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On the Feasibility of the Complementary Strip-Slot Element to Build Planar Series-fed Arrays

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***Abstract* – In this contribution, the main characteristics of the so-called complementary strip-slot radiating element are reviewed and its feasibility for building planar series-fed arrays is analyzed. This microstrip radiator was recently introduced by the authors as a modified microstrip-fed slot that presents wide impedance bandwidth. The main aspects to be considered when building series-fed arrays with the strip-slot element are studied and two different array configurations are described as examples of its potential: a linear traveling-wave array with full-space frequency-scanning capability and a ring array with circular polarization at multiple bands.**

***Index Terms* – Broad matching, microstrip, slot, radiation, series-fed array.**

I. INTRODUCTION

Microstrip antennas are one of the most common solutions for many of the current and emerging applications, due to the numerous advantages of the planar technology. However, the most common microstrip radiating elements (patches and slots) suffer from two drawbacks: a limited matching bandwidth and low radiation efficiency compared to other antennas. In order to avoid the latter problem, normally several elements are combined in an array configuration. For the narrowband matching problem, many solutions are proposed in the literature, but most of them have a complicated design and do not enhance the impedance bandwidth that much.

The authors proposed in [1] a novel radiating element in microstrip technology that overcomes the narrowband matching of the traditional microstrip radiators. It is based on a conventional slot with the incorporation of a strip in the microstrip layer. This element is broadly matched and has a series-fed configuration that makes it suitable for building series-fed arrays. This kind of arrays has the advantage of simple feeding network, with less spurious radiation from the feeding lines, compared to corporate arrays.

This contribution studies the potential of the so-called complementary strip-slot radiator as a series-fed array element.

II. THE COMPLEMENTARY STRIP-SLOT ELEMENT

The proposed element consists of a slot etched on the ground plane of a microstrip, which is modified by adding a stub aligned to it on the microstrip layer. The microstrip line is terminated by a matched load. This structure presents a significantly-enhanced impedance bandwidth compared to the conventional microstrip-fed slot. This is achieved thanks to the coupling section that the strip and the slot make up. A feature of the microstrip-slotline coupling is that, under low coupling, the even and odd modes are almost independent, since the even mode is similar to that of the microstrip line (without the slot) and the odd mode to that of a slotline (without a strip over it). Therefore, the modes can be controlled separately. On the other hand, in the proposed struture, the microstrip-slotline section corresponds to a C-section of a Schiffman phase shifter [2]. Taking into account the aforementioned characteristics of the strip-slot section, its image impedance can be written as follows [1]:

$$_{im} = 1/2\sqrt{Z_M\, Z_S cot\theta_M tan\theta_S} \qquad (1)$$

where Z_M and Z_S stand for the characteristic impedances and θ_M and θ_S for the electrical lengths of the microstrip corresponding to the strip and of the slotline corresponding to the slot, respectively. From (1) it is clear that this impedance can be made constant if $\theta_M = \theta_S$.

A design example has been fabricated on GML 1032 substrate (ε_r=3.2 and h=30 mil), in which the resonance frequencies of the slot and the strip were set at 5.4 GHz. The result of the impedance matching can be observed in Fig. 1. While the conventional slot has a highly resonant response, the strip-slot element is matched over broadband (from low frequencies to more than 15 GHz). However, the radiation behaviour of the element is not modified by the strip, therefore the proposed structure radiates as a conventional microstrip-fed slot [1].

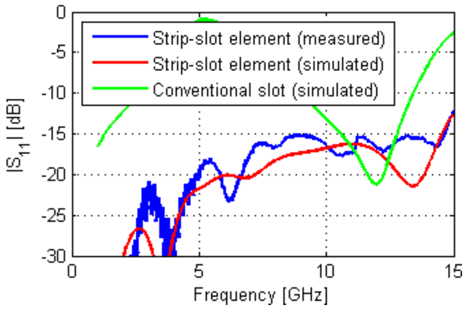


Fig.1. |S11| comparison between the strip-slot radiating element and the conventional slot.

Although the element is well matched, the resulting structure when several elements are cascaded can be mismatched at certain frequencies. This effect can be seen in Fig. 2, where the image impedance of the element is plotted. At the resonant frequencies, the real part of the image impedance has peaks far from 50 Ω. Therefore, at these frequencies, loading with 50 Ω does not lead to a 50 Ω input impedance.

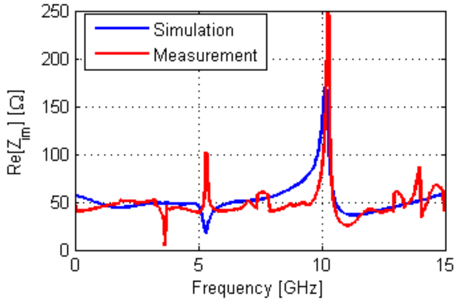


Fig.2. Real part of the image impedance of the strip-slot radiating element.

In order to build series-fed arrays, it is important to analyze the phase response of the radiating element. The intrinsic phase response of the coupling strip-slot section is depicted in Fig.3. It is observed that the element introduces a frequency-dependent phase shift. At the first resonant frequency, this phase shift is π, while at the second one is 2π or, equivalently, 0 rad.

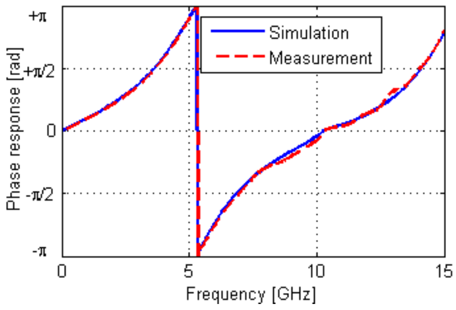


Fig.3. Phase response of the strip-slot element (without taking into account the microstrip interconnection sections).

III. ARRAYS

Due to the transmission line configuration of the complementary strip-slot element, traveling-wave arrays can be built by loading the microstrip line with several strip-slot elements. In this case, the phase shift between elements will depend on the distance between the elements. Fig. 4 shows the phase response of the element in a periodic array including the microstrip interconnection sections, for different pitches p.

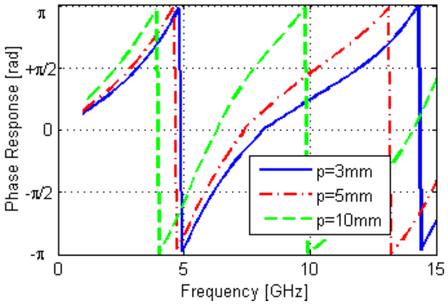


Fig.4. Phase response of the strip-slot element for different pitches *p*.

Therefore, the phase response of the element in the array can be controlled by two parameters: by the intrinsic phase response of the element, which depends on its geometry, and by the pitch. However, the pitch cannot be chosen arbitrarily, since coupling between elements can affect the performance. As an example, Fig. 5 shows the $|S_{11}|$ when five elements are loading a microstrip line with different pitch. The mismatches predicted by the image impedance can be observed in this figure. These bands are pitch-dependent as the phase response is, and are intrinsic in this kind of arrays [3]. Although for *p*=10mm and *p*=5mm only mismatching at the frequency corresponding to a phase shift of 2π is observed, for *p*=3mm an additional mismatching band is found for the frequency corresponding to a phase shift of π. This worsened behaviour for *p*=3mm is attributed to coupling effects.

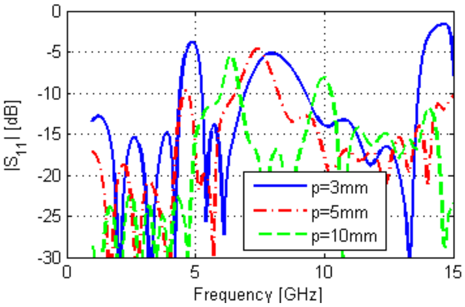
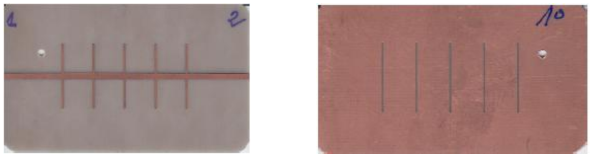


Fig.5. $|S_{11}|$ comparison between five-element arrays with different pitches.

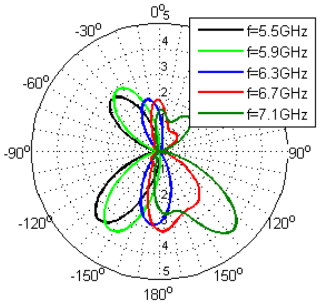
A. Full Space Frequency Scanning

Since the strip-slot element radiates into the whole space, full-space frequency scanning can be achieved when cascading several elements. In this way, a linear traveling-wave array with five elements and *p*=10mm has been built [4]. Fig. 6 shows the prototype layout and Fig. 7 the radiation patterns in the two resulting radiating bands (5.1-7.1GHz and 12.9-15.3GHz). The frequency scanning is performed from backward to forward directions and the main radiation direction depends on the frequency: for the lower band, more radiation is leaked through the slots and, for the upper band, more radiation goes to the strip half-space. A limitation of this kind of arrays is that the array is not well matched at broadside (corresponding to a phase shift of 2π rad), as it was highlighted in Fig. 5.

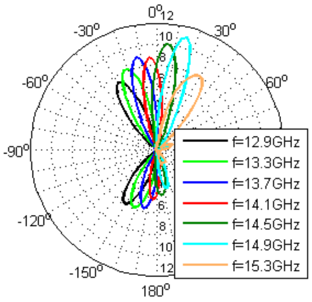


(a) Strip view. (b) Slot view.

Fig.6. Linear array prototype.



(a) First radiation band: 5.5-7.1GHz.



(b) Second radiation band: 12.9-15.3 GHz.

Fig.7. Radiation patterns of the linear array.

B. Multiband Circular Polarization

A circularly-polarized array can be built by applying the sequential rotation technique [5]. For a four-element array, each element must have an orientation and a phase shift of 90º with respect to its adjacent ones. Then, circular polarization will be achieved when this phase shift is 90º or, equivalently, 270º. Fig. 8 shows the resulting layout for an external radius ring of 12mm [6]. In this case, the condition of circular polarization is achieved at *f*=6.2, 8.3 and 12.9 GHz. This is highlighted in Fig. 9, where the axial ratio is depicted. Good polarization purity is obtained at those bands.

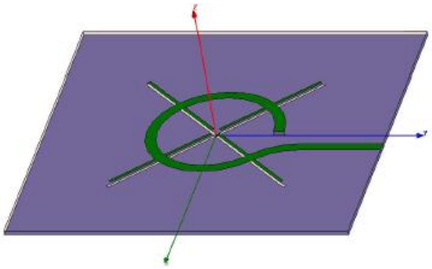


Fig.8. Layout of the ring array.

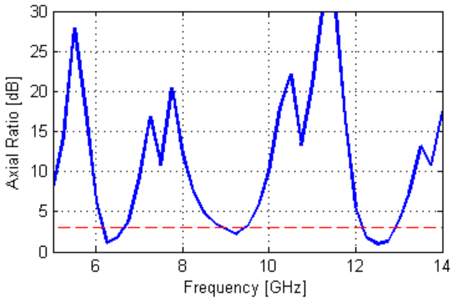


Fig.9. Axial ratio vs. frequency of the ring array.

Fig. 10 shows the radiation patterns at the three working frequencies. A pencil beam with good symmetry with respect to the z-axis is obtained. The aforementioned mismatching problem which arises when cascading several elements is due to a phase shift between elements of 0º. Therefore, it is worth mentioning that for this array very good matching is obtained at the working bands, at which there is a 90º (or 270º) phase shift between elements.

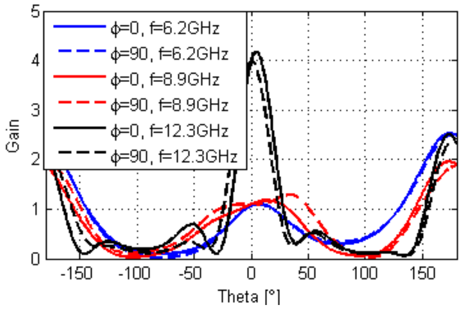


Fig.10. Radiation patterns of the ring array at the frequencies with circular polarization. ϴ=0º corresponds to broadside in the slot half-space.

IV. CONCLUSIONS

It has been shown both theoretically and experimentally that the complementary strip-slot radiating element has great potential for building planar series-fed arrays. Due to its broad impedance bandwidth, the design is not restricted to a specific band, and multiband behavior or frequency scanning over broad bands can be achieved. Moreover, the design simplicity is a key point, since no effort has to be paid in matching the element inside the array. Future work will focus on matching the structure at the frequency at which the phase shift is 0º and exploring different array configurations.

ACKNOWLEDGMENT

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