

---

**A Tutorial in AC Induction  
and  
Permanent Magnet Synchronous Motors**

***Vector Control with Digital Signal Processors***



---

### Acknowledgements

Many people around the world deserve note for their contributions to this motor control tutorial. The list is extensive but special mention must go to:

V. T. Ranganathan  
of the Indian Institute  
of Science, Bangalore, India

Alex Van Den Bossche and Piet Coussens  
of the University of Gent, Belgium

Infosys Technologies, Bangalore, India

The Motion Control Group of Analog Devices,  
Wilmington, Massachusetts USA

A work of this nature is never complete, but this first edition is testament to many years of research and the outcome of global cooperation and dedication in this enterprise.

Fred Flett

Copyright © 1994 by Analog Devices, Inc. and Infosys Technologies, Ltd.  
Printed in the United States of America

All rights reserved. This book, or parts thereof, must not be reproduced in any form without permission of the copyright owner.

Information furnished by Analog Devices, Inc. and Infosys Technologies, Ltd. is believed accurate and reliable. However, no responsibility is assumed by Analog Devices, Inc. or Infosys Technologies, Ltd. for its use.

Analog Devices, Inc. makes no representation that the interconnections of its circuits as described herein will not infringe on existing or future patent rights, nor do the descriptions contained herein imply the granting of licenses to make, use, or sell equipment in accordance therewith.

Specifications are subject to change without notice.

---

# Table Of Contents - AC Induction Motor

---

<b>1</b>	<b>Overview Of AC Drives</b> .....	3
	1.1. Types & Applications .....	3
<b>2</b>	<b>Synchronous Machine Operation</b> .....	5
	2.1. Synchronous Machine With Stationary Field .....	5
	2.2. Synchronous Machine With Rotating Field .....	5
	2.3. Calculation Of Torque .....	5
	2.4. Voltage Equation .....	6
	2.5. Phasor Diagram .....	7
<b>3</b>	<b>Induction Motors</b> .....	9
	3.1. Review Of Induction Motors .....	9
	3.2. Basic Principle of Operation .....	9
	3.3. Mechanism Of Torque Production .....	10
	3.4. Steady State Equivalent Circuit .....	11
	3.5. Steady State Equivalent Circuit Performance .....	13
	3.6. Operating From Non Sinusoidal Sources .....	14
	3.7. Effect Of Harmonics on Torque .....	16
<b>4</b>	<b>Pulse Width Modulation</b> .....	19
	4.1. Pulse Width Modulation Techniques .....	19
	4.2. Motivation for PWM .....	19
	4.3. Sub Harmonic PWM .....	20
	4.4. Current Regulated PWM .....	22
<b>5</b>	<b>Inverter Fed Drive Scheme</b> .....	25
	5.1. Block Diagram of Inverter Fed Drive .....	27
	5.2. Open Loop Drive With V/f Control .....	28
	5.3. Slip Compensation to Improve Speed Regulation .....	29
	5.4. Drive with Speed Feedback .....	30
	5.5. Summary .....	31
<b>6</b>	<b>Vector Control Of AC Machines</b> .....	33
	6.1. Summary .....	35
<b>7</b>	<b>Field Oriented Control of Induction Motors</b> .....	37
	7.1. Space Phasors .....	37
	7.2. Equations in Space Phasor Form .....	39
	7.3. Sinusoidal Steady State Performance .....	41
	7.4. Dynamics in Rotor Flux Frame of Reference .....	43
	7.5. Field Oriented Control Of Induction Motor .....	47
<b>8</b>	<b>Implementation Of Field Oriented Control in DSP</b> .....	49
	8.1. Computations For Machine Model .....	50
	8.2. Torque Loop Computations .....	51
	8.3. Speed Loop Computations .....	51
	8.4. Flux Loop Computations .....	51
	8.5. Summary .....	52
	<b>References</b> .....	53

---

# Table Of Contents - Permanent Magnet Synchronous Motor

---

<b>Glossary for PMSM</b> .....	56
<b>1 Overview</b> .....	57
1.1. Variable Speed AC Drives .....	57
1.2. Vector Control Of AC Motors .....	57
1.3. DSP Control Of Motors .....	58
1.4. Summary .....	58
<b>2 Permanent Magnet Synchronous Motors</b> .....	59
2.1. Introduction .....	59
2.2. Materials For PMSM .....	59
2.3. Classification Of PMSM .....	60
2.4. Brushless DC Motors .....	61
<b>3 Space Phasor Model Of PMSM</b> .....	63
3.1. Introduction .....	63
3.2. Space Phasor Of Stator Currents .....	63
3.3. Space Phasor Of Rotor Currents .....	65
3.4. Transformation Between Stator & Rotor Frames .....	65
3.5. Space Phasor Of Flux Linkages .....	66
3.6. Electromagnetic Torque .....	68
3.7. Summary .....	69
<b>4 Vector Control Of PMSM</b> .....	71
4.1. Introduction .....	71
4.2. Control In Rotor Frame .....	71
4.3. Mode Of Operation .....	72
4.4. Structure Of Control Loops .....	73
4.5. Summary .....	75
<b>5 Implementation In DSP</b> .....	77
5.1. Introduction .....	77
5.2. Speed Loop .....	77
5.3. Flux Loop .....	78
5.4. Current Loops .....	78
5.5. Feedback Signals .....	79
5.6. Hardware .....	80
5.7. Summary .....	80
<b>References</b> .....	80