

Dublin Institute of Technology

Kevin Street



SCHOOL OF ELECTRONIC & COMMUNICATIONS  
ENGINEERING

Communication Engineering Notes

Paul Tobin

# CONTENTS

<b>CHAPTER ONE .....</b>	
<i>INTRODUCTION TO A COMMUNICATION SYSTEM.....</i>	1
<i>THE COMMUNICATIONS CHANNEL.....</i>	2
<i>BANDWIDTH .....</i>	2
<i>FOURIER SERIES.....</i>	3
<i>PULSE SIGNAL TRANSMISSION.....</i>	4
<i>CHANNEL ATTENUATION.....</i>	4
<i>FREQUENCY RESPONSE OF A LINEAR TRANSMISSION CHANNEL .....</i>	4
<i>THE FOURIER TRANSFORM (FT) .....</i>	5
<i>SPECTRUM OF AN IMPULSE FUNCTION.....</i>	6
<i>STATIONARY AND NON-STATIONARY SIGNALS .....</i>	7
<i>NOISE AND INTERFERENCE.....</i>	8
<i>FRIIS' FORMULA .....</i>	9
<i>EXAMPLE .....</i>	9
<i>IMPULSE RESPONSE IN A BAND-LIMITED CHANNEL.....</i>	10
<i>SINGLE ROUNDED-OFF PULSE.....</i>	11
<i>QUESTION 1 .....</i>	12
<i>SOLUTION .....</i>	12
<i>QUESTION 2 .....</i>	12
<i>SOLUTION .....</i>	12
<i>SINGLE RECTANGULAR PULSE.....</i>	14
<i>INFORMATION AND ENTROPY: EXTRACTS FROM C SHANNON PAPER 1948 .....</i>	16
<i>AVERAGE INFORMATION H (ENTROPY).....</i>	16
<i>EXAMPLE .....</i>	17
<i>EXAMPLE: .....</i>	17
<i>CHANNEL CAPACITY .....</i>	18
<i>NYQUIST SIGNAL CRITERION.....</i>	19
<i>QUESTION .....</i>	19
<i>SOLUTION: .....</i>	19
<i>QUESTION .....</i>	20
<i>SOLUTION .....</i>	20
<b>CHAPTER TWO.....</b>	
<i>THE NEED FOR MODULATION .....</i>	22
<i>MODULATION.....</i>	23
<i>AMPLITUDE MODULATION.....</i>	23
<i>MODULATION INDEX.....</i>	25
<i>POWER IN AN AMPLITUDE MODULATED CARRIER .....</i>	26
<i>TRANSMISSION EFFICIENCY.....</i>	26
<i>QUESTION 1 .....</i>	27
<i>QUESTION 2 .....</i>	28
<i>AMPLITUDE MODULATORS.....</i>	28
<i>BALANCED MODULATORS: DOUBLE SIDEBAND SUPPRESSED CARRIER .....</i>	29
<i>SINGLE SIDEBAND SUPPRESSED CARRIER MODULATION .....</i>	30
<i>PHASE SHIFT METHOD .....</i>	30
<i>THE HILBERT TRANSFORM .....</i>	30
<i>THE 12-CHANNEL FDM SSBSC SYSTEM .....</i>	31

## **CHAPTER THREE.....**

<i>FREQUENCY MODULATION</i> .....	33
<i>DERIVATION OF FM EQUATION</i> .....	34
<i>EXAMPLE:</i> .....	35
<i>FREQUENCY SPECTRUM OF AN FM SIGNAL</i> .....	35
<i>EXAMPLE</i> .....	36
<i>FM RADIO</i> .....	36
<i>STEREO GENERATION</i> .....	37
<i>FM SUPERHETERODYNE RECEIVER</i> .....	37
<i>PREEMPHASIS AND DEEMPHASIS</i> .....	38
<i>EXAMPLE (PAUL YOUNG)</i> .....	39
<i>SOLUTION</i> .....	40
<i>EFFICIENCY AND NOISE</i> .....	41
<i>ADVANTAGES AND DISADVANTAGES OF FM:</i> .....	41
<i>PHASE-LOCKED LOOP</i> .....	41
<i>PLL COMPONENTS</i> .....	42
<i>CAPTURE AND LOCK RANGE</i> .....	43
<i>SUMMARY</i> .....	46
<i>QUESTIONS</i> .....	46
<i>FREQUENCY MODULATION</i> .....	32
<i>DERIVATION OF FM EQUATION</i> .....	33
<i>EXAMPLE:</i> .....	34
<i>FREQUENCY SPECTRUM</i> .....	34
<i>EXAMPLE</i> .....	35
<i>FM PERFORMANCE</i> .....	35
<i>FM RADIO</i> .....	35
<i>STEREO GENERATION</i> .....	36
<i>FM SUPERHETERODYNE RECEIVER</i> .....	37
<i>PREEMPHASIS AND DEEMPHASIS</i> .....	38
<i>EXAMPLE (PAUL YOUNG)</i> .....	39
<i>SOLUTION</i> .....	39
<i>EFFICIENCY AND NOISE</i> .....	40
<i>ADVANTAGES AND DISADVANTAGES OF FM:</i> .....	41
<i>PHASE-LOCKED LOOP</i> .....	41
<i>PLL COMPONENTS</i> .....	41
<i>CAPTURE AND LOCK RANGE</i> .....	42
<i>SUMMARY</i> .....	45
<i>QUESTIONS</i> .....	45

## **CHAPTER FOUR.....**

<i>AM-DSBFC SUPERHETERODYNE RECEIVER</i> .....	49
<i>THE SUPERHETRODYNE RECEIVER</i> .....	49
<i>ADVANTAGES OF SUPERHETRODYNING:</i> .....	50
<i>IMAGE FREQUENCY IN SUPERHETERODYNE RECEIVERS</i> .....	51
<i>ARITHMETIC SELECTIVITY</i> .....	51
<i>EXAMPLE:</i> .....	52
<i>DETECTORS AND MIXERS: DIODE DETECTOR</i> .....	52
<i>ENVELOPE DETECTOR</i> .....	53
<i>AUTOMATIC GAIN CONTROL</i> .....	55

COHERENT DETECTOR.....	55
MIXER.....	56
DOUBLE SIDEBAND SUPPRESSED CARRIER AM DSBSC.....	57
SINGLE SIDEBAND AMPLITUDE MODULATION (SSB).....	58
SSB GENERATION USING HILBERT TRANSFORM.....	59
ADVANTAGES OF SSB TECHNIQUE.....	59
RECEIVER DESIGN: PARALLEL TUNED CIRCUIT.....	60
UNIVERSAL RESPONSE CURVE FOR A PARALLEL TUNED CIRCUIT.....	63
THE LOADED $Q$ - FACTOR.....	65
EXERCISE 2.....	66
EXERCISE 3.....	67
RF TUNED AMPLIFIER.....	69
THE TRANSFER CHARACTERISTIC.....	70
SOURCE BIAS RESISTANCE VALUE.....	71
THE FET OUTPUT CHARACTERISTIC.....	71
MAGNIFIED SECTION OF THE OUTPUT CHARACTERISTIC.....	71
FREQUENCY RESPONSE OF THE RF AMPLIFIER.....	72
QUESTION.....	72
AM-DSBFC SUPERHETERODYNE RECEIVER.....	48
THE SUPERHETRODYNE RECEIVER.....	48
ADVANTAGES OF SUPERHETRODYNING:.....	49
IMAGE FREQUENCY IN SUPERHETERODYNE RECEIVERS.....	50
ARITHMETIC SELECTIVITY.....	50
EXAMPLE:.....	51
DETECTORS AND MIXERS: DIODE DETECTOR.....	51
ENVELOPE DETECTOR.....	52
AUTOMATIC GAIN CONTROL.....	54
COHERENT DETECTOR.....	54
MIXER.....	55
DOUBLE SIDEBAND SUPPRESSED CARRIER AM DSBSC.....	56
SINGLE SIDEBAND AMPLITUDE MODULATION (SSB).....	57
SSB GENERATION USING HILBERT TRANSFORM.....	58
ADVANTAGES OF SSB TECHNIQUE.....	58
RECEIVER DESIGN: PARALLEL TUNED CIRCUIT.....	59
UNIVERSAL RESPONSE CURVE FOR A PARALLEL TUNED CIRCUIT.....	62
THE LOADED $Q$ - FACTOR.....	64
EXERCISE 2.....	65
EXERCISE 3.....	66
RF TUNED AMPLIFIER.....	68
THE TRANSFER CHARACTERISTIC.....	69
SOURCE BIAS RESISTANCE VALUE.....	70
THE FET OUTPUT CHARACTERISTIC.....	70
MAGNIFIED SECTION OF THE OUTPUT CHARACTERISTIC.....	70
FREQUENCY RESPONSE OF THE RF AMPLIFIER.....	71
QUESTION.....	71

**CHAPTER FIVE .....**

BASEBAND DIGITAL TRANSMISSION.....	74
THE NEED FOR LINE CODING.....	74
SYNCHRONIZATION.....	75
LINE CODING: RETURN TO ZERO ( RZ ).....	75
MANCHESTER CODE.....	76
DIFFERENTIAL MANCHESTER CODE.....	76

<i>RECEIVER CLOCK SYNCHRONIZATION</i> .....	77
<i>COMPARISON OF LINE CODES</i> .....	79
<i>QUESTION</i> .....	79
<i>FULL DUPLEX AND HALF DUPLEX</i> .....	79
<i>SYNCHRONIZATION</i> .....	79
<i>ASYNCHRONOUS TRANSMISSION</i> .....	80
<i>FRAME SYNCHRONISATION IN ASYNCHRONOUS TRANSMISSION:</i> .....	81
<i>SYNCHRONOUS TRANSMISSION</i> .....	81
<i>ASCII – AMERICAN STANDARD CODE FOR INFORMATION INTERCHANGE</i> .....	81
<i>BASEBAND DIGITAL TRANSMISSION</i> .....	75
<i>THE NEED FOR LINE CODING</i> .....	75
<i>SYNCHRONIZATION</i> .....	76
<i>LINE CODING: RETURN TO ZERO ( RZ )</i> .....	76
<i>MANCHESTER CODE</i> .....	77
<i>DIFFERENTIAL MANCHESTER CODE</i> .....	78
<i>RECEIVER CLOCK SYNCHRONIZATION</i> .....	79
<i>COMPARISON OF LINE CODES</i> .....	80
<i>QUESTION</i> .....	80
<i>FULL DUPLEX AND HALF DUPLEX</i> .....	80
<i>SYNCHRONIZATION</i> .....	81
<i>ASYNCHRONOUS TRANSMISSION</i> .....	81
<i>FRAME SYNCHRONISATION IN ASYNCHRONOUS TRANSMISSION:</i> .....	82
<i>SYNCHRONOUS TRANSMISSION</i> .....	83
<i>ASCII – American Standard Code for Information Interchange</i> .....	83

## **CHAPTER SIX** .....

<i>DIFFERENTIAL QUADRATURE PHASE SHIFT KEYING (DQPSK)</i> .....	89
<i>QUADRATURE AMPLITUDE MODULATION (QAM)</i> .....	90
<i>EXERCISE</i> .....	92
<i>DTE TO MODEM (DCE) INTERFACE - (EIA-232-E)</i> .....	93
<i>QUESTION</i> .....	94
<i>SOLUTION</i> .....	94
<i>16-PSK</i> .....	94
<i>8 - QAM</i> .....	95
<i>DATA COMMUNICATION AND ERRORS</i> .....	95
<i>EXAMPLE</i> .....	96
<i>SOLUTION</i> .....	96
<i>MODEM PERFORMANCE</i> .....	97
<i>EYE DIAGRAM</i> .....	97

## **CHAPTER SEVEN**.....

<i>A BRIEF HISTORY OF THE IRISH TELEPHONE SYSTEM</i> .....	99
<i>ADVANTAGES OF DIGITAL COMMUNICATION NETWORKS:</i> .....	100
<i>DISADVANTAGES</i> .....	101
<i>THE SAMPLING THEOREM</i> .....	101
<i>SAMPLE DATA</i> .....	101
<i>NATURAL SAMPLING</i> .....	102
<i>EXAMPLE 1</i> .....	105

<i>IMPULSE SAMPLING</i> .....	105
<i>SAMPLING THEOREM</i> .....	106
<i>EXAMPLE 2</i> .....	109
<i>SOLUTION:</i> .....	109
<i>EXAMPLE 3</i> .....	109
<i>EXAMPLE 4</i> .....	109
<i>FLAT TOP SAMPLING</i> .....	110
<i>COMPANDING</i> .....	115
<i>UNIFORM QUANTIZER: SNR CALCULATION FOR CPCM</i> .....	115
<i>EXAMPLE</i> .....	115
<i>QUESTION</i> .....	118
<i>EXAMPLE 1</i> .....	119
<i>NON-UNIFORM</i> .....	119
<i>SIGN-EXPONENT- MANTISSA FORMAT</i> .....	121
<i>SIGNAL CODING</i> .....	121
<i>MU-LAW VERSUS A-LAW</i> .....	122
<i>TIME DIVISION MULTIPLEXING OF DIGITIZED SPEECH CHANNELS:</i> .....	123
<i>ISDN AND VOICE DIGITIZATION WITHIN THE PSTN:</i> .....	123
<i>DIFFERENTIAL PCM</i> .....	124
<i>ADAPTIVE DIFFERENTIAL PULSE-CODE MODULATION (ADPCM):</i> .....	125
<i>DELTA MODULATION</i> .....	126
<i>IDEAL DELTA MODULATOR</i> .....	127
<i>ADAPTIVE DELTA MODULATION (PAUL YOUNG P)</i> .....	127
<i>QUESTION</i> .....	128
<i>SOLUTION</i> .....	128
<i>QUESTIONS</i> .....	131
<i>1</i> .....	131
<i>2</i> .....	131
<i>3</i> .....	131
<i>4</i> .....	131
<i>5</i> .....	131
<i>6</i> .....	132
<i>SOLUTION</i> .....	132
<i>APPENDIX 1: Syllabus</i> .....	134
<i>APPENDIX 2: Examination papers and Solutions</i> .....	136
<i>APPENDIX 3: 565 IC</i> .....	139
<i>APPENDIX 4: MORE QUESTIONS</i> .....	140

# TABLE OF FIGURES

## CHAPTER ONE

FIGURE 1: ELEMENTS OF A TELECOMMUNICATION SYSTEM.....	1
FIGURE 2: RF SPECTRUM.....	2
FIGURE 3: A COMMUNICATIONS CHANNEL.....	2
FIGURE 4: FUNDAMENTAL + HARMONICS.....	3
FIGURE 5: 3-D VIEW.....	3
FIGURE 6: IMPULSE FUNCTION.....	6
FIGURE 7: SUM OF 4 SINES.....	7
FIGURE 8: SPECTRUM OF 4 SINES.....	7
FIGURE 9: NON-STATIONARY SIGNAL.....	8
FIGURE 10: A) SPECTRUM OF TWO SINES B) LOG OF AMPLITUDE OF SPECTRUM.....	8
FIGURE 11: FOURIER TRANSFORM OF A PULSE WAVEFORM.....	10
FIGURE 12: IMPULSE RESPONSE.....	11
FIGURE 13: INTER-SYMBOL INTERFERENCE.....	11
FIGURE 14: RAISED COSINE FILTER.....	13
FIGURE 15: FREQUENCY RESPONSE OF RAISED-COSINE FILTER.....	14
FIGURE 16: EFFECT OF COSINE ROLL-OFF EXCESS BANDWIDTH.....	14
FIGURE 17: SIMULATING ONE PULSE.....	14
FIGURE 18: CONSTANT $\tau$ , $T$ VARIED.....	15
FIGURE 19: DOUBLE $\tau$ VALUE.....	15
FIGURE 20: AS PULSE GETS NARROWER, THE SINC SHAPE SPREADS OUT.....	15
FIGURE 21: AS PULSE SPREADS, THE SINC SHAPE GETS NARROWER AND TALLER.....	16
FIGURE 22: ENTROPY OF BINARY SIGNAL.....	17

## CHAPTER TWO

FIGURE 1: 10 HZ MODULATING SIGNAL.....	23
FIGURE 2: MODULATED 100 HZ CARRIER.....	23
FIGURE 3: PSD OF AN AM SIGNAL.....	24
FIGURE 4: DYNAMIC RANGE AND FREQUENCY RANGE OF SPEECH AND MUSIC.....	25
FIGURE 5: DOUBLE SIDEBAND SUPPRESSED CARRIER.....	27
FIGURE 6: 180 DEGREE PHASE SHIFT.....	27
FIGURE 7: FORWARD-BIASED DIODE.....	28
FIGURE 8: RING MODULATOR.....	29
FIGURE 9: BALANCED MODULATOR.....	29
FIGURE 10: PHASE SHIFT TECHNIQUE FOR PRODUCING SSBSC.....	30
FIGURE 11: 12 - CHANNEL FDM SYSTEM.....	31
FIGURE 12: TWO-WIRE TO FOUR-WIRE CONVERSION.....	31
FIGURE 13: HIGHER-ORDER FDM MULTIPLEX SYSTEM.....	32
FIGURE 14: FDM COAX SYSTEMS.....	32

## CHAPTER THREE

FIGURE 1: VCO.....	34
FIGURE 2: VCO CHARACTERISTIC.....	34

FIGURE 3: FM SIGNAL .....	35
FIGURE 4: STEREO PRODUCTION .....	37
FIGURE 5: STEREO SPECTRUM.....	37
FIGURE 6: FM SUPERHETRODYNE RECEIVER.....	38
FIGURE 7: PRE-EMPHASIS NETWORK.....	39
FIGURE 8: PREEMPHASIS FREQUENCY RESPONSE.....	39
FIGURE 9: PHASE LOCKED LOOP BLOCK DIAGRAM.....	42
FIGURE 10: TYPE I PHASE DETECTOR .....	42
FIGURE 11: TYPE II PHASE DETECTOR .....	43
FIGURE 12: CIRCUIT SCHEMATIC FOR FM-PLL DEMODULATION .....	43
FIGURE 13: LOCK AND CAPTURE RANGE .....	44
FIGURE 14: 565 IMPORTANT PARAMETERS.....	45

## **CHAPTER FOUR**

FIGURE 1: SUPERHETRODYNING.....	49
FIGURE 2: BLOCK DIAGRAM OF A SUPERHETRODYNE RECEIVER.....	50
FIGURE 3: SUPERHETRODYNE DIAGRAM.....	50
FIGURE 4: IMAGE FREQUENCIES.....	51
FIGURE 5: DIODE RECTIFICATION.....	52
FIGURE 6: DIODE CHARACTERISTIC .....	53
FIGURE 7: ENVELOPE DETECTOR: CHOICE OF TIME CONSTANT.....	53
FIGURE 8: DIODE DETECTOR WITH AGC .....	55
FIGURE 9: DSB RECEIVER.....	56
FIGURE 10: DOUBLE-BALANCED RING MODULATOR .....	56
FIGURE 11: DSBSC MODULATOR FOR FM STEREO PRODUCTION .....	57
FIGURE 12: SPECTRUM OF AN FM STEREO SIGNAL .....	57
FIGURE 13: STEREO SIGNAL RECEIVER.....	58
FIGURE 14: SPECTRA IN SSB-SC .....	58
FIGURE 15: PHASE SHIFT METHOD OF GENERATING SSB.....	59
FIGURE 16: PARALLEL LCR CIRCUIT.....	60
FIGURE 17: PARALLEL TUNED CIRCUIT .....	60
FIGURE 18: EQUIVALENT PARALLEL LCR CIRCUIT.....	60
FIGURE 19: RF AMPLIFIER.....	69
FIGURE 20: CIRCUIT FOR OBTAINING THE FET CHARACTERISTICS.....	70
FIGURE 21: TRANSFER CHARACTERISTIC .....	70
FIGURE 22: THE TRANSISTOR OUTPUT CHARACTERISTIC.....	71
FIGURE 23: ENLARGED SECTION OF OUTPUT CHARACTERISTIC.....	71
FIGURE 24: RF AMPLIFIER FREQUENCY RESPONSE.....	72

## **CHAPTER FIVE**

FIGURE 1: CONVERTER CHANNEL LINE.....	74
FIGURE 2: LINE CODER .....	74
FIGURE 3 .....	75
FIGURE 4: MANCHESTER CODE.....	76
FIGURE 5 .....	76
FIGURE 6: NYQUIST SIGNAL.....	77
FIGURE 7: LINE CODER IMPLEMENTATION .....	77
FIGURE 8: .....	78
FIGURE 9: ALTERNATE MARK INVERSION.....	78
FIGURE 10 .....	81

## CHAPTER SIX

FIGURE 1: MODULATING A BASEBAND SIGNAL.....	83
FIGURE 2: PASSBAND TO BANDPASS CONVERTER.....	83
FIGURE 3: MULTI-LEVEL SIGNAL.....	84
FIGURE 4: FSK TIME DIAGRAMS.....	84
FIGURE 5: FREQUENCY SPECTRUM OF FSK SIGNAL.....	85
FIGURE 6 TIME DIAGRAMS OF BINARY PSK:.....	85
FIGURE 7: SPECTRUM OF DATA AND BINARY PSK:.....	86
<b>FIGURE 8: IMPLEMENTING THE ONE-BIT DELAY</b> .....	<b>87</b>
FIGURE 9: DPSK.....	87
FIGURE 10:.....	88
FIGURE 11: DQPSK MODULATOR.....	89
FIGURE 12.....	90
FIGURE 13: QAM TRANSMITTER AND RECEIVER.....	90
FIGURE 14: 16-QAM.....	90
FIGURE 15: THE CONSTELLATION CAN BE PARTITIONED INTO DECISION REGIONS.....	90
FIGURE 16: 128-QAM V 32 BIS MODEM.....	91
FIGURE 17: 8-PSK.....	93
FIGURE 18: 8-QAM.....	93
FIGURE 19: BER RATE PLOT.....	95
FIGURE 20 : PRODUCTION OF AN EYE PATTERN.....	97
FIGURE 21.....	97
FIGURE 22: ACTUAL EYE DIAGRAM.....	97
FIGURE 23: EYE DIAGRAM USING THE VERY GOOD( FREE) COMMS TOOLBOX.....	98
FIGURE 24: MATLAB EYE DIAGRAM FOR AN NRZ SIGNAL.....	98

## CHAPTER SEVEN

FIGURE 1.....	99
FIGURE 2: OVERALL SYSTEM LAYOUT.....	100
FIGURE 3: STROWGER SWITCHING.....	100
FIGURE 4: CROSSBAR SYSTEM.....	100
FIGURE 5: ALIASING FREQUENCIES.....	101
FIGURE 6: ALIASING COMPONENTS.....	101
FIGURE 7: NATURAL SAMPLING.....	102
FIGURE 8: TIME WAVEFORMS IN NATURAL SAMPLING.....	103
FIGURE 9: NATURAL AND FLAT-TOPPED SAMPLE.....	103
FIGURE 10: THE SPECTRUM OF FLAT-TOPPED SPECTRUM.....	104
FIGURE 11: THE SPECTRUM OF NATURAL SPECTRUM.....	104
FIGURE 12:.....	105
FIGURE 13.....	105
FIGURE 14: FOURIER SERIES.....	106
FIGURE 15: FOURIER INTEGRAL.....	106
FIGURE 16.....	106
FIGURE 17.....	107
FIGURE 18: SPECTRUM OF AN IMPULSE SAMPLED SIGNAL.....	108
FIGURE 19: SPECTRAL FOLD-OVER WHEN INPUT BANDWIDTH EXCEEDS $F_s/2$ .....	108
FIGURE 20.....	109
FIGURE 21.....	109
FIGURE 22: CIRCUIT TO EXTEND THE WIDTH OF FLAT TOP SAMPLES.....	110
FIGURE 23: ANALYTICAL MODEL OF FLAT-TOPPED SAMPLING.....	110
FIGURE 24: RELATIVE GAIN OF FLAT-TOP SAMPLING VS. PULSE WIDTH.....	111
FIGURE 25: TIME DIVISION MULTIPLEXING OF PAM SAMPLES.....	111
FIGURE 26.....	112

<i>FIGURE 27: FDM AND TDM MULTIPLEXING</i> .....	112
<i>FIGURE 28: FRAME AND MULTI-FRAME LAYOUT</i> .....	113

## **CHAPTER EIGHT**

<i>FIGURE 1: OUTPUT SIGNAL WITH QUANTIZING ERROR</i> .....	116
<i>FIGURE 2: LINEAR TRANSFER CHARACTERISTIC</i> .....	116
<i>FIGURE 3</i> .....	117
<i>FIGURE 4: OUTPUT SIGNAL WITH QUANTIZING ERROR</i> .....	117
<i>FIGURE 5: UNIFORM AND NON-UNIFORM QUANTIZATION</i> .....	119
<i>FIGURE 6: MU-LAW ANALOGUE COMPANDING</i> .....	120
<i>FIGURE 7: SEGMENTED U-LAW CHARACTERISTIC</i> .....	120
<i>FIGURE 8</i> .....	121
<i>FIGURE 9</i> .....	121
<i>FIGURE 10: FORMAT OF 8-BIT COMPANDED PCM SAMPLE WORD</i> .....	121
<i>FIGURE 11: A-LAW CHARACTERISTIC</i> .....	121
<i>FIGURE 12</i> .....	122
<i>FIGURE 13: MULTIPLEXING FORMATS</i> .....	123
<i>FIGURE 14</i> .....	125
<i>FIGURE 15</i> .....	126
<i>FIGURE 16: DELTA MODULATOR</i> .....	126
<i>FIGURE 17: SLOPE OVERLOAD</i> .....	127
<i>FIGURE 18: SLOPE OVERLOAD AND GRANULAR NOISE</i> .....	127
<i>FIGURE 19: DELTA MODULATOR SIGNALS</i> .....	128
<i>FIGURE 20</i> .....	129
<i>FIGURE 21: INTEGRATING DELTA MODULATOR</i> .....	129
<i>FIGURE 22: DELTA MODULATOR</i> .....	130
<i>FIGURE 23: DELTA MODULATOR SIGNALS FOR THE CIRCUIT IN FIG.22</i> .....	130
<i>FIGURE 24: DELTA DEMODULATOR</i> .....	130

## ***INTRODUCTION***

This set of notes is not meant to replace the normal textbooks as recommended in the syllabus (See appendix 4). The notes were compiled using previous years students note and Internet resources. Apologies for any plagiarism from these Internet files. The notes will be used in the classroom and augmented where necessary.