Estimating Airborne SATCOM COTM Ka-band Antenna Tracking Loss

Robert Fitting – Bit2Signal Communications Engineering

Introduction

Airborne applications utilizing wideband SATCOM the antenna system must compensate for platform motion and turbulence in order to stay properly aligned with the satellite. Deviation from the ideal pointing vector results in a lower antenna gain, and therefore reduced EIRP in the direction of the satellite. For link analysis, an allocation for the pointing loss is required. The following provides a basis for allocation of pointing loss during stable flight for an airborne terminal. Ka-band airborne antenna systems are incorporated in both commercial applications and in military manned and Unmanned Aerial Vehicles (UAV's).

To achieve the desired data rates, an aircraft terminal requires an antenna system that maintains alignment with the satellite during platform movement, this class of antenna is often referred to as a COTM (Communications on the Move) antenna. There are numerous antenna technologies available today for COTM applications, and although each antenna technology has its particular benefits, in order to reliably close the satellite link, they all require pointing algorithms often referred to as satellite tracking. Since the beam width of the antenna is narrow in order to provide good gain, the pointing accuracy of the COTM antenna becomes an important contributor the link and effects the data rate which can be reliably achieved. The accuracy of COTM antenna's pointing vector is dependent on several factors and can vary dependent on antenna control accuracy, platform motion, and antenna size. This paper evaluates transmit pointing loss for several sizes of gimbaled dish antenna operating in the Ka-band and produces pointing loss estimates to for incorporating in link analysis.

Background

A COTM antenna system derives an ideal pointing vector and attempts to compensate for disturbances due to platform motion using an arrangement of gyros, accelerometers, motors, resolvers, and gimbals enclosed in a servo control loop.

COTM antenna systems typically employ either of two approaches to maintaining correct alignment with the satellite:

Open Loop Tracking -

Open loop tracking mode generates the antennas pointing vector based on platform position information from an Inertial Navigation System (INS) and satellite position information based on the satellites known orbital position. The antenna's gimbal position control loops are closed around the gimbal resolvers. A position command generator uses the satellite coordinates, vehicle GPS location, and Inertial Navigation Unit (IRU) attitude information to calculate accurate gimbal position commands. The accuracy and timeliness of the INS data and effectiveness of antenna calibration techniques are direct drivers of pointing accuracy. In addition the INS should be mounted in close proximity to the antenna system to reduce error created by structural deformation.

Closed Loop Tracking -
With Closed Loop Tracking mode, the antenna system monitors a signal from the satellite, using either a satellite beacon or the desired signal. The antenna system performs a dither routine to determine the optimum pointing vector and the antenna's gimbal position control loops are closed around the antenna's tracking receiver.

The dither approach employed typically uses a conical scan or step scan pattern, the antenna system measures the received signal level as the pointing vector is varied over the pattern - the maximum signal level detected indicates the optimum position.

Closed loop tracking mode has a disadvantage in that it requires introducing a deliberate pointing error. In addition, for cases where the platform motion is more extreme, the scan must be performed using more rapid mechanical motion, this increases complexity and reduces accuracy.

It is also important to note that closed loop tracking requires an open loop method to initially acquire the satellite.

Analysis

Antenna Error Sources

The pointing accuracy of a satellite tracking antenna has several sources of error which must be reduced or compensated for in order to achieve accurate tracking. These errors include:

Platform Errors - This source of error is based on accuracy of the accelerometers, gyros, resolvers, encoders, and mechanical influences such as friction and balance as well as control loop response to disturbances and changes in platform attitude.

Pointing Vector Errors –These errors are based on the quality and staleness of the estimated platform position and estimated satellite position.

The pointing error is typically evaluated in degrees.
The amount of pointing loss (dB) associated with pointing error (degrees) is dependent on the dish size. Since larger dishes have a narrower beam, they exhibit a greater loss when mispointed, see Figure 1.

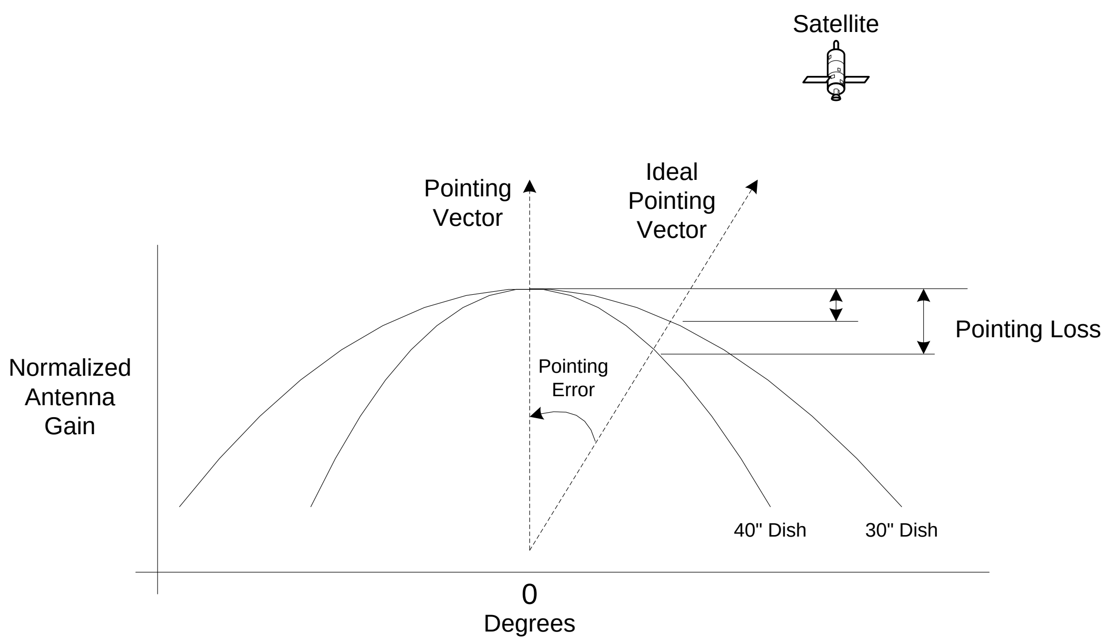

Figure 1. Normalized antenna gain for two dish sizes, pointing loss increases with larger dish due to narrower beam

Beam width vs. dish size is shown in Figure 2, the increased sensitivity to pointing error is further detailed in Figure3.

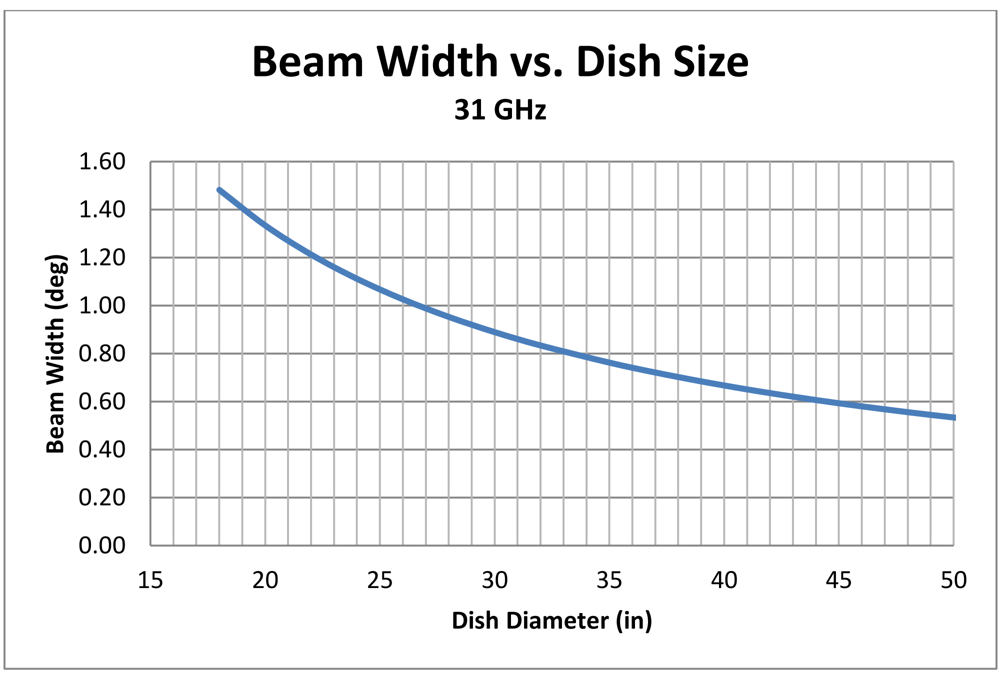

Figure 2. Half Power Beam width vs. Dish size, 31 Ghz.

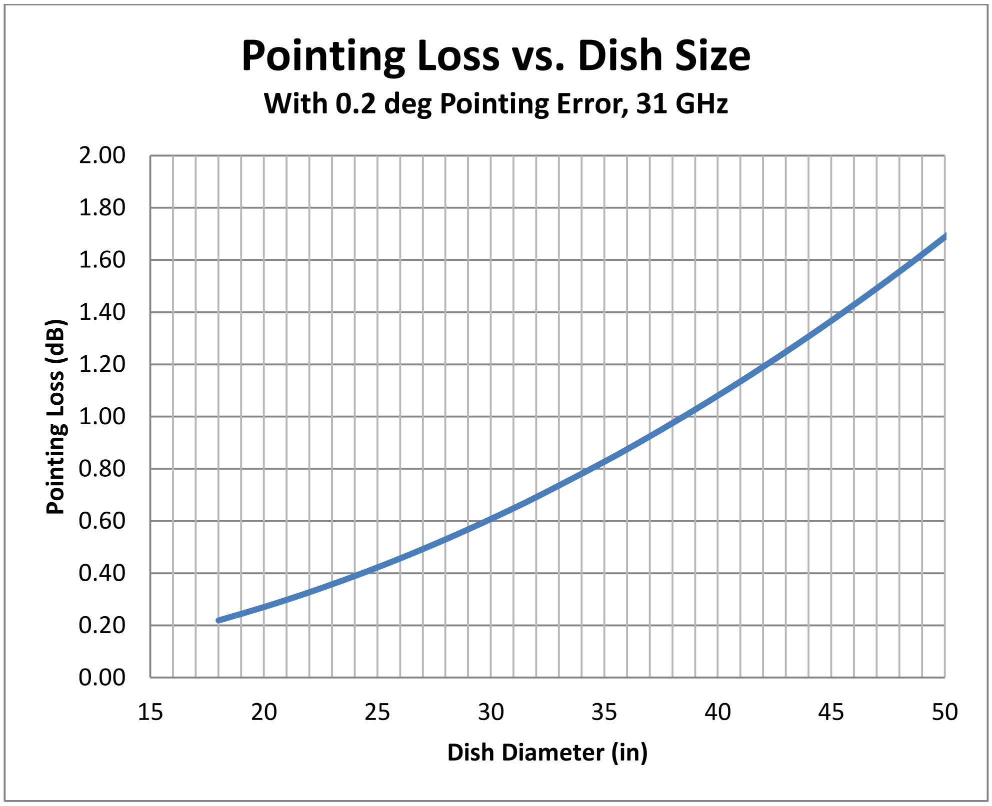

Figure 3. Pointing loss vs. Dish size for a 0.2 degree pointing error, 31 GHz

Figure 4 plots antenna gain in the direction of the satellite vs. pointing error for several size dishes. As pointing error increases, the gain advantage of a larger antenna is reduced and potentially nullified. For example, the gain advantage of a 40” over a 30” dish is nullified for a pointing error of 0.47 degrees. The gain advantage of a 50” dish over a 40” dish is nullified for a pointing error of 0.35 degrees.

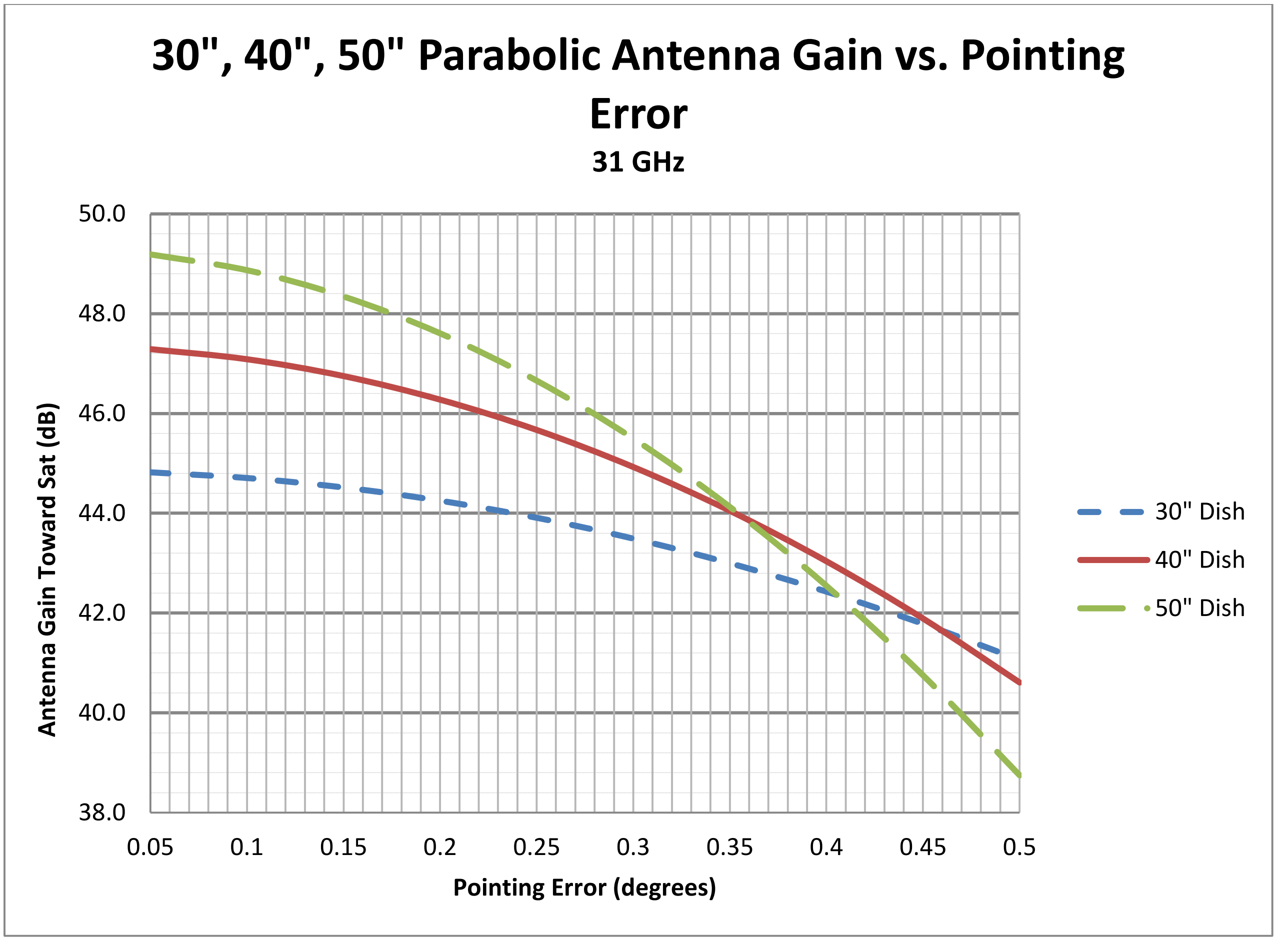

Figure 4. Antenna Gain in the direction of the Satellite vs. pointing error for 30",40",50" diameter dishes, 31 GHz.

Additional considerations for link allocation

As a reference, the following earth terminal requirements for FCC blanket licenses and MIL-STD-188-164 terminals indicate that an expectation of 0.2 degrees pointing error has been previously been accepted.

MIL-STD-188-164A, Interoperability of SHF Satellite Communications Earth Terminals, states:

"5.1.2.4 EIRP stability and accuracy. For any setting of the transmit gain and a constant IF input level, the EIRP in the direction of the satellite shall not vary more than +1.0 dB or -1.5-dB in any 24-hour period. This tolerance, added on a root-sum-square (RSS) basis, includes all ET factors contributing to the EIRP variation, including output power level instability and power variations in the direction of the satellite caused by tracking errors referenced to boresight."

FCC CFAR 25.222 Blanket Licensing provisions for Earth Stations on Vessels (Ku Band) states:

"Each ESV transmitter shall maintain a pointing error of less than or equal to 0.2° between the orbital location of the target satellite and the axis of the main lobe of the ESV antenna, or (B) Each ESV transmitter shall declare a maximum antenna pointing error that may be greater than 0.2° provided that the ESV does not exceed the off-axis EIRP spectral-density limits in paragraph (a)(1)(i) of this section, taking into account the antenna pointing error" and *"must provide a certification from the equipment manufacturer stating that the antenna tracking system will maintain a pointing error of less than or equal to 0.2 between the orbital location of the target satellite and the axis of the main lobe of the ESV antenna and that the antenna tracking system is capable of ceasing emissions within 100 milliseconds if the angle between the orbit allocation of the target satellite and the axis of the main lobe of the ESV antenna exceeds 0.5°."*

Also, according to a major manufacturer of COTM antennas, their airborne and Vehicle Mounted Earth Station (VMES) antenna systems, ranging in size from 17" to 30", exhibit ≤ 0.2 degrees (< 1dB), RSS, pointing error, 99% of the time when tested on the Churchill B course. Churchill is an off-road course using a set of defined terrain features used for VMES characterization (other road courses include Perryman A, Perryman I-IV, and Belgian Block). The road course is a more rigorous test than stable flight at high altitude. The manufacturer reports that they expect higher availability for airborne applications.

Conclusions

Summarizing, for an expected pointing error between 0.2 to .256 degrees
Expectations for pointing loss is shown in Table 1.

Dish Size (in)	Beam Width (deg)	Parbolic Ant Gain (dB)	Pointing Loss (dB)	
			0.256 degrees Error	0.2 degrees Error
30	0.89	44.9	1.0	0.6
40	0.67	47.4	1.8	1.1
50	0.53	49.3	2.8	1.7

Table 1. Pointing Loss at 31 GHz for 30", 40", 50" dishes with 0.256 and 0.2 degrees pointing error