Highly Broadband Circular Polarized Patch Antenna with 3 Phase Feed Structure

Robin Theunis[1], Maarten Baert[1], Paul Leroux[1], Wim Dehaene[1]
[1]ESAT MICAS, KULeuven, Leuven, Belgium, robin.theunis@esat.kuleuven.be

***Abstract*—In this paper a highly broadband circularly polarized patch antenna design is shown. The design features several novelties which includes the use of a 3-phase feed circular patch for optimal axial ratio and the 3-phase microstrip feed structure to excite the patch antenna. Combining those techniques provides superior bandwidth in both return loss and axial ratio compared to classical rectangular patch designs as shown by simulation and measurements.**

***Index Terms*—circular polarized antenna, patch.**

I. Introduction

One of the limiting factors in indoor communication and localization systems is multipath propagation. For communications systems this effect will introduce fading and inter symbol interference. With the use of circular polarization, it is possible to attenuate the paths with an odd number of reflections. The paths with only one reflection tend to have the most influence the channel response. For indoor positioning and localization, multipath propagation is one of the main sources of error in these kind of systems. When looking at the different paths that happen inside a room, it can be seen that most of them are grouped close together and the difference between the paths is rather small. This small path length difference needs to multiple of the maximum allowed bandwidth to be able to distinguish those from each other in some occasions. If the circular polarized antenna can remove some of those reflected paths the bandwidth can be reduced.

The design of this antenna is optimized for a center frequency of 5.8 GHz to facilitate to use of the 5.8 GHz ISM band and the 5 GHz 802.11a band.

II. Antenna design

The proposed antenna structure consists out of two printed circuit board made out of 1 mm thick FR4 with an ϵ_r of 4.2 as shown in figure 2. The patch is placed 4 mm above the reflector. The patch and bottom pcb are connected with 3 copper feed pins. These pins have a diameter of 1 mm. This provides the excitation and stabilizes the antenna mechanically. A microstrip feed network is located on the bottom side of the reflector. The bottom side of the reflector the feed network is made with microstrip transmission lines.

A circular patch has a few clear advantages compared to normal rectangular designs, when a good axial ratio is required [1]. This is mainly the result of the rotational symmetry it has around its central axis. This results into almost no side lobes with the wrong polarization. As seen in a rectangular patch antenna [2], there are points where it has a few side lobes where the axial ratio is poor.

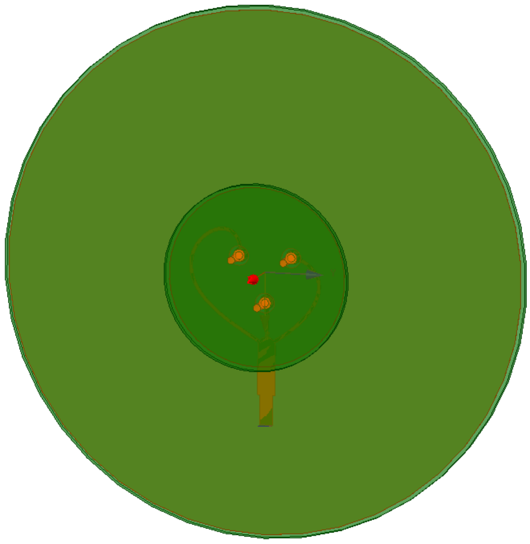

Fig. 1. 3D view of the antenna

To optimize excitation of the patch antenna a novel 3 feed point system has been designed. 3 feed points is the minimum number in which a balanced excitation of the patch is possible. Designs with only two feed points at an 90° shift have a slight imbalance because the feeds introduce a small asymmetry. This translates into a degraded axial ratio of the antenna. More feed points are possible but the matching network for those kinds of feed systems becomes more difficult.

These feeds points are called U, V and W in. The antenna is excited by applying U with 0°, V with 120° and W with 240° phase shift just like in 3 phase electric power distribution. With this arrangement a right hand polarized wave is created. Swapping two feeds points excites a left hand polarization. The same analogy appears in electric motors where a swap of two wires reverses the direction.

If this antenna is driven by a perfect feed network, the other polarization is fully canceled. In this theoretical case the axial ratio is always 1. This can be easily shown through the symmetry of the antenna. The only way the other polarization is possible is because of mechanical imperfections of the patch and as result of the network that generates the required phase

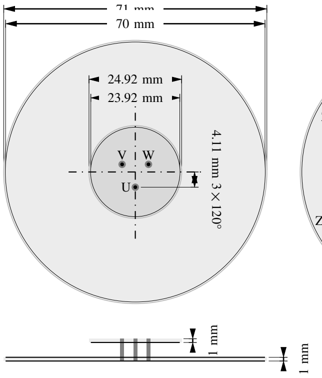

Fig. 2. Antenna: top, side and bottom view.

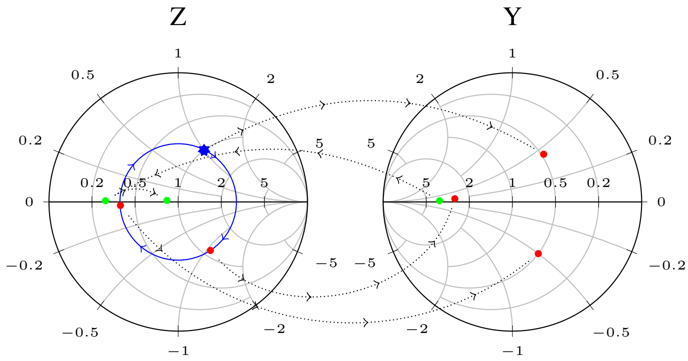

Fig. 3. Bandwidth expansion through the partial cancellation of the imaginary impedance. First rotate the V and W feeds 120° and 240°. Than with the admittance chart add up the feeds. Do the final quarter wavelength transformation back in the impedance chart.

shifts.

At first, the antenna is simulated with 3 ports, one for each feed point. In the excitation for these ports the correct phase shift is introduced to match the wanted polarization. To ease the optimization of the antenna and feed network a equivalent S_{11} has been defined in equation 1. The idea is that the equivalent return loss of one port is a combination of the simulated return loss and the sum of the couplings between that port and the others.

$$S_{11} = S_{UU} + S_{UV} \cdot \mathrm{e}^{j \cdot 120^\circ} + S_{UW} \cdot \mathrm{e}^{j \cdot 240^\circ} \quad (1)$$

The main design parameters of the antenna are the diameter of the patch, the distance between of the patch and the ground plane, the diameter of the reflector and the feed offset. The diameter of the patch sets the center frequency of the antenna. The height of the patch has influence on the bandwidth, efficiency and center frequency. An increase in the distance between the patch and the reflector improves the efficiency and bandwidth but it decreases the center frequency. The diameter of the reflector determines on the front to back ratio of the antenna. A undersized reflector will cause some of the radiated energy to move to the back of the antenna. With this particular 3-phase feed setup the offset where the patch is excited mainly influences the real part of the impedance of the 3 combined feed points. Because of this property, this parameter makes the design of the feed network easier. The port impedance was chosen to be equal to the characteristic impedance of the individual transmissions lines, 100 Ω.

III. Feed Network

The main requirement of the feed network is to match and create the required phase shifts to the feed points. The feed impedance of the patch has be chosen to be 100 Ω. This eases the matching from the parallel circuit to the required 50Ω. To get the required impedance for the phase shift transmission lines a track width of 400 um has be chosen. The antenna feed offset and diameter is adjusted until it matched to the transmission line impedance at the correct center frequency.

This network is placed on the bottom side of the reflector PCB. The main goals of these transmission lines is to create the phase shift and match the antenna to 50 Ω. The 3 feed transmission line are length matched to get the required phase delays of 0°, 120° and 240°. These 3 lines are combined to create an antenna impedance of around 33 Ω. The low antenna impedance is transformed with a quarter wavelength match to 50 Ω for use in applications and ease of measurements. Figure 2 shows the proposed network.

The minimum value of the axial ratio is mainly determined by loss in the transmission lines resulting in an amplitude mismatch. The bandwidth of the axial ratio corresponds to by the frequency range where the matching network has good enough phase matching.

The problem of the amplitude mismatch in the feed lines could be solved by slightly changing the impedance of each individual transmission line. A lower impedance line gets more power. Thus the amplitude mismatch could be canceled out. This would be implemented by introducing quarter wavelength transformers in each line. The parallel circuit impedance should still equal to 33 Ω.

The feed network also has a positive influence on the bandwidth. This is mostly due the fact of the 3-phase feed and the phase shifts as seen in the example on figure 3 where an mismatch is introduced. The feed impedance is in this case the star point on the impedance smith chart. Through the phase shift lines the round points are generated. In the feed network these are placed parallel, therefor a transformation to the Y or admittance smith chart is needed. The admittances are added and a transformation back to the impedance chart is done. The Triangle point shows a low real part and also zero imaginary component. The transformation from this point to the center is done by a simple quarter wavelength transformer. This point is fairly close to the optimal impedance.

IV. Simulation and Measurements Results

The simulation shows that a large bandwidth is possible with the proposed structure. Figure 4 shows the return loss of the antenna in different scenarios. In the case without the matching network the $-10\ dB$ bandwidth is 685 MHz or 12 %. When

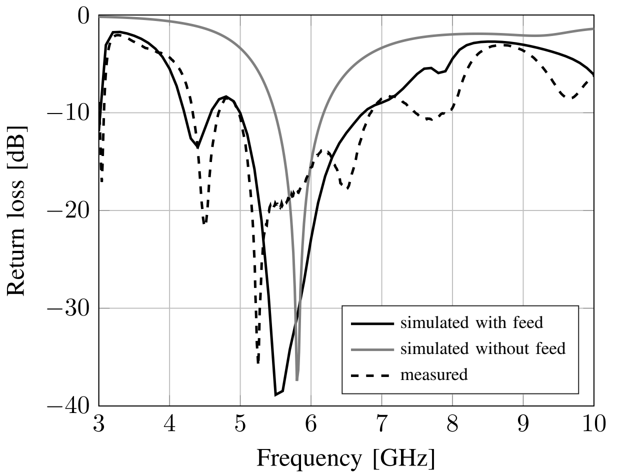

Fig. 4. Return loss [dB]: The simulated antenna without feed as a bandwidth of 685 MHz or 12%. With feed is expands to 1.7 GHz or 27 %. The measured bandwidth of the antenna is 1.8 GHz or 31 %.

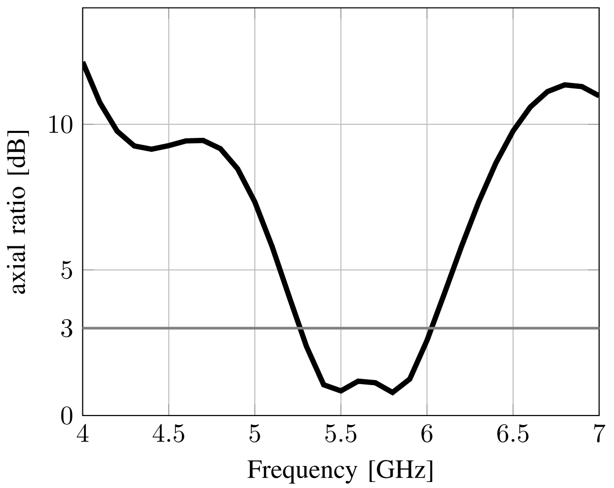

Fig. 5. Simulated with feed axial ratio [dB]: The axial ratio has a bandwidth of 790 MHz or 13.4 %.

we include the the feed structure the bandwidth increases to 1.7 GHz or 27 %.

The return loss of several prototype antennas are measured with a Rohde&Schwarz ZVA vector network analyzer. As shown in figure 4 the simulated and measured results have a similar shape and bandwidth.

In figure 5 the simulated axial ratio of the antenna is plotted. As noted in section III the phase matching of the feed network determines the axial ratio bandwidth. The minimum of the axial ratio is also dependent on the losses in the delay lines. Longer lines have more loss, thus the W feed point has a lower power compared the the others, which increases the axial ratio.

In the far field plot on figure 6 it is clear that the side lobes are almost not existing. Like in section II told that this is mainly due to the symmetry proprieties of the antenna. The realized gain of the antenna is 10 dBi, which is to be expected from a single patch antenna. The rejection of the

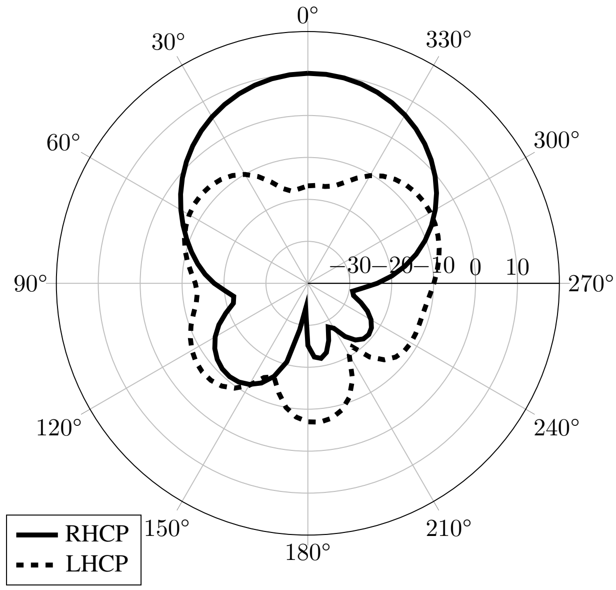

Fig. 6. Simulated realized gain in dBi with $\theta = 0°$

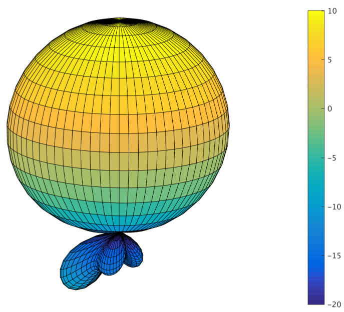

Fig. 7. Simulated realized gain in dBi

other polarization is 25 dB at the point of the highest gain.

V. Conclusion

This antenna design shows great promise due to is great bandwidth and good axial ratio. Also the proposed feed network expands the return loss bandwidth. As seen in the comparison table this design has a similar or better performance than other designs. Also the simple construction and design of the increases it usefulness. The proposed circular patch design has a axial ratio bandwidth of 13.4 %. And with the 3 phase feed network the impedance bandwidth is at least 27 %.

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TABLE I
COMPARISON TABLE

	This work	[1]	[2]	[3]	[4]
Impedance bandwidth ($-10dB$)	27%	7.1%	11%	22.4%	1.7%
Axial ratio bandwidth ($-3dB$)	13.4%	4.8%	7%	14.4%	3%
Center frequency	$5.8\ GHz$	$2.4\ GHz$	$5.8\ GHz$	$868\ MHz$	$2.4\ GHz$
Realized gain	$10\ dBi$	?	?	$9.8\ dBi$	$5.94\ dBi$
Patch geometry	circular	circular	rectangular	stacked circular	circular
Feed method	3 phase	EM coupled	angled microstrip	circular ring feed	slot + stub

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