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Published in:
2000 Asia Pacific Microwave Conference (APMC-2000)

Link to article, DOI:
10.1109/APMC.2000.926091

Publication date:
2000

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Granholm, J., & Skou, N. (2000). Probe-Fed Stacked Microstrip Patch Antenna for High-Resolution Polarimetric C-Band SAR. In *2000 Asia Pacific Microwave Conference (APMC-2000)* IEEE. https://doi.org/10.1109/APMC.2000.926091

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PROBE-FED STACKED MICROSTRIP PATCH ANTENNA FOR HIGH-RESOLUTION POLARIMETRIC C-BAND SAR

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The paper describes a C-band, dual-linear polarization wideband antenna for use in the next-generation of the Danish high-resolution, airborne polarimetric synthetic aperture radar (SAR) system, EMISAR. The design and performance of a probe-fed, stacked microstrip patch element, operating from 4.9 GHz to 5.7 GHz and a small 2x2-element test-array of these are discussed.

1 Introduction

Airborne and spaceborne imaging of the Earth is often carried out using high-resolution remote sensing techniques, such as SAR. Early SAR systems were single-polarization instruments, but during the last decade dual-polarization ("polarimetric") SAR systems have become more widely available, and have particularly been utilized for scientific purposes. It is well known that radar signatures of e.g. crops are polarization dependent. An intuitive physical explanation of this dependence is that the vertical polarization primarily are reflected by the vertical oriented structures (e.g. straws, trunks), whereas the horizontal polarization are in stead reflected by the predominantly horizontal structures (e.g. branches). Mapping an area with polarimetric SAR thus provides more information, hence allows more details to be distinguished, thereby enhancing target-classification ability. Future SAR systems for e.g. crop study and monitoring are therefore required to be polarimetric instruments, [1] - [4].

2 Resolution requirements for future airborne SAR systems

Several airborne polarimetric SAR systems have been built and flown, incl. the Danish L- and C-band system, EMISAR, developed at the Department of Electromagnetic Systems (EMI), Technical University of Denmark, [5]. The EMISAR system has a resolution of approx. 2 m in both azimuth and range. At the time of design (1993) this was state-of-the-art, but not the least due to the rapidly advancing digital technology (especially high-speed data acquisition and mass-storage systems), higher resolutions are feasible today. At the same time user demands, e.g. for surveying applications, continue to call for increased resolution. Both for scientific and commercial mapping purposes there is a desire to achieve resolution of 0.25 x 0.25 m. The maximum SAR azimuth resolution is not dependent on the bandwidth of the transmitted radar chirp but on the pulse-repetition frequency and to a first approximation to the antenna length, l_A. The SAR azimuth resolution, δR_A, is limited to:

$$\delta R_A = l_A/2 \tag{1}$$

This (frequency independent!) result shows that to obtain an azimuth resolution of 0.25 m the antenna should be max. 0.5 m long. Lower frequency results in less gain with this limited antenna length. High-resolution SAR systems therefore are difficult at lower microwave frequencies. The maximum range resolution in SAR systems, δR_R, and the bandwidth requirement are inversely proportional:

$$\delta R_R = \mathrm{c}/(2B_\mathrm{R}) \tag{2}$$

where B_R is the bandwidth of the transmitted pulse, and c is the speed of light. The present EMISAR system has 100 MHz bandwidth in both L-band and C-band, translating to approx. 2 m resolution in range, including proper weighting. To obtain 0.25 m resolution in range, the pulsed chirp must therefore have an eightfold increase in bandwidth. Although the range resolution of both the L-band SAR (with centre frequency 1.25 GHz) and the C-band SAR (centered at 5.3 GHz) is desired to be increased in the next-generation EMISAR system, technology (*and* frequency allocation!) will not allow for this in L-band. In C-band, however, it may be possible to achieve up to 800 MHz bandwidth. The goal therefore is to upgrade the C-band EMISAR into an 800 MHz high-resolution system.

3 Electrical and mechanical requirements for polarimetric SAR antenna arrays

Future polarimetric SAR-systems require compact and lightweight dual-linear polarization antenna arrays which should be flat to facilitate e.g. conformal installation onto the fuselage of aircrafts. In order to obtain a high degree of polarization discrimination of the overall SAR system, it is a further requirement that the array has low cross-polarization. An antenna element that complies fairly well with these requirements is the microstrip patch. Although narrowbanded as a single-layer structure, a stacked, parasitic patch can be added to significantly increase the bandwidth. Probe-fed patches are attractive from a feeding network point of view, since the probes easily connects the patch to its beam-forming network (BFN) with no need for cavities to be placed under the groundplane (in contrast to required in e.g. aperture-coupled patches). For this reasons probe-fed patches are chosen. The existing C-band EMISAR system, operating over an approx. 2 % bandwidth, uses single, probe-fed patches, [6]. The L-band EMISAR system, also operating over a 100 MHz bandwidth (translating to 8 %), uses stacked probe-fed patches, [7]. The idea thus was to investigate if the stacked patch concept could be adopted and optimized to operate over an 800 MHz (i.e. 15%) bandwidth in C-band.

4 Selection of dielectric substrates and design of the C-band wideband element

The bandwidth of microstrip patches depends strongly on the substrate thickness and -permittivity. For practical reasons, the C-band patch probes shall be fabricated as “integrated via’s”. Hence, for bandwidth and fabrication reasons, it is desirably to use a thick, low permittivity “hard” substrate. On the other hand, the maximum thickness is limited for several reasons: A thick PTFE-based substrate may support the propagation of excessive surface waves, and it will also be heavy. Furthermore, it will necessarily imply a long feeding probe which electrically act as a large series-inductance, thus reducing the element bandwidth. Although electrical attractive, mechanical considerations preclude the use of low loss, low permittivity foam materials, since via’s can neither be grown, nor supported, by such soft materials. In this work, low-cost 32 mil Rogers RO4003 substrate (ε_r=3.38, tanδ=0.0027 @ 10 GHz) was initially chosen for the driven patch. Although the RO4003 dielectric loss factor is somewhat higher than many PTFE-based materials, RO4003 yet is attractive in a feasibility study like the present, since RO4003 resembles FR4 in mechanical integrity and can be fabricated (fast and cheap) like basic FR4 material. A single-layer patch can far from achieve the 15 % bandwidth required, and a stacked patch is therefore necessary. The resulting configuration is shown in Fig. 1.

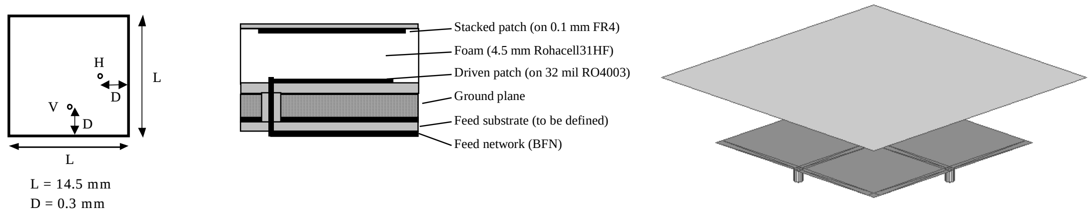

Fig. 1. Dual polarization probe-fed stacked patch; a) Top view of the lower patch, b) cross section.

The driven probe-fed patch couples to the upper patch which acts as a passive parasitic element. Although the impedance of the single (i.e. unstacked) driven patch, when fed on its edge, is very high, it is significantly reduced, when being loaded by the stacked patch. Hence, to obtain an approx. 50 Ω input impedance of the stacked patch, the driven patch is fed on the edges. The dual linear polarization requirement implies that the patch must be constructed symmetrically. A pair of quadratic and co-axially aligned patches is therefore used. Since no direct synthesis method for the design of wideband stacked microstrip patches is known, an iterative numerical design process, using an electromagnetic simulator, was adopted. The sizes of and the distance between the two patches were varied, until the desired wideband performance was obtained. During this process it was found that a good starting point was to design the driven patch first, having its resonance frequency lying in the centre of the band of interest. The stacked patch adds a second resonance, and the task is now to find the parameters so that the two resonances balance in value (i.e. are excited equally strong), and are spaced in frequency so that the impedance remains constant over the band. Using this “numerical iterative design”, combined with impedance measurements to validate the approach, a stacked C-band microstrip patch yielding an near-optimum result was found, when the size of the quadratic lower and upper patches were 14.5 mm and 19.5 mm, respectively. The upper patch is etched on a 0.1 mm FR4 substrate, and mounted inverted to let the FR4 material act as environmental protection. The spacing between the patches is 4.5 mm using a Rohacell31HF foam material having ε_r of 1.05. All layers are glued together using a 0.1 mm thick adhesive film (supplied by 3M; type 665). The measured S-parameters, input impedance and radiation patterns for this element are shown in Fig. 2. All pattern measurements have been performed in the spherical near-field test facility of EMI, [8].

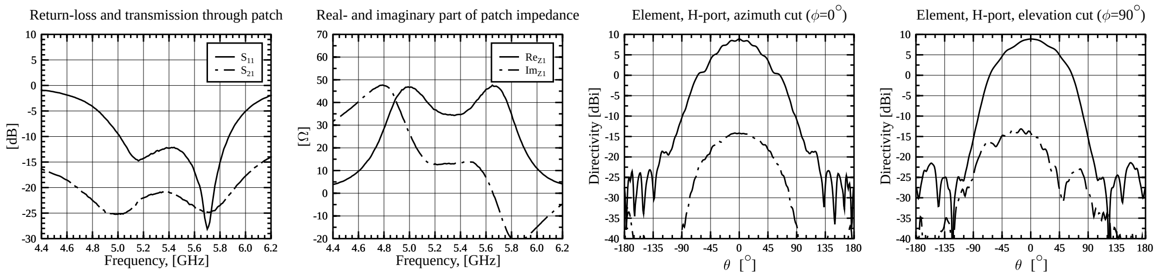

Fig. 2 Measured S-parameters, input impedance and radiation patterns (f = 5.3 GHz, horizontal polarization fed) of wideband, stacked C-band microstrip patch. Groundplane 0.5 x 0.5 m.

A wideband behaviour for the stacked patch is indeed observed. Note how the two “peaks” of the real-part input impedance balance quite well. The parasitic loading of the lower patch leads to a significant decrease of the input impedance, compared to the single-layer patch; edge-fed impedance for the latter being ≈ 300 Ω. This typical characteristic of the stacked patches eases the matching of the element to e.g. 50 Ω. It is seen that the intrinsic impedance of the stacked patch is not very far from 50 Ω (S_{11} of the unmatched stacked patch remains below -10 dB over an 860 MHz bandwidth). Rather than matching the stacked patch element to 50 Ω, however, it should be considered to design the entire BFN using a slightly lower reference impedance (e.g. 40 Ω). This will only require one transformation from 40 Ω to 50 Ω (at the input of the array), thus saving board space and reducing the overall-losses (since the loss in a 40 Ω system will be lower than the loss in a 50 Ω system). If reducing the system impedance to 40 Ω and implementing a simple microstrip matching network at the patch feeding point, this has been found to bring S_{11} of the stacked patch down below -20 dB over the full 800 MHz bandwidth. Note that the transmission through the patch (i.e. the scattering parameter S_{21}) is seen to exhibit a similar “stagger-tuned” characteristic as seen in the real-part of the input impedance. This level of S_{21} (between –20 dB and –25 dB) is typical for wideband, probe-fed stacked patches. The radiation patterns in both planes are both quite usable for arrays. The radiation pattern remains stable over the full 800 MHz bandwidth, the peak directivity increases from 8.4 dBi at 4.9 GHz to 9.0 dBi at 5.9 GHz. If the element cross-polarization level is not compliant with array requirements, simple, yet very efficient, techniques can be employed in the large array to substantially improve the overall array cross-polarization suppression over that of the basic stacked patch element. A cross-polarization improvement of typical 15 dB in microstrip patch arrays has been achieved using the method described in [9] and [10]. A practical example of the implementation of this cross-polarization improvement technique is found in [7]. This technique was not utilized in the present sub-array design. To investigate wideband array-issues, four stacked patch elements were combined into a 2 x 2-element sub-array. The S-parameters of this were measured in the case where the elements were connected to two four-way Wilkinson power splitters/combiners using coaxial cables (i.e. all elements fed in equal amplitude and phase). The measured S-parameters for this sub-array are shown in Fig. 3, and are compared with the calculated S-parameters in the two cases: a) Mutual coupling between the elements is neglected in the calculation, b) All mutual couplings (co- and cross-polar) between the elements are taken into account. In the a) case only the four eigen-impedances of the patches were connected together (in the computer) with the measured S-parameters of the four-way Wilkinson power splitters and coaxial cables. In the b) case all S-parameters of the 2 x 2 element dual-polarized sub-array (i.e. the full eight-port), all cables and the power dividers were measured and used in the computer model.

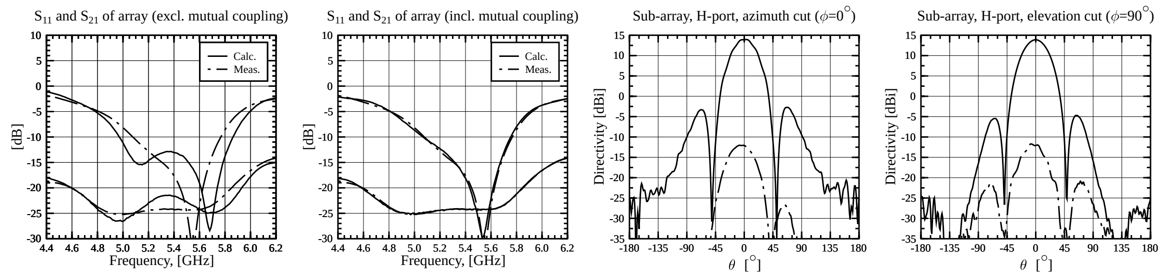

Fig. 3. S-parameters and radiation pattern of 2 x 2 element sub array (f = 5.3 GHz, uniform excitation, horizontal polarization fed). Element spacing ≈. 0.7 λ_0 at 5.3 GHz. Groundplane 0.5 x 0.5 m.

From Fig. 3 it is seen that the bandwidth of the 2 x 2-element sub-array is slightly lower than for the individual stacked element. This is due to mutual coupling between the elements, and to a lesser extent due to the finite bandwidth of the Wilkinson divider. Note that S_{21} of the sub-array is very close to that of the element. Also note that the mutual coupling certainly must be taken properly into account, otherwise measured vs. calculated S-parameters will not agree very well. The radiation pattern is symmetrical and has deep nulls. The peak directivity is 13.6 dBi at 5.1 GHz, increasing to 14.8 dBi at 5.9 GHz. The cross-polarization suppression is on the order of 25 dB which is similar to that of the individual element. Measurements confirm that the pattern is stable over a very wide frequency range (in excess of 1 GHz), and that the cross-polarization level remains approx. at the same level as S_{21}.

5 Conclusion

A low-cost dual-polarization, stacked microstrip probe-fed patch array was described which is capable of operating over a 15 % bandwidth in C-band with good performance. The C-band element described here is presently being integrated into a dual-frequency array (L- and C-band), [11].

Acknowledgements

This work was supported by the Danish National Research Foundation.

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