High Efficiency Patch Antenna for 24 GHz Anticollision Radar

Marija Slović[1], Branka Jokanović, Branko Kolundžija[2]

Abstract : **This paper presents design and measured results in synphase patch antenna for anticollision radar at 24GHz. The antenna consists of two linear arrays of 24 series-fed patches. The aim was to design an antenna that in azimuth has lobes below -20dB in ISM range of 24.05-24.25GHz, at which the anticollision radar operates. The realized antenna has gain of 21.75dB and efficiency of 60% at the frequency of 24.1GHz. Three-decibel bandwidth in azimuth is 3.6^0 and in elevation is 46^0. In the range of 24.05-24.25GHz, gain is higher than 21.15dB and the reflection coefficient is below –14dB.**

Keywords: **Anticollision radar, patch radiator, travelling wave antenna.**

I. Introduction

Enhanced vehicle security is a basic postulate of modern automotive industry. In that respect, it is necessary to be able to detect a vehicle at a critical distance and at a critical speed, in all traffic conditions. Based on the most recent standard of ETSI EN 302 288-1 V1.1.1 (2005-01) defined in January 2005, band of 22-26.625GHz is intended for automobile radar sensors.

Fig. 1. shows a spectral mask according to ETSI standards.

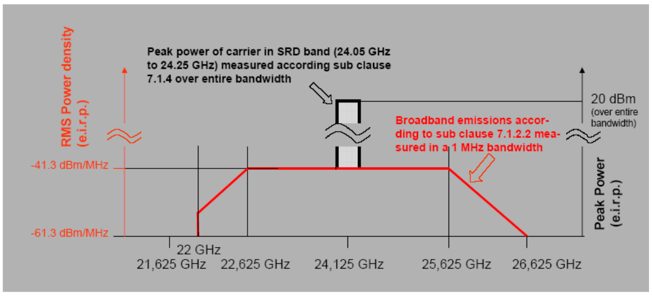

Figure 1. Transmitter maximum radiated peak power density (e.i.r.p) mask for equipment operating in the 22GHz to 26.625GHz

Emitted spectrum from the SRR (Short Range Radar) range consists of two different emissions:

1) Single carrier emission in the SRD band from 24.05 GHz to 24.25GHz.
2) Broadband emission in the 22.000GHz to 26.625GHz

Table I lists the most important restrictions introduced by the ETSI standards regarding allowed power density in respective spectrum parts in order to avoid interference with devices operating in the same range[1].

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Table I. Radiation restrictions defined by ETSI EN 302 288-1 V1.1.1 (2005-01) standards.

ETSI EN 302 288-1 V1.1.1 (2005-01)
Sensors may be active only during motor operation.
Bandwidth is 22-26.625GHz Central frequency is above 24.125GHz
Maximum radiated average power density (e.i.r.p.) in the frequency band from 22.000GHz to 26.625GHz -41.3dBm
Maximum transmitted peak power density (e.i.r.p.) in the 22.000GHz to 26.625GHz band -24.44dBm/3 MHz.
Maximum transmitted peak power in the 24.05GHz to 24.25GHz SRD band 20dBm.
Any emissions within the 23.6GHz to 24GHz band that appear 38° or greater above the horizontal plane shall be attenuated by 25dB below the specified limit.

Apart from this band, band of 76-77GHz for ACC (adaptive cruise control) radars is also in use. Its range is from 2 to 150m and its resolution is less than 1.0m. It is well-known that the radar angle coordinates resolution depends on antenna width i.e. on carrying frequency at fixed antenna dimensions whereas distance resolution is in proportion to emitted spectrum width. This implies that in band of 22-26.625GHz it is possible to realize radar sensors of high distance resolution.

The anticollision radar that is being developed at Institute IMTEL is intended for detection of vehicles moving at high speed from the opposite direction in the same lane as the vehicle with the radar. The radar first reacts to object moving at high speed and checks its distance. If the distance is critical i.e. the estimation is that collision cannot be avoided, the radar gives the signal for activation of the protection system. This is why this radar is in its characteristics more similar to ACC (adaptive cruise control) radars at 77GHz than to the concept of a miniature radar sensor with wide beam (600 in azimuth and 12-150 in elevation), which many producers have adopted for radars at 24GHz. Antenna system of the IMTEL's radar should have narrow beam in azimuth of maximally 3.50 in order to be able to recognize vehicles moving in different lanes at the distance of 50m. Elevation angle should be around 150.

The antenna for the automobile radar should be simple, easy to mount, slim so as not to impair the automobile outline and to be efficient i.e. its dimensions should be minimal for required gain.

Majority of these requirements are fulfilled by the microstrip patch antenna, with the exception of efficiency, which is not satisfactory due to much loss in the feeding network. These antennas may be fed by microstrip line or by slots if great suppression of side lobes is wanted. In feeding by slots, the antenna becomes more complicated for fabrication because two substrates are needed. However, the feeding network is isolated from the radiating element, which makes realization more flexible. Besides, a wider bandwidth is gained.

This paper presents design of linearly polarized travelling-wave microstrip patch antenna. Radiating elements are parallel-series-fed by microstrip lines. Series feeding of patches with travelling wave is chosen because it offers a wider bandwidth and better efficiency in comparison to resonant array[2]. The wave-wave array is impedance matched not only at its input location but along the feeding line as well, at points of radiating elements attachment.

Various distributions that can be applied on travelling-wave array have been tested, taking into consideration required side lobes suppression and antenna gain. By use of 3D electromagnetic simulator WIPL-D Pro[3] a synphase antenna array has been designed consisting of two linear subarrays with 24 paches each. Unlike antiphase array[4], the synphase array has a more constant gain in ISM range and a very good matching.

II. Descriptİon of the Antenna Array

The synphase array is realized on the Teflon fiberglass substrate of the relative dielectric constant of ε_r=2.17 and thickness of h=0.254mm. Distance between serially fed patches is equal to wavelength in the microstrip line i.e. D_H=0.73λ_0 where λ_0 is wavelength in air. Linear subarrays are fed by a coaxial line that is situated in the middle, between the two subarrays.

The antenna consists of 48 identical patches with appropriate network for matching, as presented in Fig. 2. Input patch impedance at resonant frequency fr=24.125GHz depends on coefficient q in the amplitude distribution (1). For q=7/8 input patch impedance is 400Ω. Patch is matched to 50Ω feeding line by $\lambda/4$ impedance transformer that transforms the 50Ω line into the 57Ω line. Thus impedance matching along feeding line at places where patches are attached is obtained.

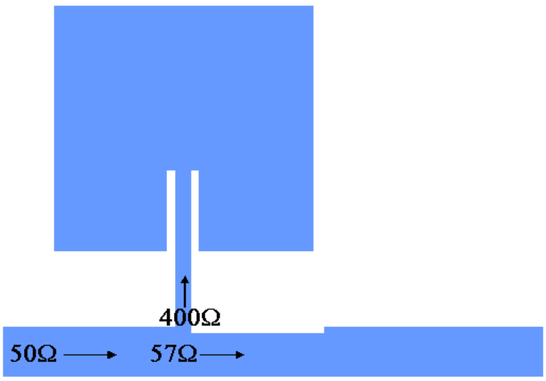

Figure 2. Picture of the 400Ω patch with the matching network

It is well-known that the array with travelling wave must be terminated by a load to absorb power left after the last radiating element. In our case, instead of the load, a $\lambda/2$ open-circuited line reflecting a part of leftover power and radiating it through patches is used. As the patches are at mutual distance of λg, the wave is reflected from the open line in phase with direct travelling wave, so that energy loss is very small.

Fig. 3 shows image of the central part of the antenna array with the feeding network. The feeding network is optimised in such a way that instead of antenna subarrays their input impedance calculated by electromagnetic simulation in WIPL-D Pro program package was used.

Upon design of the antenna array a special attention was paid to choice of optimal distribution. Unlike resonant array, which offers much more possibilities for formation of desired radiation pattern, travelling wave array offers somewhat wider band and higher efficiency of the antenna, which was crucial for us to adopt the latter. We have chosen the antenna array with identical patches with accompanying identical matching network. So that the amplitude distribution along the antenna array is given by the Eq. (1):

$$|A_i| = q^{i-1} + q^{2N-i}, \quad za \;\; i = 1,...N \tag{1}$$

where coefficient q determines which part of the incoming wave power is given to the radiating element. Total number of elements in the array is $2N$. The other part of the distribution expression originates from power reflected from the open-circuited stub at the end of the array.

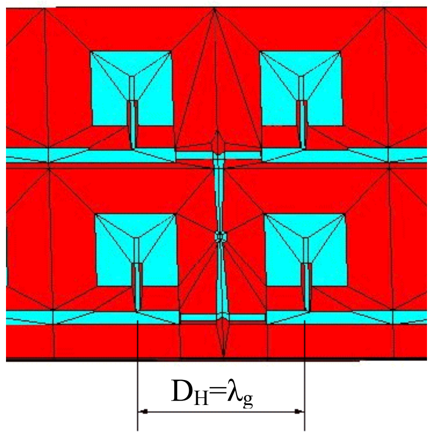

Figure 3. Meshed middle part of symphase antenna array with the feeding network (WIPL-D)

Fig. 4 shows radiation pattern for three different coefficient values q (q=1/2, 5/6 and 7/8) calculated for array of 24 isotropic radiators. Different coefficients q correspond to various ratios of amplitudes at last and middle elements of the array i.e. –31.3dB, -6.0dB and –3.0dB respectively. The pattern shows that the level of the biggerst lobe in all three cases is almost identical (n_L=-17.6dB). However, widths of the main beam and lobe positions differ a lot.

As the narrowest main beam and deepest nulls are obtained with q=7/8, we have decided to realized the antenna array with this distribution. In order to achieve adjustment along the feeding line, a patch has been designed with impedance of around 400Ω, wich in parallel with impedance of 57Ω gives 50Ω

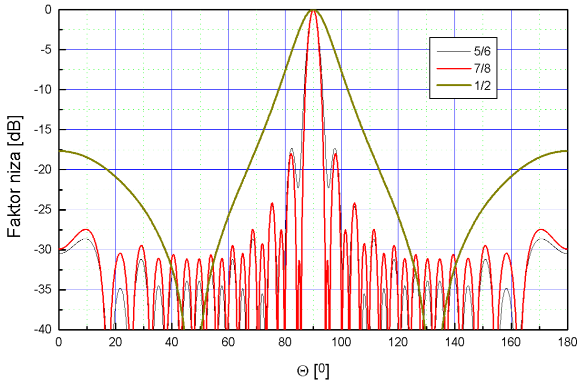

Figure 4. Radiation pattern in H-plane for different values of *q*

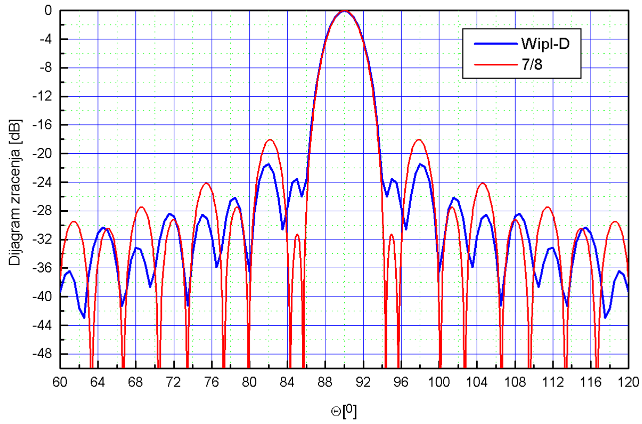

Figure 5. Radiation pattern of array in azimuth (H-plane) obtained by electromagnetic simulation at *f*=24.1GHz

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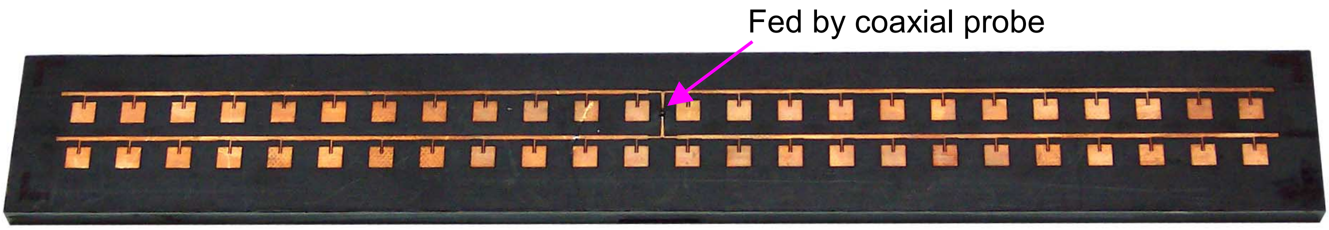

Figure 6. Realized antenna

Fig. 5 shows radiation pattern of the array in Fig. 3 obtained by electromagnetic analysis performed by WIPL-D Pro. The simulation takes into condiseration the side effects, and the anlysis accuracy is enhanced for the integral acurracy and current expansion. The number of unknowns is 12500, when one symmetry plane is used. It is obvious that designed array has somewhat lower lobes that those expected on the basis of array factor, which is the consequence of the patch coupling.

III. Measurement results

Realized synphase antenna is presented in Fig. 6. Its dimensions are 23cm x 3.1cm.

Measured co-polar radiation pattern is given in Fig. 7. The lobes are below -20dB, while measured gain is 21.75dB. Fig. 8 shows copolar and crosspolar patterns of synphase array measured together, while Fig. 9 gives the pattern in elevation plane. A very good agreement between simulated and measured patterns in both planes has been achieved.

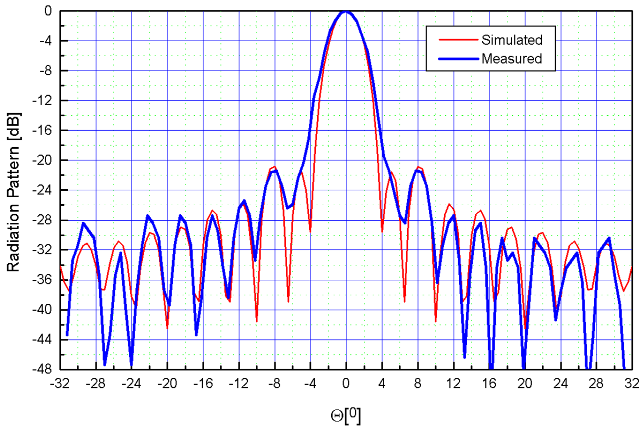

Figure 7. Measured and simulated radiation pattern at 24.1 GHz

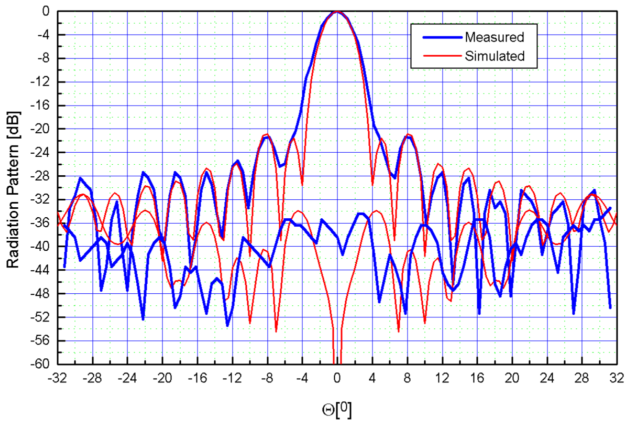

Figure 8. Co-polar and cross-polar radiation pattern at 24.1GHz

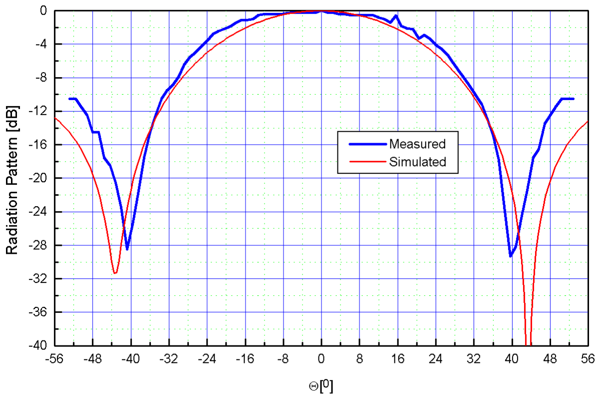

Figure 9. Elevation radiation pattern at frequency of 24.1GHz

Designed antenna array has lobes lower than –20dB and the level of cross-polarization radiation lower than –34dB, which is an exceptionally good result. Measured 3dB beamwidth in azimth is 3.60, and in elevation it is 460, which based on relation:

$$D \approx \frac{41253}{\Theta_{3dBH}\ \Theta_{3dBE}} \qquad (2)$$

gives the directivity of D=249.1. Taking into consideration the fact that measured gain of the antenna at frequency of 24.1GHz G=21.75dB, it turns out that the antenna has a very high efficiency of η=60%.

Fig. 10 shows measured gain in function of frequency for antiphase[4] and synphase antenna. Upon measurement, lower level of generator power was used (-1dBm). The synphase antenna has a little flatter gain than the antiphase one. In the ISM band the gain is higher than 21.15dB, which gives the efficiency higher than 52.3% in this range. Measured gain shows the significant gain drop that occurs at 24.5GHz because of radiation pattern splitting. In simulation, radiation pattern splitting occurs at 24.8GHz.

Reflection coefficient of the synphase antenna is measured on Agilent Series Network Analyser PNA E8364A and is shown in Fig. 11. It is obvious that in the ISM band the antenna is very well matched, as the reflection coefficient in this band (24.05-24.25GHz) is below -14dB.

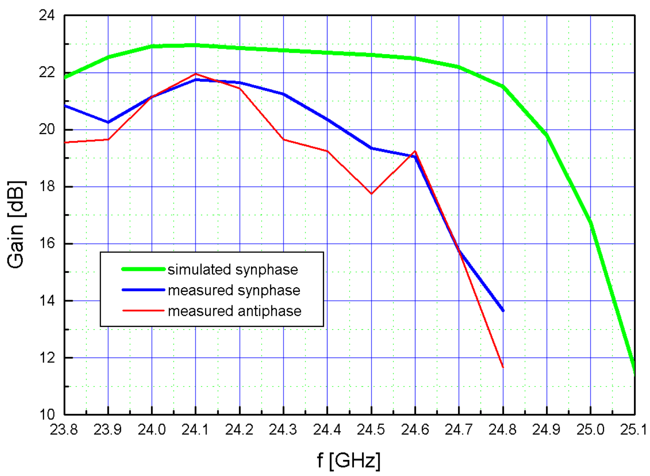

Figure 10. Gain for synphase and antiphase antenna

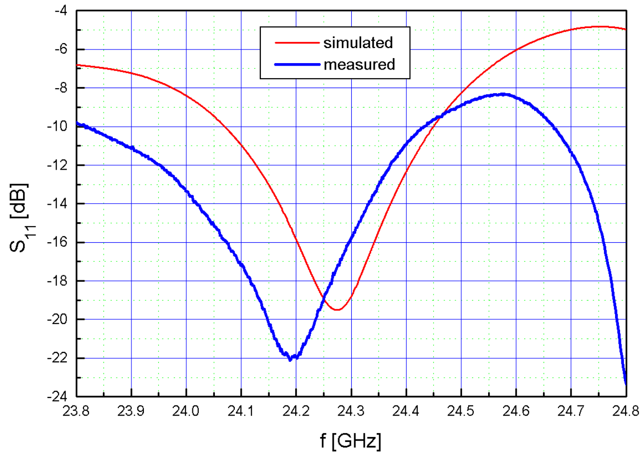

Figure 11. Reflection coefficient

IV. Conclusion

Designed array at frequency of 24.1GHz has gain of 21.75dB, lobes below –20dB and efficiency of 60%. In ISM band (24.05-24.25GHz) efficiency is higher than 52.3%, while the reflection coefficient is below –14dB.

It should be mentioned that presented design of antenna array is only part of the antenna for anticollision radar at 24GHz, which in its final version will have six liner arrays of 24 elements each in order to obtain beamwidth of 150 in elevation, unlike 460 which is the beamwidth of this array.

It should be taken into consideration that requirements concerning the side lobes in elevation are very strict. However, they are defined by average radiated power density per MHz, so that it is possible to make a compromise between radiating power and the lobe level which is at 380 above the horizonatal plane.

Acknowledgments

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