Dwi Astuti Cahyasiwi - Stacked Interdigital Filtering Antenna with Slant Polarization

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Stacked Interdigital Filtering Antenna with Slant Polarization

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***Abstract*—The studies of the filtering antenna have performed many methods and type of resonators used in co-design between the filter and antenna. But none of them using the interdigital resonator with a via through hole. Interdigital resonator with a via through hole has a unique characteristic for it is short-circuited at one end and open circuited at the other. This condition is expected to have an effect to the electric field and the surface current direction. This paper performs a second order of the interdigital filter co-design with a proximity fed rectangular patch antenna. The simulation shows that the interdigital resonator with a via through hole affects the polarization of the antenna from a vertical polarization alter to a slant polarization. The design is fabricated and measured, both the simulation and measurement show a good agreement with a bandwidth of 340 Mhz at 4.8 GHz resonance frequency, maximum gain of 8.2 dBi and a - 75° slant polarization.**

Keywords— filtering antenna, interdigital, slant polarization, via through hole.

I. Introduction

The requirement of the future telecommunication equipment is the integration of the devices that result in the multifunction component. Filtering antenna is an integration method of a filter and an antenna, presents an antenna that limits its gain only in the operation bandwidth and blocks the gain out of its bandwidth. Polarization is one of the parameters that often studied in a filtering antenna and many papers have shown the method to realize some types of the filtering antenna polarization such as circular polarization and dual linear polarization [1], [2]. There are other types of polarization that have never been presented in a filtering antenna, that is the slant polarization, which is proved to have a better gain diversity compare to dual linearly polarized antenna [3] in a multipath propagation condition. It also performed a lower Bit Error Rate compare to the horizontal/vertical polarization and has a higher channel capacity [4], [5].

Some conventional antennas performs a ± 45° slant polarization antenna but none of the designs based on a co-design between the filter and antenna [6]–[8]. In [6] a parasitic parallelepiped antenna performs a ± 45° slant polarization, having 2.5 dBi gain, has a complex design and three dimensional antenna which is not suitable for a compact requirement. Multiscreen cylindrical polarizer surround Biconical antenna performs 45° slant polarization in [7], for a 5.1 dBi maximum gain the design is complex and highly cost. An omnidirectional antenna using cross dipole is reconfigured to perform a ± 45° slant and circular polarization in [8] but both designs show a negative gain. Filtering antenna studies have not reported the method to perform a slant polarization and though some researches on the conventional antenna have obtained a method to design a slant polarization many of them have a three dimension structure which is not suitable for a miniaturization and none of the method base on the co-design between the filter and antenna.

This study proposed a novel co-design of the interdigital filter with a via through hole and rectangular patch antenna that performs not only an antenna that has a flat gain response along its bandwidth but also a slant polarization. The rectangular patch antenna acts both as a radiator and the second resonator as well. The stacked interdigital filtering antenna (SIFA) polarization direction is determined by the position of the via at the resonator's arm.

II. Design

The proposed filtering antenna is shown in Fig. 1. The filtering antenna consists of two dielectric substrates which is printed on Roger Duroid 5880 with a dielectric thickness 1.575 mm, permittivity 2.2 and loss tangent 0.0009. The 40 x 40 mm^2 stacked interdigital filtering antenna consists of two layers, on the first layer as seen in Fig.1 (b) a rectangular patch radiator is proximity fed by the second layer. An interdigital resonator with 1.2 mm diameter via through hole on the left arm and 50 Ω transmission line on the second layer shown in Fig. 1 (c) fed the radiator above. The length of the interdigital is approximately a quarter wavelength at the operating frequency and the geometry of each layer is depicted in Fig. 1 (a) which has a geometrical symmetry at *yz* plane.

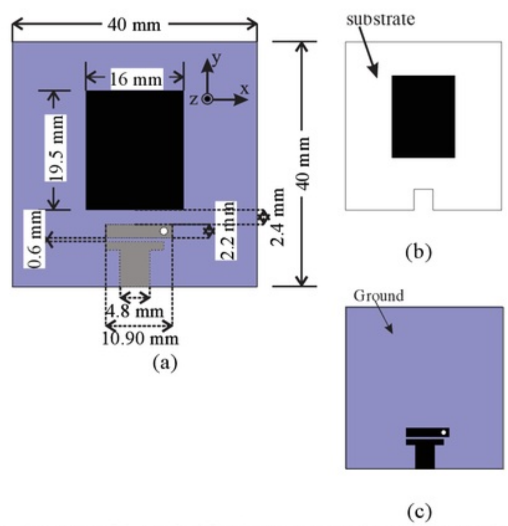


Fig. 1. Geometry of the stacked filtering antenna (a) Stacked Antenna (b) First layer (c) Second layer.

The 4.65 GHz filtering antenna is designed based on the 2[nd] order of Chebyshev bandpass filter with fractional bandwidth (FBW) 6.45 %, ripple 0.2 dB that has normalized Chebyshev element value of lowpass $g_0 = 1$, $g_1 = 0.843$, $g_2 = 0.622$, $g_3 = 1.3554$. In the co-design of filter and antenna the external quality of the filter (Q_{ext}) must be equal with the quality of the radiation of the antenna (Q_{rad}). The coupling between the input and the first resonators ($M_{0,1}$) must be equal with coupling between the resonator and the radiator ($M_{2,3}$). Using (1) and (2) the value of Q_{ext} and $M_{1,2}$ are calculated 13.06 and 0.07027 respectively.

$$Q_{\text{ext}} = \frac{g_0 \cdot g_1}{FBW} \tag{1}$$

$$M_{1,2} = \frac{FBW}{\sqrt{g_1 \cdot g_2}} \tag{2}$$

The extraction of the Q_{rad} is performed by adjusting the distance between the coupled fed and the first resonator using two ports, the result is shown with the S_{21} response and calculated using (3) where f_c is the center frequency, and Δf is the bandwidth of 3 dB. Meanwhile the extraction coupling between the resonator and the radiator is performed by adjusting the gap between the radiator and the resonator, the response of S_{21} simulation will be two peaks frequency where f_1, f_2 are the lower frequency and the higher frequency respectively, using (4) the $M_{1,2}$ can be obtained. The extraction of each parameter using CST simulator is applied in co-design

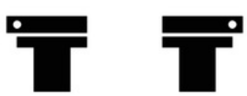
$$Q_{\text{ext}} = \frac{f_c}{\Delta f} \tag{3}$$

$$M_{1,2} = \frac{{f_2}^2 - {f_1}^2}{{f_2}^2 + {f_1}^2} \tag{4}$$

between the interdigital filter and rectangular patch antenna which final dimension is shown in Fig. 1.

III. Discussion

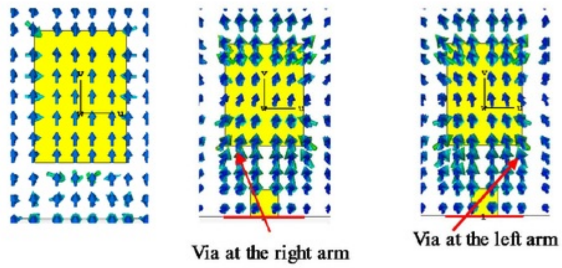
Interdigital with a via through hole on one arm has a short circuit condition while the other arm is an open circuit. Applying co-design between the 2nd order filter and the antenna in previous section, an interdigital resonator is positioned parallel with the rectangular patch antenna. In the first design, the via is placed on the right arm of the interdigital while for the second design the via is located at the opposite arm as can be seen in Fig 2.



(a) (b)

Fig. 2. SIFA with via on the (a) right arm and (b) left arm.

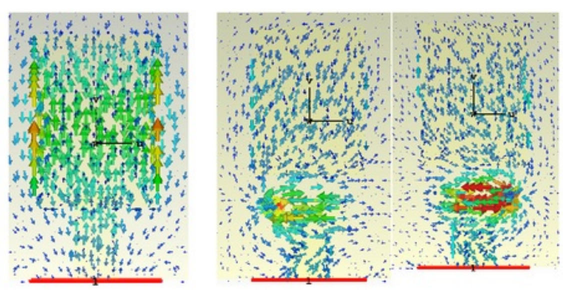
As shown in Fig. 3, the electrical field simulation reveals that SIFA inclines the polarization in some degree to the right or to the left vertical ($+v$) axis compare to the conventional antenna with proximity coupling in Fig 3 (a). The via positioning on the interdigital arm affects the direction of the polarization inclination, if the via is at the right arm of the interdigital as illustrated in the structure in Fig. 3(b) then the electrical field incline to the left side of the vertical $+v$ axis, on the contrary if the via is located at the left arm, then the electrical field inclines to the right side of the vertical $+v$ axis.



(a) (b) (c)

Fig. 3. The electrical field of (a) conventional proximity fed (b) via on the right hand (c) via on the left hand

We can also analyze the effect of the via positioning at the surface currents, the comparison between a conventional antenna and SIFA with via at the right arm and left arm shown in Fig. 4. For the conventional antenna, the surface current flows vertically from the feed line and forms a vertical polarization up to the radiator above it as illustrated in Fig. 4 (a), while the SIFA with the via at the right arm resonator, the surface current moves horizontally from the open circuit to short circuit, so that when flowing into the parallel radiator above, the direction of the current begins to form a left inclination from the vertical $+v$ axis as shown in Fig. 4 (b). The surface current inclination occurred with via at the left arm resonator but with the opposite (right) direction as depicted in Fig. 4 (c), then it can be concluded that the placement of the via through hole affects the polarization direction.



(a) (b) (c)

Fig. 4. The surface current of (a) conventional antenna (b) SIFA with via at the right arm (c) SIFA with via at the left arm

From the simulation of the surface current, it can be projected that the inclination degree (θ) of SIFA polarization with via at the left arm of the interdigital resonator as illustrated in Fig. 5 forms -75° to the $+u$ axis, slanted compare to the vertical polarization (θ=-90°) so it can be determined that if the via is on the right arm of the interdigital resonator then it will generate a +75° slant polarization.

To prove the simulation, SIFA with a via at the left arm is fabricated and measured. The picture of the fabricated filtering antenna is shown in Fig. 6 where the first layer shown in Fig.

6 (a) the rectangular radiator fed by the interdigital resonator with a coupled feed line shown in Fig 6 (b) and the two layers are stacked in Fig. 6 (c).

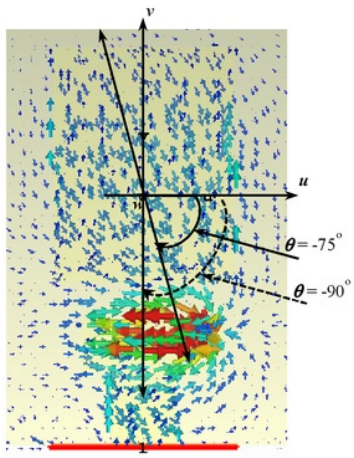
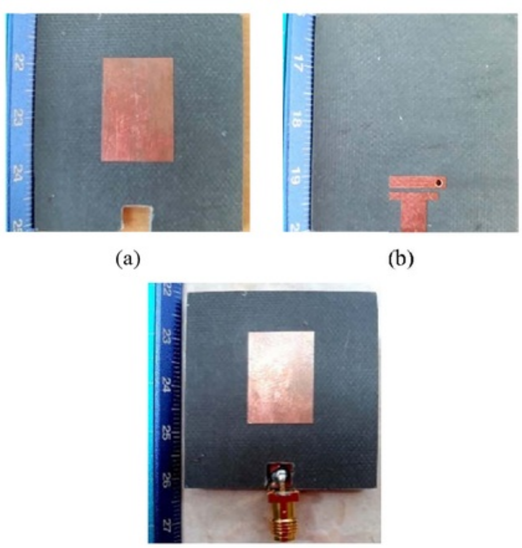


Fig. 5. SIFA with via on the left arm and its current surface inclination (θ) from the horizontal axis ($+u$) .

The simulation results of the magnitude reflection coefficient can be observed in Fig. 7 (dash line) that SIFA has a 300 MHz bandwidth or 6.45% FBW at operating frequency of 4.65 GHz while the measured -10 dB reflection coefficient (solid line) has 340 MHz bandwidth (4.587 – 4.934 GHz) 15% wider compared to the simulation result (dashed line), but the passband shifted 100 MHz to the higher frequency which originate from the air gap that may exist between the first layer and the second layer or caused from the fabrication accuracy of the via through hole diameter.



(a) (b)

(c)

Fig. 6. The picture of prototype stacked interdigital filtering antenna (SIFA) (a) Rectangular radiator at the first layer (b) Interdigital resonator with via at the left arm at the second layer (c) Stacked Filtering Antenna.

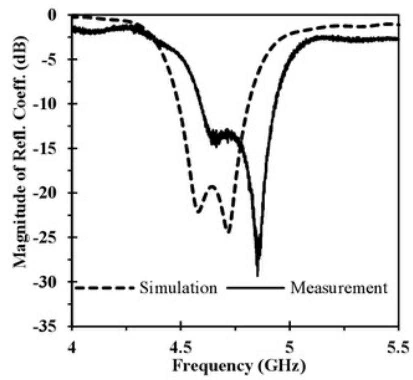


Fig. 7. Magnitude of reflection coefficient comparison between simulation and measurement.

The simulation result of the maximum gain is 6.6 dBi at 4.7 GHz and it shows a sharp shape that blocks the out of band gain. To verify the degree of the slant polarization, SIFA is measured in an anechoic chamber at Department Electrical Engineering, Faculty of Engineering, Universitas Indonesia with various polarization degree which are -90° (vertical polarization), -80°, -75°, -70° and -65°. Table I explains that the gain measurement increases from θ = -90° to -75° and decreases from θ = -75° to -65° both at 4.8 and 4.9 GHz. The measurements result from different polarization degrees show that the maximum gain is achieved at θ = -75° with the value of 7.23 and 8.2 dBi at the 4.8 and 4.9 GHz respectively.

TABLE I. MAXIMUM GAIN IN DIFFERENT POLARIZATION (θ)

Freq.(Ghz)	Gain (dBi)				
	θ(°)				
	-90	-80	-75	-70	-65
4.8	6.76	7.17	7.24	6.86	5.34
4.9	7.9	8.08	8.2	7.6	7.4

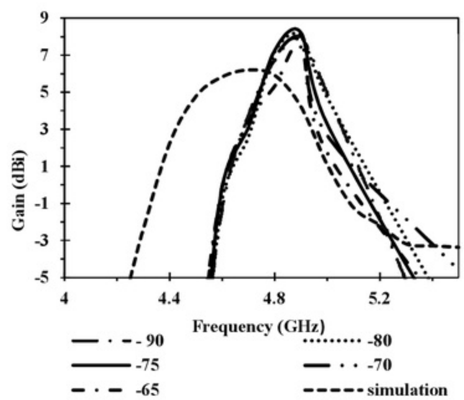


Fig. 8. Simulation and measurement result of SIFA Gain with various inclination of slant (θ) polarization

The comparison of the simulation and measurement based on the different θ along the frequency are shown in Fig 8 where at θ = -75° slant polarization (solid line) performs the highest value of gain compare to the vertical polarization or θ = -90° (dash line) and other different θ slant polarization. These measurements results verify that the SIFA polarization is at θ = -75° and we also can conclude that with the via positioned at the right arm of the resonator then the polarization will be +75° slanted. All the measurement result shows sharp shape of gain with the maximum value at 4.9 GHz, shifted 200 MHz to the higher frequency compare to the simulation.

The simulation and measurement of the radiation patterns at 4.8 GHz in Phi = 90° and Phi = 0° are presented in Fig. 9 and Fig 10. A unidirectional radiation patterns is observed at Phi = 0° and Phi = 90° co-polarization curve. Both the simulation and measurement have a good agreement. The cross-polarization level measurement is above -10 dB for both Phi = 0° and Phi = 90° which match with the simulation result.

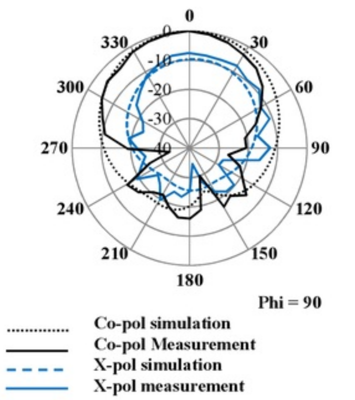


Fig. 9. Simulation and measurement result of SIFA radiation pattern at 4.8 GHz for Phi =90°

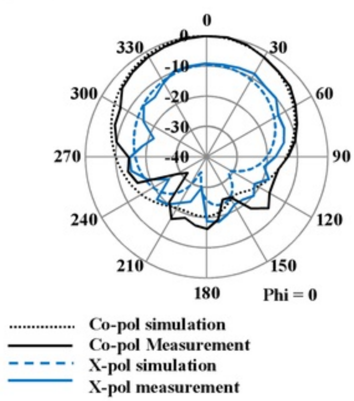


Fig. 10. Simulation and measurement result of SIFA radiation pattern at 4.8 GHz for Phi = 0°

IV. Conclusion

The interdigital resonator with a via through hole that parallelly fed a rectangular patch radiator is proved to alter the polarization from the vertical to a slant polarization. The inclination of the polarization is controlled by the position of the via through hole in the interdigital resonator's arm. The design has been confirmed by measurement and a good agreement with the simulation is achieved. The stacked interdigital filtering antenna has 340 MHz bandwidth, 8.2 dBi gain at 4.9 GHz and a unidirectional radiation pattern with -75° slant polarization.

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