UNIVERSAL TYPE APPROVALS FOR Ka-BAND GROUND EQUIPMENT

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Abstract

Ka-band offers the promise of very low-cost broadband terminals deployed in quantities an order of magnitude greater than the total number of all the two-way C- and Ku-band terminals installed since the birth of satellite communications. For small terminals, installation and commissioning costs can easily overwhelm equipment cost unless the terminal is pre-qualified for interference-limiting performance without on-site testing. The satellite industry has addressed this issue for C- and Ku-band with mutually-recognized type approval procedures, but operation at 20 and 30 GHz gives rise to special considerations in equipment design, qualification, and testing. Work is beginning to adapt existing type approval procedures for Ka-band and to review performance standards for discrepancies, with the ultimate goal of universal type approval procedures and standards recognized not only by satellite operators but also by government administrations.

1. Introduction

Satellite operators and government administrations have a duty to regulate the out-of-band, off-axis, and power characteristics of earth stations in order to protect other users from interference. Quantitative performance requirements flow down from the Radio Regulations, the satellite operator's coordination agreements with neighboring spacecraft, and the operator's transponder management policies. In the absence of an explicit or implicit type approval for a given model of ground equipment, satellite operators and administrations may require individual testing of earth station parameters, such as antenna patterns, frequency stability, G/T, and spurious signals. On-site testing of earth stations can add thousands of dollars to installed cost, as antenna mounts must be designed to allow motorized operation, field technicians must carry test equipment to the site, and test transponder time must be arranged -- often a time consuming process. On-site testing can easily exceed equipment cost, especially in consumer Ka-band applications in which field technician skill is limited and installations must be completed 'start-to-finish' within hours.

2. Satellite Operator Type Approvals

Satellite operators have effectively addressed this problem for C- and Ku-band by granting type approvals to manufacturers for specific antennas and electronics packages, obviating the need for field testing. (Under some circumstances, however, regulatory administrations separately mandate on-site testing.) For example, Intelsat® has maintained a well-documented procedure since the early 1990's[1]. An Intelsat type approval involves (i) complete range testing of several antennas randomly selected from a production batch, (ii) lab measurement of electronics such as LNA's, power amplifiers, and converters, (iii) design reviews, and (iv) production quality audits. While such Operator Type Approvals (OTAs) have helped enable the reduction in installed equipment cost observed over the past decade, each operator prefers specific test procedures, maintains different performance standards, and individually witnesses testing. Manufacturers face repeated execution of the type approval process for every satellite operator from whom approval is sought; this cost discourages manufacturers from seeking OTAs from more than a few major operators. On regional satellites with tight coverage zones, type-approved equipment is thus often not available. Satellites offering Ka-band services are likely to fall into this category, as beam footprints must be small in order to achieve acceptable availability.

3. GVF-MRA Process

Satellite operators and equipment manufacturers have now collaborated to enable the results of a single qualification campaign to be shared amongst multiple satellite operators for their consideration for issue of an OTA. The Global VSAT Forum "Mutual Recognition Arrangement" (MRA) procedure[2] defines three levels of equipment: antenna, earth station (antenna with RF electronics), and VSAT (including modem or IDU). The manufacturer nominates a Primary Operator, who selects an Authorized Test Entity (ATE). ATEs are elected by unanimous vote of the satellite-operator members of the GVF, and are empowered to witness all testing and to verify accuracy and completeness against the MRA procedure. The manufacturer submits a full design review package, and ultimately, a quantity of sample production units for testing. The ATE witnesses the full suite of tests, which include co- and cross-pol patterns, cross-pol discrimination, frequency stability, etc., and together with the Primary Operator, reviews the design review package and conducts factory quality audits. The resultant Data Package is then reviewed for compliance with the Primary Operator's own performance standards and an OTA is issued if appropriate. The manufacturer, however, retains rights to the Data Package, and may submit it to other ("Secondary") satellite operators for their consideration. While the pass/fail criteria may vary across satellite operators, no re-testing is required for evaluation of the equipment.

4. Regulatory Type Approvals

Some regulatory agencies, such as Anatel (Brazil), also mandate a type approval certificate or homologation; others, such as the U.S. FCC, rely on manufacturer representations unless an interference conflict arises.

5. Issues with Off-Satellite Measurements at Ka-Band

In the absence of a type approval, off-satellite measurements must be made after installation of the terminal. These techniques suffer from accuracy and practicality issues that are generally not significant at C- and Ku-band but have impact at Ka-band:

- Many GEO Ka-band spacecraft payloads will use on-board processing (OBP) and are not equipped with linear ("bent pipe") transponders, and if they are, the spacecraft payload may not be configurable to cross-patch uplink and downlink spot beams to the same region. Most likely, temporary Ka-band bent-pipe capacity is not available in nearby orbital slots either. In those cases, measurement of transmit antenna patterns is not possible. LEO orbits compound this problem.
- Scintillation is more pronounced at Ka-band and has temporal variations at rates faster than typical antenna pattern cut times (30-90 seconds); it appears as noise on the antenna pattern data.
- Similarly, atmospheric loss at Ka-band due to water vapor content can vary by several dB, making gain calibration difficult.
- When the rain and ice conditions along the signal path are such that 20 and 30 GHz depolarization is significant, accurate measurement of cross-pol discrimination and axial ratio is not possible.

To eliminate dependence on post-installation, off-satellite measurements, type approval is therefore particularly important at Ka-band

6. Antenna Range Measurements at Ka-Band

Type approval relies on accurate antenna range measurements. At Ka-band, several issues arise:

- **Wet antenna effect.** Liquid water on the main reflector, and even more critical, the feed window, is a major source of loss at 20 and 30 GHz [3]. Much-needed water shedding and runoff performance requirements are beginning to appear in Ka-band system specifications, but standardized test methods have not yet been established.
- **Pointing accuracy and stability.** For Ka-band antennas, beamwidths are small: for example, a consumer 66 cm antenna with 70% efficiency has a 0.5-dB transmit pointing loss with only 0.2º pointing error, while a 2.4m-antenna allows only 0.05º pointing error for 0.5-dB pointing loss. Pointing loss directly detracts from link margin and increases off-axis interference to adjacent satellites, which may be coordinated at 2º spacing. Pointing is normally done on the receive beam, but as the transmit beam is narrower due to the higher frequency, the effect of pointing error is magnified. The ability to accurately align electrical boresight toward the satellite thus can be an important mechanical design issue. Parameters such as wind deflection, distortion due to radio equipment weight, adjustment resolution, and "push-off" (the beam angle shift due to tightening of fasteners after vernier alignment) must be defined and measured as part of the type approval process.
- **Axial ratio.** Many Ka-band satellites will use circular polarization (CP). Cross-pol discrimination ("XPD") for CP links is a function of the products of the axial ratio vectors of the antennas at each end of the link. To measure axial ratio, either an extremely low axial-ratio source antenna or elaborate calibration schemes[4] are required. As most Ku-band two-way and VSAT services use linear orthogonal polarization schemes, the base of experience for short-wavelength CP antenna measurement needs to be augmented to address Ka-band type approvals.
- **Beam squint.** Circular-polarized offset prime-focus antennas exhibit a main beam squint angle (i.e., difference between mechanical and electrical boresight angles) whose sign is a function of polarization sense. This problem can manifest as a pointing loss if, for example, the receive LHCP beam is used for pointing, but transmit is on RHCP. The test range pedestal must support accurate measurement of electrical boresight angle, independent of frequency band and polarization.

7. RF and IDU Equipment Measurements at Ka-Band

EIRP stability over time, frequency stability over time, spurious emissions, and off-axis emissions spectral density are critical RF and modem metrics for interference prevention. At Ka-band, block IF upconversion schemes are even more likely to be used than at C- and Ku-band, and satellites are likely to have higher receive sensitivities due to the small-footprint uplink spot beams. Uplink power control margin can increase the dynamic range requirements of the transmitter. Taken together, these factors place a strong emphasis on characterizing wideband transmit noise density and spurious signals during type approval. Stability margin in mm-wave solid-state amplifiers is difficult to measure but is crucial for prevention of uncontrolled transmissions, which can disable entire transponders. Defining requirements and test methods for stability margin that are meaningful across production volumes of millions of terminals is an important challenge in adapting type approval procedures for Ka-band. Evaluation of fade compensation schemes, such as uplink power control, must also be considered to ensure on- and off-axis emissions limits are met, not only for protection of other satellites but for any shared-band terrestrial services, as they are often not subject to the same magnitude of rain attenuation and are thus exposed to the Ka-band terminal in its maximum EIRP state.

8. Standards

Performance standards are issued by several classes of organizations: satellite operators, international standards bodies such as ITU and ETSI, and national regulatory administrations. Standards often mix requirements for interoperability with those for interference prevention. GVF type approval procedures, however, are primarily intended to address interference prevention, so the relevant portions of various standards must be extracted and appropriately interpreted for the level of equipment under consideration (i.e., antenna, earth station, or VSAT).

Two important genealogical branches of interference-prevention standards are the ITU Radio Regulations and the European R&TTE[5] directive, as Figure 1 illustrates in very simplified form. The ITU Radiocommunications Sector (ITU-R) develops recommendations and advises the member states on adoption of International Radio Regulations (RR). Each country then generates regulations that implement the intent of the Radio Regulations as well as other recommendations and considerations seen as important to that country. Separately, satellite operators use these same fundamental recommendations, as well as coordination agreements they may have with operators of nearby satellites and their own transponder management technical polices, to generate their own standards. In Europe, equipment must be CE-marked, and compliance with the R&TTE and other directives is now required. Various ETSI standards, depending on sub-band, antenna size, and application, quantify R&TTE compliance by defining off-axis spectral density, and other performance parameters[6].

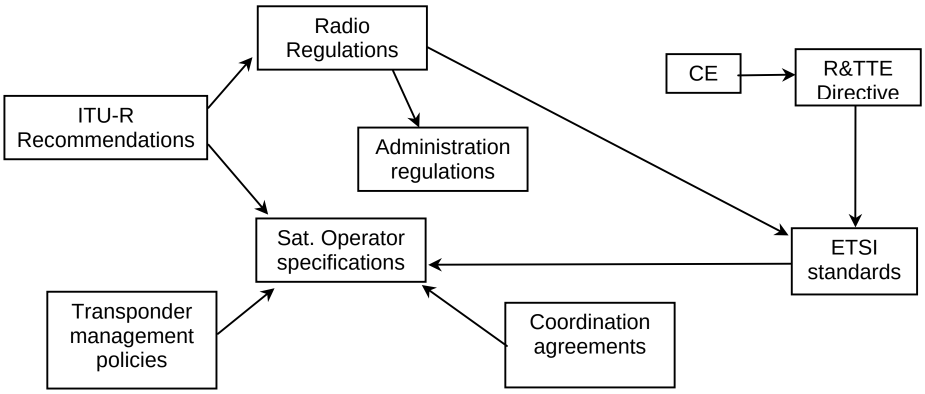

Figure 1 Families of Interference Protection Standards

Differences in interpretation and regional preferences can lead to situations in which organizations having similar objectives can define standards with differences in important details. For example, in 47 C.F.R. § 25.209, the FCC limits antenna sidelobes in a different fashion than does Rec. ITU-R S.580 and its descendants such as Intelsat IESS-207. ITU-R S.524 and ITU-R S.580 use different curves for a function that is intended to be proportional to antenna pattern. FCC § 25.209 defines antenna patterns but § 25.138 defines off-axis spectral density – an overlapping requirement.

At Ka-band, however, the regulatory environment is new and there are, as yet, relatively few conflicting performance standards. There is an opportunity for the industry to endorse uniform standards to operators of new Ka-band satellite systems and to national administrations.

9. Design and Production Qualification

Many aspects of type approval evaluation are performed by analysis of the equipment design and the associated manufacturing system. For example, at Ka-band, antenna reflector accuracy must be held to approximately 0.25mm RMS. In the type approval design review, the manufacturer must show that the design, when produced according to documented procedures and tooling, consistently meets that objective. Foundation stability over the lifetime of the terminal must be evaluated and characterized. Deformation due to uneven solar loading or alternatives for placement of heavy radio equipment must be analyzed. For Ka-band type approvals, thorough design reviews and quality audits are particularly important.

10. Conclusions

Type approvals for interference prevention are necessary to the economic success of mass-market satellite broadband networks. Type approval is especially important at Ka-band due to the tight tolerances mandated by the small wavelength, off-satellite measurement challenges, and the prohibitive costs of on-site verification testing. At this early stage of Ka-band system deployment, there is an opportunity for the industry to help establish streamlined equipment approval processes and uniform standards by both Ka-band satellite operators and regulatory agencies.

11. Acknowledgments

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[1] SSOG-220. See www.intelsat.com. Intelsat is a registered trademark of Intelsat Ltd.

[2] GVF-101, Rev C. The Global VSAT Forum is an industry-wide association of satellite operators, equipment manufacturers, integrators, and service providers. See www.gvf.org.

[3] Acosta, R. “Special Effects: Antenna Wetting, Short Distance Diversity and Depolarization,” 6th Ka-Band Utilization Conference, Cleveland, Ohio, May 31 - June 2, 2000

[4] Stutzman, W.L. & W.P. Overstreet “Axial Ratio Measurements of Dual Circularly Polarized Antennas,” Microwave Journal, October 1981.

[5] Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity (R&TTE Directive).

[6] Depending on antenna size, sub-band, and operating mode, ETSI standards such as TS 101 136, EN 301 459, and EN 301 360 may apply. See www.etsi.org.