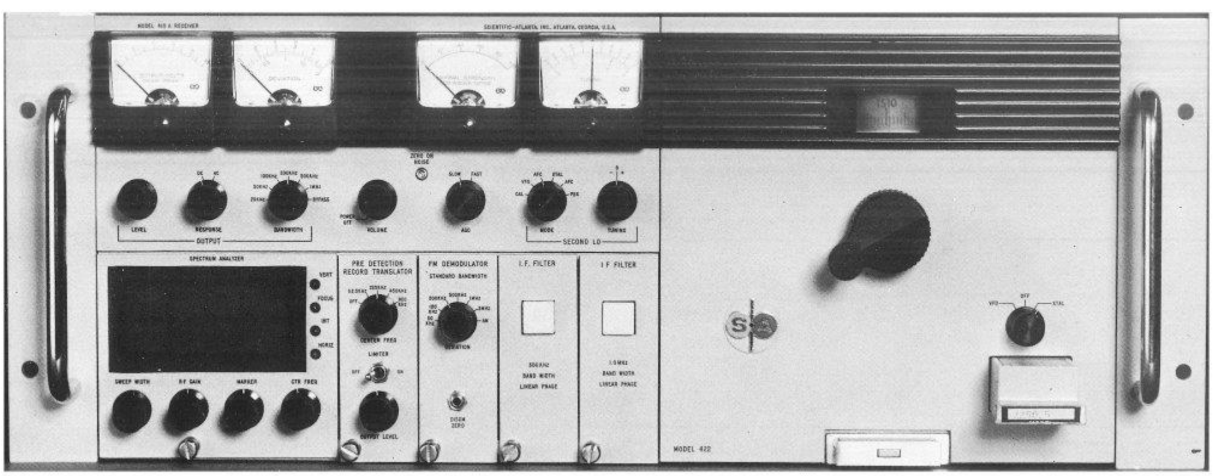

Figure 4. Model 410WA Telemetry Receiver

For fixed frequency applications, a temperature-controlled crystal oscillator was also available. The chassis was designed for up to six plug-in modules for IF filtering, Demodulators, Record and Playback Translators, and even an optional Spectrum Analyzer. The IF Filters (pre-detection filtering of 10 MHZ 2nd IF) were electronically switched with the touch of a front panel button. At that time ViaSat was the only company to offer both Butterworth (constant amplitude) and Bessel (linear phase) filter designs. For most telemetry formats, especially FM/FM and PCM/FM, a Bessel filter provided less distortion than a constant amplitude filter of twice the bandwidth. Several Demodulator plug-ins were available for the 410 Receiver to cover all IRIG telemetry formats, including Narrow, Standard and Wide FM, Wide angle PM and BPSK. The standard Model 440 FM Demod covered a deviation range that required two demodulators in other receivers. Table 2 lists some of the features, functions and modules that were part of the 410WA. The author understands that in 2009, one satellite telemetry site in Brazil still used 410 Telemetry Receivers that were over 30 years old. Talk about being robust and reliable!

Table 2. Model 410WA Receiver Characteristics

Function or Feature	Value
Receiver Type	Super heterodyne, double conversion 60 MHz 1st IF standard, 70 MHz optional 10 MHz 2nd IF
Tuning Range	60 to 4200 MHz via nine tuner plug-ins
First LO	Variable Frequency or Fixed Crystal, selectable
Second LO Crystal Mode VFO Mode AFC Mode APC Mode Playback Mode	 ±0.005% stability (±0.0025 % with oven) ± 250 kHz tuning range ± 250 kHz acquisition range ± 250 kHz tracking range 10 MHz capability with 2nd LO disabled
Input Power Impedance VSWR	 -7 dBm Signal + Noise, maximum 50 ohms 2.0:1 maximum
Dynamic Range	100 dB minimum
Linearity	± 10% to within 12 dB of noise floor
AGC Time Constant	1, 10, 100 & 1000 milliseconds plus MGC (manual control)
2nd IF Filter Modules Linear Phase (Bessel) Constant Amplitude (Butterworth)	 100, 200, 250, 300, 500, 750, 1000, 1500, 2500, 3300 and 5000 kHz bandwidths 10, 30, 50, 70, 500, 750, 100, 1500, 2500, 3300 and 5000 kHz bandwidths
Noise Figure	8.5 dB typical, 10 dB maximum
Metering	Signal Strength (0 to 100 dB), Tuning Error (kHz), Modulation (FM kHz or PM degrees and AM %)

In 1985 ViaSat introduced the micro-processor controlled Series 930 Telemetry Receiver shown in Figure 5. This unit was specifically designed to replace the venerable 410 Receiver, while incorporating features to support satellite as well as range telemetry formats at higher data rates. Two models were available: the 930A with a 70 MHz first IF and the 930B with 160 MHz first IF, both with up to three IF filters. Only two low-phase noise, digitally synthesized tuners were developed to cover 215-320 and 3600-4200 MHz in the A version. Six tuners were available for the B version, covering RF inputs from 215 to 2400 MHz. The chassis could house up to seven 20 MHz 2nd IF filters in three advanced designs: constant amplitude equalized (Cauer-Elliptic with delay equalization), linear phase (Bessel) and narrow-band linear phase crystal. In most configurations the receiver housed two of three available Demodulators (FM, PM and BPSK), either one of which could be selected by operator or remote control. The ability to remotely control and select up to ten configurations was a major feature of this receiver, particularly for satellite tracking. Today, twenty years after product introduction NASA uses the Model 930 in several remote sensing satellite ground stations around the world.

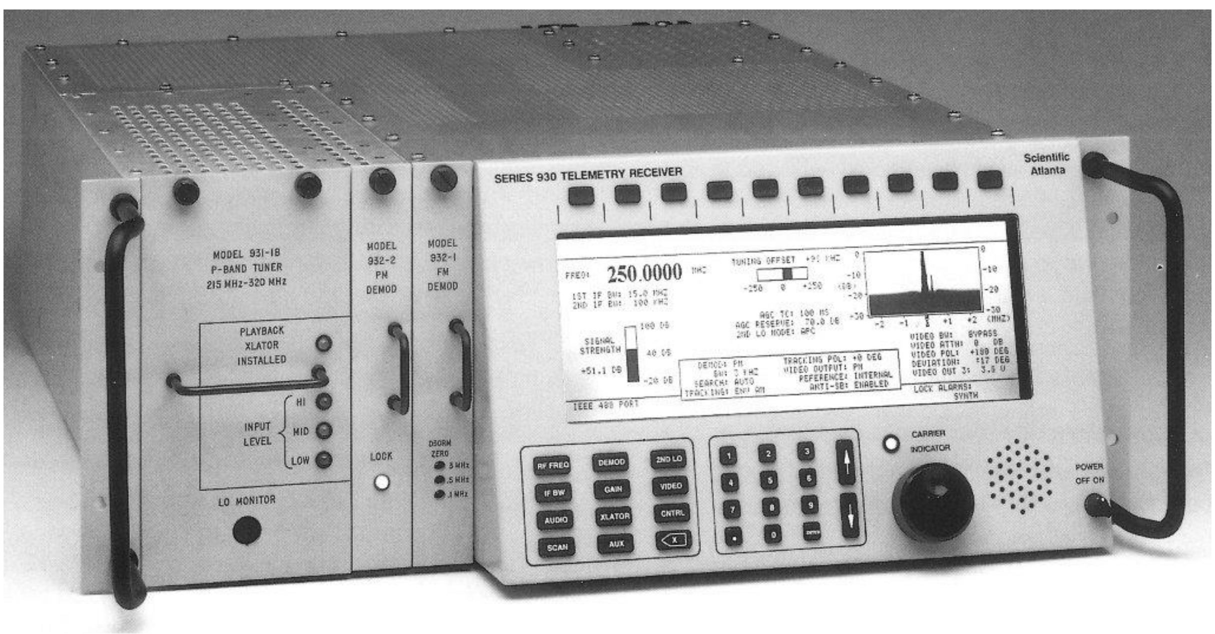

Figure 5. Series 930 Telemetry Receiver

E-Scan Autotracking

The E-Scan autotracking technique was patented by ViaSat in 1991 as an alternative to single-channel monopulse at L to S-bands. In addition to saving the cost of a monopulse comparator, the E-scan technique provided better side lobe performance while maintaining electronic scan capability beyond mechanical conscan rates. The original layout of E-Scan was a five-element array in a square pattern as diagrammed in figure 6a. For each of four tracking scan states (El 0°, Az 0°, El 180°, Az 180°) the E-Scan switching network combined two corner elements with the center, and the result was tracking AM superimposed on the sum signal similar to single-channel monopulse. But there were lessons to be learned in applying this to range telemetry! Typical requirements for telemetry antennas specify simultaneous Right-hand and Left-hand Circular reception, however the missile and aircraft antennas are quite often linear or have poor axial ratio. The use of two tracking elements at a time required very good amplitude and phase balance in order to track these polarization mismatched signals without excessive cross-talk and error gradient variance. As a result, the layout was rotated 45° and the network changed to combine a single element with the sum, a "diamond" arrangement as shown in figure 6b. Except in rare instances, all L through S-band tracking feeds produced today by ViaSat utilize the patented E-Scan architecture, regardless of aperture.

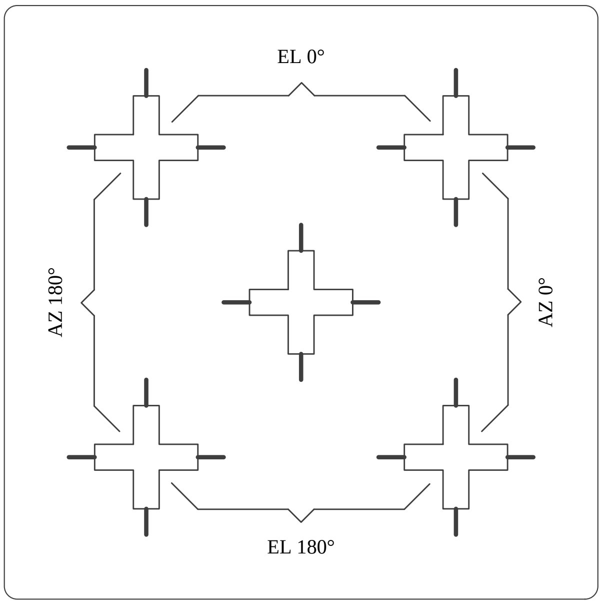

Figure 6a. Square E-Scan Array

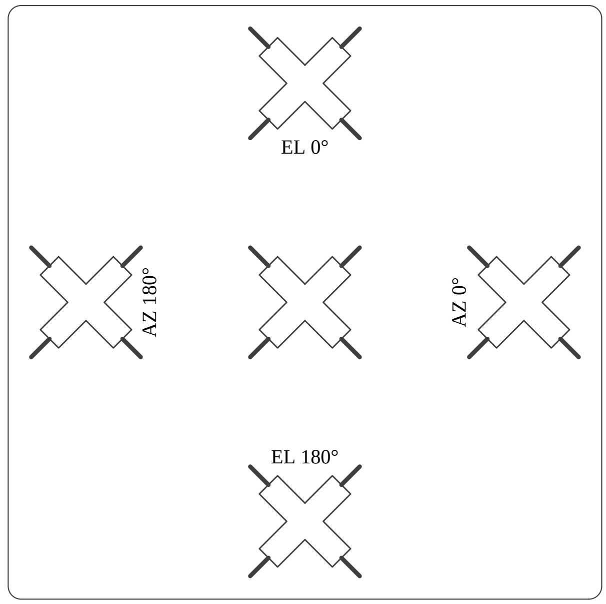

Figure 6b. Diamond E-Scan Array

PRESENT

Looking over the past few years to the present, ViaSat has continued to supply new assets, refurbishment and upgrade services to various ranges both domestic and foreign. In 2002 ViaSat successfully bid the antenna systems portion of the Space Lift Range Systems Contract (SLRSC). Three 13.5m and four 6.1m L to S-band telemetry autotrack antennas, along with ten 4.3m vehicle uplink (command destruct) slave track antennas were delivered to the Eastern and Western Launch Ranges. These antennas utilized what then was ViaSat's latest antenna control unit, the Model 3880, along with three of the latest Elevation-over Azimuth Pedestals: the 3416, 3418 and 3450. The 3450, as shown in figure 7, was designed to swing the 13.5m reflector at up to 20 °/s with 20°/s^2 acceleration and delivering 170,000 ft-lbs of peak torque. Another interesting aspect of the SLRSC program was the tracking feed design: in order to meet requirements of specifications and desires of range personnel, both feeds were conical scan utilizing brushless motor technology and speed control up to 60 Hz.

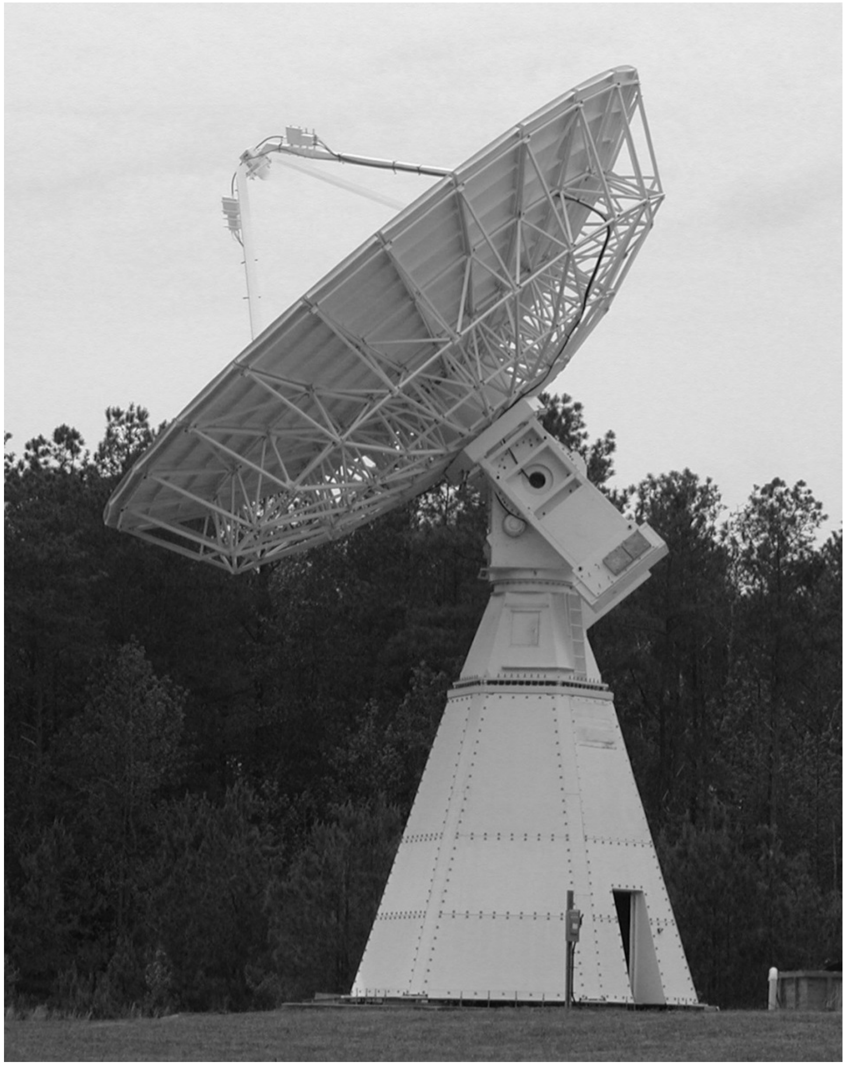

Figure 7. Model 3450 Elevation-over-Azimuth Pedestal

During the 2003 to 2009 time frame, ViaSat furnished six trailer transportable 7.3m L-to-S band tracking systems to White Sands Missile Range. Four of these systems incorporated a third pedestal axis (roll) and inertial navigation system for shipboard applications. Figure 8 is a photograph of one shipboard system staged for operation with a second system ready for transport. In addition, ViaSat upgraded five 8 ft and two 24 ft tracking antennas and in 2011 delivered two new 8 ft L to S band tracking antennas to WSMR. Also in 2003, ViaSat participated in a U.S. Air Force study contract “to examine feasibility of migrating L-/S-band and S-band Range Telemetry Tracking antennas to higher frequency bands” (quoted from an official press release). As a result of this study and others, Telemetry Ranges today are moving toward C-band for increased bandwidth and separation from older bands crowded by commercial traffic. Currently ViaSat is upgrading one each of WSMR’s 7.3m and 8 ft antennas to add simultaneous C-band operation. The new high-performance, patent pending feed for the larger aperture was described in a 2012 ITC paper titled *“High Speed Target C-band Feed Upgrade for Autotracking High Dynamic Targets”* by Mr. Ray Lewis.


Figure 8. Transportable 7.3m Antenna with El-Az-Roll 3420 Pedestal

FUTURE

The Telemetry community is experiencing new technologies, such as cellar and wireless routing that someday may supplant classic "tracking antennas" for telemetry reception. But the winds of change blow slowly across Ranges, as mission costs rise and the need to keep targets, assets and access within controlled boundaries remains a constant concern. ViaSat believes strongly in the future of supplying new tracking antenna systems as well as upgrading and refurbishing existing assets. We are embracing the change to C-band, much like the move to L and S-bands during CORTS, by designing tracking feeds to retrofit into new or existing reflectors, and provide simultaneous operation with current frequency bands. In addition to present pedestal offerings for 4.5 through 13.5m antennas, ViaSat has renewed efforts to supply cost effective systems in 8 to 12 ft diameters with innovative techniques such as a digital tracking receivers within the pedestal. And finally, ViaSat continually pursues improvements to our antenna control products, so their performance will be equal or superior to any controls for Telemetry Range applications. We believe the legacy will continue!