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New design of low profile Uniform Substrate integrated waveguide antenna with square patch loaded

***Abstract** In this paper, a new design low profile periodic microstrip substrate integrated waveguide antenna with patch loaded for scanning radiation pattern for the main beam. The radiation pattern can be changing the elevation angle (beam direction) by using the square microstrip patch loaded on the edge of microstrip line, and that's due to changing the reactive impedance of antenna. This square patches put closely of the free edge of radiation element and changing the patch load by connecting the patch with ground plane by pin vias. The gap between square patch and microstrip line is capacitor used to achieve the scanning main beam between the boreside and endfire direction. The proposed antenna can be scanning main beam direction between 25 to 78 with high realized gain 10 dBi with high performance of input impedance. The proposed design is very suitable for automotive radar.*

Streszczenie. W tym artykule przedstawiono nową konstrukcję niskoprofilowego okresowego mikropaskowego podłoża zintegrowanego z anteną falowodową z łatą załadowaną do skanowania wzorca promieniowania dla wiązki głównej. Charakterystyka promieniowania może zmieniać kąt elewacji (kierunek wiązki) za pomocą kwadratowej łatki mikropaskowej ładowanej na krawędzi linii mikropaskowej, a to ze względu na zmianę impedancji biernej anteny. Te kwadratowe łaty nakładają się blisko wolnej krawędzi elementu promieniującego i zmieniają obciążenie łaty, łącząc łatę z płaszczyzną uziemienia za pomocą przelotek pinowych. Odstęp między kwadratową łatą a linią mikropaskową jest kondensatorem używanym do uzyskania skanującej wiązki głównej między kierunkiem odwiertu i końca. Proponowana antena może skanować kierunek wiązki głównej od 25 do 78 z wysokim zrealizowanym wzmocnieniem 10 dBi z wysoką wydajnością impedancji wejściowej. Proponowana konstrukcja jest bardzo odpowiednia dla radaru samochodowego. (***Nowa konstrukcja niskoprofilowej zintegrowanej anteny falowodowej Uniform Substrate***)

Keywords: substrate integrated waveguide, microstrip line, current density, square patch, SIW.
Słowa kluczowe: falowód zintegrowany z anteną, antena szerokopasmowa

Introduction

The microstrip line substrate integrated waveguide antenna have been attractive choice since 1970 [1] due to their ease of fabrication, low planer profile, high gain, low cost, and wide capabilities of beam scanning [2]. The leakage of microstrip substrate integrated waveguide antenna from higher order mode start to studies since 1980 [3]. The radiation pattern on boresight abilities from planar low-profile structures of proposed substrate integrated waveguide antenna is best choice interactive for all researchers. The wide scanning for the main beam and the high capacity range for the substrate wave guide led to the make it suitable choice for the communication multipoint and the radar. The substrate integrated waveguide is costly and bulky technology , the waveguide can instaed of the microstrip planer. The substrate integrated waveguide has different types, especially in leaky wave antenna design based on the microstrip line are the very sutable with the microwave circuits [4]-[6]. The continuous main beam scanning of the substrate wave guide deponded on the leaky wave antenna depending on the main equation of the elevation angle of the radiation pattern with the pase constant of the propagation (β), with the angle of the forward direction θ(f), the electromagnetic wave are propagate on the forward direction in the free space constant k_o. The elevation angle direction is given by [7]-[24].

$$\theta(f) = sin^{-1}[\frac{\beta(f)}{k_o(f)}] \quad (1)$$

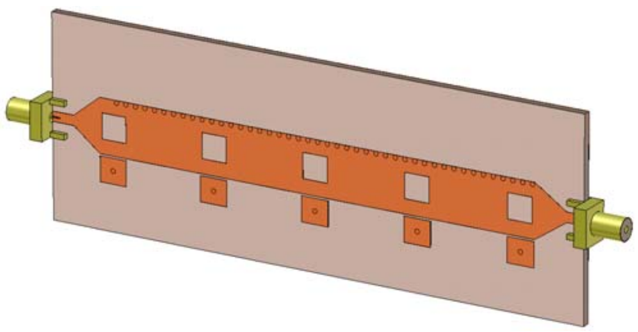
The characteristics of microstrip line in the fundamental mode does note any electric field radiated between patch element and the ground plane. In order to radiated the electric fields, need to introduce the conducting wall between microstrip patch and ground along the edge of radiation element (microstrip line) by using the array of vias, so this conducting wall forcing the microstrip line work in first higher order mode, then the electric field radiating in farfield on boresight. However, the radiation on boresight is very difficult achieve in uniform leaky wave antenna. The research community interesting attract of leaky wave antenna radiate on boresight because the limitation of uniform microstrip leaky wave is radiated on boresight. However, the researchers in[25]-[28] proposed a dual beam antenna by using single radiation element with CPW fed. This antenna das narrow beam scanning on boresight at lower frequencies and wide elevation angle at higher frequencies. Achieving wide beam scanning of half width microstrip leaky wave antenna by using some technique of double gaps capacitor, this antenna can be controlling the radiation pattern on boresight by using switch diodes is connecting the microstrip patch with ground plane by array of vias [29]. The authors in [30] proposed new design for half width microstrip leaky wave antenna has been to steering on boresight for two main beam, this design used the array of vias located on the middle of proposed antenna. The main beam on boresight can controlling in microstrip leaky wave antenna by using the capacitor lumped element it putted between the radiation element and the ground plane and connected by using the switched. However, the proposed design in [31] used two feed point on the edge of microstrip line with T junction divider power and the main beam steering by changing the position of the fed point of the proposed antenna. Main beam can be scanning wide elevation angle with high gain at high frequencies.

In this paper, new design of one elements of microstrip substrate integrated waveguide antenna is presented to radiation on boresight and scanning the main beam by changing the operation frequency with wide elevation angle with high gain. The proposed design used the power divider between two elements and fed from one side and the other side used the matching load 50 ohm to matching of characteristic impedance between the radiation elements and the ground plane. The antenna is simulated by using the Microwave CST program.

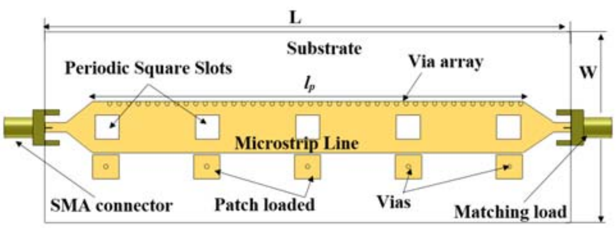
Antenna Configuration

The structure of the new design substrate integrated waveguide with rectangular unit cell for increasing the electromagnetic fields on the edge of proposed antenna as shows in Figure 1 a,b. This array is designed on RT5880 Rogers substrate, with tanδ=0.0009, and εr=2.2. height (h) of the substrate, width (W), and Length (L) are 1,575 mm, 39 mm (0.598λ_o), and 240 mm (3.42λ_o), respectively. The proposed new design of array is fed from one side of microstrip line by SMA connector with standard commercial dimension and the other side of microstrip line terminated by matching load 50 ohm in order to attenuation of reflecting wave and to achieve the good matching imperdance of the profile antenna as demonstrated in Figure 1(c). One edge of the microstrip line (radiation element) is connected with the ground plan by using the wall of the vias. The purpose of this wall to support of first higher order mode and avoid any propagation on the fundimantal mode. This the free edge of the radiation element is contain 5 sequare patch with spaced equally 20 mm between center to center of the another patch. The diamnetion of the sequare patch is 5mmx5mm. The gap is 0.2mm between the of the free edge of microstrip line and sequare patch. Each of the sequare patch is contain the vias in the center to connected it with the ground plan. The distance between of two vias naiporing (V) is 0.9mm from center to center vias. The wall of vias is contain of 123 vias, the spaceing between the first vias and the edge of the taparred fed (U) is 1.35mm, the diameter of the vias d is 0.8mm according to the equation (2) [32]-[39].

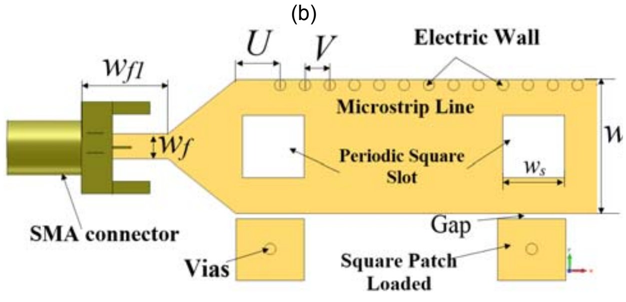
$$d > 0.2\lambda_o \; , \frac{d}{V} \leq 0.5 \qquad (2)$$



(a)



(b)



(c)

Fig. 1. uniform leaky wave array: (a) perspective view, (b) top view, (c) matching load with unit rectangular cell, and (d) port and feed line.

The width and the length of the ground plan has the same diamention of the substrate. In the radiation elements make 5 equally sequare slots with diamentins same of square patch, this sequare slots increase the current density on themicrostrip line and decrease the cross polarization on the radiation elements. Each of the sequare patch can controlling indivatually by remove the vias on the center of patch. The location of the first pin vias optimize by using parametric study in order to get impedance matching between the substrate integrated waveguide and the microstrip patch neat the free edge of microstrip line. All of the antenna parameters was optimized by using the parametric study in CST microwave program. The diamention of the tapperd line W_f and W_{f1} are 1.4mm, 7mm, respectivally. The tapperd feed is best matching between the SMA connecter and the radiation elements.

Results and Disscusion

The new design model of substrate integrated waveguide (SIW) with loaded square patch was simulated and constructed. The simulated results of proposed design indicated that operation frequency independent of main beam scanning of radiation pattern for SIW which that over 10% bandwidth frequency, from 3.9GHz to 4.9GHz, and each point of the operation frequency within wide bandwidth. The main beam of radiation pattern can be scanning from +22^o to +65^o towards to endfire. Table1 summarized the simulation results of the main beam direction and the realized gain of the proposed design of SIW with the sweeping the operating frequency are shown in Fig. 2. . In the state one the main elevation angle (main beam direction) is 22^o with realized gain is 12.9 dBi at 4.2 GHz, while the state 5 the main beam direction is +65o with released gain 11.54 dBi at 5 GHz. That's mean the gain of radiation pattern is decrease when the operation frequency increase. The main beam direction moves towards endfire. The performance and the efficiency is low because of low power density in the endfire, are shown in Fig 3. It is noted the elevation angle of the radiation pattern scanning between +22^o to +65^o in the forward direction. In the level of sidelobe is lower than -10.5 dB for all the states of the radiation pattern. The variation of realized gain between 12.9 dBi to 11.54 dBi, the maximum realized gain at 4.2 GHz. when the loaded square patch on the edge of SIW led to decrease the cross polarization on the edge of microstrip line and the vias is connected the microstrip square patch with ground plan, the high impedance between microstrip plan and the radiation elements. The radiation pattern predicted of the x-z plan for proposed design in all bands are shown in Figure 2. The radiation pattern are scanning in forward direction between +22^o to +65^o when the operation frequency sweeping between 4.2 GHz to 5 GHz, respectively. the proposed design provides high realized gain with high radiation efficiency, while the different between the total efficiency and radiation efficiency ists lower at higher frequencies are shown in figure 2. The radiation efficiency is high when the main beam near of the boresight at +22^o and is decreased at the endfire of the radiation element.

Table 1: Selected switch cases and direction of the main beam at 4.2 GHz

State No.	Operation frequency	Main beam direction(degree)	Realized gain (dBi)
1	4.2	+22	12.9
2	4.4	+27	12.8
3	4.6	+44	11.9
4	4.8	+60	11.8
5	5	+65	11.54

The surface current distribution its clear in figure 4 at 5 GHz most of the power radiation at lower frequency and the most of the power is less near of the feed point (feeder). The surface current is high in the edge of the microstrip line. The square patch close of the radiation element led change of the characteristics impedance of microstrip line then change of the direction of main beam. The variation of the gain and direction of main beam of the proposed antenna with sweeping the operation frequency. It can be seen that the long effective slot at higher operating frequency, and low effect slot at lower frequency.

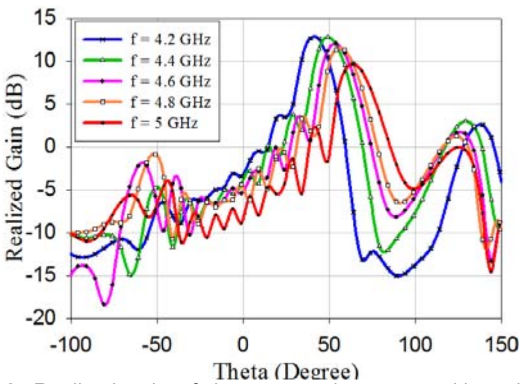


Fig. 2. Realized gain of the proposed antenna with main beam direction

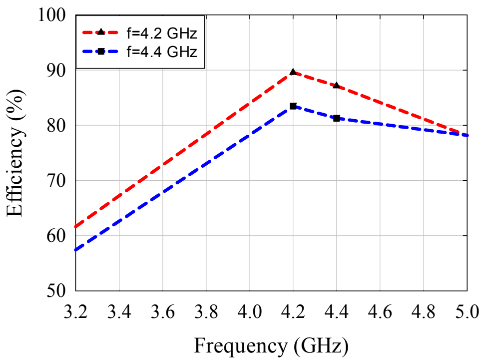


Fig. 3. Radiation efficiency for the proposed design of SIW at 4.2 GHz and 5GHz.

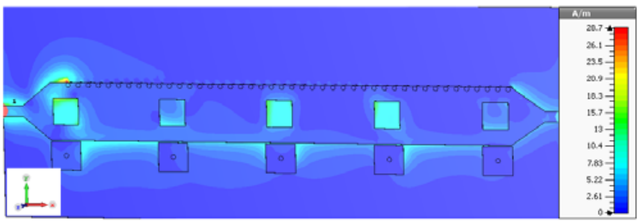


Fig. 4. Distribution of surface current field (amplitude) at 5GHz

In the figure 5 the field component near the fed SMA port are the polarized circularly type, and this type of polarization led to increase the cross polarization on the radiation pattern, however, the edge of the radiation element are polarized linearly in the y direction and the edge of the square patch is linearly polarized in the x direction that's led to decrease the cross- polarization on the radiation element then let to increase the released gain and the current density on the microstrip line.

In figure 6a the propose design has low cross polarization level at low frequency because of the square unit cell close of the edge of microstrip line and the radiation pattern near of the boresight direction. High released gain at low operating frequency 4.2 GHz. In the substrate integrated waveguide, the cross polarization significantly increases at high frequencies and the main beam of the proposed antenna close of the endfire. The is the disadvantage of the substrate waveguide when used the microstrip line. The released gain decrease because of the high cross polarization as can be seen in the figure 6b.

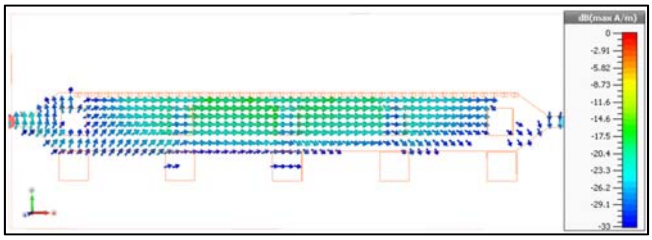
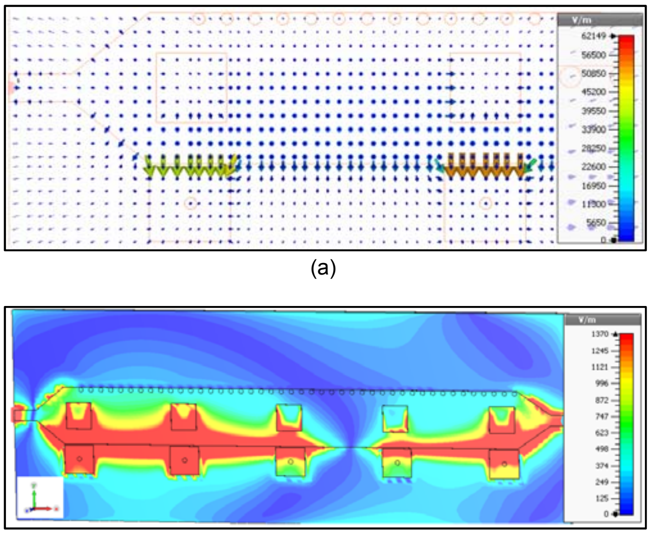


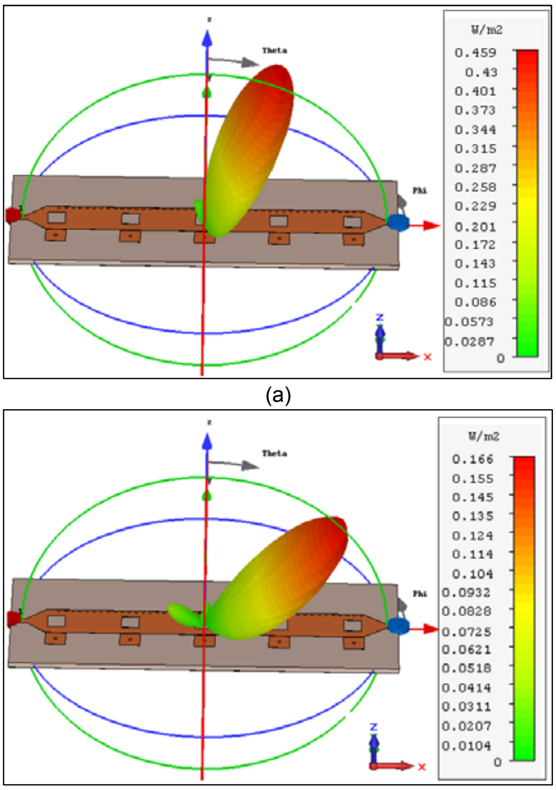
Fig. 5. Distribution of electric field of half substrate integrated waveguide at 5 GHz



(a)

(b)

Fig. 6. Electric field components distribution of Substrate integrated waveguide at: (a) 4.2 GHz (b) 5 GHz.



(a)

(b)

Fig. 7. Radiation patterns of substrate waveguide (x-z-plane) at: (a) 4 GHz (b) 5 GHz

The main beam of substrate integrated waveguide can be scanning from boresight direction to the endfire when the operation frequency sweeping between the 4 GHz to the 5 GHz, it can be seen in the figure 7a when the operating frequency at 4 GHz , the elevation angle of radiation pattern is 21^{o}, in the figure 7b the operating frequency is 5 GHz the main beam become near the endfire direction and the elevation angle is 65^{o}. By using the square patch cell near of the edge of radiation element led to increase the bandwidth scanning range of the proposed antenna. The square slots on the radiation elements cause of decrease the cross polarization of the microstrip line and improvement the characteristics impedance of the substrate integrated waveguide.

The s parameter of the proposed substrate integrated waveguide it is can see in figure 8, the reflection coefficient is lee than -10dB from 3.9 GHz to 4.9 GHz (41.1%), wide bandwidth of proposed antenna that's means wide scanning range on the forward direction of antenna. The simulated of the radiation pattern normalized of substrate integrated waveguide at 4.6 GHz and the main beam direction at 44^{o}, are shown in figure 9 whereas the side lobe level is high because of the surface current of the radiation elements.

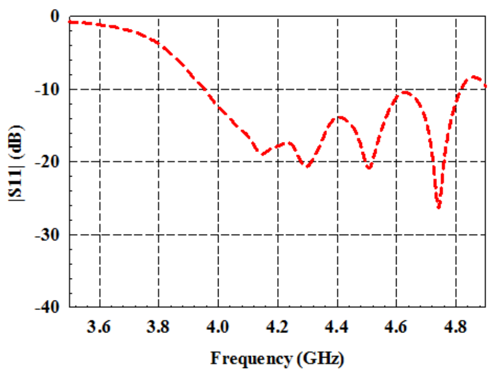


Fig. 8. |S11| for proposed substrate integrated waveguide.

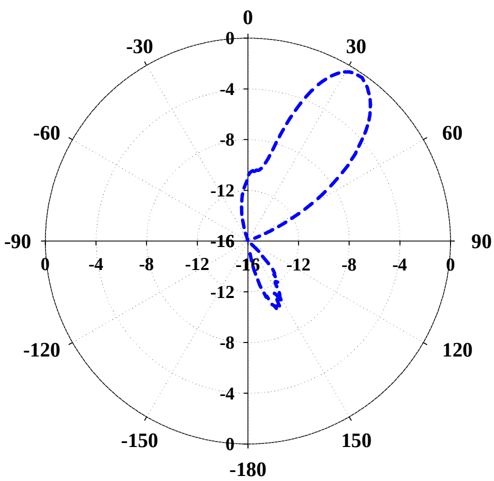


Figure 9. Simulation of normalized radiation patterns (x-z-plane) of substrate integrated waveguide at 4.6 GHz

Conclusion

A uniform substrate integrated waveguide has been designed to increase the scanning range at sweeping the operating frequency in the forward direction. The scanning of radiation pattern ranges between 22^{o} to 65^{o} when sweeping frequency between 3. GHz to 5 GHz. The maximum realized gain of the proposed antenna is 12.9 dBi at 4.2 GHz, the minimum realized gain is 11.54 at 5 GHz. The gain is reminding above the 11 GHz for all cases of sweeping operating frequency. The square slot on the radiation pattern led to decrease the cross polarization because of the increase the linear electric field on the microstrip line. The microstrip square patch near of the microstrip line led to increase the current density on the edge of proposed antenna then improvement of characteristics impedance of substrate integrated wave guide.

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