

LOW LOSS POWER DISTRIBUTION NETWORK IN STRIPLINE TECHNOLOGY FOR PLANAR ARRAY ANTENNAS

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Abstract—Nowadays low profile passive array antennas are being more and more used substituting traditional parabolic antennas in satellite communications. To achieve a good efficiency in printed arrays it is necessary to use a low loss network. A shielded suspended stripline is proposed in this paper. The main aim of this network is to distribute the power among subarrays in an array antenna with minimum losses. Several vertical transitions to subarrays are shown besides some network designs for square arrays at X band.

1. INTRODUCTION

Losses in the usual printed technologies such as microstrip are very large in X band [1, 2]. This makes it difficult to fulfill with the necessary efficiency of the ITU-R recommendation for ground stations [3].

One solution to meet with the required efficiency is to use a radial line slot antenna [4]. The problem is that this antenna only radiates with one circular polarization and is not versatile for future improvements. Another solution is to reduce the power distribution network length as much as possible using a serial distribution network [5]. The problem here is that the bandwidth is reduced and it is not possible to cover the whole X band.

The solution chosen in this paper is to divide the array antenna in subarrays and use a low loss power distribution network to distribute the signal among these subarrays. Thus, the subarrays could be done in regular printed technology allowing to have phase shifters, hybrid

Received 11 June 2013, Accepted 10 August 2013, Scheduled 13 November 2013

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circuits and other devices on them. On the other hand, the power distribution network must be done in a technology with low losses.

Traditional waveguide technology could be an option for a low loss distribution network. The problem is that the width of waveguides is larger than the width of printed networks, making it difficult to design a complex network. Another problem is that it is critical to assure a good contact in waveguide technologies, making the network more expensive and heavier. Substrate Integrated Waveguides (SIW) could be an option [6]. The problem at X band is that the ratio between the width of the waveguide for supporting the TE mode and the height of the usual commercial substrates is large. This makes the design of vertical transitions more difficult. Moreover, the losses in SIW would be larger because all the wave is confined in a region with dielectric losses. Thus, to reduce the conductor losses in printed technologies, the height or the distance between the line and the ground plane must be increased.

To increase the distance between the line and the ground plane in microstrip technology, we can use either a higher substrate, increasing the weight and the price of the antenna, or a suspended microstrip, using foam to separate a thin substrate from the ground. The disadvantage of microstrip technology is that besides the conductor and dielectric losses, the line also has radiation losses. This sets a limit in the minimal losses that can be achieved in the microstrip as it is shown in Figure 1 [2]. Moreover, increasing the distance between ground plane and line, the coupling between lines and the influence of near objects are also increased. On the other hand, in stripline technology there are not radiation losses, therefore the total losses can be reduced more than in microstrip technology.

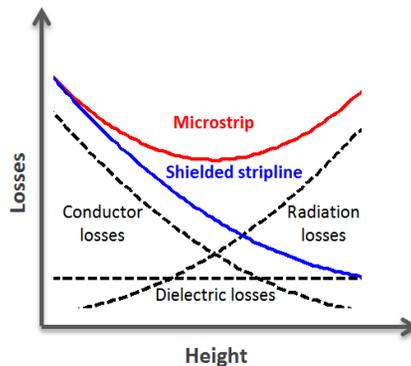


Figure 1. Losses in printed technologies.

2. SHIELDED STRIPLINE TECHNOLOGY

The line of the stripline is printed in a thin substrate. The substrate is a RO4350B with a height (h_s) of 0.254 mm. This substrate is supported by foam sheets or metallic walls screwed to the two ground planes as shown in Figure 2.

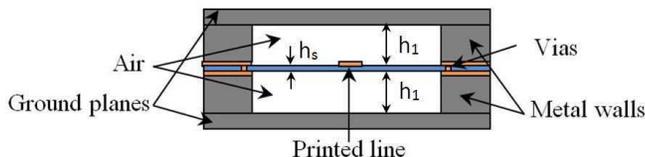


Figure 2. Shielded stripline scheme.

As it has been commented in Section 1, the stripline losses can be reduced increasing the distance between the ground planes and the printed line. Figure 3 shows the simulated losses for a stripline varying this distance (h_1). As it is shown the losses can be reduced until certain limit in which increasing the line height does not reduce the losses significantly. For this reason a height of 2 mm has been chosen as a trade-off between low losses and low profile. For this height, the line width for an impedance of 50Ω is 5.5 mm.

The main mode in asymmetric striplines is a Quasi-TEM since there are two dielectrics, the substrate with the printed lines and air or foam. Since the ratio between the substrate height and the air/foam

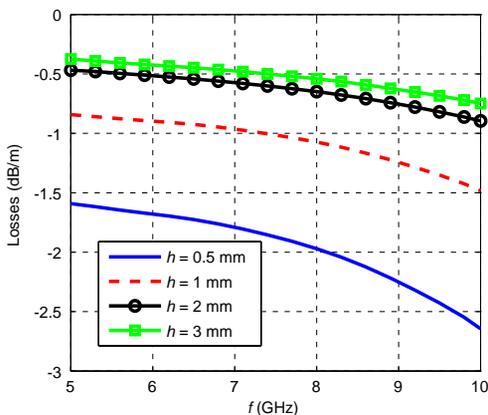


Figure 3. Losses per meter increasing the stripline height (h_1).

height are usually more than ten, the permittivity is very close to the permittivity of the foam/air. Biplate TE modes are also supported in stripline technology. These modes are especially generated in the vertical transitions and in some discontinuities in the line. These TE modes can be cut off with metallic walls along the line as in Figure 2. In this case, the stripline is called shielded stripline. The distance between walls must be large enough for not interfering with the dominant Quasi-TEM mode and small enough for cutting off the biplate TE modes. The selected distance between walls to cut-off TE modes is 14 mm.

The global input/output of the power distribution network is done through a standard SMA connector, therefore a stripline to SMA transition must be designed (Section 3). To connect each subarray to the power distribution network pluggable connectors are used, there are two options described in this paper: a solution based on commercial connectors (Section 4.1) and a solution based on ad-hoc connectors (Section 4.2). To distribute the power from the input to the outputs regular T-dividers are used (Section 5). Some designs of power distribution networks are shown in Section 6.

3. TRANSITION TO SMA CONNECTOR

The designed transition is shown in Figure 4. The stripline ground planes are hidden to show the inner part. The inner conductor of the coaxial connector is soldered to the line. The transition is shielded with a metal structure. The dielectric of the coaxial connector (PTFE) is introduced inside the stripline until the substrate where the line is printed.

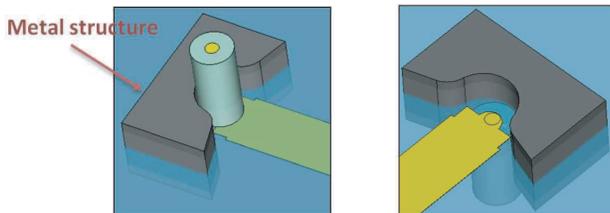


Figure 4. SMA transition.

Since the height of the stripline is large, the transition from the TEM mode in the coaxial to the Quasi-TEM mode in the stripline has to be done smoothly. That is why the edge of the metallic piece that shields the transition has to be rounded as it is shown in Figure 5. The corners in the piece have to be also rounded in order to avoid

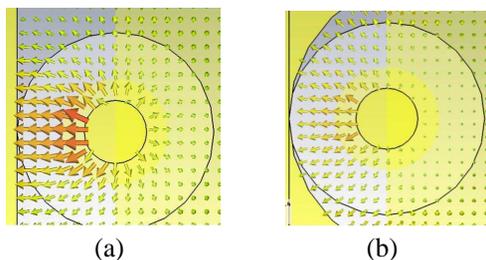


Figure 5. Cut of the SMA to stripline transition. (a) With square end. (b) With circular end.

diffraction. A small segment of stripline with a different width is used at the beginning of the transition to improve the matching.

Figure 6 shows the matching of a SMA-stripline transition. The influence of the solder process is critical and has to be done carefully in order to have a good matching.

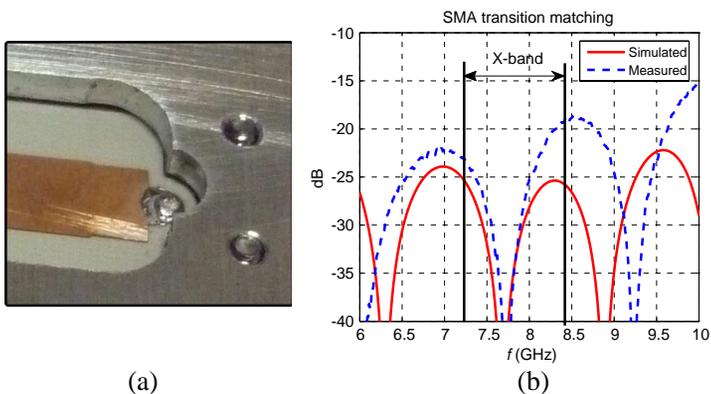


Figure 6. SMA to stripline transition. (a) SMA-stripline transition. (b) Measured matching of (a).

4. TRANSITIONS TO SUBARRAYS

In most of the cases the subarrays will be above the stripline. For this reason a vertical transition or a transition to a SMP connector is necessary.

These vertical transitions have to be pluggable in some way because nothing can be soldered between the subarrays and the power

distribution network since the distance should be small in order to have a low profile antenna.

Two approaches to connect subarrays and power distribution network have been followed. The first one is to use commercial SMP coaxial connectors (pluggable connectors) and the second one is to design an ad-hoc vertical transition.

4.1. Stripline-coaxial SMP Connectors

Usually SMP connectors are meant to be placed in regular microstrip technology with a small line width. Thus, it is necessary to design a transition between stripline and microstrip.

This transition has to be designed very carefully since the ratio between the width of the stripline and the width of the microstrip is close to ten. This ratio causes to appear a capacitive reactance between the line and ground that increases the reflection. Two ways has been followed to design the microstrip-stripline transitions.

The first way is shown in Figure 7. To compensate the capacitive reactance that appears because the line width change, a small short high impedance stripline is introduced. This line represents an inductor that cancels the capacitance in the discontinuity. This can be easily done prolonging the microstrip line into the stripline as it is shown in Figure 7(b).

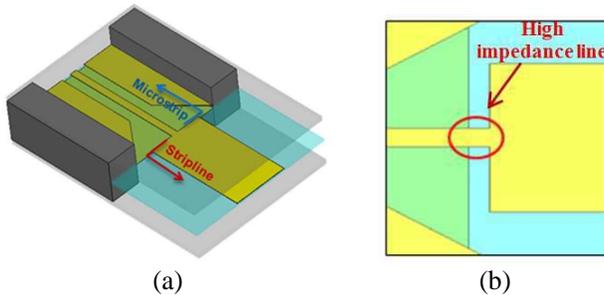


Figure 7. First stripline-microstrip transition.

The measured results compared to simulations for the first kind of transition are shown in Figure 8(b). The matching is below -20 dB in frequencies lower than 6 GHz and below -12.5 dB in frequencies between 6 and 10 GHz. The results are not good enough for the X band because the influence of the capacitive reactance caused by the change of the line width increases with frequency. For this reason, it is not

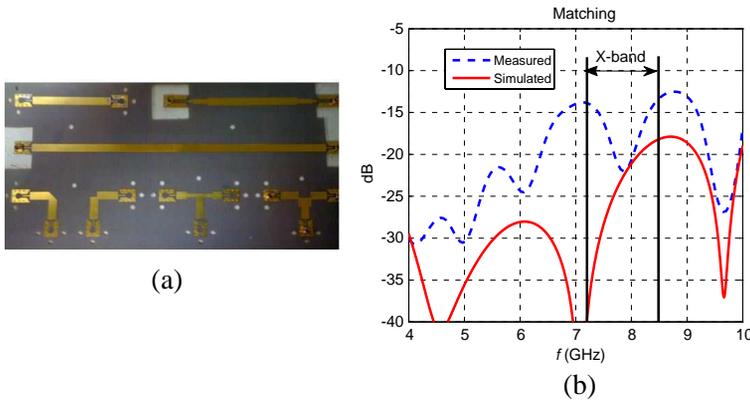


Figure 8. Realized first strip to microstrip transition. (a) Board with the 1st transitions. (b) Measured matching of the first transition.

possible to compensate the capacitive reactance with the small high impedance line in higher frequencies.

A similar microstrip-stripline transition is shown in [7]. The achieved matching at X band is very similar to the matching presented in this paper.

The second way of designing the stripline to microstrip transition is to reduce the line width gradually. The stripline width is reduced changing the impedance of the stripline from $50\ \Omega$ to $70\ \Omega$ as it is shown in Figure 9. In this way, the capacitive reactance that appears with the change of the line width is reduced. Then, this change has to be reverted in the microstrip network where the SMP connector is soldered. To change the impedance a $\lambda/4$ adapter is used.

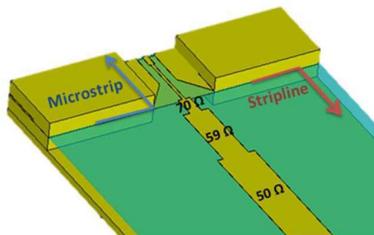


Figure 9. Second strip to microstrip transition.

Several prototypes of the second transitions have been manufactured. The total losses of the transition can be divided in three parts: the SMP connector, the small microstrip line and the stripline. The

measured losses for a stripline with two transitions (Figure 10(a)) are 1.3 dB for 50 mm stripline length and 1.2 dB for 25 mm stripline length. This means that most of the losses are due to the SMP connectors and the small microstrip networks.

Therefore, the losses in the SMP connectors plus the stripline-microstrip transition are around 0.6 dB. The measured matching compared to simulations is shown in Figure 10(b). The matching is better than -20 dB in the X band.

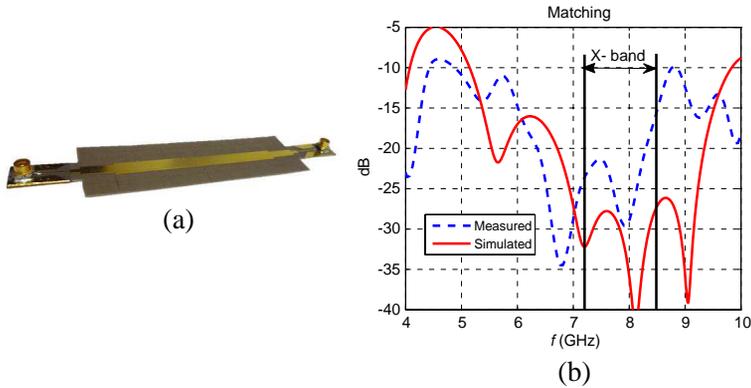


Figure 10. Results of the second Strip to Microstrip transition. (a) Second strip-microstrip tran. (b) Measured matching of (a).

4.2. Ad-hoc Connectors

To reduce the losses in the SMP connector an ad-hoc connector is designed. The main aim of this connector is to connect the stripline to a microstrip without metal contact between the inner conductors.

The connector has two parts. The first part is a coaxial line with an inner conductor of 3 mm diameter, this inner conductor is supposed to be soldered to the stripline. The second part is a smaller coaxial line with an inner conductor with a diameter of 1.3 mm, similar to a commercial SMA transition, the inner conductor of the second part is supposed to be soldered to the subarray microstrip network. Both coaxial lines have PTFE as dielectric. A scheme of the connector is shown in Figure 11.

To achieve the continuity between the two inner conductors a virtual short circuit is used. Therefore, the smaller inner conductor surrounded with PTFE penetrates $\lambda_g/4$ inside the bigger inner conductor. Since at the end there is an open circuit, $\lambda_g/4$ before there is a virtual short circuit between the two inner conductors. To

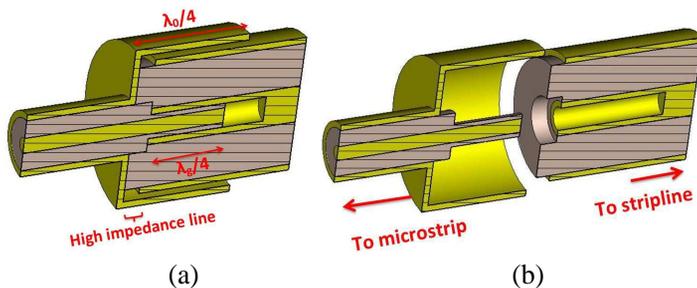


Figure 11. Ad-hoc connector model design. (a) Plugged. (b) Unplugged.

improve the matching, a small length of coaxial with high impedance is used. To achieve the high impedance line the smaller inner conductor is extended into the bigger coaxial connector.

The coaxial grounds could be coupled in the same way than the inner conductors. The only difference is that there is not PTFE between the coaxial grounds so the distance is now $\lambda_0/4$.

The first manufactured prototype of the connector is shown in Figure 12. The prototype is a through with two connectors in both ends.



Figure 12. Ad-hoc connector prototype. (a) Plugged. (b) Unplugged.

The measurement of the first prototype are shown in Figure 13. The matching is bellow -18 dB in the X band. The maximum losses are 0.25 dB in the X band. The losses are lower than the commercial SMP connectors losses that are around 0.3 dB for each (0.6 dB for the through with two connectors).

Figure 14 shows a stripline through with the ad-hoc connectors. The transition from stripline to the ad-hoc connectors is very similar to the transition to SMA presented in Section 3. The losses are lower than 0.2 dB in the X band. Compared to the through with SMP connectors the losses are much lower.

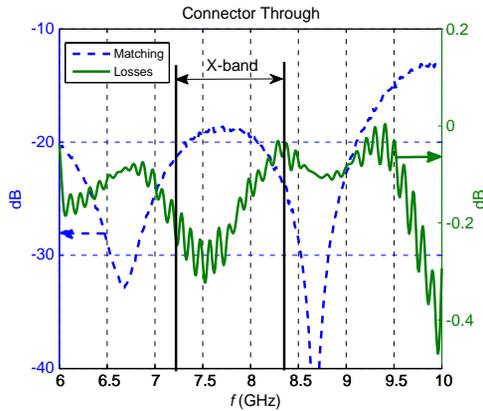


Figure 13. Measurement of the first ad-hoc connector prototype.

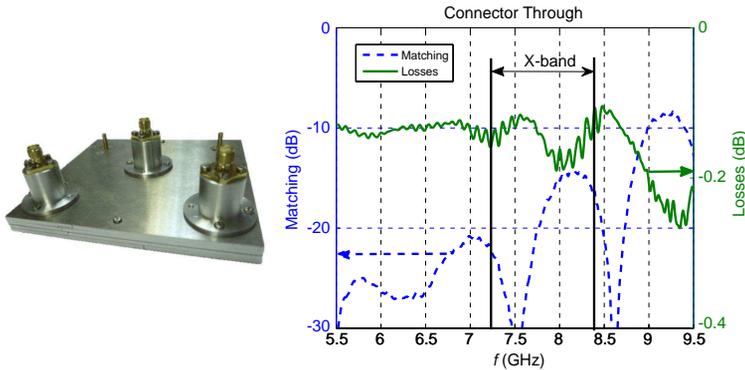


Figure 14. Stripline with ad-hoc connectors.

5. POWER DIVIDERS

Two things must be taken into account for the design of regular T -dividers in these networks.

The first issue is that a V-shape cut must be done in the main arm of the T to match the divider as it is shown in Figure 15(a). Similar T -dividers with rectangular cut can be found in [8]. The second point is that multi $\lambda/4$ adapter is used instead of one single adapter. This is possible because the distance between outputs is usually larger than λ_0 since the network feeds subarrays with several elements on them. The impedance variation used in the designs is a binomial distribution taken from [9].

In Figure 15(b) is shown the simulated S -parameters of an asymmetric power divider. It has a good matching in a large bandwidth because of the use of multi section $\lambda/4$ adapter.

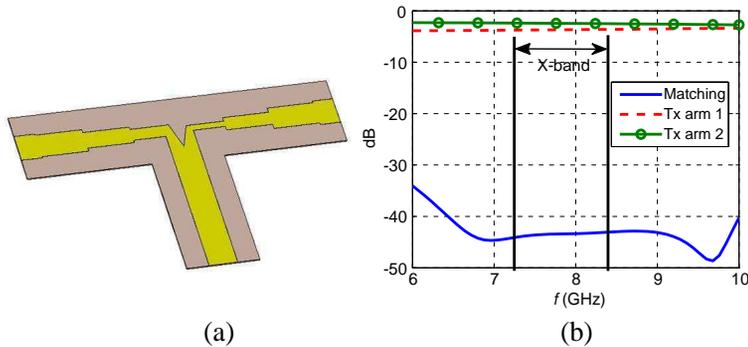


Figure 15. Power divider. (a) Model. (b) Simulation results.

6. EXAMPLES

Some of the networks designed using shielded stripline technology are shown in this section.

6.1. First Example

The first design is shown in Figure 16(a). This network is used to distribute the power to an antenna of 4 by 4 subarrays. In this design only the transitions are shielded. Figure 16(c) shows the measured outputs of one quadrant. As it can be seen there are peaks in the transmissions because TE modes are excited not only in the transitions but also in some other parts of the network.

To solve this problem, all the network is shielded as it is shown in Figure 16(b). Figure 16(d) shows that the peaks of the previous network have disappeared.

6.2. Second Example

The second design consists in two networks of 3×3 outputs with tapering. Each network is for one polarization. In this case, since all the outputs need to have the same phase, meander lines have been used to compensate paths. To avoid the problems detected before with TE modes, the line has been shielded with metallic walls as shown in Figure 17. The input of this network is done through a SMA connector and SMP connectors are used to connect the network with the subarrays.

As it is presented in Figure 18(a), the matching for the two polarizations is better than -15 dB in the whole X band. Figure 18(b) shows the outputs for one polarization. The transmissions show that the tapering is well done since the corner subarrays (C) receive in

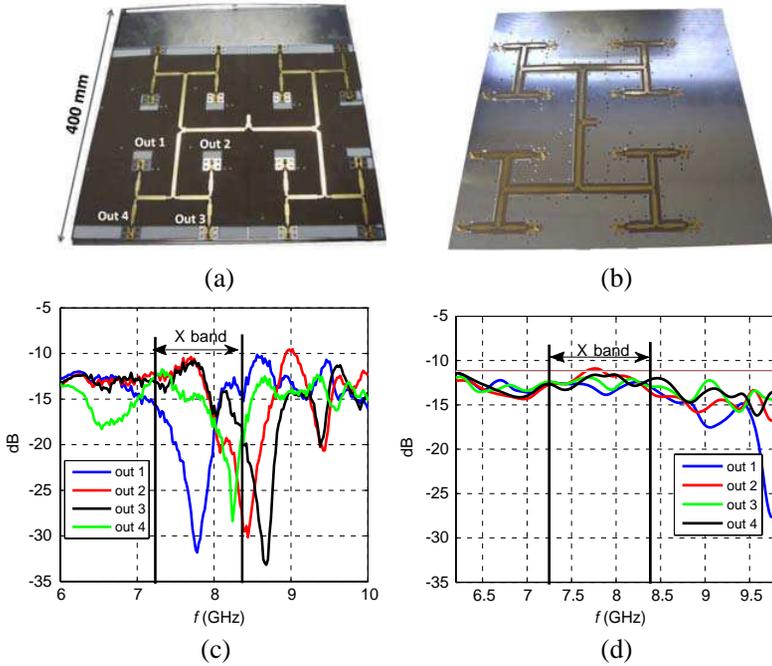


Figure 16. First example of power distribution network. (a) Without shielding the line. (b) Shielding the line. (c) Outputs of (a). (d) Outputs of (b).

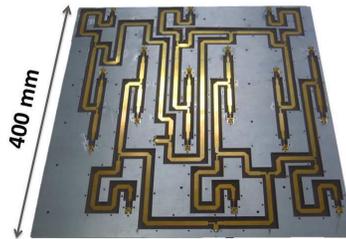


Figure 17. Second power distribution network.

average 1 dB less than the edge subarrays (B) and 2 dB less than the one in the center (A).

The losses of the second power distribution network for both polarizations are shown in Figure 19. The losses are below 1.5 dB for one polarization and below 2 dB for the other one.

The antenna in which the second design is used can be found in [10].

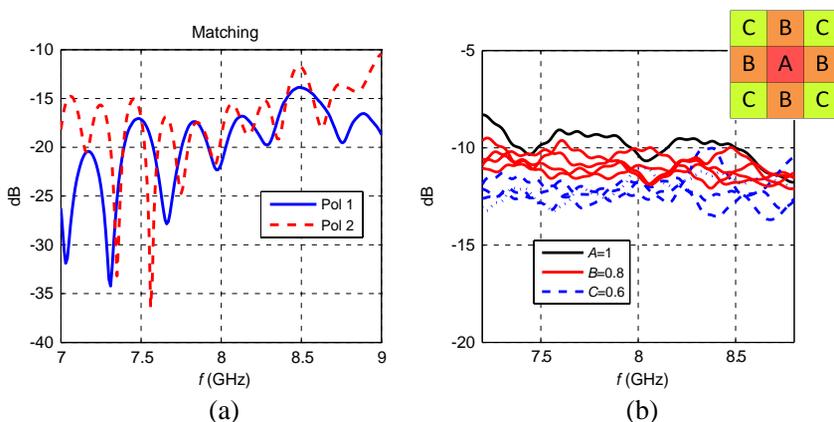


Figure 18. Measured matching and transmissions for the second design. (a) Matching. (b) Outputs.

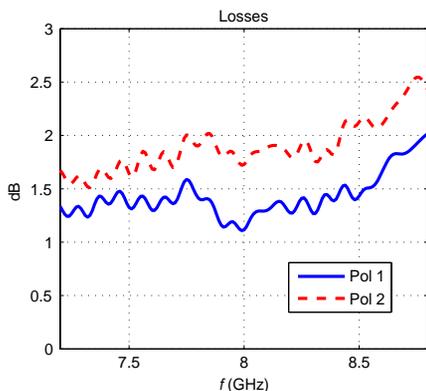


Figure 19. Losses of the second power distribution network.

6.3. Third Example

The third design is a network for an array of 2×2 subarrays. The size is 200×200 mm. There are two main differences with previous prototypes. The first difference is that in the third design the ad-hoc connectors presented in Subsection 4.2 are used. The second one is that sequential rotation technique is used, meaning that each subarray is rotated 90° and the feeding network compensates this rotation with a phase shift of 90° as it is shown in Figure 20(b). The sequential rotation technique is applied for improving the polarization purity of the antenna.

The matching and losses of the network are presented in Figure 21(a). The matching has been moved to lower frequencies. Even though the matching is below -14 dB in the X band. The losses are lower than 0.6 dB in the X band. Compared to the second example of power distribution network (Section 6.2) the losses are lower for two reasons: the use of ad-hoc connectors instead of commercial SMP connectors and the omission of the small microstrip network to place the SMP connector.

The phase of the transmissions are shown in Figure 21(b). The difference between each output is 90° in the center frequency.

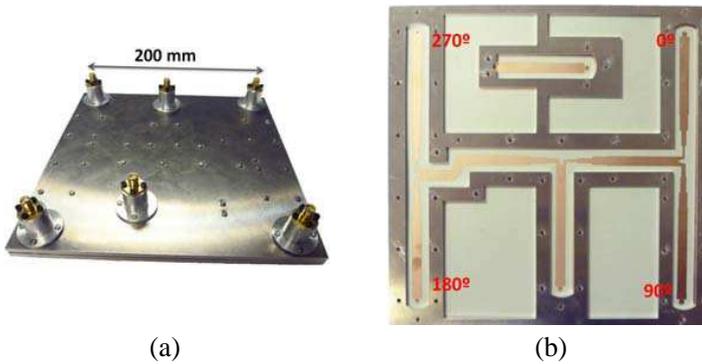


Figure 20. Third design.

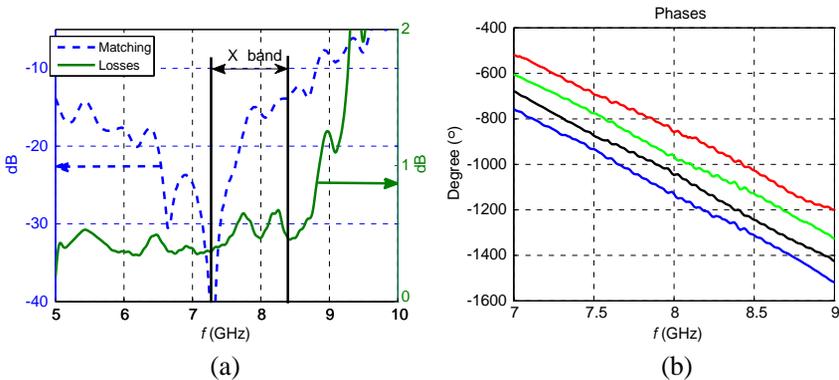


Figure 21. Third design measurements. (a) Matching and losses. (b) Output phases.

7. CONCLUSIONS

Practical designs of low losses power distribution networks in shielded stripline technology have been presented. The most critical point in the design is the vertical transition to subarrays. First designs use commercial connectors. Although the matching is good, the losses in the transitions are comparable to the losses in the whole network. For this reason a pluggable ad-hoc connector has been designed and tested, showing good results. Three prototypes have been shown. Some problems with the propagation of TE-modes were detected in first prototypes. These problems are solved shielding the line in next prototypes. In third prototype, the losses are reduced because of the use of ad-hoc connectors. The weight of the distribution network can be reduced in future prototypes substituting the metal inner parts by lighter materials as plated plastic.

ACKNOWLEDGMENT

Simulations done in this work have been realized using CST Microwave Studio Suite 2013 under a cooperation agreement between Computer Simulation Technology (CST) and Technical University of Madrid. The project is supported by Spanish Education Ministry (Comisión Interministerial de Ciencia y Tecnología) under reference TEC2011-28789-C02-02 and by an UPM grant.

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