

## 論文の内容の要旨

### Thesis Summary

論文題目      Study on Waveguide Feeder Network of Slot-Array Antenna  
for X-band Synthetic Aperture Radar Compatible with Small Satellite  
(小型衛星に搭載できる X-band 合成開口レーダ用スロットアレー  
アンテナのための導波管給電ネットワークの研究)

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This dissertation consists of three parts: It primarily studies the concept of a new waveguide feeding technique for wideband application of an X-band deployable rectangular parallel-plate slot-array antenna panel network with vertical polarization for a synthetic aperture radar on-board a 100 kg class micro-satellite (MicroX-SAR Mission). Secondly, it studies the performance of an egg-choke flange designed for wideband applications in X-band considering linear and rotational misalignment during space-borne operation. Lastly, it studies the development an accurate and efficient antenna pattern computation tool for practical planar arrays and reflectors combining Geometrical Optics and Fast Fourier Transforms for the purpose of end-to-end simulations for SAR mission design. The first two parts were done in Institute of Space and Astronautical Sciences, Japan Aerospace Exploration Agency and the last part was done in the German Aerospace Center (DLR) Microwaves and Radar Institute.

Synthetic Aperture Radar (SAR) is a remote sensing device which can operate irrespective of illumination and weather conditions, unlike conventional optical sensors used in most satellites. In recent times with an ever-increasing threat of global climate change, there has been increasing work in the research and development of low-cost light-weight space-borne SAR systems for applications such as monitoring natural disasters like tsunamis, typhoons, landslides, and volcanic eruptions especially in disaster-prone countries in the East and South-East Asia like Japan, Indonesia and the Philippines. For JAXA's MicroX-SAR mission, it is proposed to mount a SAR sensor on-board a 100 kg class small satellite for operation in X-band. Due to its simple structure and light weight, slot-array antenna is a good candidate for our mission. In order to achieve 1-meter resolution at a nadir offset angle of 30 degrees, it is necessary to achieve operating frequency bandwidth of 300 MHz. However, it is a known fact that a travelling wave antenna is prone to pattern distortion due to frequency-dependent beam

tilting effects. This distortion is not negligible for frequency bandwidths greater than 250 MHz.

Thus, for the MicroX-SAR mission, it is proposed to synthesize a wide-beam antenna to nullify this beam-shift and also suppress reflection. Hence centralized corporate-feeding with multilayer waveguides is proposed. A power divider waveguide structure called the  $\tau$ -junction is selected for implementing corporate in-phase feeding. However, due to in-phase reflection accumulation from each coupling slot, reflection power loss becomes high and the total reflection profile of the original  $\tau$ -junction degrades significantly when assembled with the coupling slots. Thus,  $\tau$ -junction is modified by adding a pair of inductive walls resulting in double resonance and suppressing the reflection level. Initially, for the Bread Board Model of MicroX-SAR antenna, the edge-feed antenna system is proposed. Although the edge-feed system is successful in enhancing the bandwidth, it requires two non-identical feeding waveguides for each antenna panel leading to structural complexity and difficulty in ensuring the mandatory condition of in-phase excitation by default. Hence, the center-feeding waveguide system is proposed which requires only one feeder per antenna panel and automatically achieves 180 degrees phase shift necessary for ensuring in-phase excitation, thereby overcoming the limitations of the previously proposed edge-feed system. At the same time, since it uses the modified  $\tau$ -junction, it can achieve wideband capabilities like the edge-feed system. Furthermore, since only one feeder is needed per antenna panel, it reduces the weight of the SAR system, which is beneficial for small satellites. First, the antenna design procedure in high-frequency structure simulator (HFSS) followed by its fabrication and measurement results are explained. Simulations and antenna array measurement results confirmed that the corporate feeding technique achieved wide-beam antenna gain 40.8 dBi with 75% aperture efficiency and 90% arraying efficiency within permissible reflection limit in 300 MHz bandwidth, thereby ensuring wideband operation.

A choke flange is widely used to avoid degradation of current conduction through a waveguide flange contact due to manufacturing imperfections or oxidization of the flange surfaces. It has a wide range of applications, one of them being in space-borne radars. The motivation behind this choke-flange design is its application in MicroX-SAR mission. The satellite bus comprises of seven antenna panels, each of which are fed from below by rectangular waveguides. Thus, it is desired to have contactless waveguide joints for connecting the waveguide feeders of two adjacent antenna panels; hence choke-flange is the ideal type of such a waveguide joint to serve this purpose. In the deployable hinge, power is transmitted between two non-contact waveguide flanges, where one is a choke-flange, and the other is a flat cover-flange. Since two adjacent waveguide feeders will be connected using metallic screws, it is difficult to ensure perfect metallic contact. Additionally, due to the possibility of thermal expansion in space, it is necessary to leave a nominal gap of about 0.5 mm to 1 mm between the

choke-flange and flat-flange. Furthermore, since there are 6 degrees of freedom, there is always the possibility of both linear and rotational misalignment during practical operation. It is critically important that with the choke-flange, the transmission loss is very low (less than 0.3 dB) taking into account a nominal gap and possible linear and rotational misalignments in the desired bandwidth of 9.5 GHz to 9.8 GHz.

The design methodology, eigen-mode analysis and measurement results of our specially designed egg-choke flange are explained. Although the initial purpose of its design was its application in 300 MHz bandwidth relevant to the MicroX-SAR project, due to careful intuitive design considerations, the fabricated egg-choke has a much wider operational bandwidth greater than 2.5 GHz with less than 0.1 dB transmission loss, thereby making it robust, unique and useful for several other wide-band applications in X-band.

A lot of attention is being paid to antenna performance for SAR Mission design, performance evaluation and end-to-end simulations. Practical points of interest are thermos-elastic surface distortions of the antenna surface, iterating on the antenna size, defocusing of antenna patterns and gain losses. Although there are a handful of reliable commercial software for accurate estimation of antenna patterns like Ansys HFSS and GRASP, unfortunately, as the antenna size increases the time taken by them to compute antenna patterns is very long, sometimes even days which make them inefficient for use for efficient performance evaluation from a SAR processing perspective. Moreover, it is not easy to take into account the effect of any irregular surface distortions on the antenna surface, which is a further bottleneck for efficient performance estimation, SAR processing and quick-fire end-to-end simulations. There are several papers in literature where attempts have been made for very fast antenna pattern estimation using Fast Fourier Transforms (FFTs) both planar arrays and reflectors, however the results are far from accurate especially in case of the latter while in the former case, FFT-based computations have been done only for uniformly spaced arrays without any surface deformations.

An FFT-based highly accurate general antenna computation tool is proposed for planar arrays with surface distortions and reflectors. For the latter, the methods of Geometrical Optics with FFT are combined for fast and accurate estimation of reflector antenna patterns for different locations of the feed array (off-set and non-offset). A novel beam-center method is proposed which is highly accurate, unlike the methods available in literature. To validate the methodology, for reflectors, a case study is done for Tandem-L antenna and the co-polarization and cross-polarization patterns are computed and compared with the simulation results obtained from GRASP software. For planar arrays, a case study is done for MicroX-SAR antenna and computed antenna patterns are compared with HFSS software simulations and hardware measurement results. Furthermore, the effect of thermos-elastic surface deformations on

MicroX-SAR antenna pattern are analyzed using the Python-based Pattern Tool. Comparisons showed that the pattern tool is highly accurate within 0.1 dB and efficient with the computation time being only a few seconds compared to several hours for GRASP and HFSS.

This dissertation work contributed to the successful realization of the Engineering Model antenna panel network for MicroX-SAR Mission. It is hoped and expected that it will lead to the realization of the Flight Model antenna panels and contribute to successful completion of JAXA's MicroX-SAR Mission. It is also hoped that this dissertation encourages future research collaborations between JAXA and DLR.

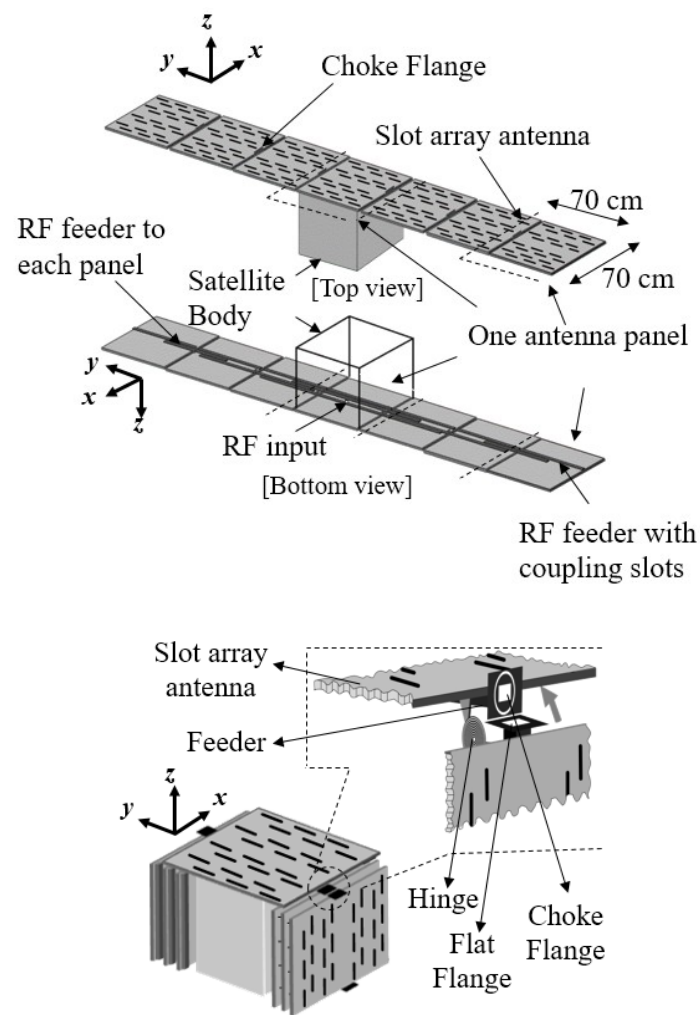


Fig.1. MicroX-SAR Antenna Panel in Deployed Condition (above) and Stowed Condition (below) with Choke-flange