# TABLE OF CONTENTS

## CHAPTER VI
**FOURIER ANALYSIS OF DISCRETE-TIME SIGNALS** ..................................................... 11

6.1 Response of discrete linear time-invariant systems to complex exponential with unitary magnitude ................................................................................................................. 11

6.2 Discrete-time Fourier series for periodic signals .................................................. 13

6.2.1 Properties of discrete-time Fourier series ....................................................... 22

6.3 Discrete-time Fourier transform ........................................................................... 30

6.3.1 Formal definition of discrete-time Fourier transform for aperiodic signals ............................ 34

6.3.2 Discrete-time Fourier transform for discrete-time periodic signals ............... 40

6.3.3 Properties of discrete-time Fourier transform ............................................. 44

6.4 Frequency response of discrete-time linear time-invariant systems .................. 55

6.4.1 Output of a discrete-time linear time-invariant system to a periodic input signal ...................................................................................................................... 56

6.4.2 Discrete-time linear invariant systems described by linear difference equations with constant coefficients ................................................................. 57

6.4.3 First and second order discrete LTI systems ................................................. 60

6.5 Correlation function. Power and energy spectral density ........................................ 69

Table 6.1 Properties of discrete-time Fourier series .................................................... 76

Table 6.2 Properties of the discrete-time Fourier transform ........................................ 77

Table 6.3 Tables of discrete-time Fourier transform for different signals ................. 78

## CHAPTER VII
**LAPLACE TRANSFORM**......................................................................................... 81

7.1 Response of a linear time-invariant system to a complex exponential with complex exponent .............................................................................................................. 81

7.2 Bilateral Laplace transform .................................................................................. 82

7.2.1 Properties of region of convergence for bilateral Laplace transform .......... 86

7.2.2 The inverse Laplace transform ........................................................................ 91

7.2.3 Defining the bilateral Laplace transform using the pole-zero plot ............. 94

7.3 Unilateral Laplace transform .............................................................................. 96

7.3.1 Relation between the bilateral and unilateral Laplace transforms .......... 97

7.4 Laplace transform of distributions ...................................................................... 98

7.5 Properties of bilateral and unilateral Laplace transforms ................................ 100

7.6 Analysis of linear time-invariant systems using the Laplace transform .......... 108

7.6.1 Transfer function of an LTI system ......................................................... 108

7.6.2 LTI system response determination using Laplace transform ................. 111
7.6.3 LTI systems described by constant-coefficient linear differential equations ................................................................. 116
Table 7.1 Properties of Laplace transform ................................................................. 130
Table 7.2 Pairs signal-Laplace transform ............................................................... 132

CHAPTER VIII
BASIC NOTIONS ON SIGNAL FILTERING .................................................... 133
8.1 Types of ideal filters ....................................................................................... 133
  8.1.1 Ideal low-pass filter ................................................................................. 133
  8.1.2 Ideal high-pass filter ............................................................................... 137
  8.1.3 Ideal band-pass filter ............................................................................... 139
  8.1.4 Ideal band-stop filter ............................................................................... 141

CHAPTER IX
SAMPLING OF SIGNALS ............................................................................... 143
9.1 The sampling theorem ................................................................................... 143
  9.1.1 The spectrum of the ideal sampled signal ............................................... 145
  9.1.2 Sampling theorem for band-limited signals ............................................ 146
9.2 Ideal sampling of periodic signals ................................................................. 156
9.3 Energy and power of original and ideal sampled signals ............................... 160
9.4 Flat top sampling. Sample-and-hold sampling ............................................... 161
9.5 Natural sampling .......................................................................................... 163
9.6 Connection between spectra of discrete and corresponding continuous signals .......................................................... 166
9.7 Sampling of discrete-time signals ................................................................. 169
9.8 Sampling of spectrum of finite duration discrete-time signals ....................... 177
9.9 Practical measures for continuous-time signals sampling ............................. 180
9.10 Sampling of band-pass signals practical measures for continuous-time signals sampling ......................................................... 182

CHAPTER X
THE Z TRANSFORM ........................................................................................ 185
10.1 The response of a discrete linear time-invariant system to discrete complex exponential with non-unitary magnitude ................................................................. 185
10.2 Bilateral Z transform ................................................................................... 186
  10.2.1 Properties of the ROC of the bilateral Z transform .............................. 189
  10.2.2 Inverse Z-transform ............................................................................... 194
  10.2.3 Bilateral Z Transform computation using its pole-zero plot ................. 195
10.3 Unilateral Z transform ................................................................................ 197
10.4 Properties of the Z transform .................................................................... 198
10.5 Connection between Z transform and Laplace transform .......................... 206
10.6 The study of discrete linear time-invariant systems using the Z transform...
10.6.1 The system function of a discrete LTI system ...
10.6.2 Response of a discrete LTI system from the Z transform ...
10.6.3 Discrete LTI systems, characterized by linear difference equations with constant coefficients ...
10.6.4 First order systems ...
10.6.5 Second order systems ...
10.6.6 System function of equivalent system for discrete systems connected in series and in parallel ...
10.7 Implementation forms of digital filters using the Z transform ...
10.7.1 Lattice form of a filter having only poles ...
Table 10.1 Properties of the Z transform ...
Table 10.2 Pairs signal-Z transform ...

CHAPTER XI
CONVERSION OF CONTINUOUS-TIME SYSTEMS TO DISCRETE-TIME SYSTEMS ...
11.1 General method for quality evaluation of approximation for band-limited systems ...
11.2 Approximation of band-limited systems by impulse invariance method ...
11.3 Approximation of band-limited systems by step invariance method ...
11.4 Approximation of band-limited systems by ramp response invariance method ...
11.5 Finite difference approximation ...
11.6 Bilinear transform ...

CHAPTER XII
CONTINUOUS WAVE MODULATION ...
12.1 Introduction ...
12.2 Amplitude modulation ...
12.3 Linear amplitude modulation ...
12.4 Frequency translation ...
12.5 Frequency division multiplexing ...
12.6 Angle modulation ...
12.7 Frequency modulation ...
12.8 Nonlinear effects in frequency modulation ...
12.9 Superheterodyne receiver ...
Annex ...
A.1 Hilbert transform ...
A.2 Complex representations of signals ...
CHAPTER XIII
STABILITY OF LINEAR SYSTEMS ................................................................. 335
13.1 Linear negative feedback systems ...................................................... 338
13.2 Applications and consequences of negative feedback ....................... 339
  13.2.1 The inverse system ................................................................. 339
  13.2.2 Compensation of nonideal circuit elements ............................. 341
  13.2.3 Stabilization of unstable systems .......................................... 342
  13.2.4 Tracking systems ................................................................. 345
  13.2.5 Instability caused by feedback .............................................. 346
13.3 Stability analysis of feedback systems using the root-locus method .... 348
  13.3.1 An introductory example ....................................................... 348
  13.3.2 Equation of poles for a closed loop system ............................. 349
    13.3.2.1 End points of root-locus: closed-loop poles for $K = 0$ and
    $|K| = \infty$ .................................................................................. 350
    13.3.2.2 Argument (angle) criterion .............................................. 351
    13.3.2.3 Properties of the root locus ............................................. 355
13.4 Nyquist stability criterion .................................................................. 364
  13.4.1 Argument variation criterion ................................................... 365
  13.4.2 Nyquist criterion for linear feedback systems, in continuous-time .... 370
  13.4.3 Nyquist criterion for linear negative feedback systems in discrete-time
                                                                 ................................................................. 379
13.5 Gain and phase margins..................................................................... 386

REFERENCES .................................................................................................. 397