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DFM(A)- ASPECTS FOR AN SMA CONNECTOR DESIGN

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Keywords: Manufacturability analysis, design for manufacturing and assembly, microwave mechanics, virtual prototyping, SMA connector.

ABSTRACT

In this research, manufacturability analysis is made for an SMA connector. Analysis and aspects of applying virtual prototyping for an SMA connector design and manufacturing are also investigated. Special questionnaires for the component and machining are made in order to enable necessary information to ensure DFM(A) –aspects of products. The aspects of easy manufacturing for machining the SMA connector are collected. Material selection is discussed, and manufacturing stages of prototype manufacturing are presented. The main focus of this research is on prototype manufacturing, but also aspects considering volume production are discussed. A special purpose SMA connector is designed for printed circuit board edge mounting.

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1 INTRODUCTION

In this research manufacturability analysis will be made for an SMA connector. Possibilities to utilize virtual prototyping -method both for designing and making manufacturability analysis for MW-/RF -components will be discussed.

For helping to establish the necessary guidelines for easy manufacturing and assembly of the MW-/ RF -component a specialized DFM(A)-questionnaire will be generated. The questionnaire gives also new information for collaborative designing approach in MW-/RF- engineering. Also the advantages and disadvantages of the selected design method are evaluated.

Practical guides and instructions for easy manufacturing are collected especially for machining. In this report we will focus in researching components, which are made of different copper alloys.

This research is part of the EU-project entitled “Collaboration for human resource development in mechanical and manufacturing engineering (Contract: ASIA-LINK -ASI/B7-301/98/679-023). Within the same series of publications belong seven reports, which are focused to following design methods:

- systematic design
- reverse engineering
- concurrent engineering
- cross-technological approach
- collaborative design
- use of integrated product teams
- virtual prototyping

All these seven reports will be published at Lappeenranta University of Technology during the year 2004 in the series of scientific reports of the Department of Mechanical Engineering.

2 TASK

The purpose of this research is to investigate analysis and aspects of applying virtual prototyping for an SMA connector design and manufacturing.

3 COMPONENT

The component is an SMA connector for printed circuit board mounting up to 18 GHz. A standard SMA connector is introduced in conjunction with holding block for printed circuit board edge mounting. Also other connector flange geometries are discussed for different joining geometries. A special SMA connector for printed circuit board edge mounting is designed in order to achieve repeatable and easy assembled interface between the cable and the microstrip like printed circuit board.

3.1 Function

SMA connector (Subminiature Version A) is generally used in microwave applications. It has a small VSWR (Voltage Standing Wave Ratio) and acceptable durability. SMA connectors have an external thread and are mechanically quite robust with good contact repeatability.

The function of presented SMA connector is to create a connection between the 50 Ω coaxial cable and the 50 Ω microstrip line on a printed circuit board. A microstrip structure consists of normal double-sided printed circuit board with a conductor pattern on the top of the board and a uniform ground plane on the bottom side of the board. The ground plane and the conductor pattern are usually copper which is plated with organic surface coating or with other coatings like gold or solder plating. The microstrip structure is shown in Fig. 3.1.

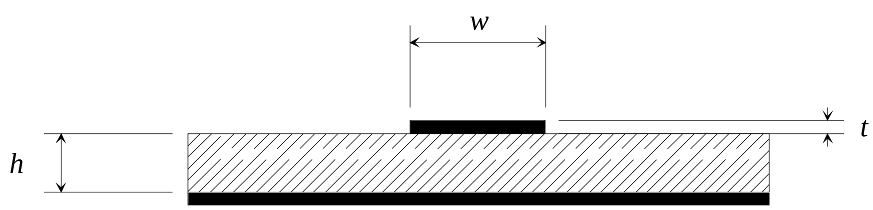


Fig. 3.1 Microstrip structure on a printed circuit board, where *h* is the laminate height, *w* line width and *t* conductor thickness.

The connection is made from the edge of the printed circuit board in order to achieve uninterrupted connection of center pin and to ensure good VSWR. The body of the SMA connector is connected to the ground plane of the printed circuit board and the center pin is soldered to the microstrip line. The connections must be firm and assured. Especially the ground connection is critical.

The height of the printed circuit board can vary with different kind of printed circuit board structures. Hence, some kind of adjustable mounting mechanism with repeatable connection should be used. In the first version of the application, the holding block ensured the proper ground contact and right positioning. In the second version, the connector itself makes the ground connection and right positioning.

3.2 Dimensions, geometry, drawings or photos

The SMA connector acts like a coaxial line extension, which has dielectric material between outer and center conductors. The impedance of the connector is defined by the diameters of the outer and center conductors and the used dielectric material. In order to achieve 50 Ω impedance e.g. with PTFE as a dielectric material (dielectric constant is around 2.2), the diameter of the center conductor is 1.28 mm and the diameter of the outer conductor 4.1 mm. These dimensions as well as several others are defined in the standards of SMA connector. Dimensions of the normal female SMA connector with a solder pot are presented in Figs. 3.2 and 3.3.

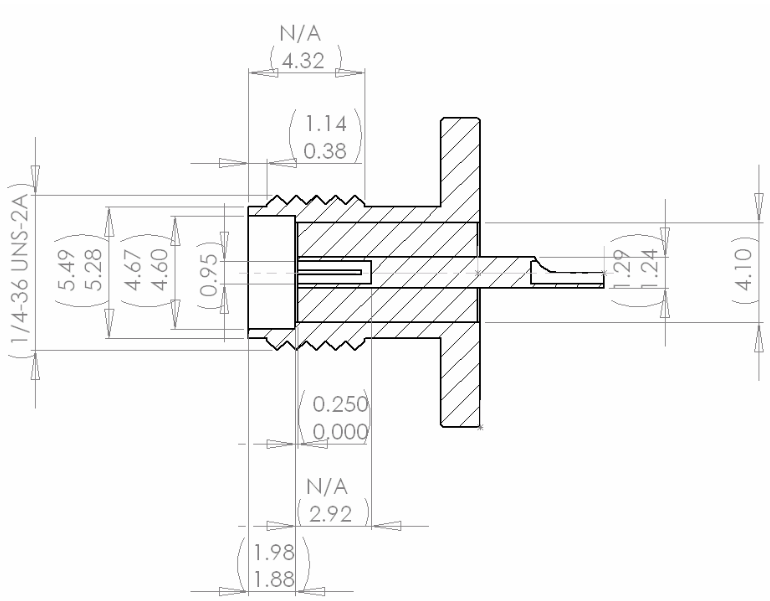


Fig. 3.2 Standard physical dimensions of a female SMA connector. [1] – [3]

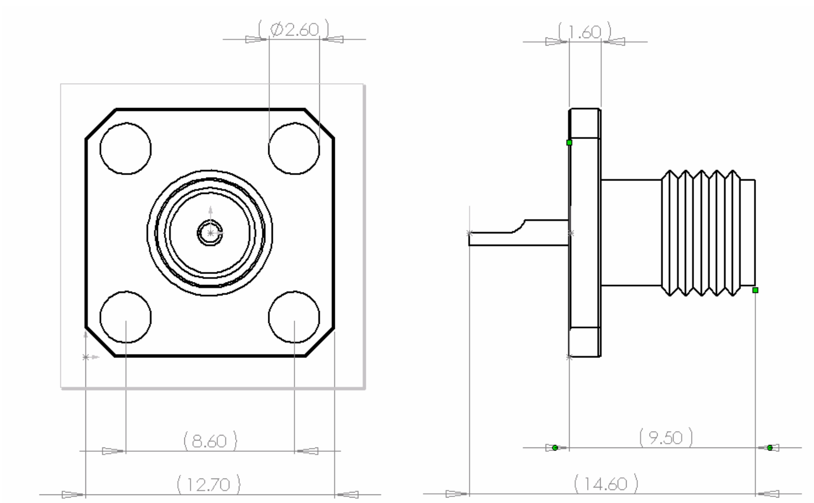


Fig. 3.3 Panel jack (female) SMA connector with a solder pot. [1] – [3]

The diameter of the center pin is 1.28 mm, but it can vary from 1.24 to 1.29 mm. The center pin has holes in both ends and the standard diameter of the hole in cable end is 0.95 mm. There are also two slots in inner conductor of the female SMA connector to ensure good connection to the center pin of the male connector.

The adjustable ground connection can be implemented e.g. with the holding block, which ensures the connection from connector body to ground plane and places the connector always with the same kind of alignment. The dimensions of the holding block are presented in Fig. 3.4. The upper plane or the plane, which is against the ground plane, must be solid and the edge against the connector body and ground plane must be sharp. Other edges and the bottom side of the holding block are not critical, so the block does not have to be whole and can be lightened from the bottom side. The four holes on top of the block are with M2.5 threads.

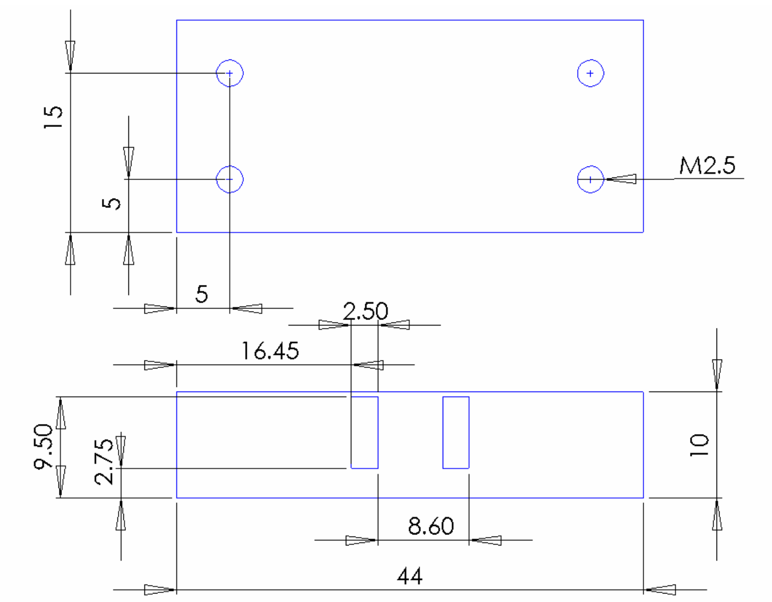


Fig. 3.4 The dimensions of the holding block.

The application of the SMA connector for printed circuit board mounting with holding block and mounting blots is presented in Fig. 3.5.

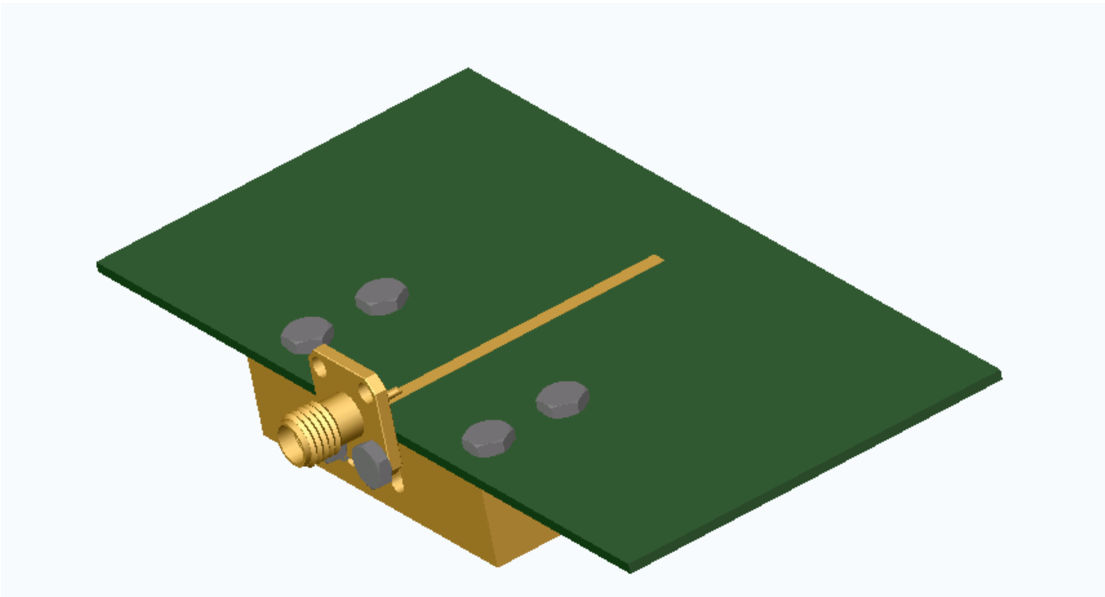


Fig. 3.5 Assembly, where are the SMA connector, holding block, printed circuit board and mounting screws and nuts.

The second and improved version of the component is the SMA connector with flange geometry suitable for edge mounting of printed circuit boards with variable board heights. The second version of the SMA connector and its application are illustrated in Fig. 3.6.

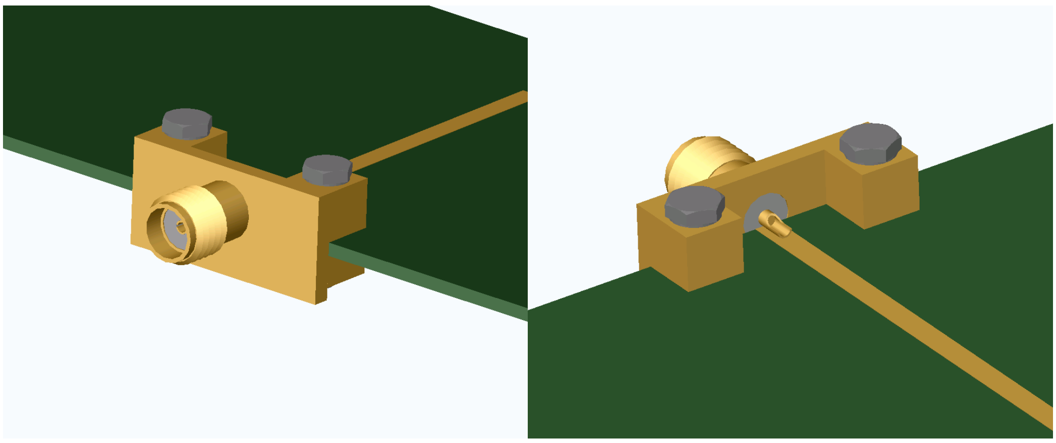


Fig. 3.6. The SMA connector with flange geometry suitable for printed circuit board edge mounting.

The connector in Fig. 3.6 has two upper blocks, which are fixed with the flange of the connector body and one lower block, which is loose and can be tightened with screws. The cable end of the connector is identical to the standard SMA connector. The bottom of the center pin is at the same level with the bottom of the upper blocks. The center pin has a solder pot, but it is possible to use connector without soldering the center pin. However, if the center pin is not soldered, the electrical performance of the connector would decrease.

3.3 Requirement list

General requirements considering electrical, mechanical and environmental requirements are listed below.

Electrical requirements of the SMA connector:

- Impedance of the connector 50 Ω
- Operating frequency range DC - 18 GHz
- VSWR less than 1.2 (up to 18 GHz).

Mechanical requirements:

- Smooth surfaces, minor surface roughness in critical parts
- Used materials should be corrosion resistant
- Center pin must be hard material
- Body, dielectric and center pin must be able to be pressed together
- Center pin must maintain at defined position without turning
- Durability more than 500 matings.

Environmental requirements:

- Operating temperature range –65°C - +165°C
- Relative humidity range 5 - 95 %.

4 VIRTUAL PROTOTYPING AND MANUFACTURING

4.1 Introduction to Virtual Prototyping and Manufacturing

One large problem in the field of electronic industry is nowadays cost-effective manufacturing, alternatively, more and more miniature electric components, or relatively (compared with the electric components) large mechanical components have to be fitted in the same construction. It is possible to find a solution to this problem by virtual prototyping and manufacturing (VM). It is suitable for both the designed circuits and necessary mechanical constructions, their environmental conditions, and suitable manufacturing processes. It is obvious that simulating is much less expensive and much more comprehensive than testing physical prototypes. Virtual prototyping and manufacturing can detect and help correct design and manufacturing problems more thoroughly than physical prototypes through highly accurate numerical analysis and an integrated design system. [4]

In general the following advantages can be achieved if Virtual Modelling techniques are applied:
- reduction in design release time,
- reduction in design cost,
- reduction in manufacturing cycle time,

- reduction in factory floor space utilisation,
- reduction in part count and
- reduction in fasteners required for the assembly.

It seems that especially different types of fasteners or fixturing systems could be designed at the same time with the product by utilizing effective virtual design environments.

Visualization of manufacturing processes has come usual in different casting processes in which the geometry of the workpiece can be very complex. These applications utilize typically 3D-modelling. Even though the area of casting is an obvious area for visualizing the manufacturing process in beforehand, any manufacturing process, which utilizes for example 3D-robotics applications, could be checked in the same way.

One other important area in which virtual environments have been utilized with good success is manufacturing automation. Various models of virtual factories have been presented. These factories consist of a set of modular machines, which a designer can drag and place in the factory to study issues such as plant layout, clusters and part flow analysis.

When a designer utilises virtual design environments the following five aspects should be emphasised:

1) It is necessary in practical work to avoid the modelling of the same geometry several times during the process but instead of that to have a way to use the same model in every stage of the flowchart. However, the model will be improved or completed during the process. This means that it must be possible to fully integrate all the software packages used in the process.
2) All the data produced during the process should be saved in a local database, which forms the basis for further development of more general databases, expert systems or artificial intelligence systems. On the other hand, by combining the data from databases the designer can formulate standard-based or/and modular constructions starting from the sketch in the very early stages of the design process.
3) The use of standardized and modular constructions forms the important starting point also for computer aided design. It is easy to add feature-based information into the data of standard components, parts, sub-assemblies or the entire construction, to be used for the design of manufacturing or process planning.
4) Different kinds of simulations and visualizations are used to illustrate the propagation of the design process. By using virtual models it is possible to combine geometrical, physical, functional and manufacturability simulations of the product.
5) The most effective way to shorten the time needed to complete the product documents for manufacturing, is the use of feature based systems. Either form features (for example not just the sphere but a

sphere of a ball bearing), geometric features (for example not just the dimensions of a bored hole but also the direction of this cylinder) or technological features (for example data of materials or tolerances) can be utilized. The model of the product can also contain information in the form of manufacturing objects (in the data-added sub-programs for manufacturing a specific geometry) or wizards (the software suggest the possible manufacturing methods and the user chooses the appropriate one).

4.2 About the suitability of Virtual Prototyping and manufacturing for MW-design

Common requirements for an effective design method are as follows:
1. The method must be applicable to every type of design activity, no matter in which specialist field.
2. The method should facilitate the search for optimum solutions.
3. The method should be compatible with the concepts, methods and findings of other disciplines.
4. The method should not rely on finding solutions by chance.
5. The method should facilitate the application of known solutions to related tasks.
6. The method should be compatible with electronic data processing.
7. The method should be easily taught and learned.
8. The method should reduce workload, save time, prevent human errors, and help to maintain active interest.

A very simple way to estimate product's manufacturability is to use the following four items:
1. Binary measures (whether or not a specific manufacturing method is suitable)
2. Qualitative measures (products can be classified according to their manufacturability e.g. into groups ”poor”, ”average”, ”good” or ”excellent)
3. Abstract quantitative (some numerical index is counted to describe product's manufacturability)
4. Time and cost comparison

If the design method does not include any of these check points in the early stages of the design process, obviously the method is not too effective for DFM(A)-analysis.

In many cases it is possible to divide the research area of design method into a function-oriented, a performance-oriented or a manufacturability-oriented product design. Alternatively various approaches can be developed for customer-oriented, quality-oriented, cost-oriented and organisation-oriented design.

The real need for improvements is between these two extremes. This means that the effective method for the designers should not be too limited (like in the performance-oriented design) or too general (like in the organisation-oriented design), but it should, however, include the context of design environment. That is why the traditional design methods are improved for specific design tasks, e.g. for MW- and RF-component or system design.

Effective virtual prototyping and manufacturing requires fully integration between CAD-, CAE- and CAM -software. The integration problem between CAM- and CAD -software seems to be "solved", but because of the present gap between CAD- and CAE -applications, designers are often hindered in their efforts to explore design alternatives and ensure product robustness. To solve this problem e.g. a multi-representation architecture (MRA) has been described: This is a design-analysis integration strategy that views CAD/CAE-integration as an information-intensive mapping between design models and analysis models. Unfortunately there is also lack of ACAD-integrated software for modelling microwave electronics, which means that there is not only the difficulty to integrate the geometric modelling and the Finite Element Analysis (FEA) of designed microwave mechanics but also the problem how to integrate geometric modelling with electric modelling.

Also problems of handling different versions of computer aided documents are nowadays very common in engineering design. New standards for documentation include instructions to ensure the control of different versions.

One typical example of how to utilise virtual design environments in MW-mechanics is presented in Fig. 4.1.

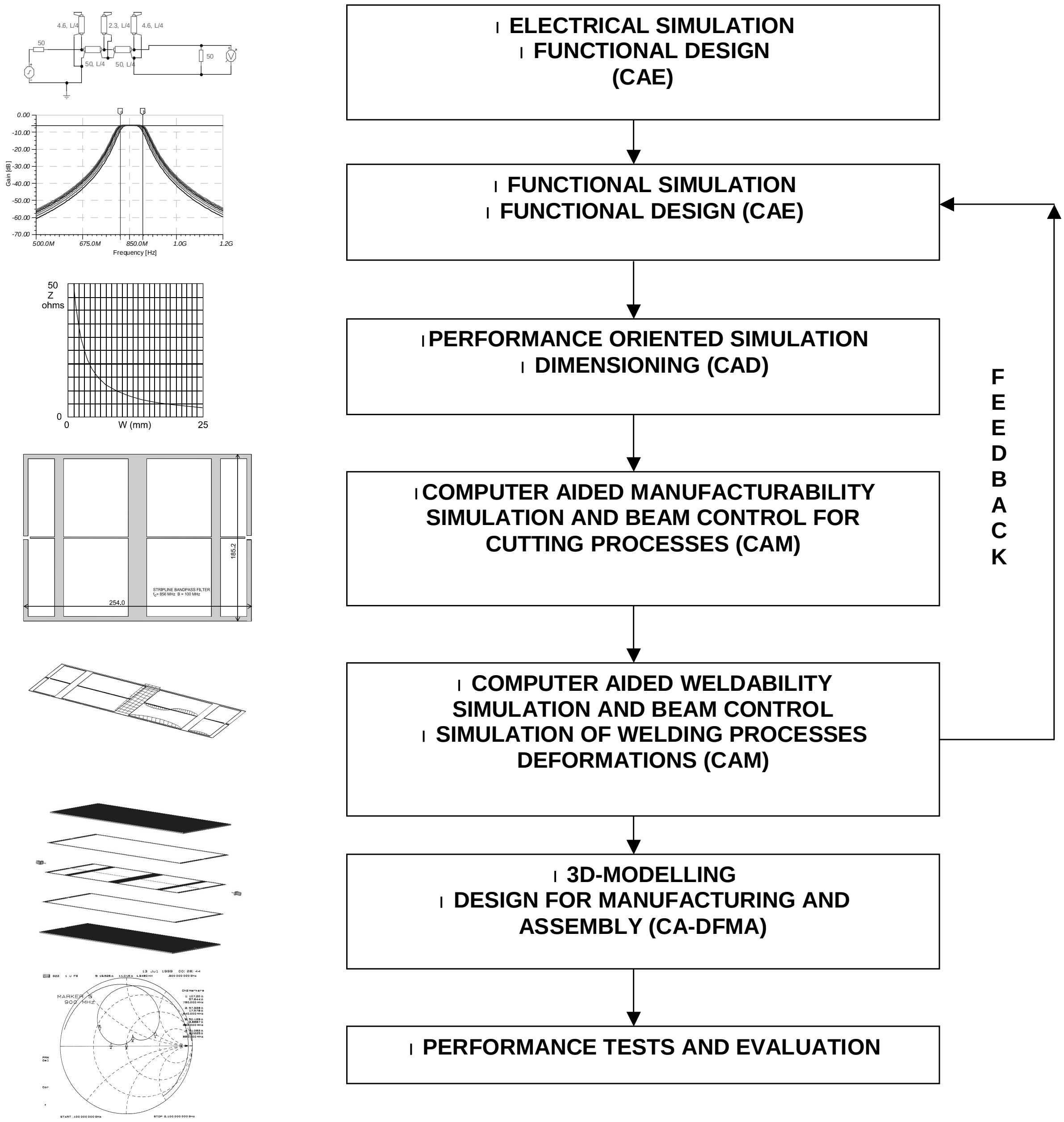


Fig. 4.1. Integration of computer aided design (CAD), simulation (CAE) and manufacturing (CAM) procedures for a MW-filter virtual design. [5]

4.3 Suitability of Virtual Prototyping and Manufacturing for SMA connector –design

SMA connector is a simple component with few critical dimensions, but because of the microwave requirements, manufacturing, assembly and use of the connector demand attention. Virtual prototyping allows designer to test components and assemblies with realistic layouts, geometries and functionality as well as to test the whole manufacturing process.

The efficient virtual prototyping requires the integration of CAD-, CAM- and CAE –software. At first, virtual prototyping starts in definition of the connector with CAD -software. The 3D–models help designer in system assembly, e.g. physical dimensions, motions and collisions of the connector parts (body, dielectric and center pin) and operating application (connector, circuit board and mounting screws) can be proved to match.

The analysis based on the physics, electronics and functionality can be carried out with the CAE –software. Mechanical effects like handling, durability and for example bending of the component center pin or the connection between connector and circuit board can be modeled. The aspect of electrical effects is interesting, because of the lack of useful and compatible software. It would be very useful to examine for example the electrical effects of the lugs or clamps which are important for immovability of the center pin and dielectric, because the surfaces must be as smooth as possible and no additional discontinuities are allowed in order to avoid reflections and increase in VSWR. The effect of different bends, airgaps or other discontinuities in center pin or ground plane connections would also be very useful to simulate, because the proper connection, especially the ground connection, plays very important role in microwave applications.

Virtual manufacturing and the use of CAM –software can be used to model machining of the connector or assembly when assembling with robots. The whole manufacturing process and factory with robots and movements can also be modeled virtually. Virtual models of prototype machining centers or milling machines clarify the movements of the cutters and arms e.g. how the cutter fits in all desired positions in order to machine the connector with minimum mountings. In volume production, the virtual manufacturing plays even more important role because of the great amount of different machining equipment and moving of the component between machining stages.

The use of the virtual prototyping in SMA connector design is somewhat practically limited in the areas of mechanics and manufacturing because of the lack of CAD- and CAM -compatible CAE -software. There are Finite Element Method (FEM) -softwares to simulate 3D electric models, but they are usually not compatible with CAD or CAM -software. If CAD- and CAM compatible electronics simulation software can be utilized, interesting electrical testing in virtual environment is possible.

5 DFM(A)-QUESTIONNAIRE FOR THE COMPONENT

5.1 General instructions to generate the questionnaire

To help to establish the special requirements of the MW- or RF-component it is possible to generate a questionnaire, which could be modified from the general presentation shown in Table 5.1. The basic idea is to collect those design aspects, which will later affect on mechanical design and from which the final requirements for design can be derived.

Table 5.1. A preliminary questionnaire for helping to form the requirement list of mechanical microwave subassemblies. [4]

Question	Answer
1. What is the expected operating frequency?	_____ GHz
2. What is the required relative bandwidth?	_____ %
3. What is the maximum radio frequency power to be handled?	_____ dBm
4. Is the unit for a) receive (RX), b) transmit (TX) or c) both?	a) b) c)
5. What is the absolute maximum attenuation allowed?	_____ dB
6. Are semiconductor components involved in the design?	yes no
7. Is the preferred transmission line a) waveguide b) planar c) coaxial d) dielectric?	a) b) c) d)
8. Should the connection to adjacent modules go a) through coaxial connectors or b) waveguide flanges or c) none?	a) b) c)
9. Is the unit a) sealed for life or b) should there be a possibility for service & repair?	a) b)

One example to show how this table guides the design process: if the expected operating frequency of the device is lower than 1 GHz, generally any material could be used and dimensional tolerances can be even > 1 mm. If the operating frequency is <15 GHz, most metals are acceptable, including steel but oxidation is to be avoided, surface and alignment tolerances should generally be < 0.1 mm. And finally if operating frequency is over 15 GHz, only highly conductive metals (Cu, Au) can be used, most impurities are extremely harmful, and tolerances should be even better than 5 – 10 μm.

Typically the questionnaire presented in Table 5.1 should be filled by MW-/ RF- engineering expert. For specific designs some additional questions might also be useful.

Expert of manufacturing technologies is needed to generate the questionnaire for a specific manufacturing stages to ensure products DFM(A)-aspects. A lot of background information is needed to manage to present the right questions to the designer. However, the designer is the only expert who is able to explain the limits or restrictions due to product's functional aspect for different manufacturing operations. Example of a questionnaire, which is made especially for a laser processed product is presented in Table 5.2. Depending on each possible manufacturing technology for the product's geometry, several questionnaires should be generated and filled in.

Table 5.2. Special DFM – questions for laser processing, illustrative examples. [4]

Question	Implementation
1. Are the possibilities to use the fixturing systems for machining considered? (typically the requirements of accuracy of fixturing in laser processing and machining are almost equal)	yes no
2.Could the carbon content of steel be kept under 0.2 % (or at least not higher than 0.3%)?	yes no
3.If highly reflective materials are welded (for example Cu- and Al-alloys), is the utilisation of Nd:YAG recommended in design documents?	yes no
4. Are the joint preparations for laser welding documented including necessary tolerances and manufacturing methods? (laser cutting or machining are recommended, however R_a < 12,5µm is appropriate)	yes no
5. Are butt welds with raised edges or lap joints with seam welds used whenever it is possible due to constructional aspects?	yes no
6. Are more than two plates welded with the same (seam) weld whenever it is possible due to constructional aspects?	yes no
7. Is the construction possible to be laser processed from one direction or at least in one plane?	yes no
8. Are the values for air gap and allowed misalignment marked in the design documents (for example: butt joint/air gap 0.15 mm ,t<10 mm, misalignment<0.3 mm)	yes no
9. If the material’s hardenability properties must be taken into consideration, are the most appropriate joint geometry utilised? (for example the weld is placed mostly on the plates to be welded)	yes no
10. If wires or strings are welded, are the most appropriate joint types used? (power density should be dealt equally to the parts to be joined)	yes no
11. If jigs are needed, are the fixturings of jigs designed and marked on the drawings? (in case when the workpiece is moving in front of the beam)	yes no
12. Is the need for grinding the reinforcement marked in the drawings if several sheet metal constructions are welded together?	yes no
13. When jigs are needed for welding partially closed structures, is the possibility of shrinking taken into account when removing the workpiece?	yes no
14. Is the possibility to use various material combinations considered?	yes no
15. Are the possibilities to use different laser processing methods for the same construction or multi-processing methods considered?	yes no
16. Are the points were laser welding starts and ends designed to meet quality aspects?	yes no
17. Is the CAD-geometry of the workpiece saved in the DXF-format (or any other suitable) for	yes no

CAD/CAM-integration?	
18. Are the traditional instructions for designing sheet metal parts taken into account? (needed for example for cut-bend-weld multi-processing)	yes no
19. Are the adjusting holes or fits marked on the drawings? (or are other additional geometries necessary for adjusting the parts together)	Yes no

In general the list of actions to put DFM(A) in practice is relatively simple: [4]
- minimize the number of parts in a construction
- design modular constructions
- try to find as many functions for a part as possible
- avoid additional components for joining other parts
- design the construction so that all the parts can be assembled from the same direction
- minimize the number of different manufacturing methods and stages to be used
- obey the rules of easy manufacturing for each manufacturing method (applied into your own production)
- check that there is enough space for necessary tools during assembly, fixturing systems during manufacturing and a robotic gripper in automated systems
- use standardized geometry, tools and components
- check the machining allowances
- check the suitability of the material for the manufacturing methods
- use appropriate general tolerances for your own production
- check the summarized errors of the assembly and design a harmless place for manufacturing errors in the construction
- check that the values of surface roughness, tolerances for linear and angular dimensions and geometrical tolerances are adjusted together
- use parts which can be assembled from several directions and still function perfectly (avoid parts which easily assembled in wrong a position or which function only in one position)
- if there are several possible manufacturing methods choose the one, which needs least preparations
- try to repeat the same manufacturing stages, think that each manufacturing stage is also ”a module”
- use parametric design
- design the products directly for automated production (in most cases they will be extremely well suitable for manual production too)
- if manual production is used check the ergonomic aspects

During different design stages this list can be used as a check list to ensure that manufacturability aspect have been taken into account.

5.2 Special questionnaire for the SMA connector

Based on previous examples the specialized questionnaire for the SMA connector is created. The questionnaire for forming the requirement list is presented in Table 5.3 and the questionnaire for machining is presented in Table 5.4. Also the list of putting DFM(A) in practice is introduced.

Table 5.3. A special questionnaire for helping to form the requirement list of mechanical microwave subassemblies.

Question	Answer
1. What is the expected operating frequency?	DC – 18 GHz
2. What is the required impedance of the component?	50 Ω
3. What is the maximum VSWR allowed?	1.2
4. What is the maximum radio frequency power to be handled?	> 30 dBm (> 1 W)
5. Are semiconductor components involved in the design?	yes no X
6. Is the preferred transmission line a) waveguide b) planar c) coaxial d) dielectric?	a) b) X c) X d)
7. Is the unit a) solid or b) does it have to endure motion?	b) more than 500 matings

Table 5.4. Special DFM – questions for machining.

Question	Implementation
1. Are the possibilities to use the fixturing systems or jigs for machining considered?	yes X no
2. Is there space for machining tools?	yes X no
3. Is there space for fastening?	yes X no
4. Are the threads documented including necessary tolerances and manufacturing methods?	yes X no
5. Is there paid attention to material machinability?	yes X no
6. Is the component sensitive for damaging caused by machining forces?	yes X no
7. Is the construction possible to be milled from one direction or at least in one plane?	yes no X
8. Are extremely hard materials being used?	yes X no
9. Is there need for cleaning before assembly?	yes X no
10. Are the geometries suitable for standard tools?	yes X no
11. If jigs are needed, are the fixturings of jigs designed and marked on the drawings?	yes no X
12. Are symmetrical geometries and constant chamfers used?	yes X no
13. Is it possible to drill on a perpendicular surface?	yes X no
14. Is the possibility to use various material combinations considered?	yes X no

15. If there are several inner diameters inside a turned hole, is there a possibility to use chamfered boundaries in between?	yes X no
16. Is there a possibility to use milled outer chamfers instead of rounded geometries?	yes X no
17. Is the CAD-geometry of the workpiece saved in the DXF-format (or any other suitable) for CAD/CAM-integration?	yes X no
18. Are equal distances between similar geometries used?	yes X no
19. Are the adjusting holes or fits marked on the drawings? (or are other additional geometries necessary for adjusting the parts together)	yes no X
20. Is surface coating needed?	yes X no

The list of actions to put DFM(A) in practice in the SMA connector design:
- minimise the number of parts in a construction
- design modular constructions
- try to find as many functions for a part as possible
- design the construction so that all the parts can be assembled from the same direction
- minimise the number of different manufacturing methods and stages to be used
- obey the rules of easy manufacturing for each manufacturing method (applied into your own production)
- check that there is enough space for necessary tools during assembly, fixturing systems during manufacturing and a robotic gripper in automated systems
- use standardized geometry, tools and components
- check the machining allowances
- check the suitability of the material for the manufacturing methods
- use appropriate general tolerances for your own production
- check that the values of surface roughness, tolerances for linear and angular dimensions and geometrical tolerances are adjusted together
- use parametric design

The list of actions to put DFM(A) in practice is very useful to be checked during all the designing stages in order to ensure manufacturability. In SMA connector design, most of these actions could be carried out. The design process in this research is however focused on prototype designing and therefore some aspects considering the volume production and automation were not considered.

6 REQUIREMENT LIST FOR A SMA-TYPE CONNECTOR

This research is focused to the female (jack) SMA connector for printed circuit board edge mounting. Connector body is made of brass. However, also alternative flange geometries will be discussed for different joining geometries. Due to special requirements of the system gold platting is required and presented briefly. Basic SMA connector geometry is presented in figure 6.1

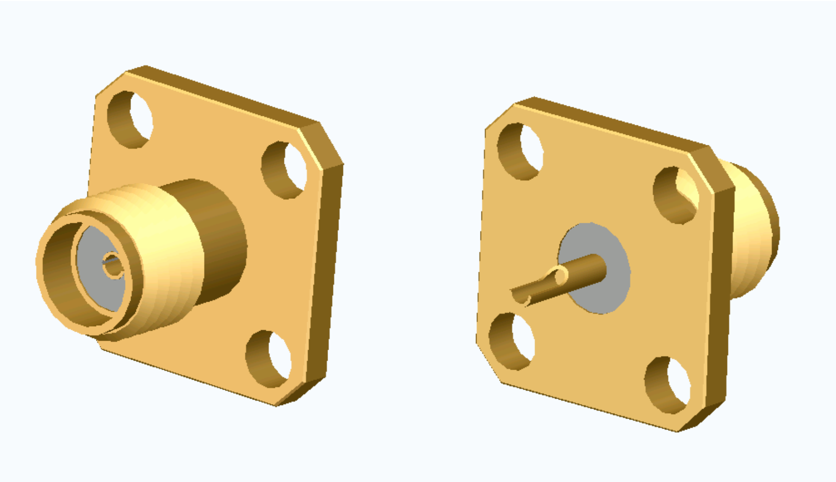


Fig. 6.1 Basic female SMA panel connector geometry.

6.1 General requirements

Geometry

In this connector design threaded connection is used as the coupling mechanism. The dimensions of this connection are fully standardized. If the standardized flange is used also the geometry of the other end of the connector is fully established. For mounting the use of screw size M2.5 is recommended. Required dimensions are presented in Figs. 6.2 and 3.3.

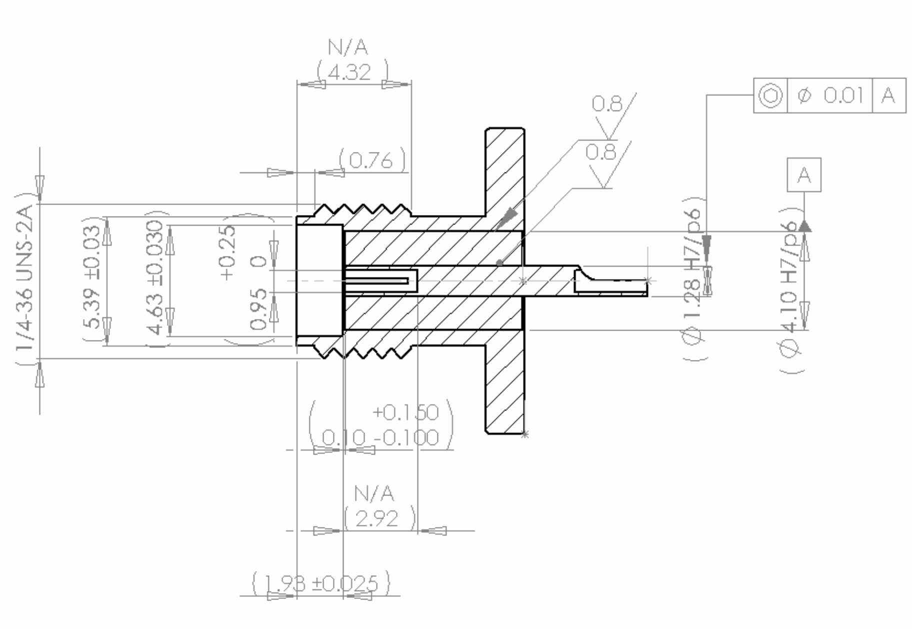


Fig. 6.2 Required dimensions and tolerances for standard female SMA connector.

The tolerances of the SMA connector are IT9-grade, except the surface roughness of the center pin and inner surface of the outer conductor. The fittings for the holes are tight.

The alternative flange geometry is presented schematically in Figure 6.3. This flange geometry is made for the special application of SMA connector for printed circuit board edge mounting for variable board thicknesses. Dimensions and tolerances of the cable end of the special purpose connector are the same as with the standard female SMA connector presented in Fig. 6.2.

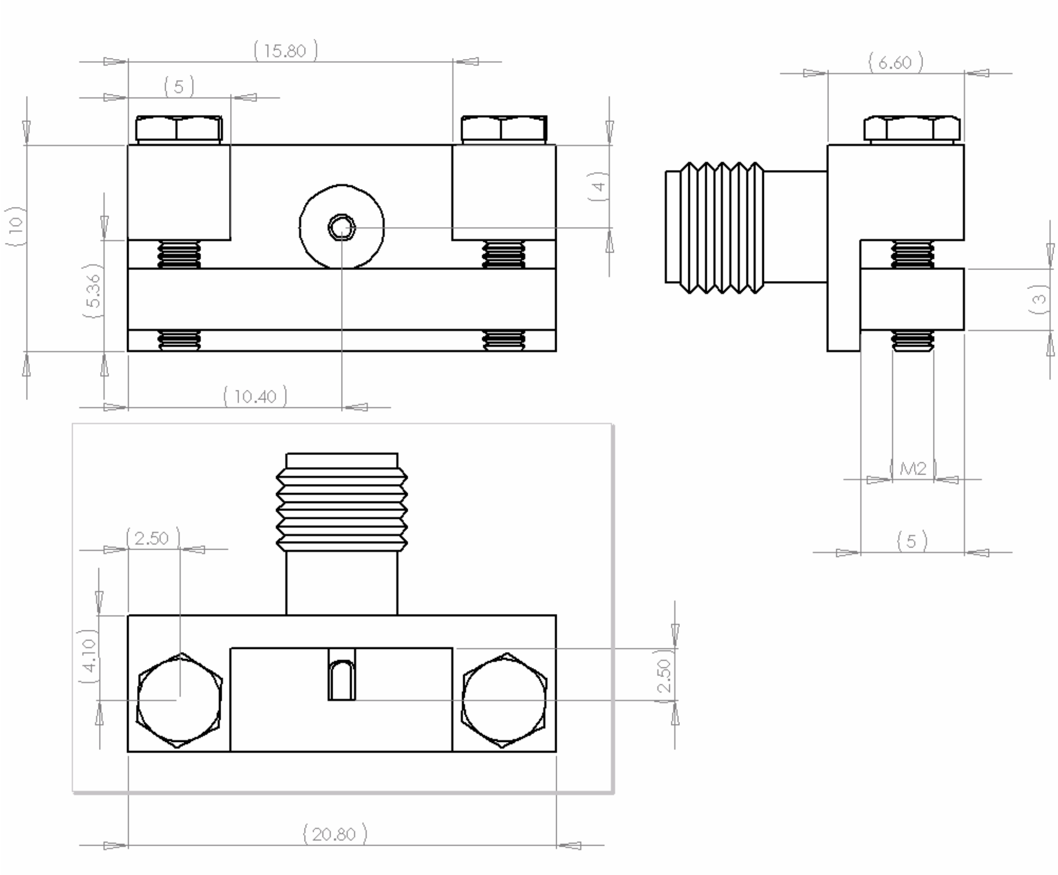


Fig. 6.3 Alternative flange geometry for printed circuit board edge mounting for variable board thicknesses.

Forces

It is required that connector structure can withstand the maximum tensile load allowed for the coaxial cable, which will be joined with the connector. The same requirement goes for the mounting screws of the flange as well. The maximum allowed tensile load for the cable is 270 N. Also the forces during manufacturing (machining) might be critical due to relative small dimensions of the workpiece.

Material

Due to required performance of the connector the following requirements are set for attenuation and insulation:

- Insertion loss < 0.1 dB at 1 GHz and < 0.45 dB at 18 GHz (frequency dependent)
- VSWR < 1.05 at 1 GHz and VSWR < 1.2 at 18 GHz (frequency depenent)
- Insulation resistance > 5 GΩ

There are no special requirements for penetration depth in the material. However the surface roughness of the center pin and the inner surface of outer conductor affect to the insertion loss of the connector and should not be notably higher than the penetration depth.

Environment

This connector should be used mostly at room temperature, but the required environmental requirements at this research are as follows:

- Temperature range from -65°C to +165°C
- Relative humidity from 5 % to 95 %

Safety and ergonomics

To ensure the easy manufacturing of the alternative flange geometry the required space for mounting screws must be checked. There must also be enough room for using the special tool for tightening the threaded connection of the cable.

Production

During this research we will focus to different machining technologies to be able to produce a small series of specialized SMA-type connectors. Materials machinability is therefore in key-role. On the other hand we must ensure that there will be enough space for machining tools. It should also be possible to use necessary fixturing systems and jigs during various manufacturing stages. This aspect will be discusses in chapter 8.

Quality control

The quality of the SMA-connector could be measured by analyzing its performance by using insertion loss and VSWR -measurements with network analyzer in function of frequency. The attenuation measurements of single connector are tricky because of the printed circuit board joint. Hence, measurements should be carried out with connector pairs. Important quality controls to be carried out are the measurements of all critical dimensions of the connectors and the repeatability tests of the connector interfaces.

Assembly
The tightening moment for the cable connection is 0.8 – 1.1 Nm according to connector's standards. The maximum value of tightening moment is 1.7 Nm. If brass is used, the tightening moment is 0.45 Nm.

Recycling
Connector body is made of brass and it could be re-used. Also the center pin is reusable.

Costs
During industrial manufacturing special automated machines are used for connector production. When specialized connectors are manufactured, main costs consists of three main aspects:
- writing the required CAM-data for machining
- manufacturing and quality control of geometries to be used for fittings
- assembly of fitted components (body, insulator and center pin)

6.2 Electrical requirements

Specialized electrical requirements for the SMA connector are presented in table 6.1.

Table 6.1. Electrical requirements.

Material characteristics		Required value
Bulk resistance	Conductivity	> 10^7 S/m
	Resistivity	< 10^{-7} Ωm
Contact resistance	Center contact	< 3 mΩ
	Outer contact	< 2.5 mΩ
Insulation resistance		> 5000 MΩ

6.3 Requirements for attachment

To ensure a proper attachment with center pin of cables and center pin of connectors the dimensions of the pin and its cutting shape are critical. Also the positioning of the center pin is important. At least the requirement of concentricity between the connector body, insulating element and the center pin must be satisfied (see figure 6.4). To ensure the quality of these components also circularity or cylindricity could be used, but only concentricity ensures the right positioning. It might be necessary also to require perpendicularity for the both ends of the center pin related to its longitudinal axis. The geometrical requirements, which in this case are concentricity requirements are presented in Fig. 6.2.

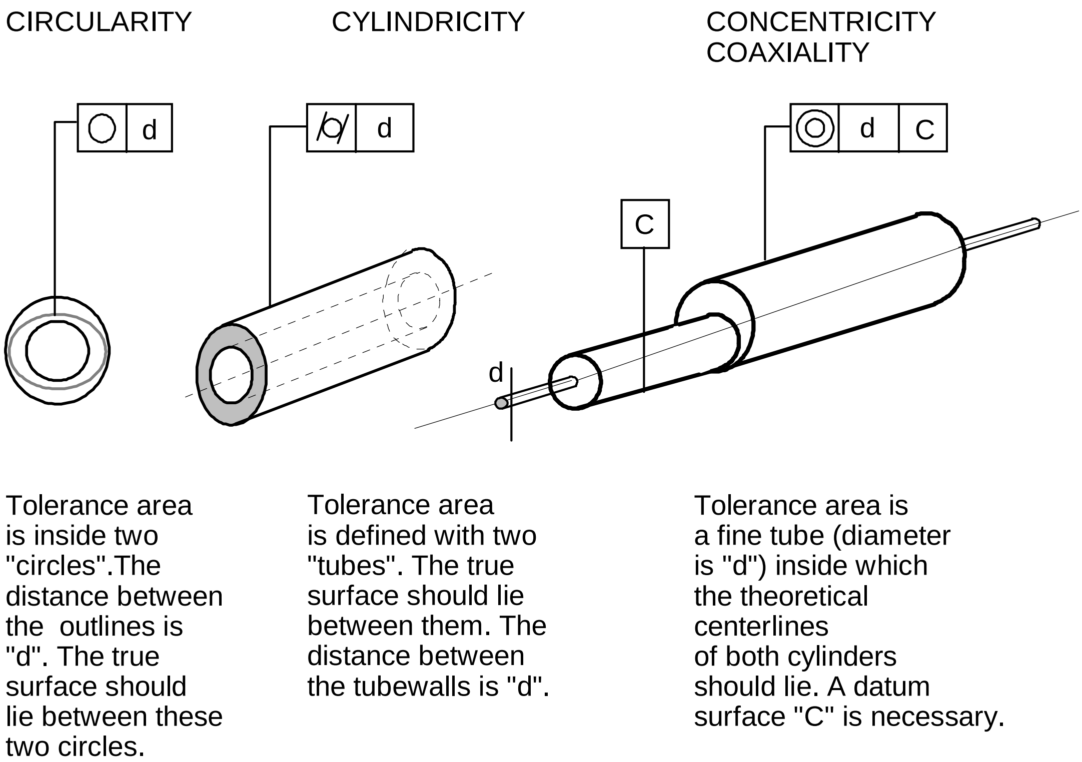


Figure 6.4. Explanation of circularity, cylindricity and concentricity. [4]

Soldering is used for joining the pin, and therefore materials solderability must be checked (related to possible platting of the pin).

Numerical estimation for the required dimensional and geometric tolerances could be estimated from table 6.2 according to the operating frequency range. However, the fittings between the center body, insulating element and the center pin should be selected more likely according to mechanical function of the joints.

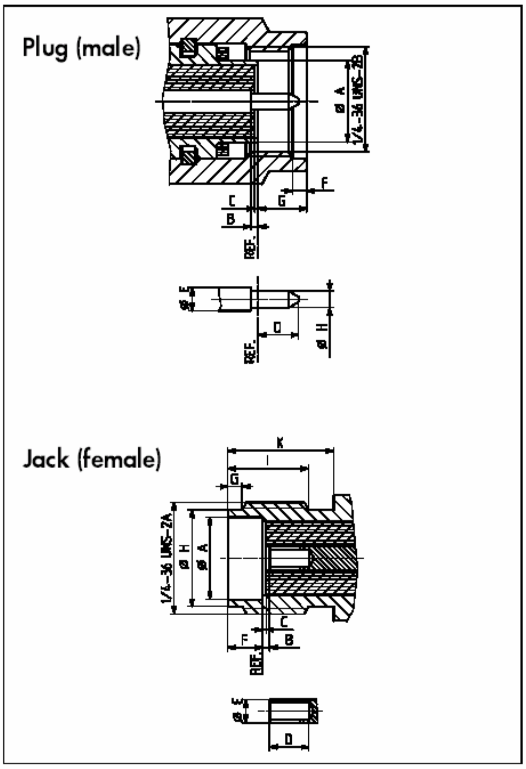
Table 6.2 estimation of the required tolerance grade according to the operating frequency. [4]

Frequency (GHz)	**Surface roughness**	**Tolerance grade**
300-600	0.8 μm	IT5
150-300	1.6 μm	IT6
75-150	3.2 μm	IT7
35-75	6.4 μm	IT8
15-35	12.8 μm	IT9-10

However, the surface roughness of the center pin and the inner contact of outer conductor are critical and should not be notably higher than the penetration depth. The penetration depth at the defined frequency range is dependent of the used material and about few micrometers or less. Therefore the surface roughness of the center pin and the inner contact of outer conductor should be smaller than 0.8 μm.

And what is important to note here- to ensure a proper assembly with other standardized SMA-type components, we should require those deviations of the dimensions, which are presented in SMA-connectors' standard sheets. Some typical values are presented in Suhner's catalogue [1], Fig. 6.5.

INTERFACE DIMENSIONS



INTERFACE DIMENSIONS (MM / *INCHES*)

	Plug		Jack	
	min.	max.	min.	max.
A	--	4.59/*.181*	4.59/*.181*	--
B	0.00/*.000*	0.25/*.010*	0.00/*.000*	0.25/*.010*
C	0.00/*.000*	0.25/*.010*	0.00/*.000*	0.25/*.010*
D	--	2.54/*.100*	2.67/*.105*	--
E	1.24/*.049*	1.29/*.051*	1.24/*.049*	1.29/*.051*
F	0.38/*.015*	1.14/*.045*	1.88/*.074*	1.98/*.078*
G	--	3.43/*.135*	0.38/*.015*	1.14/*.045*
H	0.90/*.036*	0.94/*.037*	5.28/*.208*	5.49/*.216*
I	--	--	4.32/*.170*	--
K	--	--	5.54/*.218*	--

Fig. 6.5. Interface dimensions for SMA-type plugs and jacks. [1]

6.4 System requirements

The alternative flange geometry is used with printed circuit board edge mounting. The thickness of the board varies, and therefore an adjustable mounting mechanism is required. The center pin and especially the ground contacts are critical when the connector interface is intended to work up to 18 GHz. A proper ground contact without discontinuities is required. Also the connector interface should be repeatable and the connector must be mounted always at the same position.

The first edge mounting method is presented in Figs. 3.2 – 3.5. With this method proper contacts are achieved and the mounting of the connector is repeatable. However, the assembly of the connector interface is quite awkward and takes time, because the center pin needs to be soldered and the connector as well as the board must be attached to the holding block with several screws.

One commercially available connector with ease of assembly is Suhner's SK connector 92 SK-50-0-2, but it has some disadvantages and has to be modified to fill the requirements. The connector in Figs. 3.6 and 6.3 is modified to meet the requirements. This method is straightforward with ease of assembly, because only two screws must be tightened and soldering is not essential. However soldering is recommended in order to achieve connector requirements fully.

7 MANUFACTURING TECHNOLOGIES

Production technology consists of manufacturing technology, production systems, automation, quality control and maintenance. This research is focused on the manufacturing technology and especially on manufacturing technologies for parts and assembly. The concentration of the research is illustrated in Fig. 7.1.

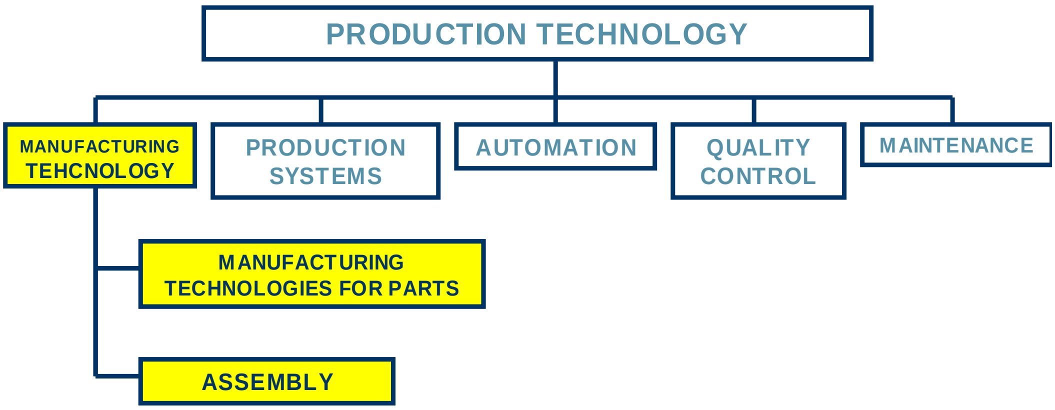


Fig. 7.1. Production technology. The parts that are in focus in the research are marked with the gray background.

The selection of manufacturing technology is applied in conjunction with material selection and with mechanical and other requirements. The machinability of the materials must be observed and a best suitable manufacturing technology for the SMA connector must be selected. The chose of the manufacturing technology depends on the construction materials and the amount of connectors to be manufactured, e.g. casting requires suitable materials and great amount of components to be manufactured, whereas machining can be implemented with most common materials and also with few prototypes. In this research the main interest is in manufacturing of special purpose SMA connector prototypes.

7.1 Alternative manufacturing technologies

The suitable manufacturing technologies for the SMA connector manufacturing are machining and pressure casting, while for example forming, cutting, joining or powder metallurgy are not suitable. The pressure casting is very expensive and requires great amount of components to be manufactured. Adaptability of casting is very poor, because changes in component geometry require new dies and models, which can be noticed as raised costs. Final geometries can be achieved with pressure casting without any additional manufacturing steps. However, in order to achieve required quality aspects usually quality control and surface finishing is needed. Pressure casting requires also materials, which are suitable for casting.

Machining is very adaptable manufacturing technology, only programming and in some cases tool changes are needed when changing component geometry. Hence, machining is useful for prototype manufacturing. Programming, setup and machining process take time, therefore machining is quite slow process. Machining requires also tooling and fixturing systems. In SMA connector manufacturing, machining includes milling, turning and drilling.

Coating is often used on the surface of the SMA connectors to ensure proper surface protection. Commonly used coatings in microwave applications are gold, silver and nickel. Nickel is often deposited under gold plating, because gold is expensive and only a thin layer of gold is used. Thin gold plating is usually easily damaged and causes diffusion of the base material (usually copper) to the surface and thereby leads to corrosion if nickel is not used as a passivating material.

The manufacturing of SMA connector includes also assembly. The dielectric and the center pin must be pressed into the connector body. With the special printed circuit board edge mounting SMA connector also the screws and the movable underneath block should be fastened.

7.2 Material selection

Usually used base materials of the SMA connector bodies are beryllium-copper, hardened copper, stainless steel, brass and spring bronze. Dielectric is usually PTFE or PFA. The center pin needs to be very hard and corrosion resistant material, thus beryllium-copper or hardened brass is used.

Stainless steel is hard and corrosion resistant, but it has a poor conductivity and machinability. The poor conductivity usually restricts the use of stainless steel in higher frequencies. Hardened copper, brass and beryllium-copper have good conductivity and they are machinable. Corrosion resistance of pure copper is poor. Therefore copper alloys like brass and beryllium-copper are used. Brass (CuZn39Pb3) is soft and very easily machined material and the surface quality after machining is good. It also conducts heat and electricity well. The material for the connector body is therefore chosen to be brass (CuZn39Pb3). Properties of CuZn39Pb3 brass can be found from Tables 7.1 – 7.3.

Table 7.1. Physical properties of brass CuZn39Pb3 (UNS C38500). [4], [6]

Melting Temperature	890 °C
Conductivity	48.3 MS/m
Resistance	22 nΩm
Tensile Strength	400 MPa
Modulus of Elasticity (tension)	96 000 MPa
Modulus of Rigidity (torsion)	37 000 MPa
Density	8.47 g/cm^3
Coefficient of Thermal Expansion	20.9 10^{-6}K^{-1}
Thermal Conductivity	122 W/(m·K)
Thermal Capacity	377 J/(kg·K)

Table 7.2. Fabricating properties of brass CuZn39Pb3. [6]

Cold Working Capacity	Poor
Hot Working Capacity	Fair
Hot Working Temperature	700 – 800 °C
Annealing Temperature	425 – 600 °C
Stress Relieving Temperature	250 – 300 °C
Machinability Rating	90 % of free cutting brass (C36000, CuZn36Pb3)
Polishing/Electroplating Finish	Good

Table 7.3 Joining Properties of brass CuZn39Pb3. [6]

Soft Soldering	Good
Silver Soldering	Fair – Good
Brazing (Hard Soldering)	Good
Oxy-Acetylene Welding	Fair
Gas Shielded Arc Welding (GTAW/TIG, GMAW/MIG)	Not Recommended
Coated Metal Arc Welding (Manual electrodes)	Not Recommended
Resistance Welding	Not Recommended

CuZn39Pb3 brass has good corrosion resistance to weathering and fair resistance to water. Free cutting brass (CuZn39Pb3) is significantly improved form of 60/40 brass, with excellent free cutting characteristics. It is used in the mass production of brass components on high-speed lathes where maximum output and longest tool life are required, and where no further cold forming after machining is needed. The superior machining characteristics of CuZn39Pb3 brass are due to the rapid chill effect of continuous casting, which gives a fine uniform lead distribution without segregation, and suppresses the formation of brittle phases which cause tool wear. [6]

Beryllium-copper CuBe2 is suitable material for center pin. There are plenty of different beryllium-copper alloys which all are under the same identification CuBe2. Suitable alloy for the center pin on the SMA connector is the CuBe2 alloy with chemical composition based on ASTM B-197, QQ-C-530 or AMS 4725. The chemical composition of the alloy is presented in Table 7.4. Usually heat treatment is required for maximum strength of CuBe2.

Table 7.4. Chemical Composition of CuBe2 (UNS C17200, from standards ASTM B-197, QQ-C-530). [7]

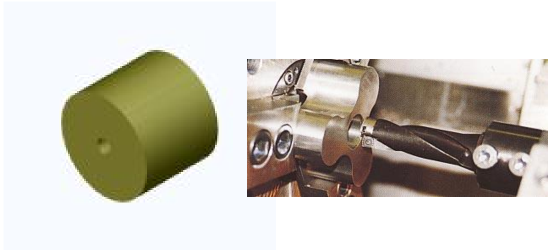
Component	**Weight (%)**
Be	1.8 to 2
Co+Ni	Min. 0.2
Co+Ni+Fe	Max. 0.6
Cu	98
Pb	Max. 0.02

The dielectric material is selected to be PTFE (Teflon). It has excellent resistance to most chemicals and it is very thermostable. Excellent electrical and dielectrical properties independent of temperature range make it suitable material for SMA connector dielectric.

7.3 Machining of SMA connector

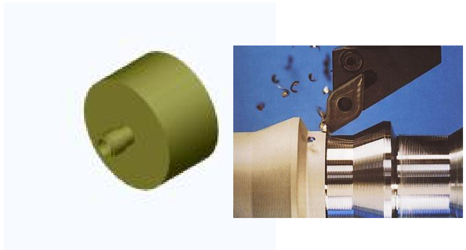
There are different possibilities to machine an SMA connector. If great amount of standardized connectors are manufactured, separate machines for each manufacturing step could be used. Volume production allows specified machining procedures to be used, e.g. several tools can be used at the same time. The interest of this research is in manufacturing of special purpose SMA connectors, therefore the interest is focused on prototype manufacturing with only a few machines. The example chain of consecutive manufacturing stages in SMA connector prototype manufacturing by machining is illustrated in Fig. 7.2.

Stage 1. Cut a suitable billet of round bar



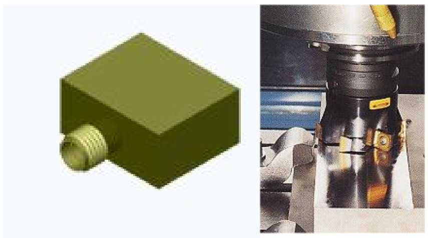
Stage 2. Drill the center hole for the dielectric and for the ground contact in a lathe

Stage 3. Turn in a lathe collar for the male connector and for the thread

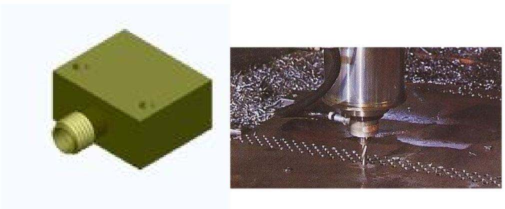


Stage 4. Turn in a lathe the neck for the male connector

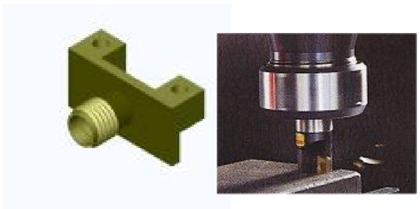
Stage 5. Turn in a lathe the threads for the male connector



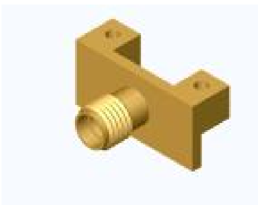
Stage 6. Mill the flange geometry



Stage 7. Drill the holes



Stage 8. Mill the flange to its final geometry



Stage 9. Plate the connector body

Stage 10. Assemble the center pin and dielectric by pressing

Fig. 7.2. Chain of consecutive manufacturing stages in machining of prototype SMA connector body. (Pictures of machining equipment are from [8].)

The connector body milling could be started from e.g. standard brass round bar of diameter 28 mm. The chain of consecutive manufacturing stages in Figure 7.2 includes the machining and plating of the connector body and assembly of the connector. The machining of dielectric, center pin and lower block consist of same kind of manufacturing stages than with the connector body and those are not presented. The center pin milling could be started from e.g. standard beryllium-copper round bar of diameter 3.2 mm and PTFE from round bar of diameter 6 mm.

8 APPLIED DFM(A) –ASPECTS

The design of the component should be carried out with manufacturability and assembly aspects in mind. Applied DFM(A) –aspects can be divided to four main changes considering construction, geometry, material, and dimensions. The main focus in this research due to DFM(A) –aspects is in changes of the construction and the geometry.

8.1 Changes of the construction

Changes of construction are usually related to the selected manufacturing technology. These changes should be made at early design stages to avoid expensive redesigning. This can be provided by simultaneous selection of manufacturing technology with material selection and material, electrical and machinability requirements in conjunction with product, manufacturing and fixturing detail design by using virtual prototyping and CAD/CAM-modelling. In some cases, changes of the construction are also required to ensure easy assembly. The constructional changes are usually quite radical changes of the component geometry or construction.

The mounting of the SMA connector and holding block presented in Fig. 3.5 is quite awkward, but the mounting of special SMA connector in Fig. 3.6 is quick and easy. The changes in construction ease the mounting and use of the connector.

The cable connection of the SMA connector is standardized, which prevents changes of that part of connector. The manufacturing stages and other end of the connector can however be modified. In the special purpose SMA connector manufacturing, the cable end of the connector is manufactured by turning and drilling in a lathe, but the printed circuit board end is manufactured by milling. The assembly of the dielectric and center pin is carried out by pressing, and tight fit is used in order to have better electrical properties and to avoid grooves and notches in the dielectric and center pin. Any fillets or chamfers are not used in order to ease milling. The geometry of the printed circuit board side is also made such a way that it is possible to mill the final geometry from one direction. The assembly of the connector is possible to be carried out from one direction. There is also enough space for mounting tools.

If it is possible to lighten the electrical requirements of the connector, the center pin could be modified to make the assembly simpler and to possible the automated assembly. If only tight fit in center pin assembly is used, it is hard to get the center pin exactly in right position. A little collar in the inner surface of the connector body cable end would ease the assembly of the dielectric in right location and some teeth or lug in center pin would ensure the right location and angle of the center pin. In practice, collars and lugs should be used in order to achieve easy assembly and assured positioning.

8.2 Changes of the geometry

The changes in geometry are usually made to enable the use of standardized tools for machining and cutting. In some cases geometrical changes are done in order to enable reliable fastening during the manufacturing. Geometrical changes are usually quite small changes of dimensions and not so radical as constructional changes.

In the SMA connector construction, much changes of the geometry could not be done, but e.g. the end of the hole in the center pin does not need to be flat and normal drills can be used. Adequate fastening possibilities are also provided with regular surfaces. The standardized dimensions of the connector interface restrict the further geometrical changes.

8.3 Choosing more acceptable material

The choosing of the material is more straightforward in cases where only one manufacturing method is needed. In cases where two or more different manufacturing technologies are needed, it is difficult to make a right compromise between competitive material properties. The most difficult are the cases, where machining and welding or casting and welding are used with the same material. In the SMA connector construction, only machining is needed, therefore the choice of the material based on the machinability is easy. The material selection is however strongly based on the electrical requirements and corrosion resistance of the material.

The selection of the material to the SMA connector is based on the compromise in machinability, conductivity and corrosion resistance of the material. Free cutting brass CuZn39Pb3 has adequate conductivity and corrosion resistance, and it has good machinability. Copper or gold would have better conductivity, but brass CuZn39Pb3 is selected as a base material of the body because of the DFM(A)- and cost aspects. The body and the center pin are anyhow plated with gold in order to ensure corrosion resistance. The center pin of the connector is chosen to be beryllium-copper CuBe2. Choosing more acceptable material for the center pin based on the DFM(A) –aspects would decrease the durability of the center pin, and the electrical and mechanical requirements of the connector would not be attained.

8.4 Detailed changes of dimensioning and tolerances

The detailed changes of dimensioning and tolerances are usually made directly to the technical drawings or other documents. The purpose of these changes is to ease the manufacturing by making it more unambiguous and avoiding further dimension calculation in manufacturing or quality control. Allowed dimensional deviations are written directly after the dimensions and clear dimensioning is used, which does not lead to any further calculations during manufacturing or quality control to establish the required dimensions of the product. The tolerances are not shown with the dimensions, which are not so critical.

The dimensions of the turned parts are presented by showing the remaining dimension and the dimensions of the milled parts are presented by showing the dimensions to be removed from the bulk material. Dimensions and tolerances of specific SMA connector are presented in Figs. 6.2 and 6.3.

9 FLOW CHART OF THE DESIGN AND MANUFACTURING STAGES

The flowchart of the tuned design methodology for machining, which includes manufacturability analysis and tuned analysis for machining, is illustrated in Fig. 9.1.

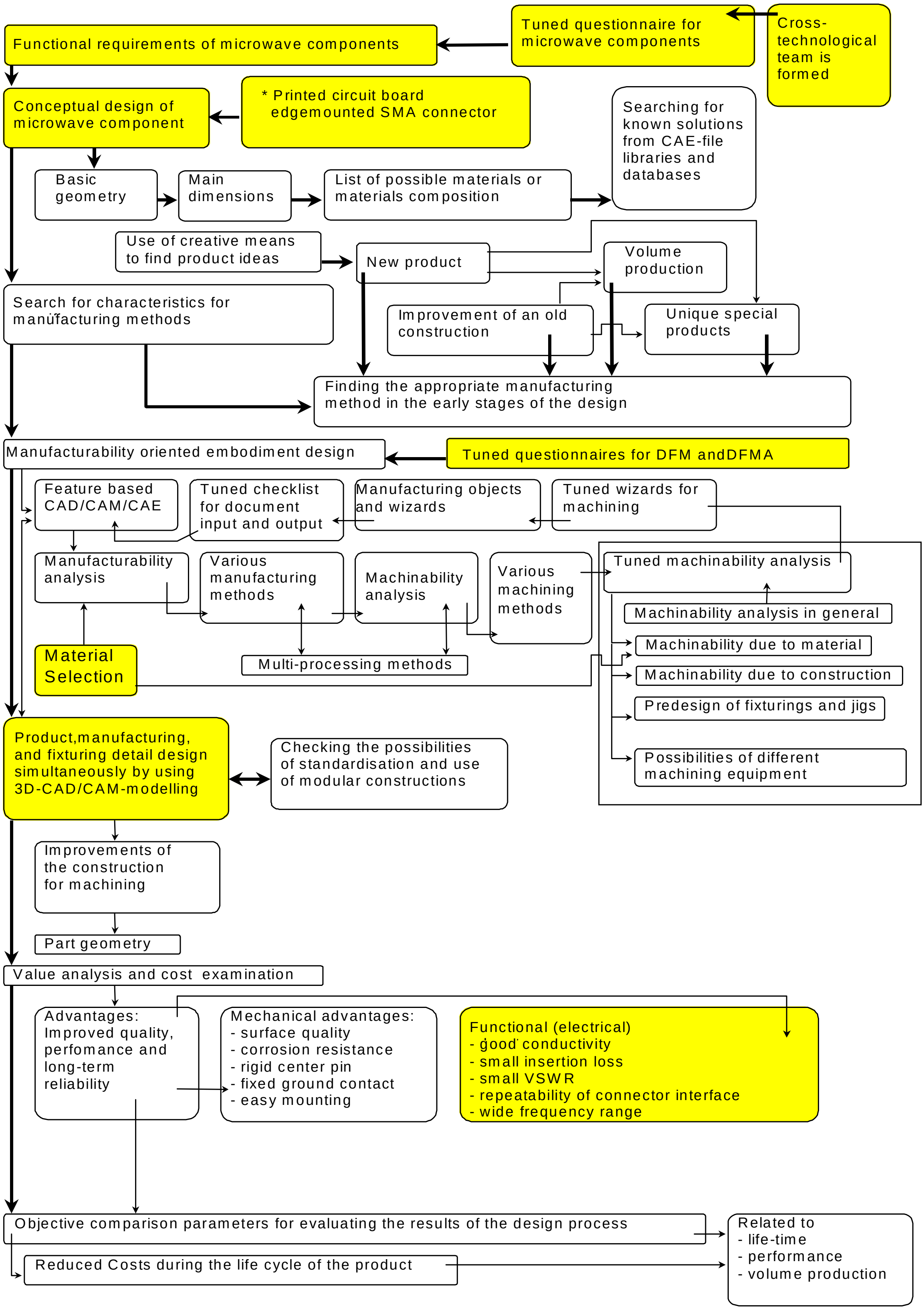


Fig. 9.1. Flowchart of the tuned design methodology of design and manufacturing stages of SMA connector. The most important stages are marked with a gray background. (Based on flowchart in [9])

The tuned methodology begins with collection of requirement list for microwave component and producing new product ideas through creative means. This is the same kind of approach as with traditional systematic design approach. An important part of the design is the stage, where product, manufacturing and fixturing detail design is done simultaneously by using 3D-CAD/CAM-modelling. Teamwork between mechanical designing and electrical designing is needed.

Tuned questionnaires for the SMA connector and for DFM(A) design are in important role, because they give valid information for the manufacturing process and for machining requirements. Material selection is also of great concern, because it affects greatly to the electrical performance and to the machinability of the component. The purpose of the design is to make an application specific component, therefore mechanical and electrical advantages as well as advantages in mounting are as outcome.

10 COSTS ASPECTS OF SMA CONNECTOR DESIGN AND MANUFACTURING

Basically there are four main cost elements, which should be taken into account when evaluating the total costs of a MW- /RF-product: [4]

- design costs
- material costs
- manufacturing costs
- costs spanning over the lifetime of the product

Many MW- /RF- applications include difficult geometries or materials regarding traditional manufacturing processes (e.g. turning, milling or casting). This means that much time is needed to develop the first prototypes to be suitable for production. The design costs of a microwave component can be estimated to be at least double compared to any "non-high-tech" product.

MW- /RF-devices utilize several precious and expensive materials. E.g. gold or silver or some specially mixed powders are needed. It is also usual that the quality grade of alloyed metals used in microwave applications is extremely good and the price therefore higher too. If expensive materials are used their price is essential. In addition to this some of these materials are difficult for traditional manufacturing processes or at least some special arrangements are needed during production. These double the effects of material selection to the price. A direct comparison between a MW- /RF-application and "non-high-tech" product is hard to make, but typically material costs is at least ten times higher. In this SMA connector construction we need these types of expensive materials. Both the connector body and center pin are plated with gold to ensure good conductivity and protection against environmental effects and oxidation. The center pin is a critical part of the connector and very thin, therefore it must be made from very hard material. The dielectric between the center pin and the connector body must have excellent electrical and dielectrical properties, which are independent of used frequency and temperature range. Therefore PTFE must be used.

In general MW- /RF-applications need specialized tooling and fixturing systems and in some applications, depending mostly of the operating frequency, quite tight dimensional tolerances down to 1 μm. These call for some extra time to make a dedicated set-up into the production system. Although the manufacturing stages themselves could be quite cost-effective, the long set-up times and specialized tools and fixturings increase production costs by about 500 to 800 per cent in prototyping or small series production. In high volume production these cost elements are marginal. There is a tight relationship between manufacturing costs and surface roughness. After the specified surface roughness level the costs will increase exponentially. Nowadays in milling and tuning the limit is 0.8 μm and in grinding 0.4 μm. A better surface finish rapidly adds costs. Many MW-/ RF-applications tend to lead to over-estimated dimensional accuracies. The surface requirements may be set too tight to ensure the products performance though an easier way might have been e.g. to change more reliable connectors to the device. The most important thing is to compose the requirements of dimensional accuracy and surface finish from the operating frequency of the device. In this construction the required IT-grade is 9, which means that the critical allowed dimensional deviations are 25 - 30 μm and corresponding required R_a is around 3 – 6 μm. The critical points are the surface of the center pin and the inner surface of the connector body, which required R_a is 0.8 μm.

In MW-/ RF-device production the traditional principles to handle tooling costs, fixed costs, capital costs, labor costs, indirect labor costs etc. are as usual. The main acts should be focused in decreasing the lead-time - that is to minimize the time required to start production.

In many cases also MW-/ RF-components should withstand environmental loads and there is a reason to compare different materials and their lifetimes. This comparison is typically made between two alternatives:

a) common base materials with an appropriate coating, a relatively short lifetime, the product must be changed due to a break-through in the coated surface, relatively cheap
b) specialized base materials, a long lifetime, no changes needed during the lifetime, extremely expensive

To make the comparison a ratio, which shows the price in the form of a "unit" like [performance/ price/ lifetime], is needed. This SMA connector construction should withstand environmental loading. Typical loads are temperature and humidity changes within the defined range, e.g. when performing environmental tests of the products. The connector should also endure more than 500 matings.

Regardless of technology - as long the dimensional accuracy is met with a standardized process - the costs depend only on the manufacturing time. Immediately if there is a need to change the process to ensure a better accuracy or dimensional tolerances the price rises essentially. To manufacture this SMA connector construction standardized processes could be used, only the surface of the center pin and the inner surface of the connector body need a special attention and probably non-standardized processes must be used.

The development process of many high-tech products normally includes several prototype phases and tests before the final design. Unfortunately these prototypes can constitute the largest portion of the total developing costs. To minimize the costs of a prototype several manufacturing technologies could be applied:

- the prototype could be made of some soft materials like foam or plastic by using simple milling or tuning operations
- the prototype could be manufactured by casting but the mould and the casting model are made of some cheap material
- scale models could be utilized
- rapid prototyping could be used (the geometry of the component is laser sintered according to the computer aided model)

One serious problem is that if the prototype is not manufactured with the final manufacturing technology, at least some of the geometrical limits are compromised. E.g. there are important rules for designing a product for casting or powder metallurgy, which are not necessary if the prototype is manufactured by milling or tuning. In practice this means re-designing for final manufacturing, which increases cost. Additionally, the surface quality or dimensional tolerances may have a weak basis if the prototyping scheme relies on a different technology. Based on the results of this research a prototype of the SMA connector construction will be manufactured. We will use simple machining technology, because it is easily adaptable technology and suitable for this kind of SMA connector prototype manufacturing.

Table 10.1 presents the most important cost factors for various groups of manufacturing technologies. In the SMA connector manufacturing, the machining is the most used technology, but pressure casting could also be used with standardized connectors when great amount of connectors are manufactured.

Table 10.1. Cost factors for various manufacturing technologies. [4]

Manufacturing technology	Most important cost factors
Forging processes	- tool and die costs related mostly to complexity of the workpiece
Extrusion and drawing processes	- tool and die costs related mostly to the selected process (e.g. hydrostatic extrusion needs special equipment)
Sheet metal work	- tool costs related to the geometry of the work piece - costs will decrease if several manufacturing stages can be done with a multi-processing machine - nesting makes it possible to use sheet metal material costs-effectively
Powder metallurgy	- die and model costs - manufacturing processes of the powder itself are expensive - finishing processes - quality checking
Casting	- die and model costs - finishing processes - quality checking
Machining	- set-up times - tooling and fixturing systems - programming (tool control)
Joining	- set up times - pre- and post treatment after joining

There are some derived ratios to estimate MW- /RF-component's total costs. These characteristics are describing the effectiveness of production and the investment costs are taken into account as well. Typical ratios could be as follows: [10]

- costs [€] [↓] / attenuation [dB] [↓]
- costs [€] [↓] / gain [dB] [↑]
- costs [€] [↓] / noise figure [dB] [usually ↓]
- costs [€] [↓] / phase error [rad] [↓]
- costs [€] [↓] / lifetime [h] [↑]
- accuracy [IT-grade] [↓] / attenuation [↓], gain [↑] or noise figure [↓] [dB]
- distance between electric components [m] [usually ↓]
- weight [kg] and dimensions [m^3] of the product [usually ↓]

When utilizing these types of ratios the designer calculates e.g. the costs due to changes, which should be made to the product to improve the maximum gain with one single dB-unit. After that the design procedure continues by calculating the cost ratios for attenuation, noise, phase error etc. The arrows [↑ or ↓] after each unit describe whether the aim is to maximize or minimize the corresponding property. E.g. the designer is searching the minimum manufacturing accuracy (IT-grade), which still satisfies the performance requirements of allowed attenuation and noise but yet gives the desired gain level. After having collected all the ratios listed above the designer is able to make a numeric and objective comparison between various product alternatives. For this research topic the most important optimizing ratios are the ratios of costs to attenuation, costs to lifetime and accuracy to attenuation.

11 SUMMARY

In this research, two different types of SMA connector applications for printed circuit board edge mounting are discussed. In some cases the use of standard connectors makes the mounting of the connector interface more tedious and decreases the connector interface optimality. The use of application specific SMA connectors ensure the optimal connector interface and easy mounting. Therefore designing and manufacturing of special connectors and prototypes as well as modifying standard connectors is very important and worthwhile, in order to achieve optimal electrical performance and easy mounting. This is also the reason why SMA connector was chosen to be the subject of this research.

The specific questionnaires for component requirements and machining quicken the manufacturability-oriented design process. These questionnaires and the list of actions to put DFM(A) in practice ease the designing process and serve as a check list to ensure manufacturability aspects during the design process.

Manufacturability analysis for the SMA connector confirmed the importance of the DFM(A) –aspects, when designing microwave mechanics. If the concentration is only in electrical aspects, manufacturability of the component easily declines and the costs increase rapidly. The use of cross-technological design team is highly recommended in order to generate competent design team and to bring forth functionally- and cost-competitive products for microwave applications.

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