THE DESIGN OF 80 GHZ ANTENNA ARRAY ON LTCC SUBSTRATE

Mohamed El-Nawawy (1), Darek Korzec (1), and Wolfgang Mahler (2)

(1) Faculty of Information Engineering and Technology, German University in Cairo.
(2) Institute of Radio Frequency Technology, Universitat Stuttgart.

ABSTRACT

A 2×2 array of an aperture coupled microstrip patch antenna (ACMPA) was designed. The antenna was designed on Low Temperature Co-fired Ceramic (LTCC) substrate with an embedded air cavity to increase gain and bandwidth. Simulated S_{11} was -21.45 dB at 81 GHz with 3.5% bandwidth and the simulated radiation pattern shows a maximum gain of 10.42 dBi. Moreover, a prototype has been fabricated and measured for an ACMPA scaled down to 15 GHz.

***Index Terms*—** ACMPA, LTCC

1. INTRODUCTION

In the future mobile communication networks, there are four types of access networks, namely, wireless wide area cellular (WWAC), wireless personal area network (WPAN), wireless local area network (WLAN), and wireless metropolitan area network (WMAN). WWAC is developed for communicating in a large or global area. WPAN, WLAN, and WMAN are proposed to realize communications in a smaller area. Some special requirements, such as high data rate, large communication capacity, limited communication area, and high angular resolution communication, are required in emerging WPAN, WLAN, and WMAN. Millimeter waves are capable of providing these desirable performances due to their unique characteristics; i.e., wide-spectrum bandwidth and short wavelength. Therefore, millimeter waves are important candidates for future WPAN, WLAN, and WMAN.
The millimeter-wave electronics for commercial applications, such as short-range broadband wireless communications, automotive collision avoidance radars and local cellular radio network (LCRN) require low fabrication cost, excellent performance, and high level integration [1]. To satisfy these needs, low temperature cofired ceramic (LTCC) technology has been extensively studied by many researchers due to its good RF properties, its excellent hermeticity, its mature lamination capability for 12+ layers and its easy integration with other RFIC technologies, especially for system on package (SOP) modules [2], [3]. However, the high dielectric constant of LTCC material is a challenge for antenna performance [4]. Although the use of high-dielectric constant substrate allows for the realization of compact sized antennas, surface waves and substrate modes propagating through the dielectric substrate cause edge diffraction effects that further deteriorate the gain and the bandwidth of antenna is significantly degraded, whereas, at millimeter wave frequency, absorption in the propagation medium (air) is so significant that high gain antennas are generally necessary to make short range wireless links possible [5].

2. ANTENNA DESIGN

In this paper, an aperture-coupled microstrip patch antenna that is backed with an air cavity is proposed to implement an integrated antenna which has a high gain and a broadband impedance matching property. To further increase the gain, a 2×2 antenna array is proposed.

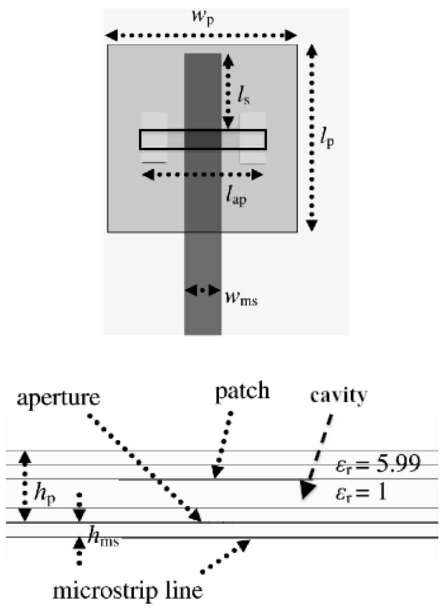


Fig. 1. ACMPA with cavity
$(l_p = w_p = 0.8\,\text{mm}, h_p = 0.5\,\text{mm}, h_{ms} = 0.1\,\text{mm}, w_{ms} = 0.6\,\text{mm}, l_s = 0.25\,\text{mm}, l_{ap} = 0.7\,\text{mm})$

The optimized patch antenna with a cavity is illustrated in Fig. 1. For simulation CST MWS software was used. Perfect electric conductors were used for the three metal layers, namely, feed line, ground and radiating patch. It should be noted here that if finite conductors were used the losses will increase especially at such high frequency due to the skin effect [6]. LTCC 100-μm-thick layers where used as a substrate with $\varepsilon_r = 5.99$. The whole structure needs only six layers of LTCC tapes. The size of the cavity in the xy-plane is 4mmx4mm.

The 200-μm-thick superstrate above the radiator focuses the electromagnetic field upward. By properly choosing the superstrate thickness, significant improvement in radiation efficiency and gain can be achieved.

A 2×2 array was designed to achieve high gain with spacings between elements d=1 mm. The importance of selecting properly the value of d is to avoid grating lobes in the radiation pattern.

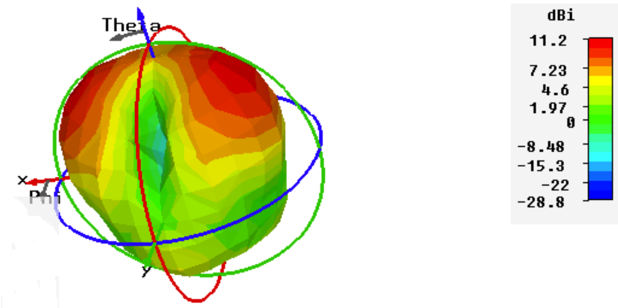
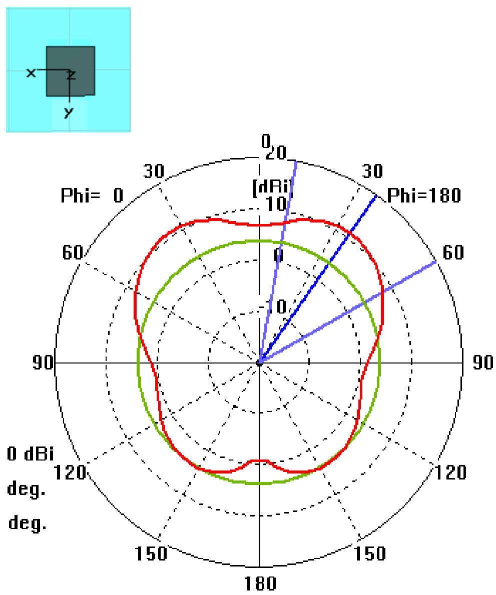


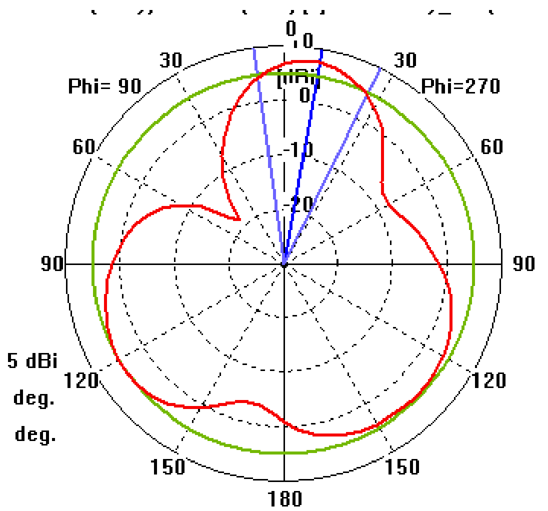
Fig.3 Three dimensional plot for array total directivity pattern

3. LTCC PROCESS

LTCC (low temperature co-fired ceramic) stands for a ceramic substrate system which is applicable in electronic circuits as a cost-effective and competitive substrate technology with nearly arbitrary number of layers [7]. Printed gold and silver conductors or alloys with platinum or palladium will be used in general. Copper conductors are available, too. The metallization pastes are screen printed layer by layer upon the un-fired or "green" ceramic foil, followed by stacking and lamination under pressure. The multilayer ceramic stack then is fired (sintered) in the final manufacturing step. The temperature of sintering is below 900° C for the LTCC glass-ceramic. This relative low temperature enables the co-firing of gold and silver conductors. The melting points of Au and Ag are 960° C and 1100° C respectively. The low line losses as well as the competitive manufacturing costs are an advantage of LTCC also for microwave and even millimeter wave applications.



(a)



(b)

4. RESULTS

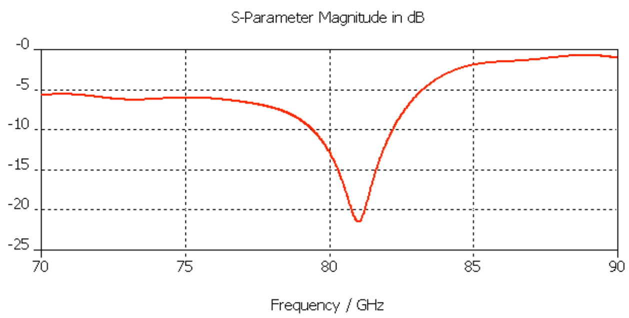
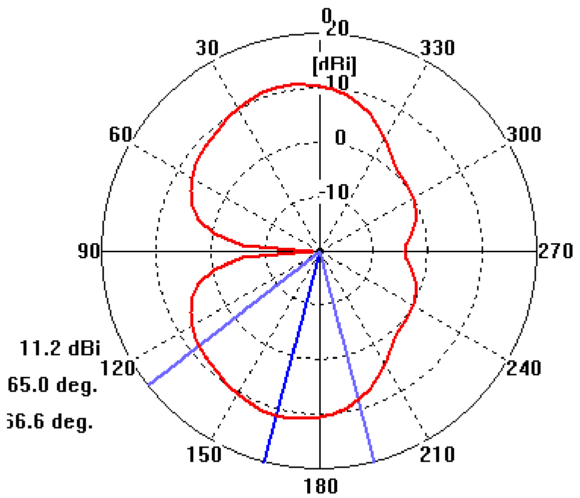


Fig. 2. S_{11} in dB for the antenna array

Fig. 2 shows the return loss for the ACMPA with cavity array using CST MWS. From the figure, S_{11} at 81 GHz is -21.45 dB. The impedance bandwidth is 3.5% calculated at -10 dB. It should be noted here that for the case of finite conductor used instead of perfect conductor in simulation the resonant frequency would decrease.



(c)

Fig. 4 Total directivity pattern: (a) x-z plane, (b) y-z plane, and (c) 45° elevation from x-y plane

Fig. 3 shows the 3-D total directivity pattern plot for the antenna array and Fig. 4 shows the total directivity pattern in (a) x-z plane , (b) y-z plane, and (c) 45° elevation from x-y plane. It is shown that the maximum directivity is 11.2 dBi at 165° in Fig. 4 (c) with half power beamwidth of 66.6° and a null at 90°. The main lobe magnitude in x-z plane is 11 dBi at 35° and the half power beamwidth is 49.4°. Furthermore, there are two notches in this plane one at 90° and the other at 180° both of magnitude 0 dBi. As for the y-z plane, the main lobe magnitude is 7.5 dBi at 10° with half power beamwidth of 34.5°and a null at 45° .The radiation efficiency is 0.933, which would be lower if finite conductors were used in simulation instead of perfect conductors.

5. PARAMETRIC ANALYSIS

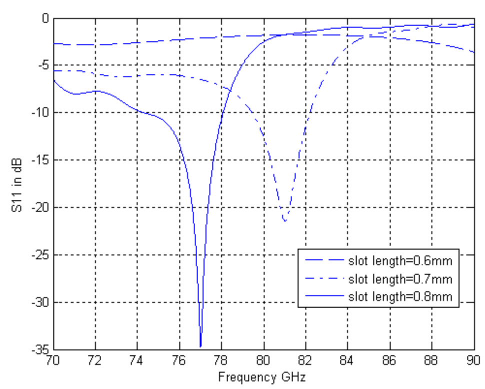


Fig. 5 S_{11} while sweeping slot length from 0.4 mm to 0.8 mm all other parameters the same.

The effect of changing the values of slot length while keeping all other parameters constant on the return loss was investigated. The slot length is responsible for coupling between the feed and the radiating patch. Its length was changed from 0.4 mm to 0.8 mm. It is seen in Fig. 5 that for slot length equal to 0.6 mm the patch is undercoupled. For slot length of 0.7 and 0.8 mm S_{11} achieved is -21 dB and -34 dB, respectively, however for slot length of 0.8 mm the S_{11} minimum is shifted below 80 GHz so slot length of 0.7 mm was chosen.

6. FABRICATION AND MEASUREMENT

A prototype has been fabricated for the proposed design. The design was scaled to have resonance at 15 GHz to be able to measure it using available network analyzer. Two substrates were used, one for the feed which is RT/duroid 6010 with ε_r = 10.2 and height 0.635 mm, and the other for the patch which is RT/duroid 5880 with ε_r = 2.2 and height 1.57 mm. The patch size is 11mmx11mm and the whole substrate size is 3cmx3cm. Fig. 6 shows a photo of the prototype of the ACMPA. The lower substrate with ground and feed is extended a distance of 5 mm more than the upper substrate to allow for the connection of the SMA connector to the structure. The measured and simulated S_{11} for the scaled design are shown in Fig. 7. The simulated S_{11} plot shows center frequency for resonance at 15.23 GHz with S_{11} reaching -39.5 dB and bandwidth at -10 dB of 8.7%. For the measured S_{11} it was -42 dB at 14.7 GHz center frequency and bandwidth of 6.8% at -10 dB. The discrepancy of resonance frequency between measured and simulated S_{11} could be due to the fact that perfect electric conductors were assumed for the metal layers in simulation. According to [8], as the resistivity of a metal film deposited on dielectric substrate increases an equivalent scheme of a series connection of a resistance and reactance should hold and the loss tangent of the equivalent surface impedance of the film should be higher. The resonance frequency decreases as the complex equivalent permittivity increases. The measured and simulated radiation patterns for E-plane and H-plane are shown in Fig. 8.

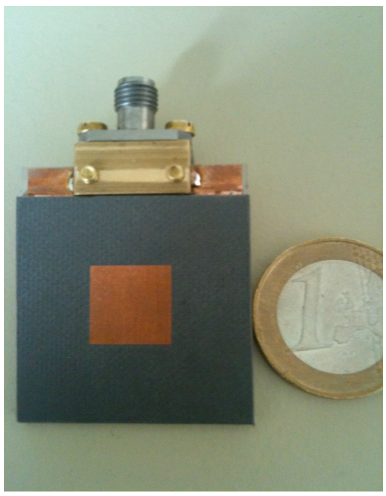


Fig. 6 Photo of the fabricated prototype of ACMPA

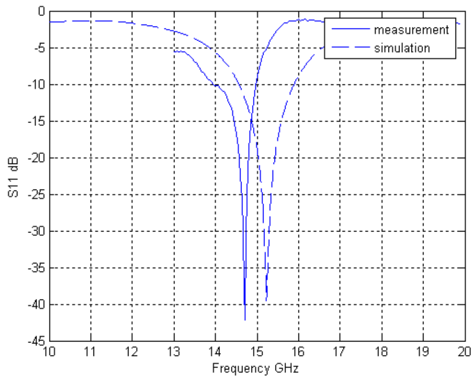
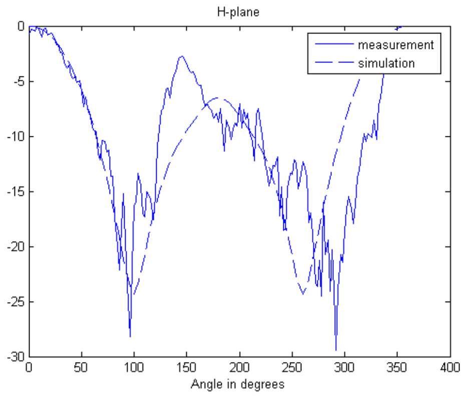
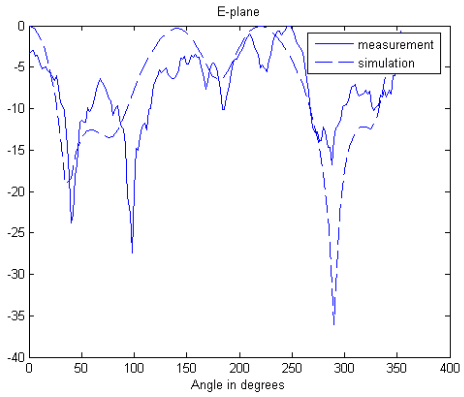


Fig. 7 Measured and simulated S_{11} for the prototype antenna.



(a)



(b)

Fig. 8 Simulated and measured radiation pattern for antenna prototype (a) H-plane (b) E-plane

7. CONCLUSION

A 2×2 array of aperture coupled microstrip patch antenna elements has been designed. A 4mmx4mm cavity was embedded inside the LTCC substrate to increase gain and impedance bandwidth. It was shown from the simulation results of CST MWS that the maximum gain was 10.42 dBi which is reasonably high however the impedance bandwidth was only 3.5%. This might be due to the fact that there is a tradeoff between gain and bandwidth so that embedding a cavity in the antenna structure increased the gain in favor of the bandwidth. Moreover, the simulated S_{11} reached -21.45 dB at 81 GHz. A prototype has been fabricated for an ACMPA scaled down to 15 GHz where good agreement has been observed between the simulated and measured results at this frequency. The calculated radiation efficiency was 0.933. The proposed design could be extended to submillimeter wave applications.

8. REFERENCES

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