. .

INTRODUCTION	i	
PART I. GENERAL DESCRIPTION 1	L	
I.I. PRELIMINARY REMARKS ON TRAVELING WAVES	L	
1. 1 The Differential Equations for a Single-Conductor System	L	
1. 2 Characteristics of Traveling Waves on a Single-Conductor System	3	
1. 3 Arrangement of Conductors and Layout of Existing Transmission Lines 5	5	
1. 4 The Kyoto University Methods for the Measurement of Transient Parameters . 7	7	
1.4.1 The First Kyoto University Method	3	
1.4.2 Example)	
1.4.3 The Second Kyoto University Method	L	
1.4.4 Example	3	
1. 5 Differential Equations for a Multi-Conductor System	5	
1. 6 Differential Equations for a Multi-Conductor System in Matrix Forms 20)	
1. 7 Modified Differential Equations for a Multi-Conductor System considering Skin		
Effect	L	
I. II. THE SYLVESTER EXPANSION THEOREM	3	
1. 8 The Sylvester Theorem in Matrix-Calculus	3	
1. 9 The Characteristic Matrix, the Characteristic Equation and the Latent		
or Characteristic Roots of a Square Matrix	ł	
1.10 Transposed and Adjoint Matrices	F	
1.11 The Cayley-Hamilton Theorem	5	
1.12 Computation of Positive Powers or Negative Powers of a Matrix 26	5	
1.13 Reduction of Polynomials of a Matrix	3	
1.14 The Frobenius Theorem	3	
1.15 Factorisation of Polynomial of a Matrix	3	
1.16 Theorem on Factorisation of $\{P(\lambda)[U]_{mm} - P([A]_{mm})\}$)	
1.17 The Lagrange Interpolation Formula)	
1.18 The Sylvester Expansion Theorem)	
1.19 The Modified Sylvester Theorem for Fractional Powers of a Matrix 35	5	
1.20 Hayashi's Modified Form of the Sylvester Theorem	5	
1.21 Generalized Form of the Sylvester Theorem)	
I. III. SYMMETRICAL COORDINATE TRANSFORMATION OF A MULTI-CONDUCTOR		
System)	

1.22	Symmetrical Coordinate Transformation Matrices applied to
	Multi-Conductor System
1,23	Successive Symmetrical Coordinate Transformation
1,24	Symmetrical Coordinate Transformation of Rational Transcendental Function
	of a Matrix as well as Function of a Fractional Power Matrix 47
PAR	T II TRAVELING WAVES ON SINGLE CONDUCTOR SYSTEMS 51
1711	
II. I. FUN	IDAMENTAL FORMULAS
2. 1	Fundamental Formulas
2. 2	Proof of the Fundamental Formulas
2. 3	Some Features of Phenomena directly estimated from the
	Fundamental Formulas
II. II. Ev.	aluation of Fundamental Contour Integrals
2. 4	The First Method
2, 5	The Second Method
II. III. Po	TENTIAL AND CURRENT TRAVELING WAVES ON SINGLE CONDUCTOR
	Systems
2. 6	Potential and Current at the Point x for the Interval $(2l-x)/g > l > 0$
	due to the E. M. F. $E_{\varepsilon} - p_0 t$ at $x=0$, when the Impedance Z_1 is zero 80
2. 7	Reflection of Incoming Waves at Critical Resistance
2. 8	Reflection of Incoming Waves at Terminal Condenser
PA	RT III. TRAVELING WAVES ON INFINITELY-LONG MULTI-
	CONDUCTOR TRANSMISSION SYSTEMS WITH
	DISSIPATION CONSTANTS
	OPOSITION OF A NEW ANALYTICAL METHOD OF TRAVELING WAVES
	ON MULTI-CONDUCTOR SYSTEMS
3 1	Boundary Value Problems of General Polyphase Transmission Lines 104
3. 2	Traveling Waves on General Polyphase Transmission Lines
III. II. An	TTENUATION AT THE WAVE FRONTS
3. 3	Traveling Wave Solutions of Multi-Conductor Transmission Lines
3. 4	Component Waves on a Multi-Conductor System
3. 5	Component Waves generated at the Wave Fronts due to Dissipation
	Constants

х

III. III. COMPONENTS OF TRAVELING WAVES AT THE WAVE FRONTS 137
3. 6 Principal Axis Transformation of Traveling Waves
3. 7 Four-Conductor System
3, 8 Five-Conductor System
3. 9 Seven-Conductor System
2 11 Nine Conductor System 11
5.11 Mine-Conductor System
III. IV. EXACT SOLUTIONS OF MULTI-CONDUCTOR SYSTEMS
3.12 Exact Solutions of Traveling Waves on Multi-Conductor Systems
3.13 Exact Solutions for a Dissymmetrical Two-Conductor System
3.14 Exact Solutions for a Dissymmetrical Three-Conductor System
3.15 Exact Solutions for a Nine-Conductor System
III. V. DISTORTION OF TRAVELING WAVES DUE TO MULTI-VELOCITIES
3.16 General Formulas for an <i>m</i> -Conductor System
3.17 Two-Conductor System
3.18 Numerical Examples
PART IV. SUCCESSIVE REFLECTIONS OF TRAVELING WAVES ON
MULTI-CONDUCTOR SYSTEMS
IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS
IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS
 IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS
 IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS
IV.I. DEDUCTION OF FUNDAMENTAL FORMULAS
IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS
 IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS
IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS
 IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS
 IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS
IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS
IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS 181 4. 1 Some Experiments on Traveling Waves on Multi-Conductor Systems 181 4. 2 Reflection Coefficient Matrices corresponding to Various Arrangements 181 4. 2 Reflection Coefficient Matrices corresponding to Various Arrangements 182 4. 3 Successive Reflections at Terminal Impedances 192 IV. II. SYMMETRICAL THREE-CONDUCTOR SYSTEMS WITH VARIOUS TERMINAL 192 V. II. SYMMETRICAL THREE-CONDUCTOR SYSTEMS WITH VARIOUS TERMINAL 195 4. 4 Fundamental Formulas 195 4. 5 Sending Ends open circuited, Receiving Ends grounded together through 196 4. 6 Sending Ends short-circuited, Receiving Ends grounded through a 196 4. 6 Sending Ends short-circuited, Receiving Ends grounded through a 196
IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS 181 4. 1 Some Experiments on Traveling Waves on Multi-Conductor Systems 181 4. 2 Reflection Coefficient Matrices corresponding to Various Arrangements consisting of Terminal Admittances 185 4. 3 Successive Reflections at Terminal Impedances 192 IV. II. SYMMETRICAL THREE-CONDUCTOR SYSTEMS WITH VARIOUS TERMINAL CONDITIONS 195 4. 4 Fundamental Formulas 195 4. 5 Sending Ends open circuited, Receiving Ends grounded together through a Single Resistance 196 4. 6 Sending Ends short-circuited, Receiving Ends grounded through a Single Resistance 198 4. 7 Both Ends grounded together through Resistances 199
IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS 181 4. 1 Some Experiments on Traveling Waves on Multi-Conductor Systems 181 4. 2 Reflection Coefficient Matrices corresponding to Various Arrangements consisting of Terminal Admittances 185 4. 3 Successive Reflections at Terminal Impedances 192 IV. II. SYMMETRICAL THREE-CONDUCTOR SYSTEMS WITH VARIOUS TERMINAL CONDITIONS 195 4. 4 Fundamental Formulas 195 4. 5 Sending Ends open circuited, Receiving Ends grounded together through a Single Resistance 196 4. 6 Sending Ends short-circuited, Receiving Ends grounded through a Single Resistance 198 4. 7 Both Ends grounded together through Resistances 199 4. 8 Two Conductors grounded together through a Resistance and One Conductor 199
IV. I. DEDUCTION OF FUNDAMENTAL FORMULAS 181 4. 1 Some Experiments on Traveling Waves on Multi-Conductor Systems 181 4. 2 Reflection Coefficient Matrices corresponding to Various Arrangements consisting of Terminal Admittances 185 4. 3 Successive Reflections at Terminal Impedances 192 IV. II. SYMMETRICAL THREE-CONDUCTOR SYSTEMS WITH VARIOUS TERMINAL CONDITIONS 195 4. 4 Fundamental Formulas 195 4. 5 Sending Ends open circuited, Receiving Ends grounded together through a Single Resistance 196 4. 6 Sending Ends short-circuited, Receiving Ends grounded through a Single Resistance 198 4. 7 Both Ends grounded together through Resistances 199 4. 8 Two Conductors grounded together through a Resistance and One Conductor open-circuited at the Sending End, the Receiving Ends grounded

•

4. 9	Sending Ends short-circuited and isolated while Two Conductors are
	open-circuited and Another Conductor grounded through a Resistance
	at Receiving End
	PART V. REFRACTION OF TRAVELING WAVES ON
	MULTI-CONDUCTOR TRANSMISSION SYSTEMS 205
VIDE	DUCTION OF REPACTION COFFECIENT MATRICES ON MULTI-CONDUCTOR
	Systems with Various Transition Points
5.1	Given the Operational Forms of Voltages at the Sending End of a Symmetrical
	Three-Conductor System, Find the Voltage and Current Operators of
	Traveling Waves at Any Point on the System
5. 2	Traveling Waves generated on a Symmetrical Three-Conductor System due to
	Electromotive Forces impressed at the Terminal through Impedances 209
5.3	Traveling Waves on a Symmetrical Three-Conductor System with Terminal
•	Impedances, Admittances and Electromotive Forces at the Sending End 214
5.4	Reflection and Refraction of Traveling Waves at the Junction of Two
	Sections of Symmetrical Three-Conductor Transmission Systems
5, 5	Reflection and Refraction of Traveling Waves at the Junction Point of
	Two Sections of Symmetrical Three-Conductors joined through
	Concentrated Impedances $[Z_n]_{22}, \ldots, \ldots, \ldots, \ldots, \ldots, 221$
56	Reflection and Refraction of Traveling Waves at the Junction Point of
	Two Sections of Symmetrical Three-Conductors and Grounding
	Admittances
V.II. Ec	UIVALENT CIRCUITS TO DETERMINE REFLECTION AND REFRACTION
	COEFFICIENT MATRICES
5.7	Deduction of Equivalent Circuit determining Reflected and Refracted Voltage
	and Current Matrices at the Transition Point
5.8	Example 1
5, 9	Example 2
5, 10	Example 3
5, 11	Deduction of Equivalent circuit determining Reflected and Refracted Voltage
	and Current Matrices at the Transition Point of Forked Line Systems 236
W TH S	HOOPSCHUE DEPRACTIONS ON MULTICONDUCTOR SYSTEMS WITH
v.m. 5	Crewin Warra 027
	GROUND WIRES
5.12	Refracted Voltage Waves on the $(n+1)$ th Section of Transmission Lines
	with Ground Wires grounded at Equal Distances through Resistances 237
5, 13	Transformation of Equivalent Refraction Coefficient Matrix $[F]_{mm}$ at the

xii

11 - Daniel 228
Wave Fronts
5. 14 The Case of One Transmission Line and One Ground whe
5.15 Attenuation of the Toes of Refracted Voltage waves on One Transmission
Line and One Ground wire System, G_g being minute
5.10 Attenuation of the Toes of Refracted Voltage waves on One Transmission
Line and One Ground Wire System, G_g being heriter zero nor minine
J. 17 Numerical Examples—Damping Enert of the Ground Whe upon the
Line 250
5.18 Analysis of Traveling Wave Characteristics of the Shin (New) Hokuriku
Trunk Transmission' Line considering Transposition Points
PART VI SURCE IMPEDANCES AND ADMITTANCES
OF MULTICONDUCTOR SYSTEMS
OF MULTI-CONDUCTOR STSTEMS
VII PERIMINARY REMARKS
VI. I REEMINART REMARKS
6. 1 Surge Impedance and Admittance Matrices
VI.II. TRANSIENT SURGE IMPEDANCES AND ADMITTANCES AT THE
WAVE FRONTS
6. 2 When $[Z]_{mm} = [L]_{mm} p + [R]_{mm}$
0. 5 Considering the Skin Effect
VI. III. EQUIVALENT NETWORKS CONSISTING OF LUMPED MESHES
6. 4 Modified Y-Type
6. 5 Modified Δ-Type of Symmetrical Transmission Lines
6. 6 Four-Conductor System ²
6. 7 Seven-Conductor System
6. 8 Five-Conductor System
6. 9 Eight-Conductor System
6.10 Examples
VI.IV. APPROXIMATE SETTING UP OF EQUIVALENT NETWORKS
6 11 General Case 285
6 12 Symmetrical Three-Phase Transmission Line
0, 12 symmetrical function fraction of the first state of the second state of the s
VI. V. EXACT SOLUTIONS OF TRANSIENT SURGE IMPEDANCES AND
Admittances of Two-Conductor Systems
6.13 When $[Z]_{22} = [L]_{22} p + [R]_{22}$
6.14 Considering the Skin Effect

٠

PART VII. SKIN EFFECT ON TRAVELING WAVES
AND DOUBLE OPERATIONAL
CALCULUS
VII I ATTENUATION AND DISTORTION OF TRAVELING WAVES ON SINGLE-
CONDUCTOR SYSTEM DUE TO SKIN EFFECT
7 1 Introduction 203
7. 2. Circuit with Wire Return
7. 3 Circuit with Ground Return
7. 4 Modified Differential Equations of a Single Conductor considering the
Skin Effect and their Solutions
7. 5 Solutions of the Modified Differential Equations of Primary Approximation 305
7. 6 Hayashi's Modified Form of Borel's Theorem
7. 7 Solutions of the Modified Differential Equations of Secondary Approximation . 309
7. 8 Solutions of the Modified Differential Equations of Third Approximation 311
VII, II. ATTENUATION AND DISTORTION OF TRAVELING WAVES ON MULTI-
CONDUCTOR SYSTEMS DUE TO SKIN EFFECT
7. 9 Introduction
7.10 Skin Effect of Primary Approximation on Traveling waves on
Multi-Conductor Systems
7.11 Skin Effect of Secondary Approximation on Traveling waves on a
Multi-Conductor System
7.12 Skin Effect of Primary Approximation on Dissymetrical Two-Conductors
7.13 Skin Effect of Primary Approximation on Symmetrical Three-Conductors
7.14 Successive Reflections on a Multi-Conductor System considering the
Skin Effect of Primary Approximation
VII. III. DOUBLE OPERATIONAL CALCULUS
7.15 What is the Double Operational Calculus?
7.16 Solution of Wave Equation by the $p-q$ Operational Computing Procedure 334
7.17 Solution of Wave Equation by the $q-p$ Operational Computing Procedure 336
VII. IV. Solutions of Simultaneous Wave Equations, Initial
DISTRIBUTIONS BEING GIVEN
7.18 Solutions of Special Simultaneous Wave Equations by the $p-q$ Operational
Computing Procedure
7.19 Solutions of General Simultaneous Wave Equations by the $p-q$ Operational
Computing Procedure

2

xiv

.

APPENDI	Κ
	Error Function and Related Function
	Modified Bessel Functions
	Hankel Functions
	Modified Hankel Functions
INDEX	

•

5