EQUIVALENT WIRE MODEL AND TRAVELLING WAVE MODE METHOD TO ANALYSE THE RADIATED EMISSION OF A BENT MICROSTRIP LINE

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This thesis is especially dedicated to my beloved parents.

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ABSTRACT

Nowadays, expeditious developments in the electrical and electronic territory due to endless demands from the markets have driven the operation frequency of the system into the gigahertz region. This had evolved into a more effectual-performance system, but also inflicts a lot of difficulties to the designers, for examples Electromagnetic Interference (EMI) problem and Signal Integrity (SI) issue. The integrity of circuit layout is inevitably compromised by bifurcated traces for examples T-junctions, Y-junctions, right-angle bends or left-angle-bends and steps planar transmission lines in order to fulfil the needs of a denser printed circuit boards. However, bifurcation often induces impedance mismatching resulting in reflection, radiated emission and power loss. This research is to investigate the radiated emission of 0^{o}, 45^{o} and 90^{o} bent microstrip lines by using an analytical formulation followed by computer simulation and experimental measurements for validation purposes. The novelty of this research is the implementation of travelling wave mode (TWM) method on bent microstrip line by adopting the equivalent wire model. The reliability of the formulation is proven from the agreement between the analytical results and computer simulation, especially in predicting the E_{ϕ} component. The analytical results clearly showed the significance of the bent in altering the radiation pattern of the microstrip line. Increasing the operating frequency and microstrip's width tend to produce more emission. One of the electric field components, E_{θ} is almost symmetrical with respect to the *bent angle/2* line on the plane of the microstrip line, while the E_{ϕ} component radiates strongly into the *bent angle + bent angle/2* direction. The magnetic field on the bent microstrip line experiences an abrupt change at the location of the bent. This change becomes apparent as the bent angle increases. Future work should focus on improving the analytical formulation so that it can predict the E_{θ} component with higher accuracy. Furthermore, effort can also be made on generating algorithm which takes into consideration the composite electric field radiation of all the bents on a practical printed circuit board.

ABSTRAK

Pada zaman yang begitu pesat membangun terutamanya dalam bidang elektrik dan elektronik, permintaan yang semakin melambung dari pasaran telah menaikkan operasi frekuensi sistem elektronik ke tahap gigahertz. Ini telah memajukan sistem kepada yang lebih cekal dan effektif, tetapi ia juga mendatangkan kesukaran dan cabaran kepada para pereka bentuk litar seperti kesan-kesan gangguan elektromagnet (EMI) dan isu-isu kualiti isyarat (SI). Tidak dapat dinafikan, kewujudan pelbagai cabangan seperti cabangan-T, cabangan-Y, pembengkokkan kekanan bersudut tegak atau pembengkokkan kekiri bersudut tegak merupakan satu fenomena yang tidak dapat dielakkan semasa mereka litar elektrik yang lebih padat. Walaubagaimanapun, dwi cabang sering kali mengakibatkan galangan tak sepadan yang menghasilkan pantulan, pancaran tersinar dan kehilangan kuasa. Dwi cabang yang mana dipertimbangkan sebagai fenomena ketidakselanjaran adalah salah satu penyumbang kepada ganguan kualiti isyarat. Kajian ini adalah bertujuan untuk mengkaji pengagihan arus serta radiasi medan elektrik bagi satu surihan garisan jalur mikro yang dibengkok pada 0^{o}, 45^{o} dan 90^{o} menggunakan analisis perumusan diikuti oleh simulasi komputer dan pengukuran eksperimen untuk tujuan pengesahan. Pembahruan di dalam penyelidikan ini adalah pelaksanaan kaedah mod gelombang bergerak (TWM) pada garis surihan jalur mikro bengkok dengan mengadaptasikan model wayar setara. Kesahihannya terbukti apabila keputusan analisis perumusan menghampiri keputusan yang diperolehi melalui simulasi computer terutamanya bagi E_ϕ komponen. Keputusan-keputusan analisis menunjukkan dengan jelas bahawa kewujudan bengkok pada garis jalur mikro telah mengubah corak pancaran elektriknya. Selain itu, adalah didapati bahawa peningkatan operasi frekuensi dan lebar jalur mikro akan meningkatkan pancaran elektriknya. Salah satu komponen medan elektrik, E_θ pada satah jalur mikro adalah sentiasa simetri pada arah *sudut bengkok /2*, manakala komponen medan elektrik yang lain, E_ϕ terpancar dengan banyak ke arah *sudut bengkok + sudut bengkok /2*. Pengagihan arus pada garisan jalur mikro bengkok mengalami perubahan yang ketara terutamanya pada bahagian pembengkokkan. Perubahan ini semakin ketara apabila sudut pembengkokkan

dipertingkatkan. Kajian lanjutan seharusnya memfokus pada penambahbaikkan analisis perumusan yang sedia ada ini supaya dapat mengira komponen E_θ dengan lebih tepat. bukan itu sahaja, focus juga boleh diletakan untuk menghasilkan algoritma baru yang mempertimbangan gabungan pancaran medan elektrik bagi semua pembengkokkan jalur mikro di atas papan litar tercetak.

TABLE OF CONTENTS

CHAPTER	CONTENTS	PAGE
	THESIS STATUS CONFIRMATION	
	SUPERVISOR'S CONFIRMATION	
	TITLE	i
	TESTIMONY	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF FIGURE	xi
	LIST OF SYMBOLS/ABREVIATIONS	xvi
	LIST OF APPENDICES	xix
CHAPTER I	INTRODUCTION	
	1.1 General	1
	1.2 Problem Statement	6
	1.3 Aim of Research	7
	1.4 Objectives	7
	1.5 Scopes of Research	8
	1.6 Importance of Research	9
	1.7 Summary	9
	1.8 Organisation of the Thesis	10

CHAPTER II	**REVIEW OF THE METHODS OF ANALYSIS**		
	2.1	Introduction	12
	2.2	Microstrip Transmission Structure	12
	2.3	Image Theory	15
	2.4	The Transmission-Line Equations	18
	2.5	Derivation of Transmission-line Equations	21
	2.6	Characteristic Impedance	22
	2.7	Propagation Constant	23
	2.8	The Transmission Matrix	23
	2.9	Transmission Line Effect	25
	2.10	Microstrip Discontinuities	26
	2.11	Compensated Microstrip Discontinuities	27
	2.12	Review of Important Research Works	28
	2.13	Summary	40
CHAPTER III	**METHODOLOGY**		
	3.1	Review of Procedures	41
	3.2	Analytical Formulation	44
		3.2.1 Forward-Backward Travelling Wave Mode Method	44
		3.2.2 Cascaded Uniform Transmission Line Model	52
		3.2.3 Expanded Hertzian Dipole Model	57
		3.2.4 Equivalent Wire Model	62
	3.3	Configuration of Computer Simulation – MICROWAVE STUDIO®	65
		3.3.1 Modelled Microstrip Line	65
	3.4	Experimental Measurements	70
	3.5	Summary	73
CHAPTER IV	**RESULTS AND DISCUSSIONS**		
	4.1	Analytical Investigation	75

4.1.1 Effect of Termination Scheme 78
4.1.2 Effect of Operating Frequency 84
4.1.3 Effect of The Trace's Width 89
4.2 Computer Simulation 94
4.2.1 0^o Bent Microstrip Line 94
4.2.2 45^o Bent Microstrip Line 96
4.2.3 90^o Bent Microstrip Line 98
4.3 Discussion on Electric Field Radiation 100
4.4 Measurements Results 105
4.3.1 0^o Bent Microstrip Line 105
4.3.2 45^o Bent Microstrip Line 107
4.3.3 90^o Bent Microstrip Line 109
4.5 Summary 111

CHAPTER V CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK
5.1 Conclusions 114
5.2 Suggestions for Future Work 116

REFERENCES 117

APPENDICES 122

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Aspects of EMC	2
1.2	EMC Sub-problems	3
1.3	Mechanisms of Electromagnetic Interference.	4
2.1	Conceptual Evolution of a Microstrip from a Two-Wire Line	14
2.2	TE Mode and TM Mode.	15
2.3	Image of a Vertical Electric Dipole	16
2.4	Image of a Horizontal Dipole	17
2.5	Induction of (a) electric field and (b) magnetic field on the transmission line.	18
2.6	A transmission line consists of per-unit-length inductance, *l*, and per-unit-length capacitance, *c*	19
2.7	The telegrapher's equations are based on infinitely cascaded circuit model.	20
2.8	The per-unit-length model for use in deriving the transmission-line equation.	21
2.9	Two-port circuit that can be represented by a four-element transmission matrix	24
2.10	Cascaded circuits may be represented by multiplying their transmission matrices	25
2.11	Configuration for Compensated (a) Step-in width, (b) right-angled bends, and (c) T-junction	28
3.1	Flowchart of the research work	43
3.2	Source and observation points on the line	47
3.3	Cascaded segments of approximate uniform transmission line	53
3.4	Illustration of the junction and segment on the cascaded uniform transmission line.	53
3.5	Conventional Hertzian dipole model.	57

3.6	Coordinate system to calculate the electric fields from a bent transmission line with bent angle ϕ_o.	58
3.7	The microstrip structure and the equivalent wire model.	63
3.8	(a) 0^o, (b) 45^o and (c) 90^o of bent microstrip line modelled by using MICROWAVE STUDIO®. (d) Ground plane	66
3.9	1 W peak-to-peak Gaussian signal as the input source.	67
3.10	Mesh view of a straight microstrip line.	69
3.11	Microstrip lines connected with SMA connectors and terminated with SMT resistors.	70
3.12	Experiment Setup.	71
3.13	Magnetic near field probe and spectrum analyzer.	72
3.14	Block diagram of the experimental setup.	72
3.15	Movement of magnetic near field probe.	73
4.1	Layout of the 90^o bent microstrip line.	75
4.2	Characteristic impedance of microstrip line with different bent angle.	77
4.3	Propagation constant of microstrip line with different bent angle.	77
4.4	2D Radiation pattern of a straight microstrip line with different terminations operating in 1 GHz. $\theta = 85^o$ plane. Results are calculated based on analytical formulation.	80
4.5	2D Radiation pattern of a straight microstrip line with different terminations operating in 1 GHz. $\theta = 45^o$ plane. Results are calculated based on analytical formulation.	80
4.6	2D Radiation pattern of a 45^o bent microstrip line with different terminations operating in 1 GHz. $\theta = 85^o$ plane. Results are calculated based on analytical formulation.	81
4.7	2D Radiation pattern of a 45^o bent microstrip line with different terminations operating in 1 GHz. $\theta = 45^o$ plane. Results are calculated based on analytical formulation.	81
4.8	2D Radiation pattern of a 90^o bent microstrip line with different terminations operating in 1 GHz. $\theta = 85^o$ plane. Results are calculated based on analytical formulation.	82
4.9	2D Radiation pattern of a 90^o bent microstrip line with different terminations operating in 1 GHz. $\theta = 45^o$ plane. Results are calculated based on analytical formulation.	82
4.10	Three-dimensional radiation pattern of bent microstrip lines with different termination scheme operating in 1 GHz. Results are calculated based on analytical formulation. (a) E_θ component of a straight microstrip line when it is matched terminated. (b) E_ϕ component of a straight microstrip line when it is matched terminated. (c) E_θ component of a 45^o bent microstrip line when it is unmatched terminated.	83

(d) E_ϕ component of a 45° bent microstrip line when it is unmatched terminated.
(e) E_θ component of a 90° bent microstrip line when it is open terminated.
(f) E_ϕ component of a 90° bent microstrip line when it is open terminated.

4.11 2D Radiation pattern of a straight microstrip line with matched termination operating in 2 different frequencies. θ = 85° plane. Results are calculated based on analytical formulation. 85

4.12 2D Radiation pattern of a straight microstrip line with unmatched termination operating in 2 different frequencies. θ = 45° plane. Results are calculated based on analytical formulation. 85

4.13 2D Radiation pattern of a 45° bent microstrip line with matched termination operating in 2 different frequencies. θ = 85° plane. Results are calculated based on analytical formulation. 86

4.14 2D Radiation pattern of a 45° bent microstrip line with unmatched termination operating in 2 different frequencies. θ = 45° plane. Results are calculated based on analytical formulation. 86

4.15 2D Radiation pattern of a 90° bent microstrip line with matched termination operating in 2 different frequencies. θ = 85° plane. Results are calculated based on analytical formulation. 87

4.16 2D Radiation pattern of a 90° bent microstrip line with unmatched termination operating in 2 different frequencies. θ = 45° plane. Results are calculated based on analytical formulation. 87

4.17 Three-dimensional radiation pattern of bent microstrip line with different termination scheme operating in 2 GHz. Results are calculated based on analytical formulation. 88
(a) E_θ component of a straight microstrip line when it is unmatched terminated.
(b) E_ϕ component of a straight microstrip line when it is unmatched terminated.
(c) E_θ component of a 45° bent microstrip line when it is matched terminated.
(d) E_ϕ component of a 45° bent microstrip line when it is matched terminated.
(e) E_θ component of a 90° bent microstrip line when it is matched terminated.
(f) E_ϕ component of a 90° bent microstrip line when it is matched terminated.

4.18 2D Radiation pattern of a straight microstrip line with different width terminated in matched termination, operating in 1 GHz. θ = 85° plane. Results are calculated based on analytical formulation. 90

4.19 2D Radiation pattern of a straight microstrip line with different 90

	width terminated in open termination, operating in 1 GHz, operating in 1 GHz. θ = 45 ° plane. Results are calculated based on analytical formulation.	
4.20	2D Radiation pattern of a 45° bent microstrip line with different width terminated in matched termination, , operating in 1 GHz. θ = 85 ° plane. Results are calculated based on analytical formulation.	91
4.21	2D Radiation pattern of a 45° bent microstrip line with different width terminated in open termination, operating in 1 GHz. θ = 45 ° plane. Results are calculated based on analytical formulation.	91
4.22	2D Radiation pattern of a 90° bent microstrip line with different width terminated in matched termination, operating in 1 GHz. θ = 85 ° plane. Results are calculated based on analytical formulation.	92
4.23	2D Radiation pattern of a 90° bent microstrip line with different width terminated in open termination, operating in 1 GHz. θ = 45 ° plane. Results are calculated based on analytical formulation.	92
4.24	Three-dimensional radiation pattern of bent microstrip line with strip's width = 5mm operating in 1 GHz. Results are calculated based on analytical formulation. (a) E_θ component of a straight microstrip line when it is open terminated. (b) E_ϕ component of a straight microstrip line when it is open terminated. (c) E_θ component of a 45° bent microstrip line when it is open terminated. (d) E_ϕ component of a 45° bent microstrip line when it is open terminated. (e) E_θ component of a 90° bent microstrip line when it is unmatched terminated. (f) E_ϕ component of a 90° bent microstrip line when it is unmatched terminated.	93
4.25	Comparisons between analytical and simulation results. The straight microstrip line is operating in 2 GHz with matched termination. θ = 45° plane.	95
4.26	Comparisons between analytical and simulation results. The straight microstrip line is operating in 1 GHz with unmatched termination. θ = 85° plane.	95
4.27	Comparisons between analytical and simulation results. The straight microstrip line is operating in 1 GHz with open termination. θ = 45° plane	96
4.28	Comparisons between analytical and simulation results. The 45° microstrip line is operating in 1 GHz with matched termination. θ = 45° plane.	97
4.29	Comparisons between analytical and simulation results. The 45° microstrip line is operating in 2 GHz with unmatched	97

	termination. θ = 45° plane.	
4.30	Comparisons between analytical and simulation results. The 45° microstrip line is operating in 1 GHz with open termination. θ = 85° plane.	98
4.31	Comparisons between analytical and simulation results. The 90° microstrip line is operating in 2 GHz with matched termination. θ = 85° plane	99
4.32	Comparisons between analytical and simulation results. The 90° microstrip line is operating in 1 GHz with unmatched termination. θ = 45° plane.	99
4.33	Comparisons between analytical and simulation results. The 90° microstrip line is operating in 2 GHz with open termination. θ = 45° plane.	100
4.34	Different configurations of transmission structure using MICROWAVE STUDIO®.	103
4.35	Comparison of radiation pattern of different transmission structure operating in 1 GHz with matched termination.	103
4.36	Comparison of radiation pattern of different transmission structure operating in 2 GHz with matched termination.	104
4.37	Magnetic field orientation of the 0° microstrip line and the placement of magnetic near field probe.	106
4.38	$H_{y'}$ component for a 0° bent microstrip line.	106
4.39	Magnetic field orientation of the 45° microstrip line and the placement of magnetic near field probe.	108
4.40	$H_{y'}$ and H_x component for a 45° bent microstrip line.	109
4.41	Magnetic field orientation of the 90° microstrip line and the placement of magnetic near field probe.	110
4.42	$H_{y'}$ and H_x component for a 90° bent microstrip line.	111
B-1	Illustration of distance between source point and observation point when $\phi_o = 0$.	126
B-2	Illustration of distance between source point and observation point when $\phi_o = 45^o$.	127
B-3	Illustration of distance between source point and observation point when $\phi_o = 90^o$.	128
D-1	Illustration of sections of transmission line.	135
E-1	Coordinate system of the dipole.	142

LIST OF SYMBOLS/ ABBREVIATIONS

E	-	Electric Field Intensity (V/m)
H	-	Magnetic Field Intensity (A/m)
f	-	Frequency (Hz)
Δz	-	Smallest Length of Transmission line, (m)
l	-	Per-unit-length Inductance, (henry)
c	-	Per-unit-length Capacitance, (farad)
r	-	Per-unit-length Resistance, (Ω)
g	-	Per-unit-length Conductance, (MHO)
Z	-	Impedance, (Ω)
γ	-	Propagation Constant (m^{-1})
ω	-	Angle Frequency (rad/s)
ψ	-	Scalar Potential, (volt)
A	-	Vector Potential, (Akg/m)
ε	-	Relative Permittivity (F/m)
ε_0	-	Relative Permittivity of Free-Space (8.854 x 10^{-12}F/m)
ε_r	-	Relative Permittivity of Material (dimensionless)
μ	-	Relative Permeability (H/m)
μ_0	-	Relative Permeability of Free-Space (μ_0=4πx 10^{-7}H/m)
μ_r	-	Relative Permeability of Material (dimensionless)
λ	-	Wavelength (m)
v	-	Velocity (m/s)
c	-	Velocity of light in free-space (2.998 x 10^{8} m/s)
k	-	Wavenumber (rad/m)
η	-	Intrinsic Impedance (Ω)

A_f	-	Forward Modal Current Constant Amplitude
A_b	-	Backward Modal Current Constant Amplitude
ξ	-	Length along the Microstrip Line, (m)
ϕ_o	-	Bent angle (degree)
h	-	Height of the Microstrip Line, (mm)
w	-	Width of the Microsrip Line, (mm)
t	-	Thickness of the Microstrip Line, (mm)
r_{eq}	-	Equivalent Radius of the Microstrip Line, (mm)
$f_{g,stat}$	-	Frequency Limit Based on Equivalent Wire Model, (GHz)
EMC	-	Electromagnetic Compatibility
EMI	-	Electromagnetic Interference
PCB	-	Printed Circuit Board
IC	-	Integrated Circuit
SI	-	Signal Integrity
EM	-	Electromagnetic Simulation
FDTD	-	Finite Difference Time Domain
MoM	-	Method of Moment
IEC	-	International Electrotechnical Commission
FCC	-	Federal Communications Commission's
CISPR	-	International Special Committee for Radio Interference
MIC	-	Microwave Integrated Circuit
TEM	-	Transverse Electromagnetic
TE	-	Transverse Electric
TM	-	Transverse Magnetic
HE	-	Hybrid Mode
RF	-	Radio Frequency
MMICs	-	Monolithic Microwave Integrated Circuits
EFIE	-	Electric Field Integral Equation
EWMoM	-	Equivalent-wire Moment of Method
TWM	-	Traveling Wave Mode

NTL - Non-uniform Transmission-line

LIST OF APPENDICES

APPENDIX	ITEM	PAGE
A	List of Published Papers	122
B	Distance Between the Observation Point and Source Point Based on the Concept of Trigonometry	124
C	Derivation of Forward Backward Impedance and Forward Backward Admittance with the Adoption of Forward Backward Modal Current	128
D	Derivation of cascaded Uniform Transmission Line Matrix	133
E	Derivation of Expanded Hertzian Dipole Formulation	140

CHAPTER I

INTRODUCTION

1.1 General

The strategy of marketing electrical and electronic products on time at the lowest cost is a priority for many manufacturers. But as the operating frequency increases, Electromagnetic Compatibility (EMC) requirements during the design cycle and development must be addressed accordingly. EMC is defined as the ability of device, equipment, or system to function satisfactorily in its environment without introducing intolerable electromagnetic disturbance to anything in that environment [1].

Consideration for EMC is now crucial for all electrical and electronic equipments from the early stage of designing until production. New electronic products which perform critical function will become futile if the devices do not meet legal requirements in the countries they are to be marketed. Consequently, Malaysian manufacturers are concerned about the EMC requirement in order to penetrate important international markets such as United States of America, European Union and Japan.

A system is classified as electromagnetically compatible if it satisfies three criteria, which are [2]:

i. It does not cause interference with other systems.
ii. It is not susceptible to emissions from other systems.
iii. It does not cause interference with itself.

EMC can be divided further into four aspects based on the mechanism of electromagnetic energy transfer. They are radiated emissions, radiated immunity, conducted emissions and conducted immunity as shown in Figure 1.1 and elaborated in Figure 1.2.

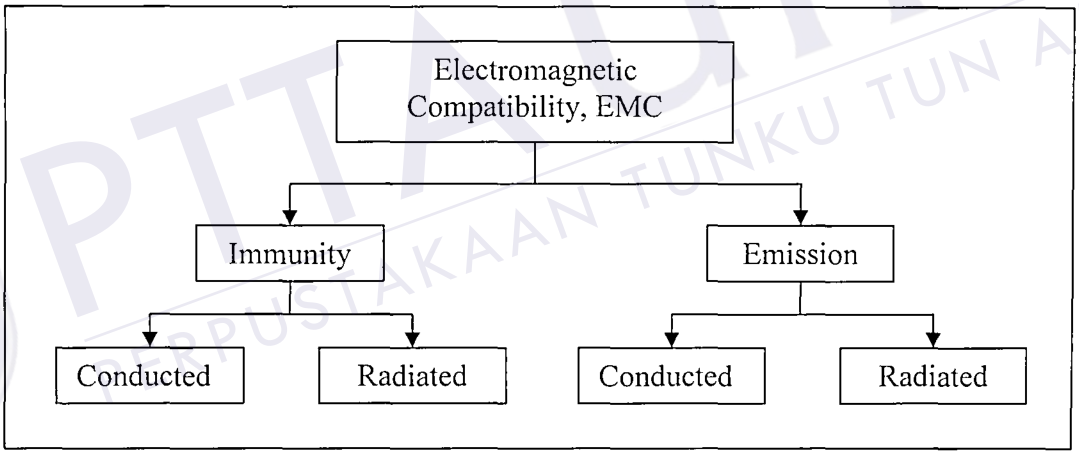
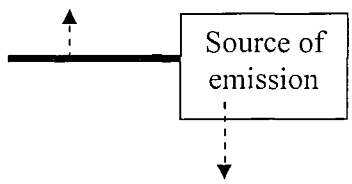
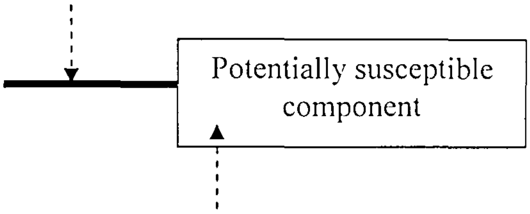


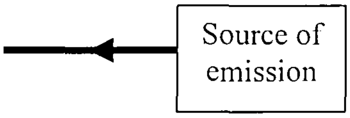
Figure 1.1: Aspects of EMC.



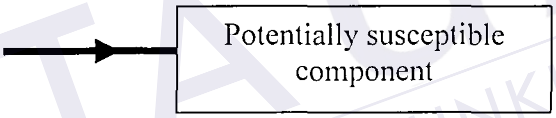
Radiated Emission – emission of electromagnetic field from the power, or signal line and the equipments to the environment (air).



Radiated Immunity – the ability of a device to perform without degradation in the presence of an electromagnetic disturbance from the environment.



Conducted Emissions – emission of electromagnetic field to external world via power or signal line.



Conducted Immunity– the ability of the device to handle the electromagnetic disturbance originated from power or signal line without degradation of its performance.

Figure 1.2: EMC sub-problems.

The emission of electromagnetic energy can be broadly classified into two aspects. Radiated emission is the electromagnetic field radiation through the air and conducted emission is the current conduction through the power or signal line. On the other hand, the immunity of a device is classified into two aspects. Radiated immunity is the ability of the device to perform in the presence of electromagnetic disturbance from the environment and conducted immunity is the ability of the device to perform although there is electromagnetic disturbance originated from power or signal line. A good EMC design must be able to control the emission or to improve the immunity of equipment so as to comply with relevant national and international standards.

Generally, electromagnetic interference (EMI) which is a subset of EMC, is the electromagnetic disturbance which causes the degradation of the performance of a device, or system. The mechanisms of electromagnetic interference are shown in Figure 1.3 and can be explained as follows:

(1) Direct radiation from source to receptor.
(2) Direct radiation from source picked up by the electrical power cables or the signal/control cables connected to the receptor, which reaches the receptor via conduction.
(3) Electromagnetic interference radiated by the electrical power, signal, or control cables of the source and the radiation is captured by the receptor.
(4) Electromagnetic interference directly conducted from the source to the receptor via common electrical power supply ground.

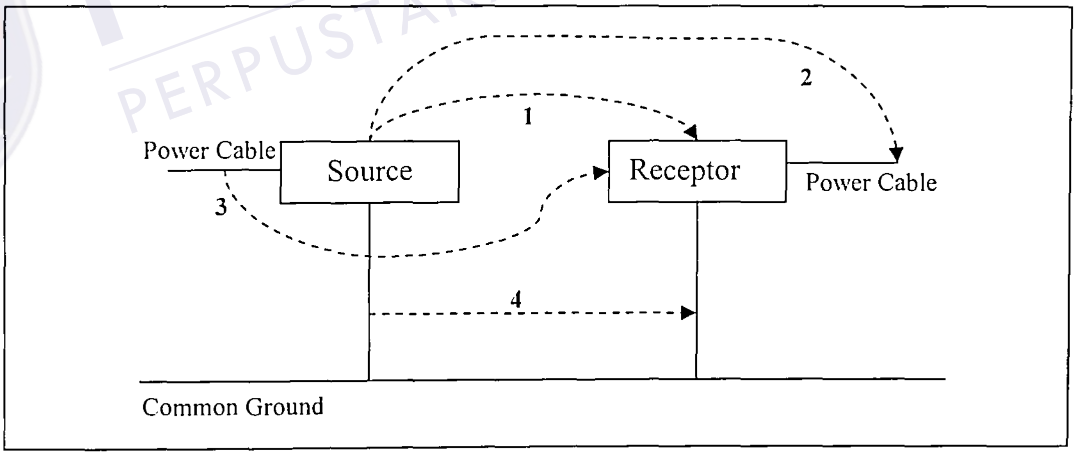


Figure 1.3: Mechanisms of electromagnetic interference.

Truthfully, some important approaches can be implemented to reduce the EMI effects such as reducing the loop area, improving the grounding system, filtering, and proper trace routing. However, to eliminate all possibilities of EMI by all those aforementioned could result in higher cost to industry and could delay new technologies from being implemented.

A printed circuit board (PCB) is an integrated part of any equipment or systems because circuits and components are located on it to perform a specific task. It is ordinary to have bifurcated traces such as T-junction, Y-junction, right-angle bends or left-angle-bended and steps planar transmission lines on nearly every PCB in the effort to produce faster and smaller system. Unfortunately, the changing of the shape and size of the microstrip trace affects its impedance which can induce mismatching in between two sections of the microstrip line. Consequently, this generates unwanted electromagnetic radiation. Since it is usual to have more than one single bifurcation on a PCB, the total radiation effects should be paid attention. Waiting until the end of the development cycle to find out whether a product passes regulatory agency requirements can be an expensive gamble. Failing the requirement will result in costly retrofitting. A successful design engineer must understand various radiation mechanisms and able to implement various techniques to ensure compliance of the system to EMC standards before the products are produced.

The use of electromagnetic simulation software in the design and optimisation of circuit performance is becoming an important tool in providing guidance towards actual design and production to achieve compliance to EMC standard before the products are marketed. Effective simulation software enables the engineers to complete the design in shortest time without sacrificing the accuracy. The actual operation behind the simulation software involves a lot of modelling approach based on the numerical method, for example, finite difference time domain (FDTD), method of moment (MoM), and finite element method. Efficient modelling approach which results in relatively faster and providing acceptably accurate results is always a challenge to the researches in order to further improve the reliability of the existing simulation techniques.

It should be realised that total reliance on commercial software, which is based on certain numerical method can implicitly retrench some important findings which the circuit designers should detect and utilise in their circuit design. Consequently, when dealing with high speed circuit design, it is desirable to apply the analytical approach in solving some of the fundamental aspects such as current distribution and emission. The work presented in this thesis is to explore a novel and accurate analytical approach to determine the radiated emissions of 0^{o}, 45^{o}, and 90^{o} bent microstrip lines.

1.2 Problem Statement

Recently, as the demands from the markets are increasing endlessly, in order to enhance the product so it can perform faster and more intelligently, not only the clock frequency increases but also the density of the circuits. Therefore, issues regarding the EMI start to receive attention from the circuit designers.

Among all of the EMI sources, the radiation from the bifurcations has been realized since the integrity of circuit layout is inevitably compromised by bifurcated traces (T-junction, Y-junction, right-angle bends or left-angle-bended and steps planar transmission lines). This phenomenon often results in the reflection and mismatching if the impedance of the bifurcated traces is not known accurately. Since there is not only one bifurcation exist in the printed circuit design, radiation from PCB will definitely becoming a critical issue and will definitely degrade the performance of the system in achieving the compliances of EMC regulation.

Hence, the prediction and reduction of EMI are important so that the performance of electronic products can be improved to suit the international standard. The prediction of the radiation is frequently assisted by electromagnetic

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