CHAPTER 3: DESCRIPTION OF THE PROJECT AND THE COMPONENTS

3.1 OBJECTIVES OF THE DESIGN

The main objective of this design is to obtain a compact SPDT using capacitive MEMS that accomplishes the specifications in Table 3.1. The presented specifications are established by ESA and CEA-Leti in the ESTEC contract 20832/07/NL/GLC. Apart from that, the design should be thought so as to be used in satellites so the technology used for its fabrication must be as simple as possible.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band</td>
<td>11.7GHz to 14.5GHz (Ku-band)</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Whole band</td>
</tr>
<tr>
<td>Maxim Input match (50Ohm)</td>
<td>-15dB</td>
</tr>
<tr>
<td>Maxim Output match (500Ohm)</td>
<td>-15dB</td>
</tr>
<tr>
<td>Minimum isolation between channels</td>
<td>50dB</td>
</tr>
<tr>
<td>Maximum input power</td>
<td>10dBm</td>
</tr>
<tr>
<td>Maximum reconfiguration time</td>
<td>1s</td>
</tr>
<tr>
<td>Temperature range</td>
<td>-20°C to 55°C</td>
</tr>
<tr>
<td>Predicted lifetime</td>
<td>15 years</td>
</tr>
</tbody>
</table>

Table 3.1: Specifications for the SPDT

3.2 DEFINITION OF THE SUBSTRATE AND FABRICATION PROCESS

The specifications of the substrate are given by CEA-Leti foundry. It is a very simple substrate with a Silicon wafer of 500um and high resistivity, and a thin layer (200nm) of SiN ($\varepsilon_r=7.35$, $\tan \delta=0.002$). The switch electrodes are made of Platinum (Pt) and its thickness is 400nm and RF lines are made of Aluminum with a thickness of 3um. Finally the bridge is also made of Aluminum with a thickness of 500nm.

Fabrication process of the Leti metal membrane capacitive switch is described in the attached table.
3.3 MEMS USED IN THE DESIGN

Since the objective of the paper is to develop an SPDT, the design and test of the used MEMS should be done as a previous step. This part of the development was done by CEA-Leti. From these results, a model of the MEMS should be extract so as to simulate its behavior in Momentum. The proposed designs are shown in Figure 3.3.
The main difference between the designs is the central frequency in the DOWN state. This variability is reached changing the dimensions of the bridge and the distances between the anchors of the bridge and the ground plane. As it is known, the enlargement of the width of the bridge (W) will increase the capacitance in both states and the enlargement of the distance between the anchors and the ground planes (l) will increase the inductance.

\[ C = \frac{2lA}{d} \quad (1) \]  
\[ L = 2l \cdot 10^{-7} \times \left[ \ln \left( \frac{2l}{W + d} \right) + 0.5 + 0.224 \left( \frac{W + d}{l} \right) \right] \quad (2) \]

A model for its electromagnetic simulation is done for each design arriving to the conclusion that there is a displacement between the real resonance frequency and the simulated one. It is due to the roughness of the surface of the contact area. The proposed solution is to change the relative permittivity of the dielectric contact (SiN) from 7.35 to 1.5 as it was seen in Chapter 2. This solution allows have an idea of the real behavior of the MEMS and will be used for following simulations and designs.

With the developed models, the equivalent SPICE circuits are computed. These circuits are based on an RLC lumped element with two CPW as it is shown in Figure 3.3. The aim of these equivalent circuits is not only to give to the designer an idea of the dimensions of the MEMS, but also to infer the possible deviations with the measures.

The deviations mentioned before are computed recalculating the equivalent circuit of the measures. The results are presented in Annex 1 and show huge deviations in the capacitance while the inductance keeps similar values. These results reassert the assumption of the change in the permittivity of the contact dielectric.

### 3.3.1 STUDY OF POSSIBLE MODIFICATIONS IN CEA-LETI DESIGNS

As it is seen in Annex 1, the measures of the proposed devices do not match with the specifications presented in 3.1. For this reason, some modifications are proposed for some of the devices. Since the most important problem of the designs is the deviation in the resonance frequency, the modifications are proposed for those designs which have lower resonance frequencies, i.e. AMA.
For the design of the modifications two restrictions are taken into account: dimension of the bridge and losses. The width of the bridge could be enlarged only till 200um, because is the biggest width which has been tested and it requires an acceptable actuation voltage, and insertion losses are limited to -0.5dB. Being conscious of that, two basic modifications are proposed: changes in dimensions of the bridge and the MEMS and insertion of inductive areas in the designs.

**Modifications in AMA design**

Assuming a permittivity of the dielectric of 1.5, it has been seen that the measures match with the simulation. However, the resonance frequency should be displaced till 13GHz (the middle of the Ku-band). With a simple calculus, it is possible to know how much the bridge should be enlarged so as to reach the desired frequency \( f_0' = 13 \text{GHz} \), as is specified below.

\[
\frac{f_{0 \text{ meas}}}{f_0} = \frac{1}{2 \pi \sqrt{LC}} \quad \text{and} \quad f_{0 \text{ desired}} = \frac{1}{2 \pi \sqrt{LC'}}
\]

\[
\frac{f_0}{f_0'} = \frac{2 \pi \sqrt{LC'}}{2 \pi \sqrt{LC}} \rightarrow C' = \left( \frac{f_0}{f_0'} \right)^2 C \quad \text{where} \quad C\text{\textsubscript{Mimux}} = 1.04 \mu \text{F} \quad \text{so} \quad C' = 3.41 \mu \text{H}
\]

\[
C' = \frac{\varepsilon_0 \varepsilon_r A'}{\delta} \quad \text{where} \quad A' = 0.2 \mu \text{m} \rightarrow A' = 51419 \mu \text{m}^2 = L'w' \quad \text{where} \quad L' = 130 \mu \text{m}
\]

\[
w' = 395.53 \mu \text{m} > 200 \mu \text{m}
\]

The computation shows that it is not possible to reach the desired resonance value by modifying only the capacitance. This means that, apart from the enlargement of the width of the bridge to the maximum (200um), the inductance should be also increased. The simplest way is increasing the \( l \) value in (2). So as to reach the desired central frequency (13GHz), the ground planes have been displaced 140um from the original point. The results are shown in Figure 3.4.

With the modifications presented in Figure 3.4, the central frequency is moved to 13.19GHz. At this frequency, an isolation of -41.6dB is achieved while the insertion losses have a maximum value of -0.23dB in Ku-Band.
However, the width of the bridge is too large and it will require higher actuation voltage. If the width is decreased, the capacitance also decreases so the central frequency increases. So as to compensate this increase in the central frequency, the inductance should be increased which implies an enlargement of the ground planes. In Figure 3.5 the new modification is shown.

Figure 3.4 Comparison of the results of the simulation of the bridge with (red) and without (blue) increasing the inductance both in DOWN state

Figure 3.5 Comparison of the results of the simulation of the bridge W=200um and L=1280um (red) and W=100um and L=1460um (blue) both in the DOWN state
In the latest modification the size of the MEMS has been increased in 180um but the desired frequency is not reached. The frequency reached is 16.23GHz with less than -40dB. Moreover, the Insertion Losses increase that means that if the size is increased more, the losses will increase also. For this reason, this design is not appropriate for the specifications.

Another solution for the enlargement of the inductance could be inserting a meander between the anchors and the ground planes. The width of bridge that has been used is 130um predicting a central frequency of 11.77GHz. However, these kinds of structures have higher losses. In Figure 3.6 the designed meander is showed.

![Figure 3.6 Layout and results in DOWN state of the design with meanders](image)

Despite it has been seen that the design in Figures 3.5 and 3.6 are not useful, they have shown that another type of enlargement of the inductance could be a solution. In [1] it is proposed to add an inductive beam into the bridge. Using a width of bridge of 130um, the design showed in Figure 3.7 is designed. The obtained central frequency is 12.88GHz with a maximum input matching at -45.37dB in the central frequency and under -20dB in the Ku-Band.

![Figure 3.7 Layout and results in DOWN state of the design with meanders in the bridge](image)

Finally, the last proposed modification is the elimination of the inductive line in the entrance of the MEMS. Originally this part was designed so as to improve the input matching of the MEMS, but for the SPDT this can be solved using other techniques. At the same time, the
modification will imply a smaller distance between the bridge and the ground planes. In Figure 3.8 both designs and their simulation results can be seen.

![Figure 3.8: Layout and results of the MEMS with (blue) and without (red) inductive part](image)

**Comparisons between the proposed designs**

Since now, five different modifications have been proposed. The aim of each modification was to adapt the basic design (AMA) to the Ku-Band. However, it has been seen that improving on characteristic of the MEMS, another one gets worth. In this part, these agreements are treated arriving to de design which will be used in the SPDT.

Concerning about the input matching, all the designs present good performance. The worst one is the one presented in Figure 3.6 whose S(1,1) parameter is 0.5dB under the others. On the other four designs, the input matching values are similar, no huge differences are appreciated.

Referring to the size of the MEMS, those ones with bigger bridge will need a higher actuation voltage to counteract the spring constant. This means that the design presented in Figure 3.4 will need a bigger actuation voltage than the other. On the other hand, design in Figure 3.6 will need the smallest one due to the designed meander [1]. The design in Figure 3.5, despite
having a small bridge, is the biggest one in terms of size due to the enlargement of the inductive parts while the design in Figure 3.8 is the smallest one.

The last reference parameter is isolation. In this case the design in Figure 3.6 presents the worst value, -20dB, while the others present similar results. A maxim isolation about -40dB is achieved in the central frequency in Figure 3.4 and 3.5 while in Figure 3.7 and Figure 3.8 it is -45dB approximately.

3.4 CONCLUSIONS

With the three parameters compared before, it is concluded that the most suitable modifications for the designs are Figure 3.5 and Figure 3.8. One of the reasons is that they present a good agreement in terms of isolation and input matching. The other one is that they do not require very sophisticated structures as meanders. However, the design in Figure 3.5 is quite big. For this reason, it will be reduced to L=1280um and the tuning to the desired frequency will be done by the matching network.

The reason why the big bridge was discarded is that it will introduce a higher probability of mechanical failure. Since the contact surface is bigger, is more difficult to reach planarity in the surface contact area. Moreover, the actuation voltage should be bigger which is usually not possible for spatial applications.

The solution of the meander on the bridge was discarded for its complexity. Since the aim of the SPDT is to work in the space, structures should be as simple as possible so as to resist extreme conditions. The sharp corners are not suitable for space applications because this usually implies accumulation of charges which can due to stiction failures. However, this design could be interesting for other kinds of applications since they present one of the best results of the modifications.

In the following chapter, the design of the SPDT is exposed using the mentioned modifications.
REFERENCES