Progress In Electromagnetics Research Letters, Vol. 9, 193–199, 2009

77 GHz MILLIMETER WAVE ANTENNA ARRAY WITH WILKINSON DIVIDER FEEDING NETWORK

F. D. L. Peters, B. Boukari, S. O. Tatu, and T. A. Denidni

INRS-EMT
University of QUEBEC
Place Bonaventure, 800, de la Gauchetière Ouest, suite 6900
Montréal (Québec), H5A 1K6, Canada

Abstract—A 77 GHz microstrip antenna array with a small surface providing high side and grating lobe suppression is presented. This may serve as a starting point for 77 GHz automotive radar applications. Multiple Wilkinson dividers guarantee both impedance matching at the input port (TX) as well as low return loss for the incoming (RX) signal. Phase shifting is done by adjusting the level of the Wilkinson dividers or by meandered sections of transmission line. The influence of the radiation caused by the feeding network is analyzed and the absolute degradation in side lobe suppression is derived in this paper.

1. INTRODUCTION

The millimeter V-band includes the recently allocated 77 GHz band for future use in automotive applications [1]. Published antenna approaches often suffer from either unmatched receiving signal paths [2, 3], or do not meet the size requirements for radar front ends. Equally the suppression of side lobes is of high importance in radar applications when a high spatial selectivity is required. This project aims to minimize the size need while keeping the feeding network bidirectional matched to 50 Ω.

2. PROJECT OUTLINES

The frequency band is 76 to 77 GHz. Substrate thickness adds up to 5 mil. According to the nominal relative dielectricity of $\varepsilon = 9.9$ the width of a 50 Ω microstrip line was fixed to $w = 4.590551$ mil. The

Corresponding author: F. D. L. Peters (peters@emt.inrs.ca).

Wilkinson divider was simulated and tested previously with very good results. Simulations with ADS-Momentum (MOM) reveal some shifts between ADS and HFSS in terms of the effective dielectricity. Based on the value of $\varepsilon = 9.9$ the results of this antenna array will provide more information about the varieties of HFSS and ADS at 77 GHz.

3. ARRAY AND PATCH ANTENNA DESIGN

The patch dimensions are derived from several resources, like [4, 5]. Inset fed impedance matching is applied according to [6]. The ten element array is designed with the aim of a high RX input matching as well as low side lobes and a small entire surface. Although of lower priority, gain and directivity should be as high as possible. The patches are fed via Wilkinson dividers with a decreasing power of −6, −9, −12, and −15 dB compared to the delivered input power. Phase shifts are either realized by adjusting the difference in level of the dividers, or by meandered transmission lines. By allowing more mm^2 all meandering could even be avoided which decreases the return loss, as it is shown in Section 4.4.

The size need for this constellation is less than 0.9 cm^2, respectively 18.7 mm × 4.5 mm = 84.15 mm^2. A direct corporate feeding network with both RX and TX matched impedances would lead to at least approximately twice the size.

The first −3 dB stage is composed by a Wilkinson divider as well as two curves with $r = 0.23$ mm and $w = 4.590551$ mil. This shape, seen in Figure 2 allows approaching all three dividers optimally. The results show a very good RX matching of below −30 dB and a good matching of −20 dB at the TX entrance. Both the upper ($S_{21} = -3.143$ dB) and the lower ($S_{31} = -3.137$ dB) branch are well designed. The phase difference given by ADS is $|(\varphi 1 - \varphi 2)| = 0.133°$.

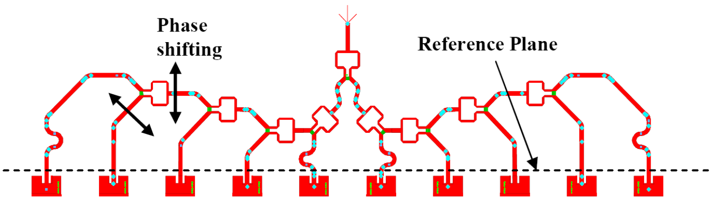

Figure 1. Ten element antenna array with diminishing feed power.

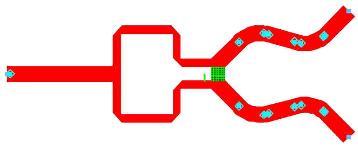

Figure 2. Wilkinson Divider and power distribution branches.

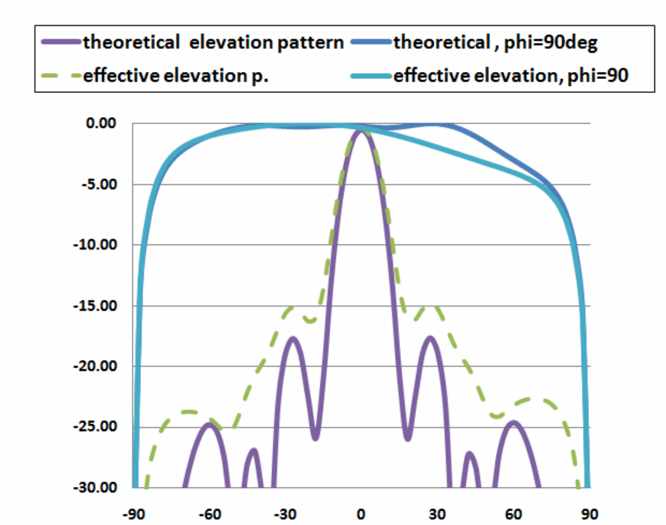

Figure 3. Radiation pattern of the array with/without feeding network.

4. RESULTS

4.1. Radiation Pattern

The radiation pattern of the ten element array without a feeding network and −6, −9, −12 and −15 dB power distribution would yield a side lobe suppression of 17.5 dB, respectively 25 dB for the 2nd lobe. The realized array provides 15 dB, respectively 23.5 dB. This is an essential parameter e.g. in automotive radar applications. The half power beam width in elevation plane adds up to HPBW = 12 degrees. Ten degrees is often considered as a reasonable value for automotive radars [3, 7].

The radiation of the feeding network may not be disregarded. Figure 4 shows that side lobes are better suppressed with closer patches but the best value for the null positions is achieved with a wide distance of 2 mm, when measured from the reference plane given in Figure 1. Figure 5 depicts the radiation of the effective feeding network together with the sum and difference pattern. Thus, the many power dividers yield discontinuities of non negligible influence in particular in the angle range of the side lobes.

In sum, the feeding network increases the power of the first side lobe by about 5 dB.

4.2. Gain

The overall (three dimensional) directivity reaches 14.3 dBi, and the gain 12.7 dBi for directly fed patches without feeding network. However, when considered from broadside in a $\phi = 90°$ cut, the peak gain reaches 24.75 dBi. Efficiency adds up to 69%. The realized array provides a peak gain of 21.9 dBi and 65.5% efficiency, thus — as a result of the analysis on the feeding network, a loss of 2.5% is introduced with an effect of about -5 dB on side lobe suppression.

4.3. Phase Error

The phase error at the patch entrances is very small. The design of such a ten element array with ADS shapes up as very difficult as the results vary from simulation to simulation even with a 20 cells per wavelength

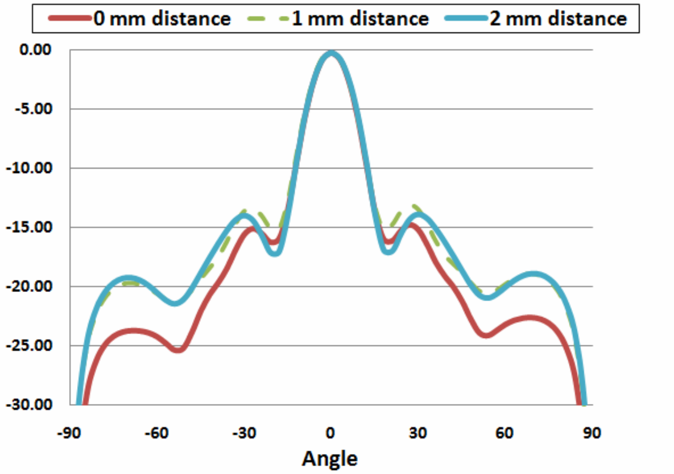

Figure 4. Influence of the patch-to-feeding-network-distance on side lobe suppression.

meshing. As a compromise $\pm 1^\circ$ is considered as a reasonable value, however most of the values are less, depicted in Figure 6.

4.4. Feeding and Radiation Bandwidth

The impedance or feeding bandwidth (RL = 10 dB), respectively S_{11} is quite large compared to common values for microstrip patches. For an automotive radar application the current value of about 3.25% is largely enough, depicted in Figure 7. The radiation bandwidth — if defined as the interval of a -3 dB decrease in gain-adds up to $> 5\%$. The mid frequency is about 76.3%. Note: The Wilkinson divider itself

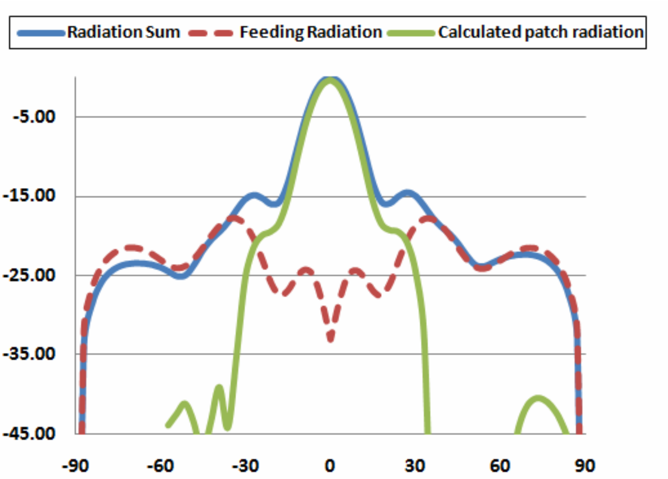

Figure 5. Effective simulated radiation pattern of the feeding network.

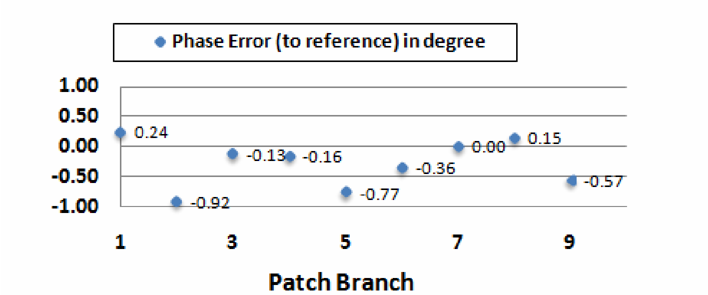

Figure 6. Phase deviation from reference phase.

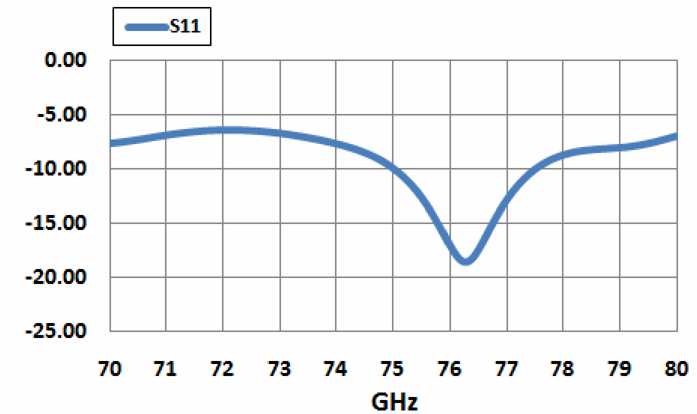

Figure 7. Impedance bandwidth.

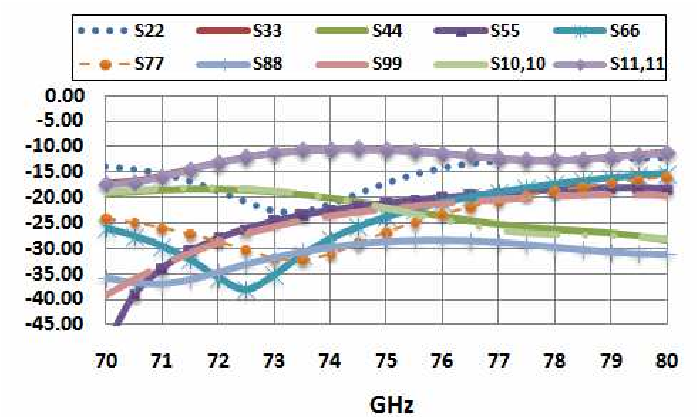

Figure 8. RX matching of all ten branches, seen from patch side.

shows its best matching at about 72.5 GHz in this project. With HFSS the Wilkinson divider was simulated and subsequently measured at INRS-EMT to have a rather flat frequency response from at least 75 to 78 GHz. For this reason the divider is considered as well matched for 77 GHz as well in this approach and an even a better result than simulated in this paper is anticipated.

As a basic requirement the RX impedance seen from the patch should be well matched as well. Fig. 8 proofs that the return loss stays below 10 dB and in most cases below 20 dB.

5. CONCLUSIONS

The proposed array gives a simple solution for a radar sensor antenna array with a competitive size need of less than 0.9 cm^2. The two dimensional beam width fulfils virtually the common criterion of 10 degree. Feeding radiation denotes an issue when lots of power dividers are used. However, while side lobes are less suppressed by 5 dB, efficiency is only decreased by 2.5%. With the shown power distribution network the peak gain reaches almost 22 dBi.

REFERENCES

1. Wenger, J., "Automotive radar — Status and perspectives," *Compound Semiconductor Integrated Circuit Symposium, 2005. CSIC'05. IEEE*, 4, 2005.
2. Cui, B., C. Wang, and X.-W. Sun, "Microstrip array double-antenna (mada) technology applied in millimeter wave compact radar front-end," *Progress In Electromagnetics Research*, PIER 66, 125–136, 2006.
3. Freese, J., R. Jakoby, H.-L. Blocher, and J. Wenger, "Synthesis of microstrip series-fed patch arrays for 77 GHz-sensor applications," *Microwave Conference, 2000 Asia-Pacific*, 29–33, 2000.
4. Jit Bahl, I. and P. Bhartia, *Microstrip Antennas*, UMI, Ann Arbor, Michigan, 1998.
5. Kumar, G., *Broadband Microstrip Antennas*, Artech House, Boston, Mass., 2003.
6. Zhang, R., X. Tang, L. Wang, and X. Zhang, "Study of microstrip-line inset-fed and two-layer electromagnetically coupled rectangular patch antennas," *Microwave Conference Proceedings, 2005. APMC 2005. Asia-Pacific Conference Proceedings*, Vol. 4, 4, 2005.
7. Porter, B. G., L. L. Rauth, J. R. Mura, and S. S. Gearhart, "Dual-polarized slot-coupled patch antennas on Duroid with teflon lenses for 76.5 GHz automotive radar systems," *IEEE Transactions on Antennas and Propagation*, Vol. 47, No. 12, 1836–1842, 1999.