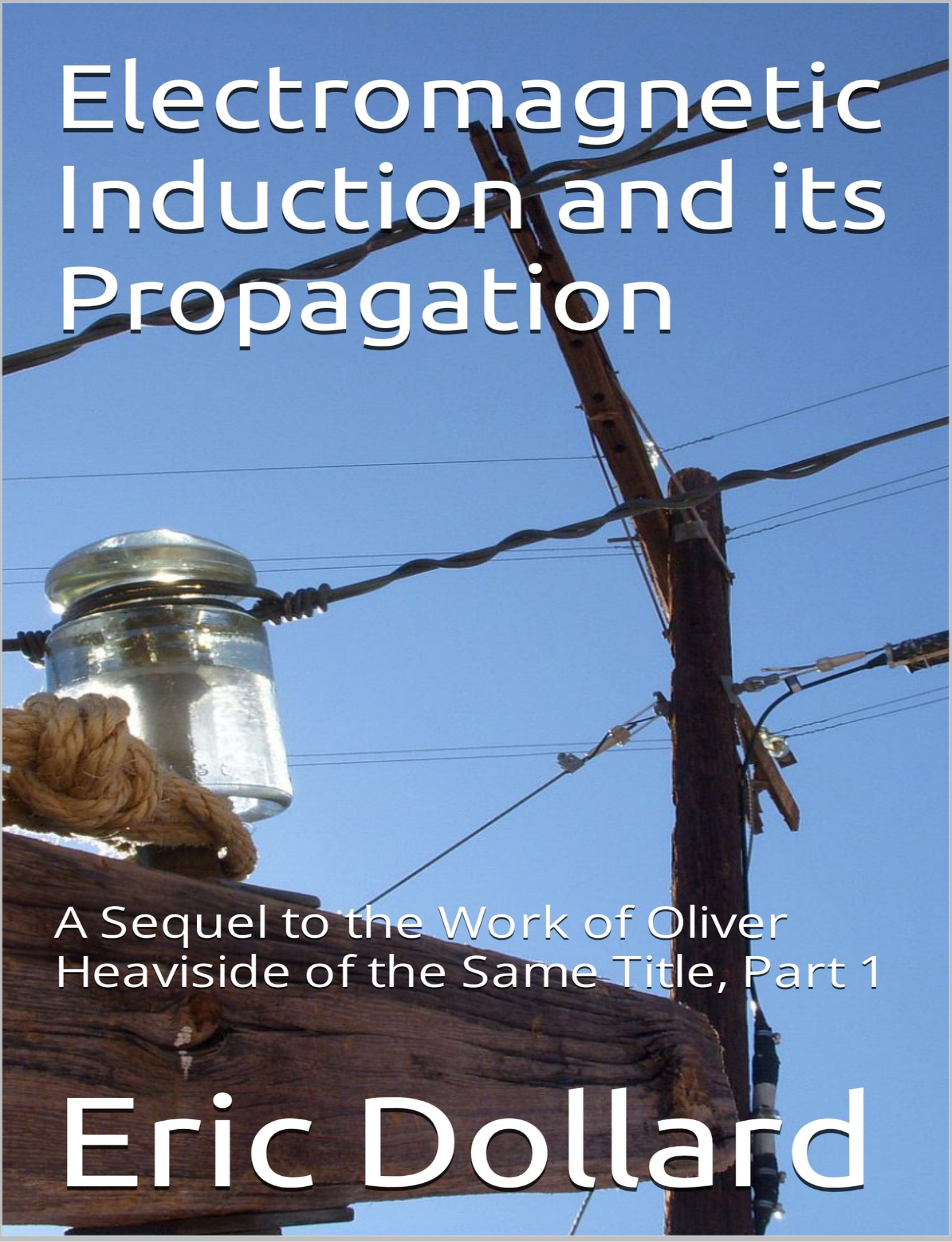
Electromagnetic Induction and its Propagation



A Sequel to the Work of Oliver Heaviside of the Same Title, Part 1

Eric Dollard

ELECTROMAGNETIC INDUCTION AND ITS PROPAGATION

A Sequel to the Work of Oliver Heaviside of the Same Title

Part 1

Electromagnetic Induction And Its Propagation

A Sequel to the Work of Oliver Heaviside of the Same Title

Part 1

By

Eric P. Dollard

Published by
Emediapress.com
Spokane, Washington

Cover Layout: Aaron Murakami
Transcribed by: Griffin G. Brock
Edited by: Griffin G. Brock, Aaron Murakami, Simon Davies

Digital Version 1.0 Released: December 2021
Print Version 1.0 Released: December 2021

ISBN-13: 9798760588807

Digital Edition Published by: Emediapress.com
PO Box 10029,
Spokane, WA 99209
https://emediapress.com

EPD Laboratories

EPD Laboratories, Inc.
PO Box 10029
Spokane, WA 99209

info@epdlabs.org
https://ericpdollard.com

Support EPD Laboratories, Inc. 501(c)3 non-profit organization with tax-deductible donations at https://ericpdollard.com

Table Of Contents

CHAPTER I

Rudiments Of Electromagnetic Theory

Fig. 1 - Open wire telephone transmission pair

1.
Transmission Physicalities

Shown in the cover photo, figure 1, is an open wire telephone transmission pair, this being isolated at face level during a cross-arm replacement procedure. While it is invisible to human sensibilities, simultaneous telephone conversations are active within the space bounded by this transmission pair. [1]

The photo represents the fundamental arch form of electromagnetic transmission in its three principal elements:

1) **Line Conductors:** Consisting of a closed boundary of metallic copper, this being reflective to the bound electromagnetic induction.
2) **Line Insulators:** Consisting of a spaced pair of dielectric glass supports, these being transparent to the bound electromagnetic induction.
3) **Electric Medium:** Consisting of an electric fluid in which the transmission pair is immersed. This medium supports the establishment of the electromagnetic induction. This is represented by the blue sky. Hence, the electromagnetic transmission process is facilitated by the elementals of reflection, transparency, and inductivity.

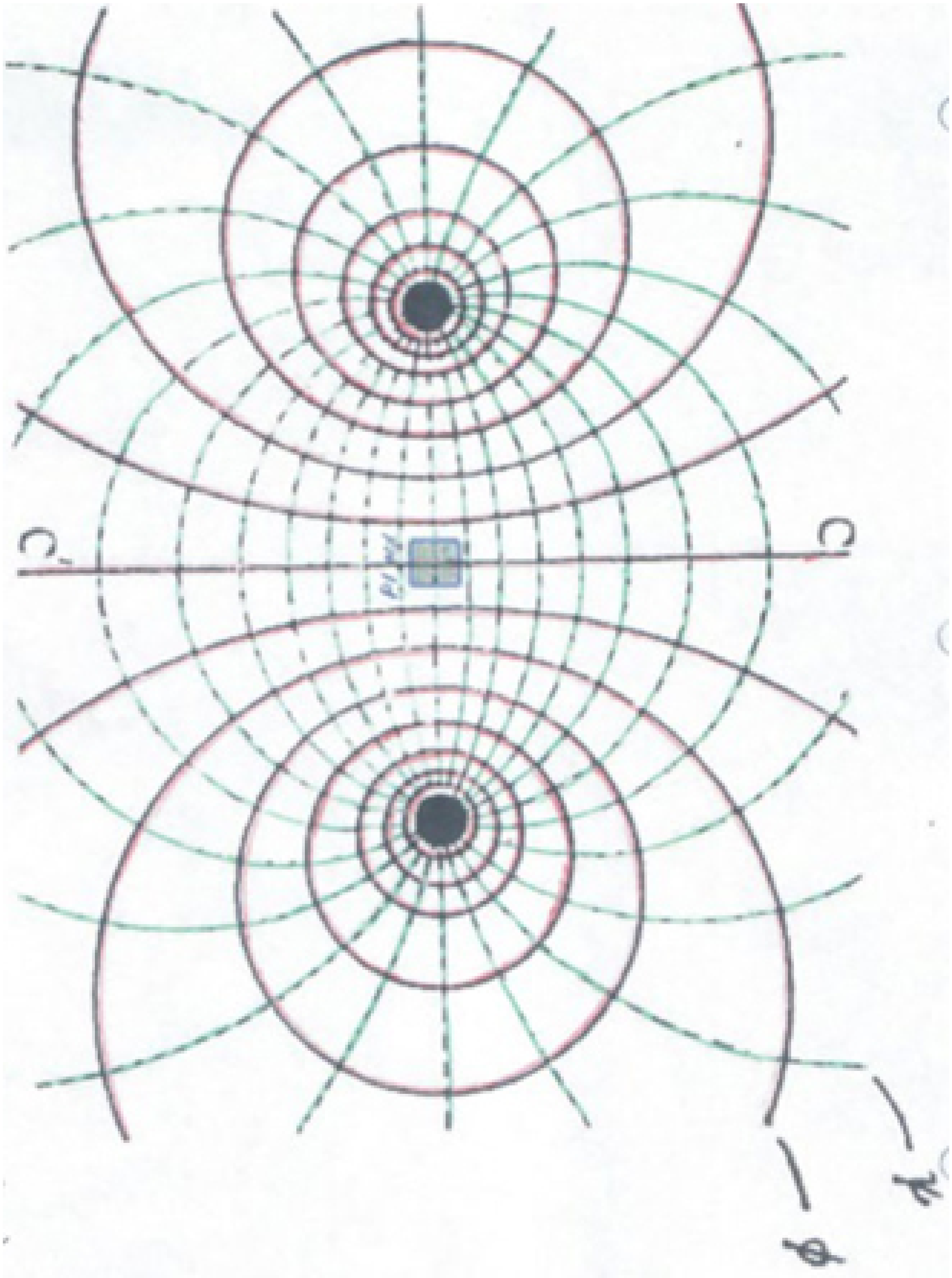


Fig. 1a - Electric medium in electro-tonic state

2.
Defining Both Inductions

Figure 1a depicts the electric medium bound by the line conductors when this medium is in an electro-tonic state. [2], [3] In this condition, the electric medium, μη, has become polarized into what have become known as “lines of force”. [4]

This portrayal is based upon the conception, introduced by Faraday, of tubes of electro-static induction. This provides a language in which to express the phenomena of the electromagnetic field of induction. It is by their tendency to contract, and the lateral repulsion which similar tubes exert on each other, which explains the forces between electrified bodies. Such tubes can be hereby called “Faraday Tubes”. [5]

It has come to pass that there exist two entirely different viewpoints in considering the pondermotive forces acting upon the line conductors. One is that adopted by the mathematical physicist, this analogous to Newton’s way of expressing the fact of gravitation. The other way is that the Newtonian conception of forces acting at a distance, through vacuous space, are mathematical fictions only, and have no real existence. What is real are the manifest stresses existing in the electromagnetic field of induction. [6], [7]

The electromagnetic field of induction divides into a pair of constituents exhibiting a conjugate inter-relation, and thus everywhere establish themselves into a right-angle relation in space with respect to each other.

The primary constituent is the electrification of the electric medium. Shown in green, these lines of force, ψ, present themselves as radial lines which exist in attachment to the bounding line conductors. These lines of force, so-called because the force manifests along their path in space, exist in a state of tension, which act to draw the conductors together as a contractive force.

The secondary constituent is the magnetization of the electric medium. Shown in red, these lines of force, Φ, present themselves as circumferential lines which surround the bounding line conductors. These lines exert an internal broadside pressure, which act to push apart the pair of conductors as an expansive force. [8], [9], [10]

It is evident, that while this pair of distinct lines of force exist in a condition of space quadrature, the acting forces they exert upon the line conductors present themselves in space opposition. It is a characteristic of the Faraday Tubes in general, that whatever tension exists within these tubes, it is matched by an equal broadside pressure between the individual tubes against each other. [11], [12]

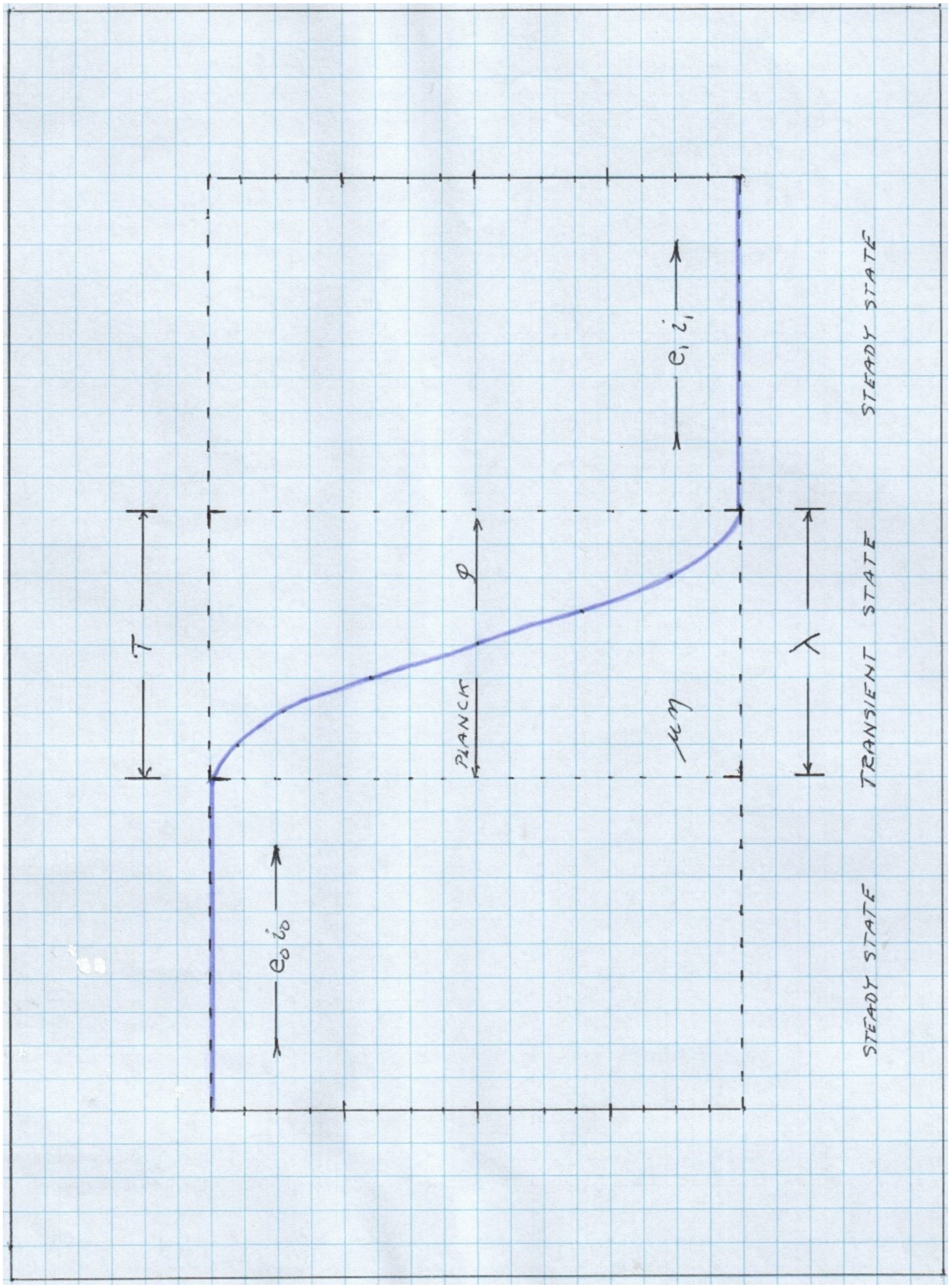


Fig. 1b - Transient impulse propagation

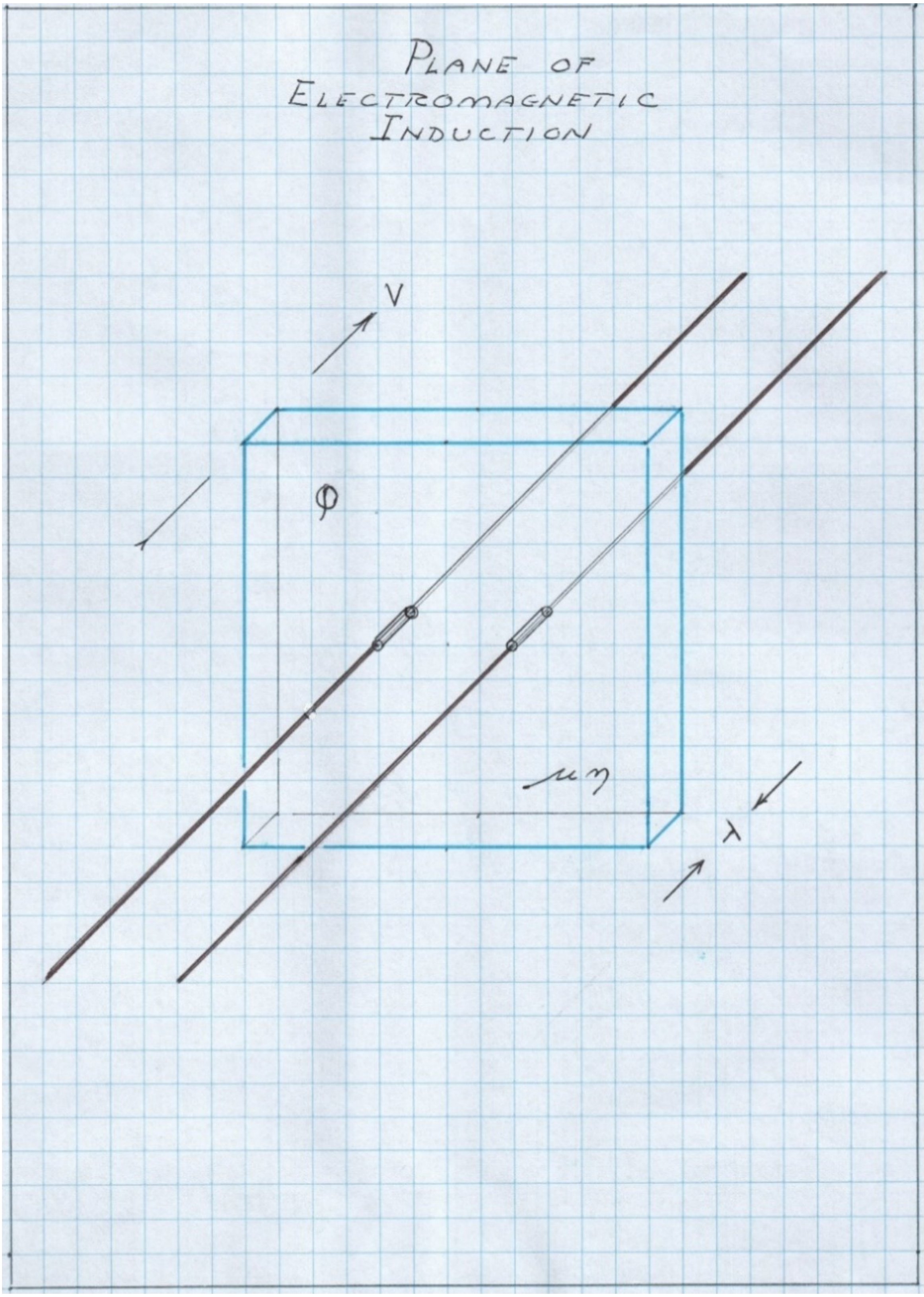


Fig. 1c - Characteristic electro-magnetic impulse

3.
Transmission Parameters

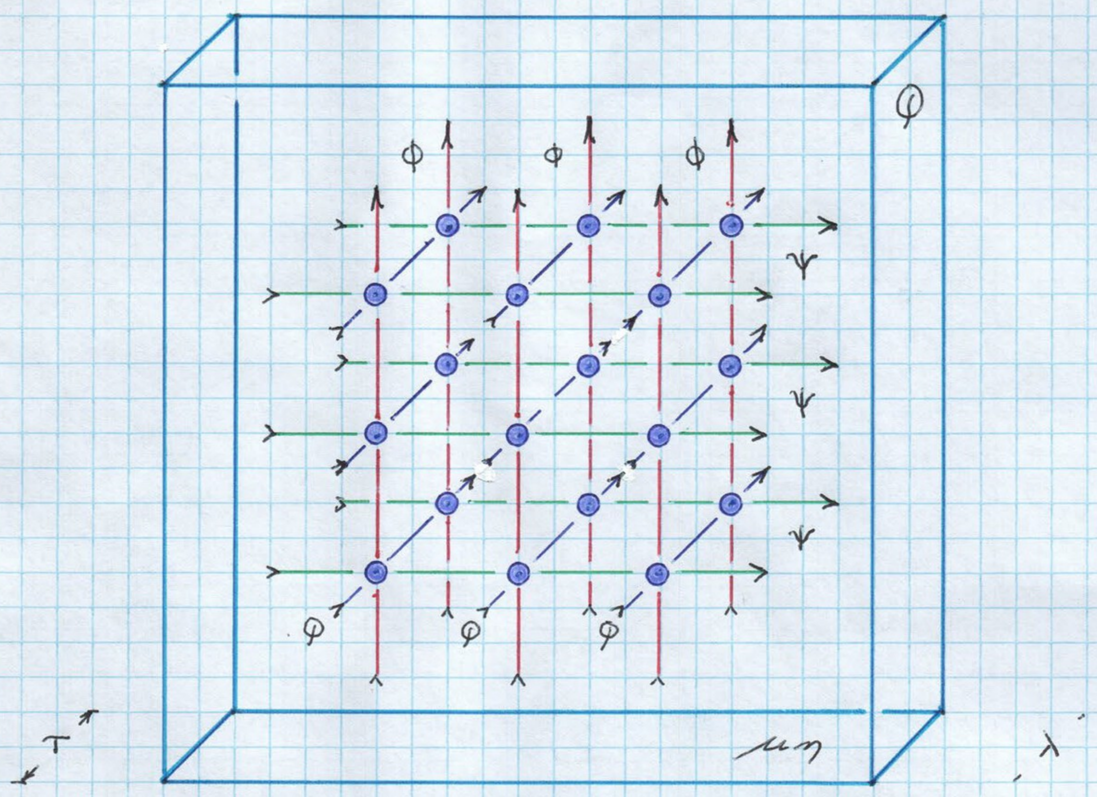
Consider the hypothetical situation where the open wire line is terminated at one end by a telephone central office (C.O.), and at the other end by a telephone subset. Initially the subset is "on hook", or in an open circuit condition, that accordingly draws no current. The C.O. end of the line supplies a 48 Volt direct current potential, through its line coil, and the line is thus in a steady state of i_1 equals zero and e_1 equals 48 Volts. No power flow exists in the line, thus P_1 equals zero. [13]

At the start time, t equals zero, the subset is lifted "off hook", closing the circuit through its network, which begins to draw a current, reaching a steady state of 20 Milliamperes over time interval, τ. Because the subset is now consuming electric power, P_0, this engenders an electro-motive force of 6 Volts. Accordingly, a line potential of 6 Volts is established giving the power, P_0, as 120 Milliwatts at the subset send of the line.

The network response to its connection to the "charged" line establishes a transient of time span, τ, seconds, and thus the transient immediately begins its propagation toward the C.O. end of the line. This condition is portrayed by the time- distance diagram, 1b and its related pictorial representation, figure 1c.

The duration and wave-shape of the network transient is preserved in the course of its propagation along the length of open wire line, and accordingly represents an impulse of electromagnetic induction, *Q*, propagating in an electric medium, μη, which is bound between the line conductors. Its field of force has been portrayed by figure 1a. [14]

Because of the finite propagation time of this impulse, initially the C.O. still sees an open circuit and its power, P_1, remains zero. The power, P_0, is initially supplied to the subset solely by the discharge of the line potential, e_1, affected by the traveling impulse, *Q*. Hence, on either side of this impulse, exists a pair of steady states, P_1, on the C.O. side of the impulse, and, P_0, on the subset side of the impulse. This electromagnetic impulse, *Q*, thus serves as an intermediary between the two steady states, converting one steady state, P_1, into another steady state, P_0, this acting within the time interval, τ, seconds, and spanning the length of the line, λ, centimetre. [15], [16], [17]



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

MAGNETIC INDUCTION

Φ

C.G.S. MAXWELL

DIELECTRIC INDUCTION

Ψ

C.G.S. COULOMB

Fig. 1d - Enlarged distribution of electric induction

4.
Transient Impulses

Figure 1c portrays the general character of the transient electromagnetic impulse, *Q*. In this idealized representation this impulse is a slab of electric fluid, which freely glides over the surface of the line conductors. This slab is affixed by the so-called conductors to the boundary condition established by the conductor geometry. Its differential length, λ, on the line is established by the properties of the electric medium, μη, in which the line is immersed, this in relation to the duration time, τ, is established by the subset network. The proportionality existing between this differential length and its co-responding duration time establishes a fictitious velocity of propagation, *V*, at which this transient impulse travels toward C.O. end of the line. This propagation is actually a contiguous step by step process in time, and it bears a certain analogy to a procession of falling dominos, one element striking the next and so forth in a sequential manner.

The element of time involved in the initiation of this transient impulse is affixed to it in the course of its travel. The start time, *t*, rides along this travel and accordingly, time is at a standstill within the span of this impulse. Behind the impulse, time is advancing toward the point of initiation at the subset, this origination point, existing in "present time". Present time advances as the traveling impulse gains in distance from its positional origin.

In the center of figure 1a will be noticed an elemental square area inset into the spatial distribution of electric induction. This is shown greatly enlarged by figure 1d. Due to the infinitesimal size of this elemental area, all magnetic lines, Φ, in red, are straight vertical lines, and all dielectric lines, ψ, in green, are straight horizontal lines. Everywhere in the space surrounding the line conductors, the magnetic and dielectric lines are crosswise with respect to each other, this being a fundamental law of electromagnetism. The electromagnetic composite, *Q*, is directed perpendicular to the plane occupied by the crosswise magnetic and dielectric lines, and this direction is co-linear with the path of propagation.

It is commonly stated that all three of these directed quantities, Φ, ψ, and Q, exist in a mutually orthogonal relation in space. [18], [19]

At the juncture of these three directed quantities the fundamental corpuscle of electromagnetism resides. It is within this corpuscle that the energy of magnetism is interchanged with the energy of dielectricity, that is, magnetism, Φ, is consumed to produce dielectricity, ψ, or conversely dielectricity, ψ, is consumed to produce magnetism, Φ. It is only when this interchange is in its process that the phenomena of electromagnetism manifests. This corpuscle will hence be called the "Planck", a quantum quantity of electromagnetic induction.

The lifespan of the Planck is that time interval, τ, in which the energy contained by one field is converted into the energy contained by the other field. Thereafter, at an elemental distance, λ, the interchange process again takes place within a subsequent corpuscle, which has another equal time span, τ. This sequential process is directed along the path of propagation established by the bounding line conductors.

The incremental proportionality between the sequential distance, λ, and the lifespan time, τ, gives an apparent velocity, V, of the electromagnetic propagation along the length of the line conductors. It must be emphasized that this so-called velocity is fictional, and in reality, it only represents a certain process existing within the units of magnetism and the units of dielectricity.

5.
Induction Parameters

For the purpose of analysis, the two primary aspects of the electric field, Q, that is, the magnetic, Φ, and the dielectric, ψ, are sub-divided into their secondary aspects as follows:

The magnetic field in the steady state is represented by a pair of constituents: the magneto-static potential, i, and the magnetic inductance, L.

The magnetic field in the transient state is represented by another pair of constituents: the electro-motive force, E, and its duration, the time span, τ.

The dielectric field in the steady state is represented by a pair of constituents: the electro-static potential, e, and the dielectric capacitance, C.

The dielectric field in the transient state is represented by another pair of constituents: the displacement current, I, and its duration, the time span, τ.

The magnetic inductance, L, commonly known as the magnetic energy co-efficient, represents the capacity for magnetism exhibited by that boundary condition defined by the geometric placement of the line conductors as well as the magnetic properties, μ, of the medium in which they are immersed.

The dielectric capacitance, C, commonly known as the dielectric energy co-efficient, represents the capacity for dielectricity exhibited by that boundary condition defined by the geometric placement of the line conductors as well as the dielectric properties, η, of the medium in which they are immersed.

It is a common misunderstanding that the magnetic inductance, and the dielectric capacitance, represent distinct and separate entities. However, just as with the magnetic induction, Φ, and the dielectric induction, ψ, it is, L and C together represent conjugate aspects of an indivisible line geometry and an indivisible electric medium in which it is immersed.

The magneto-static potential, i, presents itself as the pondermotive force, f_m, of the magnetism contained by the boundary condition of the line conductors, this force acting upon these conductors. This potential is commonly portrayed as a conduction current within the line conductors and its magnitude exists in proportion to the quantity of bound magnetism.

It must be borne in mind however, that this current, as well as its force, are inseparable from the magnetism itself, all being aspects of a unified magnetic phenomenon.

The electro-static potential, *e*, also presents itself as the pondermotive force, f_d, of the dielectricity contained by the boundary condition of the line conductors, this force also acting upon these conductors. This potential is considered to be associated with the so-called "charge" upon the conductors and its magnitude exists in proportion to the quantity of bound dielectricity.

As with the potential, *i*, this potential, *e*, is inseparable from the electrification as well as the force, all being inter-related aspects of a unified dielectric phenomenon.

The electro-motive force, *E*, represents an energetic reaction to a variation of the magnetism bounded by the line conductors. This so-called force acts upon the elements of conduction within the substance of the line conductors, and it behaves in the manner of an inertia. It may thus be considered the "inertia of magnetism".

The displacement current, *I*, represents an energetic reaction to a variation of the electrification bounded by the line conductors. This so-called current acts in the space bounded by the line conductors, and it behaves in the manner of an elastance. It can therefore be considered the "elastance of electrification".

The electro-motive force, *E*, is proportional to the time rate of, τ, at which energy, W_m, is taken from, or given to, the magnetic field bound by the line conductors. Likewise, the displacement current, *I*, is proportional to the time rate of, τ, at which energy, W_d, is given to, or taken from, the dielectric field bound by the line conductors.

While it is that the conduction current, *i*, and the displacement current, *I*, are both given in the units of the Ampere, it is incorrect to consider them the same, although this misunderstanding is commonplace. The conduction current resides within the line conductors, and the displacement current resides external to the line conductors. It is only at the boundary set by the surface of the conductors that the two currents unite.

Likewise, while it is that the electro-static potential, *e*, and the electro-motive force, *E*, are both given in the units of the Volt, it is incorrect to consider them one of the same, although this misunderstanding is commonplace. The electro-static potential resides external to the line conductors, and the electro-motive force resides within the line conductors. [20]

With this established set of parameters, constants, and coefficients, it is hereby possible to perform the mathematical analysis of electric transmission. It must be remarked however, of all these factors which take part in the transmission process, it is only the potentials, the magnetic, *i*, and the dielectric, *e*, which yield to actual physical measurement, as a consequence of the pondermotive forces they exert upon gross physical matter. It is through their actions that the general understanding of the phenomena of electricity has been arrived at. The precise definition of electricity still is an unknown.

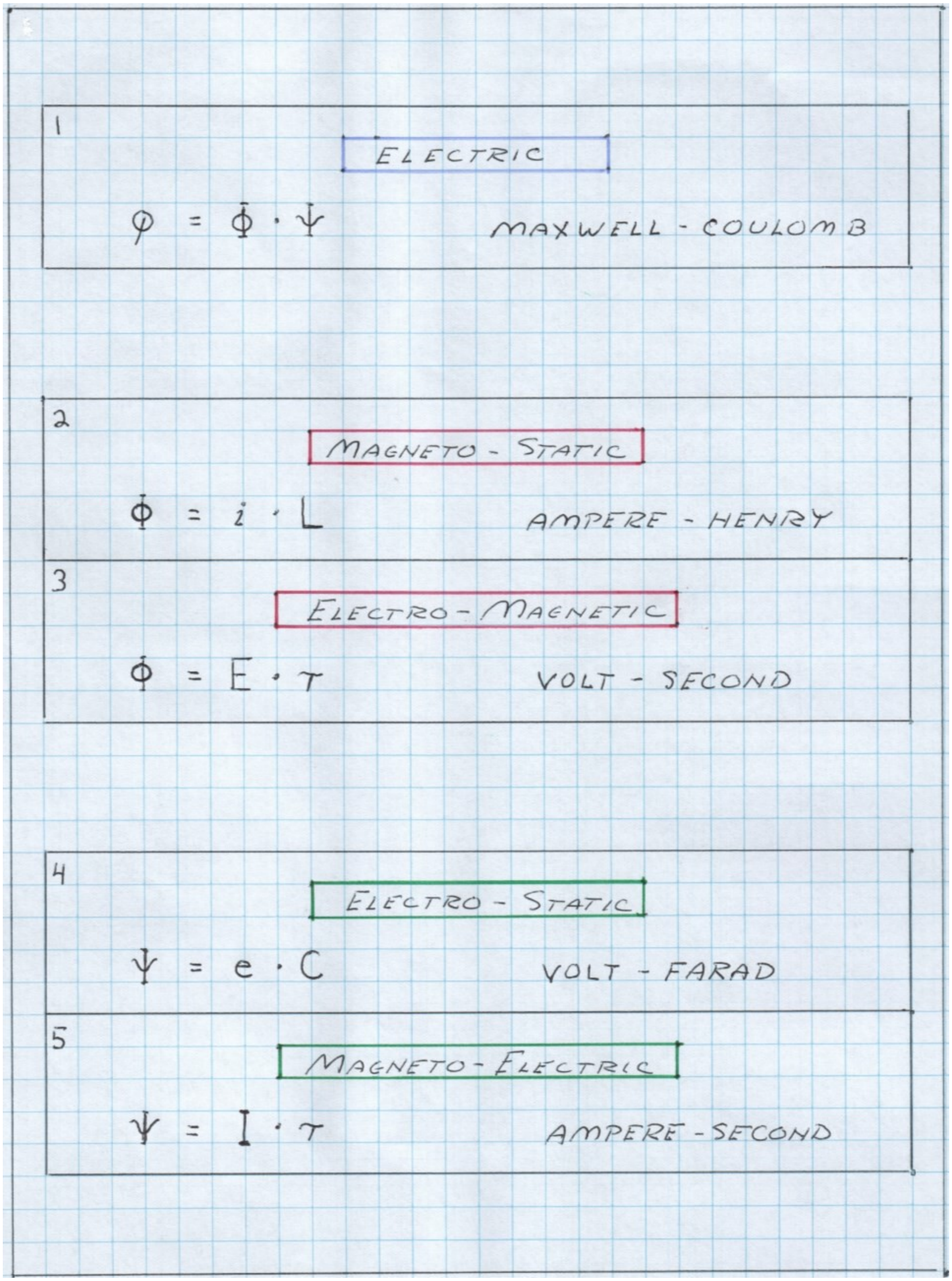


Fig. 1e - Mathematical relations

6.
Properties Of Electric Induction

In reference to figure 1d:

The fundamental quantity of electric induction, Q, in C.G.S. units of Maxwell-Coulomb, is represented as the product of the magnetic induction, Φ, in Maxwell, contained in the bound electric medium, and of the dielectric induction, ψ, in C.G.S. Coulomb, contained in the bound electric medium.

Alternately, the electromagnetic induction, Q, in C.G.S. units of Planck, is divisible into a pair of fundamental constituents, the magnetic induction, Φ, in Maxwell, and the dielectric induction, ψ, in C.G.S. Coulomb, both united within the bound electric medium.

In reference to figure 1e:

The magnetic induction, Φ, in the steady, or magneto-static, state is the product of the conduction current, i, in Ampere, and the magnetic inductance, L, in Henry, presented by the boundary condition and the character of the medium in which it is immersed. Hereby, the units of magnetic induction, Φ, are given as Ampere-Henry.

The magnetic induction, Φ, in a transient, or electro-magnetic state is represented as the product of its electro-motive, E, in volt, and the span of time, τ, seconds, in which the magnetism is in a transitional state. Hereby, the units of magnetic induction, Φ, are given as Volt-Second.

The dielectric induction, ψ, in the steady, or electro-static, state is represented as the product of its electro-static potential, e, in Volt, and the dielectric capacitance, C, in Farad, presented by the boundary condition and the character of the medium in which it is immersed. Hereby, the units of dielectric induction, ψ, are given as Volt-Farad.

The dielectric induction, ψ, in the transient or magneto- electric, state is represented as the product of its displacement current, I, in Ampere, and the span of time, τ, seconds, in which the dielectricity is in a transitional state.

Hereby, the units of the dielectric induction, ψ, are given as Ampere-Second.

It should be borne in mind that a specific distinction exists here among the terms: electric, electromagnetic, electro- magnetic, and magneto-electric.

The term “electric” denotes the general presence of both a field of magnetic induction and a field of dielectric induction, which both may, or may not, be present at, or in, the same time, τ, or space, λ, respectively.

The term “electromagnetic” denotes the specific union of a field of magnetic induction with a field of dielectric induction, both of which are unified in the same time, τ, and space, λ, presenting a proportionality of velocity, V, in centimetre per second.

The term “electro-magnetic” denotes the electrification derived from a transitional field of magnetic induction, and as such it is a magnetic phenomenon.

The term “magneto-electric” denotes the magnetization derived from a transitional field of dielectric induction, and as such it is a dielectric phenomenon.

TABLE OF DERIVED QUANTITIES & MAGNTUDES		
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

Fig. 1f - Resultants of induction

In general, a composite of these four specific conditions will represent, for practical consideration, any and all electric phenomena involved in the process of electric transmission. These elements, given in figure 1f will serve the basis for the mathematical analysis that follows.

Chapter II

Line Geometry In The Electric Medium

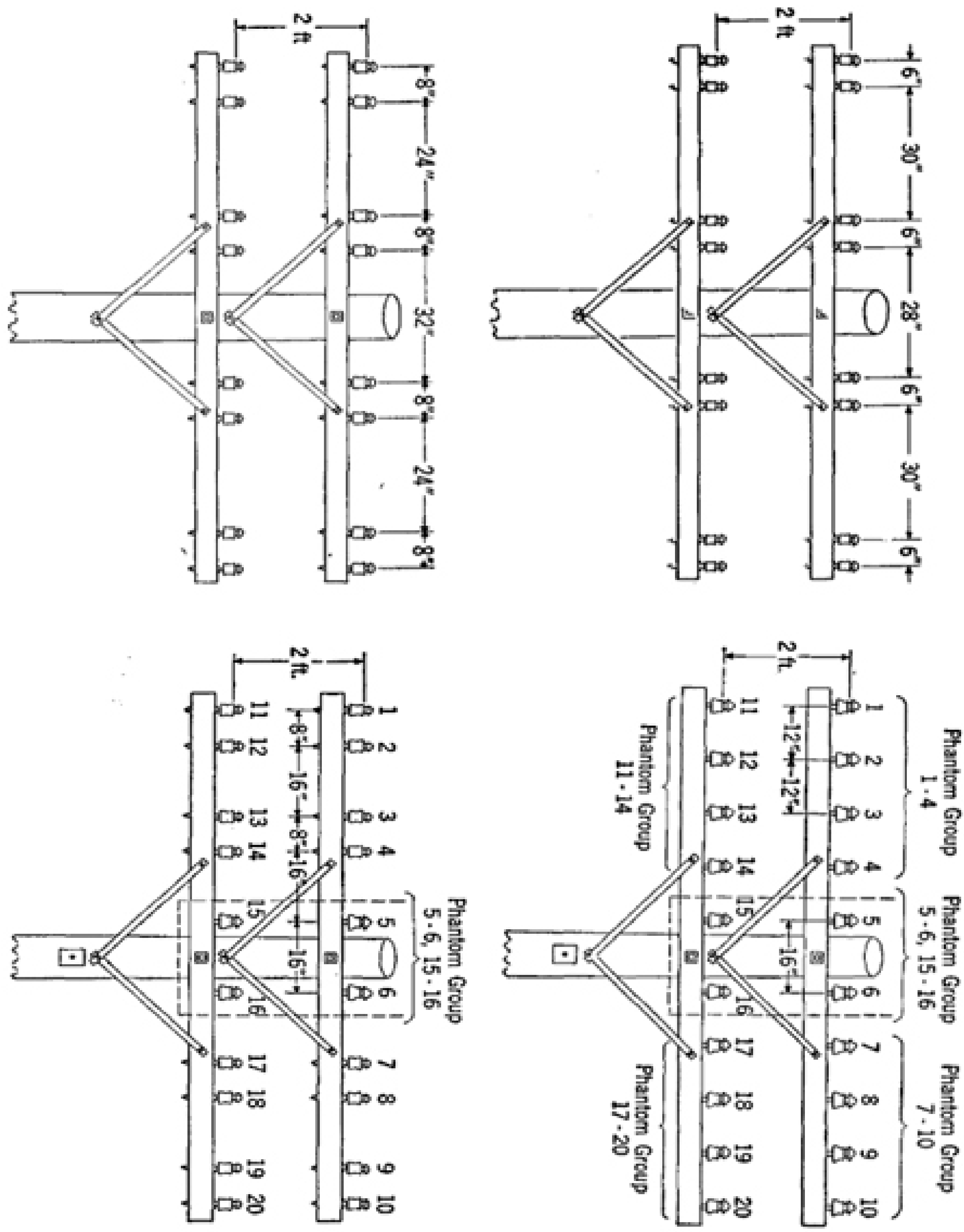
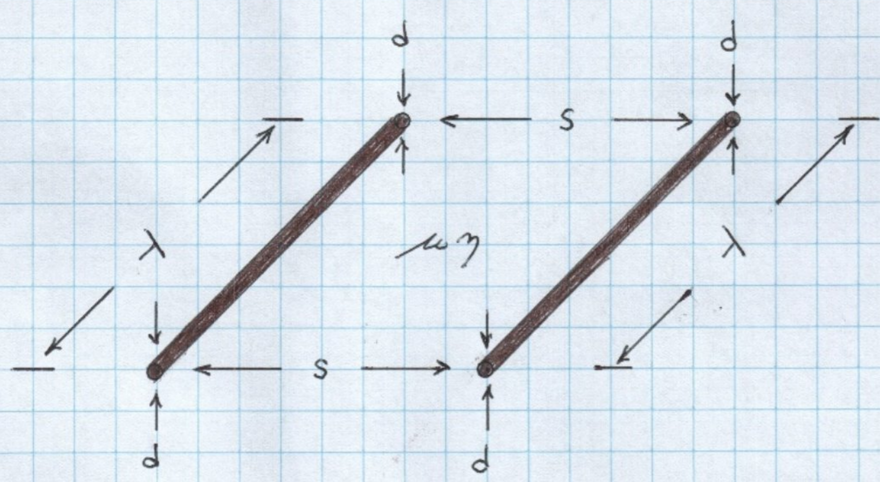


Fig. 2 - Line conductor and insulator configurations

ELECTROMAGNETIC GEOMETRY IN MEDIUM, $\mu\eta$



d , CONDUCTOR DIAMETRE

s , CONDUCTOR SPACING

λ , CONDUCTOR LEGNTH

Fig. 2a

1.
Magnetic & Dielectric Dimensions

The fundamental character of electric transmission is a direct result of the geometry of the line conductor configuration, as well as the electric medium in which this configuration is immersed. This so-called “metallic-dielectric geometry” yields the two most fundamental coefficients of electric transmission, the magnetic inductance, *L*, and the dielectric capacitance, *C*. The derivation of these coefficients from the line dimensions follow:

A typical configuration of line conductors and insulators is portrayed by figure 2, an arrangement of telephone transmission pairs. An idealized section of a single transmission pair, and its physical dimensional variables is portrayed by figure 2a. In what follows all units and dimensions will be given in the centimetre-gram-second system, from which all electrical units have been derived.

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

Fig. 2b

Figure 2b establishes the determining factors involved in the calculation of the magnetic inductance, *L*, of a transmission pair. Three fundamental factors are involved:

1) First, is the "space factor," σ, in Neper, which is a logarithmic function of the physical geometry of the line. This is a result of a dimensionless, or numerical, ratio, the magnitude of which is in direct proportion to the conductor spacing, *s*, in centimetre, and in inverse proportion to the conductor diameter, *d*, in centimetre. Hence, the dimensions are in centimetre per centimetre, that is, a numerical ratio of spatial dimensions, or space factor.
2) Second, is the magnetic permeability, μ, in centimetre, of the medium in which the line conductors are immersed. It is this property of the medium that supports the existence of the magnetic induction, Φ, regardless of geometry containing it. The ability to contain magnetism is directly proportional to the permeability which supports it.
3) Third, is the length, λ, in centimetre, of the transmission pair. This length compounds the inductive product of the space factor, σ, and the permeability, μ, to give the complete magnetic inductance, *L*.

Hence, the dimensions of magnetic inductance is established as Neper-centimetre-centimetre, or Henry, where the permeability of free space (Aether) is 4π times 10^{-9}. [21], [22]

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

$$(\cosh \sigma)^{-1} = \frac{d}{s} \quad \text{cm/cm}$$

5

C, Dielectric Capacitance

$$C = \frac{\eta}{\sigma} \cdot \lambda \quad \text{farad, EMU}$$

6

$$\eta = \frac{1}{4} \times 10^{+9} \quad \text{per cm}$$

Fig. 2c

Figure 2c establishes the determining factors involved in the calculation of the dielectric capacitance, *C*, of the transmission pair. As with the inductance, three fundamental factors are involved:

1) First, is the inverse of the space factor, σ , given as per Neper, the result of a dimensionless, or numerical, ratio, the magnitude of which is in inverse proportion to the conductor or spacing, *s*, in centimetre, and in direct proportion to the conductor diameter, *d*, in centimetre. Hence, its dimensions are centimetre per centimetre, a numerical ratio. This is the inverse of that ratio which determines the magnetic inductance, *L*.
2) Second, is the dielectric permittivity, η, in per centimetre, of the medium in which the line conductors are immersed. It is this property of the medium that supports the existence of the dielectric induction, ψ, regardless of the geometry containing it. The ability to contain dielectricity is directly proportional to the permittivity which supports it.
3) Third, is the length, λ, in centimetre of the transmission pair. This length compounds the inductive ratio of the permittivity, η, and the space factor, σ , to yield the complete dielectric capacitance, *C*.

Hence, the dimensions of the dielectric capacitance is established as centimetre per centimetre-Neper, or Farad, when the permittivity of free space (Aether) is the inverse of 4 �� times 10^{-9}. [23], [24]

2.
Electro-Static to Electro-Magnetic Units

It has been stated in chapter one, that the magnetic induction, Φ, and the dielectric induction, ψ, represent an analytical separation into parts of an otherwise unified electric, or electromagnetic, induction, Q. This situation again presents itself with regard to inductance, L, and capacitance, C. This pair of coefficients represent a similar separation into parts of an otherwise unified electric medium, $\mu\eta$. This is rendered evident by the fact that, for the free space condition, the product of the magnetic permeability, μ, and the dielectric permittivity, η, is unity, that is, simply the number one, void of dimension. Hence, for the purpose of analysis, this pair of coefficients are applied as either their ratio or product, that is, jointly they define the characteristics of transmission.

To combine this pair of coefficients into their ratio or product, each must be expressed in common units. Thus far the magnetic terms have been given in electro-magnetic units, whereas the dielectric terms have been given in electro-static units. Accordingly, the two unique set of terms cannot be meaningfully combined into a unified characteristic. In situations of this kind, it is commonplace to convert the electro-static units into electro-magnetic units. This conversion is accomplished by the employment of a dimensional coefficient, c, which may be called “Maxwell’s Coefficient”. This coefficient, c, is defined as the time, t, in seconds, taken for light to travel the unit distance, λ, in centimetre, and hence, this coefficient presents itself dimensionally as centimetre per second, or a velocity, that of light. Hereby, the proportionality between electro-magnetic units and electro-static units is given as the reciprocal of the velocity of light square.

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

Fig. 2e

3.
Transmission Characteristic, Natural Impedance, Z

In figure 2e the ratio of the magnetic inductance, *L*, to the dielectric capacitance, *C*, is developed into the transmission characteristic known as the “natural impedance”, Z_c, of the transmission conductor configuration. It is evident that the factor of length, λ, is cancelled by its appearance in both the numerator and the denominator, and thus has no bearing upon the magnitude of the natural impedance of the line. Conversely, the space factor, σ, is compounded by its appearance as a product of itself in the numerator, and thus is doubly effective in determining the magnitude of the natural impedance. Accordingly, the space factor is squared. Likewise, the permeability, μ, centimetre, and the permittivity, η, per centimetre as a ratio, compound into the dimensional relation of centimetre-centimetre, or for the free space condition, centimetre square. Lastly, the velocity of light is also expressed as a square, hence, in the final expression for the ratio of the inductance, *L*, and the capacitance, *C*, the desired characteristic, Z_c, presents itself as a squared magnitude. Therefore, to establish the actual magnitude of that transmission characteristic, the natural impedance, Z_c, the square root of the derived expression must be taken. Hereby, the natural impedance is:

1) Directly proportional to the space factor, σ, Neper.
2) Directly proportional to the luminal velocity, *c*, in centimetre per second.
3) Directly proportional to the square root of the permeability, μ, in centimetre.
4) Inversely proportional to the square root of the permittivity, η, in per centimetre.

Because this natural impedance is not a resistance or reactance, that is, not ohmic, this dimensional relation is given the name “Zobel” after the pioneer in telephone transmission theory.

It should be borne in mind that the permeability, μ, and the permittivity, η, when material dielectrics surround the line conductors, can have magnitudes significantly greater than those obtained for free space, and thereby influence the magnitude of the natural impedance, Z_c. Also, in textbooks on transmission, the terms “characteristic impedance”, or “surge impedance”, may be used to denote Z_c. [25], [26]

PRODUCT OF DIMENSIONS

7

INDUCTANCE - CAPACITANCE PRODUCT

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

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

8

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

9

ELECTRO-MAGNETIC UNITS

$$\mu \cdot \frac{\eta}{c^2}$$ $cm \cdot sec^2$ PER $cm \cdot cm^2$

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

Fig. 2f

4.
Transmission Characteristic, Natural Period, τ

In figure 2f the product of the magnetic inductance, *L*, and the dielectric capacitance, *C*, is developed into the transmission characteristic which can be called the "natural period", τ, second, of the unit length, λ, of the transmission conductor configuration. This unit of length may be the centimetre, the mile, or the limiting case the elemental length of a unit Planck.

In distinction to the ratio of the line coefficients, *L* and *C*, for the product it is the space factor, σ, that is cancelled by its appearance in both the numerator and the denominator, and thus has no effect on the duration of the natural period of the line. Conversely, the unit length, λ, is compounded by its appearance as a product of itself in the numerator, and thus is doubly effective in determining the duration of the natural period, that is, by the square of the unit length, λ. The permeability, μ, and the permittivity, η, are, in the case of the product, similarly effective in the determination of the natural period. However, in dimensional terms, their product is a numerical coefficient in centimetre per centimetre. The magnitude of this product is unity for free space but can have a magnitude greater than one for material dielectrics which surround the line conductors.

The dimensional coefficient, *c*, the luminal velocity, in the case of the product, exists as a square in the denominator, rather than a square in the numerator, as in the ratio.

In the final expression for the product of the inductance, *L*, and the capacitance, *C*, the desired characteristic, τ, second, presents itself as a squared magnitude, just as was the case for the desired characteristic, Z_c, for the ratio. Hence, to establish the duration of this transmission characteristic, the period, τ, the square root of the derived expression must be taken. Hereby, the natural period is:

1) Directly proportional to the unit length, λ.
2) Inversely proportional to the luminal velocity, *c*, in cm/sec.

3) Directly proportional to the square root of the permeability, μ, in centimetre.
4) Directly proportional to the square root of the permittivity, η, in per centimetre.

It is worthy of notice that the ratio of the natural period, τ, second, of unit length, λ, in centimetre, to the time span, *t*, second, for light to travel the unit length, λ, centimetre, is numerically equal to the product of the permeability, μ, centimetre, and the permittivity, η, per centimetre, of the dielectric medium in which the line conductors are immersed, that is, μη, equals the ratio of, τ, to that of, *t*, second per second. At all events, in the electromagnetic condition, the product of μ, η, and c^2 must always equal the apparent velocity squared, v^2, of the propagation along the line conductors. [27], [28]

CHAPTER III

Steinmetz Theory Of Complex Electric Power

Fig. 3 - Transmission line coordinates

1.
General System Of Transmission

Having established the various factors, co-ordinates, and etcetera, the mathematical analysis of the process of electric transmission will commence.

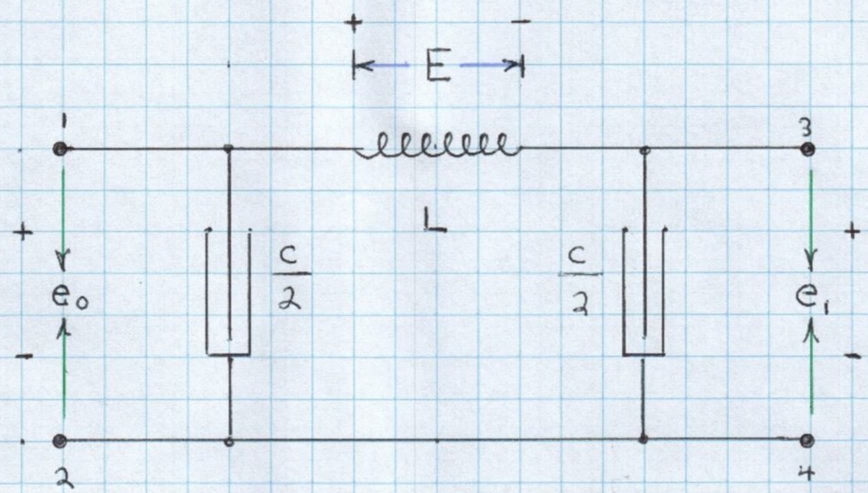
Figure 3 portrays the line coordinates of the four fundamental components of electric transmission which have been derived from the magnetic and dielectric inductions bound by a unit length of two wire line, that is:

1) Electro-static potential, *e*, Volt.
2) Conduction current, or magneto-static potential, *i*, Ampere.
3) Electro-motive force, *E*, Volt.
4) Displacement current, *I*, Ampere.

Co-linear with the axis of transmission are the conduction current, *i*, within the substance of the line conductors, and the electro-motive force, *E*, developed from within the line conductors. Broadside to the axis of transmission, are the displacement current, *I*, and the electro-static potential, *e*, each spanning the distance of separation between the line conductors. These four elements serve the abstract representation of the process of transverse electromagnetic wave propagation, (T.E.M). [29]

KIRCHOFF VOLTAGE RELATION

1 MESH

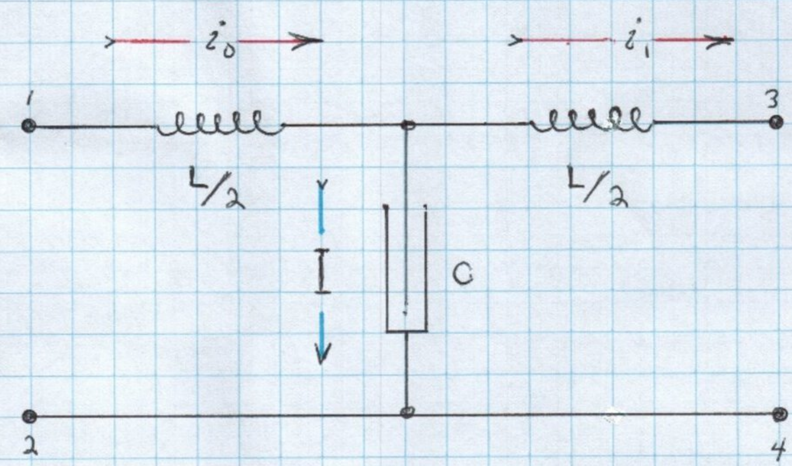


$$e_0 = e_1 + j\,E \qquad \text{VOLT}$$

FIGURE (3a)

KIRCHOFF CURRENT RELATION

2 STAR



$$i_0 = i_1 + k\,I \qquad \text{AMPERE}$$

FIGURE (3b)

Fig. 3a & 3b – Mesh and Star network configurations

2.
Reaction Of The Line Element

The unit length, λ, of line in this portrait can be represented as a four terminal network with a pair of input terminals, 1 and 2, followed with a pair of output terminals, 3 and 4. The potentials, e_0 and i_0, represent the electric forces applied to the input terminals of the line element and the potentials, e_1 and i_1, represent the electric forces delivered by the transmission process to the output terminals of the line element. It is evident, that the difference between the input potentials and the output potentials is the reaction of the line element, the electro-motive force, *E*, and the displacement current, *I*. These reactions are in turn a function of the line geometry and the medium in which it is immersed.

In order to develop an equivalent network to represent this unit length of line, the characteristics of the geometry and medium are replaced by discrete equivalent inductances and capacitances as circuit elements. This procedure is subject to a variety of restrictions, which may be obviated by its application to exceedingly short line elements, the limit being one unit Planck length, λ, belonging to one unit electromagnetic corpuscle. The resulting equivalent network of coils and condensers allows the transmission process to be defined in terms of electric circuit analysis. This results in a great simplification in the mathematics involved.

The "voltage network" is portrayed by figure 3a, and this establishes the relation between the electro-static potential, e_0, and, e_1, and related electro-motive force, *E*. The "current network" is portrayed by figure 3b, and this establishes the relation between the conduction current, i_0, and, i_1, and related displacement current, *I*. [30]

It is common practice in the application of equivalent networks, as applied to transmission analysis, to take only one line conductor of the two-wire line against a fictitious mid-point, or neutral, conductor. The existence of the second conductor is assumed. This reduces the number of required circuit elements.

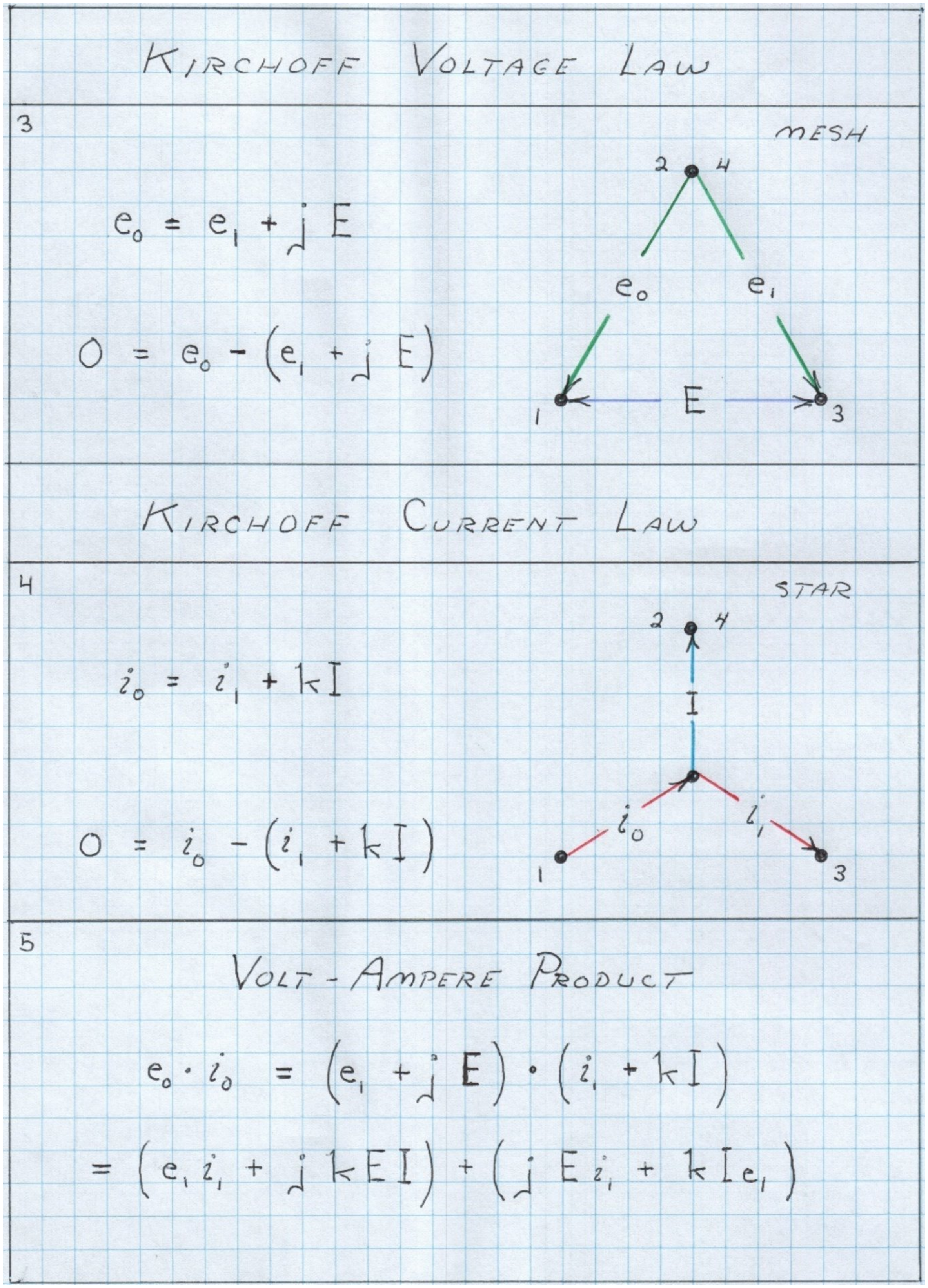


Fig. 3c - Star and mesh network configurations

3.
Network Geometry

It is immediately evident, that the voltage network as well as the current network exhibit dissimilar geometries, that for voltage is a closed, or “mesh”, geometry, and that for the current is an open, or “star”, geometry. The mesh network is presented in symbolic form in the upper part of figure 3c, and the star network is presented in symbolic form in the middle part of figure 3c. In this portrayal, the mesh is commonly called a “delta” configuration, and the star is commonly called a “wye” configuration. [31]

The employment of these equivalent networks facilitates what has become known as “Kirchhoff’s Circuital Laws”. Simply stated, the Kirchhoff Voltage Law states that the sum of the mesh voltages around a closed loop must always equal zero, and the Kirchhoff Current Law states that the sum of the star currents entering or exiting a nodal point must also always equal zero. These laws represent the most fundamental statements of electric circuit analysis and represent basic, common sense facts.

4.
Mathematical Distinction

It has been previously stated that while it is customary to represent both the electro-static potential, *e*, and the electro- motive force, *E*, by the unit of the Volt, and likewise represent both the conduction current, *i*, and the displacement current, *I*, by the unit of the Ampere, the electro-static potential, the electro-motive force, and the conduction current, as well as the displacement current, are each in themselves distinct and unique phenomenon with respect to each other. Therefore, *e*, Volt, and *E*, Volt, cannot be equated in an algebraic process. Likewise, *i*, Ampere, and, *I*, Ampere cannot be equated in an algebraic process. In mathematical terms, *e*, and, *E*, exist in separate co-ordinate systems, and, *i*, and, *I*, also exist in separate co-ordinate systems. Therefore, in order to facilitate the arithmetical combination of these heterogeneous magnitudes, a "co-ordinate operator" must be employed. Hence, in order to provide a mathematical distinction to the electro-motive force, *E*, it is prefixed by a distinguishing index, the letter, *j*, and likewise, a mathematical distinction to the displacement current, *I*, is provided by the prefixing index, the letter, *k*. At this point in presentation, these letter prefixes are not given any mathematical meaning other than their service as identifying markers. [32]

In the application of Kirchhoff's Laws to the unit length of a pair of line conductors, the mathematical expressions state the following:

The applied sending end potential, e_0, is equal to the receiving end potential, e_1, this in addition to the electro-motive force, *E*, which operates between these sending and receiving end potentials.

The applied sending end current, i_0, is equal to the receiving end current, i_1, this in addition to the displacement current, *I*, which operates between these sending and receiving end currents.

Re-arranging terms in these expressions, Kirchhoff's Voltage Law states that; the applied potential, e_0, is accounted for by that electro-motive force, *E*, developed in the line element in addition to that potential, e_1, delivered to the receiving end of the line element. Therefore, the difference between what enters the line element and what exits the line element, in addition to what resides within the line element itself, must always equal zero. The voltage produced must always equal the voltage consumed. There exists no “extra voltage,” all voltages are accounted for.

Likewise, re-arranging terms in the Kirchhoff Current Law states that the entering current, i_0, is accounted for by the exiting currents, i_1, and, I. The current produced must always equal the current consumed. There exists no “extra current,” all currents are accounted for, and the net sum of currents must always equal zero.

These are basic statements of the Law of Conservation, that is, nothing magically appears from nowhere, nor magically disappears into nothingness, a basic statement of common sense.

5.
Mathematical Analysis

It must be borne in mind that these voltages and currents are mathematical magnitudes which have been derived to facilitate measurement and analysis. However, in themselves, they are fictions representative of the magnetic and dielectric quantities involved. The mathematical product of the Voltage Law and the Current Law must be derived in order to arrive at an electric quantity. This is called the Volt-Ampere Product and is portrayed in the lower part of figure 3c. This product is representative of the electric activity in action within, into, and out of, the electromagnetic corpuscles. [33]

It will be observed that this product consists of four distinct terms:

1) The Volt-Ampere product of the receiving end potential and the receiving end current, $e_1 i_1$.
2) The Volt-Ampere product of the electro-motive force and the displacement current, EI.
3) The Volt-Ampere product of the electro-motive force and the receiving end current, Ei.
4) The Volt-Ampere product of the displacement current and the receiving end potential, Ie.

The sum of these four distinct Volt-Ampere terms defines the total Volt-Amperes applied to the sending end terminals of the line element, $e_0 i_0$.

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

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

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

Fig. 3d - Complex operator relations

The quantity, $e_0 i_0$, represents the electric power entering the line element, λ, and the quantity, $e_1 i_1$, represents the electric power exiting the line element, λ. The remaining three terms represent the electric activity within the line element, λ.

The distinguishing indices, *j* and *k*, can here be given mathematical definition as "operators" in the complex multiplication process. These operators are derived from a mathematical procedure known as the "Method of Multiple Co-ordinate Systems". [34] One such system applicable to this particular Volt-Ampere product is portrayed by figure 3d. It will be observed that this is a cyclic system of base four exponents that repeat every four operations. Accordingly, this is representative of the four distinct terms in the Volt-Ampere product. Hence, each distinct operator is symbolically representative of each distinct term.

This complex process of multiplication yields four distinct species of products:

1) *1*, dot product.
2) *h*, line product.
3) *j*, direct cross product.
4) *k*, inverse cross product.

The co-relations and identifications of these operators are tabulated at the bottom of figure 3d. [35]

Reducing these operators to their basic arithmetic equivalents and substituting these into the general Volt-Ampere relation of figure 3c, yields the fundamental Volt-Ampere relation portrayed in figure 3e. The first pair of terms of this expression, *e*, *i*, and *EI*, taken together are known as the "real" component of the product, and are defined in the units of the Watt. The second pair of terms of this expression, Ei_1, and Ie_1, taken together are known as the "imaginary" component of the product, and are defined in the units of the "VAR". The term VAR, or Volt-Ampere Reactive, is representative of what is called the "Wattless" part of the Volt-Ampere product, which expresses the surging to and fro of the electric induction within the line element.

This fundamental four-part Volt-Ampere expression may be called the "Steinmetz Equation" of electric power and double frequency products in general. It is directly applicable to the fundamental quantity of electric induction, Q, or what has been identified as the Planck. [36]

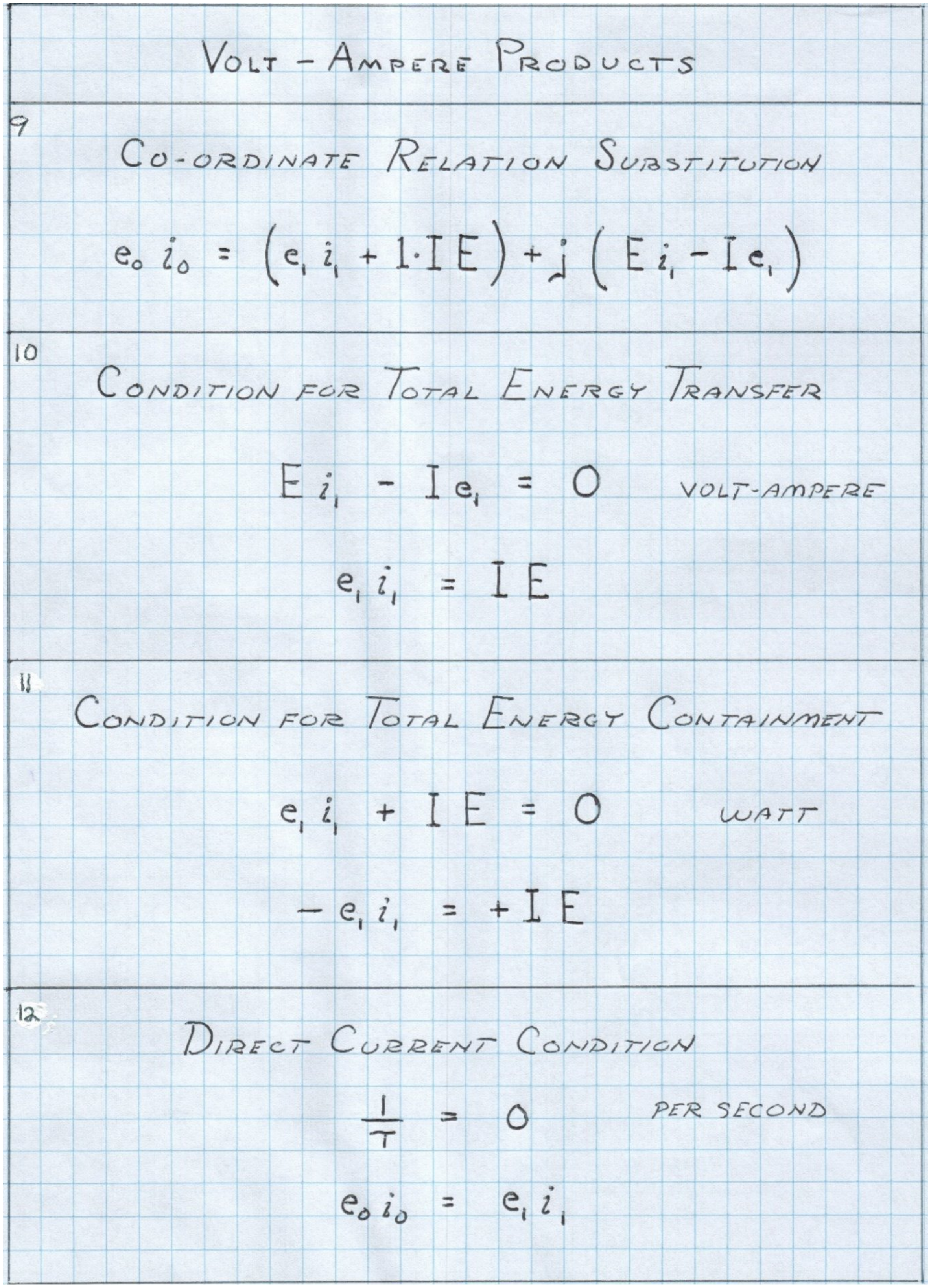


Fig. 3e - Volt-Ampere mathematical relations

6.
Expression Of Electric Activity

The Volt-Ampere product portrayed in figure 3e defines three special or limiting, conditions which are ideally possible in the behavior of the line element to the process of transmission. These are:

1. Total energy transfer from the sending end terminals to the receiving end terminals.
2. Total energy containment within the line element.
3. The direct current condition within the line element inactive in the process of transmission.

For the condition of total energy transfer all the electric activity, $e_0 i_0$, applied to the sending end of the line element eventually arrives as electric activity, $e_1 i_1$, at the receiving end of the line element. No energy remains within the line element; it is conveyed from the sending end to the receiving end with an attendant time delay, but without distortion.

In algebraic terms, the magnetic activity, Ei_1, is equal, and in opposition to the dielectric activity, Ie, hence, the resultant activity is zero. Re-arranging terms gives the relation expressing the equivalence of the electric activity, $e_1 i_1$, at the receiving end to that electric activity, EI, existing within the electric field of induction, $\Phi\psi$, contained by the line element.

This is the desired mode of transmission which is known as the "Distortionless Condition". [37]

For the condition of total energy containment, a condition in which no net electric activity enters or exits the line element, the electric activity, $e_1 i_1$, at the receiving end is cancelled by an equal but opposite electric activity, EI, contained by the electric field of induction, $\Phi\psi$, bound to the line element. Hence, the electric activity surges to and fro within the line element, reflecting at the terminal boundaries back upon itself.

For the direct current condition, the time factor, per second, vanishes since this condition represents the permanent, or "static," state. Accordingly, the electro-motive force, E, and the displacement current, I, also vanish since they are functions of variation with respect to time. The magnetic induction, Φ, and the dielectric induction, ψ, become static fields of potential energy and thereby contribute nothing to the transmission process. This condition hereby ceases to be electromagnetic and reverts into an “electronic” form where the electric activity withdraws into the substance of the line conductor.

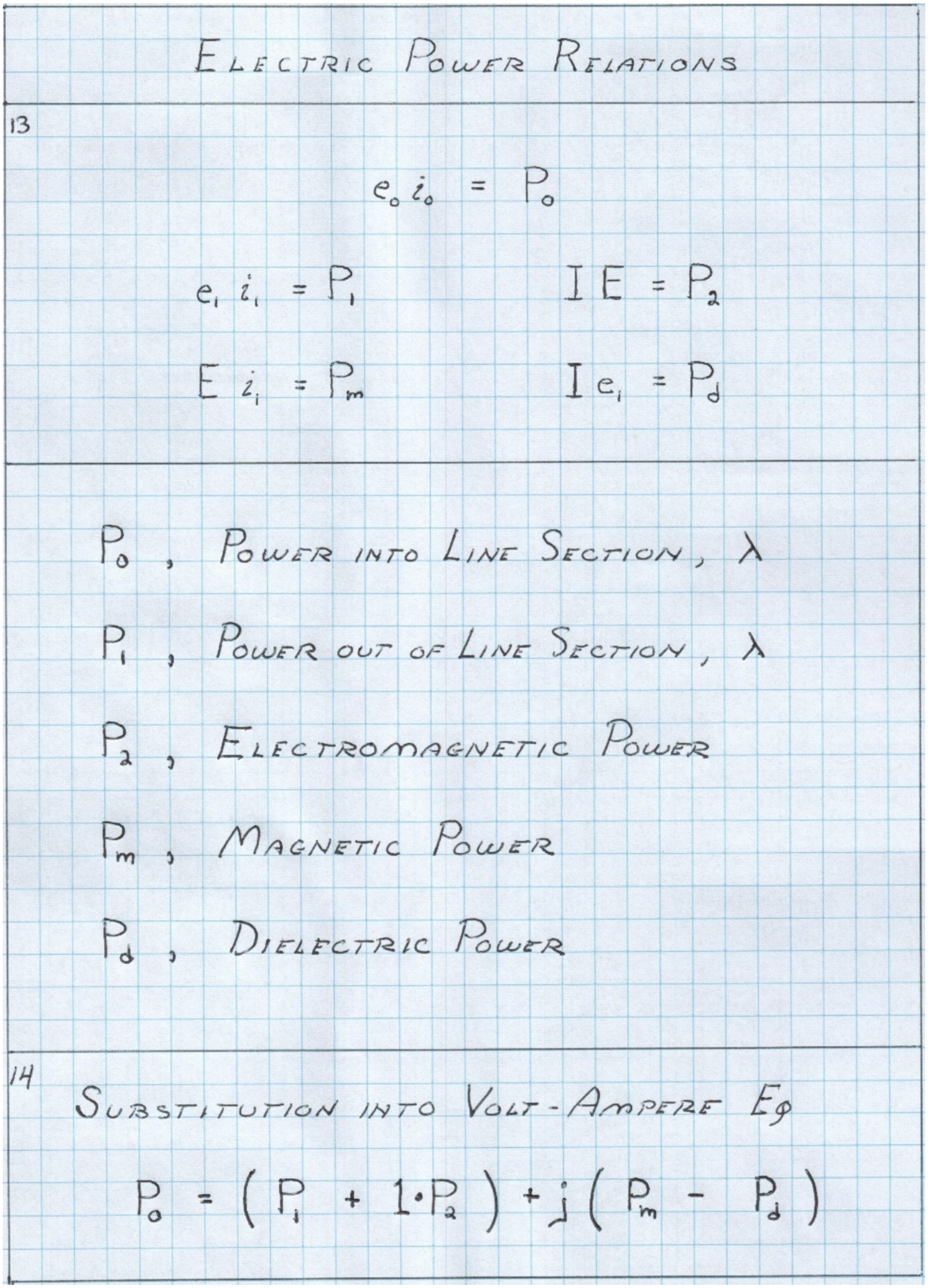


Fig. 3f - Electric power activity in volt-ampere

7.
Effective Power Flow

In general, the various forms of electric activity can be expressed in terms of electric power since power is defined as a Volt-Ampere product. Figure 3f defines these specific forms of electric power in terms of their Volt-Ampere products.

The total electric power which is applied to the sending end terminals of the line element, λ, is represented by, P_0. By the Laws of Conservation, this applied power must be accounted for by the various forms of electric power which arise from its application. Ideally, it is the electric power, P_1, existing at the receiving end terminals of the line element, λ, that is the desired quantity, and it should be equal to that power, P_0, entering the line element. However, the process of transmission within the line element manifests a variety of secondary forms of electric power, these materially modifying the proportionality between that power, P_0, entering, and that power, P_1, exiting the line element, λ. In most cases, these secondary activities serve to delay the arrival of the applied power, P_0, to the receiving end terminals, whence it appears as P_1. Moreover, the secondary forms of power within the line element may distort the relationship between that power entering, and that power exiting the line element. [37], [38]

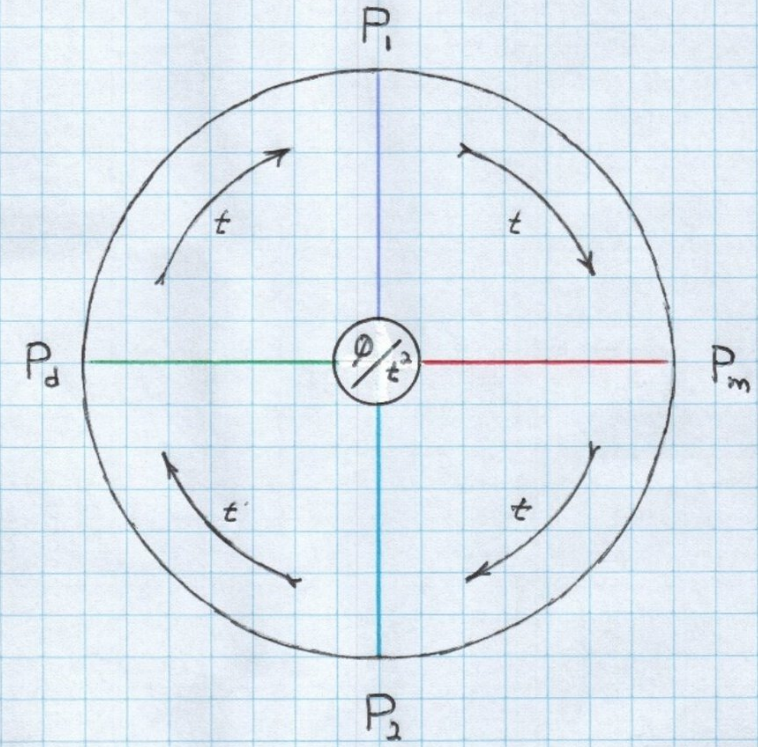
The magnetic power, P_m, is that power flow into, or out of, the magnetic field of induction, Φ, and the dielectric power, P_d, is that power flow out of, or into, the dielectric field of induction, ψ. These secondary electric activities are often called "wattless," in that energy taken in by a particular field at one moment in time is completely given back at another moment in time. No energy is retained or lost, hence the wattless condition, and this form of electric activity is considered "imaginary" since no real work is done, and it is accordingly expressed in units called Volt-Ampere Reactive, or VAR.

The electromagnetic power, P_2, is that electric activity which results from the interchange of energy between the various forms of electric power. Accordingly, this particular activity acts as a hub for energy interchange within the transmission process and is essential to the process of electromagnetism and electromagnetic transmission.

This electromagnetic power, P_2, is representative of the electric activity within the corpuscle of electromagnetism, the Planck, Q. It affects the progressive transfer of energy along the length, λ, of the line element and represents the expenditure of work, and accordingly is considered real power and is expressed in the unit of Watt.

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

Fig. 3g

8.
Cyclic Action Of Electric Power

Having established the identity of the various forms of electric activity in terms of electric power, these terms can be substituted into the general Volt-Ampere expression of figure 3e. This is presented in figure 3f.

Electric Power, P_1, is defined as the time rate, *u*, per second, at which a quantity of electric energy, *W*, Joule, undergoes any variation of that quantity. Likewise, this electric energy is defined as that time rate at which a quantity of electric induction, *Q*, Planck, undergoes any variation of that quantity. Hence, with respect to the electric induction, *Q*, the electric power, *P*, is a second order phenomenon of time, that is, Planck per second squared. Accordingly, the electric energy, *W*, presents itself as an intermediary between induction and power.

Figure 3g portrays a cycle of electric power, representing the process of electromagnetism. This is the “sequence diagram” of electric activity within the line element. The co-ordinates are defined by the matrix of figure 3d. Each quarter period, *t*, second, represents the time interval during which electric energy is transmuted from one specific form into another specific form as a progressive action in time. [39]

In the sequence diagram of figure 3g one unit step forward is expressed by the co-ordinate index, *j*. Two unit steps forward is expressed by the co-ordinate index, *h*. Three unit steps forward is expressed by the co-ordinate index, *k*. And, four unit steps forward is expressed by the co-ordinate index, *1*, thus completing one full cycle.

It will be noticed that co-ordinate index, *k*, is in opposition to co-ordinate index, *j*, and likewise, co-ordinate index, *h*, is in opposition to co-ordinate index, *1*. The axis, *j k*, locating, P_m, and P_d, denotes the “imaginary” axis of electric power. The axis, *h 1*, locating, P_1, and, P_2, denotes the “real” axis of electric power. It is evident that the imaginary axis, *j k*, is in quadrature (right angle) to the real axis, *h 1*. This right angle represents one unit step forward in the time cycle of electric power. Accordingly, the co-ordinate index, *j*, represents the “unit operator” of cyclic rotation, and any number of unit rotations in this cycle can be expressed as an integer exponent of this operator, *j*. Hence, it is given that:

Start	$j^0 = 1^0$
1st	$j^1 = j$
2nd	$j^2 = h$
3rd	$j^3 = k$
4th	$j^4 = 1^1$

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

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

Fig. 3h

This operator, *j*, is a fundamental element in engineering analysis, and is incorrectly defined as the square root of negative one. [40]

As portrayed in figure 3g, the active power, P_a, is the algebraic sum of the electric power, P_1, which exists in the line element, plus the electromagnetic power, P_2, active within the line element. The reactive power, P_b, is the algebraic sum of the magnetic power, P_m, of the electric field, plus the dielectric power, P_d, of the electric field, bound by the line element. The active power is in time quadrature with respect to the reactive power, and these combine additively into the total or "apparent" power, P_0, entering the line element. This relation is portrayed by figure 3h, and it is evidently a vector quantity in the dimension of time.

It is common practice to define what proportion of the apparent power, P_0, is active power, or what proportion of it is reactive power. This proportionality presents itself as a magnitude, which ranges from zero to unity, and is commonly expressed as the percentage of active or reactive power with respect to the apparent power. Hence, the power factor, *a*, represents what proportion of the apparent power entering the sending end terminals of the line element is active power, and the induction factor, *b*, represents what proportion of the apparent power entering the sending end terminals is reactive power. Therefore, if all the apparent power entering the line element is active power, the power factor, a, is unity, or,

100 percent

and the induction factor, *b*, is zero or,

0 percent

In this condition all the power at the sending end terminals arrives at the receiving end terminals, none remains in the line element.

Conversely, if all the apparent power entering the line element is reactive power, the power factor, *a*, is zero or,

0 percent

and the induction factor, *b*, is unity, or,

100 percent

In this condition, none of the power at the sending end terminals arrives at the receiving end terminals, but surges to and fro between the electric induction within the line element and the source of power at the sending end terminals. [41]

Because the active power, P_a, and the reactive power, P_b, are in time quadrature with respect to each other, the power factor, *a*, and the induction factor, *b*, also exist in a relative quadrature relation. Hereby, the complex addition of the real factor, *a*, and the imaginary factor, *b*, define the "propagation factor," γ. This factor, γ, is a complex quantity and uniquely defines the behavior of the line element as regards its behavior in the transmission of electric power from its sending end terminals to its receiving end terminals. The magnitude of this factor, γ, is always unity, regardless of variance in conditions, but its position is variable along the cycle of electric activity.

Hence, the propagation factor, γ, is a Versor Operator which identifies the position along the time cycle in which the apparent power operates. Accordingly, the expression for the complex power flow at the sending end terminals reduces to:

$$\gamma P_0 \qquad \text{Volt-Ampere Complex}$$

References

[1] Principles Of Electricity As Applied To Telephone & Telegraph Work, AT&T., 1953, Pages 175-178
[2] Electricity & Matter, J. J. Thomson, 1904, Pages 1-35
[3] A History Of The Theories Of The Aether & Electricity, From The Age Of Descartes To The Close Of The 19th Century, E. T. Whittaker, 1910, Pages 212 & 272
[4] A History Of The Theories Of The Aether & Electricity, From The Age Of Descartes To The Close Of The 19th Century, E. T. Whittaker, 1910, Page 190
[5] Recent Researches In Electricity And Magnetism, J. J. Thomson, 1892, Page 3
[6] Electromagnetic Theory, Oliver Heaviside, 1950, Article 86, Page 109
[7] Transient Electric Phenomena, C. P. Steinmetz, 1910, Pages 4-5
[8] Recent Researches In Electricity And Magnetism, J. J. Thomson, 1892, Page 14
[9] Electric Discharges, Waves And Impulses, C. P. Steinmetz, 1910, Pages 10-18
[10] Electromagnetic Theory, Oliver Heaviside, 1950, Article 74, Pages 89-90, Article 82a Page 102, Article 78-81, Pages 95-100, Article 176, Page 307, Article 86, Page 109
[11] Electricity & Matter, J. J. Thomson, 1904, Page 16
[12] A History Of The Theories Of The Aether & Electricity, From The Age Of Descartes To The Close Of The 19th Century, E. T. Whittaker, 1910, Page 301
[13] Transmission Systems For Communications, Bell Labs, 1970, Pages 68-74
[14] Electromagnetic Theory, Oliver Heaviside, 1950, Article 177-178, Article 190, Pages 311-313, Pages 307- 311, Page 342
[15] Electromagnetic Theory, Oliver Heaviside, 1950, Article 176-177
[16] Theory Of Electricity And Magnetism, Max Planck, 1932, Pages 1-3

[17] Communications Networks Vol. 2, Ernst Guillemin, 1931, Pages 48-50
[18] A History Of The Theories Of The Aether & Electricity, From The Age Of Descartes To The Close Of The 19th Century, E. T. Whittaker, 1910, Page 349
[19] Principles Of Electrical Engineering, T. F. Wall, 1947, Pages 495-498
[20] A History Of The Theories Of The Aether & Electricity, From The Age Of Descartes To The Close Of The 19th Century, E. T. Whittaker, 1910, Page 366
[21] Electric Discharges, Waves And Impulses, C. P. Steinmetz, 1910, Article 47, Pages 130-132
[22] Artificial Electric Lines, A. E. Kennelly, 1917, Pages 141-142
[23] Electric Discharges, Waves And Impulses, C. P. Steinmetz, 1910, Article 49, Pages 136-138
[24] Artificial Electric Lines, A. E. Kennelly, 1917, Pages 142-143
[25] Electric Discharges, Waves And Impulses, C. P. Steinmetz, 1910, Article 25, Pages 61-63
[26] Radio Antenna Engineering, E. A. Laport, 1952, Article 4.1.5, Pages 371-372, Article 4.2.15, Pages 395-398
[27] Electric Discharges, Waves And Impulses, C. P. Steinmetz, 1910, Article 25, Pages 65-66
[28] Electromagnetic Theory, Oliver Heaviside, 1950, Article 180, Page 320
[29] Communications Networks Vol. 2, Ernst Guillemin, 1931, Article 4, Page 12
[30] Network Analysis & Feedback Amplifier Design, H. W. Bode, 1945, Chapter One
[31] Network Analysis & Feedback Amplifier Design, H. W. Bode, 1945, Pages 55-57, Pages 89-100
[32] Theory And Calculation Of Alternating Current Phenomena, C. P. Steinmetz, 1900, Pages 36-38
[33] Theory And Calculation Of Transient Electric Phenomena, C. P. Steinmetz, 1900, Pages 5-8
[34] Symmetrical Components, C. F. Wagner & R. D. Evans, 1926, Pages 1-8, Pages 9-17, Pages 328-33

[35] Theory And Calculation Of Alternating Current Phenomena, C. P. Steinmetz, 1900, Appendix 1, Pages 489-496
[36] Theory And Calculation Of Alternating Current Phenomena, C. P. Steinmetz, 1900, Chapter XII, Pages 150-157
[37] Theory And Calculation Of Alternating Current Phenomena, C. P. Steinmetz, 1900, Page 487
[38] Electromagnetic Theory, Oliver Heaviside, 1950, Article 2, Pages 2-3, Article 209, Pages 409-410
[39] Aether And Matter, J. Larmor, 1900, Page 21
[40] Theory And Calculation Of Alternating Current Phenomena, C. P. Steinmetz, 1900, Article 305, Appendix 1, Page 495
[41] Theory And Calculation Of Alternating Current Phenomena, C. P. Steinmetz, 1900, Page 153

TESLA SCIENTIFIC™

www.teslascientific.com

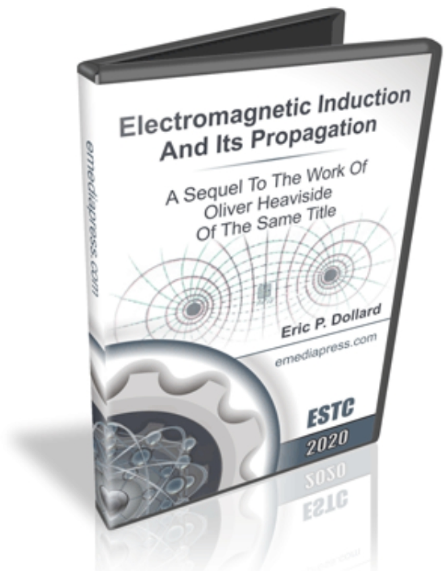
G.G. BROCK
LABORATORIES

ELECTRICAL RESEARCH AND DEVELOPMENT

www.griffingbrock.com

Electromagnetic Induction And Its Propagation

A Sequel to the Work of Oliver Heaviside of the Same Title



VIDEO PRESENTATION

This book is part of a series, which is based on a live presentation given by Eric Dollard at the 2020 Energy Science & Technology Conference in Coeur d'Alene, Idaho.

The video presentation is available at the link below.

https://emediapress.com/shop/electromagnetic-induction-propagation-sequel-work-oliver-heaviside-title/

Support
EPD Laboratories, Inc.
501(c)3 Non-Profit

Please make tax-deductible donations at:

https://ericpdollard.com/donate

Your donations are tax deductible

Make Checks or Money Orders
Payable to: **EPD Laboratories, Inc.**

EPD Laboratories, Inc.
PO Box 10029
Spokane, WA 99209

DONATE BITCOIN

BTC ADDRESS

1Cro4RfF4pFXwMa8pPVHXTk425YyXbufrW