Mikhail MOISEEV[1], Vitaliy AVDONIN[1], Andrey NELIN[1], Larisa RAGULINA[2], Mikhail RYZHAKOV[2]

Joint Stock Company «Russian Space Systems» (1)., Moscow Institute of Physics and Technology (2), Russia

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Ka-band Antennas Simulation for LTCC Antenna-on-Chip Solution

***Abstract**. Different Ka-band antenna designs optimized for LTCC technology were studied. With the help of finite element method spiral, patch and horn antennas were simulated. Calculated VSWR, radiation pattern cross section and axial ratio for described designs are presented. It was shown that the most suitable LTCC design for antenna array in Ka-band is horn antenna.*

***Streszczenie.** Analizowano różne anteny dla pasma K I technologii LTCC. Stosując metodę elementów skończonych analizowano trzy różne kształty anteny. Stwierdzono że najlepsze parametry ma antena ftpu horm (róg). (**Badania różnych kształtów anteny na pasmo K w technologii LTCC**)*

Keywords: spiral antenna, patch antenna, horn antenna, LTCC.
Słowa kluczowe: antena, pasmo K, technologia LTCC.

Introduction

While the current swift evolution of space systems leads to a significant increase in a number of spacecraft and volume of data transmitted via communication channels, capacities of the L-, S-, C- and X-bands are significantly limited as in most cases they are occupied by existing systems. In this regard, developers of advanced space communication systems face the challenge of mastering K- and Ka-bands for inter satellite and satellite-to-ground communications.

The following problems occur when building communication channels in K and Ka-bands:

- smaller distance between the antenna elements in phased arrays;
- expanded requirements to manufacturing accuracy;
- increased losses in transmission lines.

To reduce the effects of these negative factors, it is necessary to use high-density mounting technologies. LTCC (Low Temperature Cofired Ceramics) technology [1] ensures high-density mounting owing to its satisfactory electrical characteristics up to 110 GHz and sufficient number of layers. Moreover, due to LTCC higher thermal conductivity compared to RF laminates-based boards, the necessary thermal conditions for densely mounted electronic components are satisfied. Some papers are dedicated to investigation of Antenna-on-Chip (AoC) and Antenna-in-Package (AiP) integration feasibility using LTCC technology [2-7].

The integration of antenna with input/output stage of T/R-module (T/R stands for Transmitter/Receiver) significantly reduces phase distortion and signal loss in cable path and connectors. This T/R-module architecture enables to apply new structural types of radiating elements in phased arrays.

In this work several types of LTCC radiating elements (spiral, patch and horn antennas) confirmed by their simulation results are discussed. All simulations were made using finite element method. For ceramic substrate parameters data for Ferro A6M was used (ε = 5.9, tan(δ) = 0.002). Antenna dimensions were derived from defined wavelength (Ka-band).

Spiral antenna

The equiangular spiral antennas are frequency independent and known to have wide axial ratio bandwidth [8]. For simulation two-arm log-spiral antenna was used (Fig. 1).

The radiating elements of this antenna are the two spiraled conductors, connected to a feeder in the center of antenna. The radiation of such antennas is circularly polarized [8].

Substrate's height of simulated design was 2.3 mm and its diameter - 6.5 mm. The antenna simulation results are shown in Fig. 2 and Fig. 3. VSWR was calculated for 180 Ohm transmission line.

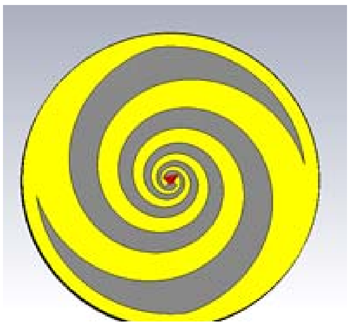

Fig.1. Two-arm spiral antenna

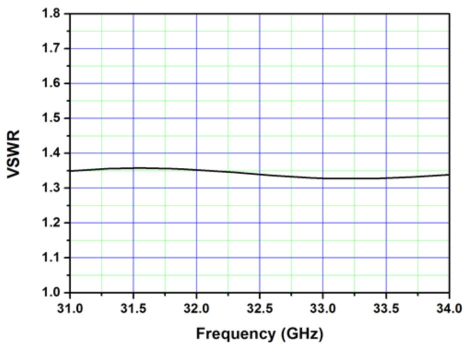

Fig. 2. VSWR of the two-arm spiral antenna (with respect to 180 Ohm transmission line)

As can be seen from Fig. 2 VSWR for spiral antenna is around 1.35 in the entire frequency band. Half power beamwidth (HPBW) is about 50° (see Fig. 3, solid curve and left axis), and axial ratio is less than 1 dB in the HPBW region (Fig. 3, dashed curve and right axis).

The main disadvantage of this antenna type is that its input impedance according to the Mushiake relationship for the simplest self-complementary planar antenna with two terminals is 188 Ohm, which requires a matching device for 50 Ohm transmission line. At the frequency band studied the matching devices will be smaller than the technological limit of LTCC technology and thus such matching device must be external [9]. This circuit structure significantly reduces antenna manufacturability.

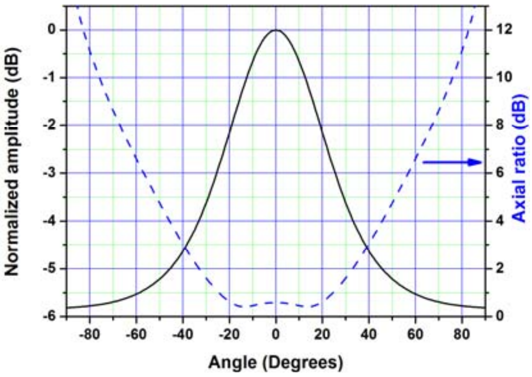

Fig. 3. Spiral antenna radiation pattern cross section and axial ratio

Patch antenna

The patch antennas are the simplest type of antennas and can be easily implemented using LTCC technology. Patch antenna consists of a metallic patch printed on top of a thin dielectric substrate with a ground plane on the bottom of the substrate. The usage of dielectric with higher permittivity reduces the overall dimensions of antenna and ensures satisfactory structural characteristics.

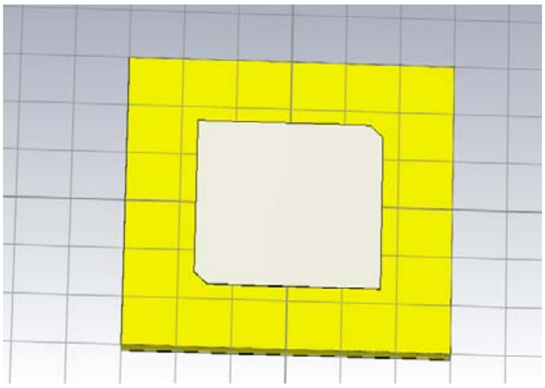

Fig. 4. Patch antenna

Fig. 4 shows the simulated 32.3-33 GHz patch antenna with 1.705 x 1.705 mm metal foil (white square) over the 3 x 3 mm dielectric substrate (Ferro A6M). The thickness of dielectric substrate was 0.013 mm. To feed antenna the probe feed with coaxial transmission line below the ground plane was used. Antenna feed point was selected to match 50 Ohm transmission line. Also to produce circular polarized radiation the corners of the square patch were trimmed as shown in the Fig. 4.

The simulated parameters of the patch antenna are shown in Fig. 5 and 6.

The VSWR of the simulated patch antenna is within the 1.25 – 2 range for the frequency band studied (see Fig. 5). The simulated patch antenna has wide HPBW of 100° (Fig.6 solid curve and left axis) and axial ratio of 2 dB in HPBW region (Fig.6 dashed curve and right axis).

Because the patch antennas belong to resonant type their main disadvantage is narrow bandwidth (generally fractional bandwidth ranges from 1 to 3%). For simulated patch antenna if we take VSWR value of 1.3 for bandwidth estimation which corresponds to about 2% loss of radiation power, we get 1 GHz bandwidth (3% of carrier frequency). This issue can be overcome to some extent by using stacked patch antennas [10] which have several resonant frequencies and thus, wider operating bandwidth. For example three patch antenna arrays for operation at 28 GHz were developed in [11]. Its fractional bandwidth was reported to be about 10%. But for wide bandwidth applications other types of antennas should be used. Also manufacturing accuracy of 1 μm is required to ensure precise frequency tuning and proper axial ratio, while LTCC technology has 5-10 μm accuracy. Therefore, the additional antenna tuning is required after fabrication.

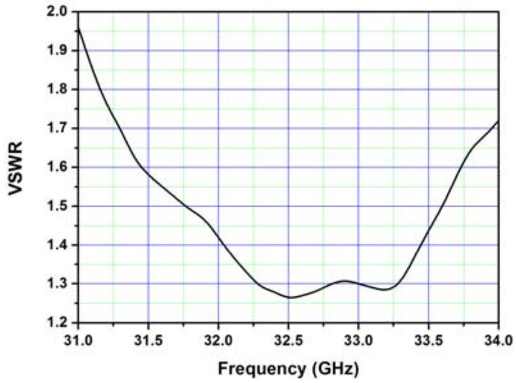

Fig. 5. VSWR of the patch antenna

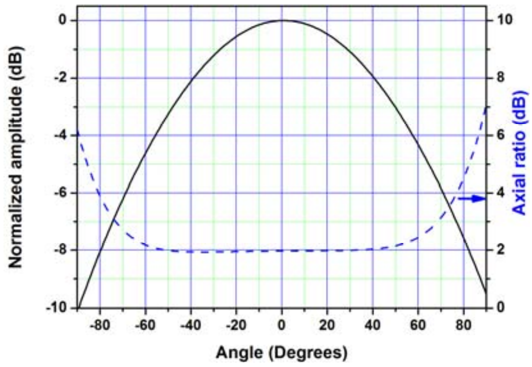

Fig. 6. Patch antenna radiation pattern cross section and axial ratio

Horn antenna

Horn antennas are quite popular antennas in the microwave region. Horns provide high gain, low VSWR and relatively wide bandwidth. At higher frequencies, dimensions of the horn antennas decrease with wavelength that makes it possible to implement a horn antenna on a basis of the LTCC technology. For example 30 GHz LTCC horn antenna with different feeding structures is discussed in [12].

Generally, the horn antenna is excited by a waveguide, however, it is also possible to feed the antenna through coaxial-waveguide or strip-waveguide transitions.

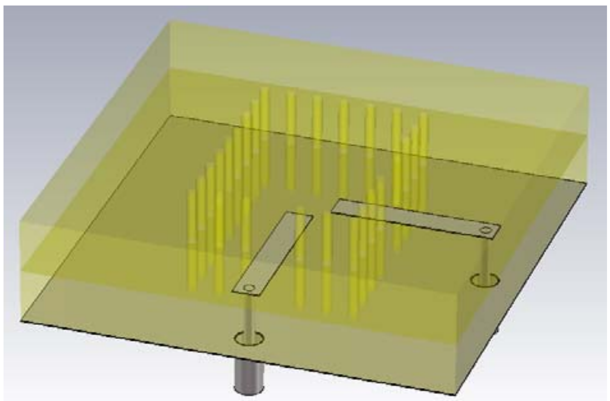

Fig. 7. LTCC horn antenna.

Figure 7 shows a model of 32-36 GHz LTCC horn antenna with 4×4×2 mm dimensions. The simulated antenna was a piece of square waveguide short circuited by ground plate. Waveguide walls were made of metallic rods in LTCC dielectric. It was excited by two mutually perpendicular strip lines. To form circular polarized radiation strip lines had their phase shifted by 90° by means of hybrid ring which was mounted in the inner metallization layers of the LTCC structure.

Figures 8 and 9 present characteristics of horn antenna model.

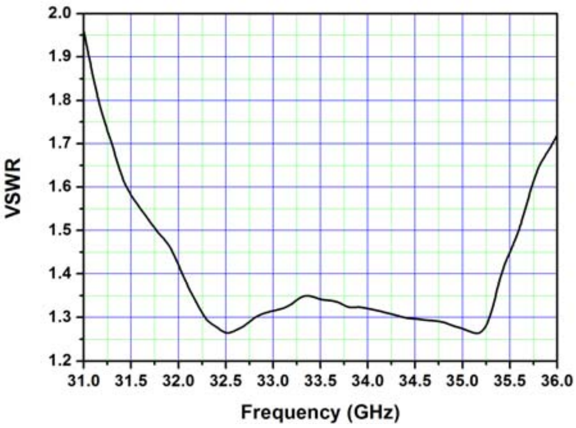

Fig. 8. VSWR of the horn antenna model

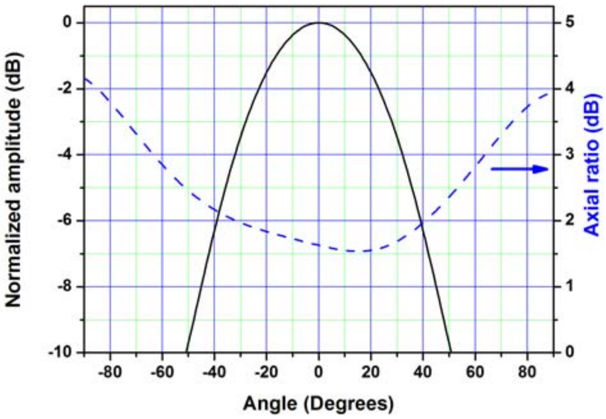

Fig. 9. Horn antenna radiation pattern cross section and axial ratio

From above figures can be seen that simulated horn antenna had 10% fractional bandwidth (32.2 – 35.2 GHz) measured by 1.3-1.4 VSWR level, 60° half power beamwidth (by -3 dB level) and axial ratio less than 2 dB in the HPBW region. The obtained parameters are quite decent for elements of phased antenna array while the antenna dimensions comply with LTCC technology.

Conclusions

To sum up we can conclude that:

1) The spiral antenna has the widest bandwidth and the best axial ratio in HPBW region but the narrowest beamwidth among the simulated antennas. Moreover, because of 188 Ohm antenna impedance the matching device which cannot be realized with the help of LTCC technology is required. That's why embedding the spiral type Ka-band antenna with T/R-module in the frame of LTCC technology does not look too attractive.

2) The patch antenna is the simplest for manufacture. It has the widest beamwidth and decent axial ratio but the narrowest bandwidth. To some extent it can be overcome using more complicated multilayered (stacked) patch antennas.

3) The simulated horn antenna has narrower beamwidth than patch antenna but wider bandwidth (10% of the carrier frequency) and also comply well with LTCC technology for the frequency band studied. Though the described horn antenna is not the simplest one for fabrication, we believe that it is the most suitable option for antenna array applications based on LTCC technology.

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Authors*: engineer, Mikhail V. Moiseev, e-mail: moiseev.mv@spacecorp.ru; engineer, Vitaliy Yu. Avdonin, e-mail: avdonin.by@spacecorp.ru; engineer, Andrey A. Nelin, e-mail: nelin.aa@spacecorp.ru - Joint Stock Company «Russian Space Systems».*

PhD, researcher, Larisa E. Ragulina, e-mail: ragulina.le@mipt.ru; head of lab. Mikhail V. Ryzhakov, e-mail: mryzhakov@applmech.mipt.ru - Moscow Institute of Physics and Technology.

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