ELECTROMAGNETIC INDUCTION AND ITS PROPAGATION

A Sequel to the work of Oliver Heaviside

by Eric P. Dollard

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Chapter 1

Rudiments of Electromagnetic Theory

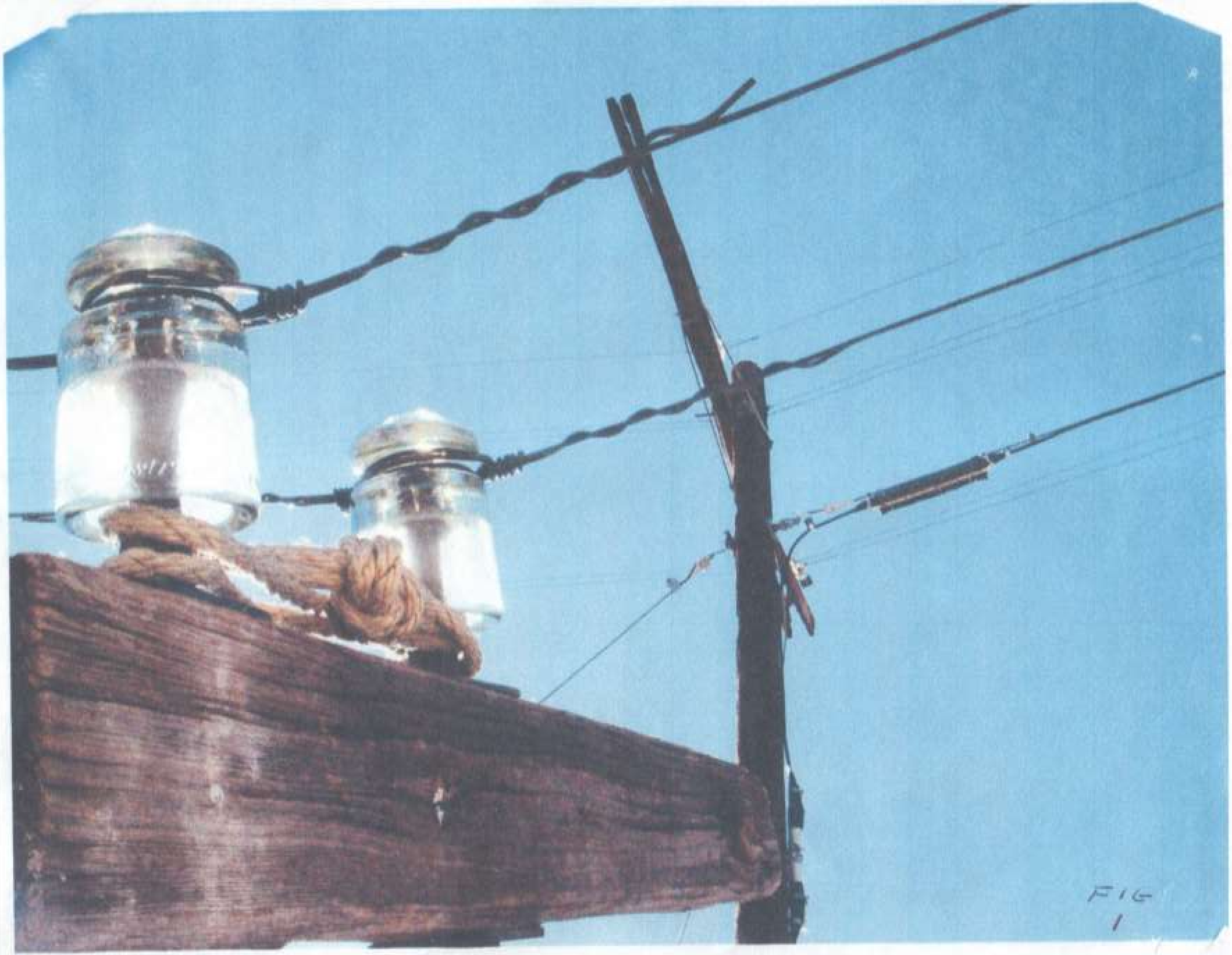


FIG 1

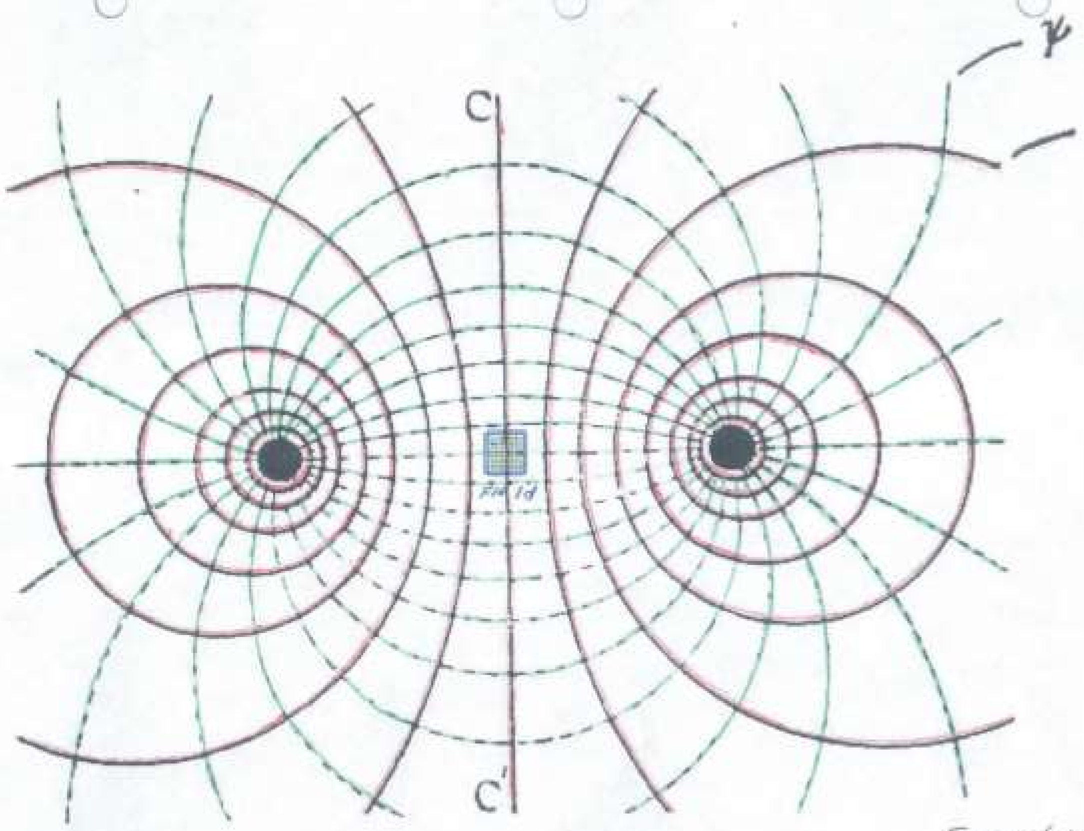


FIGURE (1a)

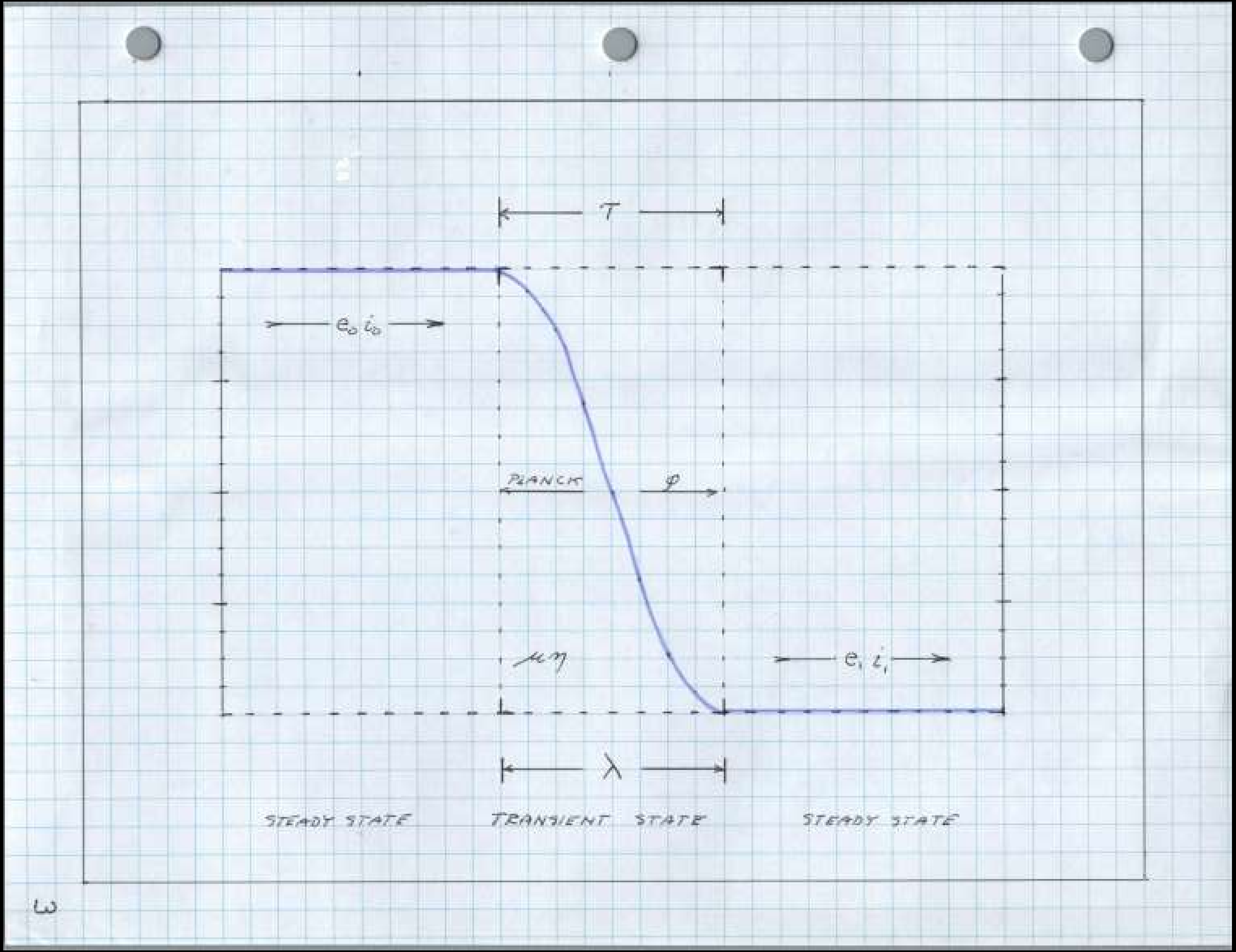

τ
$e_0 i_0$
PLANCK
φ
μη
$e_1 i_1$
λ
STEADY STATE
TRANSIENT STATE
STEADY STATE

FIGURE (1c)

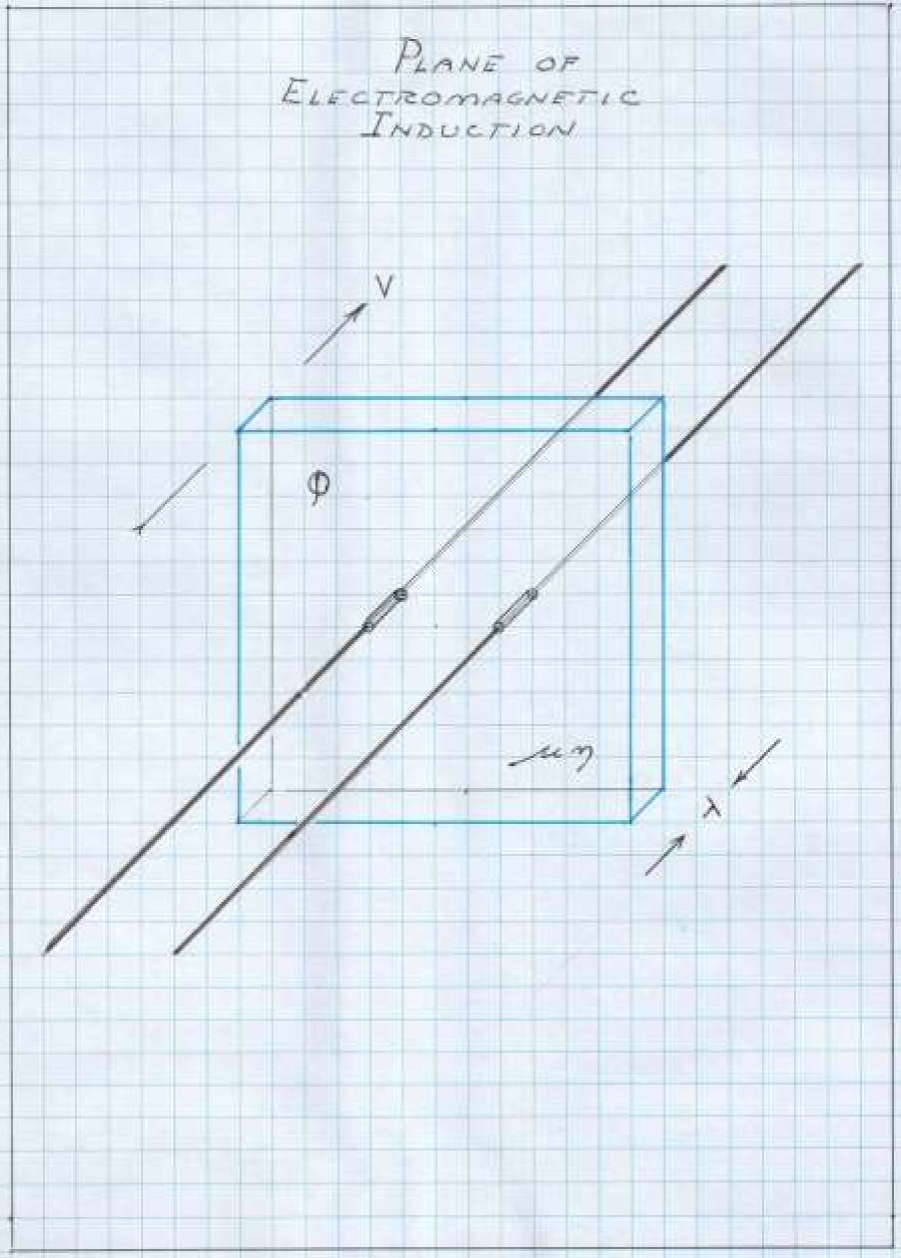
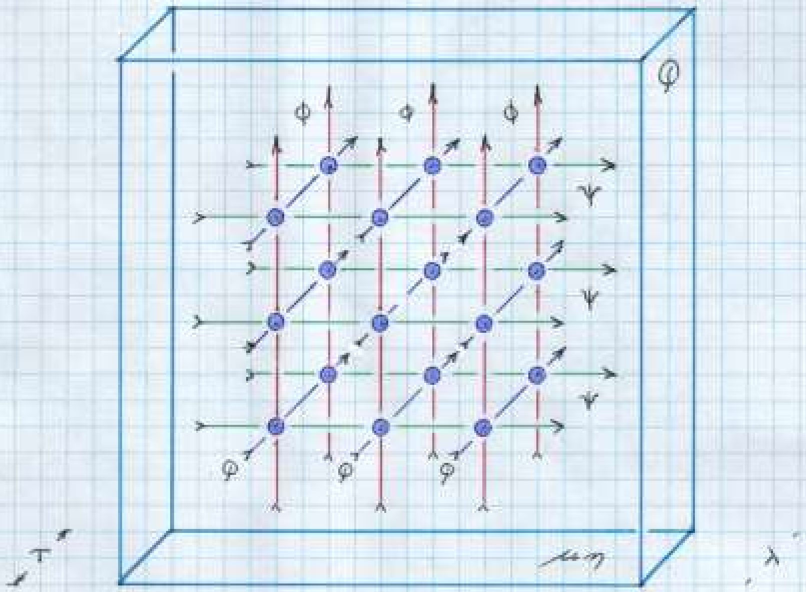


FIGURE (1d)



$\varphi = \phi \cdot \psi$, C.G.S. PLANCK

MAGNETIC INDUCTION

ϕ

C.G.S. MAXWELL

DIELECTRIC INDUCTION

ψ

C.G.S. COULOMB

FIGURE (1e)

1

ELECTRIC

$\varphi = \Phi \cdot \Psi$ MAXWELL - COULOMB

2

MAGNETO - STATIC

$\Phi = i \cdot L$ AMPERE - HENRY

3

ELECTRO - MAGNETIC

$\Phi = E \cdot \tau$ VOLT - SECOND

4

ELECTRO - STATIC

$\Psi = e \cdot C$ VOLT - FARAD

5

MAGNETO - ELECTRIC

$\Psi = I \cdot \tau$ AMPERE - SECOND

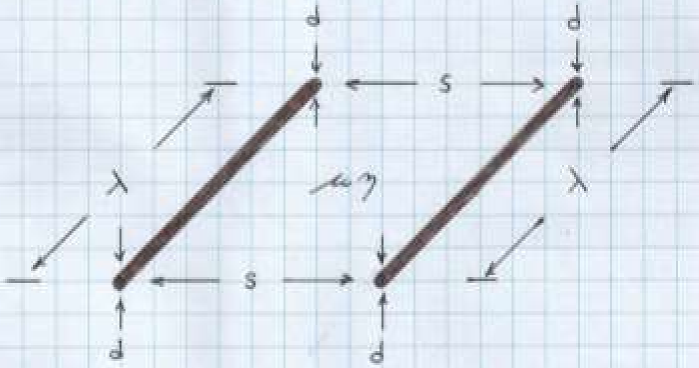
FIGURE (1f)

TABLE OF DERIVED QUANTITIES & MAGNITUDES		
6		
	Φ	MAGNETIC INDUCTION, MAXWELL
	Ψ	DIELECTRIC INDUCTION, COULOMB
7		
	i	MAGNETO-STATIC POTENTIAL, AMPERE
	L	MAGNETIC INDUCTANCE, HENRY
8		
	e	ELECTRO-STATIC POTENTIAL, VOLT
	C	DIELECTRIC CAPACITANCE, FARAD
9		
	I	DISPLACEMENT CURRENT, AMPERE
	E	ELECTRO-MOTIVE FORCE, VOLT
	T	TIME SPAN, SECOND

Chapter 2

Line Geometry in the Electric Medium

ELECTROMAGNETIC GEOMETRY IN MEDIUM, $\mu\eta$



d , CONDUCTOR DIAMETRE

s , CONDUCTOR SPACING

λ , CONDUCTOR LEGNTH

FIGURE (2b)

MAGNETIC DIMENSIONS, C.G.S. E.M. UNITS

1) λ , CONDUCTOR LEGNTH
CENTIMETRE

2) s , CONDUCTOR SPACING
CENTIMETRE

3) d , CONDUCTOR DIAMETER
CENTIMETRE

4) μ , MAGNETIC PERMEABILITY
CENTIMETRE

1

σ^{+1} , SPACE FACTOR — NEPER

$$\cosh \sigma = \frac{s}{d}$$ cm / cm

2

L , MAGNETIC INDUCTANCE,

$$L = \mu\sigma \cdot \lambda$$ HENRY

3

$$\mu = 4 \times 10^{-9}$$ CENTIMETRE

FIGURE (2c)

DIELECTRIC DIMENSIONS, C.G.S. E.S. UNITS			
1)	λ,	CONDUCTOR LENGTH CENTIMETRE	
2)	d,	CONDUCTOR DIAMETRE CENTIMETRE	
3)	s,	CONDUCTOR SPACING CENTIMETRE	
4)	η,	DIELECTRIC PERMITTIVITY PER CENTIMETRE	
4	σ^{-1},	SPACE FACTOR	PER NEPER
		$(\cosh \sigma)^{-1} = \frac{d}{s}$	cm/cm
5	C,	DIELECTRIC CAPACITANCE	
		$C = \frac{\eta}{\sigma} \cdot \lambda$	FARAD, EMU
6		$\eta = \frac{1}{4} \times 10^{+9}$	PER cm

10

FIGURE (2d)

PRODUCT OF DIMENSIONS

7

INDUCTANCE - CAPACITANCE PRODUCT

$$L \cdot C = \left[\mu\sigma \cdot \lambda\right] \cdot \left[\frac{\eta}{\sigma} \cdot \lambda\right]$$

$$L \cdot C = \mu\eta \cdot \lambda^2$$ CM · CM² PER CM

8

E.S TO E.M $\frac{1}{c^2} = \frac{t^2}{\lambda^2}$ LIGHT · SEC² PER CM²

9

ELECTRO - MAGNETIC UNITS

$$\mu \cdot \frac{\eta}{c^2}$$ CM · SEC² PER CM · CM²

10

PRODUCT OF HENRY & FARAD

$$L \cdot C = \mu\eta \cdot t^2 = \tau^2$$ HENRY · FARAD

11

NATURAL TIME

$$\left[L\,C\right]^{1/2} = \tau$$ SECOND

FIGURE (2e)

RATIO OF DIMENSIONS

12

INDUCTANCE TO CAPACITANCE

$$L \div C = \left[\mu\sigma \cdot \lambda\right] \div \left[\frac{\eta}{\sigma} \cdot \lambda\right]$$

$$L \div C = \frac{\mu}{\eta} \cdot \sigma^2$$

CM · CM · CM
PER CM

13

E.S. TO E.M. $\frac{1}{c^2} = \frac{t^2}{\lambda^2}$ LIGHT SEC^2 PER CM^2

14

ELECTRO-MAGNETIC UNITS

$$\mu \cdot \frac{c^2}{\eta}$$

CM · CM · CM^2
PER SEC^2

15

RATIO OF HENRY TO FARAD

$$L \div C = \frac{\mu}{\eta} \cdot \sigma^2 c^2 = Z_c^2$$

HENRY
PER FARAD

16

NATURAL IMPEDANCE

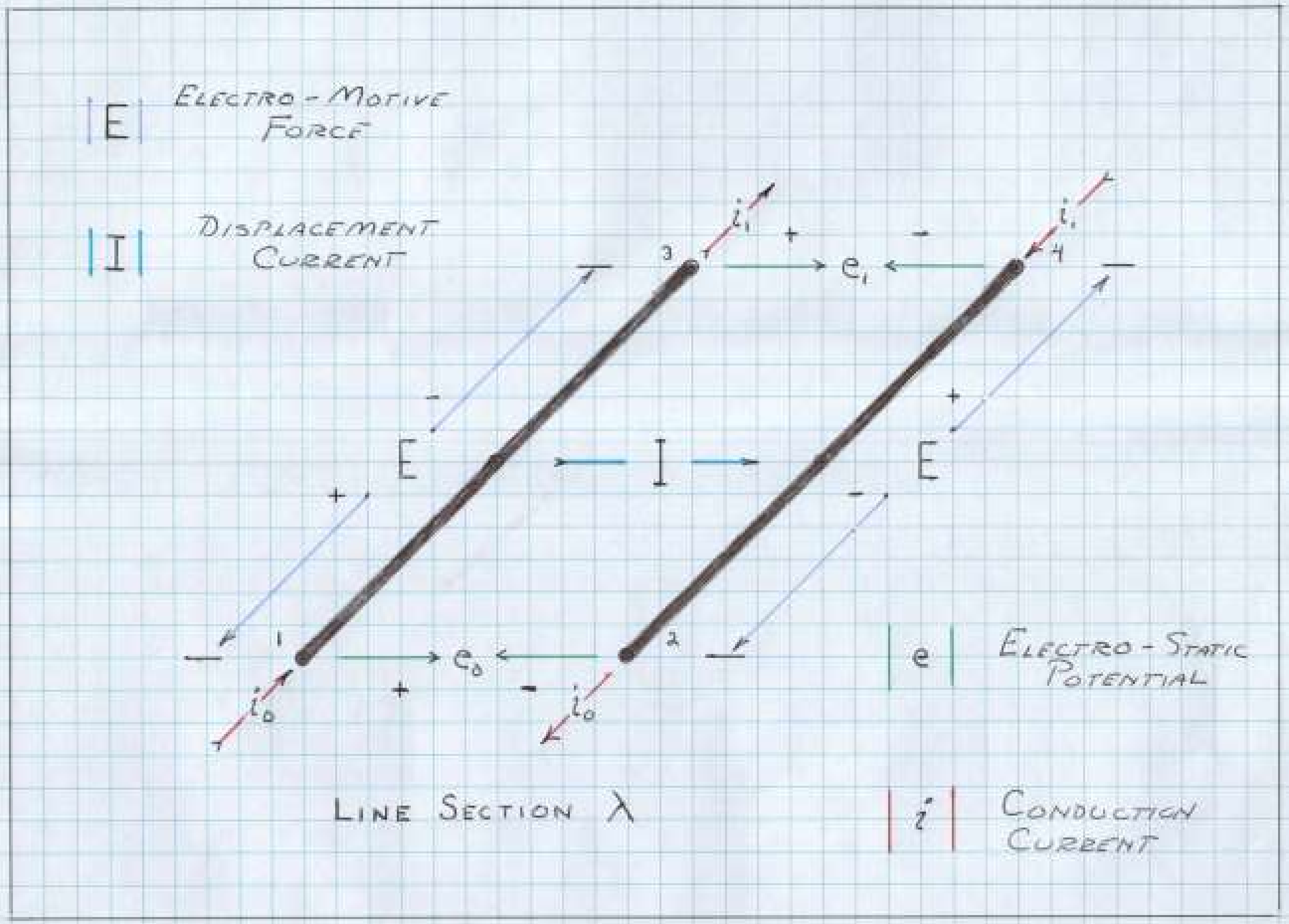
$$\left[\frac{L}{C}\right]^{\frac{1}{2}} = Z_c$$

ZOBEL

Chapter 3

Steinmetz Theory of Complex Electric Power

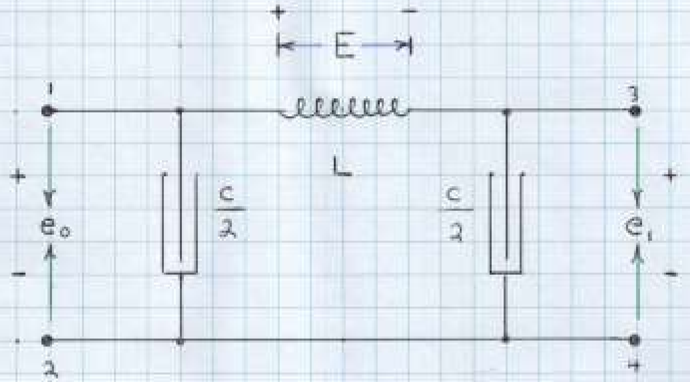
FIGURE (3)



E
ELECTRO-MOTIVE FORCE
I
DISPLACEMENT CURRENT
i₁
e₁
3
4
E
I
E
1
2
e₀
i₀
e
ELECTRO-STATIC POTENTIAL
LINE SECTION λ
i
CONDUCTION CURRENT

KIRCHOFF VOLTAGE RELATION

1 MESH

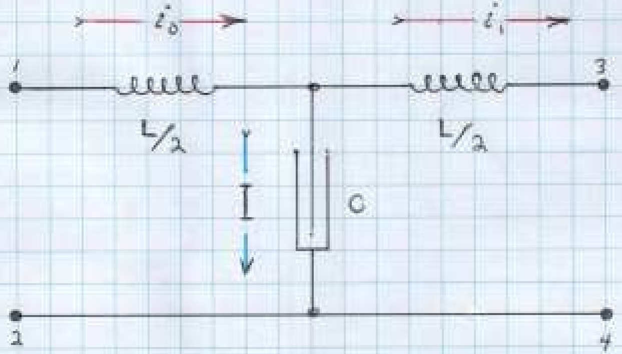


$$e_0 = e_1 + jE \qquad \text{VOLT}$$

FIGURE (3a)

KIRCHOFF CURRENT RELATION

2 STAR



$$i_0 = i_1 + kI \qquad \text{AMPERE}$$

FIGURE (3b)

FIGURE (3c)

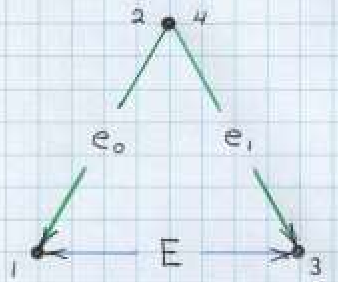
KIRCHOFF VOLTAGE LAW

3

MESH

$$e_0 = e_1 + j\,E$$

$$0 = e_0 - (e_1 + j\,E)$$



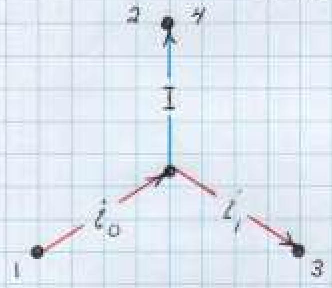
KIRCHOFF CURRENT LAW

4

STAR

$$i_0 = i_1 + kI$$

$$0 = i_0 - (i_1 + kI)$$



5

VOLT-AMPERE PRODUCT

$$e_0 \cdot i_0 = (e_1 + j\,E) \cdot (i_1 + kI)$$

$$= (e_1 i_1 + j\,kEI) + (j\,E i_1 + kI e_1)$$

FIGURE (3d)

Four Quadrant Co-ordinate System

6

$$1 = 1^{0/4} = 1^{4/4} = 1^{8/4} = 1^{12/4} \ldots$$

$$j = 1^{1/4} = 1^{5/4} = 1^{9/4} = 1^{13/4} \ldots$$

$$h = 1^{2/4} = 1^{6/4} = 1^{10/4} = 1^{14/4} \ldots$$

$$k = 1^{3/4} = 1^{7/4} = 1^{11/4} = 1^{15/4} \ldots$$

7

1 , Scalar Co-ordinate System

j , Magnetic Co-ordinate System

h , Composit Co-ordinate System

k , Dielectric Co-ordinate System

8

$j^2 = h \qquad h^2 = j\,k \qquad k^2 = h$

$j = -k \qquad h^2 = +1 \qquad k = -j$

FIGURE (3e)

VOLT - AMPERE PRODUCTS

9

CO-ORDINATE RELATION SUBSTITUTION

$$e_0 i_0 = (e_1 i_1 + 1 \cdot I E) + j (E i_1 - I e_1)$$

10

CONDITION FOR TOTAL ENERGY TRANSFER

$$E i_1 - I e_1 = 0 \quad \text{VOLT-AMPERE}$$

$$e_1 i_1 = I E$$

11

CONDITION FOR TOTAL ENERGY CONTAINMENT

$$e_1 i_1 + I E = 0 \quad \text{WATT}$$

$$-e_1 i_1 = +I E$$

12

DIRECT CURRENT CONDITION

$$\frac{1}{T} = 0 \quad \text{PER SECOND}$$

$$e_0 i_0 = e_1 i_1$$

ELECTRIC POWER RELATIONS

13

$$e_0 i_0 = P_0$$

$$e_1 i_1 = P_1 \qquad IE = P_2$$

$$E i_1 = P_m \qquad I e_1 = P_d$$

P_0 , POWER INTO LINE SECTION , λ

P_1 , POWER OUT OF LINE SECTION , λ

P_2 , ELECTROMAGNETIC POWER

P_m , MAGNETIC POWER

P_d , DIELECTRIC POWER

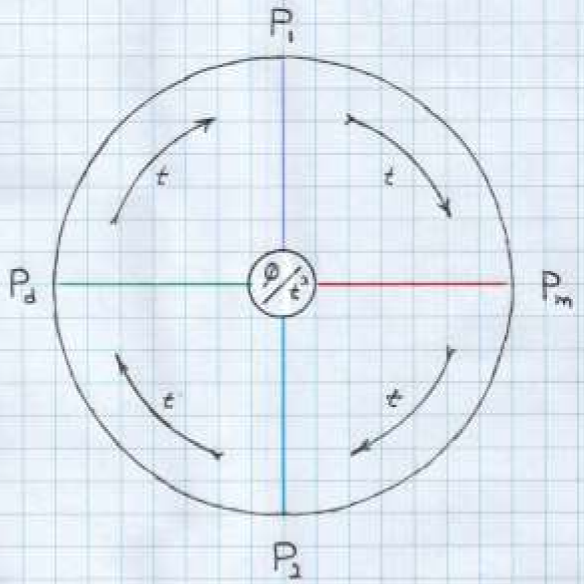
14 SUBSTITUTION INTO VOLT-AMPERE EQ

$$P_0 = (P_1 + 1 \cdot P_2) + j(P_m - P_d)$$

FIGURE (3g)

Time Cycle of Electric Power

One Time Cycle, T



$T = 4t$ SECOND

15

Active Power

$$P_a = P_1 + P_2$$ WATT

16

Reactive Power

$$P_b = P_m - P_d$$ VAR

Representation of Electric Power

17

Complex Electric Power

ACTIVE POWER	$P_a = P_1 + P_2$	WATT
REACTIVE POWER	$P_b = P_m - P_d$	VAR
APPARENT POWER	$P_o = P_a + j P_b$	VOLT-AMPERE

18

Proportionality Factors

$$\frac{P_a}{P_o} = a \qquad \text{NUMERIC}$$

$$\frac{P_b}{P_o} = b \qquad \text{NUMERIC}$$

19

Propagation Factor of Power

$$\gamma = a + j b \qquad \text{VERSOR}$$

Chapter 4

Heaviside-Maxwell Theory of Electric Propagation in Electromagnetic Systems

FIGURE (4a)

VARIATION WITH RESPECT TO SPACE

1

LAW OF MAGNETIC PROPORTION

$$i = \frac{\phi_1}{L} \qquad \text{MAXWELL / HENRY}$$

i = MAGNETO - STATIC POTENTIAL, AMPERE

2

LAW OF DIELECTRIC PROPORTION

$$e = \frac{\psi_1}{C} \qquad \text{COULOMB / FARAD}$$

e = ELECTRO - STATIC POTENTIAL, VOLT

3

ELECTRIC ACTIVITY

$$e \cdot i = \frac{\phi_1 \, \psi_1}{L \, C} \qquad \text{MAXWELL · COULOMB PER HENRY · FARAD}$$

$$e \cdot i = P_1 \qquad \text{WATT}$$

FIGURE (4b)

VARIATION WITH RESPECT TO TIME

4

LAW OF
ELECTRO-MAGNETIC INDUCTION

$$E = \frac{\phi_{11}}{T} \quad \text{maxwell / sec}$$

E = ELECTRO-MOTIVE FORCE, VOLT

5

LAW OF
MAGNETO-ELECTRIC INDUCTION

$$I = \frac{\Psi_{11}}{T} \quad \text{coulomb / sec}$$

I DISPLACEMENT CURRENT, AMPERE

6

ELECTROMAGNETIC
ACTIVITY

$$E \cdot I = \frac{\phi_{11} \Psi_{11}}{t^2} \quad \text{maxwell} \cdot \text{coulomb / sec}^2$$

$$E \cdot I = P_2 \quad \text{volt-ampere reactive}$$

FIGURE (4c-1)

SPACE-TIME CROSS PRODUCTS

7

ELECTRO-MAGNETIC ACTIVITY, METALLIC

$$E \cdot i = \frac{\phi_{I} \ \phi_{II}}{L \ \ T}$$

MAXWELL · MAXWELL
PER HENRY · SECOND

$$E \cdot i = P_m$$

VOLT - AMPERE

8

ELECTRO-STATIC ACTIVITY, DIELECTRIC

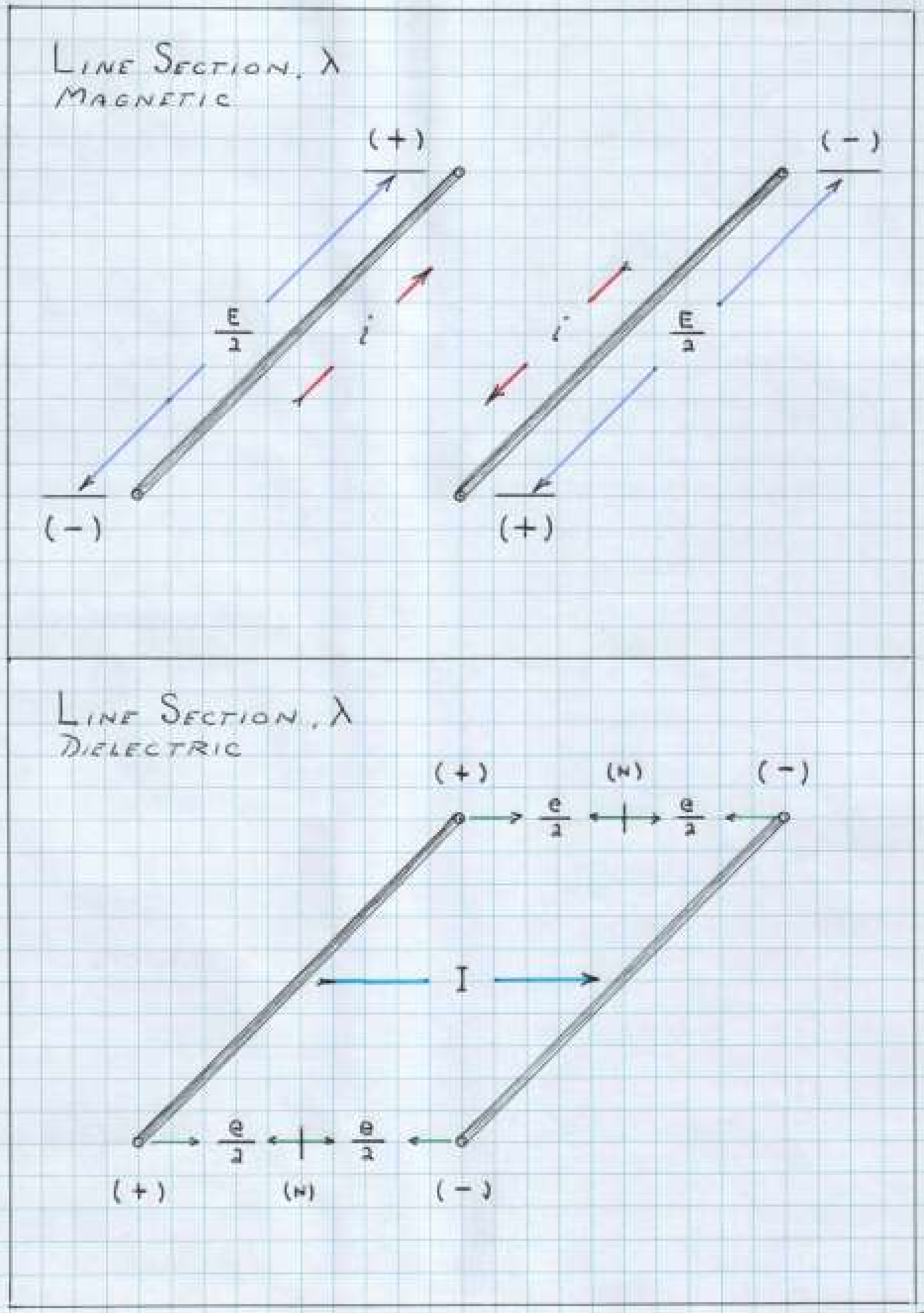
$$I \cdot e = \frac{\Psi_{I} \ \Psi_{II}}{C \ \ T}$$

COULOMB · COULOMB
PER FARAD · SECOND

$$I \cdot e = P_d$$

VOLT - AMPERE

FIGURE (4c-2)



LINE SECTION, λ
MAGNETIC
(+)
(−)
E/2
i
i
E/2
(−)
(+)
LINE SECTION, λ
DIELECTRIC
(+)
(N)
(−)
e/2
e/2
I
e/2
e/2
(+)
(N)
(−)

FIGURE (4d)

SPACE-TIME RELATIONS, VOLT

9

ELECTRO-MOTIVE FORCE
TO
ELECTRO-STATIC POTENTIAL

$$-E = e$$ VOLT

10

EQUIVILENT RELATIONS

$$E = \frac{\Phi_{11}}{T} = \frac{\Psi_1}{C} = e$$

- MAXWELL / SEC
- COULOMB / FARAD
- VOLT

11

RE-ARRANGING TERMS

$$\frac{\Psi_1}{\Phi_{11}} = \frac{C}{T}$$ COULOMB / MAXWELL

12

RESULTING ADMITTANCE

$$\frac{C}{T} = Y_s$$ FARAD / SEC

13

DIELECTRIC TRANSFER ADMITTANCE

$$Y_s = \frac{\Psi_1}{\Phi_{11}}$$ SIEMENS

FIGURE (4e)

SPACE - TIME RELATIONS, AMPERE

14

DISPLACEMENT CURRENT
TO
CONDUCTION CURRENT

$$-I = i$$ AMPERE

15

EQUIVILENT RELATIONS

$$I = \frac{\Psi_{11}}{T} = \frac{\phi_1}{L} = i$$

: COULOMB / SEC
: MAXWELL / HENRY
: AMPERE

16

RE-ARRANGING TERMS

$$\frac{\phi_1}{\Psi_{11}} = \frac{L}{T}$$ MAXWELL / COULOMB

17

RESULTING IMPEDANCE

$$\frac{L}{T} = Z_s$$ HENRY / SECOND

18

MAGNETIC TRANSFER IMPEDANCE

$$Z_s = \frac{\phi_1}{\Psi_{11}}$$ OHM

FIGURE (4 d e)

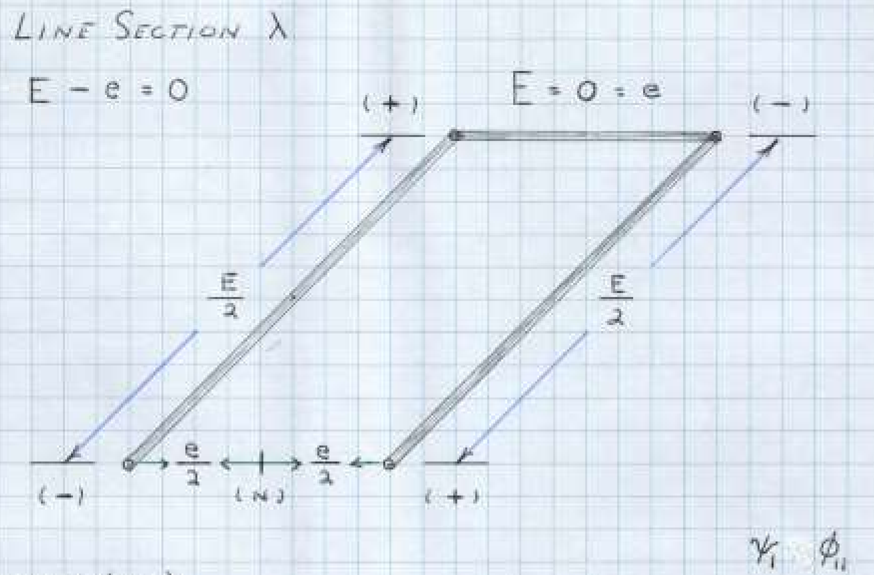


FIGURE (4d)

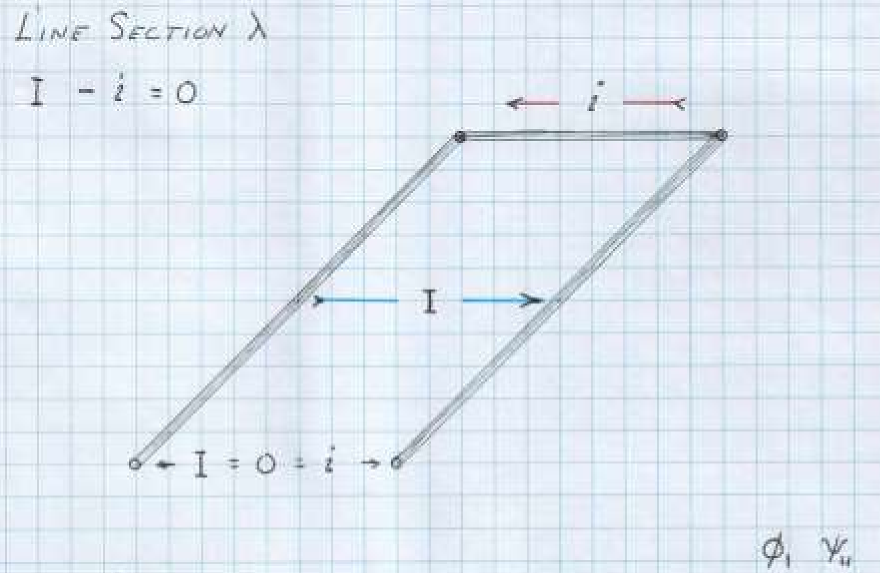


FIGURE (4e)

FIGURE (4f)

MAXWELL'S EQUATIONS

19

FIRST CIRCUITAL EQUATION
DISPLACEMENT CURRENT

$$-\frac{I}{\lambda} = \frac{\eta}{\sigma} \cdot \frac{e}{\tau}$$

AMPERE / cm

ES UNITS

20

SECOND CIRCUITAL EQUATION
ELECTRO-MOTIVE FORCE

$$-\frac{E}{\lambda} = \mu\sigma \cdot \frac{i}{\tau}$$

VOLT / cm

EM UNITS

21

PRODUCT OF EQUATIONS

$$\frac{E\,I}{\lambda^2} = \frac{\mu\eta}{c^2} \cdot \frac{e\,i}{\tau^2}$$

VOLT-AMPERE PER cm ^{2}

22

RE-ARRANGING TERMS

$$\frac{E\,I}{e\,i} = \frac{\mu\eta}{c^2} \cdot \frac{\lambda^2}{\tau^2}$$

VOLT-AMPERE PER WATT

FIGURE (4g)

MAXWELL'S EQUATIONS

23

PROPAGATION VELOCITY RELATION

$$\frac{\lambda^2}{T^2} \cdot \mu\eta = v^2 \qquad cm^2 \cdot cm / sec^2 \cdot cm$$

24

RATIO OF VELOCITY RELATIONS

$$\frac{\lambda^2}{T^2} \cdot \frac{\mu\eta}{c^2} = \frac{v^2}{c^2} \qquad cm^2 \cdot sec^2 / sec^2 \cdot cm^2$$

25

SUBSTITUTION OF TERMS

$$\frac{E\,I}{e\,i} = \frac{v^2}{c^2}$$

VOLT-AMPERE PER WATT

26

RE-ARRANGING TERMS

$$\frac{E\,I}{e\,i} = \frac{E}{i} \cdot \frac{I}{e}$$

OHM-SIEMENS

27

IMPEDANCE & ADMITTANCE

$$\frac{E}{i} = Z \text{ OHM} \quad , \quad \frac{I}{e} = Y \text{ SIEMENS}$$

FIGURE (4h)

Maxwell's Equations

28

Substituting Terms

$$Z \cdot Y = \frac{V^2}{c^2}$$ OHM-SIEMENS

29

Propagation Function

$$Z \cdot Y = \gamma^2$$ NEPER^2

30

Propagation Constant Relation

$$\frac{\gamma^2}{\lambda^2} = \beta^2$$ NEPER^2/cm^2

31

Propagation Constant

$$\frac{\gamma}{\lambda} = \beta$$ NEPER/cm

32

Maxwell's Co-efficient

ES UNITS TO EM UNITS $= \frac{1}{c^2}$ SEC^2/cm^2

FIGURE (4i)

MAXWELL'S EQUATIONS

33

FIRST CIRCUITAL EQUATION

$$-\frac{I}{\lambda} = \frac{\varepsilon}{\sigma} \cdot \frac{e}{\tau}$$

AMPERE / cm

EM UNITS

34

SECOND CIRCUITAL EQUATION

$$-\frac{E}{\lambda} = \mu\sigma \cdot \frac{i}{\tau}$$

VOLT / cm

EM UNITS

35

RATIO OF EQUATIONS

$$\frac{E}{I} = \frac{\mu\sigma^2}{\varepsilon} \cdot \frac{i}{e}$$

VOLT / AMPERE

36

RE-ARRANGING TERMS

$$\frac{E}{i} = \frac{\mu\sigma^2}{\varepsilon} \cdot \frac{I}{e}$$

VOLT / AMPERE

37

PERMITTIVITY
EM UNITS

$$\varepsilon = \frac{\eta}{c^2}$$

$sec^2 / cm^2 \cdot cm$

FIGURE (4 i)

Maxwell's Equations		
38 **Magnetic Impedance**		
$\frac{E}{i} = Z_m$		volt / ampere
39 **Dielectric Admittance**		
$\frac{I}{e} = Y_d$		ampere / volt
40 **Natural (Geometric) Impedance**		
$\frac{\mu}{\varepsilon}\sigma^2 = Z_c^2$		$cm \cdot cm \cdot cm^2 / sec^2$
41 **Substitution into Ratio Equation**		
$Z_m = Z^2 \cdot Y_d$		EM units

32

FIGURE (4k)

MAXWELL'S EQUATIONS

42

RE-ARRANGING TERMS

$$\frac{Z_m}{Y_d} = Z_c^2$$ OHM / SIEMENS

43

NATURAL IMPEDANCE

$$\left[\frac{Z_m}{Y_d}\right]^{\frac{1}{2}} = Z_c$$ ZOBEL

FIGURE (42)

	MAXWELL'S EQUATIONS		
44	EQUIVILENT FIRST EQUATION $I = \frac{C}{T} \cdot e$	VOLT · FARAD / SEC	
45	EQUIVILENT SECOND EQUATION $E = \frac{L}{T} \cdot i$	AMPERE · HENRY / SEC	
46	DIELECTRIC SUCEPTANCE $\frac{C}{T} = B$	FARAD / SEC	
47	MAGNETIC REACTANCE $\frac{L}{T} = X$	HENRY / SEC	
48	TIME VARIABLE	T	SECOND

FIGURE (Hm)

MAXWELL'S EQUATIONS

49

FIRST EQUATION SUBSTITUTION

$$I = B \cdot e$$ AMPERE

50

SECOND EQUATION SUBSTITUTION

$$E = X \cdot i$$ VOLT

51

PRODUCT OF EQUATIONS

$$E \cdot I = X B \cdot e i$$ VOLT · AMPERE

52

RATIO OF EQUATIONS

$$\frac{E}{I} = \frac{X}{B} \cdot \frac{i}{e}$$ VOLT / AMPERE

FIGURE (4 n)

DERIVED LINE CHARACTERISTICS

53

PROPAGATION FUNCTION

$$\gamma^2 = X \cdot B$$ HENRY · FARAD / SEC^2

54

PROPAGATION FACTOR

$$\gamma = \left[X B \right]^{\frac{1}{2}} = \left[\frac{L C}{T^2} \right]^{\frac{1}{2}}$$ SEC / SEC

55

PROPAGATION CONSTANT

$$\beta = \frac{\gamma}{\lambda} = \left[\frac{X B}{\lambda^2} \right]$$ SEC / SEC · cm

56

NATURAL TIME

$$T = \sqrt{L C}$$ SECOND

FIGURE (4.0)

DERIVED LINE CHARACTERISTICS

57

IMPEDANCE FUNCTION

$$Z_c^2 = \frac{X}{B}$$ OHM / SIEMENS

58

NATURAL IMPEDANCE

$$Z_c = \left[\frac{X}{B}\right]^{\frac{1}{2}} = \left[\frac{L}{C}\right]^{\frac{1}{2}}$$ ZOBEL

Chapter 4 (A)

Steinmetz-Kennelly Engineering Formulation as Applied to the Long Line Problem


FIG (4)


FIG (4) CONTINUED

FIGURE (4-1)

STEINMETZ EQUATIONS	
1 CURRENT EQUATION	
$i = ai_1 + jbI$	AMPERE
2 DISPLACEMENT CURRENT	
$I = e_1 \cdot Y_c$	VOLT / ZOBEL
3 NATURAL ADMITTANCE	
$\left[\frac{Y}{Z}\right]^{\frac{1}{2}} = Y_c$	PER ZOBEL

FIGURE (4-2)

Steinmetz Equations	
4 Voltage Equation	
$e = a e_1 + kbE$	VOLT
5 Electro-Motive Force	
$E = i_1 \cdot Z_c$	AMPERE - ZOBEL
6 Natural Impedance	
$\left[\frac{Z}{Y} \right]^{\frac{1}{2}} = Z_c$	ZOBEL

FIGURE (4-3)

STEINMETZ EQUATIONS	
7 ATTENUATION CONSTANT $\alpha = 0$	NEPER
8 DISTANCE ANGLE $\delta = \beta \lambda$	RADIAN
9 DISTANCE ANGLE FUNCTION $a = \cos \delta$	NUMERIC
10 DISTANCE ANGLE FUNCTION $b = \sin \delta$	NUMERIC

FIGURE (4-4)

LINE CHARACTERISTICS

11

LINE ANGLE

$\theta = \beta \lambda$ RADIAN

$\theta = 2.26 \times 10^{-3} \cdot 200$ RADIAN-MILE/MILE

$\theta = 0.452$ RADIAN

12

LINE ANGLE FUNCTIONS

$a = \cos\theta$ NUMERIC

$b = \sin\theta$ NUMERIC

$\cos 0.452 = 0.900$

$\sin 0.452 = 0.437$

13

NATURAL ADMITTANCE

$Y_c = 5 \times 10^{-3}$ PER ZOBEL

14

NATURAL IMPEDANCE

$Z_c = 2 \times 10^{+2}$ ZOBEL

FIGURE (4-5)

TERMINAL CONDITIONS	
15 RECIEVING END VOLTAGE e_1 = 60,000	VOLT
16 RECIEVING END CURRENT i_1 = 200	AMPERE
17 RECIEVING END IMPEDANCE $e_1 \div i_1$ = 300	OHM
18 RECIEVING END ANGLE δ = ZERO	RADIAN

FIGURE (4-6)

STEINMETZ EQUATIONS

19

DISPLACEMENT CURRENT

$$I = e_1 Y_c$$

$$I = 6 \times 10^{+4} \cdot 5 \times 10^{-3}$$

$$I = 300 \quad \text{AMPERE}$$

20

ELECTRO-MOTIVE FORCE

$$E = i_1 Z_c$$

$$E = 200 \cdot 200$$

$$E = 40{,}000 \quad \text{VOLT}$$

21

CURRENT EQUATION

$$a\, i_1 = 0.900 \cdot 200$$

$$i_a = 180 \quad \text{AMPERE}$$

22

VOLTAGE EQUATION

$$a\, e_1 = 0.900 \cdot 60{,}000$$

$$e_a = 54{,}000 \quad \text{VOLT}$$

FIGURE (4-7)

STEINMETZ EQUATIONS

23

CURRENT EQUATION

$$b\,I = 0.437 \cdot 300$$

$$I_b = 131 \quad \text{AMPERE}$$

24

VOLTAGE EQUATION

$$b\,E = 0.437 \cdot 40{,}000$$

$$E_b = 17{,}480 \quad \text{VOLT}$$

25

SENDING END CURRENT

$$i_a^2 + I_b^2 = i_o^2$$

$$i_o = 223 \quad \text{AMPERE}$$

$$\theta_i = \tan^{-1} I_b / i_a = 0.633 \quad \text{RADIAN}$$

26

SENDING END VOLTAGE

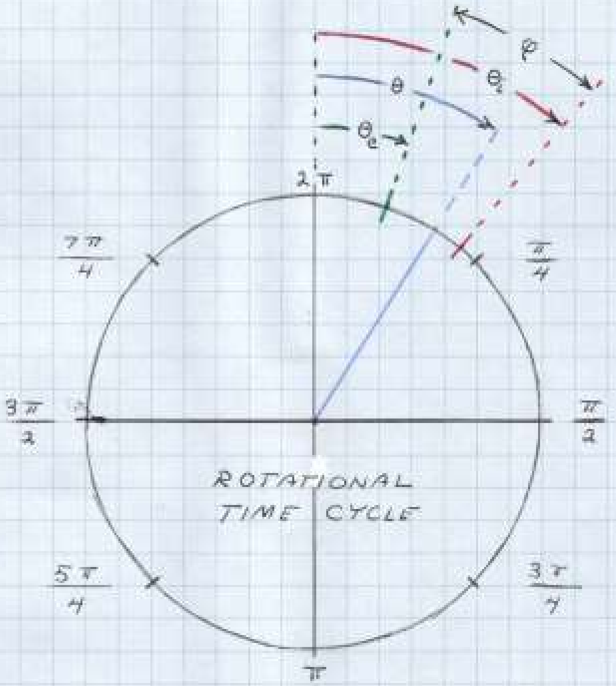
$$e_a^2 + E_b^2 = e_o^2$$

$$e_o = 56{,}800 \quad \text{VOLT}$$

$$\theta_e = \tan^{-1} E_b / e_a = 0.309 \quad \text{RADIAN}$$

FIGURE (4-8)

VOLTAGE AND CURRENT ANGLES



θ LINE ANGLE 0.452 RAD	φ PHASE ANGLE 0.324 RAD
θ_i CURRENT ANGLE 0.633 RAD , 0.181 LEAD	θ_e VOLTAGE ANGLE 0.309 RAD , 0.143 LAG

FIGURE (4-9)

SENDING END POWER

27

APPARENT SENDING END POWER

$$P_o = e_o \cdot i_o = 12,660 \quad \text{KVA}$$

28

COMPLEX POWER

$$\dot{P} = a P_o + j b \cdot P_o$$

$$\dot{P} = P_o (a + j b)$$

$$\dot{P} = P_a + j P_b \quad \text{KVA}$$

29

PHASE ANGLE $\varphi = 0.324$ RADIAN

30

POWER FACTOR

$$a = \cos \varphi \quad \text{NUMERIC}$$

31

INDUCTION FACTOR

$$b = \sin \varphi \quad \text{NUMERIC}$$

FIGURE (4-10)

POWER COMPONENTS

32

PHASE ANGLE FUNCTIONS

$a = \cos 0.324 = 0.948$ NUMERIC

$b = \sin 0.324 = 0.318$ NUMERIC

33

ACTIVE POWER

$$P_a = a P_o$$

$$P_a = 0.948 \times 12{,}660$$

$$P_a = 12{,}000$$ KILOWATT

34

REACTIVE POWER

$$P_b = b P_o$$

$$P_b = 0.318 \times 12{,}660$$

$$P_b = 4{,}000$$ KILOVAR

35

RECIEVING END POWER

$$P_1 = e_1 \cdot i_1 = 12{,}000$$ KILOWATT

FIGURE (4-11)

ACTIVITY COMPONENTS

36

ELECTROMAGNETIC ACTIVITY

$$P_2 = E I$$

$$P_2 = 40{,}000V \times 300A$$

$$P_2 = 12{,}000 \quad KVAR$$

37

MAGNETIC ACTIVITY

$$P_m = E\, i_1$$

$$P_m = 40{,}000V \times 200A$$

$$P_m = 8{,}000 \quad KVA$$

38

DIELECTRIC ACTIVITY

$$P_d = I\, e_1$$

$$P_d = 60{,}000v \times 300A$$

$$P_d = 18{,}000 \quad KVA$$

FIGURE (4-12)

POWER AND ACTIVITY

e_1	RECIEVING END POTENTIAL		
VOLT	60,000	60,000	60,000
i_1	RECIEVING END CURRENT		
AMP	200	300	450
P_1	RECIEVING END POWER		
KW	12,000	18,000	27,000

I	DISPLACEMENT CURRENT		
AMP	300	300	300
E	ELECTRO-MOTIVE FORCE		
VOLT	40,000	60,000	90,000
P_2	ELECTROMAGNETIC ACTIVITY		
KVAR	12,000	18,000	27,000
	m = 1.5 : 1	m = 1 : 1	m = 1 : 1.5

FIGURE (4-13)

MAGNETIC & DIELECTRIC

E	ELECTRO-MOTIVE FORCE		
VOLT	40,000	60,000	90,000
i_1	RECIEVING END CURRENT		
AMP	200	300	450
P_m	MAGNETIC ACTIVITY		
KVA	8,000	18,000	40,500

I	DISPLACEMENT CURRENT		
AMP	300	300	300
e_1	RECIEVING END POTENTIAL		
VOLT	60,000	60,000	60,000
P_d	DIELECTRIC ACTIVITY		
KVA	18,000	18,000	18,000
	1.5 : 1	1 : 1	1 : 1.5

11 FIGURE (4-14)

APPARENT SENDING END POWER

e_o	SENDING END POTENTIAL		
VOLT	56,800	60,000	67,000
i_o	SENDING END CURRENT		
AMP	223	300	430
P_o	SENDING END POWER		
KVA	12,660	18,000	28,790
	m = 1.5:1	m = 1:1	m = 1:1.5

P_a	ACTIVE POWER		
KW	12,000	18,000	27,000
P_b	REACTIVE POWER		
KVAR	4,000	0,000	4,000
	m = 1.3:1	m = 1:1	m = 1:1.5

FIGURE (4-15)

Power & Activity			
P_o	Sending End Power		
KVA	12,660	18,000	28,970
P_1	Recieving End Power		
KW	12,000	18,000	27,000
P_2	Electromagnetic Activity		
KVAR	12,000	18,000	27,000
P_m	Magnetic Activity		
KVA	8,000	18,000	40,500
P_d	Dielectric Activity		
KVA	18,000	18,000	18,000
P_a	Active Power		
KW	12,000	18,000	27,000
P_b	Reactive Power		
KVAR	4,000	0,000	4,000
	1.5 : 1	1 : 1	1 : 1.5

FIGURE (4-16)

COMPARATIVE MAGNITUDES

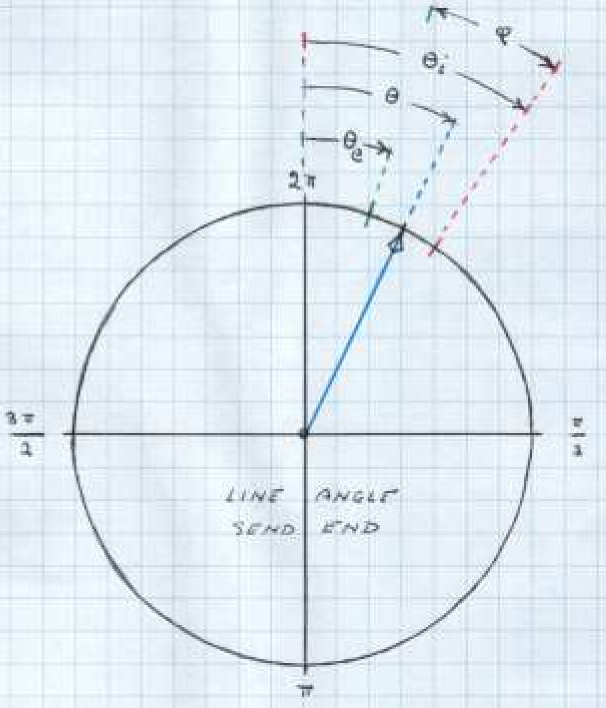
e_1	RECIEVING END VOLTAGE		
VOLT	60,000	60,000	60,000
e_a	VECTOR ELECTRO-STATIC POTENTIAL		
VOLT	54,000	54,000	54,000
E	ELECTRO-MOTIVE FORCE		
VOLT	40,000	60,000	90,000
E_h	VECTOR ELECTRO-MOTIVE FORCE		
VOLT	17,500	26,200	39,600

i_1	RECIEVING END CURRENT		
AMP	200	300	450
i_a	VECTOR CONDUCTION CURRENT		
AMP	180	270	410
I	DISPLACEMENT CURRENT		
AMP	300	300	300
I_b	VECTOR DISPLACEMENT CURRENT		
AMP	131	131	131

FIGURE (4-17)

ANGULAR DISPLACEMENTS

m = 1.5 : 1

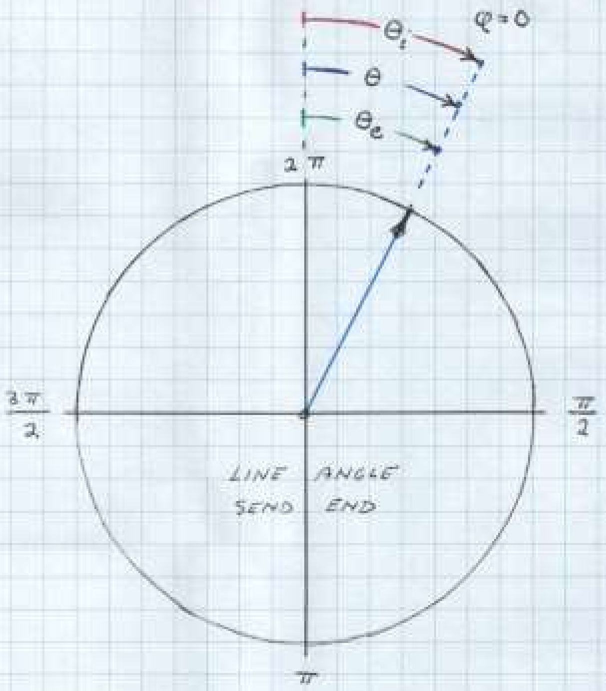


θ, LINE ANGLE	φ, PHASE ANGLE
0.452 RAD, 25.9 DEG	0.342 RAD, 18.6 DEG
θ_i, CURRENT ANGLE	θ_e, VOLTAGE ANGLE
0.633 RAD, 36.2 DEG	0.309 RAD, 17.7 DEG

FIGURE (4-18)

ANGULAR DISPLACEMENTS

m = 1 : 1

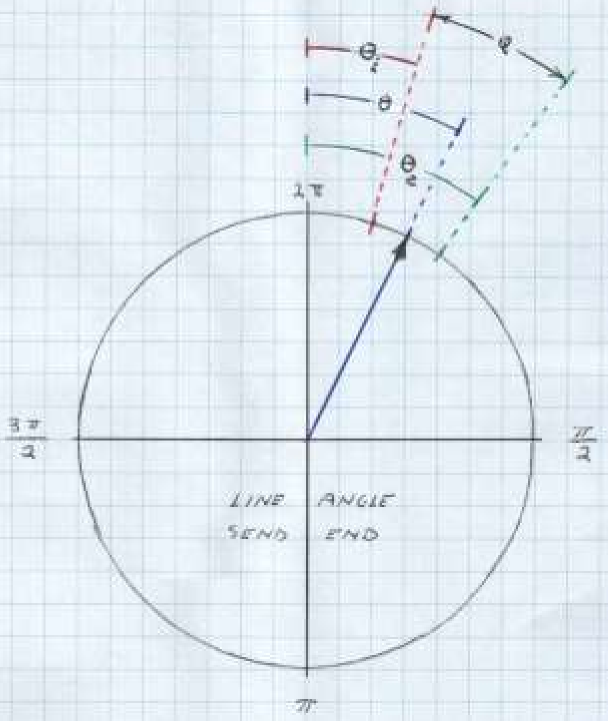


θ , LINE ANGLE	φ , PHASE ANGLE
0.452 RAD , 25.9 DEG	ZERO
θ_i , CURRENT ANGLE	θ_e , VOLTAGE ANGLE
0.452 RAD , 25.9 DEG	0.452 RAD , 25.9 DEG

FIGURE (4-19)

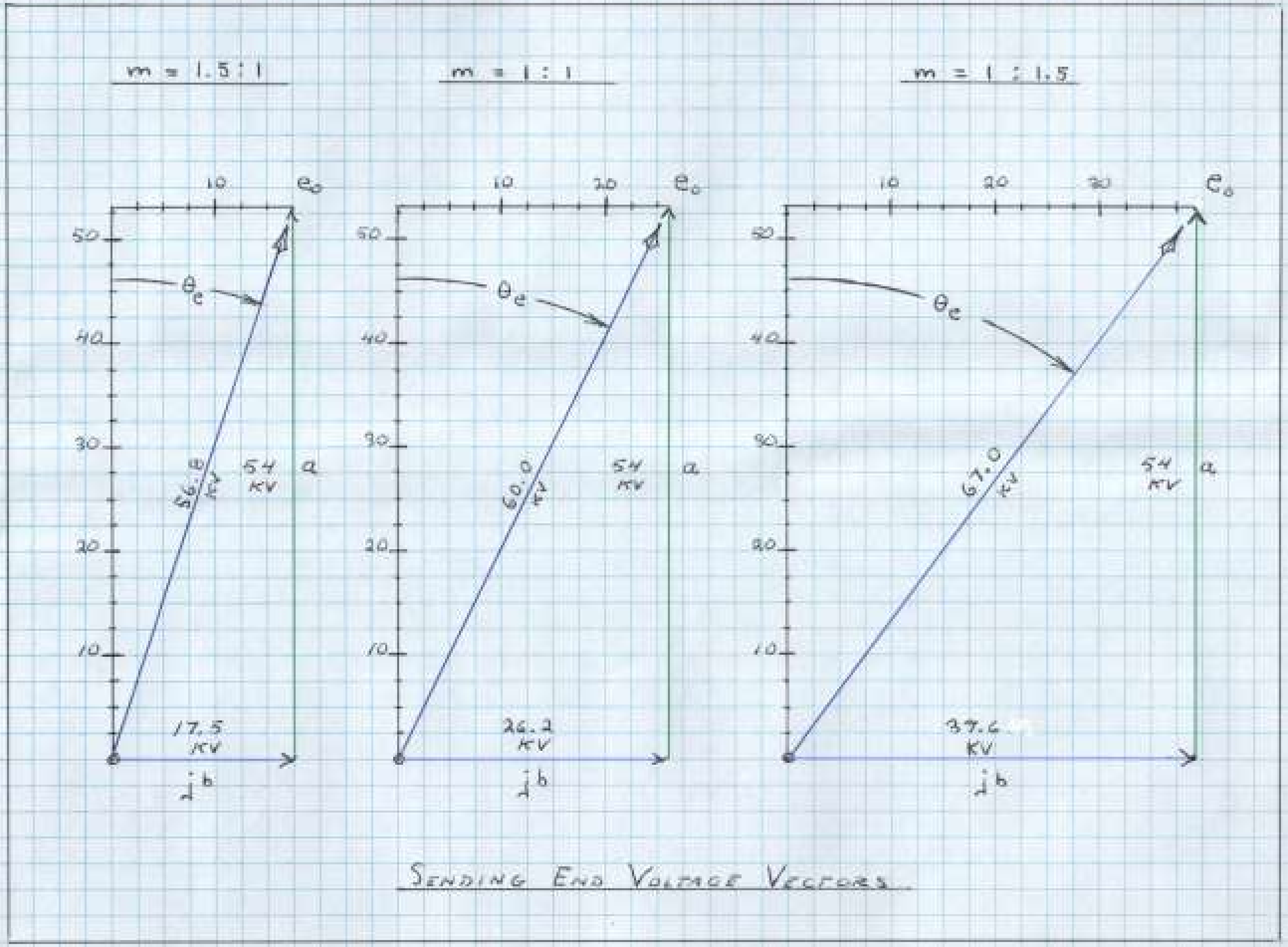
ANGULAR DISPLACEMENTS

m = 1 : 1.5



θ, LINE ANGLE 0.432 RAD, 25.9 DEG	φ, PHASE ANGLE 0.324 RAD, 18.6 DEG
θ_i, CURRENT ANGLE 0.309 RAD, 17.7 DEG	θ_e, VOLTAGE ANGLE 0.633 RAD, 36.2 DEG

FIGURE (4-20)



SENDING END VOLTAGE VECTORS

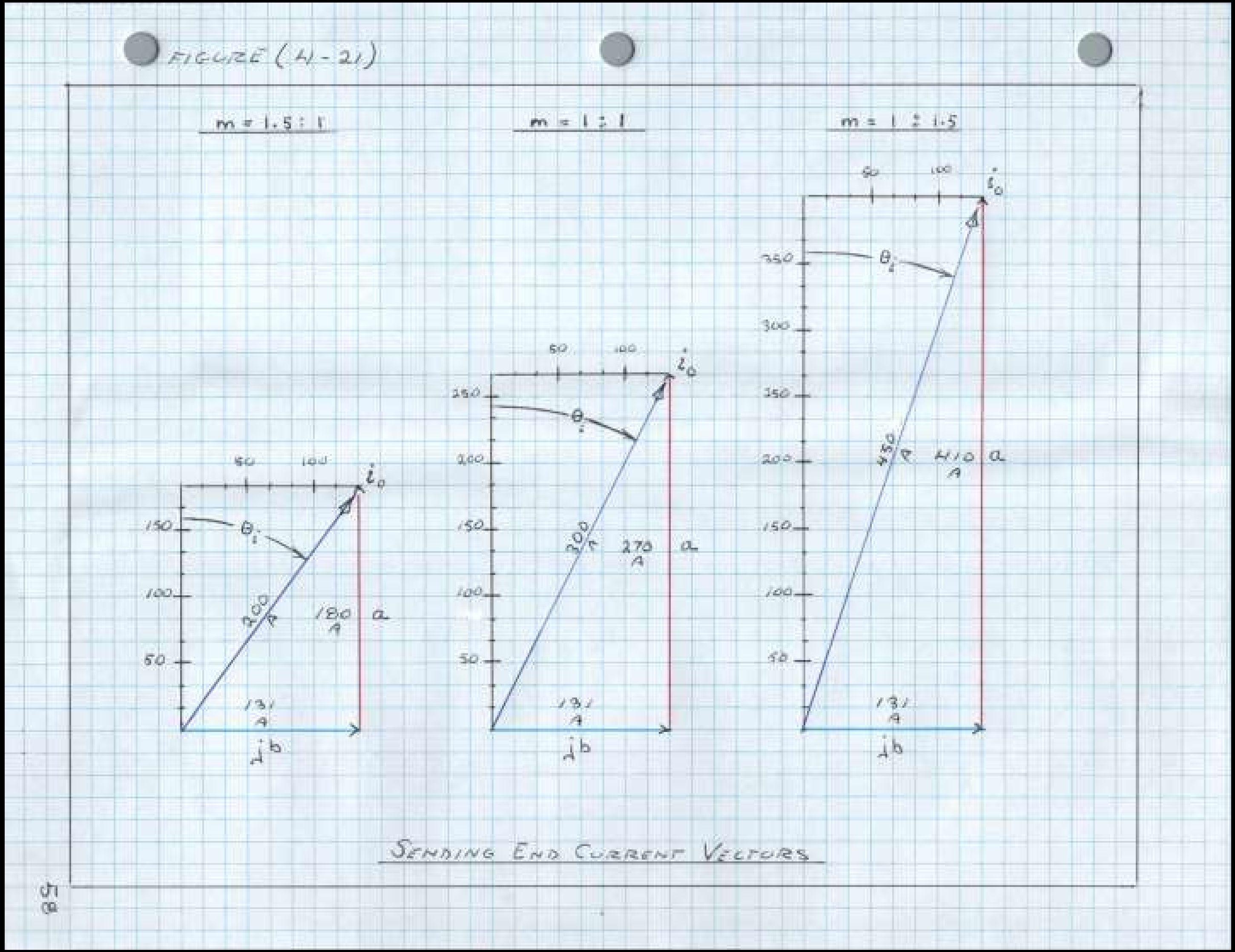


FIGURE (4-21)
m = 1.5 : 1
m = 1 : 1
m = 1 : 1.5
i_o
θ_i
200 A
180 A
131 A
a
i_b
300 A
270 A
450 A
410 A
SENDING END CURRENT VECTORS

Chapter 5

Heaviside General Equation as Applied to Power, Force & Energy

FIGURE (5a)

General Equation of Electric Induction

1

Induction

$$\phi_{I} = i_{I}\,L \quad , \quad \phi_{II} = E\,T_m$$

$$\psi_{I} = e_{I}\,C \quad , \quad \psi_{II} = I\,T_d$$

2

Time

$$T_0^2 = \frac{L\,C}{Z\,Y} \quad , \quad T_m = \frac{L}{Z}$$

$$\tau^2 = L\,C \quad , \quad T_d = \frac{C}{Y}$$

3

Substitution into Power Relation

$$P_0 = \left[\frac{\phi_{I}\,\psi_{I}}{\tau^2} + \frac{\phi_{II}\,\psi_{II}}{T_0^2} \right] + j \left[\frac{i_{I}\,\phi_{II}}{T_m} - \frac{e_{I}\,\psi_{II}}{T_d} \right]$$

$$P_0 = \left[\frac{\varphi_{1}}{\tau^2} + \frac{\varphi_{2}}{T_0^2} \right] + j \left[\frac{W_m}{T_m} - \frac{W_d}{T_d} \right]$$

FIGURE (5b)

GENERAL EQUATION OF ELECTRIC INDUCTION		
4		
φ_1	QUANTITY OF ELECTRIC INDUCTION	
	$\varphi_1 = \phi_1 \Psi_1$	MAXWELL-COULOMB
5		
φ_2	QUANTITY OF ELECTROMAGNETIC INDUCTION	
	$\varphi_2 = \phi_{11} \Psi_{11}$	PLANCK
6		
W_m	ENERGY OF MAGNETIC INDUCTION	
	$W_m = i_1 \phi_{11}$	AMPERE-MAXWELL
7		
W_d	ENERGY OF DIELECTRIC INDUCTION	
	$W_d = e_1 \Psi_{11}$	VOLT-COULOMB

FIGURE (5c)

GENERAL EQUATION OF ELECTRIC INDUCTION

8

COMPLEX ELECTRIC POWER

$$P_o = P_a + j P_b$$ VOLT - AMPERE

$$P_o = P_a + k P_b$$ VOLT - AMPERE

9

ENERGY AND FORCE TERM

$$P_b = \frac{i_1 \phi_{11}}{T_m} - \frac{e_1 \psi_{11}}{T_d}$$

$$P_b = P_m - P_d$$ VOLT - AMPERE REACTIVE

10

ENERGY RELATIONS

$$P_m = \frac{i_1 \phi_{11}}{T_m} \qquad W_m = P_m \cdot T_m$$

$$P_d = \frac{e_1 \psi_{11}}{T_d} \qquad W_d = P_d \cdot T_d$$

FIGURE (5d)

ENERGY & FORCE RELATIONS

11

MAGNETIC ENERGY

$$W_m = i_1 \phi_{11} = \frac{i_1 \cdot i_{11} \cdot L}{2}$$

$$W_m = \frac{1}{2} i^2 L \qquad \text{JOULE}$$

12

DIELECTRIC ENERGY

$$W_d = e_1 \psi_{11} = \frac{e_1 \cdot e_{11} \cdot C}{2}$$

$$W_d = \frac{1}{2} e^2 C \qquad \text{JOULE}$$

13

SUBSTITUTION INTO GENERAL EQUATION

$$W = \frac{1}{2}\left[i^2 L - e^2 C \right]$$

$$W = W_m - W_d \qquad \text{JOULE}$$

FIGURE (5e)

ENERGY & FORCE RELATIONS

14

FORCE ON CONDUCTORS, MAGNETIC

$$+f = +\frac{W}{S} \cdot \frac{N}{\sigma} \qquad \text{GRAM}$$

15

FORCE ON CONDUCTORS, DIELECTRIC

$$+f = -\frac{W}{S} \cdot \frac{N}{\sigma} \qquad \text{GRAM}$$

16

FORCE ON CONDUCTORS, RESULTANT

$$\pm f = f_m - f_d \qquad \text{GRAM}$$

17

SPACE FACTOR

$$\sigma = \cosh^{-1} \frac{s}{d} \qquad \text{NEPER}$$

18

NEWTON CO-EFFICIENT

$$N = \frac{10^7}{981} \qquad \frac{\text{ERG} \cdot \text{SEC} \cdot \text{SEC}}{\text{PER CM} \cdot \text{JOULE}}$$

FIGURE (5f)

Energy and Force Relations

19

Cancellation of Force

$$0 = f_m - f_d$$ GRAM

$$\frac{f_m}{f_d} = 1$$ UNITY

20

Substitution of Prior Relations

$$\frac{2 i^2 L s \sigma N}{2 e^2 C s \sigma N} = 1$$ UNITY

$$\frac{i^2 L}{e^2 C} = \frac{W_m}{W_d} = 1$$ UNITY

21

Re-arranging Terms

$$\frac{e^2}{i^2} = \frac{L}{C}$$ HENRY / FARAD

$$Z_1^2 = Z_c^2$$ OHM / SIEMENS

$$Z_1 = Z_c$$ ZOBEL

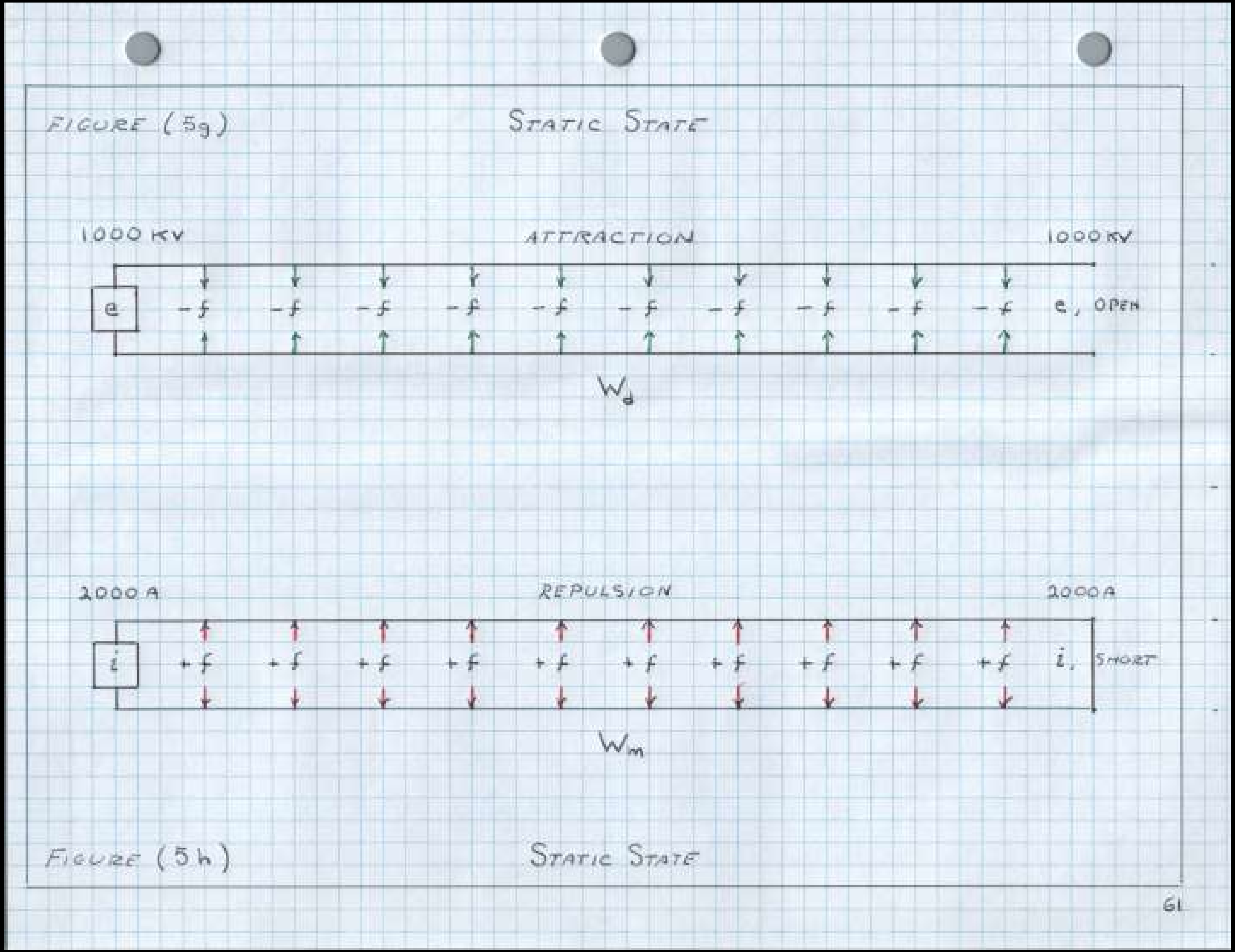
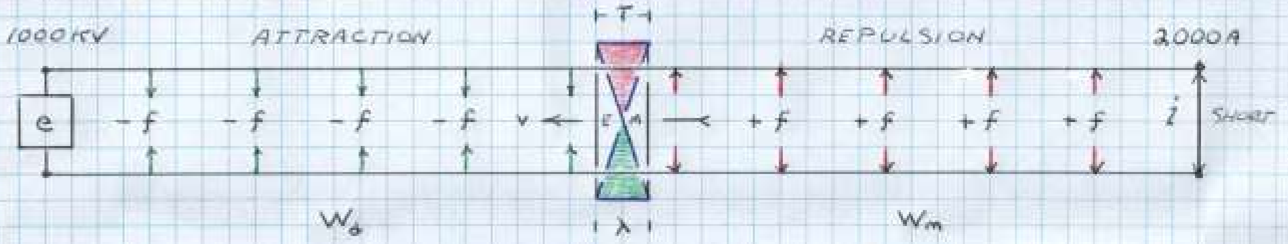


FIGURE (5g)
STATIC STATE
1000 KV
ATTRACTION
1000 KV
e
- f
e, OPEN
Wd
2000 A
REPULSION
2000 A
i
+ f
i, SHORT
Wm
FIGURE (5h)
STATIC STATE
61

FIGURE (5i) TRANSIENT STATE



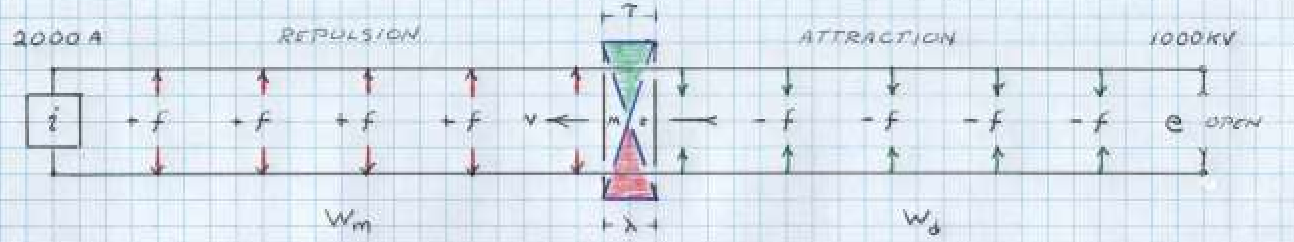


FIGURE (5j) TRANSIENT STATE

62

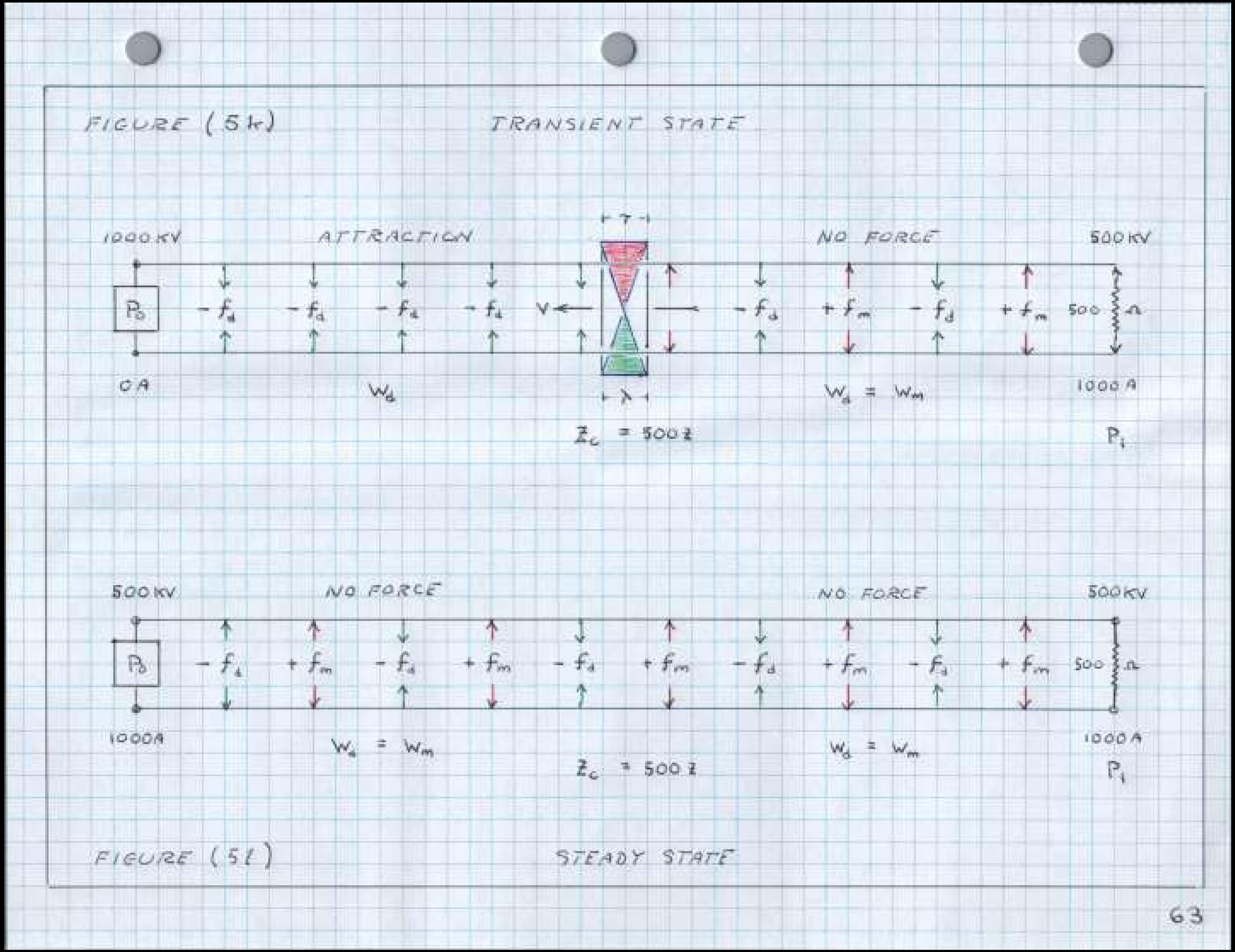


FIGURE (5k)
TRANSIENT STATE
1000 KV
ATTRACTION
NO FORCE
500 KV
P0
V
500 Ω
0 A
Wd
Wd = Wm
1000 A
Zc = 500 Ω
P1
500 KV
NO FORCE
NO FORCE
500 KV
P0
500 Ω
1000A
Wd = Wm
Wd = Wm
1000 A
Zc = 500 Ω
P1
FIGURE (5l)
STEADY STATE
63

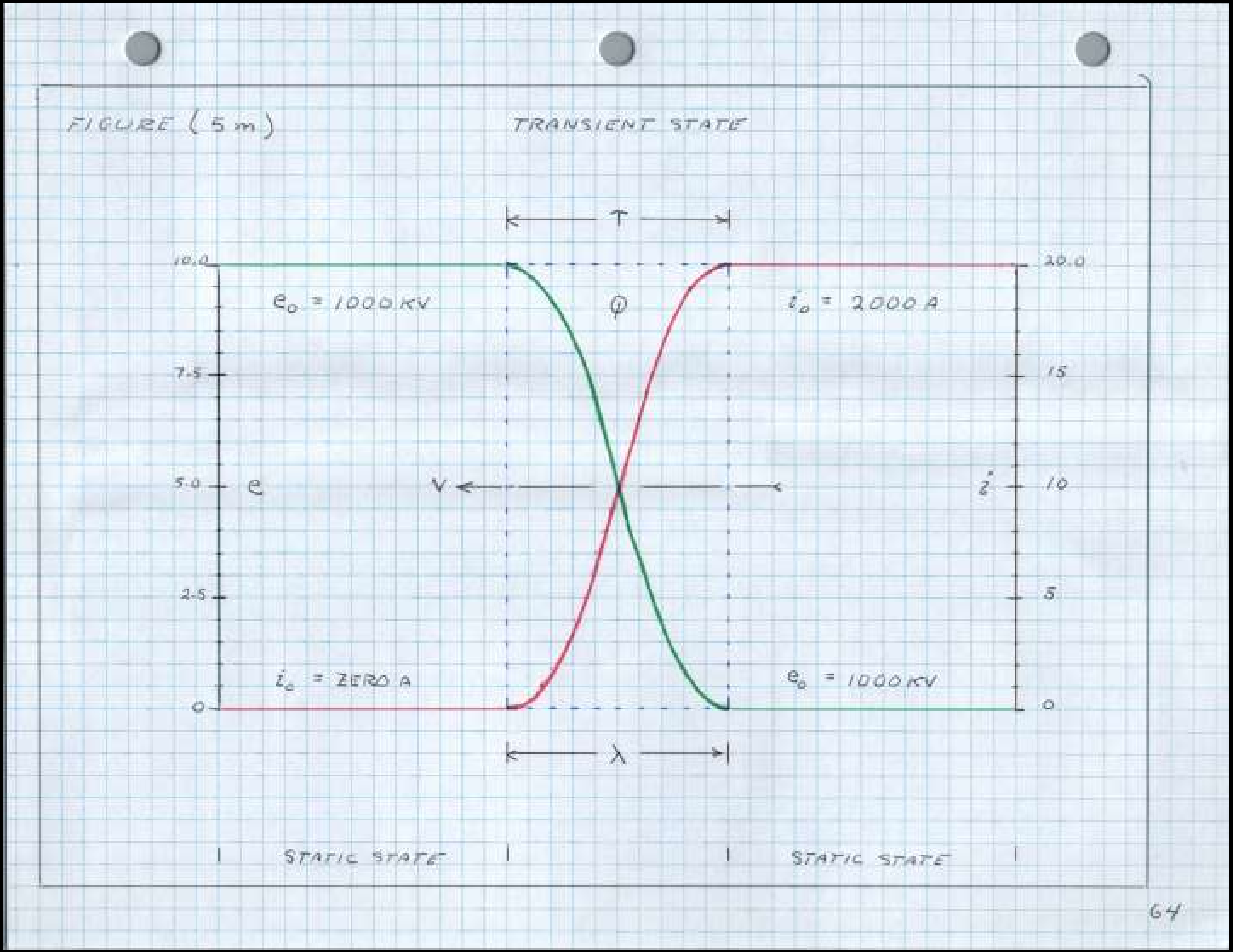


FIGURE (5 m)
TRANSIENT STATE
T
10.0
7.5
5.0
2.5
0
e_o = 1000 KV
φ
i_o = 2000 A
e
V
i
20.0
15
10
5
0
i_o = ZERO A
e_o = 1000 KV
λ
STATIC STATE
STATIC STATE
64

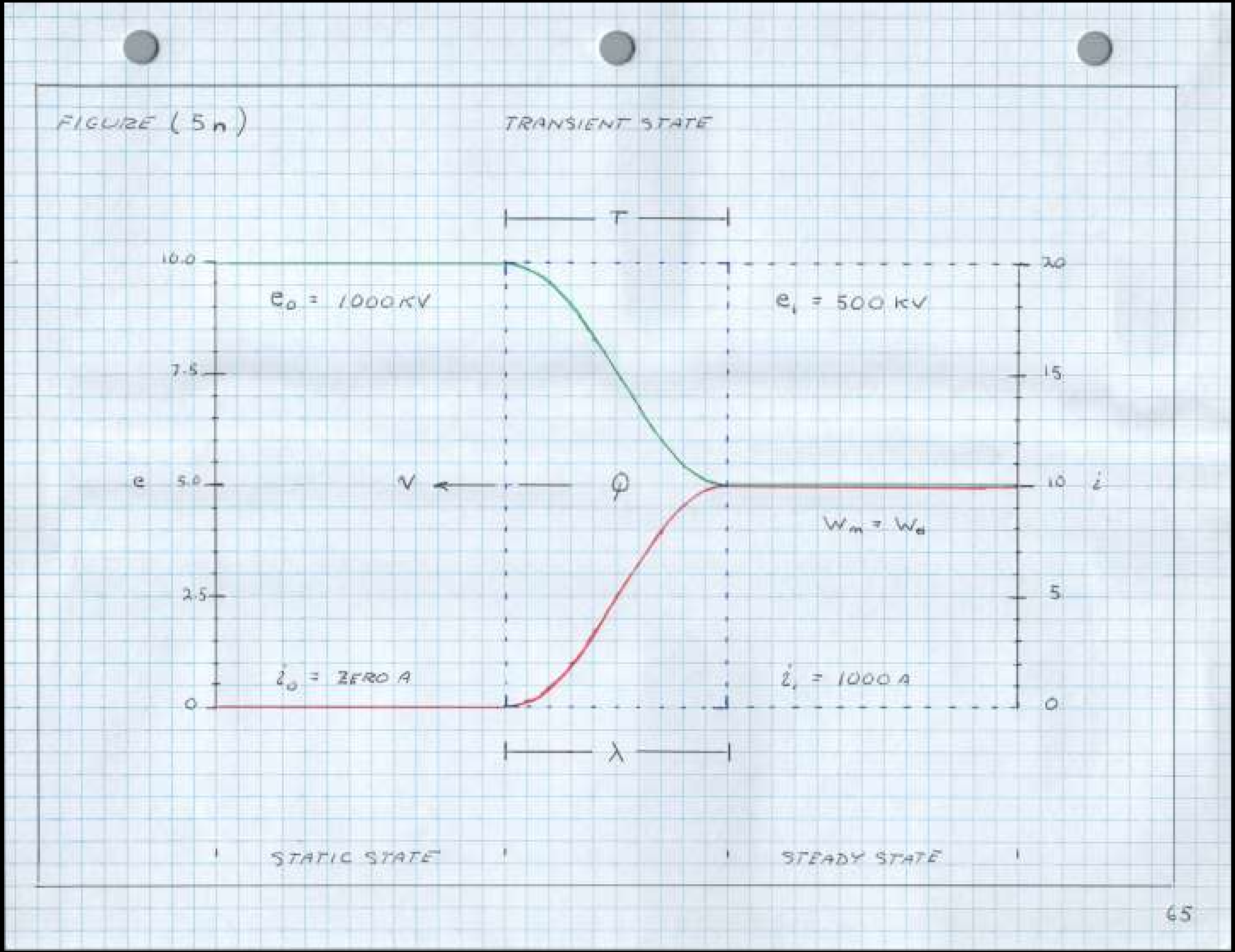


FIGURE (5n)
TRANSIENT STATE
T
10.0
7.5
5.0
2.5
0
e
e_0 = 1000 KV
e_1 = 500 KV
V
φ
i_0 = ZERO A
i_1 = 1000 A
$W_m = W_e$
20
15
10
5
0
i
λ
STATIC STATE
STEADY STATE
65

Chapter 6

Engineering Formulation of Force & Energy as Applied to Direct Current Power Transmission

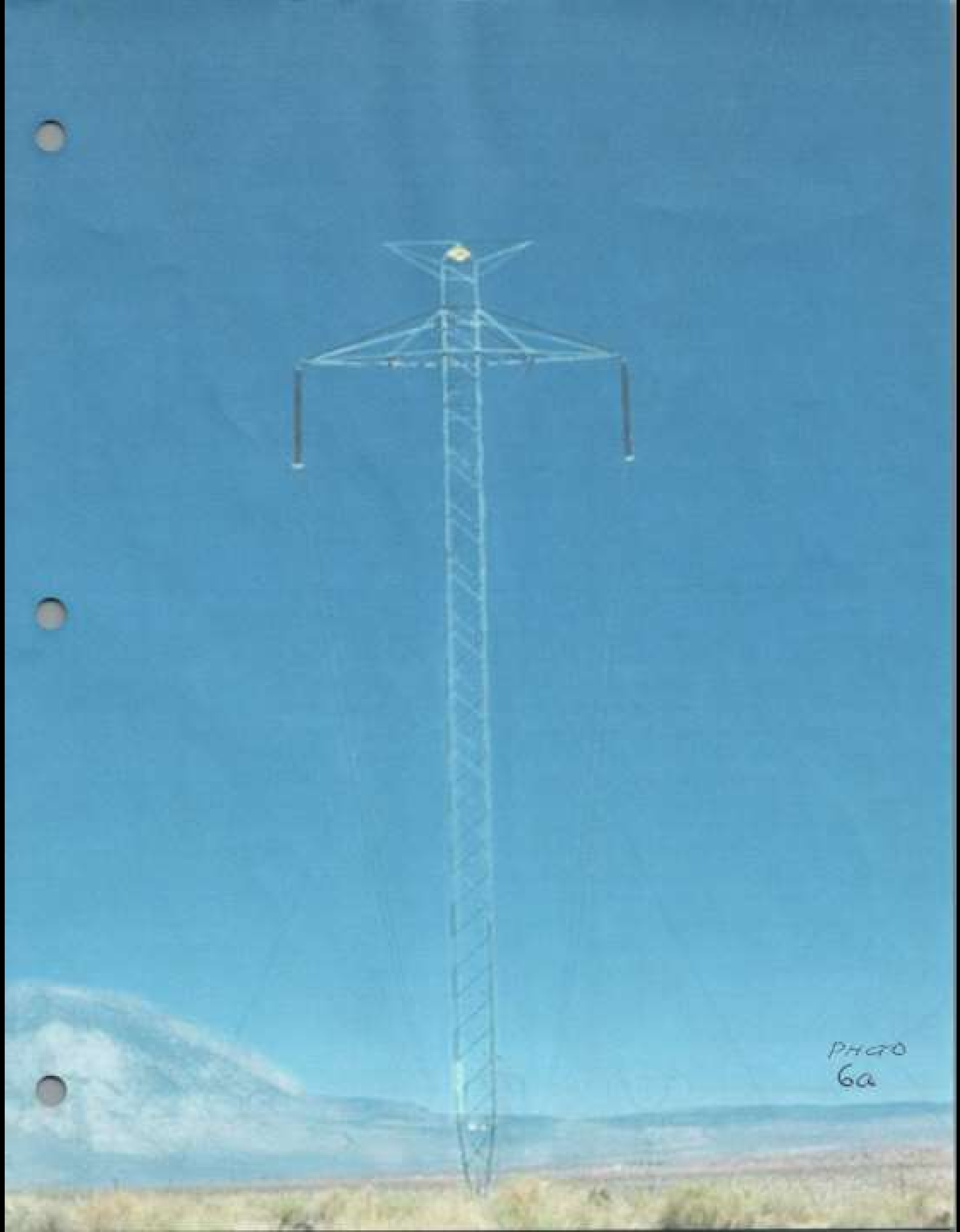


PHOTO
6a


Photo 66

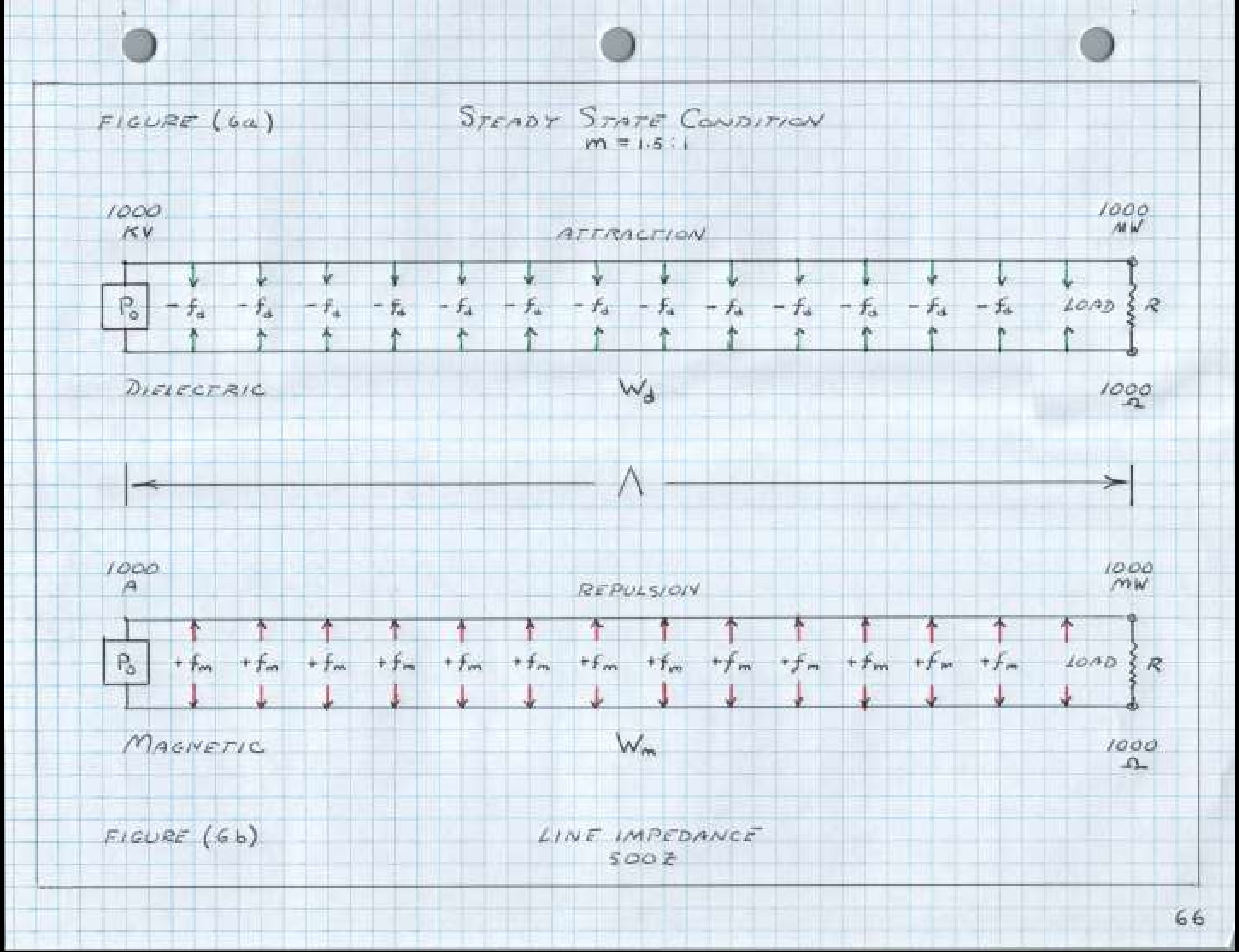


FIGURE (6a)
STEADY STATE CONDITION
m = 1.5 : 1
1000 KV
ATTRACTION
1000 MW
Po
- fd
LOAD
R
DIELECTRIC
Wd
1000 Ω
Λ
1000 A
REPULSION
1000 MW
Po
+ fm
LOAD
R
MAGNETIC
Wm
1000 Ω
FIGURE (6b)
LINE IMPEDANCE
500 Z
66

FIGURE (6c)

D.C. TRANSMISSION LINE	
LINE LENGTH	
Λ	MILE
CONDUCTOR SPACING	
s	CENTIMETRE
SPACE FACTOR	
σ	NEPER
NATURAL IMPEDANCE	
Z_c	ZOBEL
UNIT LEGNTH	
λ	MILE
UNIT LEGNTH	
λ	CENTIMETRE

FIGURE (6d)

D.C. TRANSMISSION LINE		
	LINE POTENTIAL	
e	1000	KILOVOLT
	LINE CURRENT, 1000 Ω.	
i	1000	AMPERE
	LINE CURRENT, 500 Ω	
i	2000	AMPERE
	NEWTON CO-EFFICIENT	
N	$1.0194 \times 10^{+4}$	cm/SEC·SEC
	DIELECTRIC PERMITTIVITY	
ε	2.778×10^{-13}	$SEC^2/cm^2 \cdot cm$
	MAGNETIC PERMEABILITY	
μ	4.000×10^{-9}	CENTIMETRE

FIGURE (6e)

FORCE ON LINE CONDUCTORS

1

DIELECTRIC FORCE & ENERGY

$$f_d = \frac{W_d}{s} \cdot \frac{N}{\sigma} \qquad \text{GRAM / MILE}$$

$$W_d = \frac{1}{2} e^2 \cdot \frac{\eta}{\sigma c^2} \cdot \lambda \qquad \text{JOULE / MILE}$$

2

SUBSTITUTION OF TERMS

$$f_d = \frac{1}{2} e^2 \cdot \frac{\eta N}{\sigma^2 c^2} \cdot \frac{\lambda}{s} \qquad \text{GRAM / MILE}$$

$$\frac{1}{2} \cdot \frac{\eta N}{\sigma^2 c^2} = 8.1545 \times 10^{-11} \qquad \frac{\text{cm} \cdot \text{SEC}^2 / \text{cm}^2}{\text{cm} \cdot \text{SEC} \cdot \text{SEC}}$$

$$\frac{\lambda}{s} = 1.609 \times 10^{+2} \qquad \text{cm / cm}$$

3

RESULTING FORCE

$$f_d = e^2 \cdot 1.3121 \times 10^{-8} \qquad \text{GRAM / MILE}$$

$$f_d = 13.12 \text{ KILOGRAM / MILE}$$

FIGURE (6f)

Force on Line Conductors

4

Magnetic Force & Energy

$$f_m = \frac{W_m}{s} \cdot \frac{N}{\sigma} \qquad \text{GRAM/MILE}$$

$$W_m = \frac{1}{2} i^2 \cdot \mu\sigma \cdot \lambda \qquad \text{JOULE/MILE}$$

5

Substitution of Terms

$$f_m = \frac{1}{2} i^2 \cdot \mu N \cdot \frac{\lambda}{s} \qquad \text{GRAM/MILE}$$

$$\frac{1}{2} \cdot \mu N = 2.0388 \times 10^{-5} \qquad \text{cm.cm/SEC.SEC}$$

$$\frac{\lambda}{s} = 1.609 \times 10^{+2} \qquad \text{cm/cm}$$

6

Resultant Force

$$f_m = i^2 \cdot 3.2804 \times 10^{-3} \qquad \text{GRAM/MILE}$$

$$f_m = 3.280 \qquad \text{KILOGRAM/MILE}$$

FIGURE (69)

FORCE ON LINE CONDUCTORS

7

RATIO OF FORCES, 1000 OHM

$$\frac{f_d}{f_m} = \frac{W_d}{W_m} = m^2$$ NUMERIC²

$$\frac{f_d}{f_m} = \frac{13,120}{3280} = 4.0$$ GRAM / GRAM

8

TOTAL DIELECTRIC FORCE

$f_D = f_d \cdot \Lambda$ GRAM

$f_D = 11,152 \times 10^3$ GRAM

$f_D = 24,564$ POUND

9

TOTAL MAGNETIC FORCE

$f_M = f_m \cdot \Lambda$ GRAM

$f_M = 2788 \times 10^3$ GRAM

$f_M = 6141$ POUND

10

$f_M - f_D = -18,423$ POUND

FIGURE (6h)

FORCE ON LINE CONDUCTORS

11

RATIO OF FORCES, 500 OHM

$$\frac{f_d}{f_m} = \frac{\quad}{\quad} = m^2 \qquad \text{NUMERIC}^2$$

$$\frac{f_d}{f_m} = \frac{13,120}{13,120} = 1.0 \qquad \text{UNITY}$$

12

TOTAL DIELECTRIC FORCE

$$f_D = f_d \cdot \Lambda \qquad \text{GRAM}$$

$$f_D = 11,152 \times 10^3 \qquad \text{GRAM}$$

$$f_D = 24,564 \qquad \text{POUND}$$

13

TOTAL MAGNETIC FORCE

$$f_M = f_m \cdot \Lambda \qquad \text{GRAM}$$

$$f_M = 11,152 \times 10^3 \qquad \text{GRAM}$$

$$f_M = 24,564 \qquad \text{POUND}$$

14

$$f_M - f_D = \text{ZERO} \qquad \text{POUND}$$

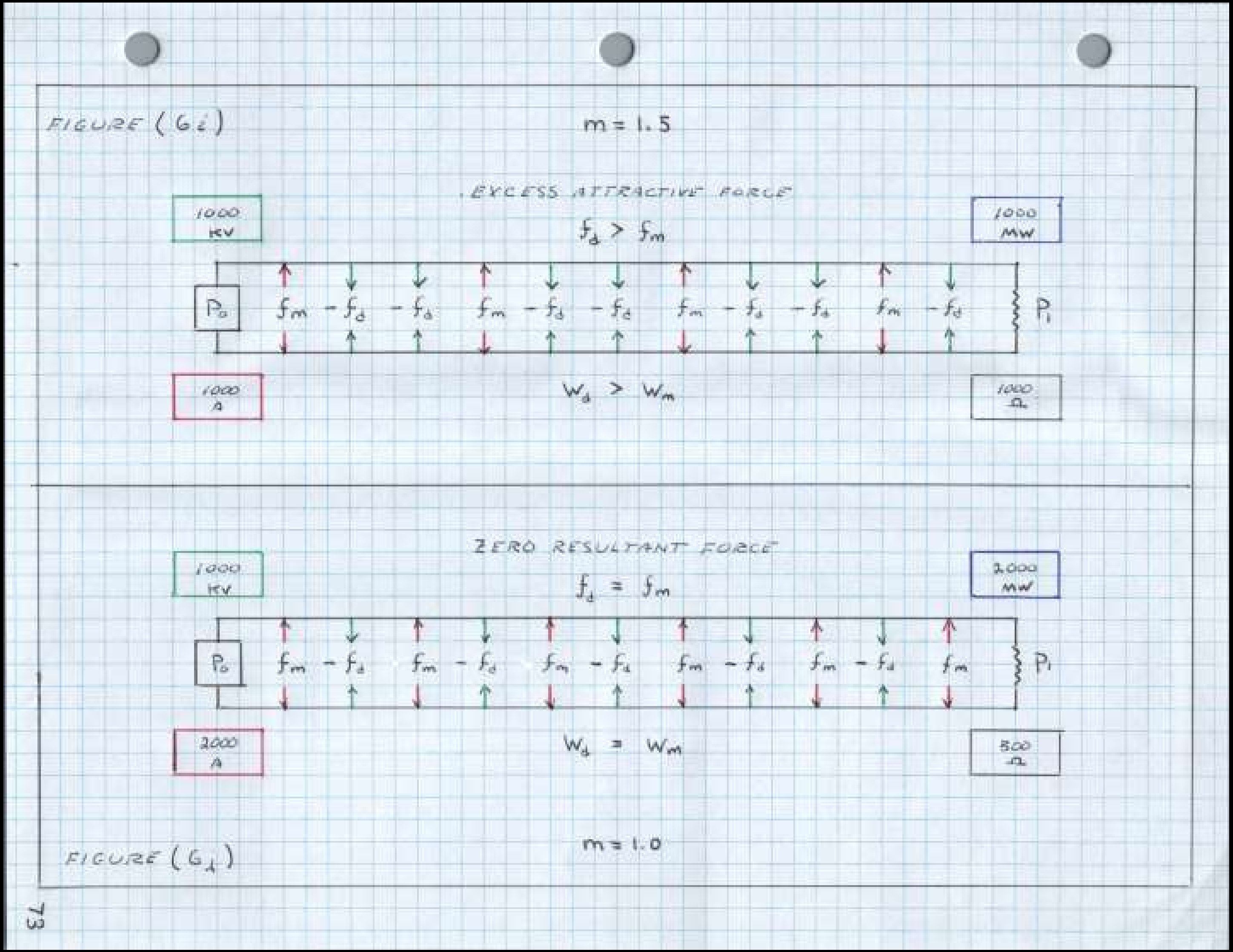


FIGURE (6i)
m = 1.5
EXCESS ATTRACTIVE FORCE
1000 KV
1000 MW
fd > fm
Po
fm -fd -fd fm -fd -fd fm -fd -fd fm -fd
P1
1000 A
Wd > Wm
1000 Ω
ZERO RESULTANT FORCE
1000 KV
2,000 MW
fd = fm
Po
fm -fd fm -fd fm -fd fm -fd fm -fd fm
P1
2000 A
Wd = Wm
500 Ω
m = 1.0
FIGURE (6j)
73

FIGURE (6k)

Force on Line Conductors

15

Condition for Zero Force

$$f_m - f_d = 0$$ GRAM

$$m^2 = 1$$ UNITY

16

Substitution of Terms

$$m^2 = \frac{i^2}{e^2} \cdot \frac{L}{C} = 1$$ UNITY

$$\frac{e^2}{i^2} = \frac{L}{C}$$ HENRY / FARAD

$$Z_1 = Z_c$$ ZOBEL

17

Natural Power of Line

$$P = e\,i$$ VOLT-AMPERE

$$i = \frac{e}{Z_c}$$ VOLT / ZOBEL

$$P_c = \frac{e^2}{Z_c}$$ WATT

Chapter 7

Traveling and Reflected Electromagnetic Impulses on Open Circuit Lone Lines

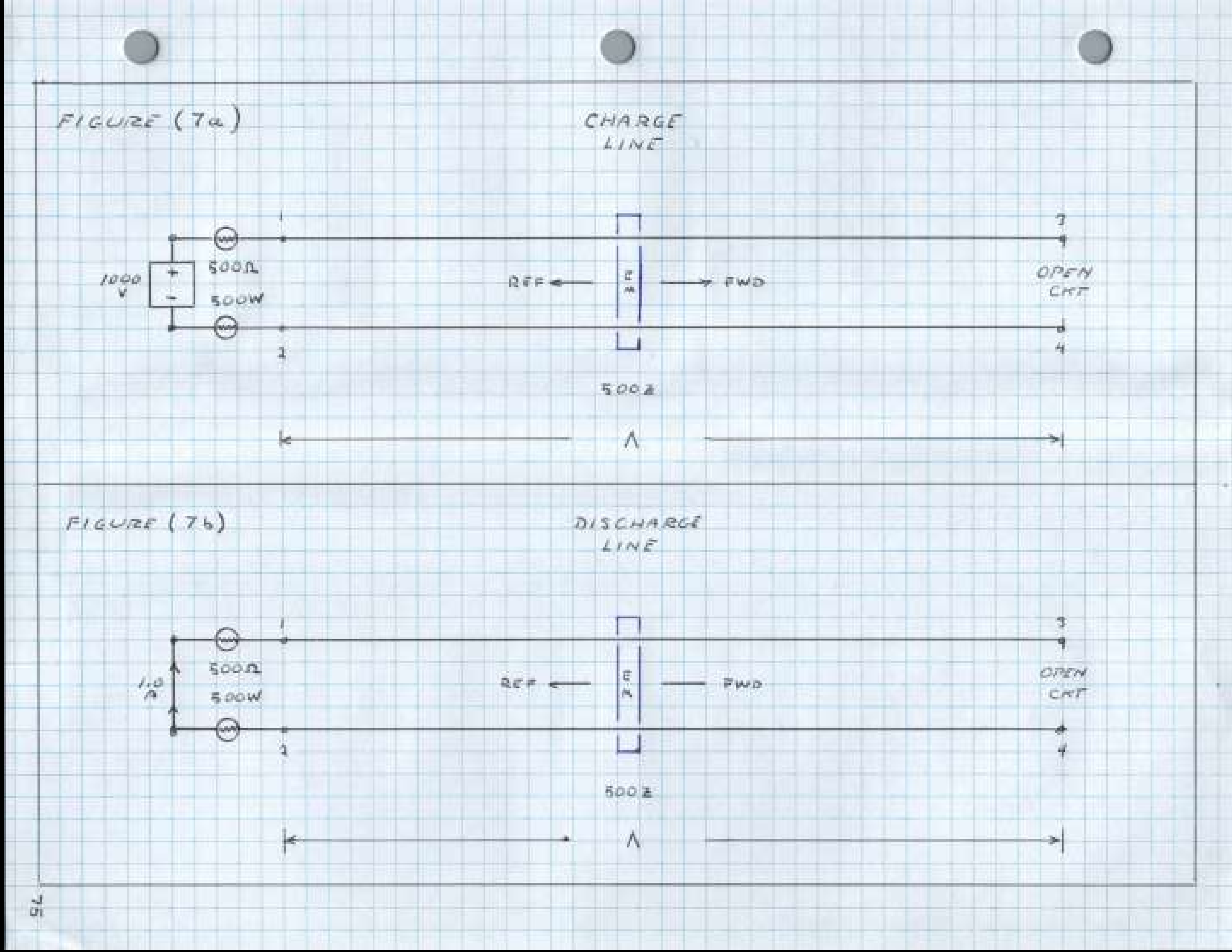


FIGURE (7a)
CHARGE LINE
1
3
1000 V
500Ω
500W
REF
FWD
E M
OPEN CKT
2
4
500 Z
Λ
FIGURE (7b)
DISCHARGE LINE
1
3
1.0 A
500Ω
500W
REF
FWD
E M
OPEN CKT
2
4
500 Z
Λ
75

FIG (7c) START CHARGE

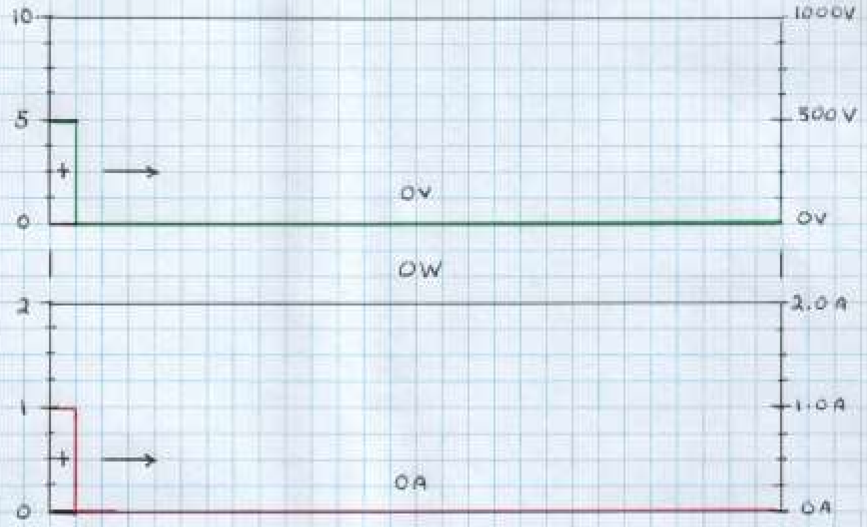


FIG (7d) 1st FWD

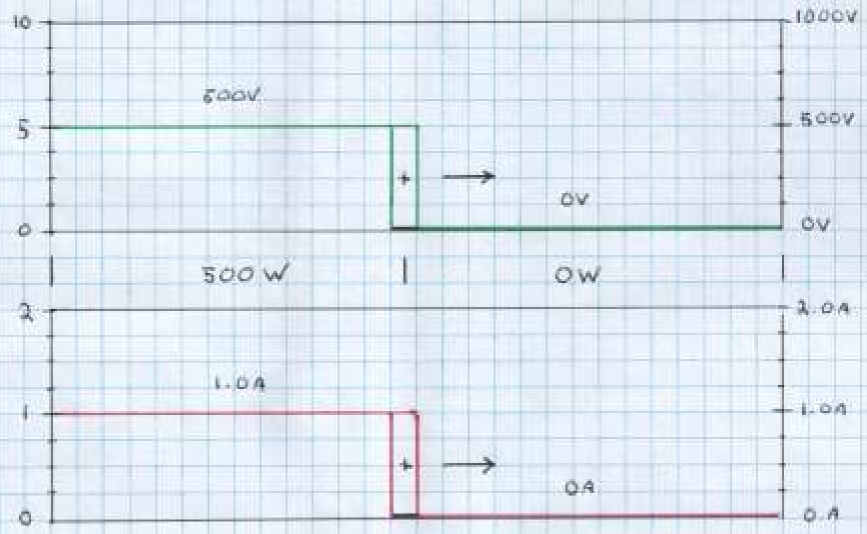


FIG (7e) REFLECTION

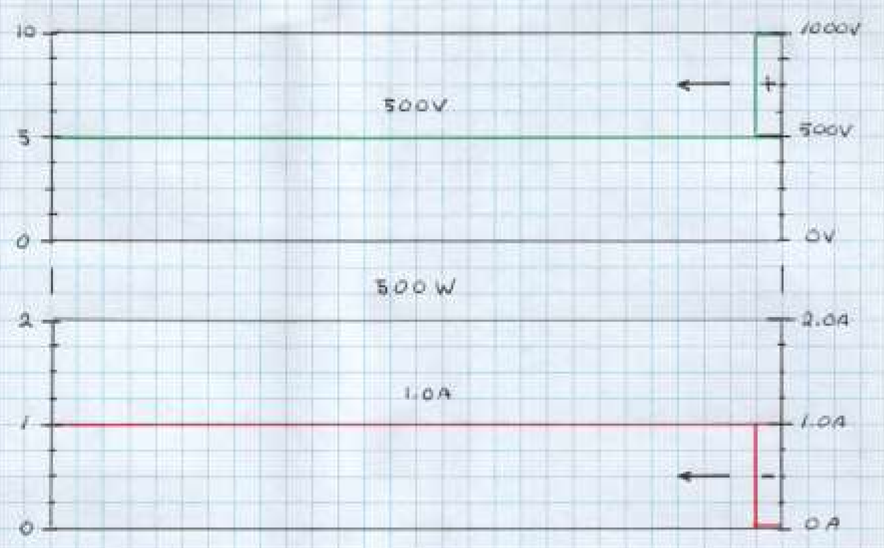
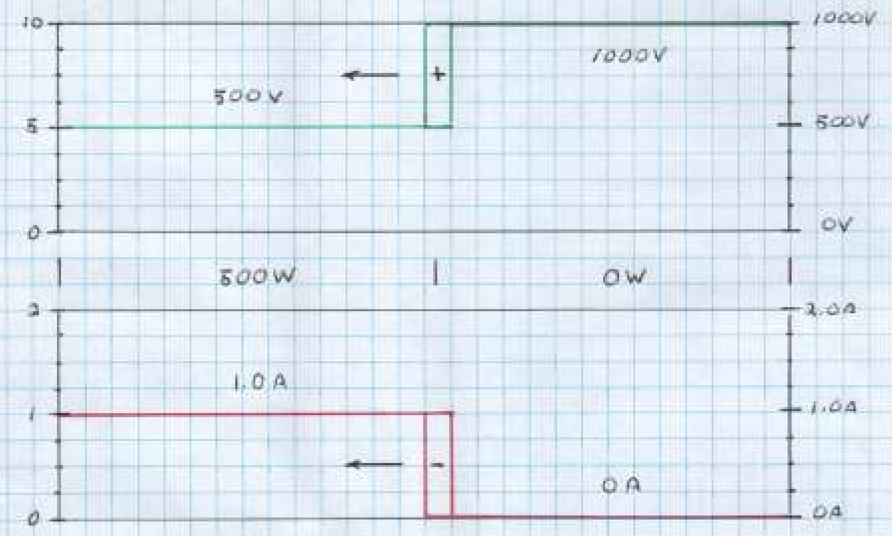


FIG (7f) 1ST REFL



77

FIG (7g) NO REFL

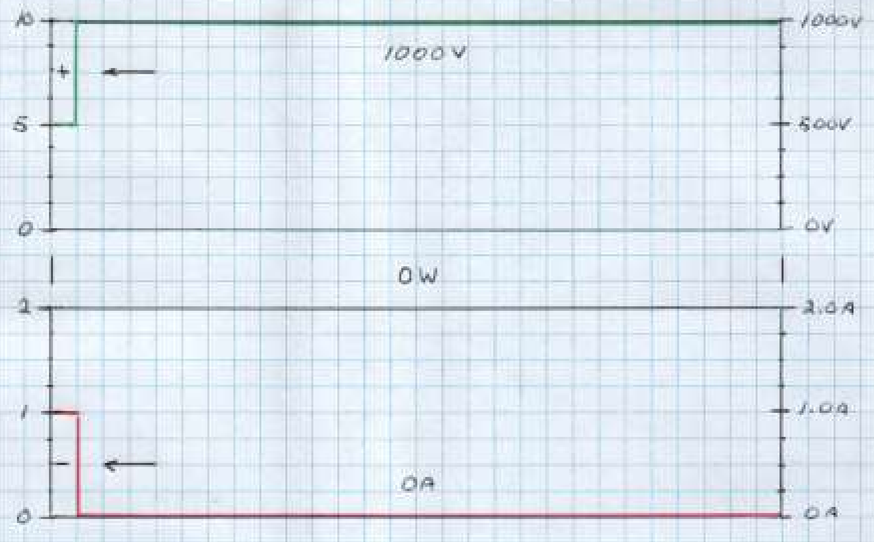
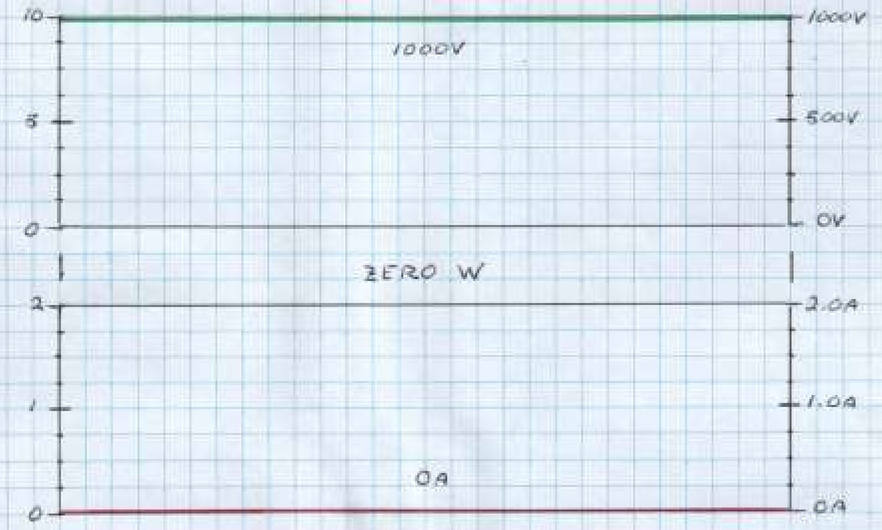


FIG (7h) STEADY STATE CHARGED



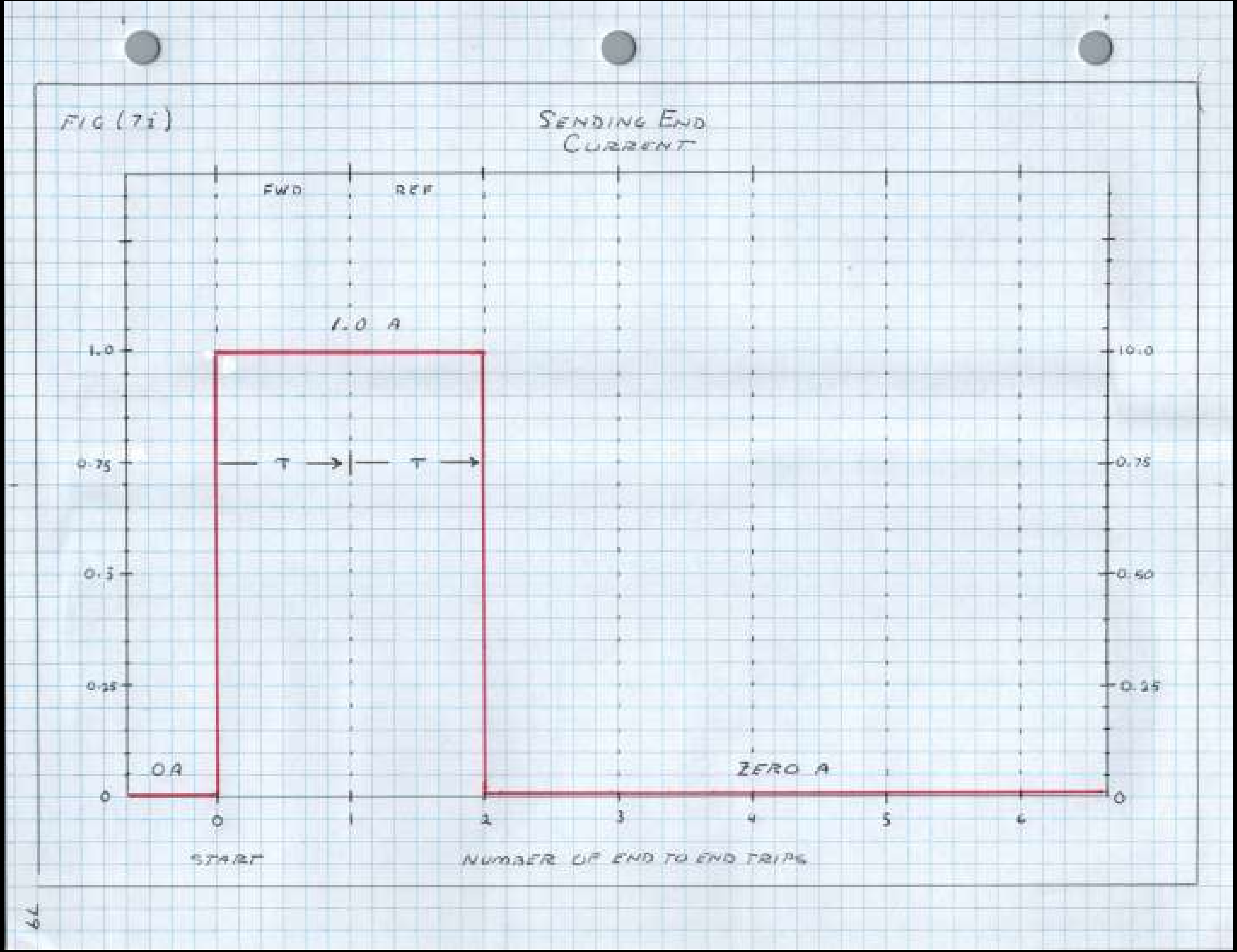


FIG (7i)
SENDING END
CURRENT
FWD
REF
1.0 A
1.0
0.75
0.5
0.25
0
10.0
0.75
0.50
0.25
0
T
T
0A
ZERO A
0
1
2
3
4
5
6
START
NUMBER OF END TO END TRIPS
79

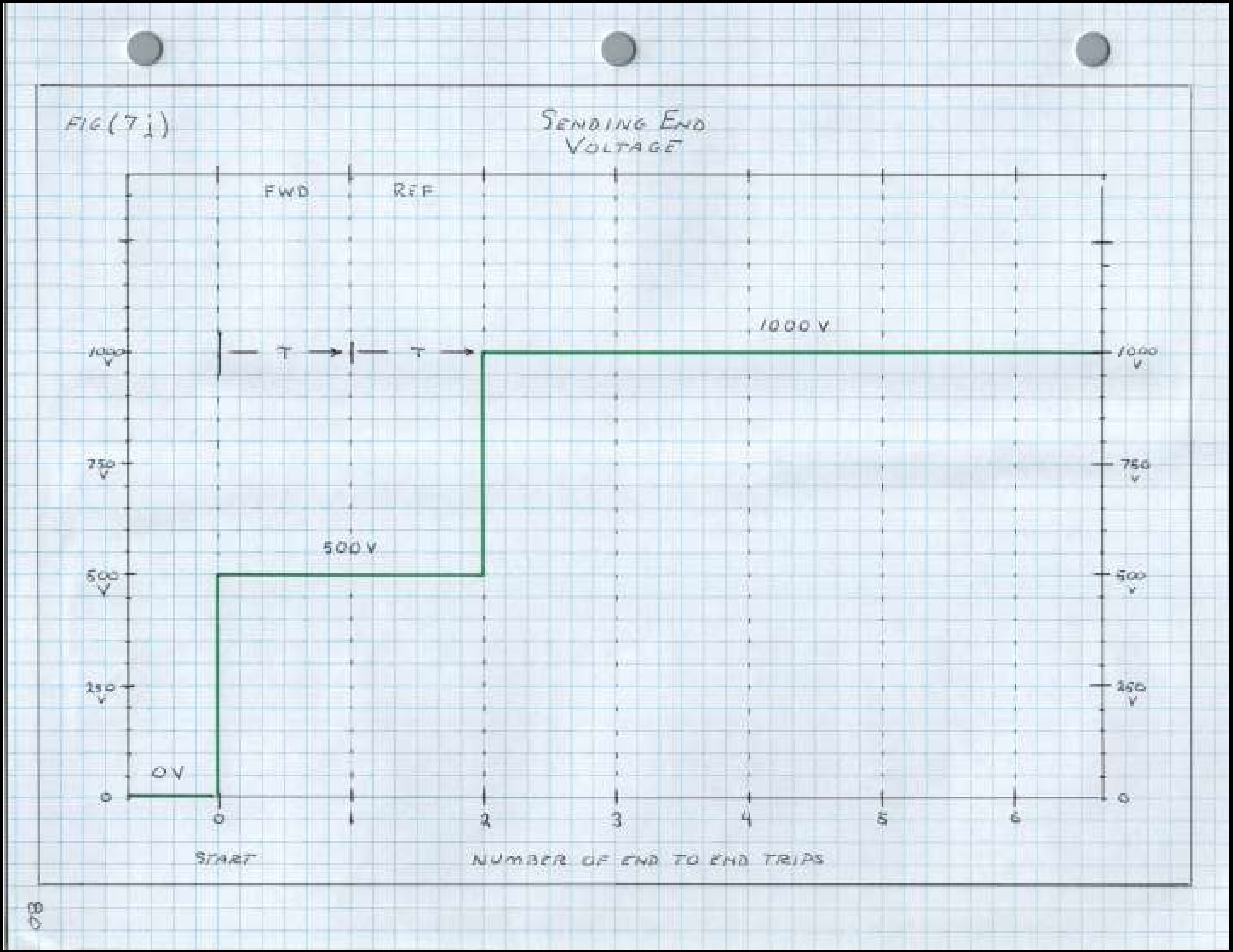


FIG (7 j)
SENDING END VOLTAGE
FWD
REF
T
T
1000 V
500 V
0 V
1000 V
750 V
500 V
250 V
0
0
2
3
4
5
6
START
NUMBER OF END TO END TRIPS

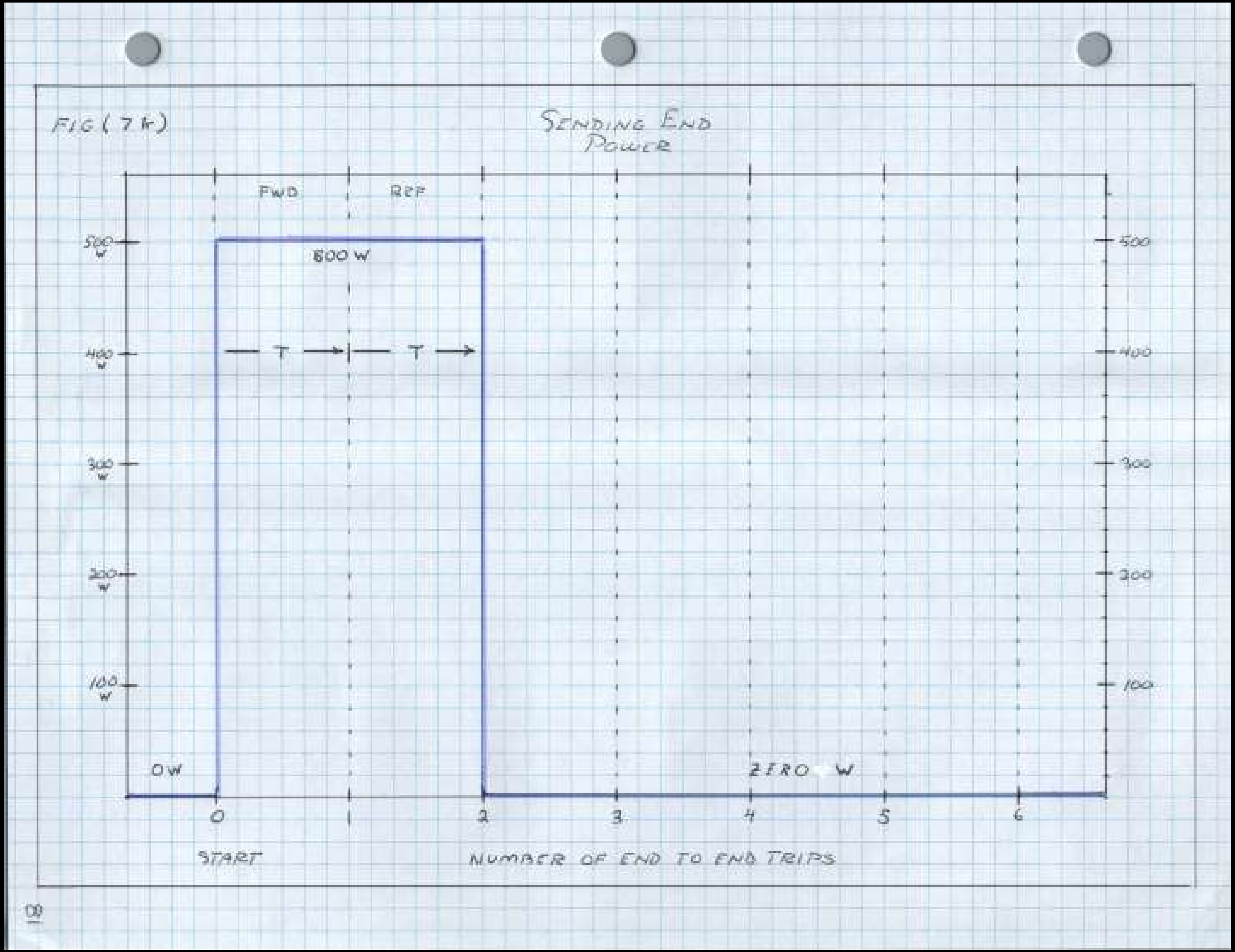


FIG (7k)
SENDING END POWER
FWD
REF
500 W
400 W
300 W
200 W
100 W
800 W
T
T
0 W
ZERO W
0
1
2
3
4
5
6
START
NUMBER OF END TO END TRIPS
500
400
300
200
100

FIG (7A)

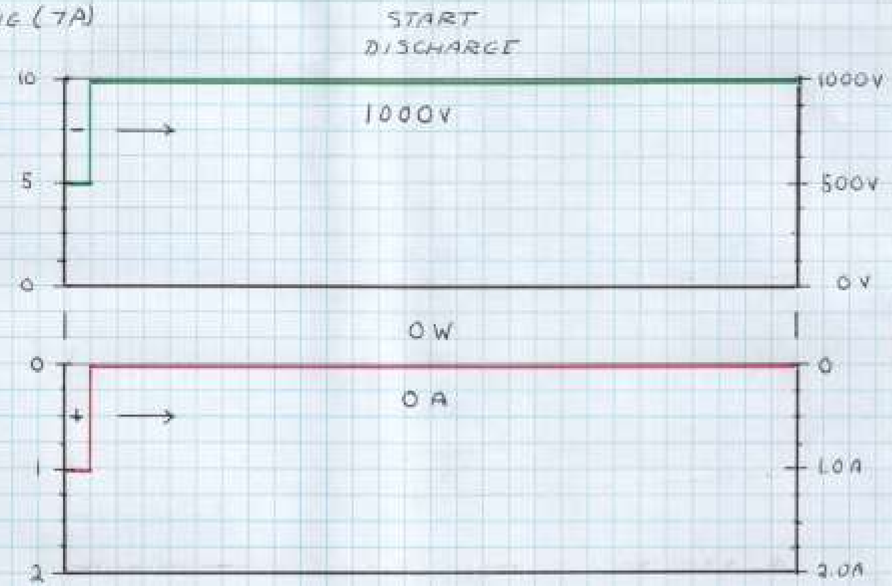

START
DISCHARGE
10
5
0
1000V
500V
0V
1000V
0W
0
1
2
0A
0
1.0A
2.0A

FIG (7B)

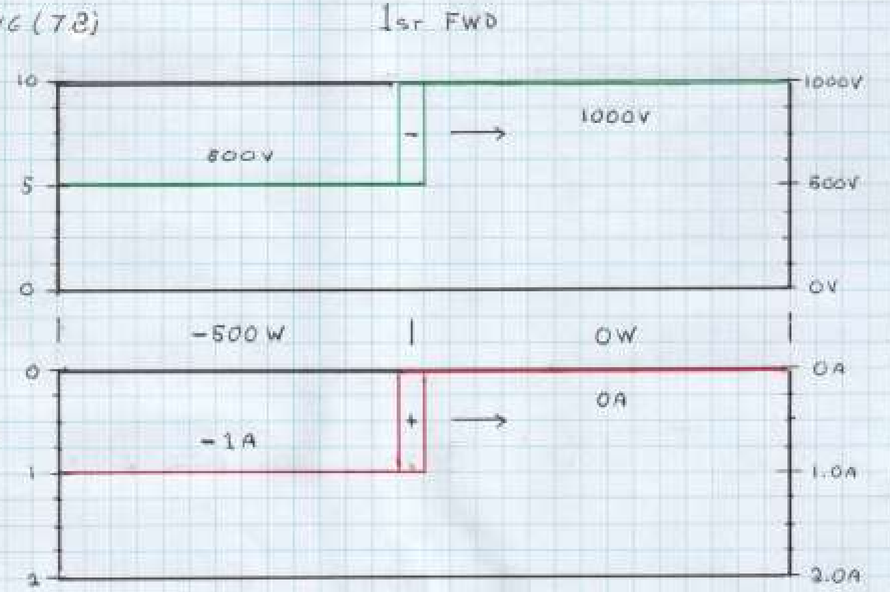

1ST FWD
10
5
0
1000V
500V
0V
800V
1000V
-500W
0W
0
1
2
0A
1.0A
2.0A
-1A
0A

FIG (7C)

1st REF

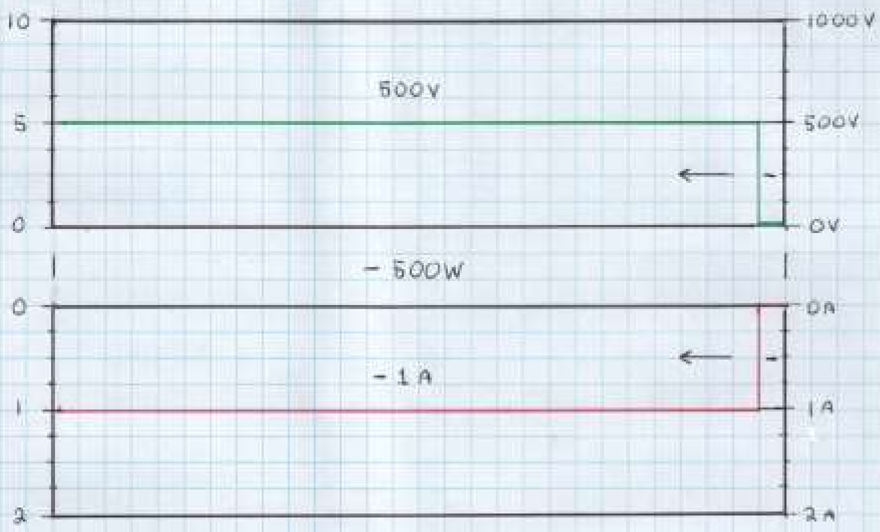


FIG (7D)

1st REF

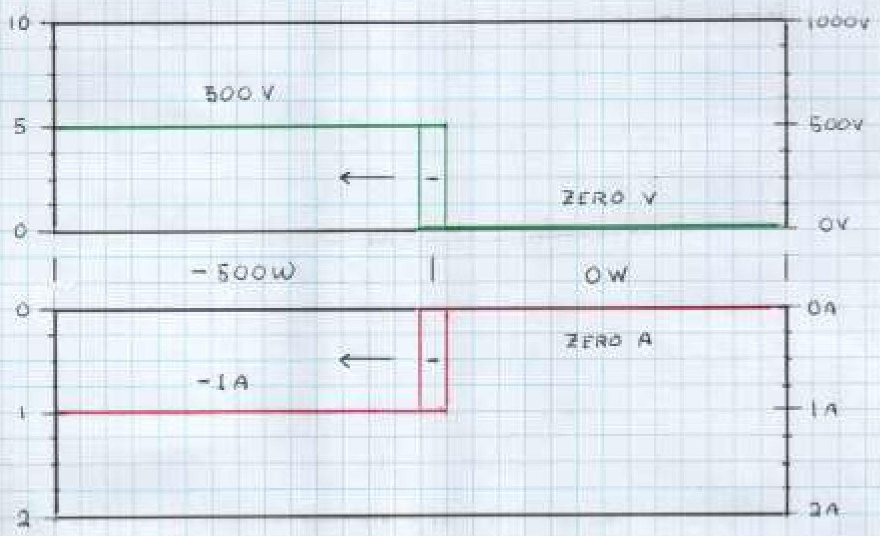


FIG (7E)

NO REFLECTION

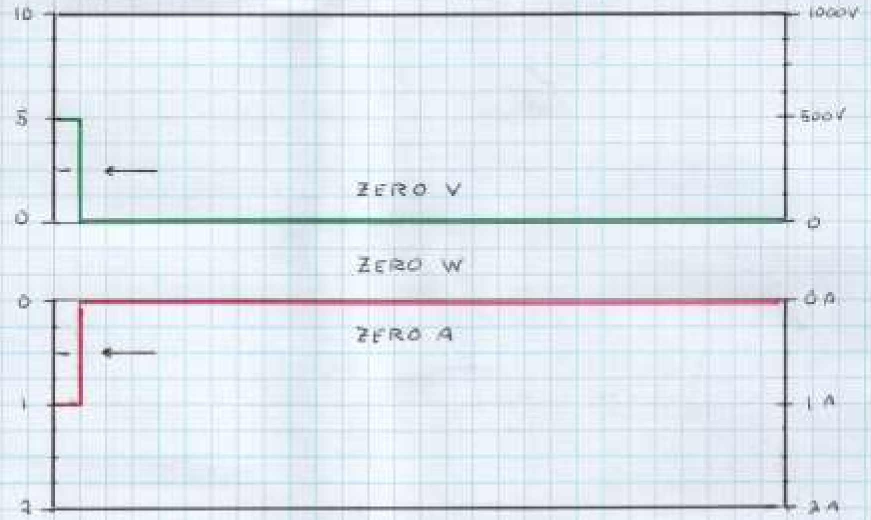


FIG (7F)

LINE DISCHARGED

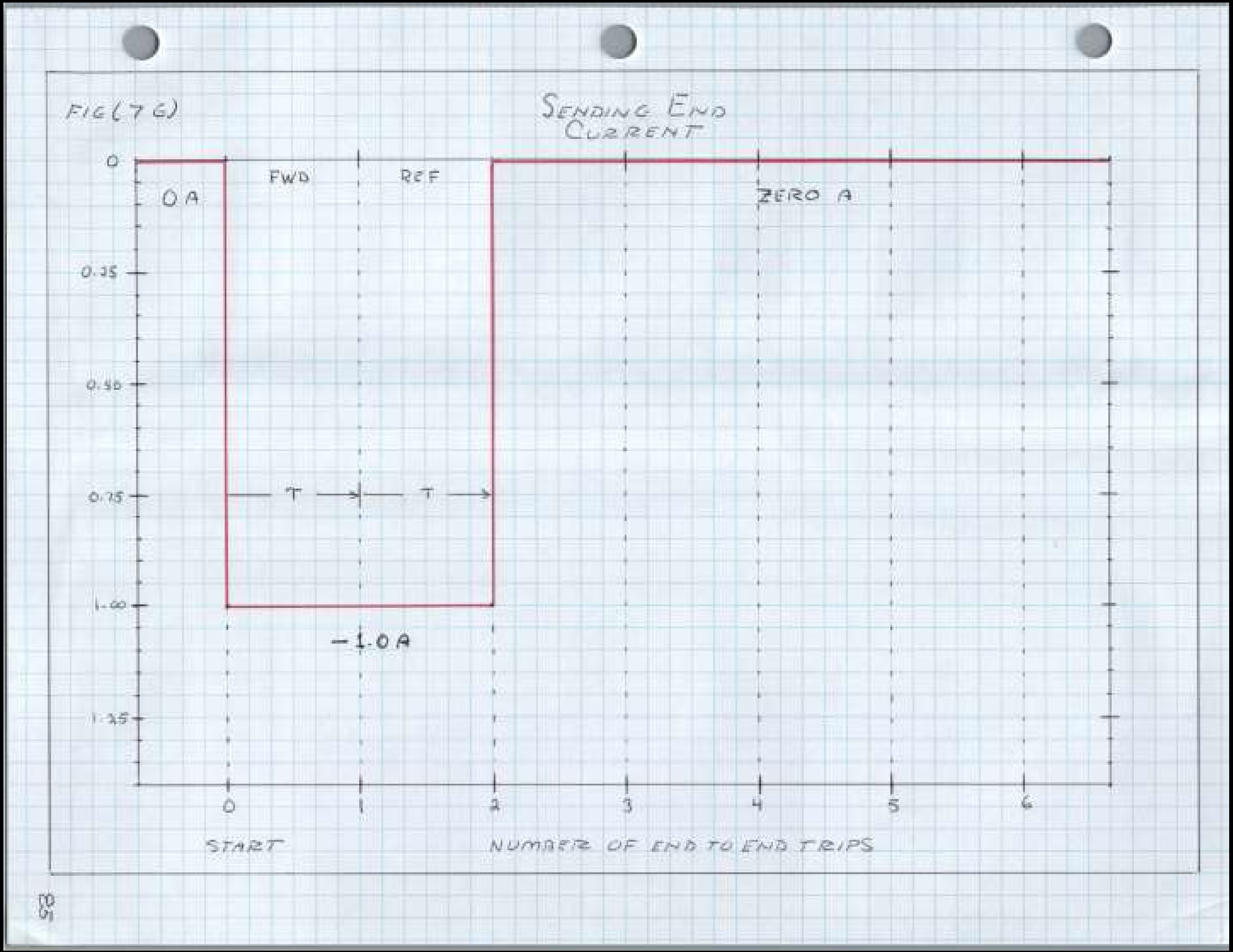


FIG (7 G)
SENDING END CURRENT
0
0.25
0.50
0.75
1.00
1.25
FWD
REF
0 A
ZERO A
T
T
-1.0 A
0
1
2
3
4
5
6
START
NUMBER OF END TO END TRIPS

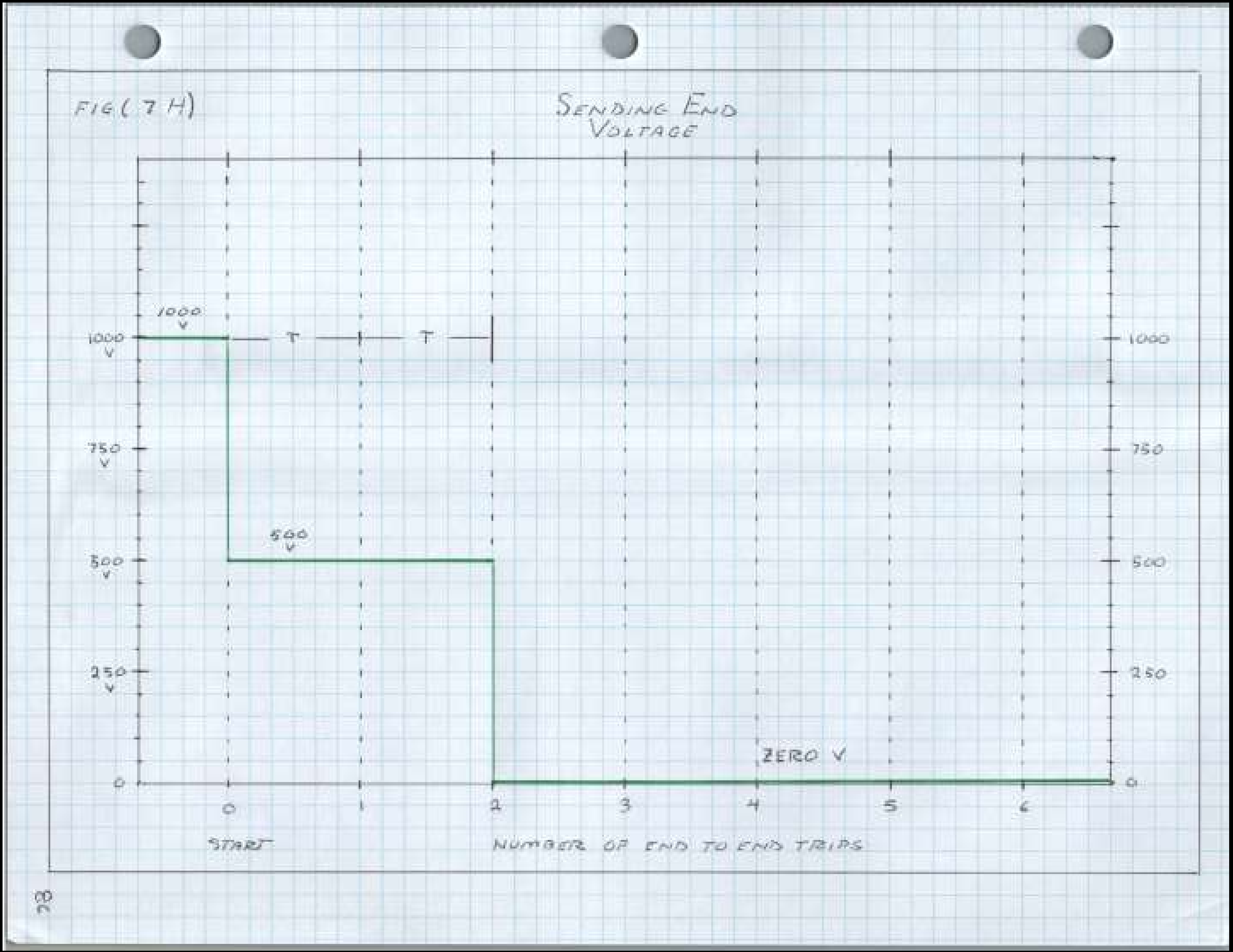
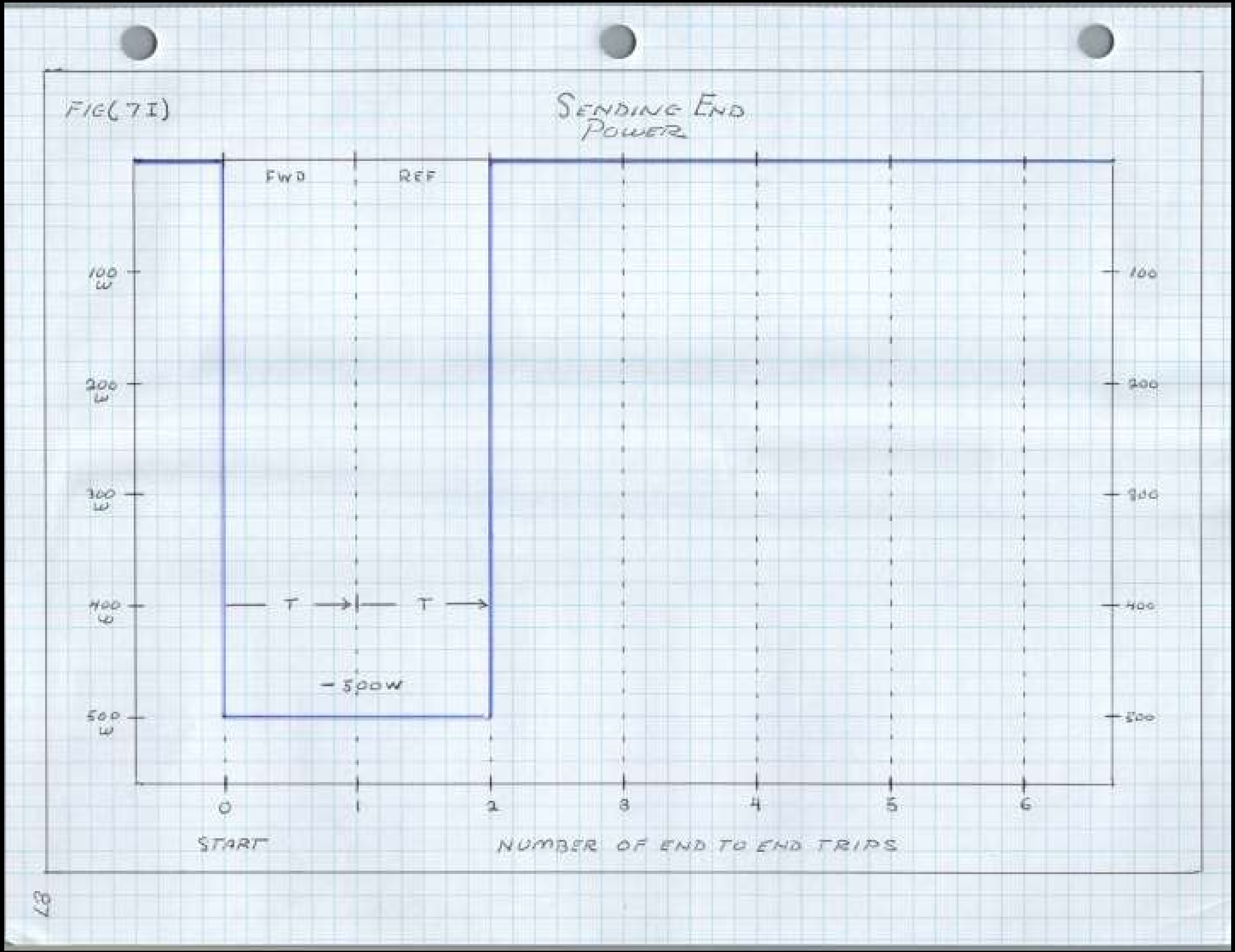


FIG (7 H)
SENDING END VOLTAGE
1000 V
1000 V
T
T
750 V
500 V
500 V
250 V
0
1000
750
500
250
0
ZERO V
0
1
2
3
4
5
6
START
NUMBER OF END TO END TRIPS



FIG(7I)
SENDING END POWER
FWD
REF
100 W
200 W
300 W
400 W
500 W
100
200
300
400
500
T
T
-500W
0
1
2
3
4
5
6
START
NUMBER OF END TO END TRIPS
87

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CHAPTER ONE, PAGE-5, ART-2

2) J.J. THOMPSON, RECENT RESEARCHES IN ELECTRICITY & MAGNETISM
CHAPTER ONE, PAGE-6, ART-9 THRU 14

3) O. HEAVISIDE, ELECTROMAGNETIC THEORY (EMT)
CHAPTER ONE, PAGE-107, ART-86

4) MAX PLANCK, THEORY OF ELECTRICITY & MAGNETISM
CHAPTER TWO, PAGE-16, ART-7

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CHAPTER ONE, ALL

6) O. HEAVISIDE, E.M.T.
PREFACE, PAGE-XXVI

7) O. HEAVISIDE, E.M.T.
PAGE-67, ART-64, & PAGE-378 TO 381, ART-200

8) O. HEAVISIDE, E.M.T.
PAGE-68, ART-65, & PAGE-378 TO 386, ART-201 & 202

9) O. HEAVISIDE, E.M.T.
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VOL - 2, PAGE - 50, ART - 7

(13) O. HEAVISIDE, E.M.T. CHAPTER IV

PAGE - 446, ART - 217, & PAGE - 449, ART - 221, &
PAGE - 44, ART - 245 IN CHAPTER VI

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CHAPTER VII, PAGE - 52 TO 57

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(16) A, KENNELLY, APPLICATION OF HYPERBOLIC FUNCTIONS TO ELECTRICAL ENGINEERING PROBLEMS

CHAPER ONE, PAGE, 1 TO 9, CHAPT VII, PAGE - 96

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CHAPTER VIII, PAGE 282

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LECTURE VI, PAGE 61, ART - 25

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CHAPTER IX, PAGE 305, ART - 2

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LECTURE VIII, PAGE-72, ART-33

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CHAPTER 11, PAGE-296 TO 297, ART-9

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PHENOMENA, 3RD EDITION

CHAPTER XII, PAGE 153, ART-103

Chapter 8

Multiple Reflections on Mis-Matched Transmission Lines

FIGURE (12)

ENERGIZING
MIS-MATCH LOAD
AT LINE SEND END

FIGS 12a → 12i

MULTIPLE REFLECTION
DIAGRAMS

2

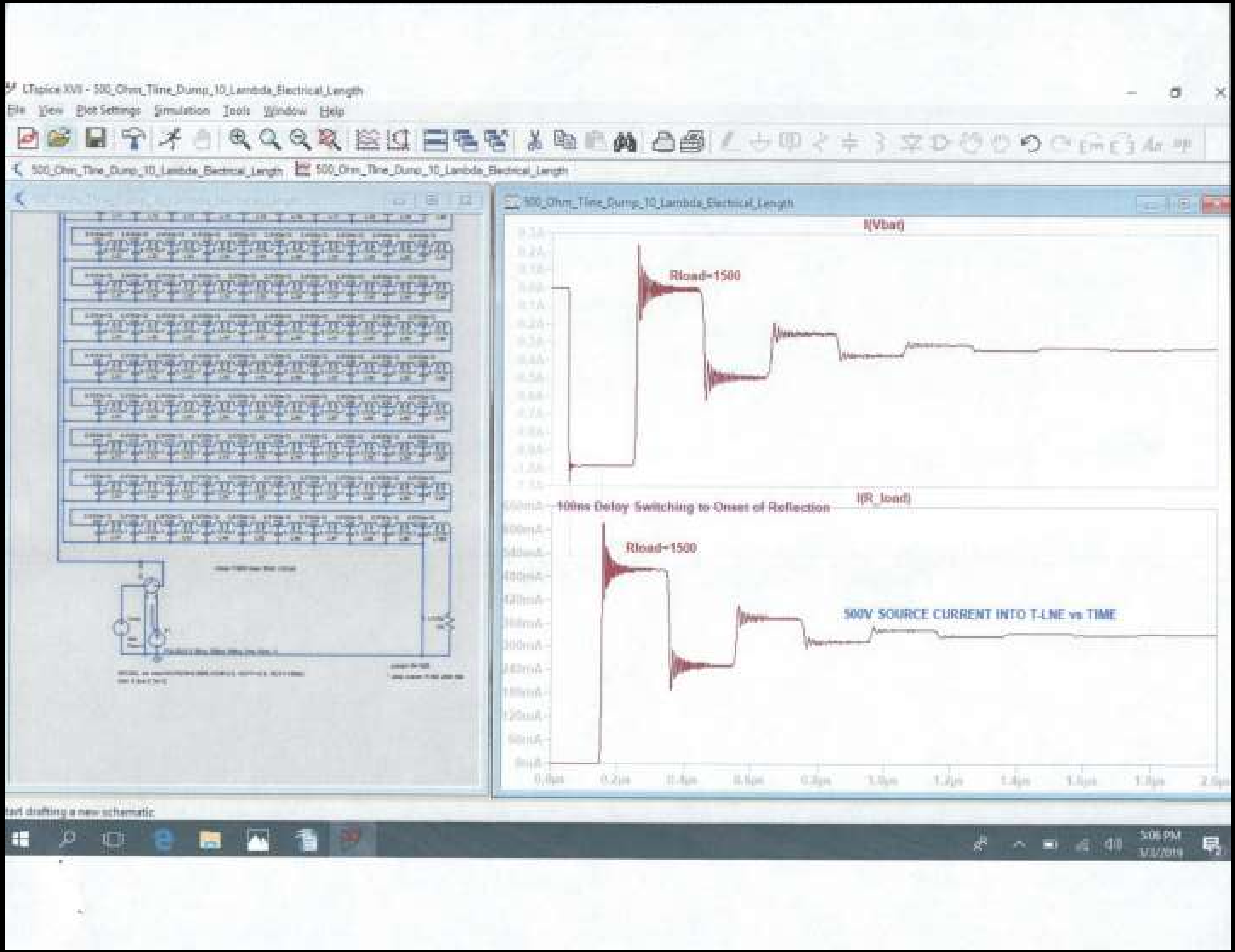
Hi Aaron, today I spoke with Eric and he wanted to see the result at 1500 Ohms load so here it is attached if you could print and send it to him he will be grateful.

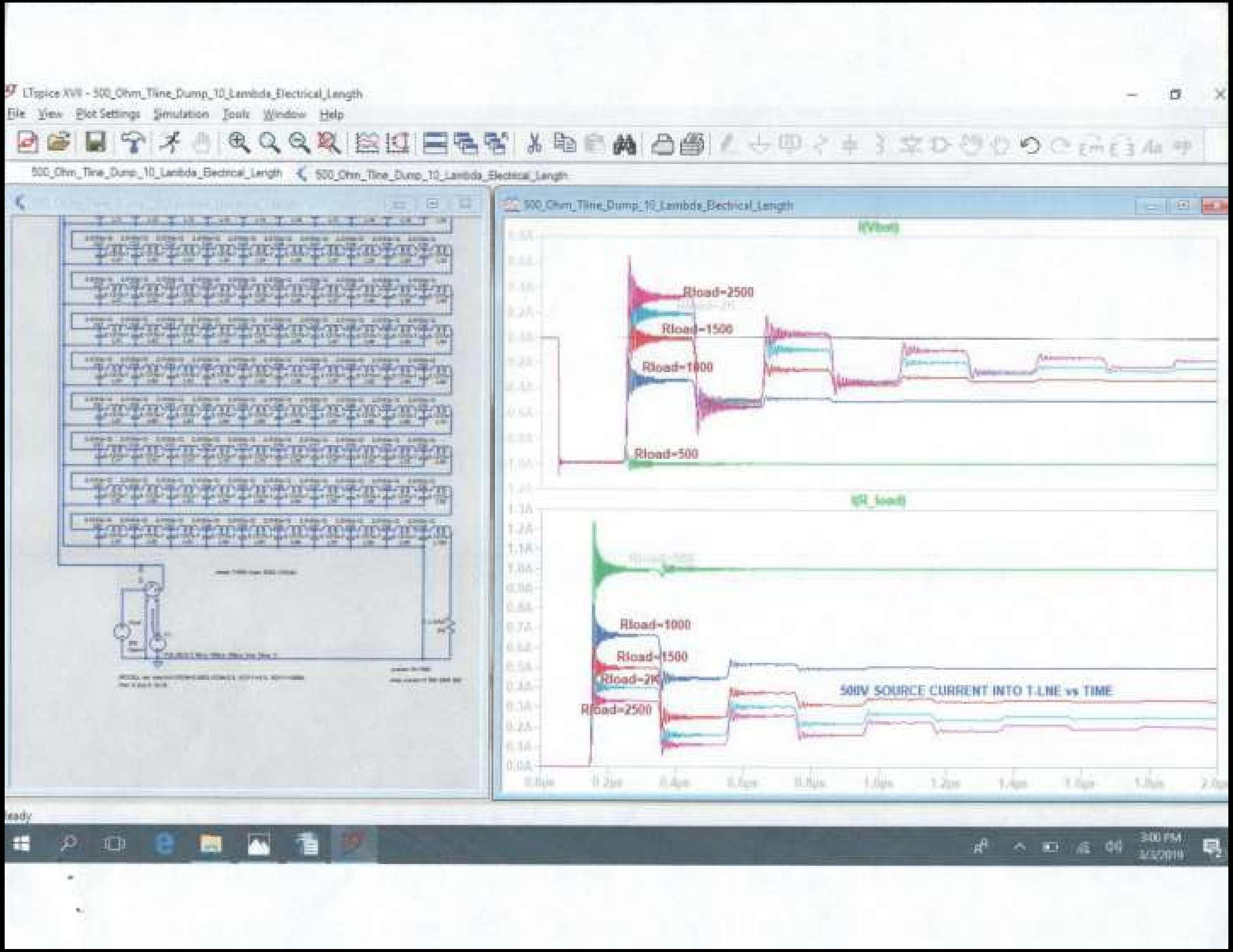
Attached please find one result for 1500 Ohms, and another result for a family of curves 500 to 2500 Ohms step 500 Ohms. With this data Eric can finally define the sought after reflection coefficient of this particular system: it represents a 500 Ohm line with an ideal 500V source switched into it and terminated by a resistive load. The slight ringing overshoot is in part to resistance in the switch chosen to be 500u-ohm. I also included the LTSPICE source file in case someone should like to duplicate or change the simulation result attached. LTSPICE is a free electrical simulator anyone an download from its owner (a major semiconductor company).

I still have to do one more set of field plots for Eric: the Electric Field plot for two parallel wires (I think you already sent him the case for the magnetic field).

Thanks,

Adam Griffin


LTspice XVII - 500_Ohm_Tline_Dump_10_Lambda_Electrical_Length
File View Plot Settings Simulation Tools Window Help
500_Ohm_Tline_Dump_10_Lambda_Electrical_Length
I(Vbat)
Rload=1500
I(R_load)
100ns Delay Switching to Onset of Reflection
Rload=1500
500V SOURCE CURRENT INTO T-LNE vs TIME



LTspice XVII - 500_Ohm_Tline_Dump_10_Lambda_Electrical_Length
File View Plot Settings Simulation Tools Window Help
500_Ohm_Tline_Dump_10_Lambda_Electrical_Length
I(Vbat)
Rload=2500
Rload=1500
Rload=1000
Rload=500
I(R_load)
Rload=1000
Rload=1500
Rload=2500
500V SOURCE CURRENT INTO T.LNE vs TIME

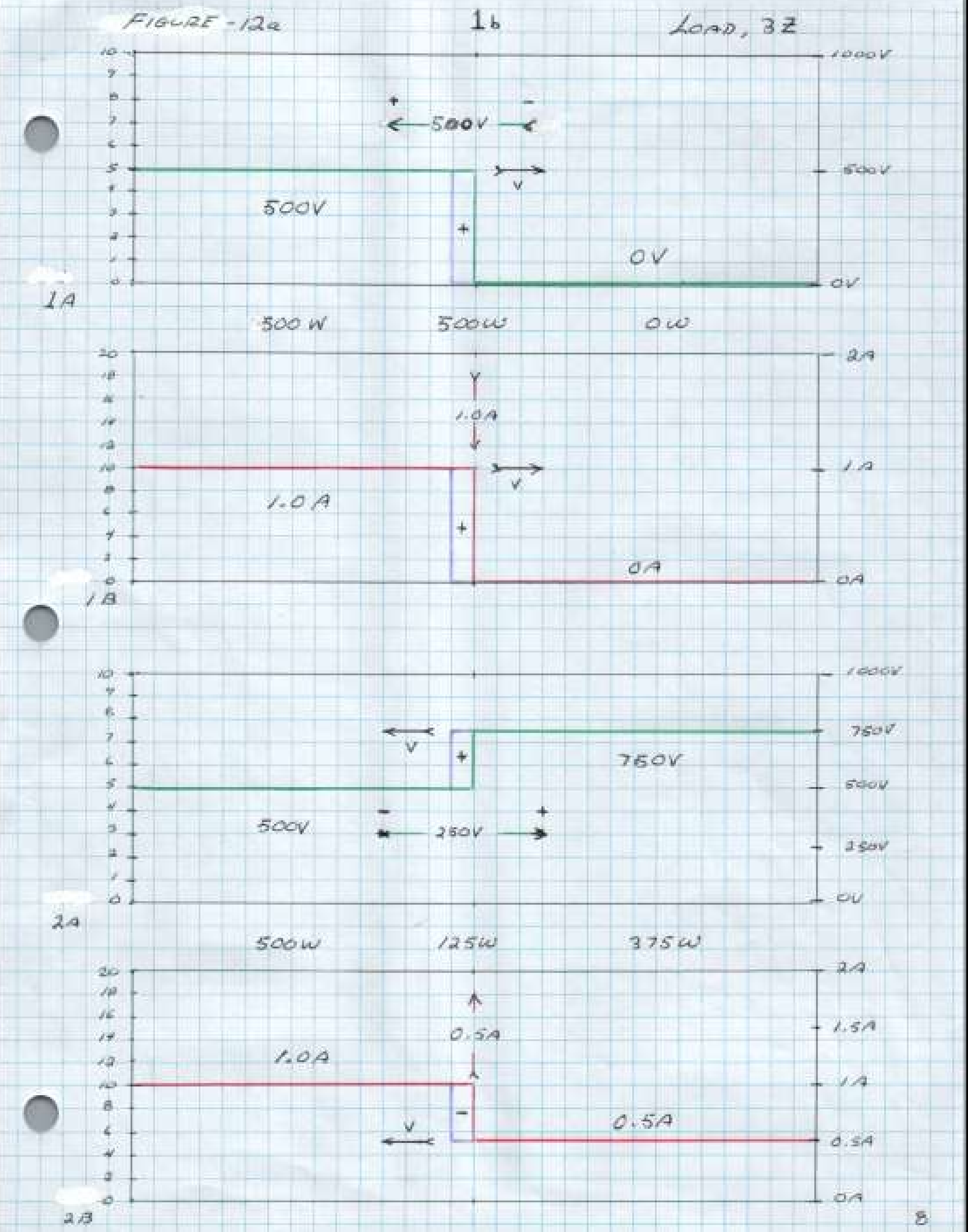


FIGURE - 12a
1b
LOAD, 3Z
500V
500V
0V
1000V
500V
0V
1A
500 W
500W
0W
1.0A
1.0A
0A
2A
1A
0A
1B
750V
500V
250V
1000V
750V
500V
250V
0V
2A
500W
125W
375W
1.0A
0.5A
0.5A
2A
1.5A
1A
0.5A
0A
2B
8

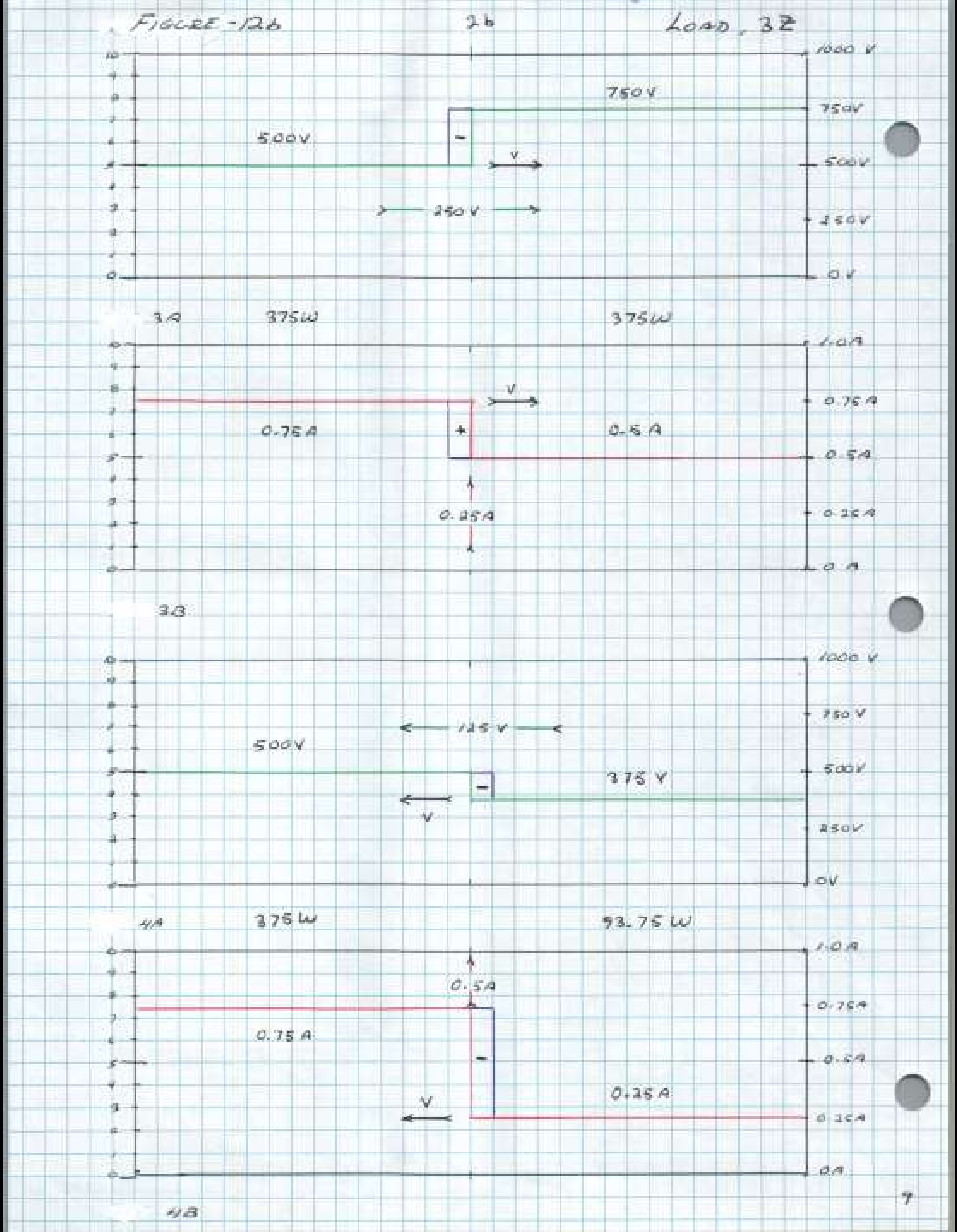


FIGURE-12b
2b
LOAD, 3Z
1000 V
750V
750V
500V
500V
250V
250V
0V
3A
375W
375W
1.0A
0.75A
0.75A
0.5A
0.5A
0.25A
0.25A
0A
3B
1000 V
750V
125V
500V
500V
375V
250V
0V
4A
375W
93.75W
1.0A
0.5A
0.75A
0.75A
0.5A
0.25A
0.25A
0A
4B

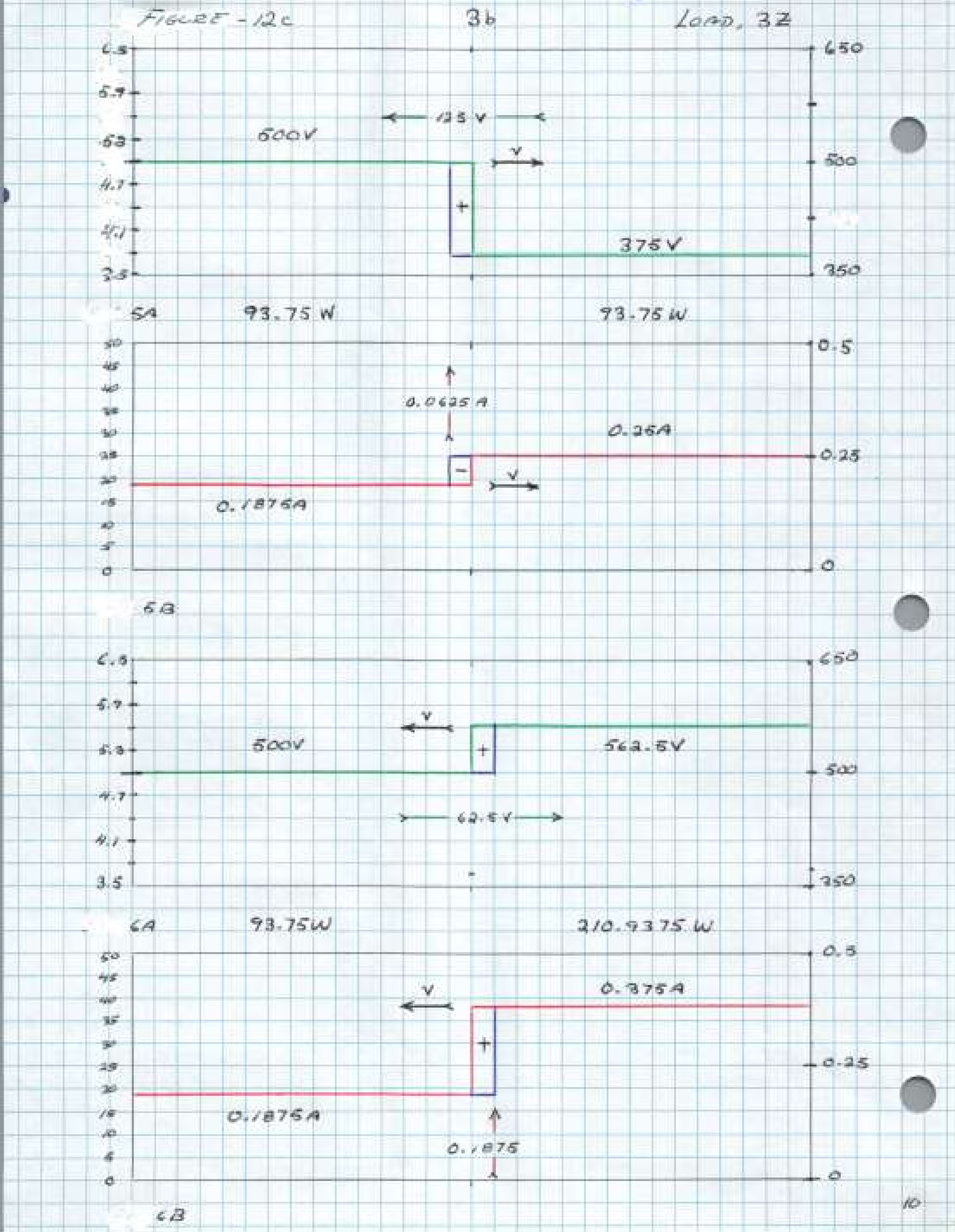


FIGURE - 12c
3b
LOAD, 3Z
125 V
500V
375V
93.75 W
93.75 W
0.0625 A
0.25A
0.1875A
500V
562.5V
62.5 V
93.75W
210.9375 W
0.375A
0.1875A
0.1875

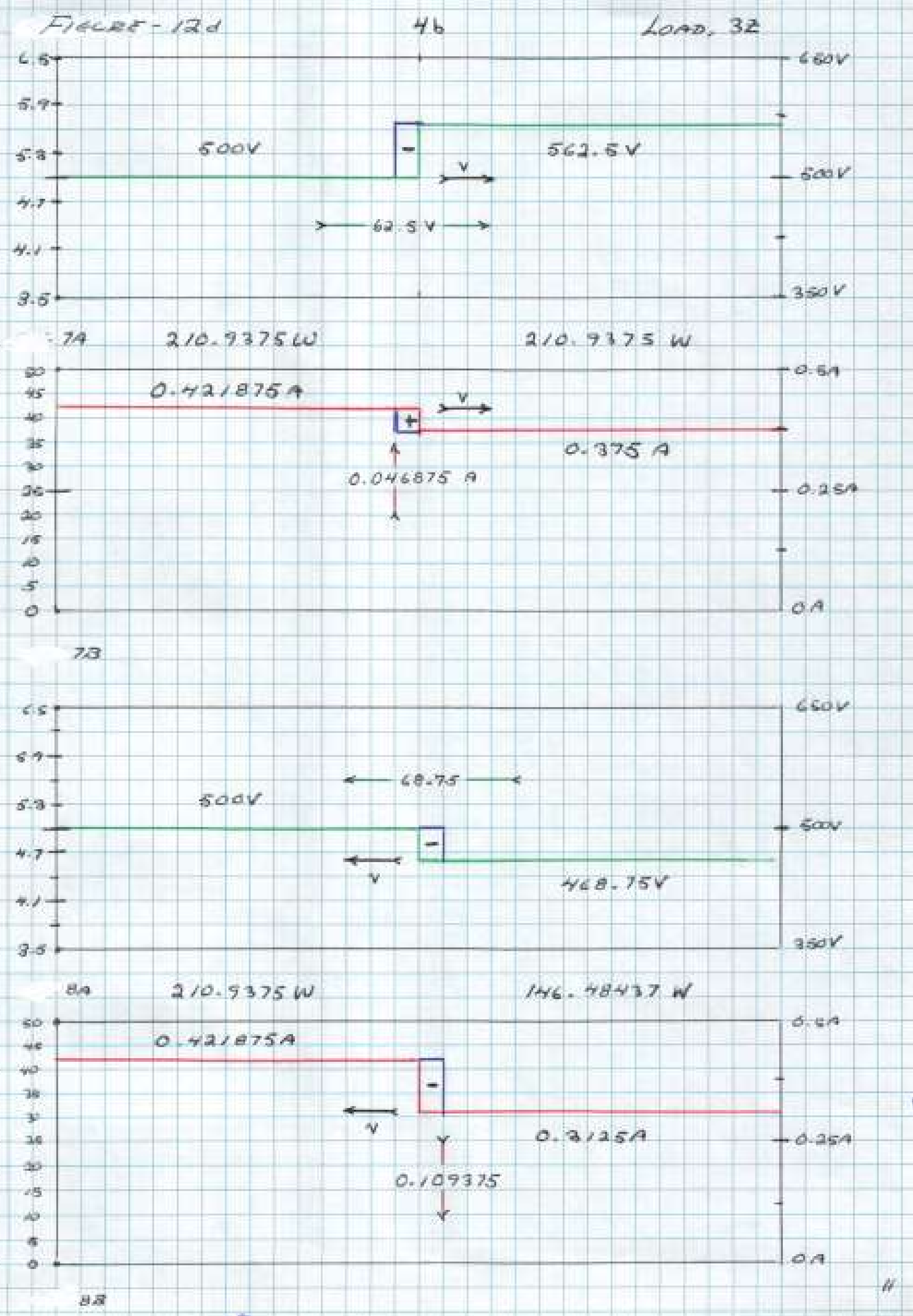


FIGURE - 12d
4b
LOAD, 32
500V
562.5V
62.5V
7A
210.9375W
210.9375 W
0.421875A
0.375 A
0.046875 A
7B
68.75
500V
468.75V
8A
210.9375W
146.48437 W
0.421875A
0.3125A
0.109375
8B

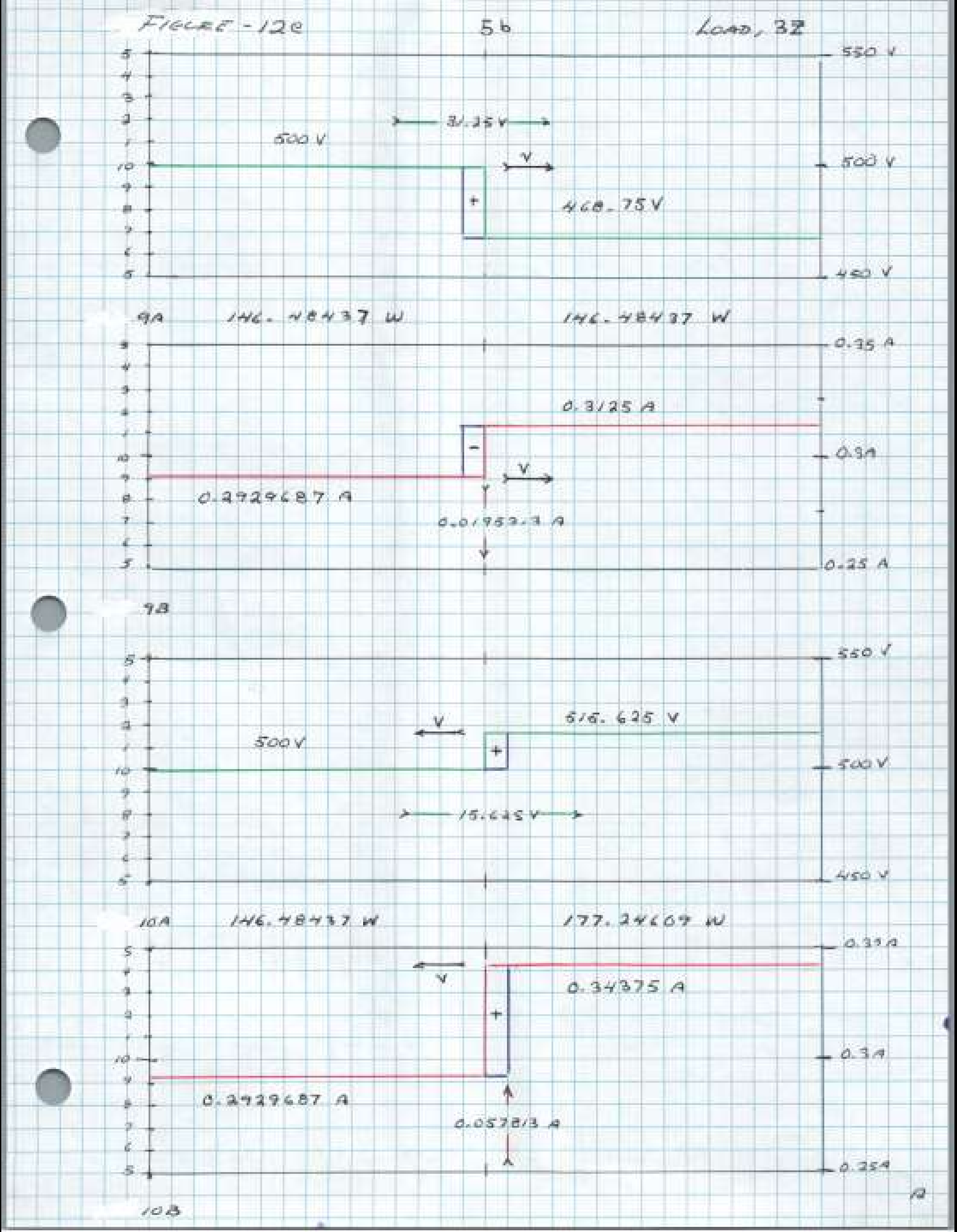


FIGURE - 12C
5b
LOAD, 32
550 V
31.25 V
500 V
500 V
V
+
468.75 V
450 V
9A
146.48437 W
146.48437 W
0.35 A
0.3125 A
-
0.3A
V
0.2929687 A
0.0195313 A
0.25 A
9B
550 V
V
516.625 V
500 V
+
500 V
15.625 V
450 V
10A
146.48437 W
177.24609 W
V
0.34375 A
+
0.3A
0.2929687 A
0.057813 A
0.25A
10B

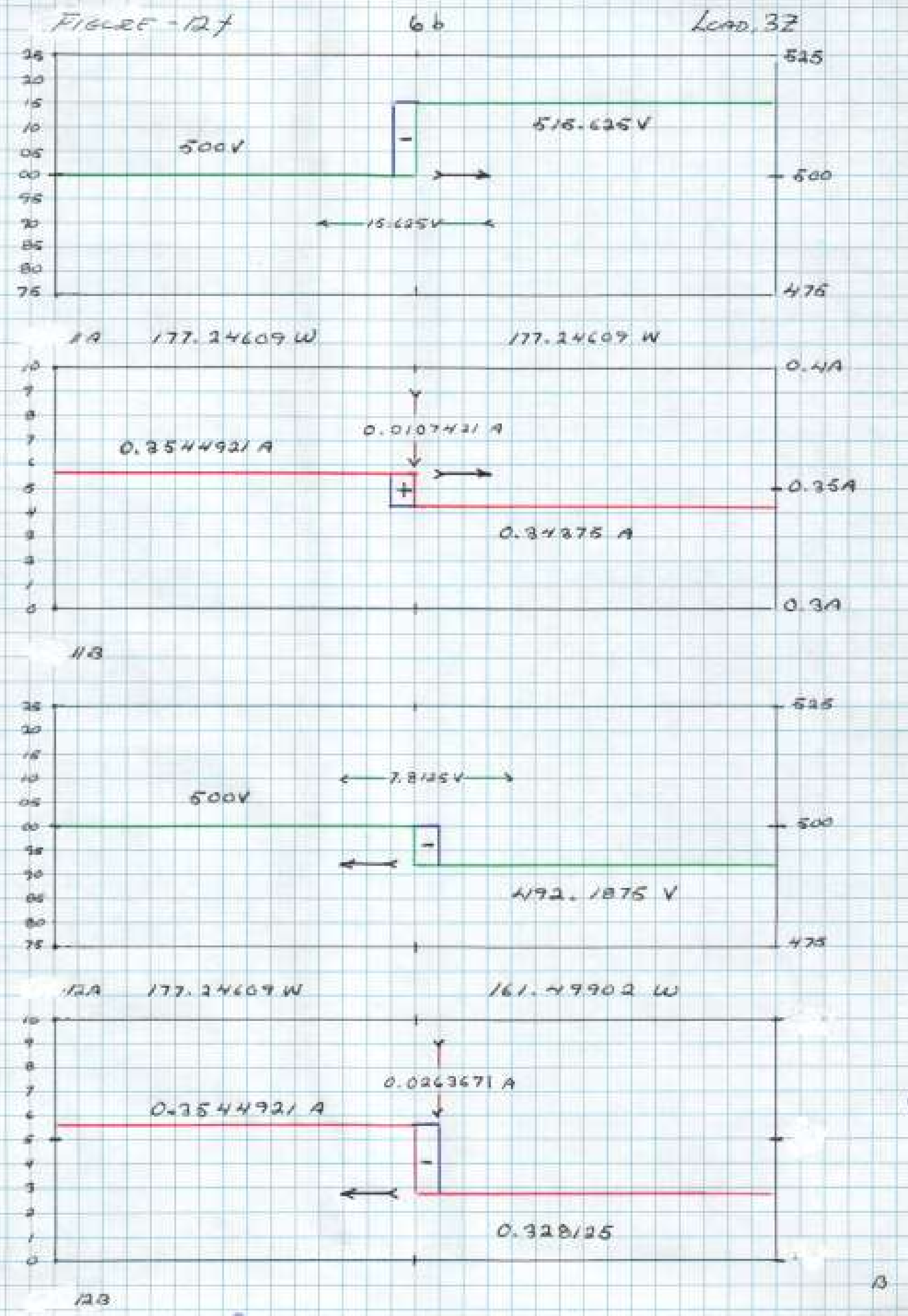
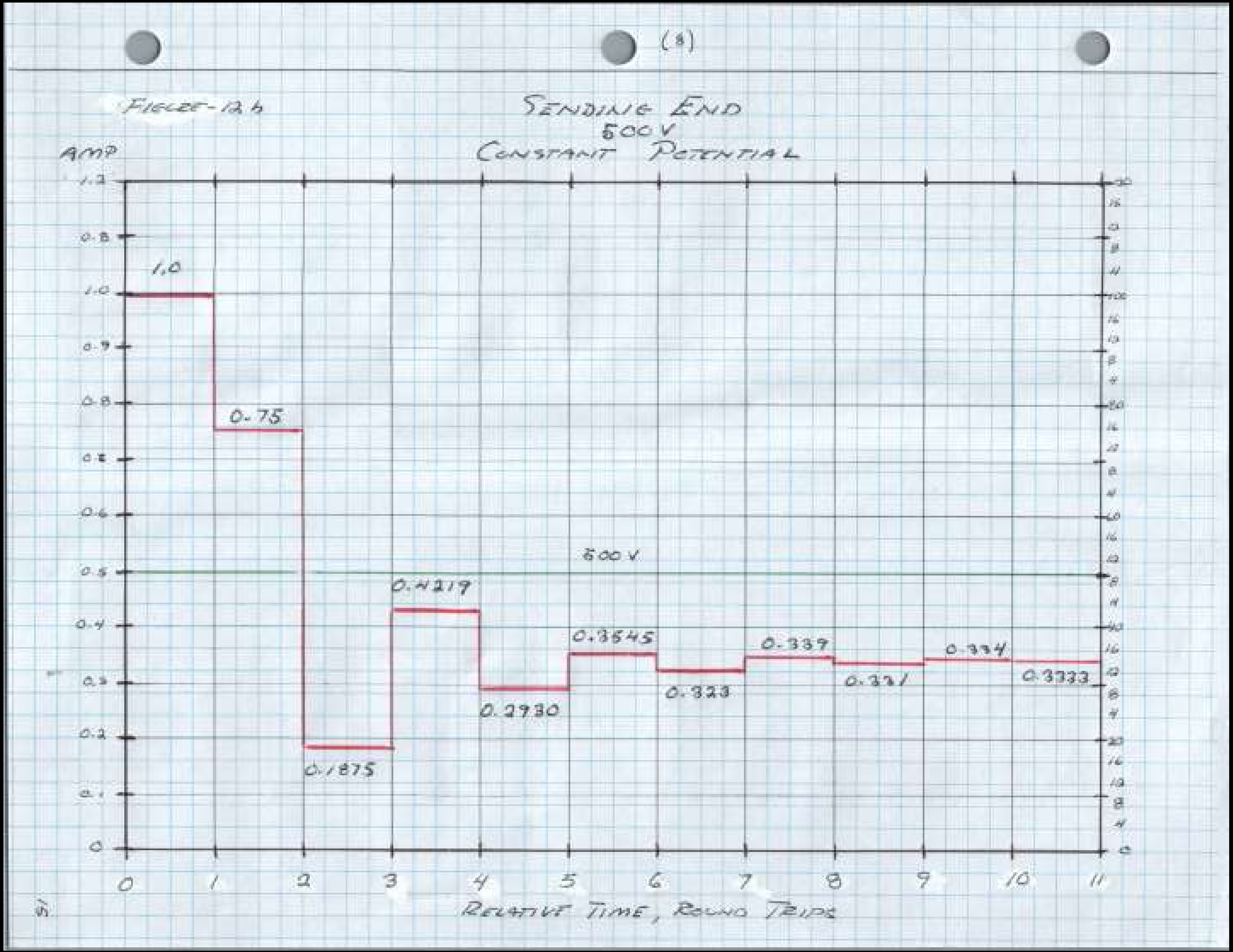


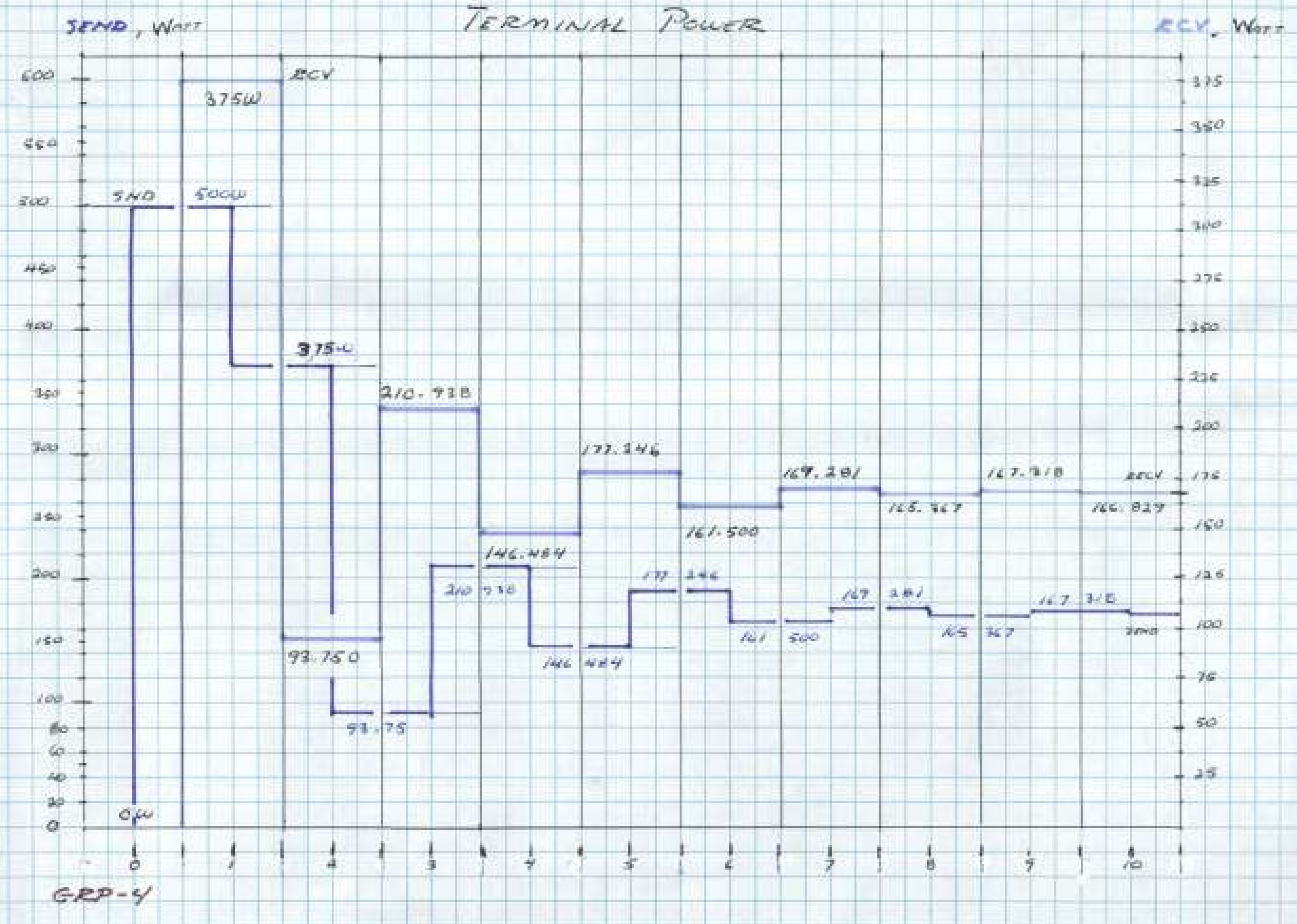
FIGURE - 12 f
6 b
LOAD 3Z
525
500V
516.625V
500
15.625V
475
11A
177.24609 W
177.24609 W
0.4A
0.0107421 A
0.3544921 A
0.35A
0.34375 A
0.3A
11B
525
7.8125V
500V
500
492.1875 V
475
12A
177.24609 W
161.49902 W
0.0263671 A
0.3544921 A
0.328125
12B


(7)
AMP i
RECIEVING END, 1500 OHM
e VOLT
750V
0.5A
562.5V
0.375A
0.25A
375V
0.3125A
468.75V
515.63V
0.3438A
492.88V
0.3281A
503.9V
0.3359A
498V
0.332A
500.9V
0.334A
500V
0.333A
0V
0A
0
1
2
3
4
5
6
7
8
9
10
FIGURE-12g
RELATIVE TIME, ROUND TRIP



(8)
FIGURE-12.b
SENDING END
500 V
CONSTANT POTENTIAL
AMP
1.0
0.75
500 V
0.4219
0.3545
0.339
0.334
0.1875
0.2930
0.323
0.331
0.3333
0 1 2 3 4 5 6 7 8 9 10 11
RELATIVE TIME, ROUND TRIPS

FIGURE-12i (7)



TERMINAL POWER
SEND, WATT
RCV, WATT
SND
500W
375W
RCV
375W
93.750
93.75
210.938
146.484
177.246
161.500
169.281
165.367
167.318
166.829
RCV
0W
GRP-4