Design and technological support for manufacturing a PAA emitter based on a 3D-model using SolidWorks CAD

V A Lebedev¹, A S Kukareko¹,* and V A Kukareko²,³
¹ Department of mechanical engineering technology, Don State Technical University, Rostov-on-Don, 344000, Russia
² Department of industrial safety, Don State Technical University, Rostov-on-Don, 344000, Russia
³ Junior researcher, Rostov branch of the Russian customs Academy, Rostov-on-Don, 344002, Russia

*e-mail: kukareko.lesha@yandex.ru

Abstract. This article presents a methodology for manufacturing the S-band phased antenna array (PAA) emitter based on a calculated 3D-model, which provides the necessary design and technological requirements. As a method of manufacturing the emitter, the technology of milling processing on a CNC machine was chosen. Verification of milling processes based on the SolidWorks CAM software package was performed.

1. Introduction
In most cases, phased antenna array S-band frequencies are a set of several symmetrically arranged basic elements of the grid, consisting of receiving and transmitting modules (TM), digital signal processing devices, power supply, etc. The fundamental elements in this system are TM, which transmit a signal to the surrounding space, and receive a useful signal from the detection object in a given sector, limited by the directional diagram of the PAA.

TM is made on the basis of a printed circuit Board with antenna emitters fixed on it, using plug-in connectors or soldering. It is the antenna emitters that are of the greatest interest from the point of view of their manufacture, since they have special requirements for shape, processing accuracy and manufacturability [1].

At the moment, in radar engineering, there are quite a large number of different types of antenna emitters that differ in their functional purpose, respectively, design, shape and size. For S-band PAA, symmetrical electric emitters made of aluminum alloys with straight or inclined arms are most often used, depending on the required characteristics. A simplified view of symmetrical emitters with straight and slanted shoulders is shown in figure 1.
2. Calculated 3D-model of the emitter
Let's consider an example of a calculated 3D-model of a symmetrical antenna emitter with straight shoulders, which has linear polarization and a wide 90° directivity diagram in the azimuthal plane relative to the main axis of the emitter (Figure 2). It should be noted that the presented 3D-model is ideal, because it fully provides all the necessary tactical and technical characteristics of a given PAA [2]. Overall dimensions of the design emitter — shoulder span 94.6 mm, base width 21 mm, shoulder width 14.5 mm, height 45.5 mm, structure height 41.5 mm, gap between structures 4 mm.

3. Design development of a 3D model of the emitter
At the stage of converting the calculated 3D-model of the emitter into a design model, it is necessary to take into account the possible options for manufacturing the emitter (processing technology), ensuring the strength of the structure, the nature of the electrical installation, and determining the attachment points.

3.1 Selection the emitter material
Aluminum deformable alloy AMg6 in accordance with SIST 4784-2019 was selected as the material for manufacturing the emitter. Aluminum alloy AMg6 has a number of advantages that make the design of the PAA emitter the most reliable, light and technological, among them: low specific gravity; corrosion resistance; vibration resistance; plasticity; low electrical resistivity [3].

3.2 Selection of manufacturing technology
When selecting the manufacturing technology of a complex part, it is necessary to take into account its shape, size and the required accuracy of surface treatment. For the emitter shown in figure 2, it is rational to use one of the two processing technologies:
1. Milling. Processing of flat surfaces and the workpiece contour on the milling machine with CNC;
2. The combined technology of milling and electrical discharge machining. Processing of flat surfaces on a CNC milling machine, contour processing on an electric erosion machine.
Often, the design of PAA uses a fairly large number of emitters, which significantly increases the cost of the product and increases its production time when using combined technology. Thus, with large production volumes, it is rational to use the technology of milling flat surfaces and the emitter contour.

Milling technology involves the use of appropriate tools — milling cutters with a cylindrical structure. Therefore, in the corners of the part, it is necessary to provide rounding of the minimum possible radius, since their excessive increase leads to a deterioration in the coordination of the wave resistance of the antenna and the feed feeder line [1].

Based on the above, the processing of the emitter contour must be performed in two stages, which allows you to reduce the milling depth to half the depth of the workpiece [4]. The minimum radius of rounding in the corners of the part is defined by the following expression (1):

\[ R = \frac{H}{k}, \]  

(1)

\( H \) – the milling depth, mm;
\( k \) – coefficient, equal to 6, for aluminum, copper alloys and plastics.

Thus, for the emitter shown in figure 2, taking into account the height of the workpiece 23 mm and finishing contour processing of the conditional joint to a depth of 1 mm, the milling depth is equal to 12 mm. From expression (1), the minimum radius of rounding at the corners of the emitter is 2 mm. Therefore, for finishing contour processing, it is necessary to choose a tool with a diameter of no more than 4 mm and a height of the working part of no less than 12 mm.

3.3 Electrical installation and mounting points

Installation of the feeding feeder line is carried out through a connector type SRG50-751FV, for this purpose, the design of the emitter must provide a threaded hole M6×0.75, located on the Central axis of the emitter. The connector is installed in accordance with VR0.364.049 TC, while the supply core is soldered to the central structure of the emitter [5].

To install the emitter on the PAA, there are 4 through-threaded holes M4, which ensure that the emitter is fixed in a given position on the underlying surface of the PAA.

The design of a symmetrical PAA emitter with straight shoulders, taking into account the manufacturability of manufacturing, the requirements for installation in the overall layout of the PAA, is shown in figure 3.

![Figure 3. Design 3D-model of a symmetrical PAA emitter](image)

4. The strategy of processing the emitter

To determine the plan for processing parts by milling, software complexes with a CAM-system are used, which allow virtually generating technological transitions, analyzing tool paths, evaluating deviations of the processed surfaces, etc. The algorithm for working in the CAM system includes three stages [6]:

**Stage 1. Geometry selection:**
- selection of geometric elements of the model to be processed (working, processed, and controlled elements);
determining the size and shape of the workpiece based on the actual allowance;
• determining the position of the workpiece relative to the zero point;

Stage 2. The selection of a strategy and tool, and the setting of processing parameters:
• selecting a processing strategy (rough, finish, 2D-geometry; 3D-volume geometry; radial
 geometry; contour geometry, etc.)
• purpose of cutting tools;
• the definition of the cutting modes;
• generation of processing paths.

Stage 3. Backplot and verification:
• checking the correctness of created paths (Backplot function).
• solid-state verification of the workpiece material removal process.

To determine the processing plan for a symmetrical PAA emitter, use the SolidWorks CAM software package. We will perform a technological analysis of this detail based on the above algorithm for working in the CAM-system.

4.1 Plan for milling the emitter
Let’s define the geometric elements of the emitter to be processed in accordance with the first stage of work in the CAM-system. The sequence of surface treatment of the part is shown in figure 4.

![Figure 4. Sequence of processing geometric data emitter elements](image)

a) the base flat surface;
b) flat surface, milling depth 3.25 mm;
c) flat surface, the milling depth 6.5 mm;
d) contour surface treatment, milling depth 12 mm.

To determine the size of the workpiece, it is necessary to rely on two main parameters, namely the overall dimensions of the emitter (94.6×45.5×21) and the actual allowance (min 1 mm, to ensure the 5th class of surface cleanliness) [4]. Based on the design of the emitter, the deviation tolerance of its surfaces relative to the calculated 3D-model, and the actual allowance, the overall dimensions of the workpiece are 97×48×23 mm.

4.2 Strategy for surface milling of the emitter
Determine the processing sequence of the emitter and assign the cutting tool. The CAM-system provides a function for selecting a machine and adding a tool basket. The type of milling machine is selected based on the complexity of the part shape and the number of surfaces to be processed.

To manufacture the emitter will take the standard type of machine provided CAM system, namely a 2.5-axis machine Mill – Metric, class capacity Medium duty, with a maximum flow 16500 mm/min, spindle speed of 12000 rpm [6].

The tool crib is a set of different types of milling cutters that are set by the operator depending on the required part processing strategy. The CAM-system also provides a wide selection of different milling tools that can be changed after generating transitions, depending on the required accuracy and shape of the part.
Now let's use the feature for automatic recognition of geometric elements in a solid-state model, called element extraction. Depending on the previously planned part processing sequence, we make the necessary corrections to the element extraction program using the element recognition functions and processing the part perimeter to the specified milling depth. In this way, the CAM-system determines the emitter processing plan (Figure 5).

![The first milling operation](image1.png)
![The second milling operation](image2.png)

**Figure 5.** The treatment plan emitter

To create an emitter surface treatment plan, the CAM-system uses the processing plan generation function, which creates transitions for all processed surfaces based on the rules set in the Technology Database [6]. Note that the presented transitions are preliminary and require correction in terms of their logical combination, replacement of the cutting tool and/or its feed rate, allowance for roughing, changing the sequence of transitions and/or removing them. Thus, to ensure the manufacturability of the emitter, we will correct the transitions generated by the CAM-system.

First, we will replace the proposed cutting tool depending on the processing strategy of the emitter, as well as the cutting speed \( V \).

Secondly, we will conduct a technological analysis of preliminary transitions to combine them and correct them. To avoid tool breakage during processing, we will reduce the tool feed rate by 30% during angular movement [4]. Thus, the plan for surface treatment of a symmetrical PAA emitter acquires the structure shown in table 1.

| №  | Milling strategy                        | Type of milling tool          | Cutting speed \( V, \text{ mm/min} \) |
|----|----------------------------------------|-------------------------------|--------------------------------------|
|    | The first milling operation             |                               |                                      |
| 1  | Rough flat-contour processing of base planes | End mill, 6×24×68 4FL         | 220÷250                              |
| 2  | Finishing flat-contour processing of base planes | End mill, 4×14×51 2FL       | 130÷150                              |
| 3  | Rough flat-contour processing of the groove 1 | End mill, 6×24×68 4FL         | 180÷200                              |
| 4  | Finishing flat-contour processing of the groove 1 | End mill, 4×14×51 2FL       | 130÷150                              |
| 5  | Rough flat-contour processing of the groove 2 | End mill, 6×24×68 4FL         | 180÷200                              |
| 6  | Finishing flat-contour processing of the groove 2 | End mill, 4×14×51 2FL       | 130÷150                              |
|    | The second milling operation             |                               |                                      |
| 1  | Rough flat-contour processing of base planes | End mill, 6×24×68 4FL         | 220÷250                              |
| 2  | Finishing flat-contour processing of base planes | End mill, 4×14×51 2FL       | 130÷150                              |
| 3  | Rough flat-contour processing of the groove 3 | End mill, 6×24×68 4FL         | 180÷200                              |
| 4  | Finishing flat-contour processing of the groove 3 | End mill, 4×14×51 2FL       | 130÷150                              |

**Table 1.** Plan of surface treatment of the emitter and the purpose of the cutting tool.
4.3 The tool path generation function.
To analyze tool paths for each planned transition, as well as to change the tool entry points, pass coordinates, or cutting tool, use the tool path generation function. Some tool paths in accordance with the processing plan are shown in figure 6.

![Figure 6. The trajectory of the cutting tool.](image)

4.4 The backplot and processing verification
To confirm the correctness of the created processing plan, the backplot and verification functions are performed. The backplot function is designed to detect errors when processing part surfaces, such as a tool colliding with a part/work piece, a tool holder colliding with a part/work piece, or a mandrel colliding with a part/work piece. Verification is intended for simulation and graphical verification of the material removal process based on the shape of the workpiece and cutting tool. In the CAM-system, it corresponds to the trajectory simulation function. Figure 7 shows some simulations of the cutting tool trajectory when processing the emitter surfaces.

![Figure 7. Simulation of the cutting tool trajectory using the verification function](image)

After verification, the programmer-technologist automatically creates a control program (CP) based on G- M-codes using the CAM-system. Then the CP is loaded on a CNC milling machine [6].

5. Conclusion
Thus, this article presents a methodology for manufacturing a symmetrical S-band PAA emitter based on a 3D-model that provides the necessary design and technological requirements. The method of
manufacturing the emitter using the technology of milling on a CNC machine is determined, which allows reducing the cost and production time of the emitter in comparison with the often used combined technology of milling and electroerosion processing. To confirm the applicability of the milling technology, verification of the surface treatment processes of the emitter was performed on the basis of the SolidWorks CAM software package.

References
[1] Kubanova V P 2016 Fundamentals of the theory of antennas and radio wave propagation: study guide (Samara: Volga state University of telecommunications and Informatics) p 258
[2] Krotova E I 2013 Fundamentals of design and production technology of RES: study guide (Yaroslavl: Yaroslavl state University named after Demidov) p 192
[3] SIST 4784-2019. Aluminium and wrought aluminium alloys. Grades: approved and put into effect by the Federal Agency for technical regulation and Metrology on July 31 2019 paragraph N 435
[4] Vereina L I 2017 Milling technology: study guide (Rostov-on-Don: Phoenix) p 187
[5] MD 107.434511.001-90. Radio frequency connectors. Selection guide: put into effect by the Directive letter of the SSTU of 23.11.90 N 017-107/K/2622.
[6] Lovigin A A and Teverovskiy L V 2015 Modern CNC machine and CAD / CAM-system (Moscow: DMK Press) p 280