User Equipment Antennas for Broadband NGSO Satellite Communications Systems

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Abstract **The demand for high speed information delivery direct to the home has led to proposal(s) to construct a constellation of Ka band satellites operating in nongeo-stationary orbit. This type of constellation can provide high elevation angle (>40 degrees) service to the user, low time delay and high spectrum efficiency, i.e. a large number of frequency reuses. The NGSO system, however, imposes the requirement that the User Equipment (UE) terminal must be capable of tracking the satellite and performing handover from one satellite to another. In addition, the UE terminal must have a low profile, preferably have no moving parts, have an aesthetically pleasing appearance and be affordable. In this presentation, the Ka band NGSO UE terminal design is addressed in the light of these requirements. The discussion focuses on the antenna portion of the terminal since the antenna is the critical element of the UE.**

I. INTRODUCTION

The demand for high speed information delivery direct to the home has heightened the interest in broadband communication systems. And it is expected that satellite communications will have role in satisfying this demand. Satellite communications systems have the capability of providing direct access to the home (and, of course, a business enterprise). The user simply installs a terminal capable of viewing the satellite(s).

In attempting to identify the type of satellite system best suited to provide this type of service, it is instructive to review some important considerations. First it is essential that the user be capable of viewing the satellite(s) at an elevation angle no less than a value of 40 degrees or so. This requirement is driven primarily by visibility conditions (i.e. local horizon, tress, buildings, etc.) but is also influenced by Ka band rain attenuation under operating conditions. The user terminal should be reasonably small, inconspicuous, easy to install and preferably have no moving parts (it must be reliable). And, of course, the terminal must be affordable. The system must be designed for high spectrum efficiency. This implies that the satellite system will cover the earth (or at least the inhabited portions of the earth) with spot beams with small footprint size allowing a large number of frequency reuses. Finally, the system should provide time delay commensurate with the protocols generally employed in broadband communications systems. A satellite system operating at geosynchronous altitude has difficulty meeting most of these requirements, particularly the high viewing angle, the small beam footprint size and the low time delay. But a constellation of satellites operating in nongeostationary orbits (NGSO) can be designed to accommodate all of these requirements and is, therefore, under serious consideration for broadband Ka band direct to the home application.

An NGSO satellite communication system imposes additional requirements on the user terminal design. It must provide a beam which can be continuously pointed at a moving satellite over a prescribed field-of-view (FOV). In addition, it must be capable of handling satellite to satellite handovers.

In the following the general requirements relevant to NGSO user equipment (UE) terminal design will be reviewed. Subsequently, the state of antenna design commensurate with these requirements will be discussed.

The UE is a critical component in the successful implementation of a NGSO satellite communications system. In view of this critical character a plan to assure the timely availability of suitable UE technology has been drafted and is presently being executed. An overview of the elements of that plan will be reviewed.

II. NGSO REQUIREMENTS ON THE UE TERMINAL ANTENNA

In the foregoing it was indicated that the minimum elevation for UE antenna operation should be 40 degrees or greater. This infers a field-of-view (FOV) requirement of +/- 50 degrees from the vertical. This value is, of course, constellation dependent and it will be assumed that whatever the specifics of the constellation are they will be consistent with this FOV. Furthermore, it will be assumed that the spacecraft payload will be designed to provide EIRP and G/T values consistent with the prescribed link availability and the following UE terminal performance levels. This assumption implies a “UE-centric” system design, a concept which is believed essential to NGSO business success.

An NGSO system will be designed to accommodate enterprise users, small home office users and residential users. The needs of the enterprise user, it is surmised, can be satisfied with relatively conventional technology. Mechanically steerable antennas (two are required to accommodate handover) can be employed, reliability issues can be addressed by redundancy and the design is not overly sensitive to aesthetic or cost considerations. On the other hand, terminal size, aesthetic, reliability (moving parts) and cost are major design issues for the small residential user application. Consequently, the present discussion will focus on that discussion.

In the Ka band link performance is strongly influenced by rain attenuation. Therefore the G/T is specified in the most severe rain environment for which the link must operate satisfactorily. Under this condition the residential terminal must have a minimum G/T of about 3 dB and an EIRP of about 33 dBW. These values obtain at the limits of the FOV. Sidelobe requirements are driven by intra-system and intersystem interference issues. The former is a function of constellation specific and the latter is driven by regulatory factors. In the absence of specific constraints pertaining to these factors, the sidelobe requirement imposed on terminals for the geostationary spacing for 2 degree satellite spacing, viz: 29-25log(theta). In this expression the logarithm is base 10, theta is in degrees and the sidelobe levels are given in dB relative to isotropic. Some "smoothing" is allowed and the envelope requirement obtains over the range staring at the first sidelobe and continuing out to the –10dBi (approximately) and is taken constant from that point on.

In the area of beam handover, 10ms has been allocated to accommodate this function. In general, this can not be satisfied with mechanically steered antennas. So these systems must employ multiple apertures to satisfy this requirement.

Small size, low profile, aesthetically pleasing appearance and ease of installation are important considerations for the residential terminal. In addition, mechanically steered antennas are considered less desirable for this application. In consideration of these requirements (and desirements) the planar electronically scanned antenna (ESA) emerges as a very attractive candidate. However, historically the planar ESA has been a high cost product. But some emerging new technologies show promise of breaking through this historic barrier and bring the ESA into the realm of affordability.

III. THE ELECTRONICALLY STEERED UE TERMINAL ANTENNA

Serious development of electronically scanned array antennas began in the early 1960's in the context of the ballistic missile defense system. These early designs incorporated diode based or ferrite based phasers, bipolar transister amplifiers and tube type power amplifiers. They frequently employed rigid or semi-rigid coaxial cable for power distribution/combination. The emergence of MMIC technology allowed for a high degree of integration and some significant cost reduction. Nealy all of these systems were based on the active aperture in which an amplifier is placed behind every radiating element. These systems offered high efficiency, graceful failure, rapid beam steering, multifunction capability (multiple beams, track while scan, etc.) but were generally too expensive to allow broad deployment. Extensive studies conducted over the past few years have suggested that cost reduction could be achieved perhaps to a level of less than $3 per element. Most of this cost reduction was achieved by drastically reducing the amount of touch labor, utilizing more automation in assembly and test and postulating the availability of larger GaAs wafers (6" or 8" wafers). But while the $3 per element represents significant improvement relative the historic levels it is still too high for deployment in commercial markets.

It is generally found that the cost per element is limited by the cost of the GaAs and that leads to the conclusion that, fully active arrays are not affordable (at least at the present and near future state of the art). And that leads finally to the passive array architecture in which amplification is done at the beam port level rather than the element level. Since the noise figure and radiated power levels for this architecture are influenced by the losses of the beamforming and steering hardware, the success of the passive array depends on reducing the losses of these networks to acceptable levels.

In the case of the beamformer – the power distribution or combining network – the space feed approach or the flat plate radial waveguide approach offer viable low loss designs. Both of these approaches are well known and represent well established technology. The space feed can be either a transmission type feed or a reflective type system. The latter is generally referred to as a reflectarray and is likely to be the preferred embodiment. The radial waveguide feed takes the form of a radial parallel plate structure fed at the center and fitted with radially disposed coupling holes which provide the RF connections to the phaser circuits and radiating elements.

It should be noted that, in general, the requirements for the residential terminal can be satisfied with a phase shift steered array. True time delay steering is not essential.

It also should be noted that while the previous discussion migrated directly from fully active to fully passive array architecture, there is a middle ground with which conceivably could yield affordable designs. The array could be sectioned into subarrays and amplification introduced at the subarray level.

In the realm of low loss phaser design, two emerging technologies show great promise. The first is the MEMS based RF switch technology. The second is ferroelectric material.

MEMS switches are micromachined devices having dimensions typically 10 or 20 microns. They can be employed in phaser networks in a manner identical to the PIN diode switch. Thus they can be used in loaded line type devices or in switched line type phasers. The advantage of the MEMS switch is that it is very low loss (0.1 dB has been demonstrated at 40 Ghz) and they promise to be very inexpensive.

Ferroelectric material is a ceramic composite with characteristic similar to, in a dual sense, to the ferroemagnetic material. The material is operated in the paraelectric region – well above the Curie temperature. The charactristic that makes the material so interesting is that it’s permittivity can be controlled by application of a voltage. It can be used in either waveguide or transmission line implementation. In a typical application a thin layer of ferroelectric material deposited on a substrate supports a transmission circuit. Modulation of the biasing voltage controls the wave velocity through the circuit and thus the resultant phase shift. These devices are expected to be low cost devices.

The present plan is to bring together both MEMS technology and ferroelectric technology with the low loss feed network architectures and demonstrate the characteristics of these antennas. Demonstration of the ability to produce these antennas at low cost is also a goal.

These antenna designs will, in general, be narrowband designs, i.e. transmit and receive functions will utilize separate, adjacent apertures. Typical element count per aperture is expected to be in the range of 400 to 1000 elements. LNAs with noise figure less than 2 dB will be employed. The power amplifier will typically sized in the 1 watt range (or thereabouts). Each antenna will generate a single beam. Beam steering to accomplish beam handoff can easily be accommodated in the 10ms allocated time.

IV. SUMMARY

The features of the NGSO broadband Ka band satellite system were reviewed and the associated requirements imposed on the UE terminal antenna identified. It was indicated that the characteristics of the electronically steered antenna represented a good match to the NGSO UE requirements provided that the associated affordability issue could be resolved. It was pointed out that MEMS based switches and ferroelectric material technology represented promising solutions to the affordability issue.

It should be added that there are other approaches to the affordable UE antenna design in addition to those presented herein. There are designs which employ unique architectures which show promise. There are also some novel mechanical configurations which may provide acceptable solutions. In this note the discussion has been limited to the dominant technologies compatible with conventional array antenna architectures.

In view of the critical role that UE antenna technology plays in the successful deployment and subsequent business success of a NGSO system, a plan has been drafted with the goals of retiring the risks associated with the design and production of the UE antennas. That plan is in its early stages of execution. Multiple contracts have been written focussing on alternative approaches. As efforts progress it is expected that the number of viable technologies will be reduced to two or three. The major risk elements associated with these technologies should be retired in an approximate two year time frame. Prototyping and pilot production will follow the risk reduction phases.

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