



UNIVERSITI PUTRA MALAYSIA

**DESIGN OF GALLIUM PHOSPHATE SURFACE ACOUSTIC WAVE
RESONATOR USING FINITE ELEMENT METHOD**

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**DESIGN OF GALLIUM PHOSPHATE SURFACE ACOUSTIC WAVE
RESONATOR USING FINITE ELEMENT METHOD**

By

SAYED ALIREZA MOUSAVI

Thesis Submitted to the School of graduate Studies, University Putra Malaysia, in
Fulfillment of Requirements for the Degree of Master of Science

March 2009



DEDICATION

To my Mother, who her love and compassion endlessly pours on me

To my Father, who his words and support constantly encourages me

To my lovely sisters, Baharak and Safoora

And to all my Friends, specially Mahmood who warmly helped me in everything



Abstract of thesis presented to the senate of University Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

**Design of Gallium Phosphate Surface Acoustic Wave Resonator
Using Finite Element Method**

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March 2009

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The research into Surface Acoustic Wave (SAW) devices began in the early 1970s and led to the development of high performance, small size, rigorous and high reproducibility devices. SAW devices have been recognized for their versatility and efficiency in controlling and processing of electrical signals. Much research has now been done on the application of such devices to consumer electronic, communication systems and process function, such as delay lines, filters, resonator, and pulse compressors.

The use of novel material, such as Gallium phosphate (GaPO_4), extends the operating temperature of the SAW elements. In this thesis SAW devices based on this new material, operating at resonance frequency of 433.92 MHz been studied for passive wireless application. The SAW devices consist of interdigital transducer (IDT) with 1.4 μm finger gap ratio of 1:1 of platinum and under-layer of chromium metallization. A modeling using lumped equivalent circuit (LEC) of the device and finite element



modeling (FEM) was done. The frequency responses of device were simulated by S-parameter and impedance.

The impedance was used to study the mass loading effect of the Platinum electrodes of the SAW devices. The analysis of the result shows that the mass loading affects the resonant frequency of the SAW device. Furthermore, the results show that FEM approach is more precise than LEC for design and simulation of SAW resonator.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

**Rekaan Dan Analisa Simulasi Resonator Gelombang Akustik Permukaan Bagi
Applikasi Tanpa Wayar**

Oleh

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Kajian berkenaan peranti gelombang akustik permukaan (SAW) telah bermula seawal tahun 1970an dan membawa kepada perkembangan peralatan pelaksanaan tinggi, bersaiz kecil, tahan lasak dan pengeluaran yang tinggi. Peranti SAW memang telah dikenali dengan kecekapan dan serba-bolehnya di dalam mengawal dan memproses signal elektrik. Sehingga kini, banyak kajian yang telah dilakukan dalam pelaksanaan yang berkaitan dengan peranti elektronik pengguna, sistem komunikasi, dan sistem pemrosesan seperti talian tunda, penapis, resonator dan pemampat denyutan.

Penggunaan bahan baru seperti Gallium phosphate (GaPO_4) telah menambah baik tahap suhu peranti SAW. Melalui tesis ini, peranti SAW yang menggunakan bahan yang baru ini, beroperasi pada 433.92 MHz frekuensi resonan telah dikaji bagi pelaksanaan tanpa wayar tidak aktif. Peranti SAW ini mengandungi penerima gelombang antara-angka (IDT) dengan $1.4\mu\text{m}$ nisbah jarak jari 1:1 terdiri dari platinum dan lapisan bawah chromium. Model litar persamaan cantuman dan model



pembezaan terhingga (FEM) telah digunakan. Tindakbalas frekuensi peralatan ini telah di simulasikan dengan parameter S dan impedans.

Impedans digunakan untuk mengetahui kesan jisim muatan oleh elektrod platinum peranti SAW. Analisa telah menunjukkan bahawa kesan jisim muatan boleh mempengaruhi resonan peranti tersebut. Bawasanya Keputusan telah menunjukkan bahawa pendekatan FEM adalah lebih tepat dari LEC bagi rekabentuk dan simulasi resonator SAW.

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I certify that a Thesis Examination Committee has met on 3 March 2009 to conduct the final examination of Sayed Alireza Mousavi on his thesis entitled "Design of Gallium Phosphate Surface Acoustic Wave Resonator Using Finite Element Method " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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DECLARATION

I hereby declare that this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutes.

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TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENT	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
LIST OF ABBREVIATIONS	xvii
CHAPTER	
1 INTRODUCTION	1
1.1 Introduction	1
1.2 Problem Statement	7
1.3 Aims and Objectives	9
1.4 Novelty of Project	10
1.5 Layout of Thesis	10
2 REVIEW OF SURFACE ACOUSTIC WAVE	12
2.1 Classification of Acoustic Device	14
2.2 Surface Acoustic Wave Application	14
2.3 Elastic Waves	17
2.4 Acoustic Wave Terminologies	18
2.5 Wave Propagation Equation	21
2.6 Surface Wave Solution in Unbounded Anisotropic Media	23
2.7 Surface Wave Solution in Bounded Media	24
2.7.1 Surface Boundary Condition	25
2.7.2 Displacement Profile for Surface Wave	26
2.8 Surface Wave with Piezoelectric Effect	28
2.9 Important Parameters of SAW	32
2.9.1 Crystal Cut	32
2.9.2 Mass Loading	34
2.9.3 Quality Factor	37
2.10 Material Properties	39
2.10.1 Gallium Phosphate (GaPO ₄)	40
2.10.2 Interdigital Transducer Conductor Material	45
2.11 Review of SAW Base on GaPO ₄	47
2.11 Summary	50
3 METHODOLOGY OF SURFACE ACOUSTIC WAVE RESONATOR	52
3.1 Principles of Device Structure	52
3.1.1 Interdigital Transducer Structure	53
3.1.2 IDT Structure of SAW	55
3.2 Operational Principle and Structure Geometric for One-port SAW Resonator	58
3.3 The Lumped Equivalent Circuit (LEC) Model for One-port SAW	66



3.3.1	Grating and Cavity	70
3.3.2	Parameters of Lump Equivalent Circuit	73
3.4	Finite Element Method (FEM) for One-port SAW Device	74
3.4.1	CAD as Simulator	77
3.4.2	Limitation of Finite Element Method Due to Tools	80
3.4.3	Assumption for Reduced Finite Element Model	81
3.4.4	Modeling of Periodic Structure	82
3.5	Summary	87
4	RESULT AND DISCUSSION OF SURFACE ACOUSTIC WAVE RESONATOR	88
4.1	Result for One-port SAW Resonator Design	88
4.2	The LEC Result for One-port SAW Resonator Modeling	92
4.2.1	Determination of Grating and Cavity	92
4.2.2	Determination Parameters of Lumped Element Circuit	94
4.3	FEM Result for One-port SAW Resonator	97
4.3.1	SAW Propagation on a Free Surface	97
4.3.2	Finite Element Result for Periodic Structure	100
4.3.3	Modal Analysis	101
4.3.4	Harmonic Analysis	104
4.4	Result of Mass Loading in SAW Resonator	109
4.5	Comparison Between LEC and FEM	113
4.6	Validation of Result	114
4.7	Final Stage	116
4.8	Summary	118
5	CONCLUSION AND FUTURE WORK	119
5.1	Conclusion	120
5.2	Future Work	122
	REFERENCES	125
	APPENDICES	131
	BIODATA OF STUDENT	137
	LIST OF PUBLICATIONS	138



LIST OF TABLES

Table		Page
1.1	Frequency Bands Available for ISM Applications [6]	6
2.1	Reduction of Subscript	21
2.2	A Comparison of GaPO ₄ with Other Piezoelectric Materials	41
2.3	Parameters of GaPO ₄ with 11.1° and 5.0° Y-Boule Cut [28, 51], Quartz ST-cut	44
2.4	Constant of GaPO ₄ 5° ((CE _{ij})×e ⁻¹¹)	45
2.5	Summary of Metal Properties Used in the SAW Device	47
2.6	Summary of Turnover Temperature Results [29]	48
2.7	Resonant Frequency vs. Pt Thickness ([29])	49
2.8	Calculated Crystal Cuts Properties of BAW Resonator [59]	49
4.1	Consideration Design for One-port SAW Resonator at 433.92 MHz Centre Frequency	92
4.2	Measure Important Distance Parameter in One-port SAW Resonator	93
4.3	Parameter for Modeling of One-port SAW Resonator	94
4.4	Material Variable Employed in FEM Simulation	102
4.5	Type and Thickness of Metal Used for Metallization from Calculation	109
4.6	Type and Thickness of Metal Used for Metallization from Simulation Process	111
4.7	Type and Thickness of Metal Used for Metallization from Literature [28]	115
4.8	Comparison Simulation Result with Fabricated one	116
4.9	Design 433.92 MHz SAW Device	117



LIST OF FIGURES

Figure	Page
1.1 Stimulus-strain Relationship for Piezoelectric Substrate	3
1.2 IDT in a SAW Device	4
1.3 IDT Periodicity and Wavelength	4
1.4 Schematic Drawing of SAW Delay line and Resonator: (a) Single-port Delay Line; (b) Two-port Delay Line; (c) Two-port Resonator; (d) Single-port Resonator on Piezoelectric Material	5
2.1 IDT in the SAW Device [5]	12
2.2 Bidirectional IDT: Delay Line and Transversal Filter	15
2.3 SAW Resonator with Reflectors	16
2.4 Elastic Waves – Types [17]	18
2.5 Coordinate System for Surface Wave Solution [19]	25
2.6 Longitudinal and Vertical Displacement Variation in Isotropic Media [19]	27
2.7 Longitudinal and Vertical Displacement Variation with Depth. Propagation in 100 Axis of Anisotropic Nickel [19]	28
2.8 Rayleigh Wave with Displacements in the Sagittal Plane [17]	28
2.9 Orientation of Crystal Cut (a) No-rotated (Y-cut) and (b) Singly and Doubly Rotated [24]	33
2.10 Theoretical Variation of Turnover Temperature as a Function of the Rotation Angle for Y-cut Quartz [23]	34
2.11 Piezoelectric Plate Resonator	36
2.12 Unit Cell Crystal Structure of GaPO ₄ [2]	41
2.13 (a) Crystal Singly Rotated Y cuts and (b) 5° Y-Boule Cuts	43
2.14 Design of Two Port SAW Resonators [29]	48
2.15 Resonator Geometry [59]	50
3.1 Design Process Flow Chart for This Project	53



3.2	Top (left) and Cross (right) View of IDT	54
3.3	Schematic Drawing of SAW Delay Line on Piezoelectric Substrate (a) Two-port Delay Line and (b) Single-port Delay Line	56
3.4	Schematic Drawing of SAW Resonator on Piezoelectric Substrate (a) Single-port Resonator and (b) Two-port Resonator	58
3.5	Schematic Representation of a Short-circuited Reflector, a Gap, and an IDT	60
3.6	Metallization Ratio and Electrode Height	61
3.7	Schematic of Synchronous Resonator	62
3.8	Equivalent Circuit for a SAW IDT Using Crossed-field Model [12]	63
3.9	Input/Output Circuit for a SAW Filter in Crossed-Field Model	65
3.10	LEC Simulation Flow Chart for This Project	67
3.11	(a) One-port SAW Resonator. (b) Butterworth-van Dyke Equivalent Circuit [11, 12, 66]	67
3.12	Circuit to Measure S12 and S11	68
3.13	Typical Admittance Curve of One-port SAW Resonator	69
3.14	Important Distance Parameters in Design of a One-port SAW Resonator	71
3.15	FEM Simulation Process Flow Chart for This Project	75
3.16	Discretization of Problem Domain in FEM	76
3.17	Field Approximation by Linear and Quadratic Elements	76
3.18	Typical Dimension of SAW Resonator	80
3.19	Reduction of Model to 2 Dimensions	81
3.20	Periodic Structure in a Resonator	82
3.21	Meshing	85
3.22	Geometry Employed in the Simulation	86
4.1	One-port SAW Resonator with 50 Ω Source Impedance and 50 Ω Load Impedance	89
4.2	Measuring Dielectric Permittivity of GaPO ₄ with 5° Cut-angle at 433.92 MHz	91



4.3	Frequency Response Computation for LEC Circuit	95
4.4	Simulation S11 Values of a 433.92 MHz One-port SAW Resonator	96
4.5	Usage of the Smith Chart to Determine the S11	96
4.6	Displacement at Free Surface Velocity of GaPO ₄ 5° cut with $10l$ Height	99
4.7	Displacement at Free Surface Velocity of GaPO ₄ 5° Cut with $1l_0$ Height	100
4.8	The Mesh Model of SAW Model	101
4.9	Mode Shapes for SAW Propagation	103
4.10	Impedance of SAW Resonator Simulated Using FEM	106
4.11	Total Displacement Contour at 433.92 MHz Showing Minimum and Maximum Displacement	107
4.12	Uy Displacement Contour at 433.92 MHz Showing Minimum and Maximum Displacement Regions	107
4.13	Ux Displacement Contour Showing Minimum and Maximum Displacement Regions	108
4.14	Potential Contour Showing Maximum and Minimum Potential Regions	108
4.15	Profile of Impedance Signal from Resonator in Development Stage Batches	112
4.16	Mass Loading versus Resonance Frequency	112
4.17	Comparison Impedance of SAW Resonator Simulated Using FEM (Dash Line) and (Solid Line) LEC	114
4.18	Profile of Impedance Signal from Resonator in Development Stage Batches	115
4.19	Mass Loading versus Resonance Frequency	116
4.20	The one-port SAW Resonator Layout for the Project	118
5.1	Schematic of One-port SAW Resonator	121
5.2	Schematic of Passive Wireless Sensing Systems	123



LIST OF ABBREVIATIONS

AFM	Atomic Force Microscopic
Au	Gold
AVL	AVL GmbH
BAW	Bulk Acoustic Wave
COM	Coupling Of Mode
Cr	Chromium
CVD	Chemical Vapor Deposition
DOF	Degree Of Freedom
EBL	Electron-beam Lithography
EMI	Electromagnetic Interference
EUV	Extreme Ultraviolet
FEM	Finite Element Model
GaPO₄	Gallium Phosphate
IDT	Interdigital Transducer
IF	Intermediate Frequency
ISM	Industrial, Scientific, and Medical
ITO	Indium Tin Oxide
LEC	Lump Equivalent Circuit
LGS	La ₃ Ga ₅ SiO ₁₄ langasite
LiNbO₃	Lithium niobate
LiTaO₃	Lithium Tantalite
MEMS	Micro-Electro-Mechanical-Systems
MR	Metallization Ratio
Ni	Nickel



PCB	Printed Circuit Board
pC/N	Pico Coulomb over Newton
PDE	Partial Differential Equation
PEC	Parameters of Equivalent Circuitry
ppm	part per million
PMMA	Polymethyl Methacrylate
Pt	Platinum
RF	Radio Frequency
SEM	Scanning Electron Microscope
SAW	Surface Acoustic Wave
SAWR	Surface Acoustic Wave Resonator
Zr	Zirconium
<i>g</i>	beam steering angle
<i>m</i>	Cut angle
<i>K</i>	Coupling factor
<i>t</i>	Delay time
<i>r</i>	Density
<i>C</i>	Stiffness Coefficient
<i>D</i>	Electric displacement
<i>e</i>	Dielectric permittivity
<i>E</i>	Electric field
<i>u₀</i>	Free-surface velocity of SAW
<i>u_m</i>	Metallized velocity of SAW
<i>R</i>	Mass loading in term of ratio



U	Displacement
S	Strain
T	Stress
S	Mass per unit area
Q	Mechanical quality factor
p	Period
J	Phase shift
d	Piezoelectric coefficient
P	Polarization
f_s	Potential
Y	Propagation angle
j	Amplitude of acoustic wave
f	SAW frequency
l	SAW wavelength
q	Temperature
TC	Temperature Coefficient
$G_a(f)$	Radiation conductance
$B_a(f)$	Susceptance conductance
$Y(f)$	Admittance
$Z(f)$	Impedance
w	Acoustic aperture
ω	Angular frequency
N_p	Number of finger-pairs in IDT



N_g	Number of strip in Reflector
L	Length
Γ	Magnitude of reflection coefficient
d	Detuning parameter
C_0	Capacitance/finger pair/ cm
C_r	Series capacitance
C_t	IDT static capacitance
L_r	Series inductance
R_r	Series resistance
d_p	Penetration depth
d_e	Effective cavity length
d_t	IDT distance
d_g	Distance cavity between IDT and reflector
t_g	Delay
c_{12}	Reflectivity
r_s	Strip reflection coefficient
Q	Quality Factor
q	Complex Charge

CHAPTER 1

INTRODUCTION

1.1 Introduction

There has been a tremendous growth in the telecommunications industry over the past few decades with a subsequent increase in demand for high quality and reliable components. Surface Acoustic Wave (SAW) is being used as the main principle component in devices that are successfully applied to electrical signal processing for more than three decades. They are prevalently applied in the telecommunication industry, particularly as band-pass filters both in IF and RF sections, or in resonators due to their perfect performance, high accuracy, and smallness of size.

It is also employed in wireless communication systems due to demanding of higher operating frequencies, wider bandwidth and lower insertion loss. Besides, the high accuracy and crystal stability over time make SAW a suitable device in sensors application (e.g. pressure, temperature, and strain). Consequently, there is an increasing urgent need to improve this device in design, modeling, simulating, techniques of fabrication, and response prediction. The recent advances in sensor technology have become mainly possible by means of microtechnology, particularly with microfabrication technique to produce this device in real-life [1].

With the large number of components that are indispensable to achieve of the required functionality, the electric wiring of spatially distributed systems becomes complex and causes difficulties in system handling and installation. Through the use of wireless systems these problems can be overcome. Wireless systems have been successfully applied to the processing of electrical signals for more than 30 years,



particularly in the telecommunication industry. This was first demonstrated in 1965, by the use of voltage-excited metal-film interdigital transducers on the surface of piezoelectric substrate as described by White and Voltmer [2]. Since then, however, SAW devices have become popular in consumer and communications systems [3, 4]. These wireless systems also can be used as a sensor, where they can communicate by ultrasonic or infrared signals [1].

The advantage of being wireless is that these SAW devices can be placed in unrestricted locations, and therefore making measurement close to its occurrence possible, independent of potentially harsh circumstances, such as in the power plant. At present, this knowledge is gained from costly periodic shutdowns and manual inspection. Because of the characteristics of SAW devices such as small in size, rugged and light weight which makes them a good choice for highly integrated wireless transceivers.

In addition, with the introduction of passive SAW devices in wireless application, no local power source for the device is required. SAW devices offer new and exciting perspectives for remote monitoring and control of moving parts, even in harsh environments where no other devices can operate. Another advantage is that no semiconductors are used in conjunction with the sensors, which are able to withstand a high dose of radiation and a powerful electromagnetic interference (EMI) up to the power endurance of the devices.

Surface acoustic waves are essentially mechanical waves (i.e. conventionally called acoustic waves) which propagate on the surface of an elastic medium with most of its energy concentrated near the substrate surface. In general, piezoelectric substrates such as quartz are used as elastic medium. The physical phenomenon on which the SAW devices are based is piezoelectricity, (i.e. the virtue by which certain materials



produce electrical charge when mechanically strained or vice versa), which follows as structure depicted in Figure 1.1.

Figure 1.1 illustrates the relationship between stimulus and strain. It is valid for stationary/slowly changing events (i.e. piezoelectric actuator or sensor) or dynamic events (i.e. SAW device excited by an RF signal).

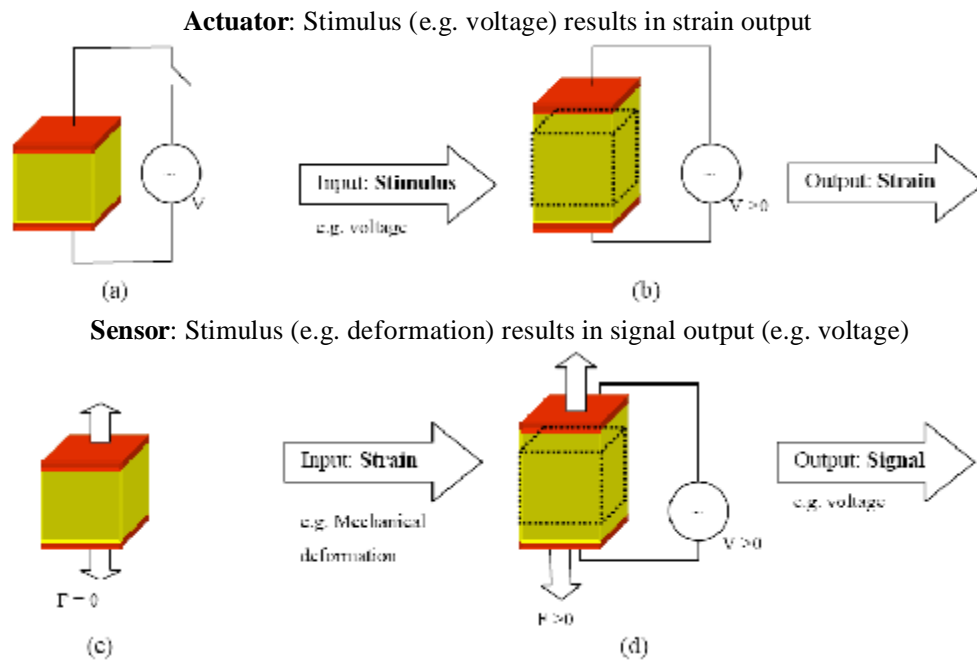


Figure 1.1: Stimulus-strain Relationship for Piezoelectric Substrate

The most important part of a SAW device is the Interdigital Transducer (IDT) or electrodes as shown in Figure 1.2. IDT is patterned on the surface of the piezoelectric substrate by using lithographic techniques. When an alternating electric input signal is applied to the electrodes, the electric field penetrates the piezoelectric substrate and surface acoustic waves are induced due to piezoelectric coupling. Similarly, charge accumulates on the electrodes in response to the acoustic waves, which in turn induces secondary acoustic waves. In this manner, IDTs can act as transmitters, receivers and reflectors collectively [5].

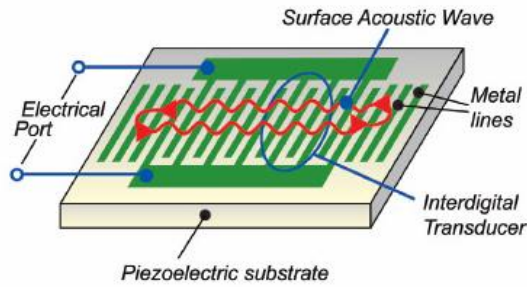


Figure 1.2: IDT in a SAW Device

Acoustic wavelength λ is given by u/f where u is the velocity of SAW and f the frequency. The periodicity of the required interdigital electrodes is related to the acoustic wavelength λ , and is equal to $\lambda/2$ as shown in Figure 1.3. The surface wave velocity is typically five orders of magnitude smaller than that of electromagnetic waves in free space and therefore the wavelength is also much smaller at the same frequencies, which translate into smaller device sizes.

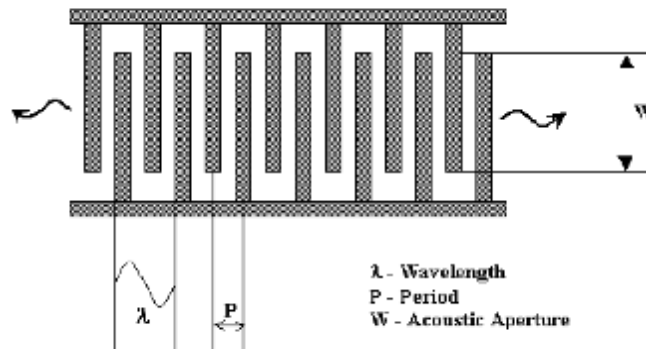


Figure 1.3: IDT Periodicity and Wavelength

Basically, there are two types of structure for SAW devices: delay line and resonator. A delay line is shown in Figures 1.4 (a) and (b), consists of two interdigital transducers (IDTs) (or an IDT and reflector), and a propagation path between them, while a resonator has one or two IDTs between the reflectors as shown in Figures 1.4