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**PENGURANGAN MUTUAL COUPLING
ANTENA ARRAY VIVALDI COPLANAR
UNTUK APLIKASI TELEKOMUNIKASI S&C BAND**

Tahun ke-1 dari rencana 1 tahun

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RINGKASAN

Teknologi telekomunikasi dan radar banyak digunakan diantaranya pengawasan wilayah, surveillance, navigasi, pengamatan cuaca, satelit, medical imaging, astronomi dan GPR. Antena merupakan salah satu perangkat penting dalam front end sistem telekomunikasi. Antena Vivaldi adalah antena planar yang bekerja pada bandwidth yang lebar sehingga dapat diaplikasikan untuk banyak aplikasi dan dapat menampung data dengan kapasitas tinggi. Untuk mendapatkan gain yang tinggi dan beamwidth yang kecil maka antena disusun array. Pengaturan array harus memperhatikan jarak antar feeding karena dapat terjadi mutual coupling yang dapat mempengaruhi kinerja antena. Tujuan dari penelitian ini adalah mengembangkan metode pengurangan mutual coupling antena array Vivaldi Coplanar.

Tahap awal penelitian ini yaitu mendesain elemen antena dan antena array. Langkah selanjutnya adalah membuat metode pengurangan mutual coupling antena array vivaldi. Hasil pemodelan akan diverifikasi dengan hasil simulasi dan hasil pengukuran. Spesifikasi antenna yang akan dibuat adalah antena Vivaldi Coplanar, bekerja pada frekuensi S& C Band (2-10 GHz), menggunakan bahan FR4, dengan VSWR<2 dengan nilai S12/S21 mencapai dibawah -20 dB.

Dari hasil simulasi dan pengukuran didapatkan Exponential Corrugated Truncated (ECT) slot pada Coplanar Vivaldi Array (CVA) dapat diaplikasikan untuk mengurangi mutual coupling dan juga memperbaiki performansi pola radiasi. Desain CVA yang dibuat dapat bekerja pada ratio bandwidth 5:1 dari 2-10 GHz dapat mengurangi mutual coupling kurang dari -20 dB di sebagian besar frekuensi dari 2-10 GHz menghasilkan gain 3.9-10.2 dBi di band 2-10 GHz, meningkatkan performansi SLL di frekuensi 4-9 GHz jika dibandingkan dengan CVA tanpa menggunakan slot.

Kata kunci: vivaldi, coplanar, mutual coupling, broadband, array antenna

PRAKATA

Puji dan syukur yang tak terhingga kami panjatkan kepada Allah SWT karena atas berkat rahmat-Nyalah kami dapat menyelesaikan laporan kemajuan hibah doktor yang berjudul: ‘PENGURANGAN MUTUAL COUPLING ANTENA ARRAY VIVALDI COPLANAR UNTUK APLIKASI TELEKOMUNIKASI S&C BAND’. Penelitian hibah doctor ini membantu penulis dalam menyelesaikan studinya di program pasca sarjana Teknik Elektro, Fakultas Teknik Elektro, Institut Teknologi Sepuluh Nopember.

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Kami menyadari laporan kemajuan ini masih terdapat banyak kekurangan sehingga masukan dan saran sangat dibutuhkan demi penyempurnaan laporan kemajuan ini. Semoga laporan kemajuan ini dapat memberikan manfaat bagi para pembaca.

Hormat kami

Penulis

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BAB I

PENDAHULUAN

1.1. Latar Belakang

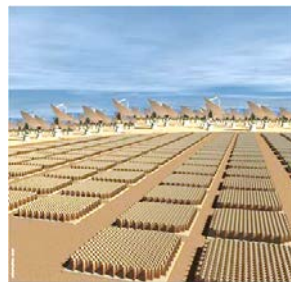
Indonesia merupakan negara kepulauan dan diperlukan teknologi pengawasan (surveillance) wilayah perairan dan udara, teknologi telekomunikasi pendukung bidang transportasi, pertahanan keamanan, pendidikan, agrikultur, kesehatan, pemerintahan dan sebagainya. Banyak kebutuhan telekomunikasi diperlukan pada frekuensi S-Band diantaranya komunikasi WLAN, Wifi, *base station* (2.3-2.7 GHz) , WiMAX (2.3-2.7 GHz atau 3.3-3.8 GHz), *weather radar* (2.7- 3 GHz), *aeronautical radio navigation*(2.7-2.9 GHz), *maritime radio-navigation* (2.9-3.1 GHz) (euro consult,2014). Telekomunikasi C Band juga banyak digunakan pada sistem komunikasi WiMAX (4.9-6.4GHz), TV satelit, amateur radio 5.650-5.925 GHz, amateur satellite (5.830-5.850 GHz) (Agarwal,dkk,2016). Antena merupakan komponen penting *front end* sistem telekomunikasi. Pengembangan teknologi antena dan analisa kinerja antena perlu dilakukan untuk mendukung kinerja sistem telekomunikasi dan Radar. Antena mikrostrip memiliki berat ringan, berbentuk planar, ukuran dan volume kecil, biaya fabrikasi rendah, kompatibel dengan teknologi MMIC, sehingga dapat diproduksi dalam jumlah yang banyak. Antena mikrostrip banyak digunakan dalam banyak aplikasi, namun antena mikrostrip memiliki bandwidth yang sempit 1-5%, dan gain yang rendah(G.Kumar,dkk,2003). Penelitian pada frekuensi S Band dilakukan menggunakan antenna Yagi dengan Spiral Ring Metamaterial(O. M. Khan,dkk,2014), Patch antenna rectangular dengan V asimetrik untuk aplikasi nanosatelit yang bekerja pada frekuensi S Band(M. T. Islam,dkk,2014), triple band monopole dengan parasitic elemen untuk S dan C Band(Shu,dkk,2014), Dual Band U-Slot Microstrip(S.Gupta,dkk,2013). Pada penelitian tersebut antena hanya bekerja pada beberapa daerah frekuensi S band maupun frekuensi C-Band, yang tidak memenuhi semua frekuensi dalam semua band frekuensi. Antena broadband

dapat dimanfaatkan untuk beberapa aplikasi. Menurut *Federal Communications Commission*(FCC) antena UWB jika $BW \geq 20\%$.

	Directional	Omn-directional
Two-dimensional	Vivaldi Antenna Tapered Slot Antenna Log-periodic Antenna Planar Log-Spiral Antenna Conical Spiral Antenna	Planar Dipole Slot Antenna Printed Antenna on PCB
Three-dimensional	TEM Horn Antenna Ridge Horn Antenna Reflector Antenna	Loaded Cylindrical Dipole Bi-conical Antenna Disc-cone Antenna Roll Antenna

Gambar 1.1. Kategori antena broadband(Haupt,2010).

Gambar 1.1. menunjukkan gambar klasifikasi antena broadband berdasarkan arah pola radiasi dan dimensi ruang antena. Untuk mendapatkan gain yang tinggi biasanya antena Vivaldi disusun array. Ada beberapa aplikasi antena Vivaldi yang disusun array.



(a) *Square Kilometre Array*



(b) *Thousand Element Array*

Gambar 1.2. Aplikasi antena vivaldi

Gambar 1.2. mendeskripsikan aplikasi antena Vivaldi yang disusun array untuk aplikasi astronomi yang bekerja pada frekuensi 300 MHz – 3 GHz dan pada Gambar 1.2 (b) adalah gambar aplikasi antena array vivaldi untuk radio teleskop yang bekerja pada frekuensi 200-2000 MHz. Aplikasi antena Vivaldi tersebut bekerja pada frekuensi yang sangat lebar dan menggunakan puluhan bahkan ribuan elemen antena

Vivaldi untuk mendapatkan kinerja gain dan beamwidth yang diharapkan. Penelitian antenna array Vivaldi yang disusun secara sub array(Schaubert,dkk,2004), array polarisasi tunggal (Schaubert,dkk,1997),dua polarisasi(Schaubert,dkk,1999) telah dilakukan oleh beberapa peneliti. Pada publikasi antena array Vivaldi tersebut belum dilakukan analisa mutual coupling. Bahkan untuk aplikasi radar salju(Yan,dkk,2016) antena array yang dibuat memiliki lebar substrat yang sangat kecil, bekerja pada bandwidth yang sangat lebar serta pengaturan array antena secara berhimpit. Pengaturan array pada antena Vivaldi harus memperhatikan terjadinya mutual coupling yaitu interaksi scattering parameter dengan elemen antena yang berdekatan sehingga terjadi coupling antara jalur pencatu. Adanya mutual coupling dapat merubah karakteristik pola radiasi, merubah impedansi antena dan tegangan pada antena di penerima sehingga kinerja antena akan tidak sesuai dengan yang diharapkan. Penelitian yang membahas pengurangan mutual coupling antena mikrostrip dengan simulasi komputasi elektromagnetik telah dilakukan oleh beberapa peneliti diantaranya dengan membuat struktur electronic bandgap (EBG) dan dapat menurunkan mutual coupling sebesar 8dB(Yang,dkk,2010), Neutralization line(Zhang,dkk,2016), Small interdigital Capacitor Loaded Slots dengan penurunan sebesar 17 dB(Abdel,dkk,2012), Defected Ground Structure(DGS) dengan penurunan mutual coupling sebesar 3 dB(Zulkifli,dkk,2008). Beberapa penelitian pengurangan mutual coupling telah dilakukan untuk antena mikrostrip. Sejauh ini dari literatur yang telah dipelajari, penelitian pengurangan mutual coupling antena Vivaldi Coplanar belum ada yang meneliti sehingga perlu diadakan penelitian pengurangan mutual coupling antena Vivaldi Coplanar.

1.2. Perumusan Masalah

Dari latar belakang tersebut, permasalahan yang akan dibahas adalah

Bagaimana pengembangan metode pengurangan mutual coupling antena Vivaldi Coplanar?

1.3. Tujuan

Tujuan penelitian ini adalah:

Mengembangkan metode yang efektif untuk mengurangi mutual coupling antena Vivaldi Coplanar.

1.4. Kontribusi dan Originalitas Penelitian

Mendapatkan metode yang efektif untuk mengurangi mutual coupling antena Vivaldi.

Selama ini metode pengurangan mutual coupling antena Vivaldi Coplanar belum ada yang membahas. Pengurangan mutual coupling kebanyakan dilakukan pada antena mikrostrip. Metode pengurangan mutual coupling untuk antena Vivaldi Coplanar perlu dilakukan karena pada pengaturan array biasanya antena Vivaldi disusun berhimpit dan akan berpengaruh pada kinerja antena jika spacing antar feeding kurang dari $0.5 \lambda_0$. Antena Vivaldi juga dapat bekerja pada bandwidth yang sangat lebar sehingga dibutuhkan metode pengurangan mutual coupling agar kinerja antena seperti pola radiasi, impedansi, scattering parameter dapat terpenuhi.

Tabel. 1.1. Kontribusi Penelitian

No	Jenis Luaran				Indikator capaian		
	Kategori	Sub Kategori	Wajib	Tambahan	TS	TS+1	TS+2
1	Artikel ilmiah dimuat di jurnal	Internasional bereputasi	published	Tidak ada	√		
2	Artikel ilmiah dimuat di prosiding	Internasional Terindeks	published	Tidak ada	√		
		Nasional					
3	Invited speaker dalam tema ilmiah	Internasional	Tidak ada	Tidak ada			
		Nasional					
4	Visiting lecturer	Internasional	Tidak ada	Tidak ada			
5	Hak Kekayaan Intelektual (HKI)	Paten	Tidak ada	Tidak ada			
		Paten Sederhana					

		Hak Cipta					
		Merek Dagang					
		Rahasia dagang					
		Desain Produk Industri					
		Indikasi Geografis					
		Perlindungan Varietas tanaman					
		Perlinungan Topografi Sircuit Terpadu					
6	Teknologi Tepat Guna	produk	Tidak ada				
7	Model/Purwarupa/Desain/Karya seni/ Rekayasa Sosial	produk	produk	√			
8	Bahan ajar	Tidak ada	Tidak ada				
9	Tingkat Kesiapan Teknologi (TKT)	6	6				

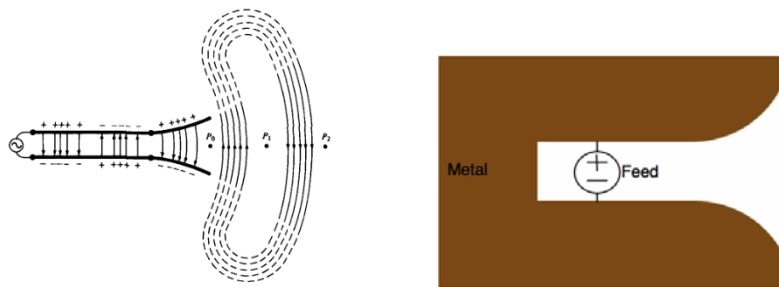
BAB 2

TINJAUAN PUSTAKA

2.1. Teori Penunjang.

2.1.1. Elemen antenna Vivaldi Coplanar

Antena pada pemancar adalah device yang dapat merubah energi listrik dari saluran transmisi menjadi gelombang elektromagnetik ke ruang bebas.



Gambar. 2.1. Konsep dasar Vivaldi antenna

Pada gambar 2.1 menjelaskan jika sebuah sumber tegangan dihubungkan ke dua konduktor saluran transmisi akan menciptakan medan listrik antara dua konduktor (Balanis, 1997). Pada antenna Vivaldi coplanar propagasi gelombang akan terjadi ditengah tapered slot dengan persamaan eksponensial tapered slot (Frank, 2011):

$$y = C_1 e^{Rx} + C_2 \quad (1)$$

$$C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}} \quad (2)$$

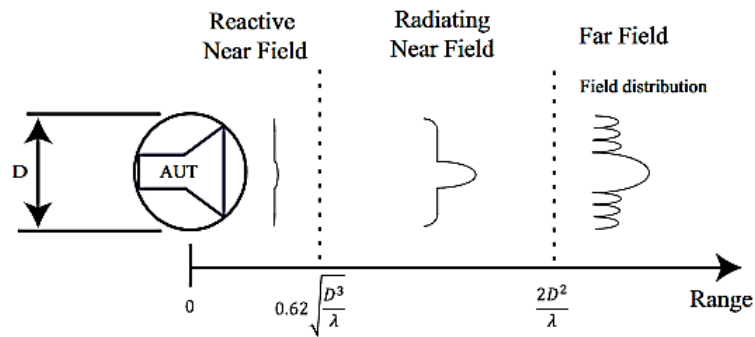
$$C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}} \quad (3)$$

R adalah exponential tapered slot, sedangkan titik awal x_1, y_1 merupakan awal kordinat opening rate dan x_2, y_2 adalah titik akhir opening rate.

2.1.2. Parameter kinerja antenna.

a. Pola Radiasi

Pola radiasi yaitu besaran yang menentukan ke arah sudut mana antenna memancarkan/ mendistribusikan energinya.



Gambar 2.2. Pola radiasi antenna

b. VSWR (Voltage Standing Wave Ratio)

VSWR adalah perbandingan tegangan maksimum dan minimum pada suatu gelombang berdiri akibat adanya pantulan gelombang yang disebabkan tidak matchingnya impedansi input antenna dengan saluran transmisi

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{2.15}$$

c. Bandwidth

Bandwidth antenna dinyatakan sebagai daerah frekuensi dimana performansi antenna memenuhi Voltage Standing Wave Ratio < 2. Persentase bandwidth dinyatakan:

$$BW = \frac{f_{hi} - f_{lo}}{f_{center}} \times 100 \tag{2.20}$$

Sinyal dikatakan UWB bila bandwidth lebih besar dari 0.25 terhadap frekuensi tengah

$$bw = \frac{2(f_H - f_L)}{(f_H + f_L)} \geq \begin{cases} 0.25 & \text{DARPA} \\ 0.20 & \text{FCC} \end{cases} \tag{2.22}$$

2.1.3. Antena Array

Antena dapat mencapai gain yang tinggi dan beamwidth yang kecil dengan disusun array. Total pola radiasi array dinyatakan perkalian pola medan elemen dan factor array (Haupt, 2010)

$$AP(\theta, \varphi) = g_{ae}(\theta, \varphi) \cdot AF(\theta, \varphi) \tag{14}$$

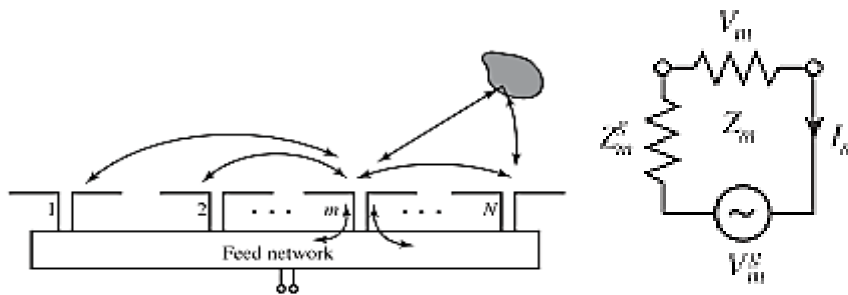
$$AF = \sum_{n=1}^N w_n e^{j\psi_n} \quad (15)$$

$$\psi_n = kd \sin \theta \quad \delta_n = -\beta d \sin \theta_0$$

Pola radiasi suatu array dapat dipengaruhi: Amplitudo dari elemen, Phase elemen, Jarak antar elemen, Jumlah elemen, Pola radiasi elemen

2.1.4. Mutual Coupling

Mutual coupling adalah interaksi elektromagnetik antar elemen antenna yang dapat disebabkan oleh pencatu elemen antenna lain yang berdekatan. Mutual coupling akan mempengaruhi kinerja elemen antenna karena dapat merubah pola radiasi, tegangan pada antenna penerima, merubah karakteristik impedansi elemen antenna (Hon Tat Hui)



Gambar 2.3. Mutual Coupling antenna array (Stuzman, dkk, 2012)

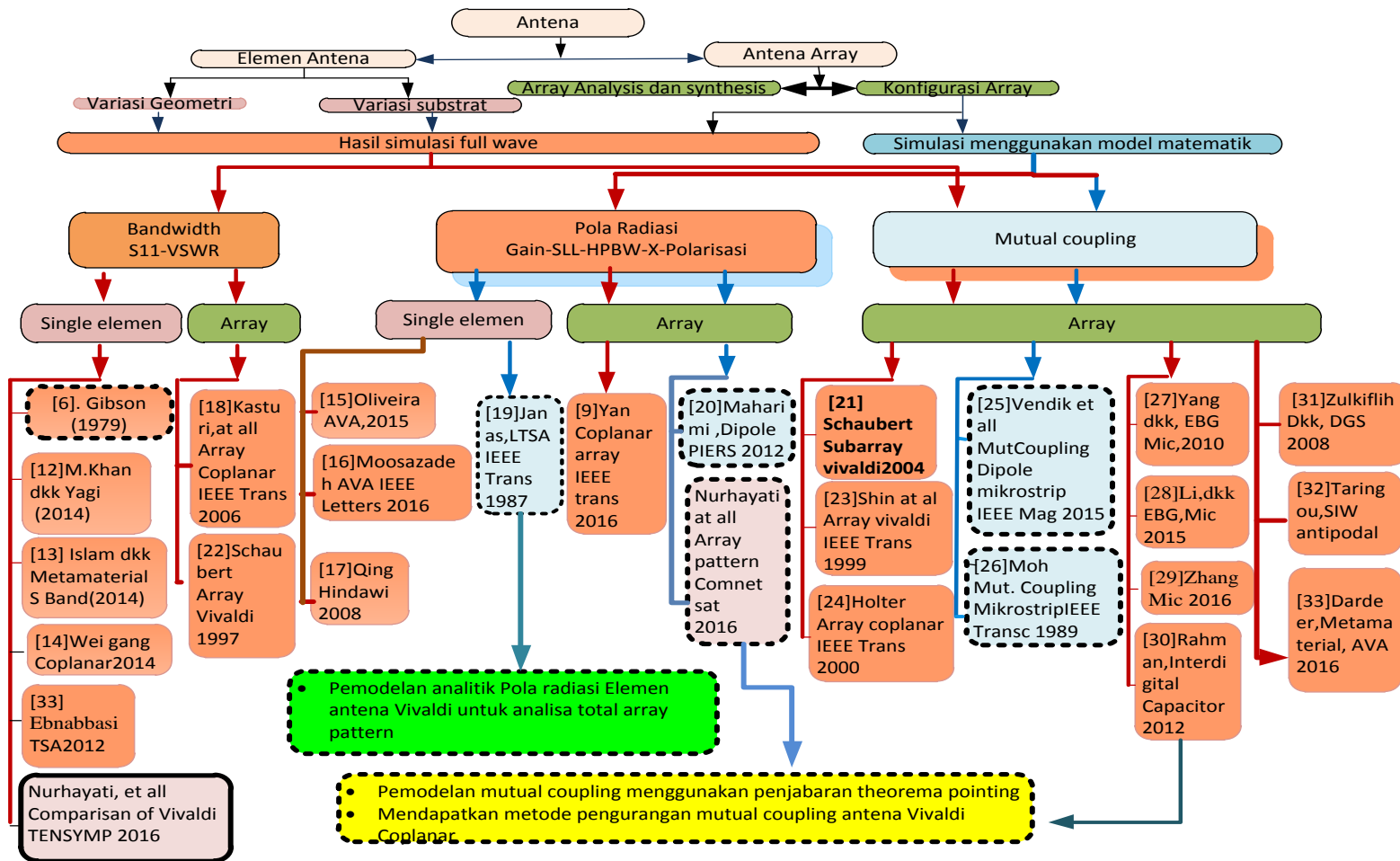
$$V_1 = Z_{11}I_1 + Z_{12}I_2 + \dots + Z_{1N}I_N$$

Dimana V_n dan I_n adalah tegangan dan arus elemen ke n , Z_{nn} adalah selfimpedance dan Z_{mn} atau Z_{nm} adalah mutual impedansi. Coupling antara port m dan n dalam dB dinyatakan:

$$C_{mn} = 20 \log |S_{nm}| \text{ dB} \quad (2.37)$$

2.2. Studi Pendahuluan yang telah dilaksanakan

Penelitian elemen antenna Vivaldi dan antenna array telah banyak dilakukan. antenna array Vivaldi yang disusun secara sub array, array polarisasi tunggal, dua polarisasi telah dilakukan oleh beberapa peneliti. Pada publikasi antenna array Vivaldi tersebut belum dilakukan analisa mutual coupling.



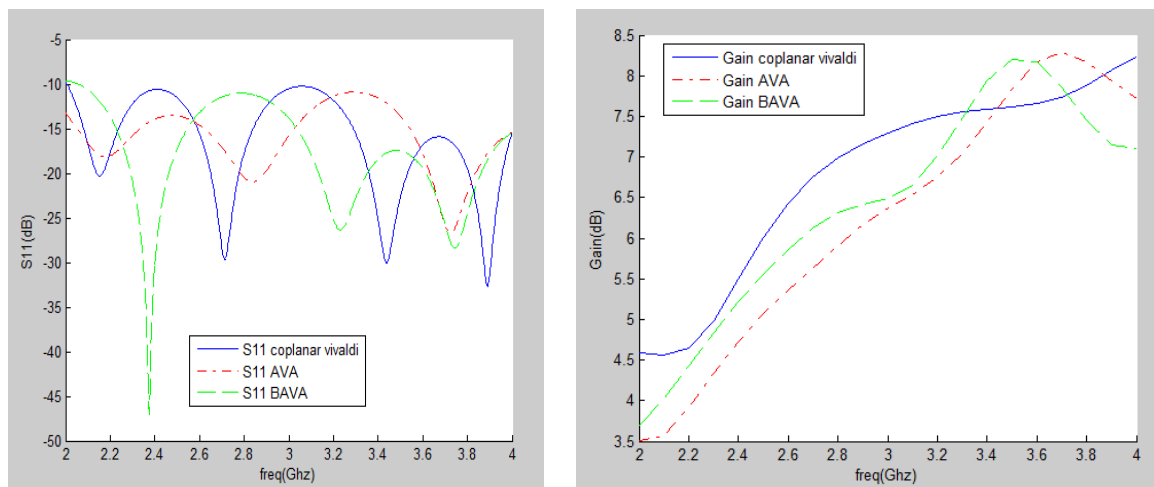
Gambar 2.4. Road map penelitian

2.3. Hasil yang sudah dicapai

Sebelumnya peneliti sudah meneliti antenna Vivaldi dan telah diseminarkan pada beberapa seminar internasional.

2.3.1. Comparison Studi of S-Band Vivaldi – Based Antenna (TENSYPMP), Bali, Indonesia, 2016)

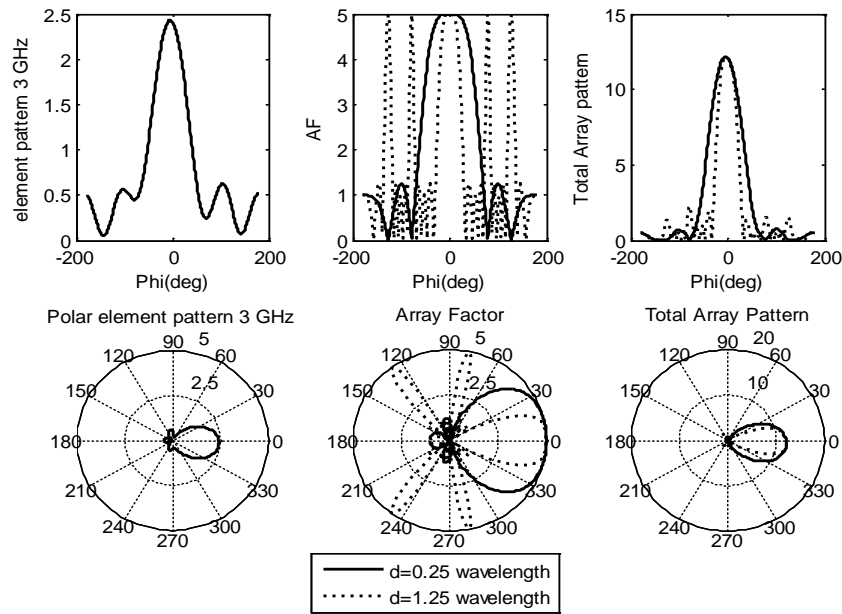
Pada paper ini penulis membandingkan ketiga jenis antenna Vivaldi. Desain dan analisa antenna Vivaldi Coplanar, *Antipodal Vivaldi Antenna (AVA)* dan *Balance Antipodal Vivaldi Antenna (BAVA)* dilakukan menggunakan substrat yang sama yaitu FR4 dengan konstanta dielektrik 4.3, dengan ukuran yang sama, bukaan eksponensial taper yang sama. Performansi return loss terbaik di dapatkan oleh antenna AVA sedangkan performansi gain dan SLL yang paling baik diperoleh untuk antenna Coplanar.



Gambar 2.5 Return Loss S11 (dB) dan gain

2.3.2. Pengaruh Pola elemen Vivaldi terhadap pola radiasi Antena array linear uniform (Seminar Internasional: International Conference on Communication, Networks and Satellite (COMNETSAT), Surabaya, Indonesia)

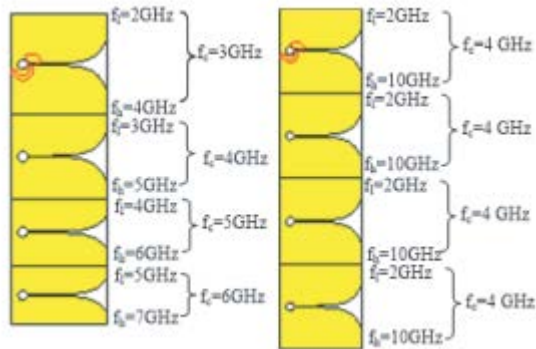
Pada paper ini penulis memaparkan bahwa total array pattern antenna berbeda disetiap frekuensi. Bila pola radiasi antenna pada masing-masing frekuensi dikalikan dengan Array faktor maka akan mendapatkan performansi total array pattern yang berbeda-beda. Gambar menggambarkan total array pattern pada frekuensi 3 GHz.



Gambar 2.6 Pola radiasi di $f=3$ GHz.

2.3.2. Total Array Pattern Characteristics of Coplanar Vivaldi Antenna in E-Plane with Different Element Width for S and C Band Application (Seminar Internasional: Progress In Electromagnetics Research Symposium (PIERS), Singapore, 2017)

Paper ini membandingkan total array pattern beberapa elemen Vivaldi dengan beberapa ukuran elemen antenna yang berbeda dengan elemen vivaldi yang memiliki ukuran yang sama. Dari hasil simulasi didapatkan bahwa array dengan perbedaan elemen menghasilkan direktivity 11.6 dBi dan SLL -9.2 dB sedangkan array dengan lebar elemen yang sama menghasilkan direktivity 10.7 dBi dan SLL -4 dB. Sehingga dapat digunakan untuk aplikasi array.



Gambar 2.7 Antena array dengan beberapa ukuran lebar antena

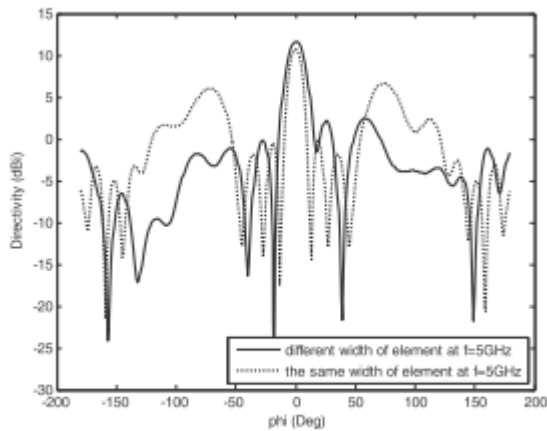


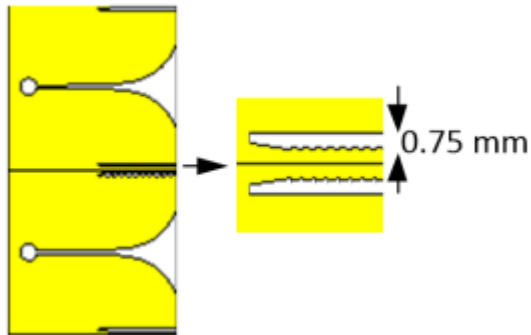
Figure 9: Comparison directivity at $f = 5$ GHz.

Gambar 2.8. Perbandingan direktiivty pada 5 GHz

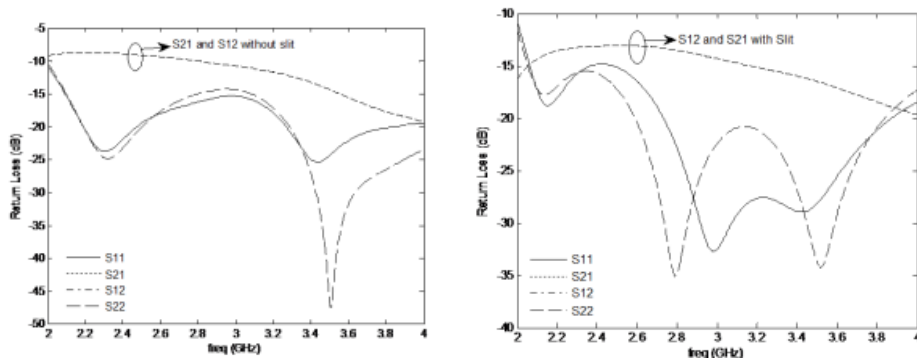
2.3.2. Mutual Coupling and Radiation Pattern of Vivaldi Antenna with Slit (Seminar Internasional: International Conference on Communication and Information Processing (ICCIP), Tokyo, Japan, 2017)

Paper ini membahas metode pengurangan mutual coupling antena Vivaldi dengan menambahkan slot sempit lurus di pinggir elemen antena yang disebut slit. Dengan adanyapenambahan slit maka solasi dapat meningkat sebesar 7.12 DB dari -9.1437 menjadi

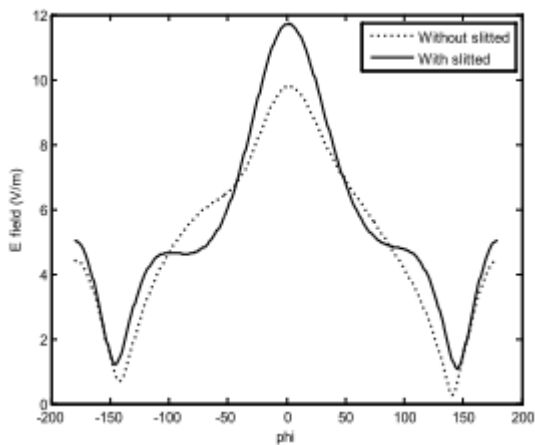
-16.283 pada frekuensi 2 GHz. Selain itu dapat meningkatkan E Field sebesar 1.9 V/m, meningkatkan 0.4 dB SLL.



Gambar 2.9. Antenna array dengan ragged slit



Gambar 2.10. S-Parameter tanpa slit dengan slit



Gambar 2.11. Pola radiasi tanpa dan dengan Slit

2.4.Road Map Penelitian

Ada beberapa tahapan dalam penelitian yaitu:

Tabel 2.1. Peta Jalan penelitian

No	Tahapan	Kontribusi	Publikasi	Status
1	Mensimulasikan 3 jenis antena vivaldi	Analisa kinerja jenis-jenis antena Vivaldi	Ten Symposium IEEE (TenSymp), Bali, mei 2016,	Selesai
2	Analisa mutual coupling antena array	Total array patern	Seminar Internasional Comnetsat	Selesai
3	Menemukan metode pengurangan mutual coupling antena vivaldi	metode pengurangan mutual coupling antena coplanar Vivaldi dengan Corrugated	<ul style="list-style-type: none">• Seminar internasional• jurnal (Antena and propagation letter)	Submit
4	Pengukuran dan verifikasi hasil simulasi , pemodelan dan pengukuran	Pengukuran di PENS/LIPI		terlaksana

BAB 3.

TUJUAN DAN MANFAAT PENELITIAN

Mutual coupling adalah interaksi elektromagnetik antar elemen antena yang dapat disebabkan oleh pencatu elemen antena lain yang berdekatan. Mutual coupling akan mempengaruhi kinerja elemen antena karena dapat merubah pola radiasi, tegangan pada antena penerima, merubah karakteristik impedansi elemen antena.

Tujuan Penelitian ini adalah menganalisa mutual Coupling dan kinerja pola radiasi antena array Coplanar Vivaldi.

Tahapan yang dilakukan adalah:

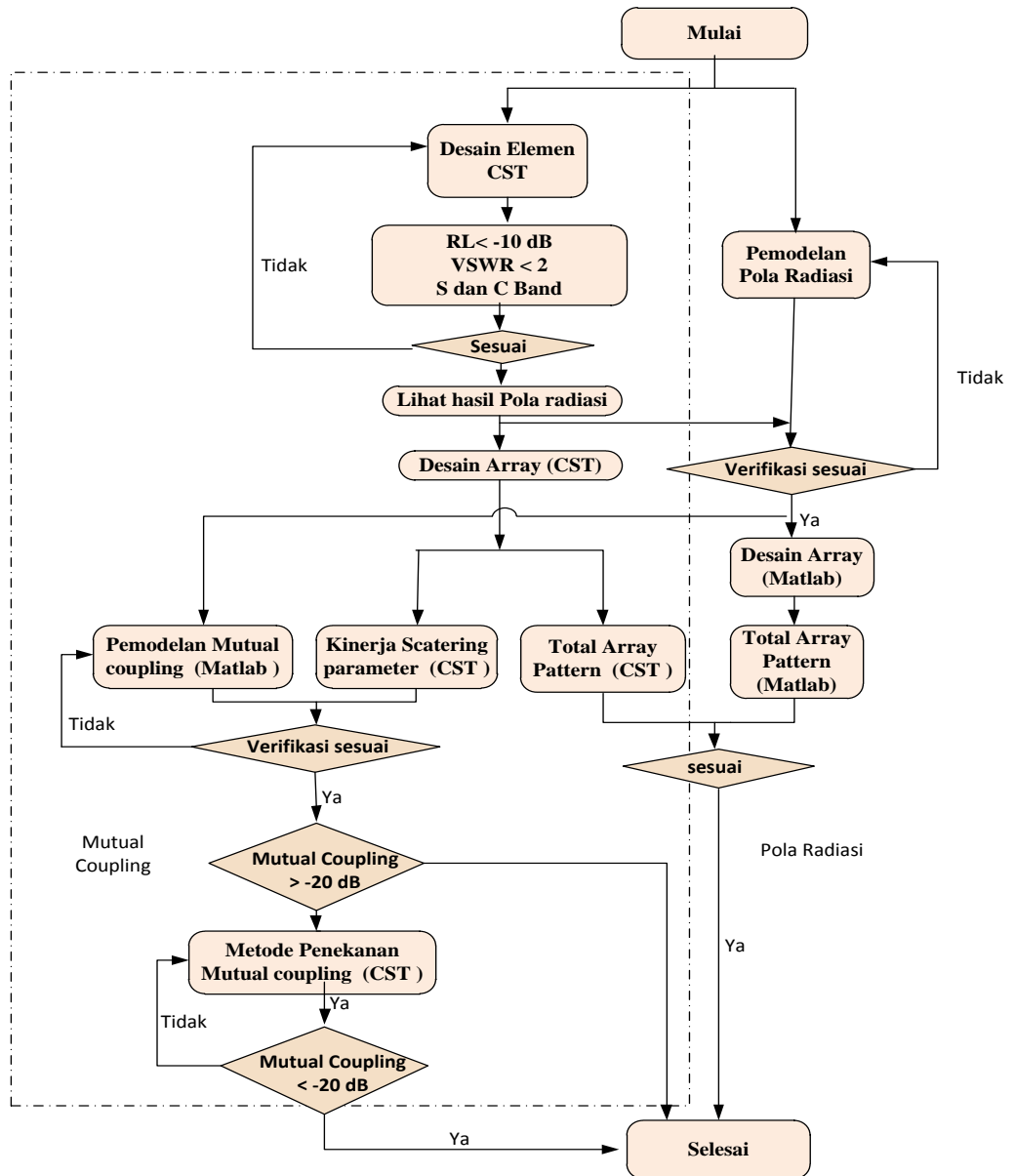
1. Mendesain elemen antena.
2. Melihat kinerja scattering parameter antena dengan variasi geometri dan jumlah elemen di E plane dan H plane
3. Mendesai beberapa metode pengurangan mutual coupling yaitu: No Structure (NS), Exponential Corrugated Truncated (ECT),

BAB 4.

METODE PENELITIAN

4.1. Tahapan Penelitian

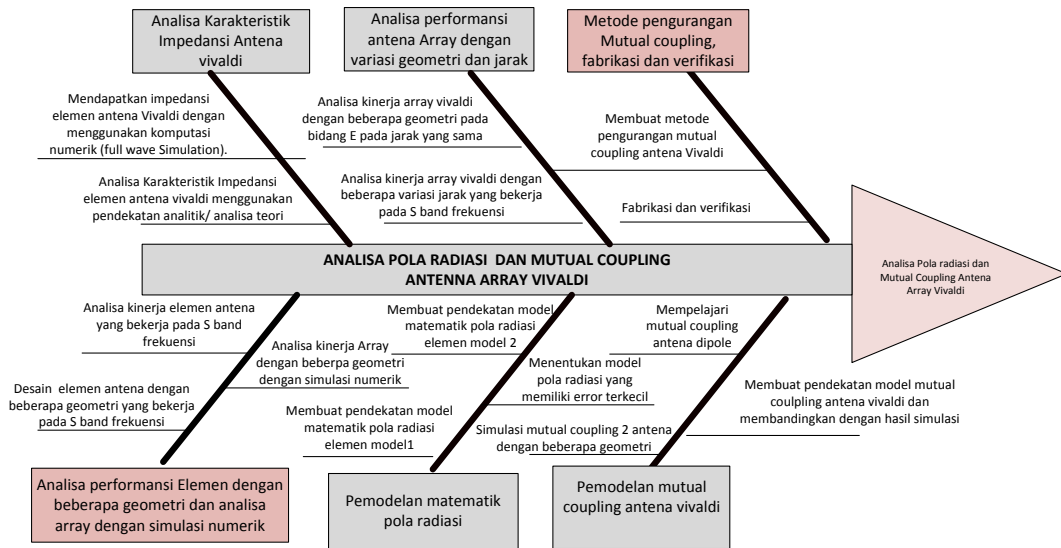
Tahapan penelitian yang dilakukan mengikuti diagram alir seperti gambar 3.1.



Gambar 4.1. Tahapan penelitian

4.2. Fishbone Diagram

Fisbone penelitian ini adalah



Gambar 4.2. Fish bone diagram penelitian

Gambar 4.1. dan gambar 4.2. merupakan tahapan penelitian. Penelitian ini merupakan bagian dari penelitian disertasi yang mana penelitian disertasi menganalisa karakteristik pola radiasi dan mutual coupling antena Vivaldi. Tahapan awal penelitian adalah mendesain antena dan memodelkan secara teori pola radiasi antena Vivaldi. Pemodelan tersebut juga akan digunakan untuk analisa pemodelan mutual coupling secara analitik. Pengurangan mutual coupling diawali dengan menganalisa kinerja scattering parameter dua antena array terutama pada performansi S_{12}/S_{21} yang menggambarkan koefisien refleksi antena yang dipengaruhi oleh elemen yang berdekatan. Antena array akan diletakkan pada jarak berhimpit dan akan terlihat mutual coupling yang tinggi terutama pada frekuensi rendah. Apabila nilai S_{21}/S_{12} di atas -20 dB berarti mutual coupling antena masih tinggi. Sehingga perlu dilakukan metode pengurangan mutual coupling.

4.3. Metode yang digunakan

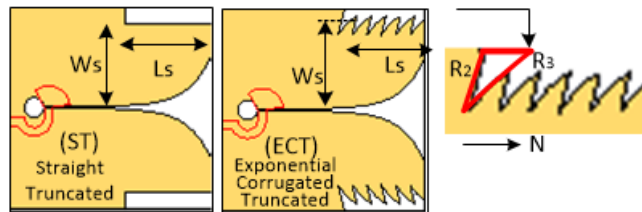
Metode mutual coupling yang akan digunakan adalah membuat corrugated diantara dua bukaan tapered slot. Corrugated dibuat mengikuti kelengkungan kedua bukaan tapered slot dengan kemiringan tapered slot:

$$y = C_1 e^{Rx} + C_2 \tag{1}$$

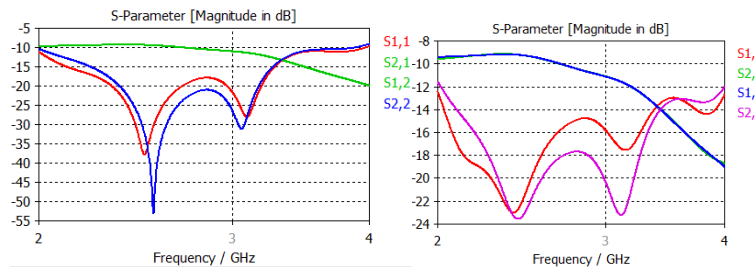
$$C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}} \tag{2}$$

$$C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}} \tag{3}$$

R adalah exponential tapered slot, sedangkan titik awal x_1, y_1 merupakan awal kordinat opening rate dan x_2, y_2 adalah titik akhir opening rate. Mutual coupling antenna yang tinggi terlihat terjadi pada frekuensi rendah sehingga bila mutual coupling antenna tinggi maka pada frekuensi rendah antenna tidak dapat dipakai dalam pengukuran.



Gambar 4.3. Corrugate pada Coplanar Vivaldi



- a. Scatering parameter tanpa Corugate b. Scatering parameter dengan corugate

Gambar 4.4. Scatering parameter antenna Vivaldi coplanar

Dari gambar 3.4. terlihat bahwa pemberian struktur baru diantara dua bukaan tapered slot akan merubah performansi scattering parameter. Mutual coupling yang diharapkan pada antenna array adalah yang memiliki nilai $S_{mn} < -20$ dB.

BAB 5

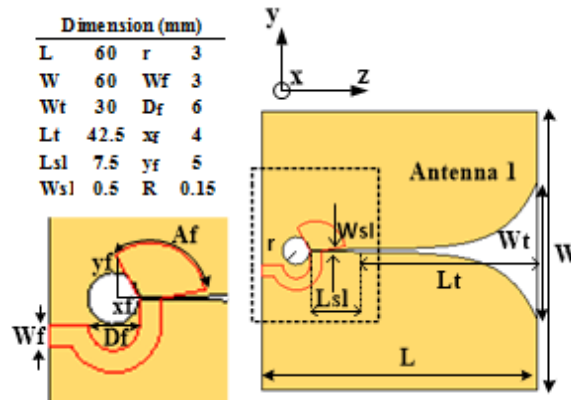
HASIL DAN LUARAN YANG DICAPAI

5.1. Hasil Yang Dicapai

Awal dari penelitian ini adalah kami mendesain antenna Vivaldi dengan dimensi sesuai gambar 1, menggunakan bahan FR4 yang memiliki permitivity 4.6, ketebalan substrat 1.6mm dan ketebalan copper 0.035mm dengan kemiringan tapered slot mengikuti:

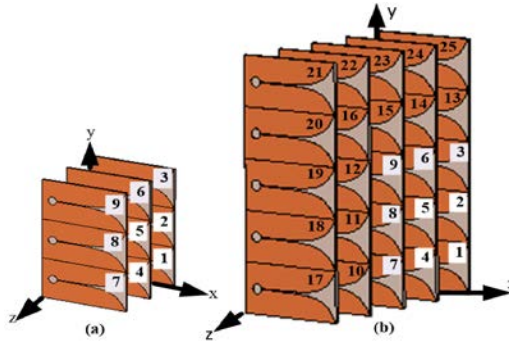
$$y = C_1 e^{Rx} + C_2, \quad C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}}, \quad C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}}$$

Antena vivaldi awal yang kami desain merupakan antenna ultrawideband dimana antenna memiliki fraksional bandwidth sebesar 133% yang ditunjukkan dengan nilai VSWR < 2 terpenuhi untuk frekuensi 2-10 GHz.

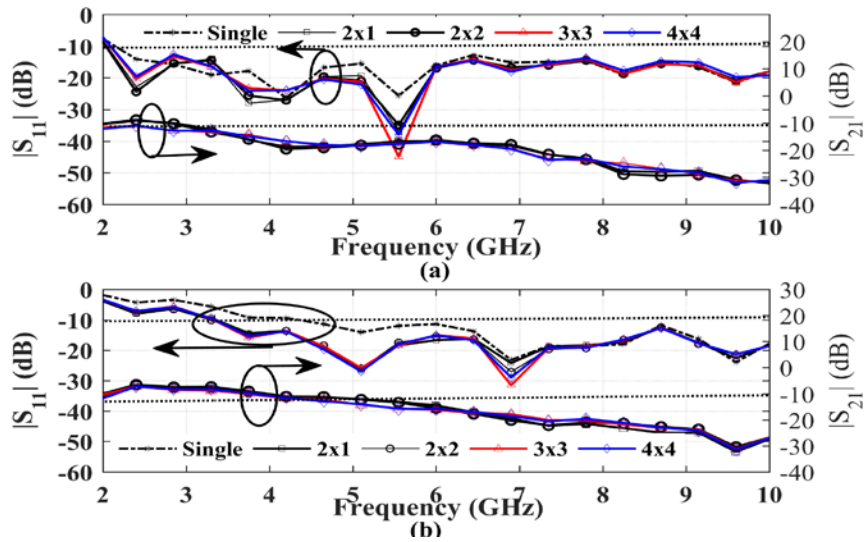


Gambar 5. 1. Dimensi elemen

Coplanar Vivaldi Array dengan dimensi yang berbeda dianalisa untuk mendapatkan parameter scattering seperti gambar di bawah ini:

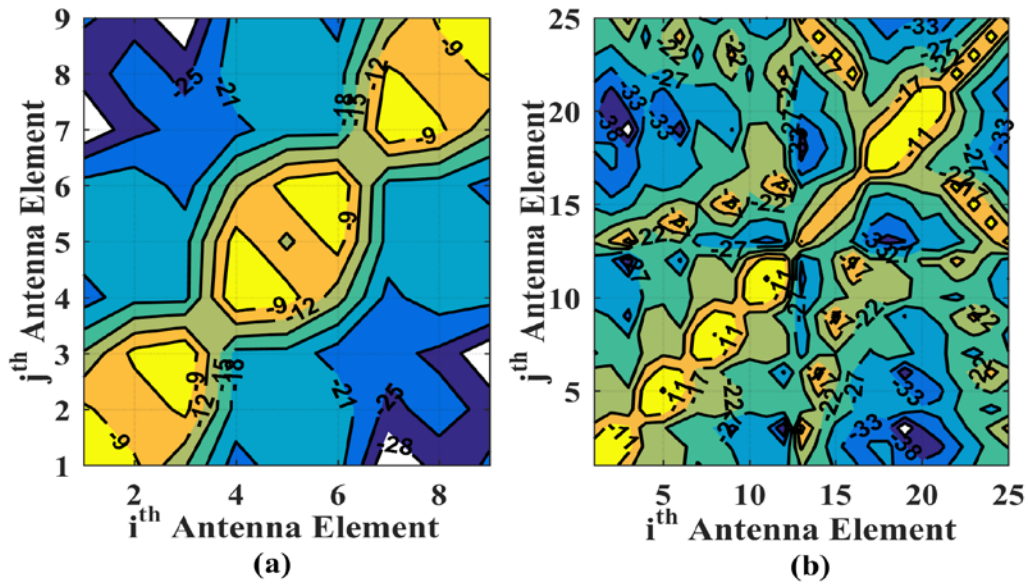


Gambar 5.2. Dimensi CVA (a). 3x3 dan (b). 5x5



Gambar. 5.3. Performansi S_{11} dan S_{21} dari array dengan (a). elemen $0.4\lambda \times 0.4\lambda$ (b). elemen $0.2\lambda \times 0.4\lambda$.

CVA dengan dimensi yang berbeda seperti pada gambar 5.2 dianalisa untuk mendapatkan parameter skatering sebelum membahas mutual coupling. Pada frekuensi 2 GHz, jarak pusat ke pusat dari struktur array dengan lebar 30mm ekuivalen dengan $0.2\lambda_0$, namun untuk lebar elemen 60mm ekuivalen dengan $0.4\lambda_0$. Kedua antenna memiliki lebar elemen yang berbeda dengan parameter yang lain dibuat tetap. Kedua antenna memiliki mutual coupling yang tinggi diatas -10 dB disekitar frekuensi terendah terlihat pada gambar 5.3. Dari gambar terlihat bahwa dengan jumlah elemen tertentu, semakin meningkatnya jumlah elemen, array dengan lebar 30mm (0.2λ) menunjukkan peningkatan bandwidth yang terlihat dari grafik S_{11} di grafik atas gambar 3(b). Namun mutual coupling tetap tinggi. Elemen yang lebih kecil dengan radiator patch yang lebih kecil dan semakin kecil bukaan mulut tapered slot akan menggeser



Gambar 5. 4. Plot scattering parameter dengan contour plot

frekuensi bawah dimana S_{11} dibawah -10dB . Untuk mendesain return loss yang rendah Vivaldi antena biasanya didesain dengan lebar slot satu panjang gelombang. Untuk lebar elemen yang kecil jika jumlah elemen meningkat hingga tak terhingga maka bandwidth akan meningkat karena pengaruh coupling. Namun gambar 3 array hanya disimulasikan dengan jumlah array tertentu sehingga frekuensi terendah masih tinggi. Ini berbeda dengan array dengan lebar elemen (0.4λ) , bandwidth tidak meningkat dengan meningkatnya jumlah elemen. Jarak yang lebih kecil di antena array pada bidang E akan meningkatkan terjadinya coupling environment sehingga terjadi anomaly impedansi. Namun peningkatan jumlah elemen dapat meningkatkan bandwidth.

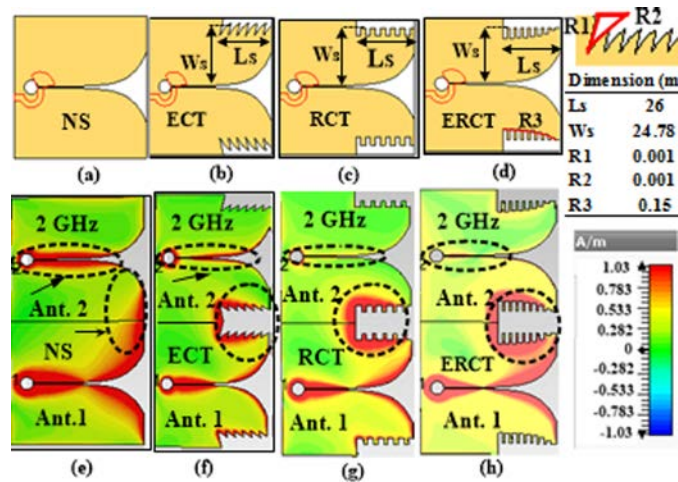
Scattering parameter untuk array 3×3 ditunjukkan di gambar 5.4 (a) dan array 5×5 di gambar 5.4(b) di frekuensi 2.4 GHz untuk lebar elemen 0.2λ dengan nomer elemen yang diberikan di gambar 5.2. Dari contour plot menunjukkan bahwa dengan bertambahnya elemen maka dapat meningkatkan performansi return loss dan mutual coupling. Ini dapat terlihat S_{33} untuk array 3×3 sebesar -9 dB sedangkan S_{33} untuk array 5×5 sebesar -11 dB . Untuk array 3×3 nilai S_{98} -9 dB namun untuk array 5×5 S_{98} sebesar -11 dB dimana S_{ij} adalah coupling dari elemen j ke elemen i . Semakin meningkatnya jumlah elemen maka mutual coupling dapat

berkurang karena dipengaruhi coupling antar elemen di semua sisi. Mutual coupling di bidang E terlihat lebih besar dibandingkan mutual coupling di bidang H.

Untuk array 5x5 di bidang E S_{56} bernilai -11 dB lebih besar dibandingkan mutual coupling di bidang H dengan S_{58} sekitar -22dB. Di bidang E arus permukaan mengalir di elemen sebelahnya yang menyebabkan coupling antar elemen sedangkan di bidang H coupling disebabkan induksi elektrik field melalui udara. Dari pengamatan ini diketahui bahwa Mutual coupling memiliki pengaruh yang besar sebagaimana dengan return loss di antena array Vivaldi coplanar dan mutual coupling di bidang E lebih besar dibandingkan dengan di bidang H.

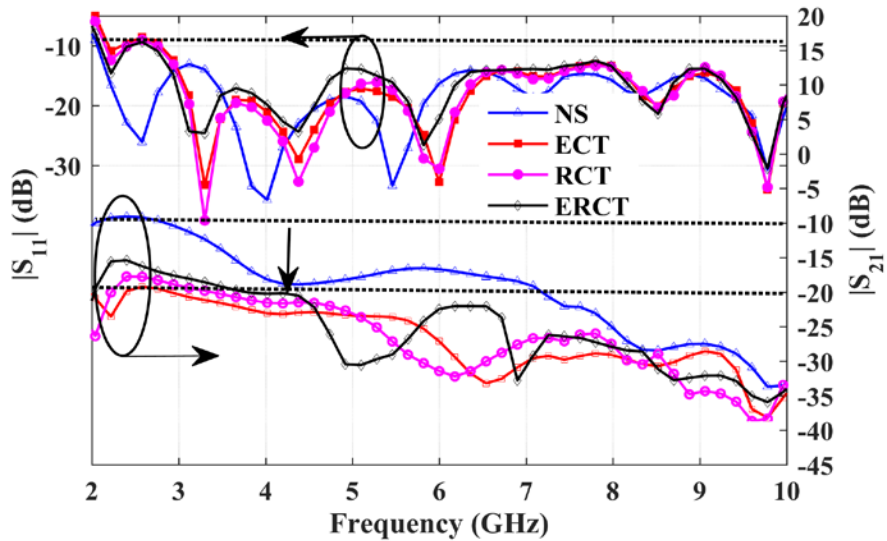
Ada tiga struktur slot yang dipertimbangkan sebagai metode pengurangan mutual coupling yaitu exponential corrugated truncated slot (ECT), rectangular corrugated truncated slot (RCT), and exponential rectangular corrugated truncated slot (ERCT). Seluruh struktur disimulasikan dengan amplitude eksitasi yang sama dan menganggap power divider bersifat ideal (lossless) yang dihubungkan dengan konektor SMA.

Gambar 5 menggambarkan geometri dari elemen Vivaldi coplanar dan surface current dari dua elemen array ketika elemen yang bawah dieksitasi dan elemen atas diterminasi pada frekuensi 2 GHz. Surface current di gambar 5(e) saling menginduksi ke elemen yang atas yang dapat diamati dengan garis terputus lingkaran pada gambar 5(e). Hal ini berbeda pada ECT di gambar 5(f), RCT pada gambar 5(g), ERCT di gambar 5(h), dimana surface current terkonsentrasi disepanjang struktur slot sehingga mengurangi arus yang mengalir ke elemen sebelahnya. Untuk meningkatkan konsentrasi disekitar struktur slot, corrugasi seperti gigi gergaji dapat diterapkan dimana kemiringan korugasi yang lebih tinggi akan menghasilkan hasil yang lebih baik. Pada korugasi surface current merambat ke elemen disebelahnya dengan lintasan yang lebih panjang dan saling bertabrakan sehingga meningkatkan isolasi.



Gambar.5.5: Geometri Vivaldi dengan struktur slot

Gambar 6 membandingkan S_{11} dan S_{21} dari antenna array Vivaldi dengan beberapa variasi struktur slot. S_{11} terbaik didapatkan oleh struktur ERCT, RCT, ECT dan NS, sedangkan isolasi terbaik didapatkan oleh ECT, RCT, ERCT dan NS di 4 GHz. Isolasi terbaik didapatkan ECT sehingga disarankan menggunakan corrugated dengan truncated untuk isolasi. Peningkatan L_s dengan W_s tetap $W_s=0.5\lambda_g$ pada 4 GHz dapat meningkatkan performansi return loss tetapi mengurangi isolasi seperti ditunjukkan gambar 5.7(a). Semakin panjang L_s membuat surface current menyebar sepanjang truncated melalui lintasan yang lebih panjang kemudian memutar balik dengan arah U. Beberapa dari surface current secara langsung mengalir ke arah area di awal tapered slot di elemen sebelahnya dan mengurangi isolasi. Sebaliknya semakin pendek ECT membuat surface current menyebar didekat bukaan tapered di elemen yang tereksitasi dan meningkatkan return loss di frekuensi bawah. Setelah surface current menempuh belokan U ke elemen sebelahnya, mengalir ke elemen sebelahnya dengan lintasan yang lebih panjang sehingga meningkatkan isolasi.

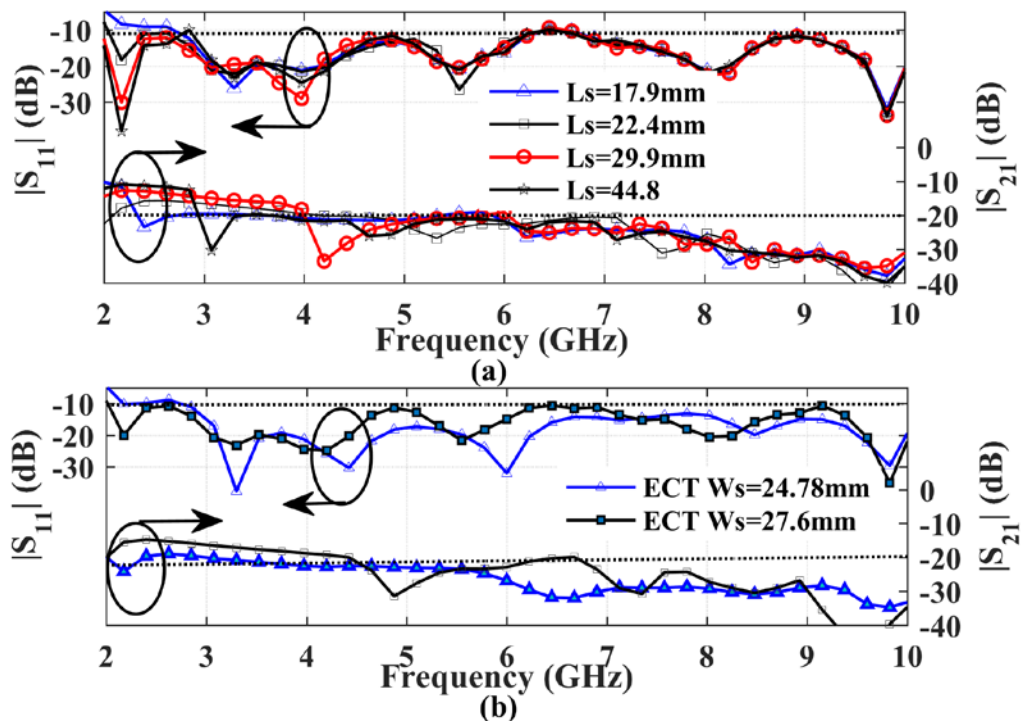


Gambar. 5.6. S-Parameters array antenna dengan struktur slot

S_{11} dibawah -10 dB dapat dicapai dari $2-10$ GHz dengan mengatur panjang L_s sebesar $0.5\lambda_g$ dengan λ_g diperoleh dari beberapa nilai frekuensi (GHz) dimana $f_L \leq f \leq (f_c - 2)$ dan mengatur W_s to $0.5\lambda_g$ dimana $f_L + 1 < f < (f_c - 2)$, dengan f_L dan f_c adalah frekuensi bawah dan frekuensi tengah. Langkah ini memberi aturan untuk dimensi minimum L_s dan W_s seperti yang ditunjukkan gambar 5. Dengan mempertimbangkan konstanta dielektrik efektif nilai W_s dan L_s dapat di tentukan:

$$L_s \text{ or } W_s = 0.5\lambda_g = \frac{c}{2f(\sqrt{\epsilon_{eff}})} = \frac{\sqrt{2}\lambda}{2\sqrt{\epsilon_r + 1}}$$

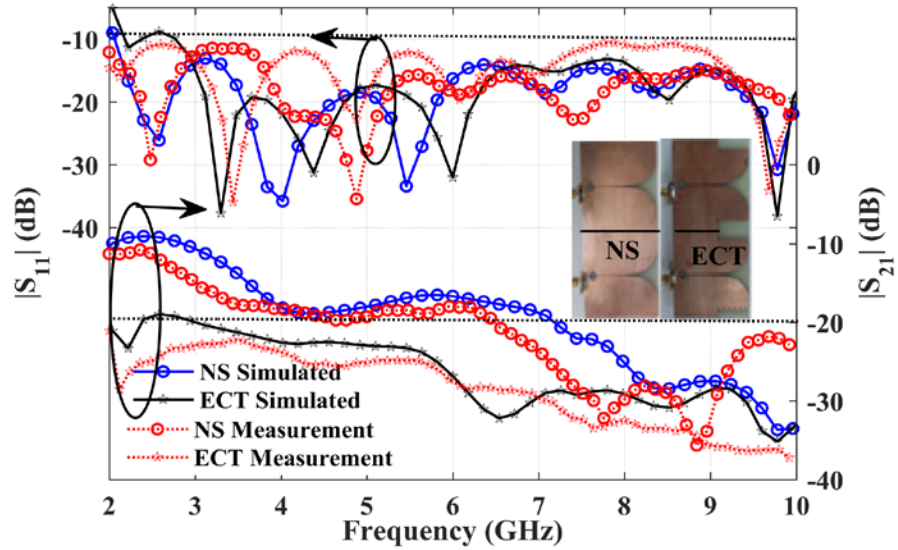
S_{11} dan S_{21} untuk ECT dengan perbedaan nilai W_s dengan L_s constant ditunjukkan pada gambar 5.7(b). Semakin kecil W_s mengurangi performansi return loss tetapi meningkatkan isolasi. Untuk mengusahakan terpenuhinya performansi return loss dengan W_s yang kecil maka dapat memperbesar L_s .



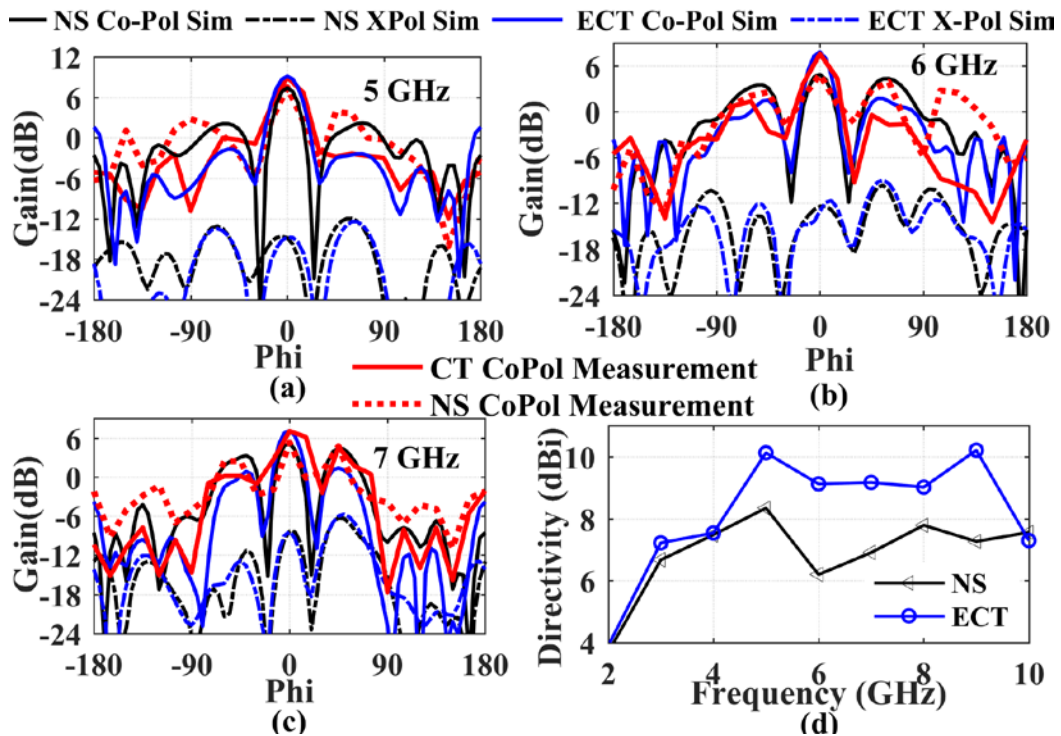
Gambar . 5.7. S-Parameter dengan variasi L_s dan W_s

Hasil simulasi dan pengukuran S_{11} dan S_{21} untuk array dengan ECT dan NS dinyatakan di gambar 5.8. Dengan simulasi pada frekuensi 2.16 GHz array tanpa slot menghasilkan S_{21} - 9.23 dB dengan ECT memberikan S_{21} -24.19 dB. Dari gambar juga terlihat bahwa hasil simulasi dan pengukuran juga menunjukkan kemiripan.

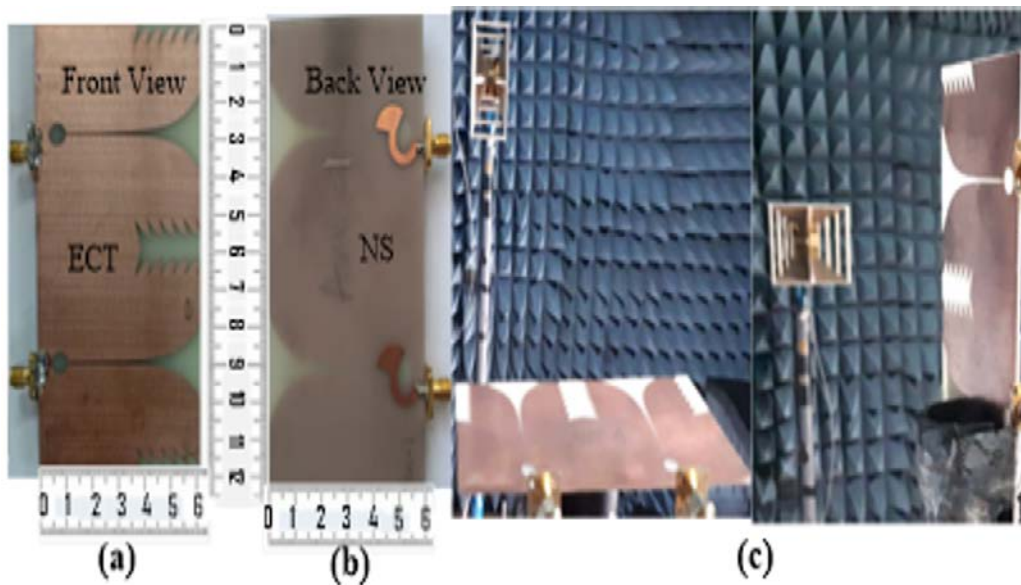
Gambar 9 menunjukkan hasil simulasi dan pengukuran dari gain copular dan crosspolar di bidang E antara ECT-CVA dan NS-CVA. Array menunjukkan direktifity yang wideband yang ditunjukkan di gambar 5.9 (d). Pola radiasi dan S_{21} dari array dengan ECT dan NS pada beberapa frekuensi ditunjukkan pada table 1. Direktivity, copular gain dan S_{21} dari ECT-CVA lebih baik dari NS di keseluruhan band 2-10 GHz sedangkan cross polar gain untuk ECT lebih baik NS di frekuensi bawah. ECT hanya meningkatkan SLL pada frekuensi 4-9 GHz sedangkan pada 10 GHz, array dengan lebar elemen 60mm memiliki jarak 2λ akan menghasilkan grating lobe. Corrugated slot akan memfokuskan medan listrik dan meningkatkan surfaces current diseluruh permukaan patch sehingga meningkatkan directivity dan pola radiasi. Ada trade off antara return loss, isolasi dan performansi SLL di antena UWB yang mana dipengaruhi oleh geometri antena, bentuk feeding, desain patch dan substrat.



Gambar. 5.8. Hasil simulasi dan pengukuran S11 ECT dan NS



Gambar. 5.9 Hasil simulasi dan pengukuran pola radiasi NS dan ECT



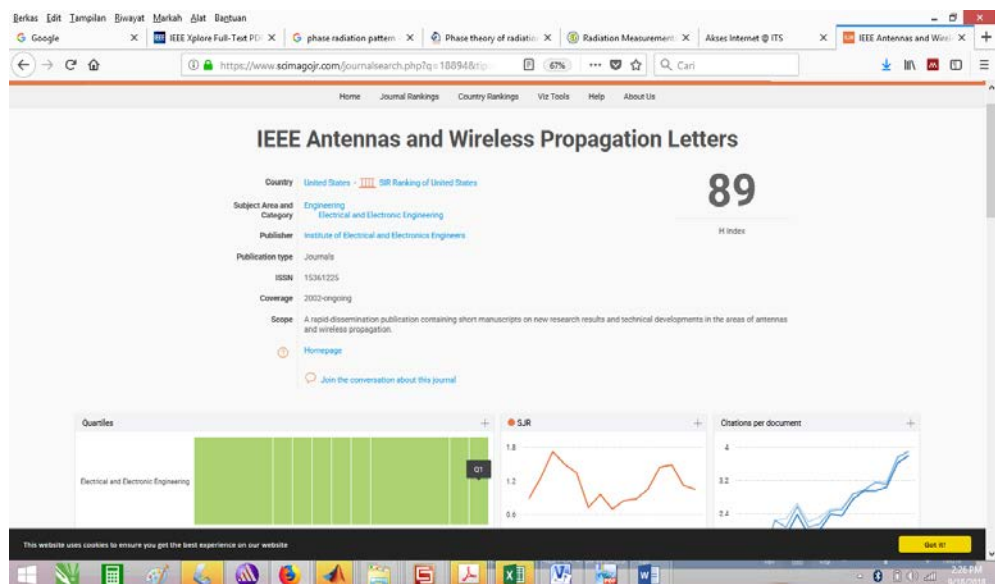
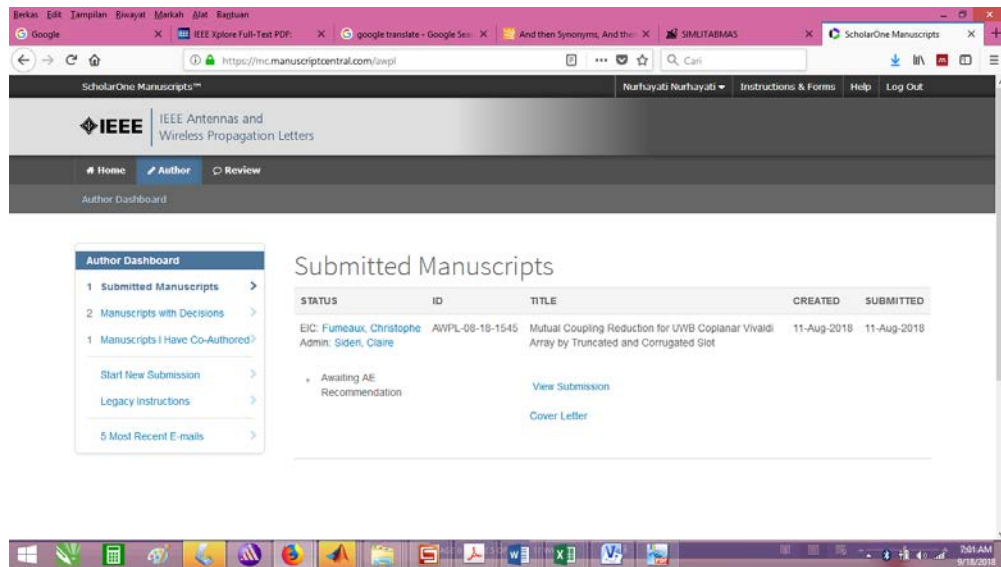
Gambar 5.10. Hasil fabrikasi antenna dan proses pengukuran

TABEL 5.1
PERBANDINGAN ECT DAN NS

f (GHz)	Dir (dBi)		Co-Pol (dB)		X-Pol (dB)		SLL(dB)		S ₂₁ (dB)	
	ECT	NS	ECT	NS	ECT	NS	ECT	NS	ECT	NS
2	3.9	3.7	3.5	3.3	-26	-22	-7.2	-7.2	-20	-9.8
3	7.2	6.7	6.8	6	-17	-15	-7.8	-8.7	-16	-11
4	7.5	7.5	6.8	6.7	-15	-14	-6.3	-5.3	-18	-18
5	10.1	8.3	9.1	7.4	-12	-12	-7.5	-5.3	-29	-18
6	9.1	6.2	7.8	4.8	-9	-9	-6	-1.6	-23	-17
7	9.2	6.9	7.1	5.1	-5.7	-6	-5.8	-2.1	-29	-19
8	9	7.8	6.6	5.8	-4	-4	-3.3	-2.8	-27	-25
9	10.2	7.3	7.1	4.9	-2.5	-3	-6.9	-1.2	-30	-28
10	7.3	6.6	0.7	-0.5	3.8	3	-1.6	-1	-34	-33

5.2 . Luaran Penelitian

- Antena Vivaldi yang bekerja S dan C Band
- Jurnal Internasional (Jurnal Internasional :IEEE Antennas and Propagation letters).
Mutual Coupling Reduction for Coplanar Vivaldi Array using Truncated and Corrugated Slot



Publish:

<https://ieeexplore.ieee.org/search/searchresult.jsp?newsearch=true&q=>

Mutual Coupling Reduction for a UWB Coplanar Vivaldi Array by a Truncated and Corrugated Slot

Nurhayati ; Gamantyo Hendranto ; Takeshi Fukusako ; Eko Setijadi
 IEEE Antennas and Wireless Propagation Letters
 Year: 2018 , Volume: 17 , Issue: 12
 Page s: 2284 - 2288
IEEE Journals & Magazines
 ▶ Abstract ((html)) (3645 Kb)

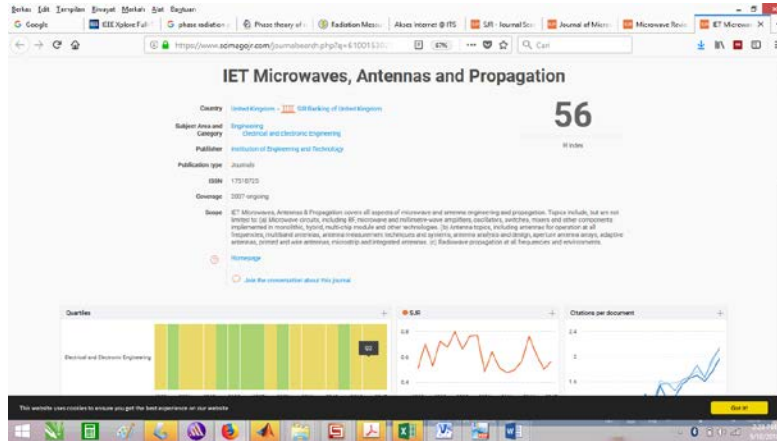
Submit Jurnal Internasional : IET Microwaves, Antennas & Propagation Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for L and S Band Applications

Thank you for your manuscript submission - IET Microwaves, Antennas & Propagation

Dear Mrs Nurhayati Nurhayati,
 The paper entitled
 Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for L and S Band Applications
 has been submitted by Joao Francisco Justo and will be given full consideration for publication in IET Microwaves, Antennas & Propagation.
 The manuscript details are:
 Manuscript ID: MAP-2018-5783
 Title:
 Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for L and S Band Applications
 Authors: Nurhayati Nurhayati, Alexandre Maniçoba de Oliveira, Joao Francisco Justo, Eko Setjadi, Bagus Edy Sukoco
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 You can view the status of your paper at any time by logging in to <https://www.iet-review.rivervalleytechnologies.com/> and going to My Submissions or Co-author Submissions. Please also take the time to make sure your contact details are up-to-date by clicking your name on the top right of the page.

Thank you for your manuscript submission - IET Microwaves, Antennas & Propagation

Dear Mrs Nurhayati Nurhayati,
 The paper entitled
 Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for L and S Band Applications
 has been submitted by Joao Francisco Justo and will be given full consideration for publication in IET Microwaves, Antennas & Propagation.
 The manuscript details are:
 Manuscript ID: MAP-2018-5783
 Title:
 Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for L and S Band Applications
 Authors: Nurhayati Nurhayati, Alexandre Maniçoba de Oliveira, Joao Francisco Justo, Eko Setjadi, Bagus Edy Sukoco
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Proses In review

BAB 6.

KESIMPULAN DAN SARAN

Analisa mutual coupling telah dilakukan untuk beberapa lebar elemen dan ditemukan bahwa mutual coupling di bidang E lebih besar dibandingkan di bidang H. Ada beberapa metode pengurangan mutual coupling dengan beberapa variasi slot dipinggir elemen yaitu ECT, RCT dan ERCT. Struktur ECT adalah metode pengurangan mutual coupling yang lebih efektif dibandingkan dengan metode lain karena memiliki isolasi yang lebih tinggi diseluruh band terutama di frekuensi rendah. Struktur ECT juga meningkatkan directivity diseluruh band frekuensi dari 2-10 GHz dan meningkatkan performansi SLL dari 4-9 GHz sehingga dapat diterapkan untuk aplikasi antena array coplanar Vivaldi UWB.

Analisa mutual coupling antena array Vivaldi dapat dilakukan menggunakan hasil metode komputasi secara elektromagnetik maupun secara analitik. Analisa menggunakan metode analitik dilakukan dengan menganalisa mutual resistansi dan mutual impedansi yang didapatkan dengan cara mengalikan model pola radiasi elemen antena dengan pointing vector.

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Dear Mrs Nurhayati Nurhayati,

The paper entitled
Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for L and S Band Applications
has been submitted by Joao Francisco Justo and will be given full consideration for publication in IET Microwaves, Antennas & Propagation.

The manuscript details are:
Manuscript ID: MAP-2018-5783
Title:
Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for L and S Band Applications
Authors: Nurhayati Nurhayati, Alexandre Maniçoba de Oliveira, Joao Francisco Justo, Eko Setijadi, Bagus Edy Sukoco

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Mutual Coupling Reduction for a UWB Coplanar Vivaldi Array by a Truncated and Corrugated Slot

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Abstract—This letter reports mutual coupling reduction in an ultrawideband coplanar Vivaldi array (CVA) by incorporating truncated and corrugated slot at the border between adjacent elements. An examination of CVAs shows that mutual coupling in the E-plane is more significant than in the H-plane. Subsequently, arrays using exponential and rectangular corrugated slot are compared with those without a slot structure through the simulation of a surface current distribution. A novel exponential corrugated truncated (ECT) structure is implemented to improve a mutual coupling performance, while maintaining or even improving copolar field patterns. The results of simulation and measurement indicate that mutual coupling and return loss performance can be improved by controlling the length of corrugated structure and the distance of the slot structure from the center of the Vivaldi's tapered slot. The CVA achieves bandwidth ratio of 5:1, i.e., from 2 to 10 GHz. The ECT-CVA structure reduces mutual coupling to below -20 dB in a large portion of the whole band, shows 3.9–10.2 dBi gain over the entire band, increases a sidelobe level performance at 4–9 GHz compared to the CVA without slot structure.

Index Terms—Antenna array, corrugated antenna, mutual coupling, Vivaldi antenna.

I. INTRODUCTION

VIVALDI antenna was first proposed by Gibson [1] for large bandwidth and high directivity. Other advantages include ability in realizing a desired gain, beamwidth, and beam scanning, as well as practicability for an arrangement into an array. The minimum bandwidth requirement of 2:1 for an ultrawideband (UWB) antenna [2] can be fulfilled by Vivaldi, which has been used in such applications as void detection inside concrete, wearable communications, and sensing systems [3]–[7]. This letter focuses on the coplanar Vivaldi antenna that gives higher gain and more symmetrical radiation pattern than the antipodal Vivaldi antenna (AVA) [8].

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Attempts have been made to realize Vivaldi with larger bandwidth and minimized dimension [9]–[11]. However, smaller antennas reduce efficiency and hardly yield return loss above 10 dB at lowest frequency. While in an array smaller elements can reduce grating lobe at high frequency, such elements can increase mutual coupling if the spacing is less than half wavelength of its lowest frequency, which in turn degrades radiation pattern and return loss.

Mutual coupling reduction techniques between non-Vivaldi elements have been reported, such as meander line [12], meta-material [13], and strip wall [14], which are complex, employing either double layer or wall. Radiation pattern improvement by corrugated structure has been reported in [15] and [16], but mutual coupling induced has not been studied. Mutual coupling has been studied for the array of AVAs [17], but a return loss for each element and mutual coupling (given by S_{ij} , where $i \neq j$) have not been researched thoroughly.

A previous study [18] shows that the infinite array of the Vivaldi elements benefits from mutual coupling in terms of larger bandwidth. But some applications might only require finite array, for which mutual coupling and return loss at lower band are problematic. Accordingly, our main contribution is the study of mutual coupling and its reduction by applying various types of slot structure at the border between elements in coplanar Vivaldi arrays (CVAs) with limited number of elements built as continuous patch. The first part of this letter evaluates mutual coupling in such arrays, which demonstrates that mutual coupling in the E-plane is more significant than that in the H-plane, as presented in Section II.

The latter part of this letter discusses mutual coupling reduction in the E-plane for CVA by introducing slot structures at the border between adjacent elements oriented transverse to the direction of surface current, strengthened by corrugation and truncation. We compare arrays with different structures in terms of surface current distribution, return loss, mutual coupling, and copolar and cross-polar field patterns. We also provide equations for a length of the slot structure and its distance to the element's tapered slot that determines mutual coupling and return loss. Simulation using computer simulation technology (CST) and measurement show that arrays with exponential corrugated truncated (ECT) slot performs the best in mutual coupling, gain, and sidelobe level (SLL). This is discussed in Section III, while the overall conclusion is given in Section IV.

II. MUTUAL COUPLING IN CVA

The Vivaldi elements are designed as in Fig. 1 on FR4 materials with dielectric constant of 4.6, substrate thickness of 1.6 mm,

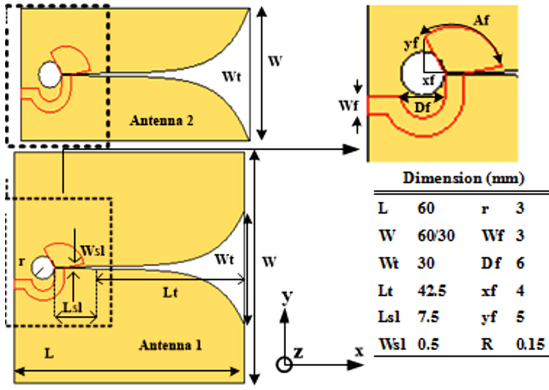


Fig. 1. Dimension of coplanar Vivaldi antenna elements.

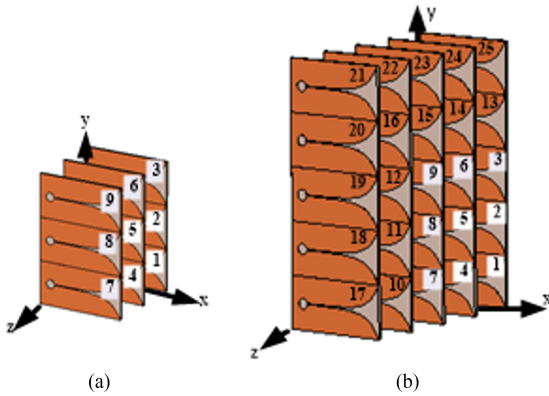


Fig. 2. CVA with dimensions (a) 3×3 and (b) 5×5 , which is an extension from 3×3 .

and copper thickness of 0.035 mm. The 60 mm \times 60 mm element has bandwidth ratio of 5:1, i.e., return loss is better than 10 dB in the 2–10 GHz range, typical of UWB antennas. The tapered slot of Vivaldi can be designed as [17]

$$y = C_1 e^{Rx} + C_2, \quad C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}},$$

$$C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}} \quad (1)$$

where y denotes the tapered slot curve, x_1 , y_1 , x_2 , and y_2 the coordinates of the start and end of tapered slot's slope.

CVAs with different dimensions in Fig. 2 are analyzed to get scattering a parameter performance in Figs. 3 and 4 before discussing a mutual coupling method. The center-to-center spacing of 30 mm at 2 GHz for an array structure with continuous patch is equivalent to element width of $0.2 \lambda_0$, but 60 mm is equivalent to element width of $0.4 \lambda_0$. Both antennas have different element widths with other parameters fixed. It yields high mutual coupling ($S_{21} > -10$ dB) around the lower end frequency. Fig. 3(a) and (b) shows S_{11} and S_{21} performance in decibel scale at 2 GHz for element width of 60 mm (0.4λ) and 30 mm (0.2λ), respectively. With finite yet increasing number of elements, the array with 30 mm (0.2λ) element width shows increasing bandwidth as shown by the S_{11} curve in the upper side of Fig. 3(b), but the mutual coupling remains high. Smaller elements with narrower radiator patch and narrower mouth opening of tapered slot

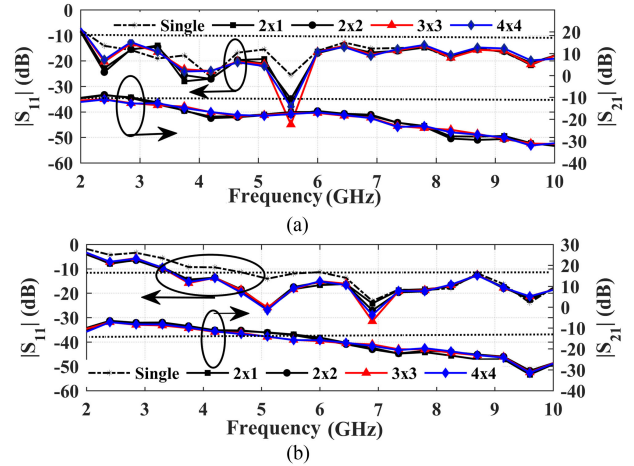


Fig. 3. S_{11} and S_{21} performance of arrays with (a) $0.4 \lambda \times 0.4 \lambda$ elements and (b) $0.2 \lambda \times 0.4 \lambda$ elements.

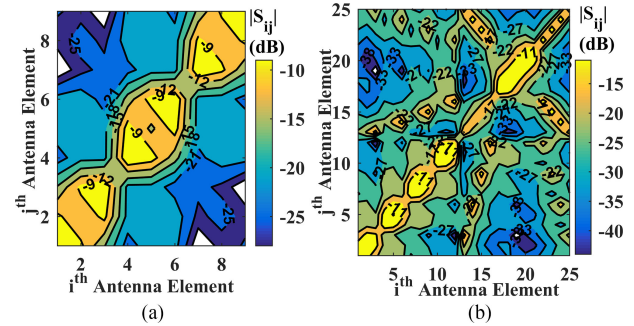


Fig. 4. Contour plot of scattering parameter (S_{ij}) for j th element to i th element for (a) 3×3 array and (b) 5×5 array, respectively.

shifts upward the lower bound of operating frequency range at which S_{11} is below -10 dB. To obtain low return loss, a Vivaldi antenna is usually designed with slot width of one wavelength [19]. For smaller element width, if the number of elements in the array is gradually increasing to infinity, the bandwidth increases because of a coupling environment. However, in Fig. 2, those arrays are just simulated with the finite number of elements, and therefore, the lowest frequency is still high. In contrast, in Fig. 3(a), for arrays with 60 mm (0.4λ) element width, the bandwidth does not increase significantly with more elements. Smaller spacing between feeding points in the E-plane changes the coupling environment so that anomalies of impedance occur. However, the increasing number of element can increase the bandwidth.

The S -parameters at 2.4 GHz of 3×3 arrays in Fig. 4(a) and 5×5 arrays in Fig. 4(b) are shown in contour plots for element width of 0.2λ with the numbering of antenna element is the same as a port number of the antenna given in Fig. 2. They reveal that increasing number of elements enhances the performance of a return loss as well as a mutual coupling parameter. It can be seen for the 3×3 array, S_{33} is -9 dB, while the 5×5 array has S_{33} of -11 dB. For the 3×3 array, S_{98} is -9 dB but for the 5×5 array, S_{98} is -11 dB, where S_{ij} for $i \neq j$ is the coupling from j th element to i th element for an arrangement shown in Fig. 2. By increasing the number of elements, mutual scattering can be reduced because it is induced by coupling from elements on

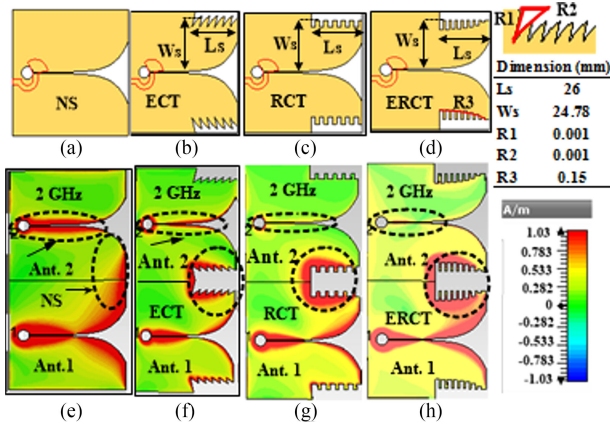


Fig. 5. Geometry of the Vivaldi element with slot structures. (a) NS, (b) ECT, (c) RCT, and (d) ERCT with their corresponding current distribution in (e)–(h).

all sides. In the E-plane, mutual coupling appears to be larger than it is in the H-plane. For the 5×5 array, in the E-plane, S_{56} is around -11 dB, which is higher than mutual coupling in the H-plane with S_{58} of around -22 dB. In the E-plane, surface current flows in the adjacent element, which causes coupling between elements, whereas in the H-plane, coupling is induced by electric field through the air. The diagonal of contour plot shows $S_{ij} = S_{ji}$. Over all, these observations indicate that mutual coupling is a bigger issue than return loss in CVAs, with greater impact shown in the E-plane than the H-plane.

III. MUTUAL COUPLING REDUCTION

A. Vivaldi Antenna and Surface Current Performance

We consider several slot structures, i.e., straight, exponential, corrugated and truncated, or their combinations. Truncated slot has been used in [18] but how it reduces mutual coupling is not explained. Corrugated slots have been used in [15] and [16] for different purposes to improve radiation pattern, as well as in our previous work [20]. Aside from no slot structure (NS), there are three types of slot structure evaluated herein for mutual coupling reduction, as shown in Fig. 5, namely, ECT slot, rectangular corrugated truncated slot (RCT), and exponential RCT slot (ERCT). All structures are simulated with the same amplitude excitation with ideal (lossless) power divider connected to SubMiniature version A (SMA) connectors.

B. Surface Current Performance

Fig. 5 shows geometry of coplanar Vivaldi element and surface current in two element array when the lower antenna (antenna 1) is excited and the upper (antenna 2) is terminated at 2 GHz. Surface currents in NS array in Fig. 5(e) couple to the upper antenna, which is observable from the direction of the surface current in the areas encircled. This happens because there is no transverse structure in between the elements that disturbs the flow of the leaking surface current. In contrast, surface current on array with ECT in Fig. 5(f), RCT in Fig. 5(g), ERCT in Fig. 5(h), concentrated along the slot structure at the border, thus, reducing the current that flows to the next element. To further enhance the current concentration around the slot structure and minimize the leakage, saw tooth corrugation can

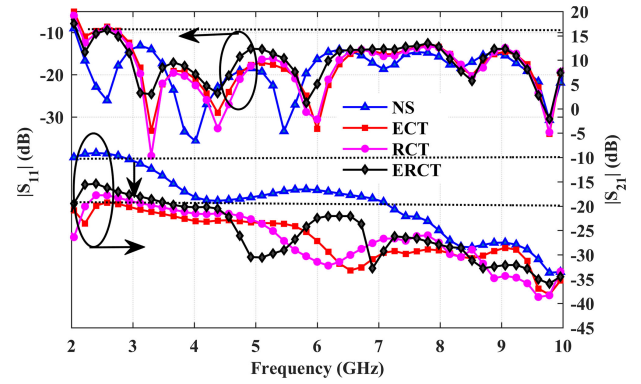


Fig. 6. S-parameters for arrays with various structures.

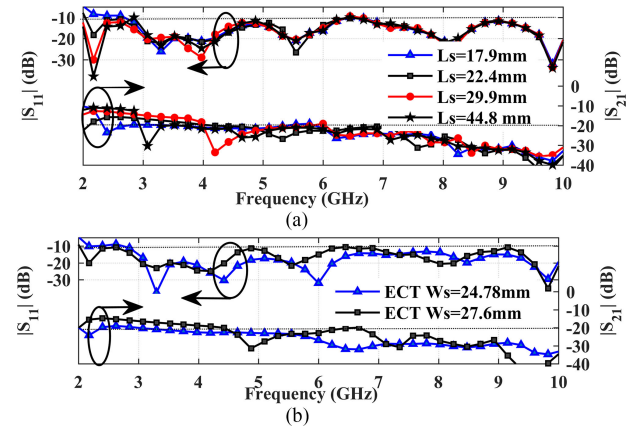


Fig. 7. S-parameters. (a) Varying L_s . (b) Varying W_s .

be applied to the slot, for which higher corrugated slope gives better result. In the corrugated slot, surface currents propagate to adjacent element along a longer path than in the straight structure and also crash each other, thereby increasing isolation.

C. Scattering Parameter Performance

Fig. 6 compares S_{11} and S_{21} of Vivaldi arrays with various slot structures. The array structures in the order of superiority in S_{11} performance at 2.2 GHz are ERCT, RCT, ECT, and NS. Better isolation is achieved with ECT, RCT, ERCT, and NS in the descending order of superiority at around 4 GHz. The best isolation is achieved for ECT. Accordingly, it suggests that corrugated structure should be used with truncation for the isolation.

Increasing L_s with a constant $W_s = 0.5 \lambda_g$ (at 4 GHz) can improve return loss performance but reduce isolation as shown in Fig. 7(a). Longer L_s makes surface current spread along truncated slot over longer path and subsequently make the U-turn. Some of the surface current directly flows towards the area in the beginning of tapered slot in the adjacent element and reduces isolation. In contrast, the shorter corrugated truncated slot makes some of surface current spread near opening of tapered slot in the excited element and escalates return loss at lower frequency. After the surface current makes a U-turn to the next element, it flows to the center slot with longer trajectory that enhances isolation. S_{11} performance below -10 dB can be reached from 2 to 10 GHz by setting the length of L_s

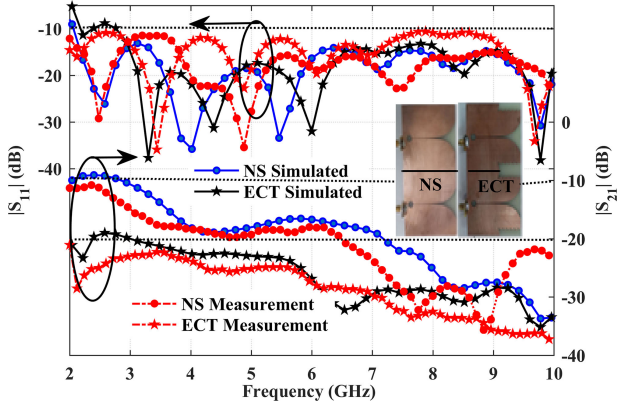


Fig. 8. Simulation and measurement S_{11} and S_{21} : NS and ECT.

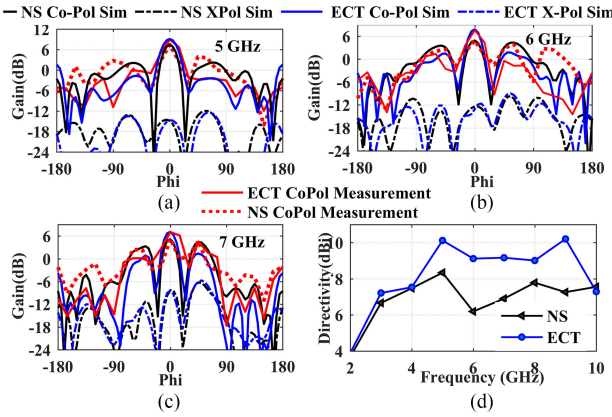


Fig. 9. Simulation and measurement results of copolar gain and simulation of cross-polar gain in the E-plane at (a) 5 GHz, (b) 6 GHz, and (c) 7 GHz. (d) Directivity at 2–10 GHz for ECT and NS.

to $0.5 \lambda_g$ with guided wavelength λ_g obtained from any value of f (GHz) where $f_L \leq f \leq (f_c - 2)$ and setting W_s to $0.5 \lambda_g$ where $f_L + 1 < f < (f_c - 2)$, with f_L and f_c is the lowest and the center frequency, respectively. This step gives the rule for minimum and maximum dimensions of L_s and W_s as shown in Fig. 5. By considering effective dielectric [16], the value of L_s and W_s should be set as

$$L_s \text{ or } W_s = 0.5\lambda_g = \frac{c}{2f(\sqrt{\epsilon_{eff}})} = \frac{\sqrt{2}\lambda}{2\sqrt{\epsilon_r + 1}}. \quad (2)$$

S_{11} and S_{21} for ECT with different values of W_s with a constant $L_s = 0.5 \lambda_g$ (at 3.5 GHz) are shown in Fig. 7(b). Smaller W_s appears to reduce a return loss performance but leads to higher isolation in both structures. To comply return loss requirement with smaller W_s , larger L_s can be used. Results of simulation and measurement of S_{11} and S_{21} for array with ECT and NS are presented in Fig. 8. By simulation, at 2.16 GHz, the arrays without slot yield S_{21} of -9.34 dB, whereas those with ECT give S_{21} of -24.19 dB. It is found that both simulation and measurement show consistency.

D. Radiation Pattern Performance

Fig. 9 compares simulation and measurement (see Fig. 10) results of a copolar gain and simulation of a cross-polar field

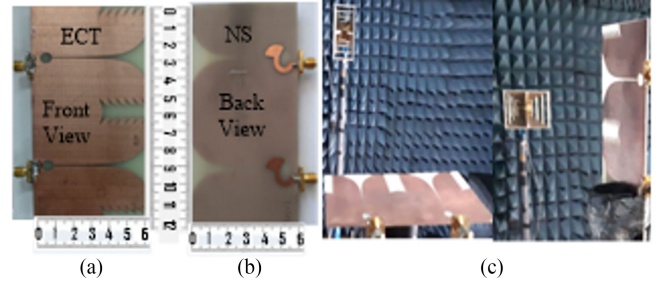


Fig. 10. Fabricated antenna. (a) ECT, (b) NS, and (c) ECT measurement.

TABLE I
COMPARISON OF ECT AND NS ARRAYS

f (GHz)	Dir (dBi)		Co-Pol (dB)		X-Pol (dB)		SLL(dB)		$ S_{21} $ (dB)	
	ECT	NS	ECT	NS	ECT	NS	ECT	NS	ECT	NS
2	3.9	3.7	3.5	3.3	-26	-22	-7.2	-7.2	-20	-9.8
3	7.2	6.7	6.8	6	-17	-15	-7.8	-8.7	-16	-11
4	7.5	7.5	6.8	6.7	-15	-14	-6.3	-5.3	-18	-18
5	10.1	8.3	9.1	7.4	-12	-12	-7.5	-5.3	-29	-18
6	9.1	6.2	7.8	4.8	-9	-9	-6	-1.6	-23	-17
7	9.2	6.9	7.1	5.1	-5.7	-6	-5.8	-2.1	-29	-19
8	9	7.8	6.6	5.8	-4	-4	-3.3	-2.8	-27	-25
9	10.2	7.3	7.1	4.9	-2.5	-3	-6.9	-1.2	-30	-28
10	7.3	6.6	0.7	-0.5	3.8	3	-1.6	-1	-34	-33

pattern in the E-plane between ECT-CVA and NS-CVA. The arrays generally preserve the wideband directivity as shown in Fig. 9(d). Radiation pattern and S_{21} performance of arrays with ECT and NS at various frequencies are shown in Table I. Directivity, copolar gain and S_{21} of ECT-CVA is better than NS over the whole band of 2–10 GHz, whereas the cross-polar gain for ECT is better than NS in the lower end frequency. ECT only improves SLL at 4–9 GHz, while at 10 GHz, array with element width of 60 mm has center-to-center spacing of $2 \lambda_0$, which yields grating lobes. A corrugated slot in antenna focuses electric field and enhances surface current over the whole patch, thus, improving directivity and radiation pattern. There are tradeoff between return loss, isolation, and SLL performance in an UWB antenna, which is influenced by the geometry of the antenna, feeding shape, patch design, and substrate.

IV. CONCLUSION

We have found that mutual coupling in UWB-CVA is more prevalent in E-plane than in H-plane. A family of mutual coupling reduction methods for CVA with various slot structures at the edges of adjacent elements has subsequently been demonstrated. Generally, the reduction of mutual coupling is achieved by placing a slot structure transverse to the direction of surface current at the border between elements to reduce surface current flowing to the next. The ECT structure is effective to improve isolation in all bands, especially at lower frequency, directivity in the whole band of 2–10 GHz, and SLL in 4–9 GHz. Therefore, it can be applied for the UWB CVA antenna application.

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Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for L and S Band Applications

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Abstract: The Vivaldi antenna is an ultra-wideband device that has high gain and directional radiation pattern. This paper performs a comparison of conventional, regular and exponential edges of a Palm Tree Vivaldi antenna that could operate in L and S band frequencies. The Conventional Coplanar Vivaldi Antenna (C-CVA), Regular Coplanar Vivaldi Antenna (R-CVA), Exponential Slot Edge Coplanar Vivaldi Antenna (ESE-CVA), Regular Antipodal Vivaldi Antenna (R-AVA), and Exponential Edge Antipodal Vivaldi Antenna (ESE-AVA), all with the same dimensions, are compared in terms of return loss and radiation pattern performance. Gain improvement is achieved as 6.22 dB, 7.72 dB, 7.90 dB, 7.92 dB, and 10.74 dB at 3 GHz respectively for R-AVA, ESE-AVA, C-CVA, R-CVA, and ESE-CVA. The number, height, and opening rate of slot edges predispose current distribution and radiation pattern of CVA. Our results show that the Exponential Slot Edge Coplanar Vivaldi Antenna provides the best gain and derives the best side lobe level at -7.14 dB, which confirmed the possibility of applying the Palm Tree technique to Coplanar Vivaldi antennas, in addition to the Antipodal ones, as originally proposed.

1. Introduction

Vivaldi antenna is a simple and robust planar device, which has been the focus of recent intensive research, mostly due to its superior unique properties, it is compact, easy to manufacture, with small dimensions and high gain, and could be integrated directly in a circuit board [1]. As a result, it is suitable for many ultra-wideband (UWB) microwave applications. There are many applications for L and S bands, such as cell phone and wireless communication [2], ground penetrating radar [3], software defined and cognitive radios [4], medical imaging and on-body telemetry [5,6], astronomy [7], satellite communication, surveillance and amateur radio. All such application need reliable system mainly for antenna optimization as front end of telecommunication device.

Despite such features, the Vivaldi antenna still carries many shortcomings. The original antenna design has limitations, particularly on directivity and gain, such that a design optimization procedure is generally required for a specific application. Over the last few years, many strategies have been developed to improve those properties, for example by adding trapezoid lens [8], using double antipodal structures [9], and metamaterials [10]. However, all those solutions compromise the main constructive advantage, by increasing the final antenna dimensions and making the design more complex. Therefore, it is important to search for new design strategies, in order to overcome those limitations, but not compromising the original design simplicity. Recently, several investigations have explored the design of the slot edges on Antipodal Vivaldi Antennas (AVA) [11-19], using rectangular and comb structure, exponential, and fractal patterns.

It has been shown that the Exponential Slot Edge for AVA (ESE-AVA), labelled as the Palm Tree antenna, has superior radiation patterns when compared to antennas with other slot edge designs [17]. This antenna simultaneously increases the gain, boosts the main lobe, and reduces the Side Lobe Level (SLL), all without making the design more complex or increasing its volume. While investigations have so far explored the design of the slot edge in antipodal configuration, a recent investigation has indicated that CVA could also benefit from slot edge optimization, in order to increase gain and enhance the main lobe of radiation patterns [20].

This investigation explores the design of slot edges on both AVA and CVA, and the resulting radiation properties for applications in L and S bands. We compare the return loss and radiation performance of Conventional Coplanar Vivaldi Antenna (C-CVA), Regular Coplanar Vivaldi Antenna (R-CVA), Exponential Slot Edge Coplanar Vivaldi Antenna (ESE-CVA), Regular Antipodal Vivaldi Antenna (R-AVA), and Exponential Slot Edge Antipodal Vivaldi Antenna (ESE-AVA), by keeping the geometry with the same dimensions. We also compare the effect of the number, height, and opening rate of slot edges to the radiation pattern and current distribution. From simulations and measurements, we find that CVA has better overall radiation pattern performance than AVA. Particularly, among all tested designs, the ESE-CVA provides the best gain at 10.74 dB and -7.14 of SLL.

This manuscript is presented as follows: section 2 presents the design procedure of the AVA and CVA, section 3 presents results on the antenna performance, section 4 presents experimental results specifically for the ESE-CVA, and finally section 5 presents some concluding remarks.

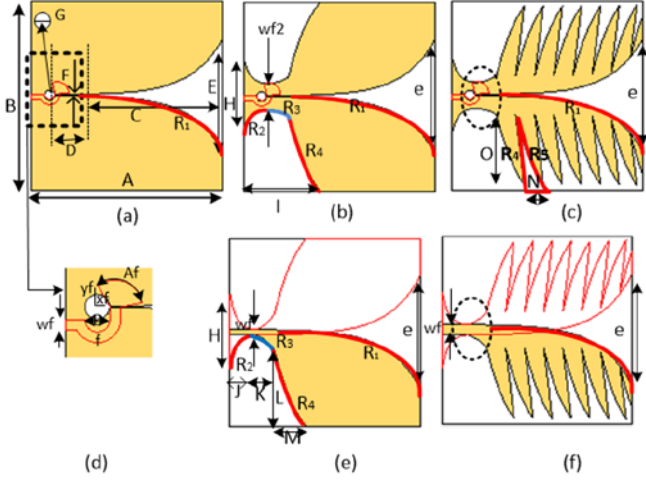


Fig. 1. Antenna dimensions of (a) C-CVA, (b) R-CVA, (c) ESE-CVA, (d) feeding shape of CVA, (e) R-AVA, and (f) ESE-AVA.

Table I. Antenna parameters (in mm) based on Fig. 1.

A	150	F	0.9	xf	4	L	60	R1	0.04
B	150	G	8	H	60	M	25	R2	-0.2
C	120	wf	4	I	60	N	15	R3	0.1
D	13	wf2	20	J	20	O	60	R4	0.05
E	90	Yf	8	K	15	Af	120	R5	-0.05

2. Vivaldi Antenna

We consider five types of Vivaldi antennas with the same dimensions as 1.25λ and 1.25λ at center frequency, as shown in Fig. 1 and with dimensions given in Table I. The antennas are designed considering a FR4 substrate with permittivity of 4.6, and 1.6 mm of thickness and 0.035 mm of patch thickness. Although the Antipodal and Coplanar Vivaldi antennas have different feeding shapes, they have the same width of transmission line. All the parameters of exponential slot edge for both antennas have the same dimensions except for the transmission line and the part in the circle dash. The exponential tapered slot and exponential slot edge are designed by [15]:

$$y = C_1 e^{Rx} + C_2, \quad (1)$$

$$C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}}, \quad C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}}$$

where y is exponential curve and $x_1, y_1 (x_2, y_2)$ are the start (end) points of the tapered slot. All the exponential shape for tapered slot and slot edge are determined by setting some opening rate (R), as indicated in Table I.

3. Antenna Performance

3.1. CVA and AVA Return Loss and Surface Current Performance

We compare the return loss performance of the antennas in coplanar (C-CVA, R-CVA, and ESE-CVA) and antipodal (R-AVA and ESE-AVA) configurations, as shown in Fig. 2. The first return loss at -10 dB is obtained from CST simulations for ESE-CVA at 1.23 GHz, C-CVA at 1.32 GHz, R-CVA at 1.34 GHz, R-AVA at 1.51 GHz, and ESE-AVA at

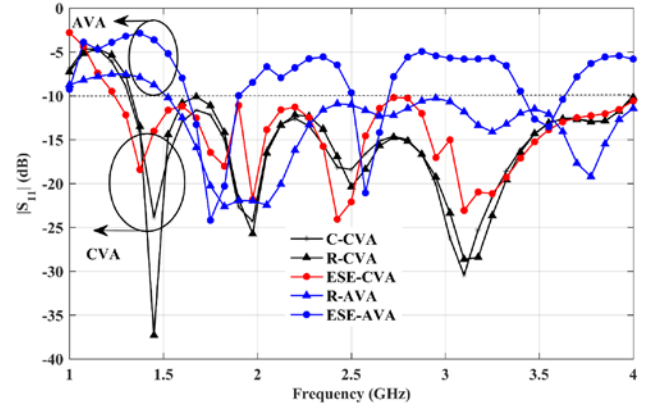


Fig. 2. Return Loss performance of CVA and AVA.

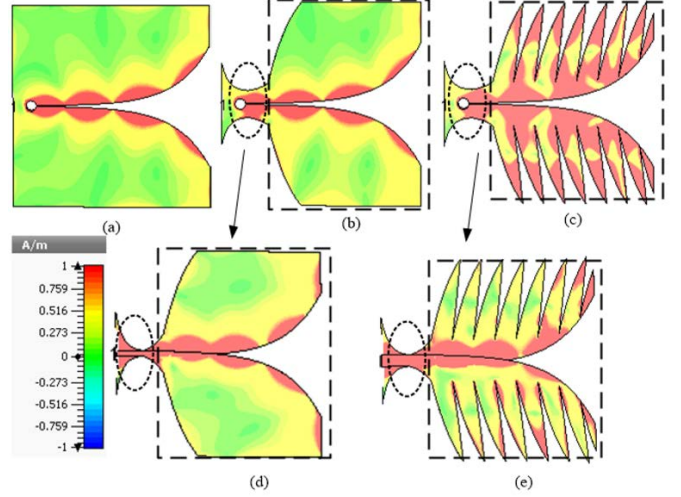


Fig. 3. Surface current performance for (a) C-CVA, (b) R-CVA, (c) ESE-CVA, (d) R-AVA, and (e) ESE-AVA.

1.63 GHz. Although both CVA and AVA are designed with the same tapered slot value (shown with dash line in the square area in Fig. 3) and the same width of transmission line, the coplanar antenna provides better performance of return loss at lower frequency than the antipodal one. Electric field in the tapered slot is stronger in CVA than in AVA, as shown in the comparison between results in Figs. 3(c) and 3(e). The intensity of electric field at the beginning of tapered slot indicates good resonance at higher frequencies and in the opening mouth of tapered slot indicates good resonance at lower frequencies.

Fig. 3 shows the surface currents at 3 GHz for all antennas, indicating that, despite the same dimensions, the ESE-CVA has the highest surface current. By exciting the feeding of antenna, it yields electric field and produces higher current distribution. The exponential slot edge traps the propagation of electric field and surface current, leading to an antenna with a higher gain than the one without the exponential slot edge. However, the intensity of electric field depends on an impedance matching from the feeding to slot line and from the tapered slot to free space.

3.2. CVA and AVA Radiation Pattern Performance

Fig. 4 shows the antenna gain at 3 GHz for the coplanar antennas, indicating that ESE-CVA provided the best gain, followed by R-CVA and C-CVA. For antipodal antennas, the

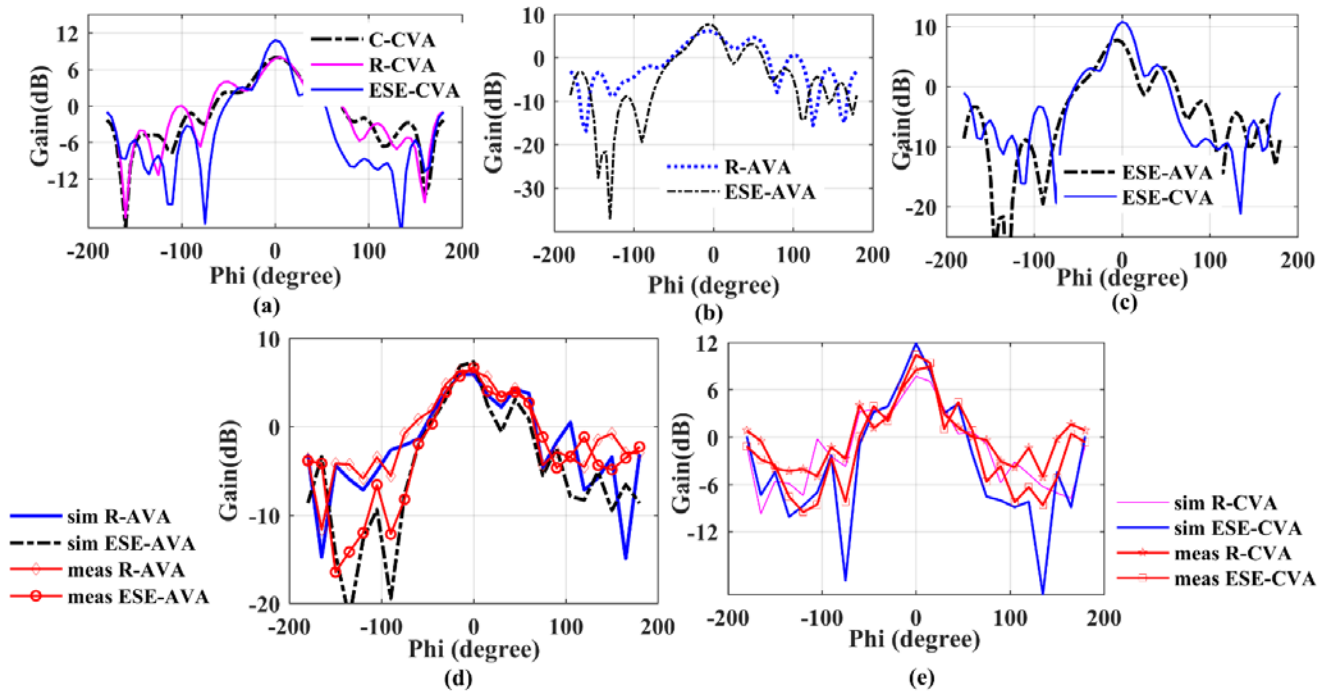


Fig. 4. Antenna gain at 3 GHz: (a) simulation results of CVA, (b) simulation results of AVA, (c) simulation results of ESE-AVA and ESE-CVA, (d) simulation and measurement results of R-AVA and ESE-AVA, and (e) simulation and measurement results of R-CVA and ESE-CVA.

ESE-AVA has a larger gain than R-AVA. However, the ESE-AVA has a more asymmetric radiation pattern than the ESE-CVA, as shown in the lower part of Fig. 4. Fig. 5 shows a comparison of the gain at several frequencies for all antennas, indicating that the best results are obtained with the ESE-CVA. The gains at 3 GHz are 10.74 dB for ESE-CVA, 7.92 dB for R-CVA, 7.90 dB for C-CVA, 7.72 dB for ESE-AVA, and 6.22 dB for R-AVA.

The CVA has two tapered slots in the same side of the substrate and the feeding of CVA is located on the reverse side of substrate. If the feeding has matching impedance with the slot line, it yields resonance between two tapered slots. In CVA, electric field propagates between two tapered slots in the same side of substrate. CVA can be designed with specific feeding shape and it influences the CVA bandwidth. ESE-CVA also has high gain because the electric field is strengthened by the exponential slot edge. In AVA, current from feeding propagates directly from the transmission line in the straight line to the tapered slot, which is located on the opposite side of substrate. In this case, we compare all Vivaldi antennas with the same width of transmission line, and the CVA provides better performance than AVA.

4. ESE-CVA: Optimization and Measurement Results

4.1. ESE-CVA Radiation Pattern

ESE-CVA provides the best performance in radiation pattern and bandwidth, as discussed in the previous section. However, there are several parameters to design the slot edge that affect radiation pattern performance. The radiation pattern of the ESE-CVA could be optimized by varying some parameters of the exponential slot edge. The number of exponential slot edges interferes on gain, side lobe level, back lobe, and beam width. From simulation results at 2.5 GHz as

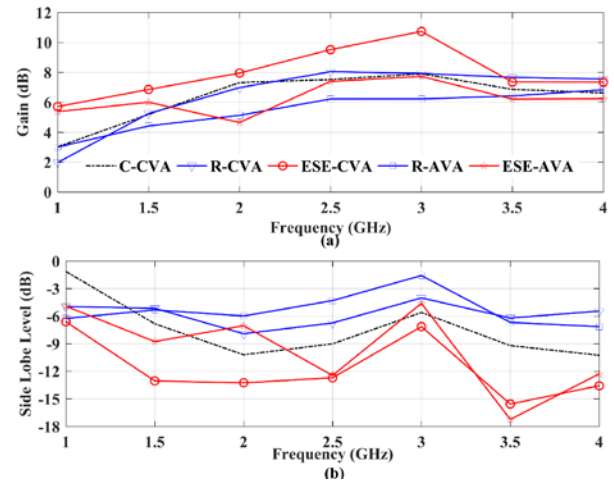


Fig. 5. (a) Gain and (b) SLL performance of the antennas.

the center frequency, as shown in Fig. 6, the ESE-CVA with seven slots has the main lobe of 9.5 dB, SLL of -12.7 dB, and beam width of 39.8 degrees. On the other hand, the antenna with five slots has the main lobe of 9.3 dB, SLL of -12.6 dB, and beam width of 40.7 degrees, whereas for four slots has the main lobe of 9 dB, SLL of -12.5 dB, and beam width of 42.2 degrees. Therefore, more slots can increase the main lobe and reduce SLL, but provide a larger beam width. This occurred because the electric field resonates between slot edges, improving the radiation pattern.

The height of ESE from the center of tapered slot, shown in Fig. 7(a), and represents the slope of exponential slot edge, shown in Fig. 7(b), interfere with the radiation pattern performance. When the height of ESE (h_A) is 15 mm, the antenna gain is 10.7 dB and SLL -7.1 dB. On the other hand,

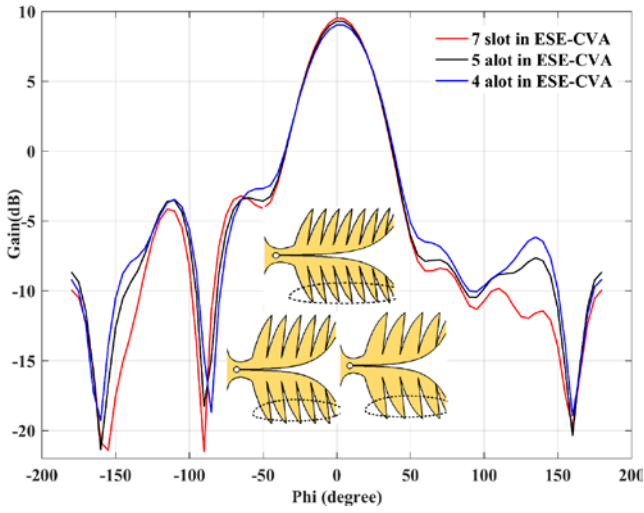


Fig. 6. Radiation pattern of ESE-CVA with varying the number of slot at 2.5 GHz.

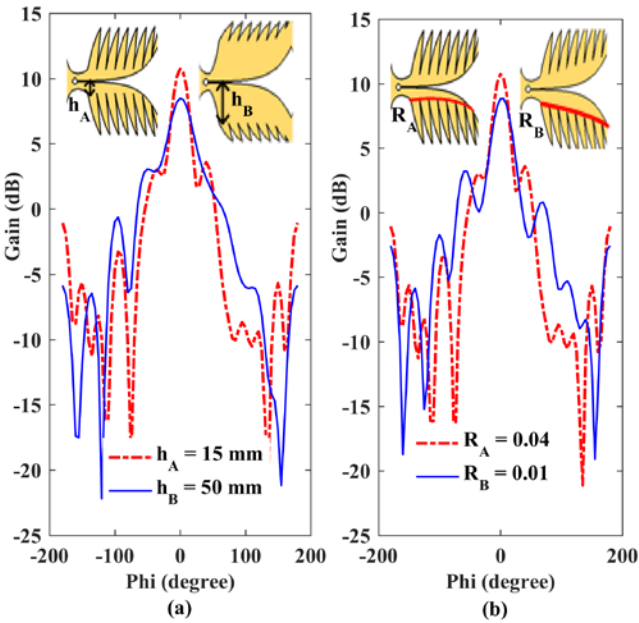


Fig. 7. Gain of ESE-CVA by varying depth of slot and slope of ESE at 2.5 GHz.

when h_B is 50 mm, the antenna gain is 8.1 dB and SLL -5.4 dB. The shorter the height of slot edge to the center of the opening tapered slot, as shown in Fig 7(a), the more electric field induces the slot edge and enhances the gain. For the antenna with $R=0.04$, the main lobe is 10.7 dB, SLL is -7.1 dB, and squint is 0 degree, while for $R=0.001$, the main lobe is 8.8 dB, SLL is -5.6 dB, and the squint is 5 degrees. This indicates that the slope of ESE could control radiation pattern performance. It shows that the shorter height (h) of slot edge from center of tapered slot and higher opening rate (R) of slot edge improve the gain, SLL performance, and the squint performance of the main lobe.

4.2. Surface Current of ESE-CVA

The surface current performance for ESE-CVA with different heights of slot edge from the center of the element, different number of slot edge, and different slope of slot edge is shown in Fig. 8. Higher intensity of electric current, represented by surface current distribution, is reached for

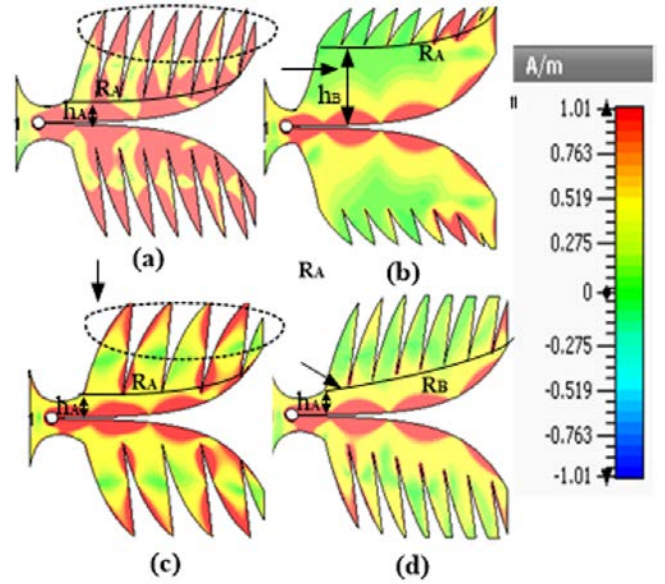


Fig. 8. Surface current of CVA at 3 GHz with (a) number of slot = 7, height of slot (h_A)=15 mm, slope of slot (R_A)=0.04, (b) number of slot = 7, h_B = 50mm, R_A = 0.04, (c) number of slot = 4, h_A = 15 mm, R_A = 0.04, and (d) number of slot = 7, h_A = 15 mm, R_B = 0.01.

shorter height (h_A) of slot edge, as shown in Fig. 8(a), while higher height (h_B) of slot edge yields less surface current distribution, as shown in Fig. 8(b). Higher densities of surface current, which resulted from electric field in the mouth opening of the tapered slot, appears in the slot edge of CVA that has higher depth of slot edge. Higher depth in the slot edges means shorter height (h_A) of slot edge to the center of tapered slot. However, for short depth of slot edge only shows a small surface current at the corner of the slot edge, represented in red color in Fig. 8(b).

Figs. 8(a) and 8(c) show a comparison on the surface current for the element with different number of slot edges. CVAs in Figs. 8(a) and 8(c) are designed with the height of slot edge $h_A=15$ mm and slope of slot edge $R_A=0.04$. Those CVA have the same height of slot edge to the center of tapered slot, but they have different number of slot edge. At 3 GHz, the CVA with seven slot edges presents the maximum surface current in the most part of all sections, as shown in Fig. 8(a), while the CVA with smaller number of slot edges presents less portion of surface current, as shown in Fig. 8(c). Therefore, more slot edges lead to more electric field induced in the slot gap and it also yield surface currents trapped in the slot edge. An increase in the number of exponential slots increases surface current in CVA.

Surface current performance for CVA with different slope is shown in Figs. 8(a) and 8(d), designed with $R_A=0.04$ and $R_B=0.01$, respectively. A higher slope of tapered slot edge to the center of the antenna increases performance of surface current. In the middle and towards the end of mouth opening of tapered slot, higher slope (R_A) has smaller distance of slot edge from opening tapered slot. It conversely for smaller slope (R_B) that has longer distance of slot edge from opening of tapered slot. The slope of slot edge influences the spacing of slot edge to the mouth opening of tapered slot in the middle and in the end of tapered slot and it causes the flowing of surface current to the slot edge.

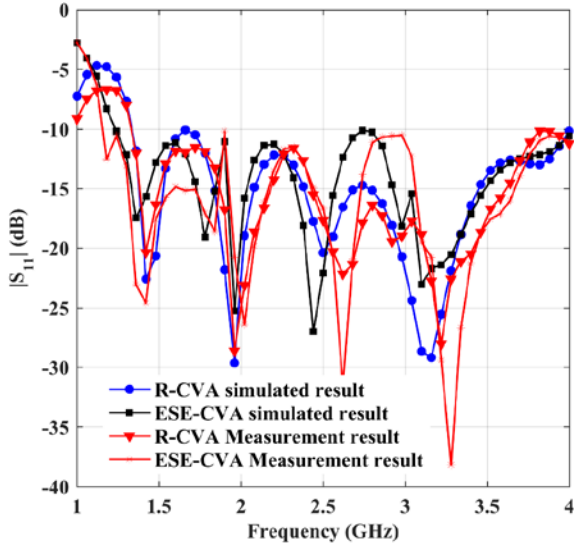


Fig. 9. Simulation and measurement results of R-CVA and ESE-CVA on S_{11} as a function of frequency.

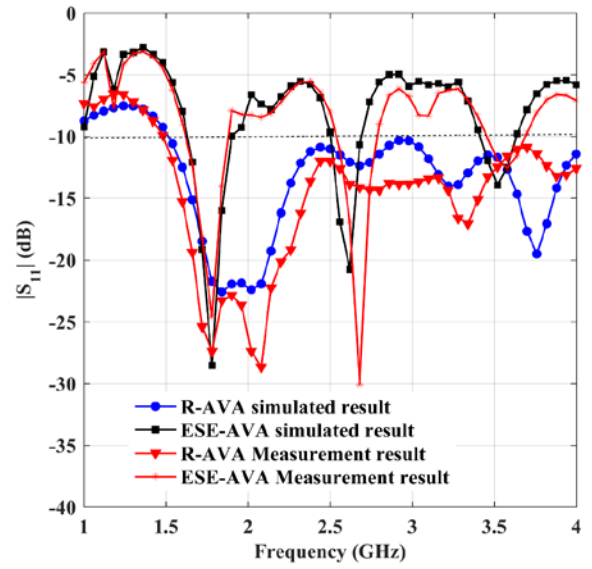


Fig. 10. Simulation and measurement results of R-AVA and ESE-AVA on S_{11} as a function of frequency.

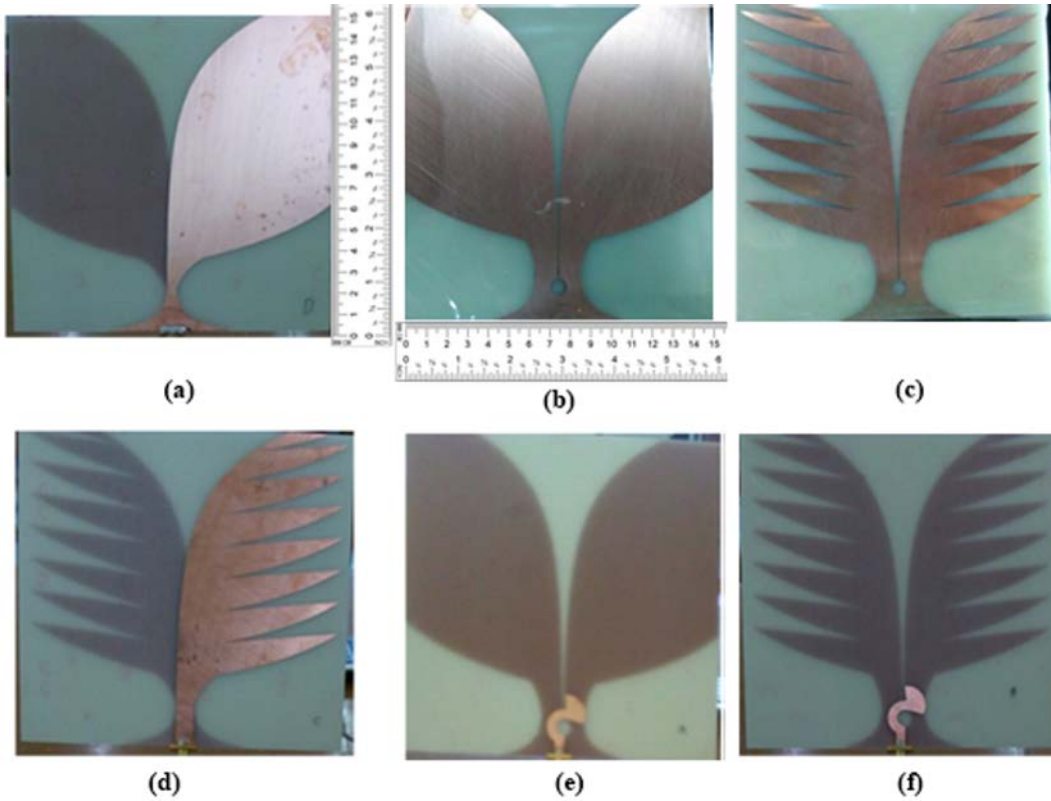


Fig. 11. Fabricated antennas: (a) R-AVA front view, (b) R-CVA front view, (c) R-CVA back view, (d) ESE-AVA front view, (e) ESE-CVA front view, and (f) ESE-CVA back view.

4.3. Measurement Results of CVA and AVA

Fig. 9 shows a comparison of simulations and measurements of the return loss (S_{11}) for regular (R) and exponential slot edge (ESE) of CVA, whereas Fig. 10 clarifies simulations and measurements of R-AVA and ESE-AVA. CVA provides better performance in bandwidth than AVA, especially at low end of the frequency band. Table II shows the values of gain, SLL, squint, and the lowest

frequency that occupies return loss performance below -10 dB, between simulations and measurements. ESE-CVA gets the best performance of Gain, SLL, and squint at 2.5 and 3 GHz. It also improves the lowest of frequency band. Fig. 11 shows the AVA and CVA fabricated antennas with regular and exponential slot edges. Figs. 11 (a), (b), and (c) show the front view of R-AVA, R-CVA and ESE-CVA, respectively, while Figs. 11(d), (e), and (f) show their respective feeding in back views.

Table II. Comparison between antennas: gain, SLL, squint from simulations and measurements.

Freq. (GHz)	Gain (dB)		SLL (dB)		squint	Lowest frequency	
	2.5	3	2.5	3	3	Simulation result	Measurement result
R-AVA	6.2	6.2	-4.31	-1.58	-5	1.52	1.48
ESE-AVA	7.39	7.72	-12.46	-4.61	-5	1.63	1.62
C-CVA	7.51	7.9	-9.02	-5.61	0	1.32	
R-AVA	8.04	7.93	-6.74	-4.02	5	1.34	1.34
ESE-CVA (proposed antenna)	9.52	10.74	-12.71	-7.14	0	1.23	1.16

5. Conclusion

We compared the properties of Vivaldi antennas consisting of R-AVA, ESE-AVA, C-CVA, R-CVA, and ESE-CVA with the same dimensions of substrate and similar shape of exponential edge and tapered slot. The results indicate that ESE-CVA provides the best performance of gain and side lobe level. Although the width of feeding is designed with the same width for AVA and CVA, the feeding shape influences considerably the performance of resonance frequency and radiation pattern. The number of exponential slot edges, the distance of exponential slot edge to the center of the antenna and the slope of exponential slot edge can control radiation pattern performance. ESE-CVA has better performance of radiation pattern compared to others. Gain improvement is obtained for ESE-CVA of 3.02 dB and SLL of -2.53 dB at 3 GHz when compared to ESE-AVA.

6. Acknowledgments

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Teknologi :
Antenna array Vivaldi Coplanar dengan Corrugated dan
Truncated slot yang bekerja di S dan C band

No	Identitas	Keterangan
1	NIK	3578094412780006
2	Nama	Nurhayati
3	Umur	40 tahun
4	Jenis Kelamin	Perempuan
5	Pendidikan Terakhir	S2
6	Lembaga	LPPM Universitas Negeri Surabaya
7	Jabatan dalam Lembaga	Tenaga Pengajar di Jurusan Teknik Elektro Fakultas Teknik
8	Jabatan dalam kegiatan inovasi	Ketua
9	Nomor Telepon dan Email	1. Hp 087854127188 2. nurhayati@unesa.ac.id

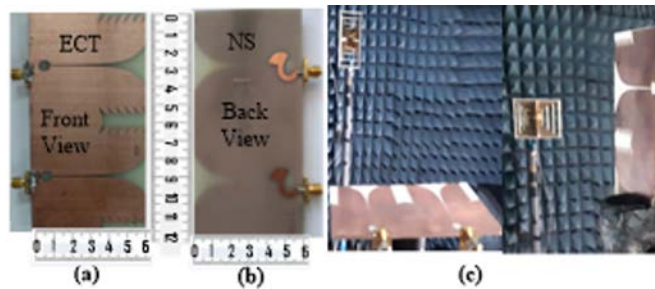
No	Identitas Produk Teknologi	Keterangan
1	Nama Produk Inovasi	Antena bekerja pada S&C Band
2	Bidang Fokus*	Teknologi Telekomunikasi
3	Tahun Pengembangan Produk	2018
4	Lembaga	LPPM Universitas Negeri Surabaya
5	Jumlah Anggota	-
6	Inovator	1. Nurhayati. ST.,MT. 2. Prof Gamantyo Hendranto 3. Prof. Takeshi Fukusako 4. Eko Setijadi., PhD

Deskripsi Produk

*Foto Antenna Array
Vivaldi Coplanar
Exponensial Corrugated
Truncated (ECT)



*Foto antenna dan proses pengukuran antenna



Fabricated antenna: (a) ECT, (b). NS, and (c). ECT measurement.

Narasi deskripsi produk

Antena coplanar vivaldi yang kami buat merupakan antena planar yang memiliki pola radiasi direksional yang dapat beroperasi di frekuensi ultrawideband. Antena coplanar Vivaldi memiliki fraksional bandwidth sebesar 133% yang ditunjukkan dengan nilai $VSWR < 2$ untuk frekuensi 2-10 GHz. Elemen antena Coplanar Vivaldi, berukuran 60 mm x 60 mm menggunakan bahan FR4 yang memiliki permitivity 4.6, ketebalan substrat 1.6 mm dan ketebalan copper 0.035mm dengan kemiringan tapered slot mengikuti:

$$y = C_1 e^{Rx} + C_2, \quad C_1 = \frac{y_2 - y_1}{e^{Rx_2} - e^{Rx_1}}, \quad C_2 = \frac{y_1 e^{Rx_2} - y_2 e^{Rx_1}}{e^{Rx_2} - e^{Rx_1}}$$

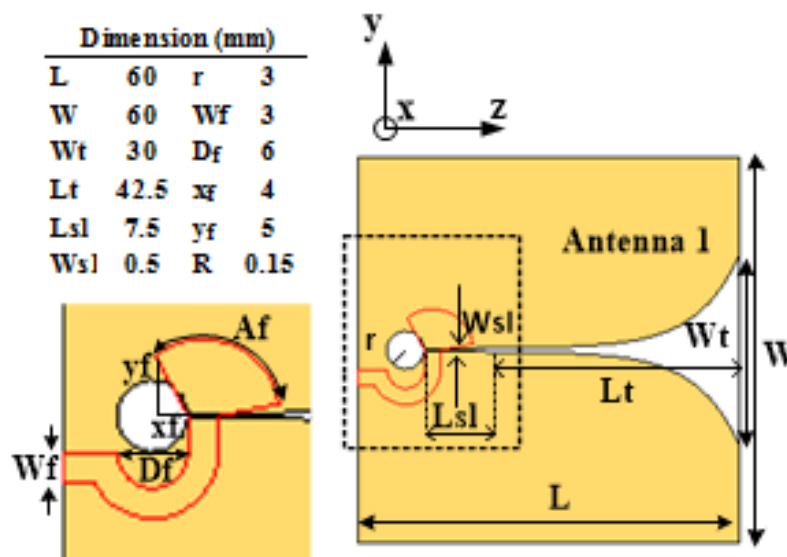
Dua elemen antena disusun array di bidang E plane sehingga ukuran antena array menjadi 60 mm x 120 mm. Antena Vivaldi Coplanar jika disusun array pada bidang E akan memiliki permasalahan mutual coupling di frekuensi rendah dan permasalahan pola radiasi yaitu side lobe level terutama di frekuensi tinggi. Antena Vivaldi Coplanar yang bekerja dengan bandwidth yang sangat lebar jika tidak diberikan struktur tambahan (No Slot Structure /NS) akan memiliki permasalahan yaitu mutual coupling yang tinggi terutama di frekuensi rendah sehingga perlu

analisa mutual coupling. Kami menemukan metode pengurangan mutual coupling antenna Vivaldi Coplanar serta peningkatan performansi pola radiasi antenna yaitu menggunakan metode exponential corrugated truncated (ECT). Dari hasil simulasi didapatkan performansi antenna :

TABEL 5.1
PERBANDINGAN ECT DAN NS

f (GHz)	Dir (dBi)		Co-Pol (dB)		X-Pol (dB)		SLL(dB)		S ₂₁ (dB)	
	ECT	NS	ECT	NS	ECT	NS	ECT	NS	ECT	NS
2	3.9	3.7	3.5	3.3	-26	-22	-7.2	-7.2	-20	-9.8
3	7.2	6.7	6.8	6	-17	-15	-7.8	-8.7	-16	-11
4	7.5	7.5	6.8	6.7	-15	-14	-6.3	-5.3	-18	-18
5	10.1	8.3	9.1	7.4	-12	-12	-7.5	-5.3	-29	-18
6	9.1	6.2	7.8	4.8	-9	-9	-6	-1.6	-23	-17
7	9.2	6.9	7.1	5.1	-5.7	-6	-5.8	-2.1	-29	-19
8	9	7.8	6.6	5.8	-4	-4	-3.3	-2.8	-27	-25
9	10.2	7.3	7.1	4.9	-2.5	-3	-6.9	-1.2	-30	-28
10	7.3	6.6	0.7	-0.5	3.8	3	-1.6	-1	-34	-33

Performansi antenna pada table diatas di dapatkan dengan membuat array dua elemen antenna di bidang E plane dengan ukuran elemen antenna:



Gambar Dimensi ukuran elemen antenna vivaldi coplanar

Sedangkan hasil fabrikasi antenna dan proses pengukuran terdapat pada gambar di bawah iniL

Antena Vivaldi coplanar yang memiliki bandwidth yang sangat lebar jika disusun secara array akan memiliki permasalahan tingginya mutual coupling di frekuensi rendah dan akan menimbulkan grating lobe di frekuensi tinggi. Inovasi dari temuan ini adalah antenna kami memiliki bandwidth yang sangat lebar yaitu 133% (UWB) yang dapat bekerja di frekuensi 2-10 GHz dan dengan diberikannya struktur corrugated secara melintang di pinggir elemen antenna dengan digabungkan dengan struktur truncated maka mutual coupling antara elemen antenna dapat dikurangi dan dapat memperbaiki performansi pola radiasi. Peningkatan perbaikan pola radiasi terlihat pada gain yang meningkat dan side lobe level yang berkurang. Dengan pemberian struktur ECT didapatkan hasil bahwa isolasi antenna yang semakin meningkat atau mutual coupling yang semakin berkurang serta performansi pola radiasi yang meningkat maka antenna array dapat digunakan untuk aplikasi sistem komunikasi antenna array ultra wide band yang beroperasi di S dan C band.

Penelitian kami telah diterima dan di publish di jurnal *Antenna Wireless and Propagation Letters* yang merupakan jurnal Q1 dengan H indeks 89

Elemen antenna Vivaldi Coplanar dengan Corrugated slot yang bekerja di L dan S band

No	Identitas Produk Teknologi	Keterangan
1	Nama Produk Inovasi	Antena Vivaldi Palm Tree Coplanar yang bekerja pada L dan S Band
2	Bidang Fokus*	Teknologi Telekomunikasi
3	Tahun Pengembangan Produk	2018
4	Lembaga	LPPM Universitas Negeri Surabaya
5	Jumlah Anggota	-
6	Inovator	1. Nurhayati. ST.,MT. 2. Alexandre M. De Oliveira 3. Joao F Justo 4. Eko Setijadi., PhD

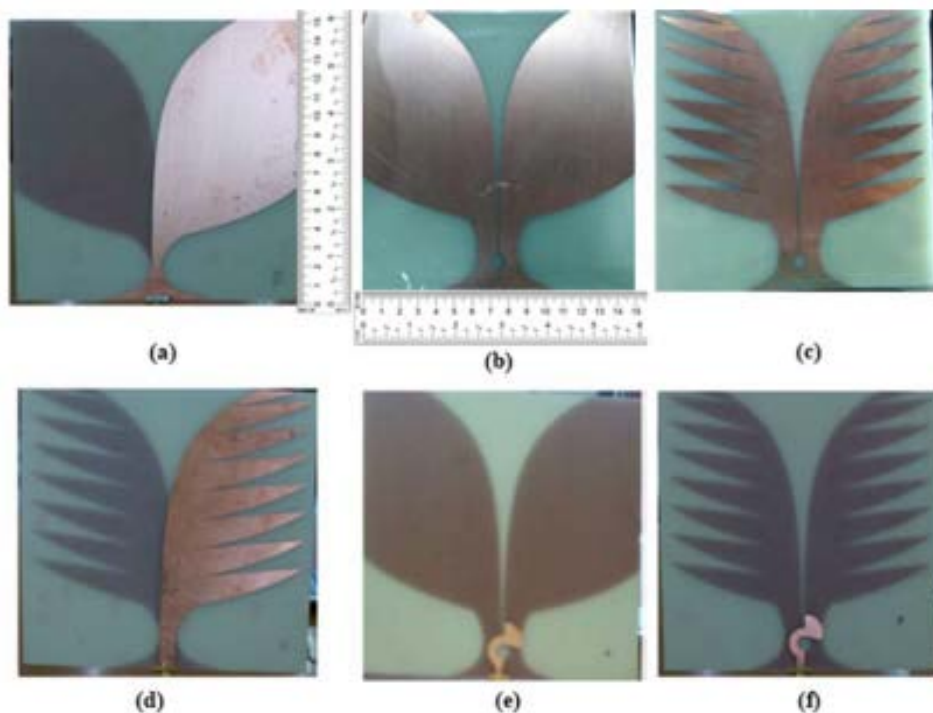


Fig. 11. Fabricated antennas: (a) R-AVA front view, (b) R-CVA front view, (c) R-CVA back view, (d) ESE-AVA front view, (e) ESE-CVA front view, and (f) ESE-CVA back view.

BORANG CAPAIAN LUARAN KEGIATAN TAHUN TERAKHIR PENELITIAN HIBAH DOKTOR 2018 (Tahun I)

Ketua : Nurhayati., ST., MT
 Perguruan Tinggi : Universitas Negeri Surabaya (Unesa)
 Judul : Pengurangan Mutual Coupling Antenna Array Vivaldi Coplanar untuk Aplikasi Telekomunikasi S dan C Band.

Waktu Kegiatan : Tahun ke-1 dari rencana 1 tahun

Luaran yang direncanakan dan capaian tertulis dalam proposal awal:

No.	Luaran yang direncanakan	Capaian (Judul)
1	Publikasi	Ada 2 (dua) judul artikel (sebagai ketua) telah dipublikasi dan disubmit pada: 1. <i>Jurnal Internasional</i> , Q1, Impact factor 3.4500, H Indeks 89: IEEE Antennas and Wireless Propagation Letters. (status publish) 2. <i>Jurnal Internasional</i> , Q2, Impact Factor 1.7500 IET Microwaves Antennas & Propagation (status: submit)

CAPAIAN (Lampirkan bukti-bukti luaran dari kegiatan dengan judul yang tertulis di atas, bukan dari kegiatan penelitian/pengabdian dengan judul lain sebelumnya)

1. PUBLIKASI ILMIAH

Artikel Jurnal Ke-1	
Nama jurnal yang dituju	<i>Jurnal : IEEE Antennas and Wireless Propagation Letters</i>
Klasifikasi jurnal	Jurnal Internasional (p-ISSN: 1536-1225, e-ISSN: 1548-5757)
Impact factor jurnal	3.450
Judul artikel	Mutual Coupling Reduction for UWB Coplanar Vivaldi Array by a Truncated and Corrugated Slot
Status naskah (beri tanda √)	
- Draft artikel	-
- Sudah dikirim ke jurnal	-
- Sedang ditelaah	-
- Sedang direvisi	-
- Revisi sudah dikirim ulang	-
- Sudah diterima	-
- Sudah terbit (proofreading)	√
Artikel Jurnal Ke-1	
Nama jurnal yang dituju	<i>Jurnal : IET Microwaves, Antennas & Propagation</i>
Klasifikasi jurnal	Jurnal Internasional (p-ISSN: 1751-8725, e-ISSN: 1751-8733)
Impact factor jurnal	1.750
Judul artikel	Comparison Study of Palm Tree Coplanar and Antipodal Vivaldi Antennas for L and S Band Applications
Status naskah (beri tanda √)	
- Draft artikel	-
- Sudah dikirim ke jurnal	-

- Sedang ditelaah	√
- Sedang direvisi	-
- Revisi sudah dikirim ulang	-
- Sudah diterima	-
- Sudah terbit (proofreading)	-

2. BUKU AJAR

Buku ke-1	
Judul :	
Penulis :	
Penerbit :	

Jika masih ada buku ke-2 dan seterusnya, uraikan pada lembar tambahan

3. PEMBICARA PADA PERTEMUAN ILMIAH (SEMINAR/SIMPOSIUM)

	Nasional	Internasional
Judul makalah (sebagai Ketua)		-
Nama pertemuan ilmiah		-
Tempat pelaksanaan		-
Waktu pelaksanaan		-
- Draft makalah	-	-
- Sudah dikirim	-	-
- Sudah direview	-	-
- Sudah dilaksanakan	-	-

Jika masih ada pertemuan ke-2 dan seterusnya, uraikan pada lembar tambahan

4. SEBAGAI PEMBICARA KUNCI (KEYNOTE SPEAKER)

	Nasional	Internasional
- Bukti undangan dari Panitia	-	-
- Judul makalah	-	-
- Penulis	-	-
- Penyelenggara	-	-
- Waktu pelaksanaan	-	-
- Tempat pelaksanaan	-	-
- Draft makalah	-	-
- Sudah dikirim	-	-
- Sedang direview	-	-
- Sudah dilaksanakan	-	-

5. UNDANGAN SEBAGAI VISITING SCIENTIST PADA PERGURUAN TINGGI LAIN

	Nasional	Internasional
- Bukti undangan	-	-

- Perguruan tinggi pengundang	-	-
- Lama kegiatan	-	-
- Kegiatan penting yang dilakukan	-	-

Jika masih ada undangan ke-2 dan seterusnya, uraikan pada lembar tambahan

6. CAPAIAN LUARAN LAINNYA

HKI	
TEKNOLOGI TEPAT GUNA	-
REKAYASA SOSIAL	-
JEJARING KERJA SAMA	-
PENGHARGAAN	-
LAINNYA (Tuliskan)	<ol style="list-style-type: none"> 1. Antenna array Coplanar with Truncated and Corrugated bekerja pada S dan C Band 2. Elemen Antenna Conventional Coplanar Vivaldi C-CVA, Regular-CVA, Regular Antipodal Vivaldi Antenna dan Exponential Slot Edge Vivaldi Antenna- AVA yang bekerja pada L dan S Band

Jika luaran yang direncanakan tidak tercapai, uraikan alasannya:

-

Surabaya, 13 Nopember 2018
Ketua,



Nurhayati., ST., MT
NIP. 197812042006042002

Laporan - penelitian yang berjudul

Mutual Coupling Reduction for a UWB Coplanar
Vivaldi Array by a Truncated and Corrugated Slot

Anggota tim peneliti sebagai berikut:

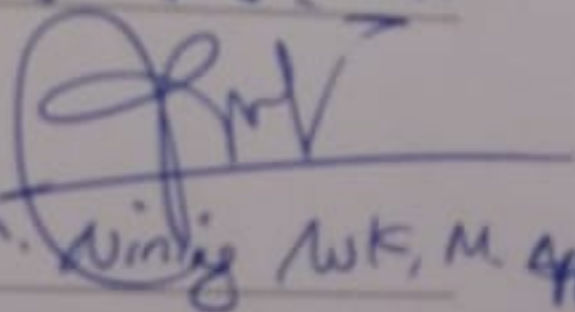
Nurhayati

Laporan akhir segera direvisi sesuai
panduan.

Segera lakukan program ujian untuk
mendapatkan gelar doktor.

Surabaya,
Reviewer,

5 Des 2018



Dr. Nining Luk, M. Appl. S.

NIP

LEMBAR PEMBAHASAN

Laporan : - penelitian yang berjudul

Pengurangan Mutual Coupling Antena Array Vivaldi Coplanar Untuk Aplikasi Telekomunikasi S & C Band

Dengan tim peneliti sebagai berikut:

1. Herhayati, S.T.M.T.
- 2.
- 3.
- 4.

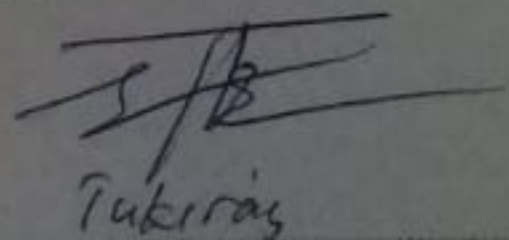
Catatan:

o Laporan tugas terakhir → lampirkan artikel lengkap.

o Bab 6. Rencana Tahapan Berikutnya → tidak perlu.

o

Surabaya, 5-12-2018
Reviewer,



NIP 196602081992031002