HANDOUT

G3ABR32430 002-I
Book 1 of 2

Technical Training

Precision Measuring Equipment Specialist

METROLOGY HANDBOOK

January 1984

3400TH TECHNICAL TRAINING WING
3450th Technical Training Group
Lowry Air Force Base, Colorado

Designed For ATC Course Use

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Supersedes Metrology Handbood dated August 1977.

GREEK ALPHABET

NAME	UC	COMMONLY DESIGNATES	LC	COMMONLY DESIGNATES
Alpha	Α		α	Angles, area, absorption factor, atten. constant, I gain CB confg.
Beta	Β		β	Angles, coefficients, phase constant, flux density, I gain CE confg.
Gamma	Γ	Complex propagation constant	γ	Angles, specific gravity, elect. conductivity, propag'n constant
Delta	Δ	Increment, determinant, permittivity, variation	δ	Angles, density, increment
Epsilon	Ε		ε	Base of natural logs, dielectric constant, electrical intensity
Zeta	Ζ	Impedance	ζ	Coordinates, coefficients
Eta	Η		η	Hysteresis, coordinates, efficiency intrinsic impedance
Theta	Θ		θ	Angular phase displacement, time constant, reluctance
Iota	Ι	Current	ι	Unit vector
Kappa	Κ		κ	Coupling coefficient, susceptibility, dielectric constant
Lambda	Λ	Permeance	λ	Wavelength, attenuation constant
Mu	Μ		μ	Prefix micro, amplification factor, Permeability
Nu	Ν		ν	Frequency, reluctivity
Xi	Ξ		ξ	Coordinates, output coefficients
Omicron	Ο		ο	Reference point
Pi	Π		π	3.1416
Rho	Ρ		ρ	Resistivity, volume charge density, coordinates
Sigma	Σ	Summation	σ	Electrical conductivity, leakage coefficient, complex propag'n constant
Tau	Τ		τ	Time constant, time phase displacement, transmission factor, torque
Upsilon	Υ		υ	
Phi	Φ	Scalar potential, magnetic flux, radiant flux	φ	Phase angle
Chi	Χ		χ	Angles, electrical susceptibility
Psi	Ψ		ψ	Angles, coordinates, dielectric flux, phase difference
Omega	Ω	Resistance in ohms	ω	Angular velocity ($2\pi f$)

MATHEMATICAL SYMBOLS

$+$	Positive. Plus. Add	$\perp$	Perpendicular to
$-$	Negative. Minus. Subtract	$\parallel$	Parallel to
$\pm$	Positive or negative Plus or minus	π	Pi, 3.1416
X or $\cdot$	Multiplied by	ϵ	Base of natural log, 2.718
$\div$ or /	Divided by	$\sqrt{\ }$	Square root
$=$ or ::	Equals	$\sqrt[3]{\ }$	Cube root
$\equiv$	Identical with	$\sqrt[n]{\ }$	n^{th} root
$\neq$	Not equal to	$\lvert n \rvert$	Absolute value of n
$\cong$ or $\approx$	Approximately equal to	n°	n degrees
$>$	Is greater than	n'	n minutes of a degree n feet or n prime
$<$	Is less than	n''	n seconds of a degree n inches or n second
$\geq$	Greater than or equal to	$\bar{n}$	Average value of n
$\leq$	Less than or equal to	j	Square root of minus one
::	Is proportional to	%	Percentage
:	Ratio	n_1	Subscript of n
$\therefore$	Therefore	( )	Parentheses
∞	Infinity	[ ]	Brackets
Δ	Increment or small change	{ }	Braces
$\angle$	Angle	—	Vinculum

MATHEMATICAL CONSTANTS

Symbol	Number	$\log_{10}$	Symbol	Number	$\log_{10}$
π	3.1416	0.4971	$\frac{4}{\pi}$	1.2732	0.1049
π^2	9.8696	0.9943	$\frac{1}{2\pi}$	0.1592	9.2018-10
2π	6.2832	0.7982	$\frac{1}{4\pi}$	0.0796	8.9008-10
$2\pi^2$	19.7392	1.2953	$\frac{1}{6\pi}$	0.0531	8.7247-10
3π	9.4248	0.9742	$\frac{1}{8\pi}$	0.0398	8.5998-10
4π	12.5664	1.0992	$\frac{\pi}{180}$	0.0175	8.2419-10
$4\pi^2$	39.4784	1.5964	$\frac{180}{\pi}$	57.2958	1.7581
8π	25.1327	1.4002	$\frac{1}{\pi^2}$	0.1013	9.0057-10
$\frac{\pi}{2}$	1.5708	0.1961	$\frac{1}{2\pi^2}$	0.0507	8.7047-10
$\frac{\pi}{3}$	1.0472	0.0200	$\frac{1}{4\pi^2}$	0.0253	8.4036-10
$\frac{\pi}{4}$	0.7854	9.8951-10	$\sqrt{\pi}$	1.7725	0.2486
$\frac{\pi}{6}$	0.5236	9.7190-10	$\frac{\sqrt{\pi}}{2}$	0.8862	9.9475-10
$\frac{\pi}{8}$	0.3927	9.5941-10	$\frac{\sqrt{\pi}}{4}$	0.4431	9.6465-10
$\frac{2\pi}{3}$	2.0944	0.3210	$\sqrt{\frac{\pi}{2}}$	1.2533	0.0980
$\frac{4\pi}{3}$	4.1888	0.6221	$\sqrt{\frac{2}{\pi}}$	0.7979	9.9019-10
$\frac{1}{\pi}$	0.3183	9.5029-10	π^3	31.0063	1.4914
$\frac{2}{\pi}$	0.6366	9.8039-10	$\frac{1}{\pi^3}$	0.03225	8.5086-10

POWER of TEN MULTIPLIER CHART

Multiple or Submultiple	Symbol	Prefix	Name
10^{12} = 1,000,000,000,000	T	tera	Trillion
10^{9} = 1,000,000,000	G	giga	Billion
10^{8} = 100,000,000			Hundred million
10^{7} = 10,000,000			Ten million
10^{6} = 1,000,000	M	mega	Million
10^{5} = 100,000			Hundred thousand
10^{4} = 10,000			Ten thousand
10^{3} = 1,000	k	kilo	Thousand
10^{2} = 100	h	hecto	Hundred
10^{1} = 10	dk	deka	Ten
10^{0} = 0			One
10^{-1} = .1	d	deci	One tenth
10^{-2} = .01	c	centi	One hundredth
10^{-3} = .001	m	milli	One thousandth
10^{-4} = .000 1			One ten-thousandth
10^{-5} = .000 01			One hundred-thousandth
10^{-6} = .000 001		micro	One millionth
10^{-7} = .000 000 1			One ten-millionth
10^{-8} = .000 000 01			One hundred-millionth
10^{-9} = .000 000 001	n	nano	One billionth
10^{-12} = .000 000 000 001	p	pico	One trillionth
10^{-15} = .000 000 000 000 001	f	femto	One quadrillionth
10^{-18} = .000 000 000 000 000 001	a	atto	One quintillionth

NUMERICAL CONSTANTS (extended)

= 3.14159 26535 89793 23846 26433 83279 50288 41971

= 2.71828 18284 59045 23536 02874 71352 66249 77572

SEQUENCE of MATHEMATICAL OPERATIONS

Remember

My Dear Aunt Sally	Multiply	(M)
	Divide	(D)
	Add	(A)
	Subtract	(S)

POWERS of TWO CHART

2^n	n	2^{-n}
1	0	1.0
2	1	0.5
4	2	0.25
8	3	0.125
16	4	0.062 5
32	5	0.031 25
64	6	0.015 625
128	7	0.007 812 5
256	8	0.003 906 25
512	9	0.001 953 125
1 024	10	0.000 976 562 5
2 048	11	0.000 488 281 25
4 906	12	0.000 244 140 625
8 192	13	0.000 122 070 312 5
16 384	14	0.000 061 035 156 25
32 768	15	0.000 030 517 578 125
65 536	16	0.000 015 258 789 062 5
131 072	17	0.000 007 629 394 531 25
262 144	18	0.000 003 814 697 265 625
524 288	19	0.000 001 907 348 632 812 5
1 048 576	20	0.000 000 953 647 316 406 25
2 097 152	21	0.000 000 476 837 158 203 125
4 194 304	22	0.000 000 238 418 579 101 562 5
8 388 608	23	0.000 000 119 209 289 550 781 25
16 777 216	24	0.000 000 059 604 644 775 390 625
33 554 432	25	0.000 000 029 802 322 387 695 312 5

BINARY CONVERSION

Example:

2^9	2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	
512	256	128	64	32	16	8	4	2	1	
0	0	1	0	1	0	1	1	0	0	= 172

Binary Number	Decimal Number
1	1
10	2
11	3
100	4
101	5
110	6
111	7
1000	8
1001	9
1010	10
110010	50
1100100	100

EXPONENTS

Zero exponent $a^0 = 1$

Negative exponent $a^{-x} = \frac{1}{a^x}$

Multiplication $a^x \cdot a^y = a^{(x + y)}$

Division $a^x \div a^y = \frac{a^x}{a^y} = a^{(x - y)}$

Power of a product $(ab)^x = a^x b^x$

Power of a power $(a^x)^y = a^{xy}$

Root of a power $\sqrt[y]{a^x} = a^{x \div y}$

Fractional exponents $a^{\frac{1}{4}} = \sqrt[4]{a}$ $a^{\frac{x}{y}} = \sqrt[y]{a^x}$

Radicals $\sqrt{\frac{a}{b}} = \frac{\sqrt{a}}{\sqrt{b}}$ $\sqrt{ab} = \sqrt{a} \cdot \sqrt{b}$

LOGARITHMS

The exponent of that power of a fixed number, called the base, which equals a given number.

$10^2 = 100$, therefore 2 = log of 100 to the base 10.

Exponential Form	Logarithmic Form
$2^4 = 16$	$4 = \log_2 16$
$10^2 = 100$	$2 = \log_{10} 100$
$10^3 = 1000$	$3 = \log_{10} 1000$
$a^b = c$	$b = \log_a c$

Multiplication	$\log (6 \cdot 4) - \log 6 + \log 4$
Division	$\log \frac{3}{4} = \log 3 - \log 4$
Raising to a power	$\log N^3 = 3 \log N$
Extracting roots	$\log \sqrt[3]{N} = \frac{\log N}{3}$
Common to natural	$\log_{10} N = 2.3026 \log_\epsilon N$
Natural to common	$\log_\epsilon N = 0.4343 \log_{10} N$

SCIENTIFIC NOTATION

A whole number between 1 and 10 times the proper power of ten, also called standard form.

Example: 4.30×10^4

SIGNIFICANT FIGURES

Figures arrived at by counting are often exact. On the other hand, figure arrived at by measuring are approximate. Significant figures express the accuracy of the measurement.

When counting significant figures, all digits (including zero) are counted EXCEPT those zeros that are to the left of the number.

Example: 4.3 contains 2 significant figures
0.0234 contains 3 significant figures
0.1100 contains 4 significant figures

ROUNDING OFF NUMBERS

If the last digit is a 5 and the number immediately prior to that is an EVEN number, DROP the five.

Example: 2.065 becomes 2.06
.205 becomes .20

If the last digit is a 5 and the number immediately prior to that is an UNEVEN number, drop the 5 and ADD 1 to the last figure retained.

Example: 2.055 becomes 2.06
.215 becomes .22

If the remaining sequence of numbers is larger than 5, add 1 to the last figure retained. Never round off one digit at a time. Consider all digits to the right of the point that you wish to round off as a single quanity when judging whether is is more or less than 5.

Example: 3.45678 becomes 3.5

Remember

Oscar Had $\frac{O}{H}$ = S Sick

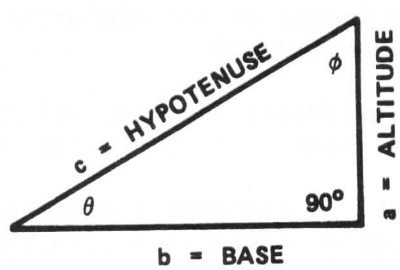
A Heap $\frac{A}{H}$ = C Call

Of Apples $\frac{O}{A}$ = T Tomorrow

PYTHAGOREAN THEOREM

In a right triangle, the square of the hypotenuse is equal to the sum of the squares of the other two sides.

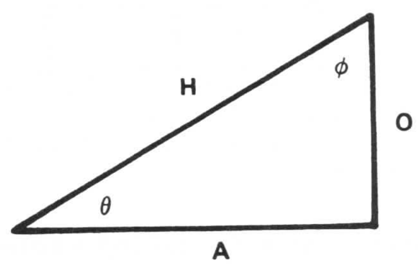
$$c^2 = a^2 + b^2$$



TRIGONOMETRIC RELATIONS

In a right triangle,

H = hypotenuse
A = adjacent side
O = opposite side
θ = angle between hypotenuse and adjacent side (base)
ϕ = angle between hypotenuse and the opposite side

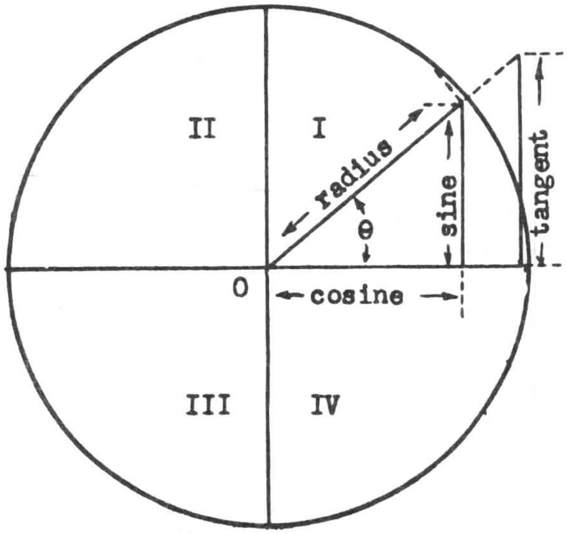


$\sin\theta = \frac{O}{H}$	$\csc\theta = \frac{H}{O}$	$\sin\theta = \cos\phi$	$\csc\theta = \sec\phi$
$\cos\theta = \frac{A}{H}$	$\sec\theta = \frac{H}{A}$	$\cos\theta = \sin\phi$	$\sec\theta = \csc\phi$
$\tan\theta = \frac{O}{A}$	$\cot\theta = \frac{A}{O}$	$\tan\theta = \cot\phi$	$\cot\theta = \tan\phi$

LENGTH of SIDES for RIGHT-ANGLE TRIANGLES

Length of Hypotenuse =	Side opposite	x	Cosecant
	Side opposite	÷	Sine
	Side adjacent	x	Secant
	Side adjacent	÷	Cosine
Length of side Opposite =	Hypotenuse	x	Sine
	Hypotenuse	÷	Cosecant
	Side adjacent	x	Tangent
	Side adjacent	÷	Cotangent
Length of side Adjacent =	Hypotenuse	x	Cosine
	Hypotenuse	÷	Secant
	Side opposite	x	Cotangent
	Side opposite	÷	Tangent

ANGLE FUNCTIONS



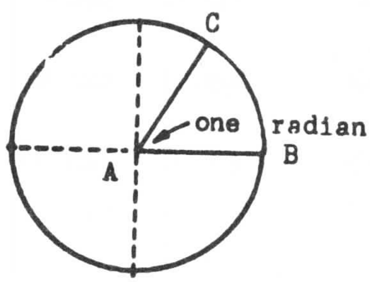
Signs of the Functions

Quadrant	sin	cos	tan
I	+	+	+
II	+	-	-
III	-	-	+
IV	-	+	-

RADIAN MEASURE

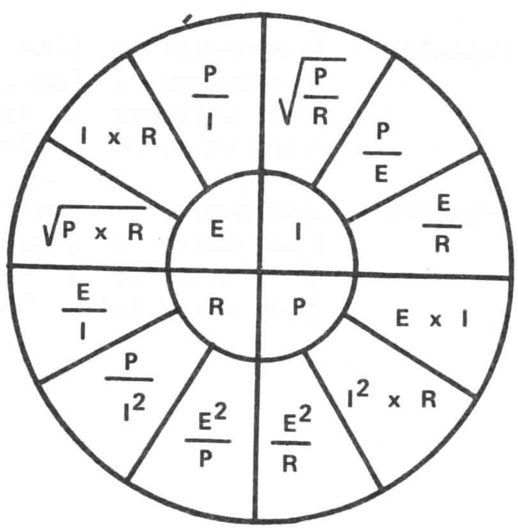
The circular system of angular measurement is called radiun measure.

A radian is an angle that intercepts an arc equal in length to the radius of a circle as illustrated below.



Length of arc BC = radius of circle
6.28 radians = 360°
2 π radians = 360°
π radians = 180°
1 radians = 57.2958°
1 degree = 0.01745 radian

VOLTAGE, CURRENT, POWER, AND RESISTANCE RELATIONSHIP CHART



QUADRATIC EQUATIONS

A quadratic equation that contains only terms of the second degree of the unknown is called a pure quadratic equation.

Example: $a^2 = 9$
$2x^2 + 5y^2 = 20$

A quatratic equation that contains terms of both the first and second degree of the unknown is called a complete quadratic equation.

Example: $x^2 + x + 3 = 15$
$ax^2 + bx + c = 0$

The quadratic formula:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Where: a = coefficient of the first term
b = coefficient of the second term
c = constant or third term

j OPERATOR

Operator	Mathematical Equivalent	Direction of Rotation	Degree of Rotation
j	$\sqrt{-1}$	ccw	90
j^2	-1	ccw	180
j^3	$-\sqrt{-1}$	ccw	270
j^4	1	ccw	360
$-j$	$-\sqrt{-1}$	cw	-90
$(-j)^2$	-1	cw	-180
$(-j)^3$	$\sqrt{-1}$	cw	-270
$(-j)^4$	1	cw	-360

ACCELERATION due to GRAVITY

Acceleration due to gravity at sea level, 40 degrees latitude, is:

32.1578 feet/sec/sec

DECIBELS and POWER RATIO

The ratio between any two amounts of electrical power is usually expressed in units on a logarithmic scale. The decibel is a logarithmic unit for expressing a power ratio.

$$PR_{(dB)} = 10 \log \frac{P_2}{P_1}$$

Where: PR = power ratio in db
P_1 = power in (small)
P_2 = power out (large)

When the output of a circuit is larger than the input, the device is an amplifier and there is a gain. When the output of a circuit is less than the input, the device is an attenuator and there is a loss. In the last example, use the same formula as above and place the larger power over the smaller power and put a minus sign in front of PR to indicate a power loss or attenuation.

Basically, the decibel is a measure of the ratio of two powers. Since voltage and current are related to power by impedance, the decibel can be used to express voltage and current ratios provided the input and output impedances are taken into account.

Equal Impedances:

$$dB = 20 \log \frac{E_2}{E_1} \qquad dB = 20 \log \frac{I_2}{I_1}$$

Where: E_1 = input voltage
E_2 = output voltage

Where: I_1 = input current
I_2 = output current

Unequal Impedances:

$$dB = 20 \log \frac{E_2 \sqrt{R_1}}{E_1 \sqrt{R_2}} \qquad dB = 20 \log \frac{I_2 \sqrt{R_2}}{I_1 \sqrt{R_1}}$$

Where: R_1 = impedance of the input in ohms
R_2 = impedance of the output in ohms
E_1 = voltage of the input in volts
E_2 = voltage of the output in volts
I_1 = current of the input in amperes
I_2 = current of the output in amperes

The NEPER

The neper, based on natural logarithms to the base ϵ, is a unit used to measure difference in power level in the same manner as the dB is used in the system of common logarithms.

1 dB = 0.115 neper
1 neper = 8.686 dB

DECREASE (—) VOLTAGE AND CURRENT RATIO	DECREASE (—) POWER RATIO	NUMBER OF DBs	INCREASE (+) VOLTAGE AND CURRENT RATIO	INCREASE (+) POWER RATIO
1.0000	1.0000	0	1.0000	1.0000
.9886	.9772	.1	1.0120	1.0230
.9772	.9550	.2	1.0230	1.0470
.9661	.9330	.3	1.0350	1.0720
.9550	.9120	.4	1.0470	1.0960
.9441	.8913	.5	1.0590	1.1220
.9333	.8710	.6	1.0720	1.1480
.9226	.8511	.7	1.0840	1.1750
.9120	.8318	.8	1.0960	1.2020
.9016	.8128	.9	1.1060	1.2300
.8913	.7943	1.	1.0960	1.2590
.7943	.6310	2.	1.2590	1.5850
.7079	.5012	3.	1.4130	1.9950
.6310	.3981	4.	1.5850	2.5120
.5623	.3162	5.	1.7780	3.1620
.5012	.2512	6.	1.9950	3.9810
.4467	.1995	7.	2.2390	5.0120
.3981	.1585	8.	2.5120	6.3100
.3548	.1259	9.	2.8180	7.9430
.3162	.1000	10.	3.1620	10.0000
.1000	.0100	20.	10.000	100.0000
.03162	.0010	30.	31.6200	1,000.0000
.0100	.0001	40.	100.0000	10,000.0000
.00316	.00001	50.	316.200	1×10^{5}
.0010	1×10^{-6}	60	1,000.0000	1×10^{6}
.000316	1×10^{-7}	70	3,162.0000	1×10^{7}

26067
330603A

Table Showing the Relationship Between DBs
and the Power, Voltage and Current Ratios

dBm

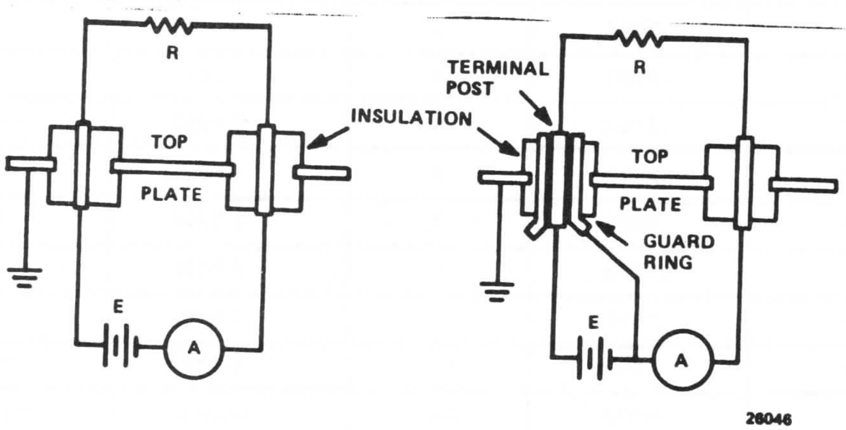
The decibel does not represent actual power, but only a measure of power ratios. It is desireable to have a logarithmic expression that represents actual power. The dBm is such an expression and it represents power levels above and below one milliwatt.

The dBm indicates an arbitrary power level with a base of one milliwatt and is found by taking 10 times the log of the ratio of actual power to the reference power of one milliwatt.

$$P_{(dBm)} = 10 \log \frac{P}{1 \text{ mw}}$$

Where: $P_{(dBm)}$ = power in dBm
P = actual power
1 mw = reference power

GUARDING ILLUSTRATED

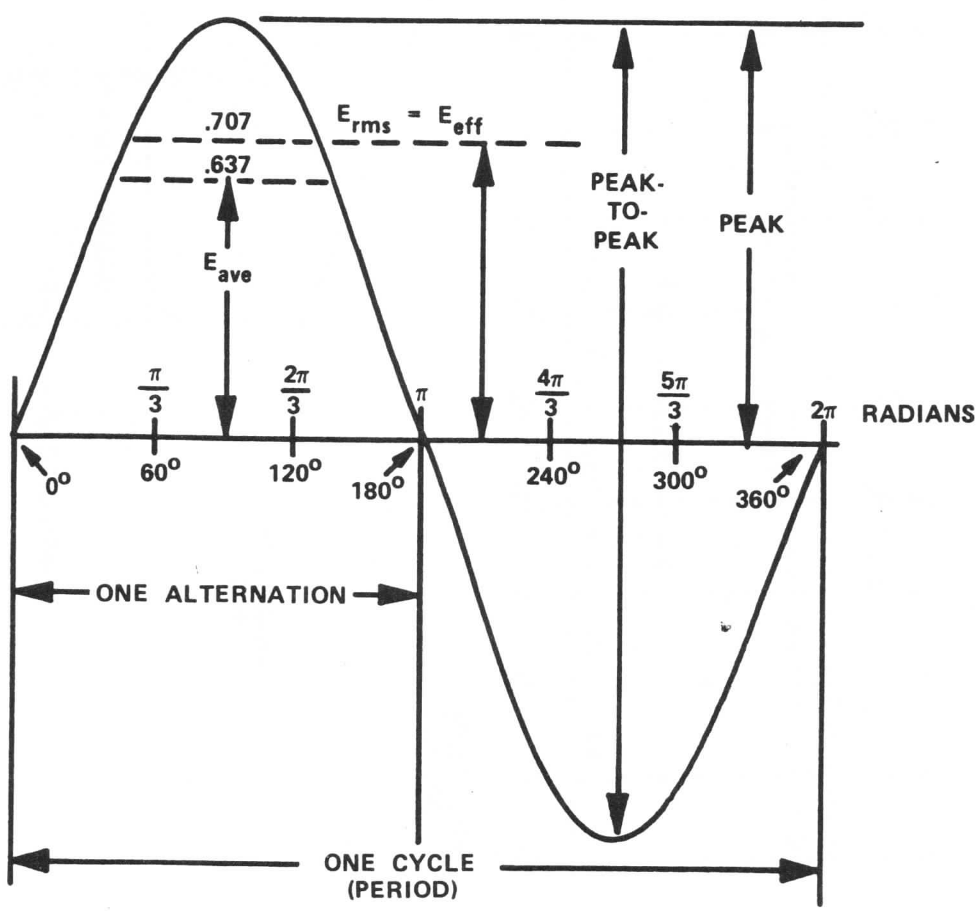


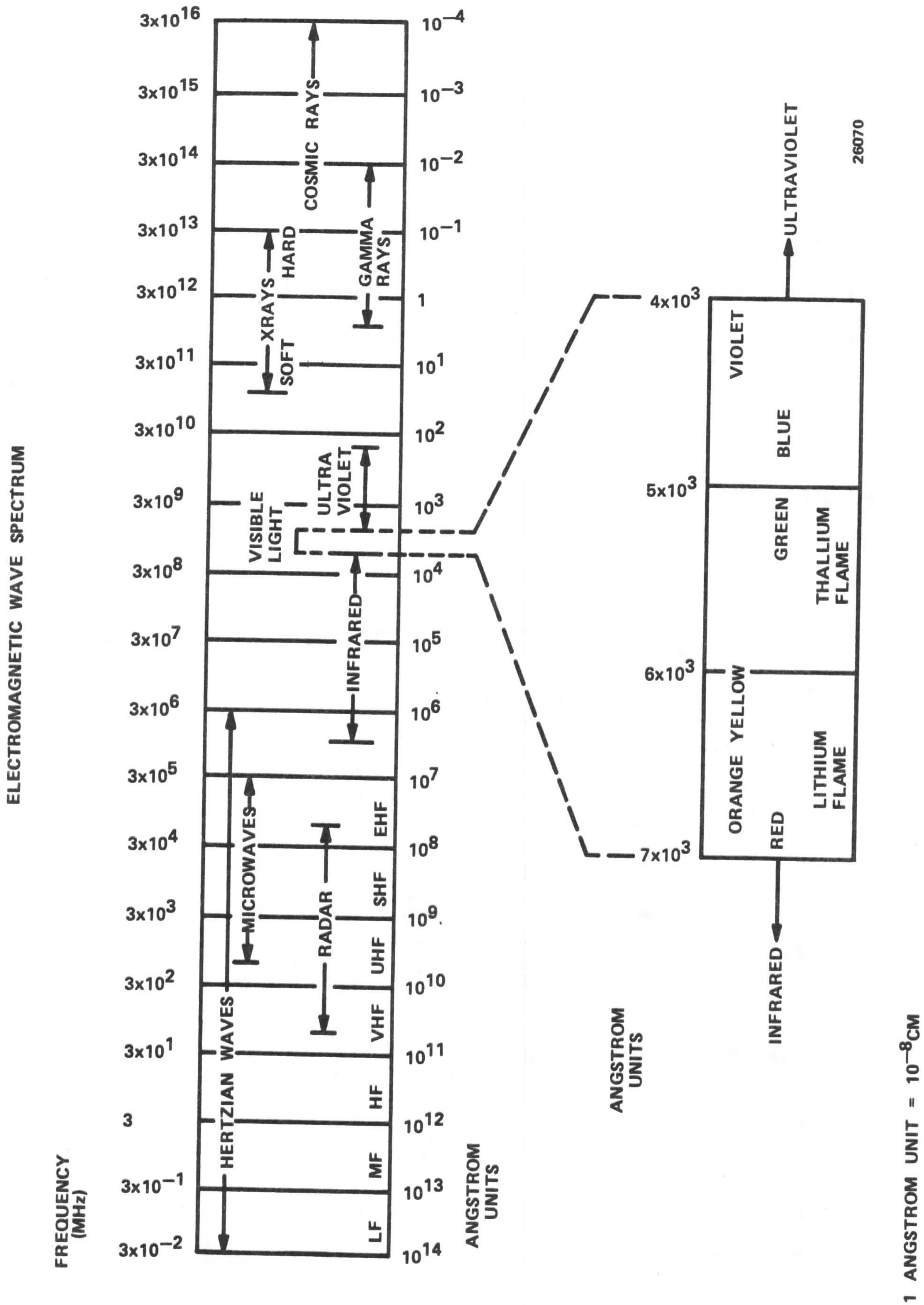
Un-guarded Circuit | Guarded Circuit

SINE WAVE VOLTAGE CONVERSION CHRT

	To			
	Effective	Average	Peak	Pk-to-Pk
Effective (RMS)		0.900	1.414	2.828
Average	1.110		1.571	3.142
Peak	0.707	0.637		2.000
Pk-to-Pk	0.354	0.318	0.500	

SINE WAVE ILLUSTRATED




ELECTROMAGNETIC WAVE SPECTRUM
FREQUENCY (MHz)
ANGSTROM UNITS
COSMIC RAYS
GAMMA RAYS
XRAYS
HARD
SOFT
ULTRA VIOLET
VISIBLE LIGHT
INFRARED
MICROWAVES
RADAR
HERTZIAN WAVES
EHF
SHF
UHF
VHF
HF
MF
LF
4x10³
5x10³
6x10³
7x10³
VIOLET
BLUE
GREEN
THALLIUM FLAME
ORANGE
YELLOW
RED
LITHIUM FLAME
ULTRAVIOLET
INFRARED
26070
1 ANGSTROM UNIT = 10⁻⁸CM

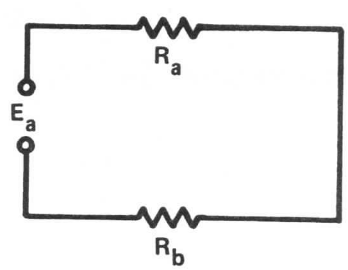
FREQUENCY CLASSIFICATION

Frequency	Classification	Abbreviation
3-30 KHz	Very low frequencies	VLF
30-300 KHz	Low frequencies	LF
300-3,000 KHz	Medium frequencies	MF
3-30 MHz	High frequencies	HF
30-300 MHz	Very high frequencies	VHF
300-3,000 MHz	Ultra-high frequencies	UHF
3,000-30,000 MHz	Super-high frequencies	SHF
30,000-3000,000 MHz	Extremely high frequencies	EHF
300,000-3,000,000 MHz	. . . .	. . . .

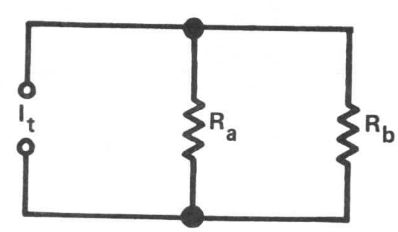
DIVIDER NETWORKS

The division of voltage and current in a circuit can be determined in the following manner.

Voltage Divider



Current Divider



$$E_{R_a} = \frac{R_a}{R_a + R_b} E_a \qquad I_{R_a} = \frac{R_b}{R_a + R_b} I_t$$

Where: E_a = applied voltage in volts
I_t = total current in amperes
R_a = resistance in ohms
R_b = resistance in ohms
E_{R_a} = voltage across R_a in volts
I_{R_a} = current through R_a in amperes

NETWORK CONVERSIONS

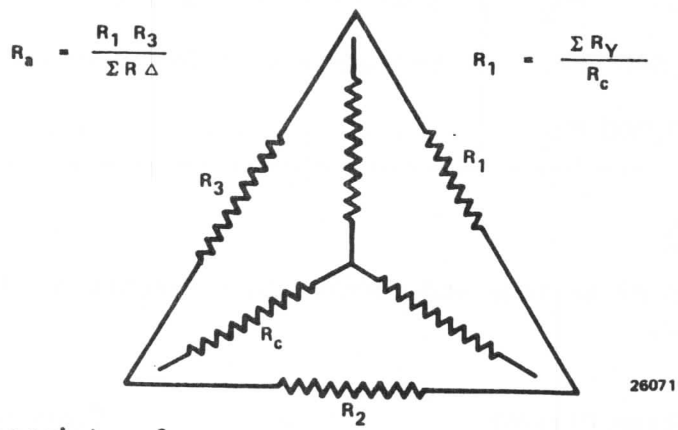
A simple method for remembering the Δ to Y and Y to Δ conversions is given using the illustration.

Δ to Y

The value of each Y resistor is equal to the product of the two adjacent Δ resistors divided by the total Δ resistance.

Y to Δ

The value of each Δ resistor is found by dividing the sum of all the Y resistances by the value of the opposite Y resistance.



Delta circuit consists of :

R_1, R_2, and R_3

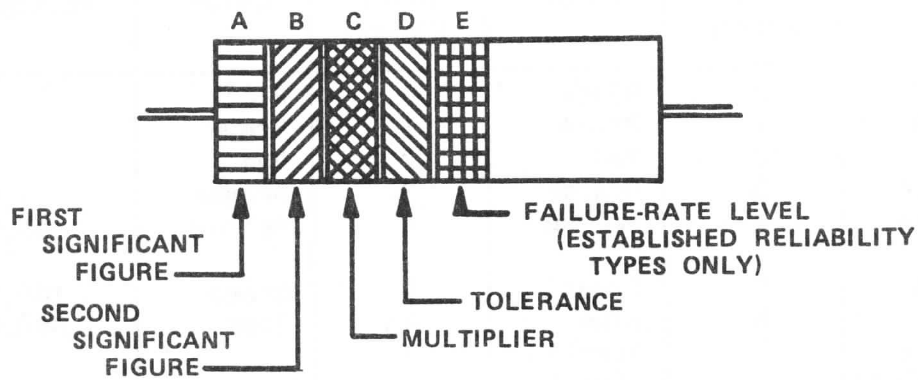
Wye circuit consists of:

R_a, R_b, and R_c

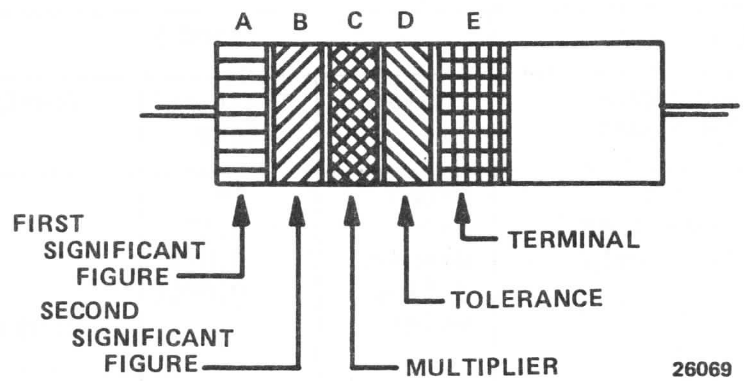
Σ = the sum of the resistors in the network specified.

COLOR-CODE MARKING FOR RESISTORS

COMPOSITION-TYPE RESISTORS



FILM-TYPE RESISTORS



Band A - The first significant figure of the resistance value. (Bands A thru D are of equal width)

Band B - The second significant figure of the resistance value.

Band C - The multiplier is the factor by which the two significant figures are multiplied to yield the nominal resistance value.

Band D - The resistance tolerance.

Band E - When used on composition resistors, band E indicates the established reliability failure-rate level. On film resistors, this band is approximately 1 1/2 times the width of the other bands, and indicates type of terminal.

COLOR-CODE CHART

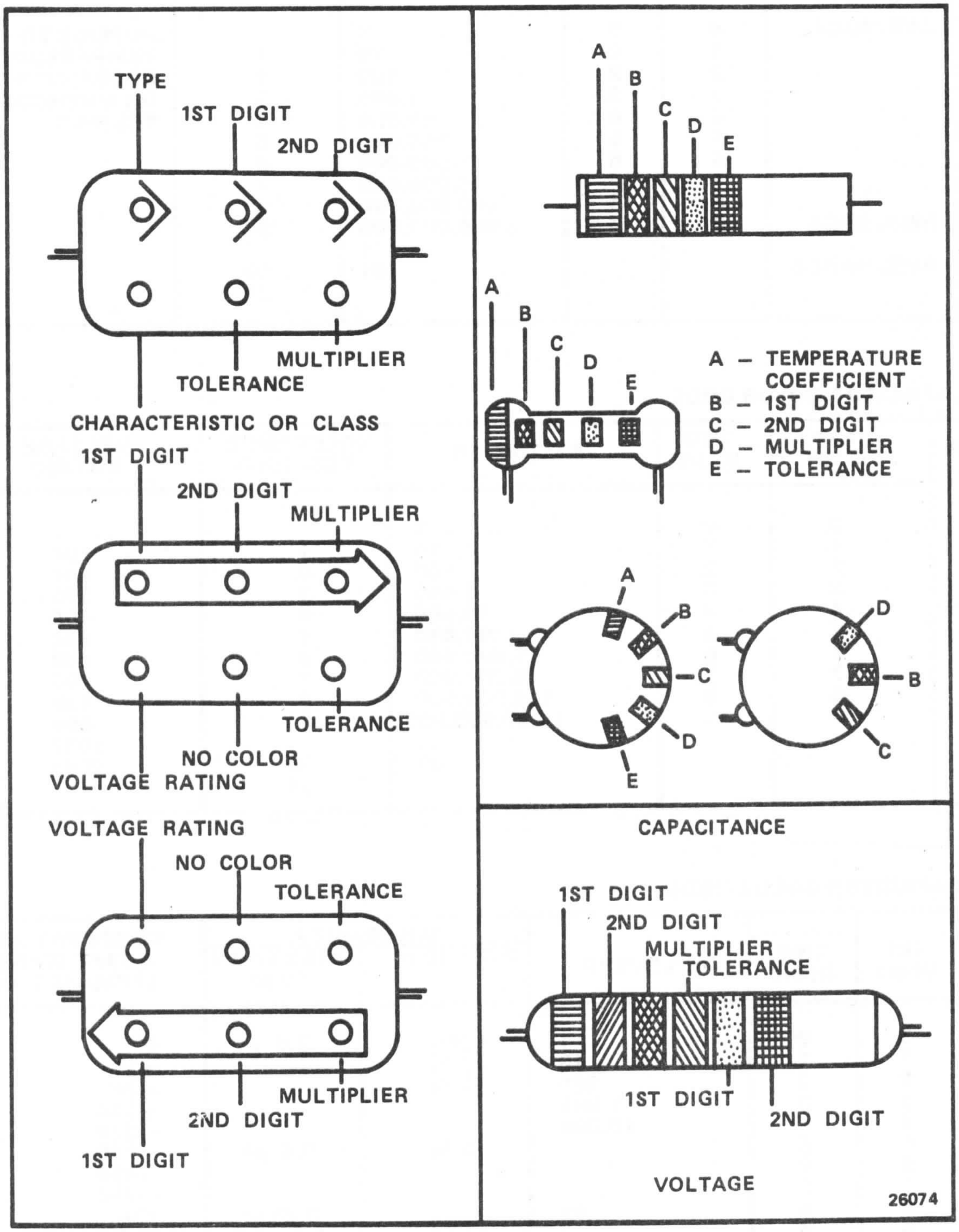
Band A		Band B		Band C	
Color	First Figure	Color	Second Figure	Color	Multiplier
Black	0	Black	0	Black	1
Brown	1	Brown	1	Brown	10
Red	2	Red	2	Red	100
Orange	3	Orange	3	Orange	1,000
Yellow	4	Yellow	4	Yellow	10,000
Green	5	Green	5	Green	100,000
Blue	6	Blue	6	Blue	1,000,000
Purple (violet)	7	Purple (violet)	7		
Grey	8	Gray	8	Silver	0.01
White	9	White	9	Gold	0.1

Band D		Band E		
Color	Tolerance (percent)	Color	*Failure Rate	Terminal
Silver	±10 Composition type only	Brown	1%	
		Red	0.1%	
		Orange	0.01%	
		Yellow	0.001%	
	± 5	White	--	Solderable
Red	± 2 not applicable to established reliability			
No Color	±20			

*This is the percentage of failure per 1000 hours of use.

COLOR CODE – CAPACITORS

ONLY A FEW OF THE MANY TYPES AND FORMS OF CAPACITORS ARE PRESENTED.



6-DOT RMA-JAN-AWS STANDARD CAPACITOR COLOR CODE

COLOR	TYPE	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLERANCE (PERCENT)	CHARACTERISTIC OR CLASS
BLACK	JAN, MICA	0	0	1		APPLIES TO TEMPERTURE COEFFICIENTS OR METHODS OF TESTING
BROWN		1	1	10	1	
RED		2	2	100	2	
ORANGE		3	3	1,000	3	
YELLOW		4	4	10,000	4	
GREEN		5	5	100,000	5	
BLUE		6	6	1,000,000	6	
PURPLE		7	7	10,000,000	7	
GRAY		8	8	100,000,000	8	
WHITE	RMA, MICA	9	9	1,000,000,000	9	
GOLD				.1		
SILVER	AWS, PAPER			.01	10	
BODY					20	

5-COLOR CAPACITOR COLOR CODE

COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLERANCE (PERCENT)	VOLTAGE RATING
BLACK	0	0	1		
BROWN	1	1	10	1	100
RED	2	2	100	2	200
ORANGE	3	3	1,000	3	300
YELLOW	4	4	10,000	4	400
GREEN	5	5	100,000	5	500
BLUE	6	6	1,000,000	6	600
PURPLE	7	7	10,000,000	7	700
GRAY	8	8	100,000,000	8	800
WHITE	9	9	1,000,000,000	9	900
GOLD			.1		1000
SILVER			.01	10	2000
BODY				20	

CERAMIC CAPACITOR COLOR CODE

COLOR	1ST DIGIT	2ND DIGIT	MULTIPLER	TOLERANCE		TEMPERATURE COEFFICIENT (PPM/DEG. C)
				OVER 10 pf	LESS THAN 10 pf	
BLACK	0	0	1	+20%	2.0 pf	0
BROWN	1	1	10	+1 %		−30
RED	2	2	100	+2 %		−80
ORANGE	3	3	1,000			−150
YELLOW	4	4	10,000			−220
GREEN	5	5		+5 %	0.5 pf	−330
BLUE	6	6				−470
PURPLE	7	7				−750
GRAY	8	8	.01		0.25 pf	+30
WHITE	9	9	.1	+10%	1.0 ppf	+500 TO −330
GOLD						+100

READING CAPACITOR CODES

Different marking schemes are used mainly because of the varying needs fulfilled by different capacitor types. Temperature coefficient is of minor importance in an electrolytic filter capacitor, but it is very important in ceramic trimmers for attenuator use. You never find temperature coefficient on an electrolytic label, but it is always present on ceramic trimmers.

Ceramic Disc Capacitors. Information is usually printed. Capacitance is in pf. Capacitance tolerance is shown in percent or by letter. Temperature coefficient is indicated by P200 which means +200 P/M/°C, or N100 for -100 P/M/°C, etc.

M = ± 20%
K = ± 10%
J = ± 5%
G = ± 2%
F = ± 1%

Ceramic Tubular Capacitors. These capacitors are usually white enamel coated with parallel radial leads and look like "dog bones." The code consists of color dots which indicate temperature coefficient, capacitance, and tolerance.

Button Mica Capacitors. The most difficult part of reading the code on these capaciotrs is to remember to read the dots moving in a clockwise direction. The dots are usually printed more to one side than they are to the other.

Molded Mica Capacitors. This was once a very popular type, rectangular with dots and arrow or similar directional indicator. Standard color code applies. The characteristic in mica capaciotrs refers to the temperature coefficient and capacitance drift.

Dipped Mica Capacitors. This type of capacitor has a printed label like that appearing on ceramic disc capacitors.

Paper and Film Capacitors. Aluminum and tantalum electrolytic capacitors, in nearly all cases, have printed or stamped labels indicating capacitance, tolerance, and voltage ratings. Other characteristics are usually unimportant.

Air Trimmers. The same information applies as with paper and film capacitors. Often only the capacitance range is indicated.

PERIODIC TABLE OF THE ELEMENTS

	GROUP ▼ / PERIOD ▶	1	2	3	4	5	6	7	
	1a	1 H Hydrogen 1.0080	3 Li Lithium 6.939	11 Na Sodium 22.990	19 K Potassium 39.102	37 Rb Rubidium 85.47	55 Cs Cesium 132.91	87 Fr Francium (223)	Alkali and Alkaline Earth Metals
	2a		4 Be Beryllium 9.0122	12 Mg Magnesium 24.312	20 Ca Calcium 40.08	38 Sr Strontium 87.62	56 Ba Barium 137.34	88 Ra Radium (226)	
	3b				21 Sc Scandium 44.956	39 Y Yttrium 88.905	57 - 71 Rare Earth Metals	89 - 103 Actinide Metals	
	4b				22 Ti Titanium 47.90	40 Zr Zirconium 91.22	72 Hf Hafnium 178.49		
First Transition Metals	5b				23 V Vanadium 50.942	41 Nb Niobium 92.906	73 Ta Tantalum 180.95		
	6b				24 Cr Chromium 51.996	42 Mo Molybdenum 95.94	74 W Tungsten 183.85		
	7b				25 Mn Manganese 54.938	43 Tc Technetium * (99)	75 Re Rhenium 186.2		
	8				26 Fe Iron 55.847	44 Ru Ruthenium 101.07	76 Os Osmium 190.2		
The Triads Second Transition Metals	8				27 Co Cobalt 58.933	45 Rh Rhodium 102.91	77 Ir Iridium 192.2		
	8				28 Ni Nickel 58.71	46 Pd Palladium 106.4	78 Pt Platinum 195.09		

57 La Lanthanum 138.91	89 Ac Actinium (227)
58 Ce Cerium 140.12	90 Th Thorium 232.04
59 Pr Praseodymium 141.91	91 Pa Protactinium (231)
60 Nd Neodymium 144.24	92 U Uranium 238.03
61 Pn Promethium * (147)	93 Np Neptunium * (237)
62 Sm Samarium 150.35	94 Pu Plutonium * (242)
63 Eu Europium 151.96	95 Am Americium * (243)

Third Transition Metals	1b				29 Cu Copper 63.54	47 Ag Silver 107.87	79 Av Gold 196.97
	2b				30 Zn Zinc 65.37	48 Cd Cadmium 112.40	80 Hg Mercury 200.59
Boron and Carbon Families	3a		5 B Boron 10.811	13 Al Aluminum 26.982	31 Ga Gallium 69.72	49 In Indium 114.82	81 Tl Thallium 204.37
	4a		6 C Carbon 12.011	14 Si Silicon 28.086	32 Ge Germanium 72.59	50 Sn Tin 118.69	82 Pb Lead 207.19
Nitrogen and Oxygen Families	5a		7 N Nitrogen 14.007	15 P Phosphorus 30.974	33 As Arsenic 74.922	51 Sb Antimony 121.75	83 Bi Bismuth 208.98
	6a		8 O Oxygen 15.999	16 S Sulfur 32.064	34 Se Selenium 78.96	52 Te Tellurium 127.60	84 Po Polonium (210)
The Halogens	7a		9 F Fluorine 18.998	17 Cl Chlorine 35.453	35 Br Bromine 79.909	53 I Iodine 126.90	85 At Astatine (210)
Inert Gases		2 He Helium 4.0026	10 Ne Neon 20.183	18 Ar Argon 39.948	36 Kr Krypton 83.80	54 Xe Xenon 131.30	86 Rn Radon (222)

Rare Earth Metals	Actinide Metals
64 Gd Gadolinium 157.25	96 Cm Curium * (247)
65 Tb Terbium 158.92	97 Bk Berkelium * (247)
66 Dy Dysprosium 162.50	98 Cf Californium * (251)
67 Ho Holmium 164.93	99 Es Einsteinium * (254)
68 Er Erbium 167.26	100 Fm Fermium * (253)
69 Tm Thulium 168.93	101 Md Mendelevium * (256)
70 Yb Ytterbium 173.04	102 No Nobelium * (254)
71 Lu Lutetium 174.97	103 Lw Lawrencium * (257)

* Synthetically prepared.

Numbers in ( ) are most stable isotope.

PERIODIC TABLE OF THE ELEMENTS

Atomic Number	Symbol	Name	Atomic Weight	Electron Configuration K	L	M	N	O	P	O
1	H	Hydrogen	1.0080	1						
2	He	Helium	4.0026	2						
3	Li	Lithium	6.93	2	1					
4	Be	Berylium	9.0122	2	2					
5	B	Boron	10.811	2	3					
6	C	Carbon	12.011	2	4					
7	N	Nitrogen	14.007	2	5					
8	O	Oxygen	15.999	2	6					
9	F	Fluorine	18.998	2	7					
10	Ne	Neon	20.183	2	8					
11	Na	Sodium	22.990	2	8	1				
12	Mg	Magnesium	24.312	2	8	2				
13	Al	Aluminum	26.982	2	8	3				
14	Si	Silicon	28.086	2	8	4				
15	P	Phosphorus	30.974	2	8	5				
16	S	Sulfur	32.064	2	8	6				
17	Cl	Chlorine	35.453	2	8	7				
18	Ar	Argon	39.948	2	8	8				
19	K	Potassium	39.102	2	8	8	1			
20	Ca	Calcium	40.08	2	8	8	2			
21	Sc	Scandium	44.956	2	8	9	2			
22	Ti	Titanium	47.90	2	8	10	2			
23	V	Vanadium	50.942	2	8	11	2			
24	Cr	Chromiun	51.996	2	8	13	1			
25	Mn	Manganese	54.938	2	8	13	2			
26	Fe	Iron	55.847	2	8	14	2			
27	Co	Cobalt	58.933	2	8	15	2			
28	Ni	Nickle	58.71	2	8	16	2			
29	Cu	Copper	63.54	2	8	18	1			
30	Zn	Zinc	65.37	2	8	18	2			
31	Ga	Gallium	69.72	2	8	18	3			
32	Ge	Germanium	72.59	2	8	18	4			
33	As	Arsenic	74.922	2	8	18	5			
34	Se	Selenium	78.96	2	8	18	6			
35	Br	Bromine	79.909	2	8	18	7			
36	Kr	Krypton	83.80	2	8	18	8			
37	Rb	Rubidium	85.47	2	8	18	8	1		
38	Sr	Strontium	87.62	2	8	18	8	2		
39	Y	Yttrium	88.905	2	8	18	9	2		
40	Zr	Zirconium	91.22	2	8	18	10	2		
41	Nb	Niobium	92.906	2	8	18	12	1		
42	Mo	Molybdenum	95.94	2	8	18	13	1		
43	Tc	Technetium	(99)	2	8	18	13	2		
44	Ru	Ruthenium	101.07	2	8	18	15	1		
45	Rh	Rhodium	102.91	2	8	18	16	1		
46	Pd	Palladium	106.1	2	8	18	18			
47	Ag	Silver	107.87	2	8	18	18	1		
48	Cd	Cadmiun	112.40	2	8	18	18	2		
49	In	Indium	114.82	2	8	18	18	3		
50	Sn	Tin	118.69	2	8	18	18	4		
51	Sb	Antimony	121.75	2	8	18	18	5		
52	Te	Tellurium	127.62	2	8	18	18	6		
53	I	Iodine	126.90	2	8	18	18	7		
54	Xe	Xenon	131.30	2	8	18	18	8		

55	Cs	Cesium	132.91	2	8	18	18	8	1	
56	Ba	Barium	137.34	2	8	18	18	8	2	
57	La	Lanthanum	138.91	2	8	18	18	9	2	
58	Ce	Cerium	140.12	2	8	18	19	9	2	
59	Pr	Praseodymium	140.91	2	8	18	21	8	2	
60	Nd	Neodymium	144.24	2	8	18	22	8	2	
61	Pm	Promethium	(147)	2	8	18	23	8	2	
62	Sm	Samarium	150.35	2	8	18	24	8	2	
63	Eu	Europium	151.96	2	8	18	25	8	2	
64	Gd	Gadolinium	157.25	2	8	18	25	9	2	
65	Tb	Terbium	158.92	2	8	18	26	9	2	
66	Dy	Sysprosium	162.50	2	8	18	28	8	2	
67	Ho	Holmium	164.93	2	8	18	29	8	2	
68	Er	Erium	167.26	2	8	18	30	8	2	
69	Tm	Thulium	168.93	2	8	18	31	8	2	
70	Yb	Ytterbium	173.04	2	8	18	32	8	2	
71	Lu	Lutetium	174.97	2	8	18	32	9	2	
72	Hf	Hafnium	178.49	2	8	18	32	10	2	
73	Ta	Tantalum	180.95	2	8	18	32	11	2	
74	W	Tungsten	183.85	2	8	18	32	12	2	
75	Re	Rhenium	186.2	2	8	18	32	13	2	
76	Os	Osmium	190.2	2	8	18	32	14	2	
77	Ir	Iridium	192.2	2	8	18	32	15	2	
78	Pt	Platinum	195.09	2	8	18	32	17	1	
79	Au	Gold	196.97	2	8	18	32	18	1	
80	Hg	Mercury	200.59	2	8	18	32	18	2	
81	Tl	Thallium	204.37	2	8	18	32	18	3	
82	Pb	Lead	207.19	2	8	18	32	18	4	
83	Bi	Bismuth	208.98	2	8	18	32	18	5	
84	Po	Polonium	(210)	2	8	18	32	18	6	
85	At	Astatine	(210)	2	8	18	32	18	7	
86	Rn	Radon	(222)	2	8	18	32	18	8	
87	Fr	Francium	(223)	2	8	18	32	18	8	1
88	Ra	Radium	(226)	2	8	18	32	18	8	2
89	Ac	Actinium	(227)	2	8	18	32	18	9	2
90	Th	Thorium	232.04	2	8	18	32	18	10	2
91	Pa	Protactinium	(231)	2	8	18	32	20	9	2
92	U	Uranium	238.03	2	8	18	32	21	9	2
93	Np	Neptunium	(237)	2	8	18	32	22	9	2
94	Pu	Plutonium	(242)	2	8	18	32	24	9	2
95	Am	Americium	(243)	2	8	18	32	25	8	2
96	Cm	Curium	(247)	2	8	18	32	25	9	2
97	Bk	Berkelium	(247)	2	8	18	32	27	8	2
98	Cf	Californium	(249)	2	8	18	32	28	8	2
99	Es	Einsteinium	(254)	2	8	18	32	29	8	2
100	Fm	Fermium	(253)	2	8	18	32	30	8	2
101	Md	Mendelevium	(256)	2	8	18	32	31	8	2
102	No	Nobelium	(254)	2	8	18	32	32	8	2
103	Lw	Lawrencium	(257)	2	8	18	32	32	9	2

MASS and WEIGHT CONVERSION TABLE

1 gram = 0.035 ounce
1 centigram = 0.154 grain
1 kilogram = 2.2046 pounds
1 pound = 0.4536 kilogram = 7000 grains = 454 grams
1 ounce = 28.349 grams = 437.5 grains
1 grain = 0.0648 grams = 0.002285 ounce

LENGTH CONVERSION TABLE

1 inch = 2.540 centimeters = 0.083 feet = 0.027 yards
= 25.4 millimeters = 25,400 microns
1 foot = 30.480 centimeters = 12 inches = 0.333 yards
1 yard = 0.914 meters = 3 feet = 36 inches

1 meter = 39.37 inches = 1.094 yards
1 kilometer = 0.6214 statute miles
1 centimeter = 0.3937 inch
1 micron = 0.0001 centimeter = 10^{-6} meter
1 angstrom = 0.00000001 centimeter = 10^{-10} meter
1 statute mile = 1.609 kilometers = 5280 feet = 1760 yards
1 nautical mile = 6076.115 feet = 1852.0 meters

VOLUME and PRESSURE CONVERSION TABLE

1 cubic inch = 16.387 cubic centimeters
1 cubic foot = 0.028 cubic meters = 1728 cubic inches
1 cubic yard = 0.765 cubic meters = 27 cubic feet
1 cubic centimeter = 0.061 cubic inch
1 quart = 946 cubic centimeters = 57.75 cubic inches
1 liter = 1000 cubic centimeters = 1.057 quart
1 atmosphere = 14.7 psi = 760 mm of Hg at 0°C at sea level
1 psi = 51.7 mm of mercury
1 inch of mercury at 0°C = 0.491 pounds per square inch
1 cm of mercury at 0°C = 13.6 grams per square centimeter
1 foot of water = 0.433 psi
1 cubic centimeter of water = 1 gram
1 cubic foot of water = 62.416 pounds
1 g = 386 inches/sec^2

1 gallon = 231 cubic inches
1 gallon = 0.1336788 cubic feet
1 gallon water @ 4°C = 8.3454 lbs
1 millibar = 0.02953 in Hg = 0.750062 mm Hg
1 Torr = 1/760 atmosphere = 1 millimeter

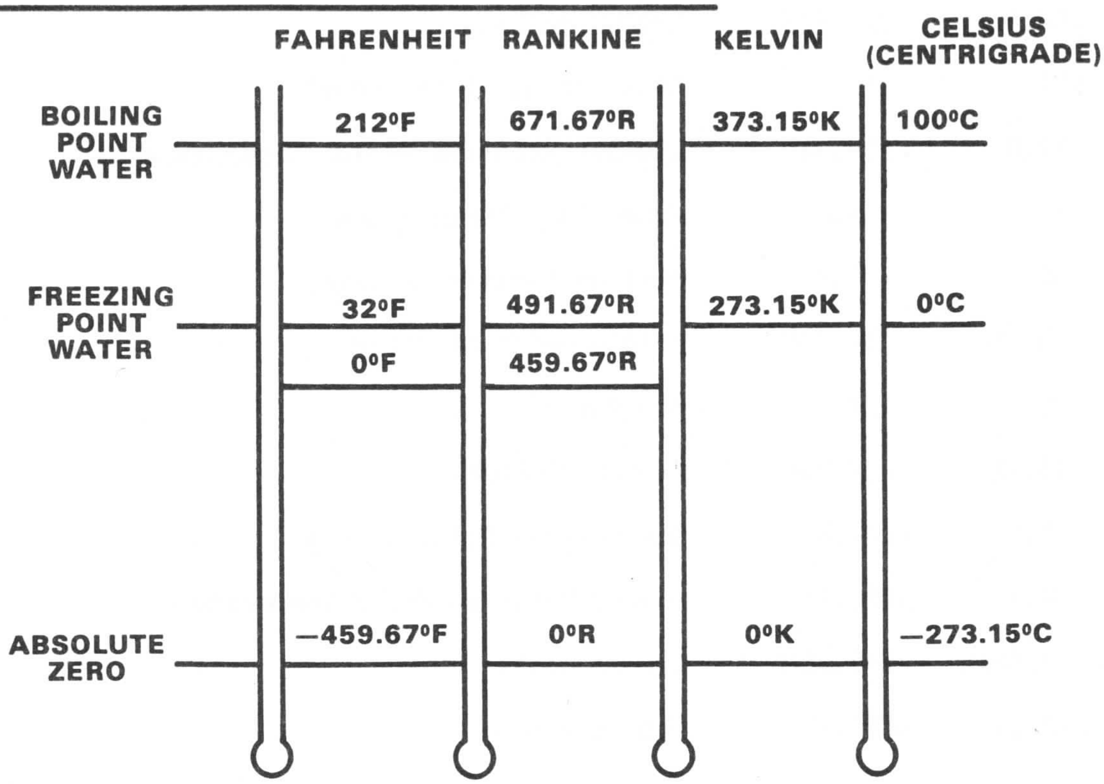
POWER, WORK, and HEAT CONVERSION TABLE

1 Btu = 252 calories = 778 foot-pounds
1 watt = 44.28 foot-pounds per minute
1 kilowatt = 1000 watts = 1.34 horsepower
1 horsepower = 746 watts = 550 ft/lbs/sec = 33,000 ft/lbs/min
1 erg = 1 dyne centimeter
1 joule = 10^7 erg = 0.239 calorie
1 calorie = 4.18 joules
1 watt = 1 joule per second = 3.4 Btu per hour

TEMPERATURE CONVERSION CHART

FROM	TO	FORMULA
CLESIUS	KELVIN	$K = C + 273.15$
FAHRENHEIT	KELVIN	$K = (5/9)\ (F + 459.67)$
RANKINE	KELVIN	$K = (5/9)\ R$
FAHRENHEIT	CELSIUS	$C = \frac{(F - 32)}{1.8}$
KELVIN	CELSIUS	$C = K - 273.15$
CELSIUS	FAHRENHEIT	$F = 1.8C + 32$
FAHRENHEIT	RANKINE	$R = F + 459.69$

BASIC TEMPERATURE SCALES COMPARISON CHART



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THERMAL SPECTRUM

Celsius Scale	Fahrenheit Scale	
1410	2570	Silicon Melts
1083.4	1982.12	Copper Melts
1964.43	1947.974	Freezing Point of Gold
937.4	1719.32	Germanium Melts
961.93	1763.474	Freezing Point of Silver
660.37	1220.666	Aluminum Melts
630.74	1167.332	Silver Solder Melts
630.74	1167.332	Antimony Melts
444.674	832.4132	Boiling Point of Silver
216	420	50/50 Lead/Tin Solder Melts
156.61	313.898	Indium Melts
100	212	Steam Point at Sea Level
57.8	136.04	Highest Recorded World Temperature
37	98.6	Human Body Temperature
4	39.2	Maximum Density of Water
0.010	32.018	Triple Point of Water
0	32	Ice Point
-38.87	-37.966	Mercury Freezes
-78.5	-109.3	Sublimation Point of CO_2
-88.3	-126.94	Lowest Recorded World Temperature
-182.962	-297.3316	Oxygen Boils
-273.15	-459.67	Absolute Zero

DECIMAL EQUIVALENTS OR COMMON FRACTIONS

1/64 = 0.015 625	11/32 = 0.343 75	43/64 = 0.671 875
1/32 = .031 25	23/64 = .359 375	11/16 = .687 5
3/64 = .046 875	3/8 = .375	45/64 = .703 125
1/16 = .062 5	25/64 = .390 625	23/32 = .718 75
5/64 = .078 125	12/32 = .406 25	47/64 = .734 375
3/32 = .093 75	27/64 = .421 875	3/4 = .75
7/64 = .109 375	7/16 = .437 5	49/64 = .765 625
1/8 = .125	29/64 = .453 125	25/32 = .781 25
9/64 = .140 625	15/32 = .468 75	51/64 = .796 875
5/32 = .156 25	31/64 = .484 375	13/16 = .812 5
11/64 = .171 875	1/2 = .50	53/64 = .828 125
3/16 = .187 5	33/64 = .515 625	27/32 = .843 75
13/64 = .203 125	17/32 = .531 25	55/64 = .859 375
7/32 = .218 75	35/64 = .546 875	7/8 = .875
15/64 = .234 375	9/16 = .562 5	57/64 = .890 625
1/4 = .25	37/64 = .578 125	29/32 = .906 25
17/64 = .265 625	19/32 = .593 75	59/64 = .921 875
9/32 = .281 25	39/64 = .609 375	15/16 = .937 5
19/64 = .296 875	5/8 = .625	61/64 = .953 125
5/16 = .312 5	41/64 = .640 625	31/32 = .968 75
21/64 = .328 125	21/32 = .656 25	63/64 = .984 375

LENGTH EQUIVALENT CONVERSION CHART

330603C1-27

FROM

TO	FEET	METERS	YARDS	CENTIMETERS	INCHES	MILLIMETERS
FEET	1.0	0.3048	0.3333	30.48	12.0	304.8
METERS	3.281	1.0	1.0936	100.0	39.37	1000.0
YARDS	3.0	0.9144	1.0	91.44	36.0	914.4
CENTIMETERS	0.03281	0.01	0.01094	1.0	0.3937	10.0
INCHES	0.08333	0.0254	0.02778	2.540	1.0	25.40
MILLIMETERS	0.003281	0.001	0.001094	0.1	0.03937	1.0

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ZEKE's REVERSIBLE FORMULA (C° -F° /-C°)

For converting degrees Celsius to degrees Fahrenheit and visa versa.

1. Add 40
2. Multiply by either (5/9 F to C) or (9/5 C to F)
3. Subtract 40

SPECIFIC GRAVITY OF SOLIDS

Aluminun	2.7	Ice	0.917
Brass	8.2-8.7	Iron, steel	7.6-7.8
Carbon	1.9-3.5	Lead	11.34
Copper	8.9	Oak	0.60-0.98
Gold	19.3	Pine	0.37-0.64
Human body	1.07	Silver	10.5

SPECIFIC GRAVITY OF LIQUIDS

Water, Distilled @ 4°C	1.000	Mercury @ 0°C	13.5951
Alcohol, Ethyl	0.789	Milk	1.029
Carbon Tetrachloride	1.60	Oil, Linseed	0.942
Gasoline	0.66-0.69	Water, Sea	1.025
Kerosene	0.82		

SPECIFIC GRAVITY OF GASES (air = 1.000)

Ammonia	0.596	Neon	0.696
Carbon dioxide	1.529	Nitrogen	0.967
Hydrogen	0.069	Oxygen	1.105

TORQUE INDICATING HANDLES

Tolerances for torque indicating handles IAW Federal spec GGG-W-686.

Range	Tolerance
0 - 19.9% of full scale	± 7% of indicated value
20 - 79.9 of full scale	± 4% of indicated value
80 - 100% of full scale	± 5% of indicated value

SPEED OF LIGHT IN AIR

The speed of light is stated differently in various reference sources. In this handbook we will accept the speed of light as being:

Approximately 186,000 miles per second or 2.9979 X 10^8 meters per second.

VOLUMETERIC EXPANSION COEFFENCIENTS

Substance	$\frac{n \times 10^{-4}}{°C}$	$\frac{n \times 10^{-4}}{°F}$
Alcohol, Ethyl	11.0	6.10
Benzene	13.9	7.70
Petroleum (Pennsylvania)	9.0	5.0
Mercury	1.82	1.01
Sulfuric Acid	5.56	3.10
Turpentine	9.70	5.40
Water	2.07	1.15

LINER COEFFICIENTS OF EXPANSION

Material	$\frac{n \times 10^{-6}}{°C}$	$\frac{n \times 10^{-6}}{°F}$
Aluminum	24.5	13.6
Copper	16.2	9.0
Iron (Cast)	11.7	6.5
Nickel	12.6	7.0
Platinum	9.0	5.0
Steel (Carbon)	11.3	6.3
Tungsten	4.3	2.4
Zinc	30.6	17.0

PRESSURE UNITS	psi	in H_2O	ft H_2O	in Hg	ATM	G/cm²	KG/cm²	cm H_2O	mm Hg
1 psi	1.000	27.68	2.307	2.036	0.06805	70.31	0.07031	70.31	51.72
1 INCH H_2O (4°C)	0.03613	1.000	0.08333	0.07355	0.002458	2.540	0.002450	2.540	1.868
1 FOOT H_2O (4°C)	0.4335	12.00	1.000	0.8826	0.02950	30.45	0.03048	30.48	22.42
1 INCH HG (0°C)	0.4912	13.60	1.133	1.000	0.03342	34.53	0.03453	34.53	25.40
1 STANDARD ATMOSPHERE	14.70	406.8	33.90	29.92	1.000	1033.	1.033	1033.	760.0
1 GRAM/CM²	0.01422	0.3937	0.03281	0.02896	0.0009678	1.000	0.001000	1.000	0.7356
1 KILOGRAM/CM²	14.22	393.7	32.81	28.96	0.9678	1000.	1.000	1000.	735.6111
1 CM H_2O (4°C)	0.01422	0.3937	0.03281	0.02896	0.0009678	1.000	0.001000	1.000	0.7355
1 MM Hg (0°C)	0.01934	0.5353	0.04461	0.03937	0.001316	1.360	0.001360	0.001360	1.000

PRESSURE UNIT CONVERSION CHART

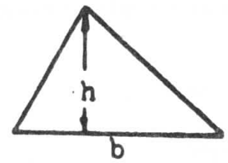
26066
330603B1-27
330603A1-27

VARIOUS MEASUREMENTS

Plane figures bounded by straight lines.

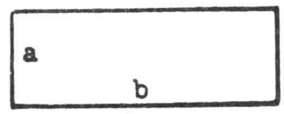
Area of a triangle whose base is (b) and altitude (h).

$$\text{area} = \frac{bh}{2}$$



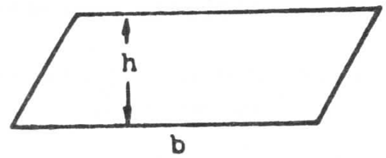
Area of a rectangle with sides (a) and (b).

$$\text{area} = ab$$



Area of a parallelogram with side (b) and perpendicular distance to the parallel side (h).

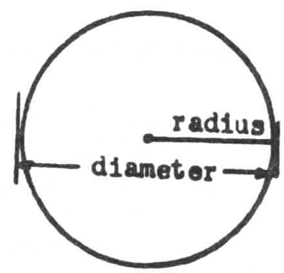
$$\text{area} = bh$$



Plane figures bounded by curve lines.

Circumference of a circle whoes radius is (r) and diameter (d)

$$\text{circumference} = 2\pi r = \pi d$$

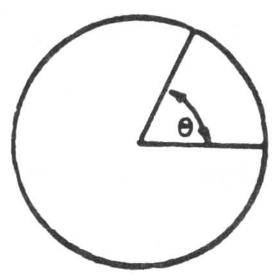


Area of a circle

$$\text{area} = \pi r^2 = 1/4\, \pi d^2 = .7854d^2$$

Length of an arc of a circle for an arc of degrees

$$\text{length of arc} = \frac{\pi r \theta}{180}$$



FORMULAS

ELECTROSTATICS

1. The force between two charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between the charges.

$$F = \frac{Q_1 Q_2}{Kd^2}$$

Where F = force in dynes

Q_1 = strength of charge one in electrostatic units (e.s.u.)

Q_2 = strength of charge two in electrostatic units.

d = distance separating charges in cm.

K = dielectric constant of the medium through which the force is exerted.

2. The following equation is used to show the work performed on an electrostatic field where a charge has been transferred.

$$W = \frac{K(Q_1 Q_2)}{d}$$

Where W = work in joules

Q_1 = strength of charge one in electrostatic units.

Q_2 = strength of charge two in electrosatic units.

d = distance separating charge in cm.

K = dielectric constant of the medium through which the force is exerted.

3. The formula for electrical potential difference is as follows:

$$E = \frac{W}{Q}$$

Where E = the potential in volts

W = work in joules

Q = charge in coulombs

4. The following formulas are used to determine the deflection factor or deflection sensitivity of a CRT.

deflection factor $df = \frac{1}{ds}$

df = deflection factor

ds = deflection sensitivity

deflection sensitivity $ds = \frac{1}{df}$

ds = deflection sensitivity

df = deflection factor

MAGNETISM AND ELECTROMAGNETICS

1. The force between two poles is directly proportional to the product of the pole strengths and inversely proportional to the square of the distance between the poles.

$$F = \frac{m_1 m_2}{\mu d^2}$$

Where F = force between the poles in dynes

m_1 = magnetic strength of the first pole in unit poles

m_2 = magnetic strength of the second pole in unit poles

d = distance between the poles in cm

μ = permeability of the medium through which the force acts

2. The number of flux lines per unit area is known as flux density.

$$\beta = \frac{\Phi}{A}$$

Where β = flux density

Φ = total lines of flux

A = cross sectional area in cm^2

3. The density of a magnetic field is directly related to the magnetic force exerted by the field. The formula for field intensity (H) is as follows:

$$H = \frac{f}{m}$$

Where H = field intensity in oersteds

f = force acting upon a magnetic pole in dynes

m = strength of magnetic pole in unit poles

4. The formula for magnetomotive force in a coil is as follows:

$$mmf = \frac{4 \pi NI}{10}$$

Where mmf = magnetomotive force in gilberts

N = number of turns

I = current in amperes

5. The formula for reluctance in a coil is as follows:

$$R = \frac{L}{\mu A}$$

Where R = reluctance in rels

μ = permeability of the medium

L = length of winding in cm

A = area in square cm

6. The formula for permeability is as follows:

$$\mu = \frac{\beta}{H}$$

Where μ = permeability of medium

β = flux density in gausses

H = magnetic intensity in oersteds

7. Amplitude of induced EMF is affected by the rate at which lines of force are cut. This can be expressed mathematically by the following formula:

$$E_{ave} = \frac{N\Phi}{10^8 t}$$

Where E_{ave} = average value of induced voltage

N = number of turns

t = time in seconds taken to cut all flux lines

Φ = the number of lines of force

RESISTANCE

1. The resistance of a resistor is determined by the type of material used, its cross sectional area and its length. The resistance value is directly proportional to the length, and inversely proportional to its cross sectional area.

$$R = \rho \frac{l}{d^2} = \rho \frac{l}{A}$$

Where R = resistance in ohms

ρ = resistance in ohms per circular mil foot of the material (specific resistance)

l = length of the conductor

d = diameter of material in mils

A = cross sectional area in circular mils

2. Resistance as a function of temperature (approximation).

$$R_t = R_0 (1+\alpha t)$$

Where R_t = resistance at a given temperature

R_0 = resistance at a reference temperature

α = temperature coefficient of resistance at the reference temperature

t = elevation of the second temperature above the reference temperature in degrees Celsius

CONDUCTANCE

1. Conductance is the ability of a material to pass electrons. It can be found by using the following formula:

$$G = \frac{A}{\rho l}$$

Where G = conductance measured in mhos

A = cross sectional area in circular mils

l = length measured in feet

ρ = specific resistance

2. The conductance is the reciprocal of resistance.

$$G = \frac{1}{R}$$

Where G = conductance in mhos

R = resistance in ohms

METERS

1. The sensitivity of a meter movement is often stated in terms of ohms per volt. This relationship is shown in the following formula:

$$\Omega/V = \frac{R_m}{E_m} = \frac{1}{I_m}$$

Where Ω/V = ohms per volt

R_m = resistance of the meter movement

E_m = full scale reading in volts

I_m = full scale current in amperes

NOTE: The imput of a VTVM is constant over its entire range for any given frequency input.

2. The value of multiplier resistance needed to extend the range of a voltmeter can be determined using the following formula:

$$R_{mul} = E(\Omega /V) - R_m$$

Where R_{mul} = resistance of the multiplier

E = extended range of the voltmeter

Ω /V = ohms per volt

R_m = resistance of the meter movement

3. To extend the range of an ammeter the appropriate shunt resistor is determined using the following formula:

$$R_s = \frac{I_m R_m}{T_t - I_m}$$

Where R_s = shunt valve required

I_m = full scale deflection current of the meter movement

R_m = resistance of the meter movement

I_t = total current of desired range

4. To extend the range of a milliammeter using a ring (universal) type shunt the following formula will be used. Some of the resistors may be in series with the meter movement and some in parallel depending on the range used.

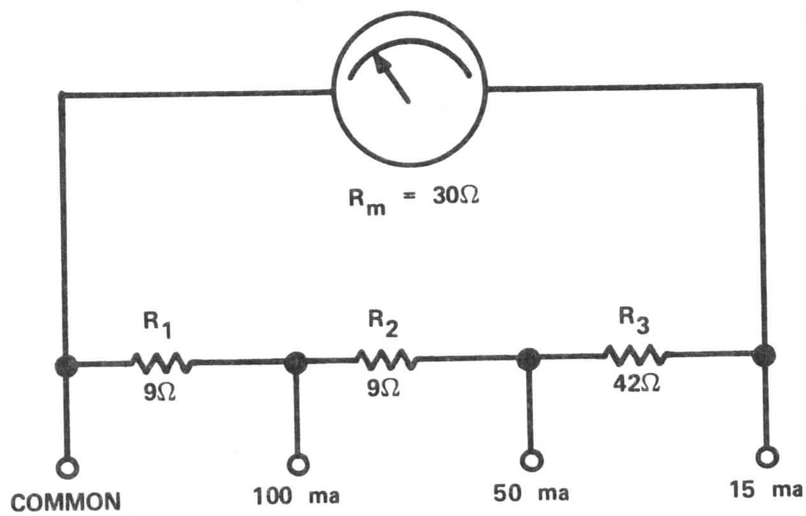
$$R_s = \frac{R_t I_m}{I_t}$$

Where R_s = shunt value required

R_t = sum of all resistance in the meter circuit, including the meter resistance

I_m = full scale deflection current of the meter

I_t = total current of the desired range



RING SHUNT AMMETER 26072

OHM'S LAW FOR DC CIRCUITS

When any two values are known, the other two circuit parameters may be determined. There are shown on the following formulaw chart:

I = current in amperes	R = resistance in ohms	E = voltage in volts	P = power in watts
known	known	$E = IR$	$P = I^2R$
known	$R = E/I$	known	$P = EI$
known	$R = P/I^2$	$E = P/I$	known
$I = E/R$	known	known	$P = E^2/R$
$I = P/E$	$R = E^2/P$	known	known
$I = \sqrt{P/R}$	known	$E = \sqrt{PR}$	known

OHM'S LAW FOR AC CIRCUITS

When any two circuit values are known, the other two circuit parameters may be determined. These are shown in the following chart.

I = current in amperes	Z = impedance in ohms	E = voltage in volts	P = power in watts
known	known	$E = IZ$	$P = I^2Z \cos\theta$
known	$Z = E/I$	known	$P = IE \cos\theta$
$I = E/Z$	known	known	$P = E^2 \cos\theta /Z$
known	$Z = \frac{P}{I^2 \cos\theta}$	$E = \frac{P}{I \cos\theta}$	known
$I = \frac{P}{Z \cos\theta}$	known	$E = \frac{PZ}{\cos\theta}$	known
$I = \frac{P}{E \cos\theta}$	$Z = \frac{E^2 \cos\theta}{P}$	known	known

SERIES DC CIRCUIT COMPUTATION

The following formulas assume that the source of power has negligible resistance.

1. Total resistance (R_t). The total resistance is the sum of the individual resistances.

$$R_t = T_1 + R_2 + R_3 + \ldots.$$

2. Total voltage (E_t). The total voltage in a series circuit is the sum of the individual voltage drops, and is equal to the voltage of the source.

$$E_t = E_1 + E_2 + E_3 + \ldots.$$

3. Total current (I_t). The total current is determined by the total resistance of the circuit and the applied voltage and will be of the same value at any point in the circuit.

$$I_t = I_1 = I_2 = I^3 = \ldots.$$

4. Total power (P_t). The total power dissipated in a series circuit is the sum of all power losses in the circuit.

$$P_t = P_1 + P_2 + P_3 + \ldots.$$

5. Total conductance (G_t).

$$G_t = \frac{1}{\frac{1}{G_1} + \frac{1}{G_2} + \frac{1}{G_3}}$$

PARALLEL DC CIRCUIT COMPUTATION

The following formulas assume that the source of power has negligible resistance.

1. Total resistance (R_t). The total resistance is the reciprocal of the sum of the reciprocals. It will always be less than the resistance of the smallest parallel resistor.

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots}$$

For resistors of like value:

$$R_t = \frac{\text{value of one resistor}}{\text{number of resistors}}$$

For <u>two</u> parallel resistors:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

2. Total voltage (E_t). The total voltage is applied to each branch of the parallel circuit.

$$E_t = E_1 = E_2 = E_3 = \ldots .$$

3. Total current (I_t). The total current is the sum of the currents in the individual branches. The current flow in each branch is inversely proportional to the resistance of that branch.

$$I_t = I_1 + I_2 + I_3 + \ldots .$$

4. Total power (P_t). The total power dissipated in a parallel circuit is the sum of all power losses in the circuit.

$$P_t = P_1 + P_2 + P_3 + \ldots . .$$

5. Total conductance (G_t).

$$G_t = G_1 + G_2 + G_3 + \ldots .$$

CAPACITANCE

1. The quantity of electricity stored within a capacitor is determined by the potential impressed across the capacitor and the capitance of the capacitor.

$$Q = CE$$

Where: Q = the quantity stored in coulombs

E = the potential impressed across the capacitor in volts

C = capacitance in farads

2. The capacitance of a capacitor is determined by the dielectric constant of the dielectric used, plate area, and distance between the plates.

$$C = 0.0885 \frac{\epsilon S(N-1)}{d}$$

Where: C = capacitance in picofarads

= dielectric constant (see table below)

*S = area of one plate in square centimeters

N = number of plates

*d = thickness of the dielectric in centimeters (same as the distance between the plates)

* When S and d are given in inches, change constant 0.0885 to 0.224. The answer will still be in picofarads.

TABLE of DIELECTRIC CONSTANTS			
Dielectric	ϵ Value*	Dielectric	ϵ Value*
Air	1.0	Mica	6.0
Bakelite	5.0	Paper (paraffin)	3.5
Beeswax	3.0	Porcelain	6.0
Cambric	4.0	Pyrex	4.5
Fibre	5.0	Quartz	5.0
Glass	8.0	Rubber	3.0
*True value depends upon quality of material			

3. The total capacitance (C_t) of capacitors in series is the reciprocal of the sum of the reciprocals. The total capacitance will be less than the value of the smallest capacitor.

$$C_t = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} + \ldots .$$

For series capacitors of like value:

$$C_t = \frac{\text{value of capacitors}}{\text{number of capacitors}}$$

For two series capacitors:

$$C_t = \frac{C_1C_2}{C_1 + C_2}$$

4. The total capacitance (C_t) of capacitors in parallel is the sum of the individual capacitors.

$$C_t = C_1 + C_2 + C_3 \ . \ . \ . \ .$$

SELF INDUCTANCE

A number of factors determine the inductance of a coil, such as the number of turns, ratio of the diameter to length, type of core material used and the method of winding.

1. One common formula for self indictance is as follows:

$$L = \frac{e}{\frac{\Delta i}{\Delta t}} = \frac{\Delta te}{\Delta i}$$

Where L = self inductance in henrys

e = induced voltage in volts (CEMF)

Δi = change in current in amps

Δt = change in time in seconds

2. The formula for the CEMF produced in an inductor is as follows:

$$= \frac{0.4\,\pi\,n^2\,\mu\,A}{l} \quad \frac{\Delta i}{\Delta t} \quad = \frac{-L\,\Delta i}{\Delta t}$$

Where: = counter emf in volts

0.4 = a constant factor which will cause the answer to be in volts

n = number of turns of the coil

μ = permeability

A = area of the cross section of the coil in cm^2.

Δi = change in current

Δt = change in time

l = length of the coil

L = inductance in henrys

3. The total inductance (L_t) of inductors in series is the sum of individual inductances. (Assume zero coupling between inductors).

$$L_t = L_1 + L_2 + L_3 \cdot \cdot \cdot \cdot$$

4. The total inductance of inductors in parallel is the reciprocal of the sum of the reciprocals. The total inductance will always be less than the value of the smallest inductor. (Assume zero coupling between inductors.)

$$L_t = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}}$$

For inductors of like value:

$$L_t = \frac{\text{value of one inductor}}{\text{number of inductors}}$$

For two inductors in parallel:

$$L_t = \frac{L_1 L_2}{L_1 + L_2}$$

COUPLED INDUCTANCE

When the magnetic field of an inductor interacts with the field of another inductor in the circuit the inductance will be changed as indicated by the following formulas.

1. Inductors in series with aiding fields:

$$L_a = L_1 + L_2 + 2M$$

Where L_a = total inductance with aiding fields

M = mutual inductance

2. Inductors n series with opposing fields:

$$L_o = L_1 + L_2 - 2M$$

Where L_o = total inductance with opposing fields

M = mutual inductance

3. Inductors in parallel with fields aiding:

$$L_a = \frac{1}{\frac{1}{L_1 + M} + \frac{1}{L_2 + M}}$$

Where L_a = total inductance with fields aiding

M = mutual inductance

4. Inductors in parallel with fields opposing:

$$L_o = \frac{1}{\frac{1}{L_1 - M} + \frac{1}{L_2 - M}}$$

Where L_o = total inductance with fields opposing

M = mutual inductance

MUTUAL INDUCTANCE

The amount of mutual inductance present in a circuit depends on the amount of inductance in each coil and the coupling between them.

$$M = K \sqrt{L_1 \times L_2}$$

Where M = mutual inductance in henrys.

K = coefficient of coupling expressed as a decimal factor.

L_1 = inductance of the primary in henrys.

L_2 = inductance of the secondary in henrys.

ALTERNATING CURRENT GENERATION

1. The voltage generated in a generator winding may be found by using the following formula:

$$E_{ave} = \frac{N\phi}{t} \times 10^{-8}$$

Where E_{ave} = average induced voltage

N = number of turns in the coil

ϕ = change of flux in maxwells

t = change of time increments in seconds

2. The instantaneous induced voltage during the generation of a sine wave is determined by the following formula:

$$e = E_{max} (\sin \theta)$$

Where e = The instantaneous value of the induced voltage

E_{max} = the maximum induced voltage

θ = the instantaneous angular displacement of the rotating vector

3. The maximum generated current is directly proportional to the generated voltage and inversely proportional to the load resistance.

$$I_{max} = \frac{E_{max}}{R}$$

Where I_{max} = maximum generated current

E_{max} = maximum generated voltage

R = load resistance

4. The instantaneous currents can be calculated using the following formula:

$$i = I_{max} (\sin \theta)$$

Where i = the instantaneous value of the current

I_{max} = maximum generated current

θ = the instantaneous angular displacement of the rotating vector

5. The frequency of an alternator output can be determined by the following formula:

$$f = \frac{PS}{120}$$

Where f = frequency in Hertz

P = the number of generator poles

S = the speed in RPM

6. The period of a sine wave is the reciprocal of its frequency.

$$T = \frac{1}{f}$$

Where T = period in seconds

f = frequency in Hertz

7. To determine phase angle, the following equation is used:

$$\frac{\theta}{360°} = \frac{t}{T} \qquad \text{OR} \qquad \theta = 360° \, tf$$

Where θ = angle in degrees

t = given amount of time in seconds

f = frequency in Hertz

T = period of the wave in seconds

8. Circular velocity such as that of an armature of an alternator is called angular velocity and is symbolized by the Greek letter omega It is determined by the following formula

$$\omega = 2\pi f$$

Where ω = angular velocity in radians per second

f = frequency in Hertz

2π = 6.28 radians, which equals 360°

REACTANCE

1. The inductive reactance of an inductor is determined by the following formula:

$$X_L = 2\pi fL$$

Where X_L = inductive reactance in ohms

f = frequency in Hertz

L = inductance in henrys

2. The capacitive reactance of a capacitor is determined by the following formula. Note that an increase in frequency or capacitance will result in a lower X_C.

$$X_C = \frac{1}{2\pi fC} = \frac{0.159}{fC}$$

Where X_C = capacitive reactance in ohms

f = frequency in Hertz

C = capacitance in farads

RESONANCE

1. To determine the resonant frequency of a given inductance and capacitance combination the following formula is used:

$$f_r = \frac{1}{2\pi\sqrt{LC}} = \frac{0.159}{\sqrt{LC}}$$

Where f_r = resonant frequency in Hertz

L = inductance in henrys

C = capacitance in farads

2. To determine the value of an inductor needed to produce a known resonant frequency with a given capacitor, the following formula is used:

$$L = \frac{1}{4\pi^2 f_r^2 C}$$

Where L = inductance in henrys

f_r = resonant frequency desired in Hertz

C = capacitance in farads

3. To determine the value of a capacitor needed to provide a known resonant frequency with a given inductor, the following formula is used:

$$C = \frac{1}{4\pi^2 f_r^2 L}$$

Where C = capacitance in farads

f_r = resonant frequency desired in Hertz

L = inductance in henrys

AC CIRCUIT COMPUTATION

Impedance is the total opposition in an AC circuit. In an AC circuit that is purely resistive, the Z is equal to the total resistance. This is also true when the AC circuit is resonant. However, when an AC circuit is either inductive or capacitive, the computation is more involved.

1. The impedance of a series AC inductive circuit can be determined by the following formula:

$$Z = \sqrt{X_L^2 + R_t^2}$$

Where Z = impedance in ohms

X_L = inductive reactance in ohms

R_t = total circuit resistance in ohms

2. Impedance of a series capacitive circuit can be determined by the following formula:

$$Z = \sqrt{X_C^2 + R_t^2}$$

Where Z = impedance in ohms

X_C = capacitive reactnce in ohms

R_t = total circuit resistance in ohms

3. Impedance of a series ciruit containing resistance, inductance and capacitance can be determined by the following formula:

$$Z = \sqrt{R_t^2 + (X_C - X_L)^2}$$

Where Z = impedance in ohms

X_L = inductive reactance in ohms

X_C = capacitive reactance in ohms

4. The voltage drop across any component in a series AC circuit is the product of the current and resistance, or reactance, of that component.

$$E_R = IR$$
$$E_C = IX_C$$
$$E_L = IX_L$$

Where E_R = voltage drop across a resistor

E_C = voltage drop across a capacitor

E_L = voltage drop across an inductor

5. The applied voltage of a series AC circuit may be computed in the same manner as the impedance.

$$E_a = \sqrt{E_R^2 + (E_C - E_L)^2}$$

Where E_a = applied voltage

E_R = voltage drop across the resistor

E_L = voltage drop across the inductor

E_C = voltage drop across the capacitor

6. The current of a series AC circuit is the same at all points in the series circuit.

$$I_t = I_R = I_L = I_C$$

Where I_t = total current in amps

I_R = current through resistor in amps

I_L = current through inductor in amps

I_C = current through capacitor in amps

7. The current of a series AC circuit can be determined by using Ohm's law for Ac circuits.

$$I = \frac{E_a}{Z}$$

Where I = current flow in amps

E_a = applied voltage in volts

Z = impedance of the series AC circuit in ohms

8. The voltage of a parallel AC circuit is the same across each branch and is equal to the applied voltage.

$$E_a = E_R = E_L = E_C$$

Where E_a = applied voltage

E_R = voltage across the resistor

E_L = voltage across the inductor

E_C = voltage across the capacitor

9. The current flow in each branch of a parallel AC circuit is proportional to the R, X_L or X_C of that branch.

$$I_R = \frac{E}{R}$$

$$I_L = \frac{E}{X_L}$$

$$I_C = \frac{E}{X_C}$$

Where I_R = current in resistive branch in amps

I_L = current in inductive branch in amps

I_C = current in capacitive branch in amps

E = voltage across the parallel branch

10. The total current of a parallel AC circuit can be found using the Pythagorean theorem as indicated below.

$$I_t = \sqrt{I_R^2 + (I_C - I_L)^2}$$

Where I_t = total current in amps

I_R = current through the resistor in amps

I_C = current of capacitor in amps

I_L = current through inductor in amps

11. The impedance of a parallel AC circuit can be found by using Ohm's law for a AC circuit.

$$Z = \frac{E_a}{I_t}$$

Where Z = impedance in ohms

E_a = applied voltage in volts

I_t = total current in amps

12. The plane angle is the angle, expressed in degrees, by which the current lags the voltage in an inductive circuit, or leads the voltage in a capacitive circuit. In a purely theoretical circuit, current leads or lags by 90°.

In a pure resistive circuit, $\theta = 0°$
In a pure reactive circuit, $\theta = 90°$
(capacitive) $\theta = -90°$
(inductive) $\theta = +90°$

In a resonant circuit, $\theta = 0°$

The phase angle is equal to the angle whose tangent is:

For series circuit, $\theta = \text{arc tan } \frac{X}{R}$

For parallel circuit, $\theta = \text{arc tan } \frac{R}{X}$

Where θ = phase angle in degrees

X = reactance in ohms

R = resistance in ohms

arc tan = the angle whose tangent is

13. Voltage phase angle is the angle, expressed in degrees, that the output voltage of a circuit varies in phase with respect to the input voltage.

$$E\theta = \frac{Z_{out}\,\theta}{Z_{tot}\,\theta}$$

Where $E\theta$ = phase of the output voltage

$Z_{out}\,\theta$ = phase angle across the output impedance

$Z_{tot}\,\theta$ = phase angle across the total impednce of the circuit.

14. The apparent power in an AC circuit is obtained by multiplying the effective value of voltage and current in a reactive circuit, and is expressed in terms of volt-amperes.

$$P_a = EI$$

Since $E = IZ$ in an RC or RL circuit

$$P_a = I^2Z$$

Where P_a = apparent power in volt-amperes

E = voltage in volts

I = current in amperes

Z = impedance in ohms

15. True power is the actual amount of power consumed by the resistive circuit elements in an AC circuit, and is expressed in terms of watts. The power expended in a circuit may be found by using any of the following formulas.

$$P_t = I^2R$$

$$P_t = E_RI$$

$$P_t = EI\,pf$$

Where P_t = true or active power in watts

I = current in amperes

R = resistance in ohms

E_R = voltage across the resistance

E = voltage in volts

pf = power factor

16. The power factor is the ratio of true power to apparent power in a reactive resistave circuit. It is an expression of the lead or lag as represented by the cosine of the phase angle.

$$\text{power factor} = \frac{\text{true power}}{\text{apparent power}}$$

$$pf = \frac{P_t}{P_a} = \frac{I^2R}{I^2Z} = \frac{R}{Z} = \cos$$

Where pf = power factor

P_t = true power in watts

P_a = apparent power in volt-amperes

I = current in amperes

R = resistance in ohms

Z = impedance in ohms

cos = cosine angle theta

17. The figure of merit, or quality factor (Q) of a component is a measure of its energy storing ability. It is the ratio of reactance for a reactive component or a circuit containing a reactive component to resistance.

a. For an inductor and resistance in series the formula is:

$$Q = \frac{X_L}{R_s}$$

Where Q = quality factor

X_L = inductive reactance in ohms

R^S = series resistance in ohms

b. For a capacitor and resistance in series the formula is:

$$Q = \frac{X_C}{R_s}$$

Where Q = quality quality factor

X_C = capacitive reactance in ohms

R_s = series resistance in ohms

c. For an inductor and resistance in parallel the formula is:

$$Q = \frac{R_p}{X_L}$$

Where Q = quality factor

X_L = inductive reactance in ohms

R_p = parallel resistance in ohms. This value is relatively high. Remember that any additional resistance in parallel will lower the Q.

d. For a capacitor and resistance in parallel the formula is:

$$Q = \frac{R_p}{X_C}$$

Where Q = quality factor

X_C = capacitive reactance in ohms

R_p = parallel resistance in ohms. This value is relatively high. Remember that any additional parallel resistance will lower the Q.

e. For a series resonant circuit the Q of the circuit expressed at the resonant frequency is:

$$Q = \frac{X_L \text{ or } X_C}{R_{t_s}}$$

Where Q = quality factor

X_L = inductive reactance in ohms

X_C = capacitive reactance in ohms

R_{t_s} = total effective series resistance in ohms

f. For a parallel resonant circuit the Q of the circuit expressed at the resonant frequency is:

$$Q = \frac{R_{t_p}}{X_L}$$

Where Q = quality factor

X_L = inductive reactance in ohms

R_{t_p} = total effective parallel resistance in ohms

18. The Q of an inductor, or a capacitor, can be <u>decreased</u> by adding series resistance to the series resistance that the inductor or capacitor possesses by reason of its design. The total value of resistance needed can be found using the following formulas.

$$R_t = \frac{X_L}{Q_L} \qquad R_t = \frac{X_C}{Q_C}$$

Where R_t = total resistance needed to achieve desired Q

X_L = inductive reactance in ohms

X_C = capacitive reactance in ohms

Q_L = desired Q value of the inductor

Q_C = desired Q value of the capacitor

19. The Q of an inductor, tank circuit, or capacitor can be lowered by adding parallel resistance. In order to ascertain the value of parallel resistance needed to obtain the desired new Q, three operations are performed as follows.

a. Find the total value of parallel resistance needed to lower the Q to the desired value.

$$R_t = Q_L X_L \qquad R_t = Q_C X_C$$

Where R_t = total parallel resistance needed to produce the desired Q

X_L = inductive reactance in ohms

X_C = capacitive reactance in ohms

Q_L = quality of the inductive circuit desired

Q_C = quality of the capacitive circuit desired

b. Determine the value of parallel equivalent resistance.

$$R_E = Q_L X_L \qquad\qquad R_E = Q_C X_C$$

Where R_E = parallel equivalent resistance

X_L = inductive reactance in ohms

X_C = capacitive reactance in ohms

Q_L = quality of inductor that now exists

Q_C = quality of capacitor that now exists

c. Find the actual value of parallel resistance needed.

$$R_P = \frac{1}{\frac{1}{R_t} + \frac{1}{R_E}}$$

Where R_p = actual parallel resistance needed

R_t = total resistance

R_E = Parallel equivalent resistance

20. The dissipation factor (D) of a capacitor or inductor can be determined by the following formulas:

$$D = \frac{R}{X_C} = \frac{1}{Q}$$

$$D_L = \frac{R}{X_L} = \frac{1}{Q}$$

Where D = dissipation factor of a capacitor

D_L = dissipation factor of an inductor

X_C = capacitive reactance in ohms

Q = quality factor of inductor or capacitor

21. For solution of complex RC or RL circuits, each branch can be treated as a separate circuit in order to calculate the Z for each. The total impedance can then be determined by the following formula.

NOTE: Total impedance must be in rectangular notation.

$$Z_t = \frac{1}{\frac{1}{Z_{B1}} + \frac{1}{Z_{B2}} + \frac{1}{Z_{B3}}}$$

$$Z_t = \frac{Z_{B1}\ Z_{B2}\ Z_{B3}}{Z_{B1}\ (Z_{B2} + Z_{B3})\ +\ Z_{B2}Z_{B3}}$$

Where Z_t = total impedance in ohms

Z_{B1} = impedance of branch one

Z_{B2} = impedance of branch two

Z_{B3} = impedance of branch three

22. In order to compute the total current of a complex RC or RL circuit, the current of each branch is computed and the branch currents are then added.

$$I_t = I_{B1} + I_{B2} + I_{B3}$$

Where I_t = total current

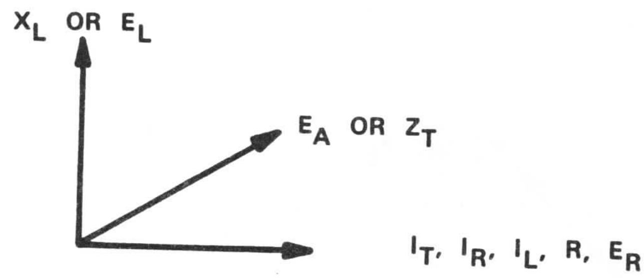
I_{B1} = current of branch one

I_{B2} = current of branch two

I_{B3} = current of branch three

SERIES AC CIRCUIT VECTORS

1. SERIES RL CIRCUITS

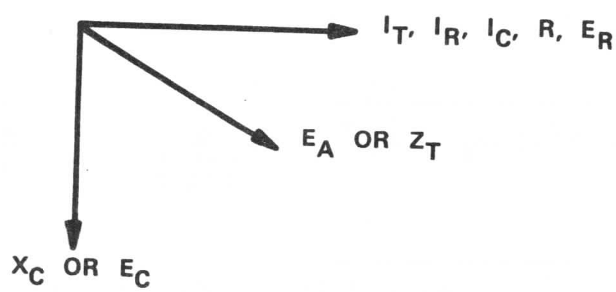


$$Z_T = \sqrt{R^2 + X_L^2} = \frac{R}{\cos\theta} = \frac{X_L}{\sin\theta}$$

$$E_Z = \sqrt{E_R^2 + E_L^2} = \frac{E_R}{\cos\theta} = \frac{E_L}{\sin\theta}$$

$$\theta = \text{INV (ARC) TAN } \frac{E_L}{E_R} = \text{INV (ARC) TAN } \frac{X_L}{R}$$

2. SERIES RC CIRCUITS



$$Z_T = \sqrt{R^2 + X_C^2} = \frac{R}{\cos\theta} = \frac{X_C}{\sin\theta}$$

$$E_A = \sqrt{E_R^2 + E_C^2} = \frac{E_R}{\cos\theta} = \frac{E_C}{\sin\theta}$$

$$\theta = \text{INV (ARC) TAN } \frac{E_C}{E_R} = \text{INV (ARC) TAN } \frac{X_C}{R}$$

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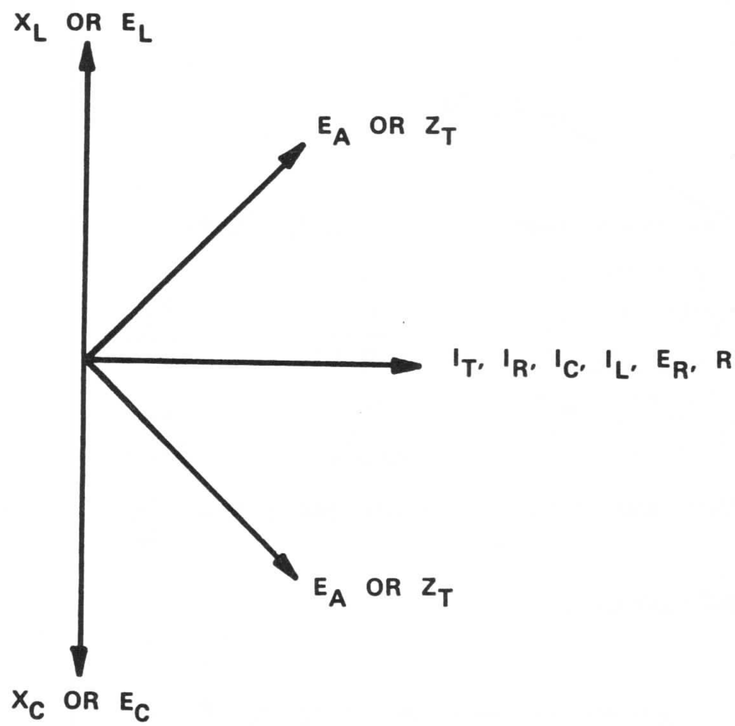
3. SERIES RCL CIRCUITS



$$Z_T = \sqrt{R^2 + (X_L - X_C)^2} = \frac{R}{\text{COS } \theta} = \frac{X_L - X_C}{\text{SIN } \theta}$$

$$E_A = \sqrt{E_R^{\,2} + (E_L - E_C)^2} = \frac{E_R}{\text{COS } \theta} = \frac{E_L - E_C}{\text{SIN } \theta}$$

$$\theta = \text{INV (ARC) TAN } \frac{E_L - E_C}{E_R} = \text{INV (ARC) TAN } \frac{X_L - X_C}{R}$$

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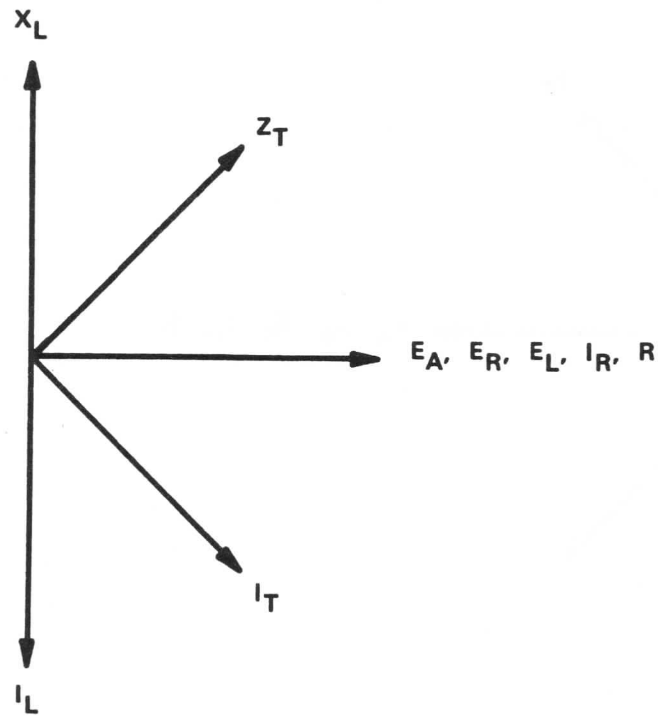
PARALLEL AC CIRCUIT VECTORS

1. PARALLEL RL CIRCUITS



$$Z_T = \frac{E_A}{I_T}$$

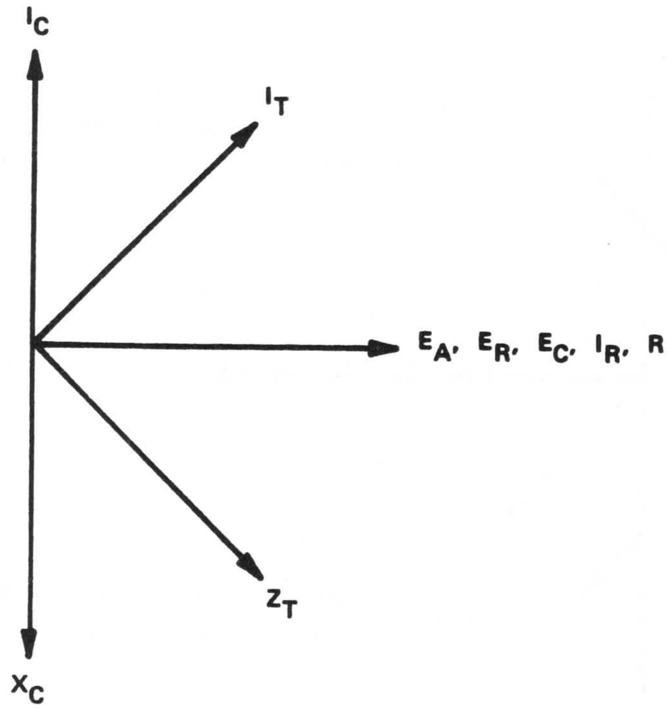
$$I_T = \sqrt{I_R^2 + I_L^2} = \frac{I_R}{\text{COS } \theta} = \frac{I_L}{\text{SIN } \theta}$$

$$\theta = \text{INV (ARC) TAN } \frac{I_L}{I_R} = \text{INV (ARC) TAN } \frac{R}{X_L}$$

NOTE: THE PHASE ANGLE OF Z_T WILL ALWAYS BE THE SAME NUMERICAL VALUE AS I_T BUT OPPOSITE IN POLARITY.

26053

2. Parallel RC Circuits



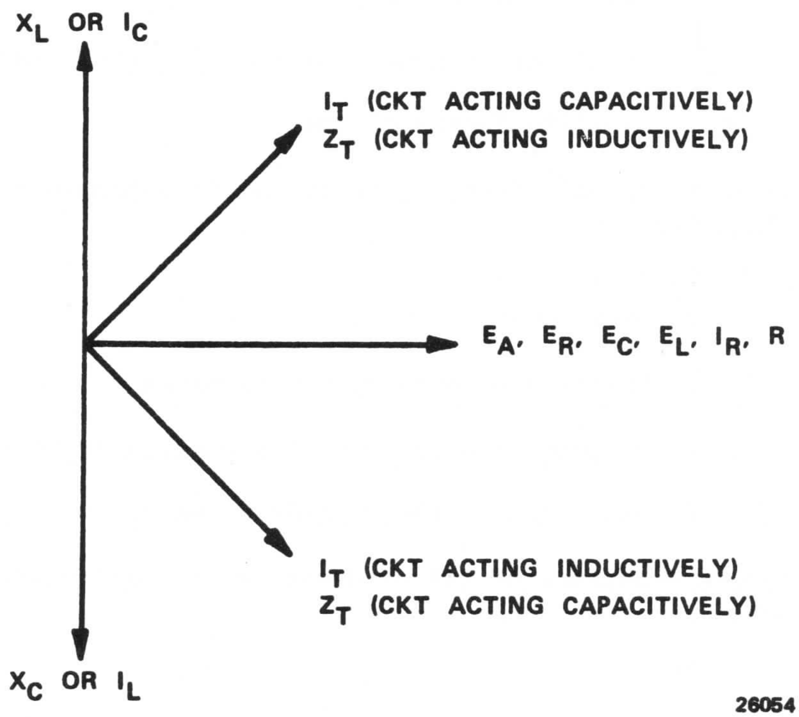
$$Z_T = \frac{E_A}{I_T}$$

$$I_T = I_R^2 + I_C^2 = \frac{I_R}{\cos\theta} = \frac{I_C}{\sin\theta}$$

$$= \text{INV (ARC) TAN } \frac{I_C}{I_R} = \text{INV (ARC) TAN } \frac{R}{X_C}$$

NOTE: The Phase angle of Z_T will always be the same numerical value as I_T but opposite in polarity.

3. Parallel RCL Circuits



$$Z_T = \frac{E_A}{I_T}$$

$$I_T = \sqrt{I_R^2 + (I_C - I_L)^2} = \frac{I_R}{\cos\theta} = \frac{I_C - I_L}{\sin\theta}$$

$$= \text{INV (ARC) TAN } \frac{I_C - I_L}{I_R}$$

NOTE: The Phase Angle of Z_T will always be the same numerical value as I_T but opposite in polarity.

BANDWIDTH

1. The bandwidth (Δf) of a circuit is largely dependent on the Q of that circuit. This is shown in the following formula:

$$\Delta f = \frac{f_r}{Q}$$

Where Δf = bandwidth in Hertz

f_r = resonant frequency of the circuit in Hertz

Q = quality factor of the circuit

2. The lowest frequency of the bandpass can be determined by the use of the following formula:

$$f_1 = f_r - \frac{\Delta f}{2}$$

Where f_1 = lowest frequency of the bandpass

f_r = resonant frequency of the circuit in Hertz

Δf = bandwidth of the circuit in Hertz

3. The highest frequency of the bandpass can be determined using the following formula:

$$f_2 = f_r + \frac{\Delta f}{2}$$

Where f_2 = highest frequency of the bandpass

f_r = resonant frequency of the circuit in Hertz

Δf = bandwidth of the circuit in Hertz

TRANSFORMERS

1. The relationship between voltage, current, and number of turns is shown in the following formulas:

$$\frac{E_p}{E_s} = \frac{I_s}{I_p} = \frac{N_p}{N_s}$$

Where E_p = voltage of the primary

E_s = voltage of the secondary

I_p = current of the primary

I_s = current of the secondary

N_p = number of turns of the primary

N_s = number of turns of the secondary

2. The power relationship between the primary and secondary circuit in a ideal transformer is shown as follows:

$$P_p = P_s \quad \text{or} \quad E_p I_p = E_s I_s$$

Where P_p = power of the primary

P_s = power of the secondary

E_p = voltage of the primary

E_s = voltage of the secondary

I_p = current of the primary

I_s = current of the secondary

3. The relationship between impedance and the number of turns is shown by the following equation.

$$\frac{Z_p}{Z_s} = \left(\frac{N_p}{N_s}\right)^2$$

Where Z_p = impedance of the primary

Z_s = impedance of the secondary

N_p = number of turns of the primary

N_s = number of turns of the secondary

4. The relationship between the primary and secondary voltages, currents and impedances are shown in the following equation.

$$\frac{Z_p}{Z_s} = \left(\frac{E_p}{E_s}\right)^2 = \left(\frac{I_s}{I_p}\right)^2$$

Where Z_p = impedance of the primary

Z_s = impedance of the secondary

E_p = voltage of the primary

E_s = voltage of the secondary

I_p = current of the primary

I_s = current of the secondary

5. The impedance reflection from the secondary to the primary can be determined using the following formula.

$$Z_r = \frac{-Z_m^2}{Z_2 + Z_s}$$

Where Z_r = reflection impedance

Z_m = mutual impedance

Z_2 = impedance in series with the secondary

Z_s = impedance of the secondary winding

6. The total impedance when looking into the primary of a transformer may be found using the following formula:

$$Z_t = Z_1 + Z_p - \frac{Z_m^2}{Z_2 + Z_s}$$

Where Z_t = total impedance when looking into the primary

Z_1 = impedance in series with the primary winding

Z_p = impednce of the primary winding

Z_m = mutual impedance

Z_2 = impedance in series with the secondary winding

Z_s = impedance of the secondary winding

7. The voltage induced in a stator leg of a synchro from a rotor:

$$E_{ind} = E_{max} \cos \theta$$

Where E_{ind} = voltage induced in the stator leg

E_{max} = maximum voltage that can be induced in the stator leg for that input

cos = cosine of the angle between the rotor and stator

RC TIME CONSTANTS

1. The time of one time constant in an RC circuit is found by using the following formula:

$$TC = RC$$

Where TC = time for one time constant

R = resistance in ohms

C = capacitance in farads

2. The number of time constants per any given time must often be known before we can ascertain what effect the RC circuit will have on an input waveform. If an RC circuit has a time constant at least ten times longer than the period of the input, it is said to have a long time constant. The number of time constants per a given time can be found by using the following formula:

$$\text{Number of time constants} = \frac{t}{RC}$$

Where t = any given time in seconds

R = resistance in ohms

C = capacitance in farads

3. The voltage across a capacitor in an RC circuit at a given instant can be determined roughly with the Universal Time Constant Chart. It can be determined more accuractely by using the following equation.

$$e_C = E_a \left(1 - \epsilon^{\left(\frac{-t}{RC}\right)}\right)$$

Where e_C = instantaneous capacitor voltage

E_a = applied voltage

t = time in seconds

R = resistance of the RC circuit in ohms

C = capacitance in farads of the RC circuit

ϵ = the base of natural logarithms, 2.718

4. The voltage across a resistor in an RC circuit at a given instant can be determined roughly with the Universal Time Constant Chart. It can be determined more accurately by using the following formula.

$$e_r = E_a \left(\epsilon^{\left(\frac{-t}{RC}\right)}\right)$$

Where e_r = instantaneous resistor voltage

E_a = applied voltage

t = time in seconds

R = resistance in ohms

C = capacitance in farads

ϵ = the base of natural logarithms, 2.718

5. If e_c or e_r, and the applied voltage of an RC circuit are known, the unknown parameter can be readily determined using the formulas:

$$e_c = E_a - e_r$$

$$e_r = E_a - e_c$$

Where e_c = instantaneous capacitor voltage

e_r = instantaneous resistor voltage

E_a = applied voltage

6. The instantaneous charge current in an RC curcuit can be found by the following formula:

$$i = \frac{E_a}{R}\left(\epsilon\left(\frac{-t}{RC}\right)\right)$$

Where i = instantaneous charge current in amps

E_a = applied voltage in volts

R = resistance in ohms

t = time in seconds

C = capacitance in farads

ϵ = the base of natural logarithms, 2.718

7. The discharge of a capacitor, through a resistor, follows the same exponential curve as the charge through a resistor. The following formula can be used to determine the instantaneous voltage across a resistor during discharge.

$$e_r = E_C \left(\epsilon^{\left(\frac{-t}{RC}\right)} \right)$$

where e_r = instantaneous voltage across a resistor

E_C = voltage of the capacitor

t = time in seconds

R = resistance in ohms

C = capacitance in farads

ϵ = the base of natural logarithms, 2.718

RL TIME CONSTANTS

1. The time of one time constant in an RL circuit is found by using the following formula.

$$TC = \frac{L}{R}$$

Where TC = time for one time constant

L = inductance in henrys

R = resistance in ohms

2. The number of time constants per any given time can be determined by using the following formula:

$$\text{number of time constants} = \frac{-tR}{L}$$

where t = any given time in seconds

L = inductance in henrys

R = resistance in ohms

3. The voltage across the inductor in an LR circuit at a given time may be found by using the following formula:

$$e_L = E_a \left(\epsilon^{\left(\frac{-Rt}{L}\right)} \right)$$

Where e_L = instantaneous inductor voltage

E_a = applied voltage

R = resistance in ohms

t = time in seconds

L = inductance in henrys

ϵ = the base of natural logarithms, 2.718

4. The voltage across a resistor in an LR circuit at a given instant can be determined roughly with the Universal Time Constant Chart. It can be determined more accurately by using the following equation.

$$e_r = E_a \left(1 - \epsilon^{\left(\frac{-Rt}{L}\right)} \right)$$

Where e_r = instantaneous resistor voltage

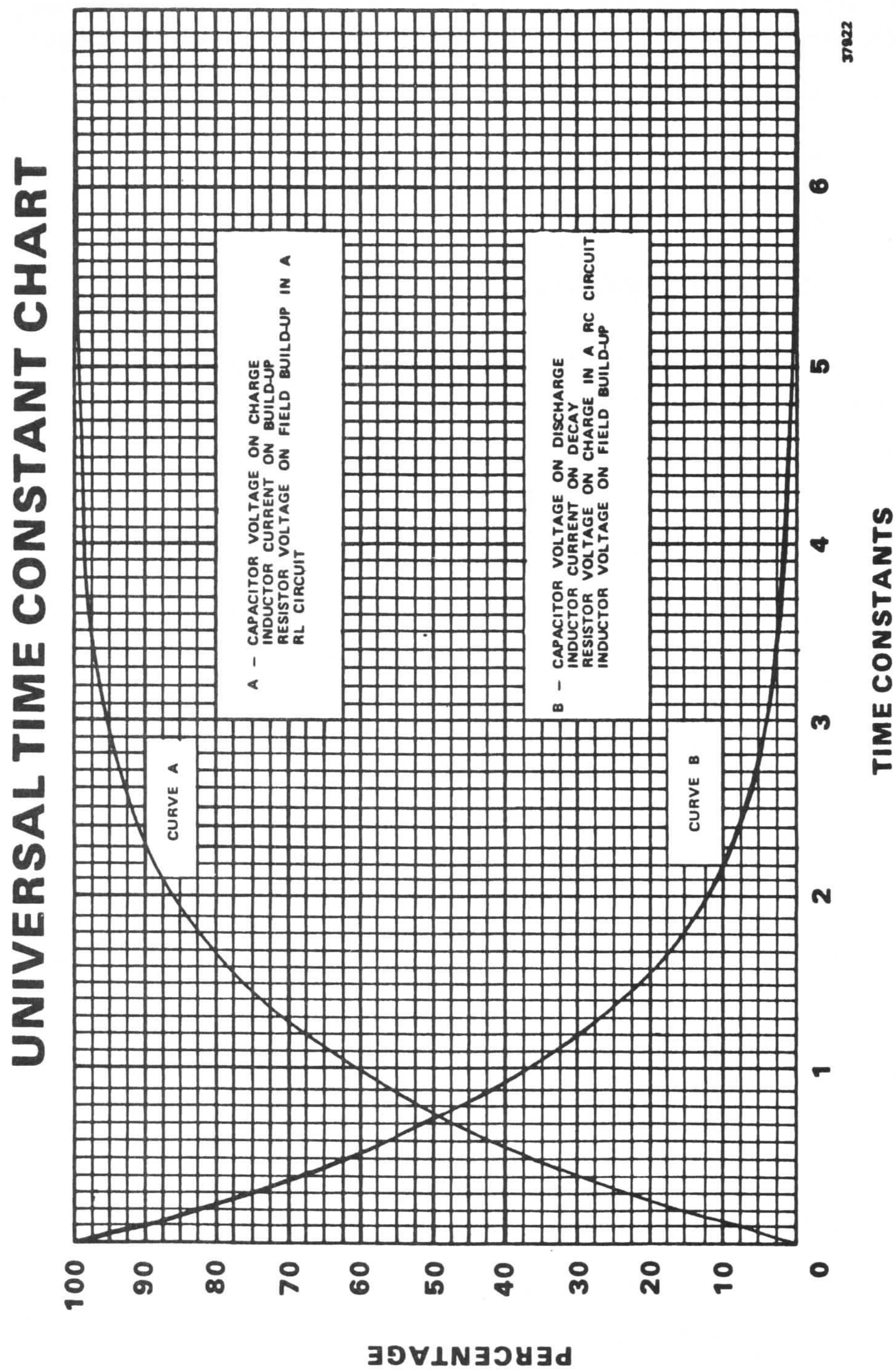
E_a = applied voltage

R = resistance in ohms

t = time in seconds

L = inductance in henrys

ϵ = the base of natural logarithms, 2.718



UNIVERSAL TIME CONSTANT CHART
CURVE A
CURVE B
A – CAPACITOR VOLTAGE ON CHARGE
INDUCTOR CURRENT ON BUILD-UP
RESISTOR VOLTAGE ON FIELD BUILD-UP IN A RL CIRCUIT
B – CAPACITOR VOLTAGE ON DISCHARGE
INDUCTOR CURRENT ON DECAY
RESISTOR VOLTAGE ON CHARGE IN A RC CIRCUIT
INDUCTOR VOLTAGE ON FIELD BUILD-UP
PERCENTAGE
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
TIME CONSTANTS
37922

5. If e_L or e_r and the applied voltage of a RL circuit is known, the unknown parameter can be determined by using the following formulas:

$$e_L = E_a - e_r \qquad\qquad e_r = E_a - e_L$$

e_L = the instantaneous inductor voltage

e_r = the instantaneous resistor voltage

E_a = the applied voltage

6. The instantaneous charge current in an LR circuit can be found by the following formula.

$$i = \frac{E_a}{R}\left(1 - \epsilon^{\left(\frac{-tR}{L}\right)}\right)$$

Where i = instantaneous charge current in amps

E_a = applied voltage

R = resistance in ohms

t = time in seconds

L = inductance in henrys

ϵ = the base of natural logarithms, 2.718

POWER SUPPLIES

1. The percentage of ripple can be determined by the formula:

$$\text{percentage of ripple} = \frac{E_{rms} \times 100}{E_o}$$

Where E_{rms} = rms value of the ripple in volts

E_o = DC output of the power supply in volts

2. The percentage of regulation can be determined using the equation:

$$E_{reg} = \frac{E_{NL} - E_{FL}}{E_{FL}} \times 100$$

E_{reg} = percentage of regulation

E_{NL} = no load voltage

E_{FL} = full load voltage

ELECTRON TUBES

1. The following formula is used to compute the DC resistance of a diode.

$$R_p = \frac{E_p}{I_p}$$

Where R_p = DC resistance in ohms

E_p = the potential between plate and cathode in volts

I_p = the plate current in amps

2. The AC plate resistance is the opposition offered to the flow of alternating current by an electron tube. It can be determined by using the following formula:

$$r_p = \frac{\Delta e_p}{\Delta i_p} \quad (E_g \text{ constant})$$

Where r_p = Ac plate resistnce in ohms

e_p = the change in instantaneous voltage at the plate

i_p = the change in instantaneous current through the tube

3. The amplification factor can be determined by using the following formula:

$$\mu = \frac{\Delta e_p}{\Delta e_g} \quad (I_p \text{ constant})$$

Where μ = amplification factor

e_p = the potential between the plate and cathode in volts

e_g = grid voltage in volts

Δ = a change of

4. Transconductance is a term used to express the ratio of the change in current in one electrode to the change in voltage of another electrode while other voltages are constant. It can be found using the following formula:

$$g_m = \frac{\Delta i_p}{\Delta e_g} \quad (E_p \text{ constant})$$

Where g_m = transconductance in mhos

i_p = plate current in amps

e_g = grid voltage in volts

Δ = a change of

5. The following formulas express the relationship between three dynamic characteristics of electron tubes.

$$g_m = \frac{\mu}{r_p}$$

$$\mu = g_m r_p$$

$$r_p = \frac{\mu}{g_m}$$

Where g_m = transconductance in mhos

μ = (mu) amplification factor

r_p = AC plate resistance in ohms

AMPLIFIERS

1. The voltage gain of an amplifier can be defined as the ratio of output voltage to input voltage, as indicated in the following formula:

$$A = \frac{e_o}{e_g}$$

$$A = \frac{e_o}{e_i}$$

Where A = voltage gain of the amplifier

e_o = output voltage

e_i = input voltage

e_g = grid voltage

2. Since the voltage gain of an amplifier is the ratio of the output to the input, and the input was the grid voltage (e_g), the following formula can be used to determine gain.

$$A = \frac{\mu Z_L}{r_p + Z_L}$$

Where A = voltage gain of an amplifier

μ = amplification factor

Z_L = impedance of the load

r_p = AC plate resistance

3. The voltage or current gain of an amplifier in decibels can be computed by using the following formulas. These formulas assume that the input resistance and the output resistance are the same.

$$dB = 20 \log \frac{E_o}{E_{in}}$$

$$dB = 20 \log \frac{I_o}{I_{in}}$$

Where dB = voltage or current gain in decibels

log = logarithm to the base 10

E_o = output power

E_{in} = input power

I_o = output current

I_{in} = input current

4. The power gain of an amplifier in decibels may be determined by using the following formula. This formula assumes that the input resistance and the output resistance are the same.

$$dB = 10 \log \frac{P_o}{P_{in}}$$

Where dB = power gain in decibels

log = logarithm to the base 10

P_o = output power

P_{in} = input power

5. The power gain of an amplifier in decibels may be determined by using the following formula, even though, the input and output resistance are not the same.

$$dB = 10 \log \frac{\dfrac{E_o^2}{R_o}}{\dfrac{E_{in}^2}{R_{in}}}$$

Where dB = power gain in decibels

log = logarithm to the base 10

E_o = output voltage

R_o = output resistance

E_{in} = input voltage

R_{in} = input resistance

6. The total voltage gain of amplifier stages in cascade can be found by the following formula.

$$A_t = A_1 A_2 A_3$$

Where A_t = total gain of the stages

A_1 = first stage

A_2 = second stage

A_3 = third stage

7. The formula for the equivalent resistance of the constant current equivalent circuit at mid-frequencies is as follows:

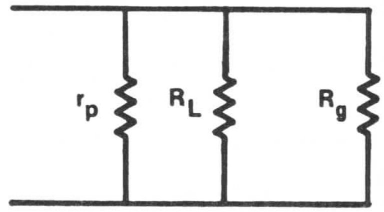
$$R_{eq} = \frac{1}{\dfrac{1}{r_p} + \dfrac{1}{R_L} + \dfrac{1}{R_g}}$$

Where R_{eq} = the equivalent resistance of the constant current equivalent circuit at mid-frequencies

r_p = AC plate resistance in ohms for stage V_1

R_L = plate load resistor in ohms for stage V_1

R_g = grid resistance in ohms for stage V_2



MID FREQUENCY EQUIVALENT CIRCUIT (CONSTANT CURRENT)

8. The formula for gain at mid frequencies is as follows:

$$A_m = g_m R_{eq}$$

Where A_m = mid frequency gain

g_m = transconductance of V_1

R_{eq} = equivalent resistance of the constant current equivalent circuit at mid frequencies

9. The formula for determining the Miller effect capacitance for high frequency consideration is as follows:

$$C_m = C_{gp} (A_m + 1)$$

Where C_m = Miller capacitance

A_m = mid frequency gain

C_{gp} = capacitance between grid and plate of V_1

10. The input or looking in capacitance of V_1 can be determined by use of the formula shown below. This represents the shunt capacitance (C_s) of a single stage amplifier.

$$C_{in} = C_w + C_{gk} + C_{gp} (A_m + 1)$$

Where C_{in} = input capacitance of V_1 or shunt capacitance (C_s)

C_w = wiring capacitance

C_{gk} = capacitance between grid and cathode of V_1

$C_{gp} (A_m + 1)$ = Miller capacitance of V_1

11. The total shunt capacitance of a two stage amplifier can be determined by the use of the following formula:

$$C_s = C_{pk} + C_{gk} + C_{gp}(A_m + 1) + C_w$$

Where C_s = total shunt capacitance of a two stage amplifier

C_{pk} = plate to cathode capacitance of V_1

C_{gk} = grid to cathode capacitance of V_2

$C_{gp}(A_m + 1)$ = Miller cpacitance of V_2

C_w = Wiring capacitance of the circuit. This can be dropped if not given.

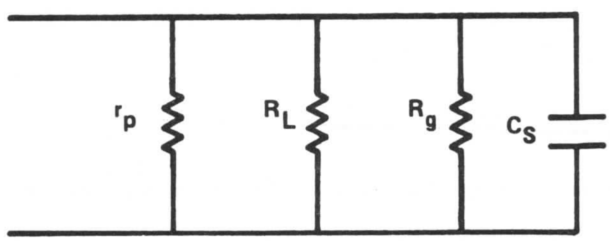
12. The frequency at the upper half power point can be determined by the following formula:

$$f_h = \frac{0.159}{(r_{eq})(C_s)}$$

Where f_h = frequency at upper half power point

R_{eq} = equivalent resistance of constant current equivalent circuit at mid freauency

C_s = total shunt capacitance of the amplifier used



HIGH FREQUENCY EQUIVALENT CIRCUIT (CONSTANT CURRENT)

13. The gain at the upper half power point can be determined by the following formula:

$$A_h = (A_m)(0.707)$$

Where A_h = gain at the upper half power point

A_m = mid frequency gain

14. The formula used to determine the equivalent resistance of the constant voltage equivalent circuit at low frequency is as shown below.

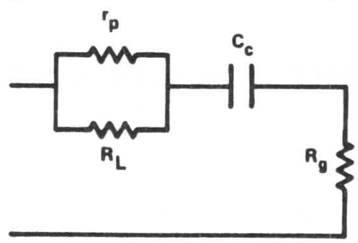
$$R_{eq}' = \frac{R_g + r_p R_L}{r_p + R_L}$$

Where R_{eq}' = equivalent resistance of the constant voltage equivalent circuit at low frequency

r_p = AC plate resistance in ohms for stage V_1

R_L = plate load resistance in ohms for stage V_1

R_g = grid resistor in ohms for stage V_2



LOW FREQUENCY EQUIVALENT CIRCUIT (CONSTANT VOLTAGE)

$R_{eq}' = R_g$ if $\frac{r_p R_L}{r_p + R_L}$ is less than 10% of R_g

15. The frequency at the lower half power point can be determined by the following formula:

$$f_L = \frac{0.159}{R_{eq}' C_c}$$

Where f_L = frequency at the lower half power point

R_{eq}' = equivalent resistance of the constant voltage equivalent circuit at low frequency

C_c = coupling capacitor between V_1 and V_2

16. The gain at the lower half power point can be determined by the following formula:

$$A_L = (A_m)(0.707)$$

Where A_L = gain at lower half power point

A_m = mid frequency gain

17. The bandwidth of an amplifier is determined by using the formula shown below.

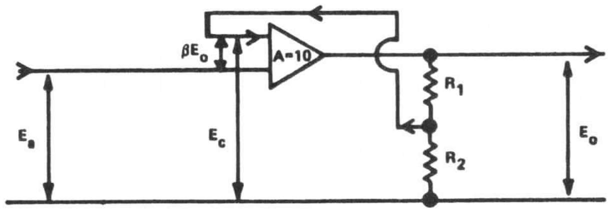
$$BW = f_h - f_L$$

Where BW = bandwidth of amplifier

f_h = frequency at upper half power point

f_L = frequency at lower half power point

AMPLIFIERS WITH FEEDBACK



1. The gain of an amplifier with feedback can be determined by the following formula:

$$A' = \frac{A}{1 - (\pm \beta A)}$$

Where A' = gain with feedback

A = gain without feedback

β = amount of feedback

2. The percentage of feedback can be determined by the following formula:

$$|\beta| = \frac{R_2}{R_1 + R_2}$$

Where $|\beta|$ = the percentage of feedback

R_1 = ohmic value of resistor R_1

R_2 = ohmic value of resistor R_2

3. The voltage gain of a cathode follower is as follows:

$$A = \frac{\mu R_k}{r_p + R_k(\mu + 1)} \qquad \text{or} \qquad A = \frac{\mu}{\mu + 1}$$

Where A = voltage gain of the cathode follower

μ = amplification factor (mu)

R_k = resistance of the cathode

r_p = AC plate resistance in ohms

4. The input capacitance of a cathode follower can be determined by the following formula:

$$C_{in} = C_{gp} + C_{gk}(1 - A)$$

Where C_{in} = input capacitacne of the cathode follower

C_{gp} = grid to plate capacitance

$C_{gk}(1 - A)$ = anti-Miller effect

5. The input impedance of a conventional cathode follower is as follows:

$$Z_{in} = R_g$$

Where Z_{in} = input impedance of the conventional cathode follower

R_g = grid resistor

6. The output impedance of a cathode follower can be determined by using the following formula:

$$Z_o = \frac{R_k r_p}{r_p + R_k(\mu + 1)} \qquad Z_o = \frac{1}{gm}$$

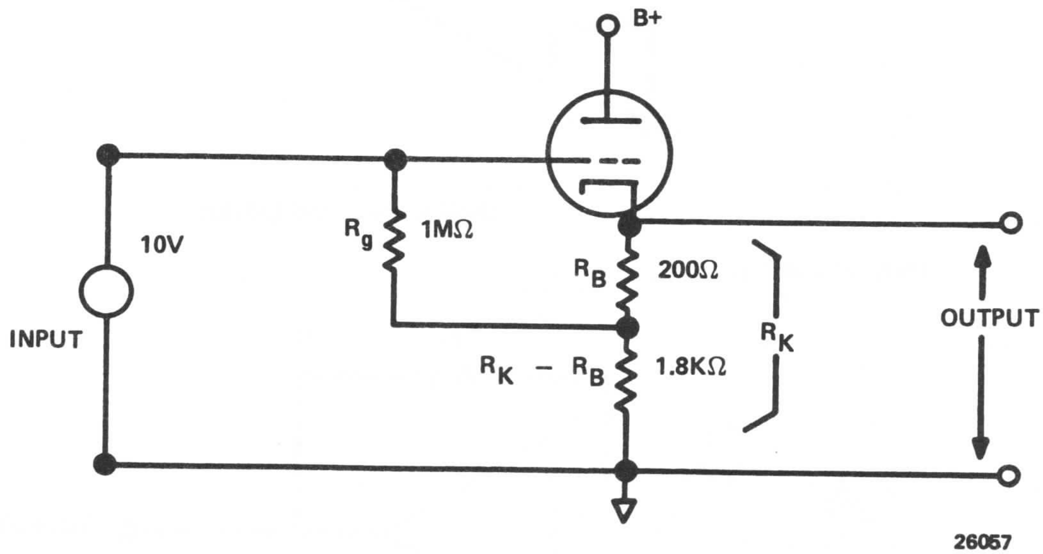
Where Z_o = output impedance in ohms

R_k = cathode resistor

r_p = AC plate resistance

μ = amplification factor (mu)

7. The input impedance of a cathode follower with grid resistor returned to cathode circuit is as follows:



$$Z_{in} = \frac{R_g}{1 - A \dfrac{R_k - R_B}{R_k}}$$

Where Z_{in} = input impedance of the long-tailed cathode follower

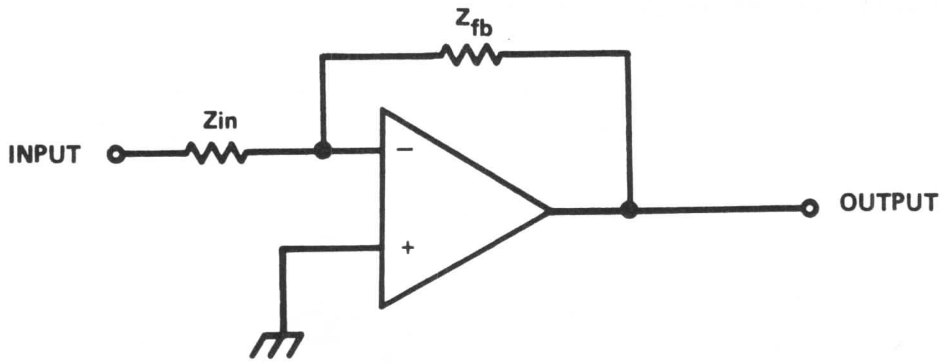
R_g = grid resistor

A = gain of the cathode follower

R_k = total cathode resistance

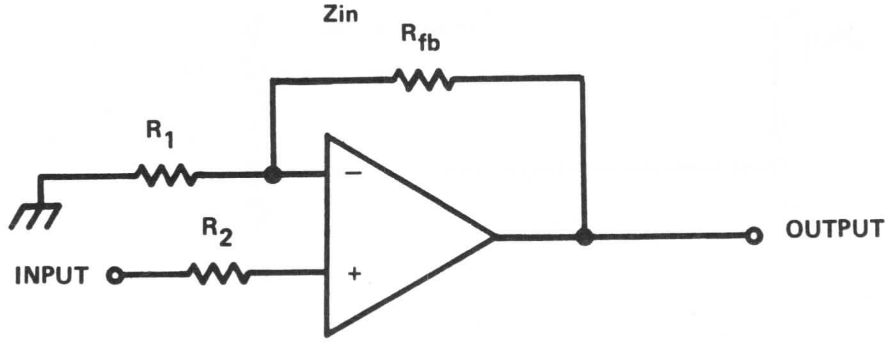
R_B = top resistor of the two cathode resistors

OPERATIONAL AMPLIFIERS WITH FEEDBACK.



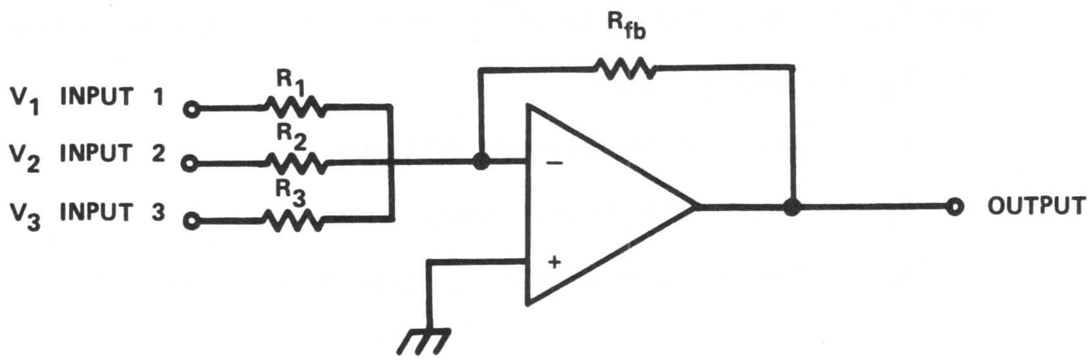
INVERTING AMPLIFIER

GAIN FORMULA $A = \frac{Zfb}{Zin}$



NON-INVERTING AMPLIFIER

GAIN FORMULA $A = \frac{Rfb}{R1} + 1$



SUMMING AMPLIFIER

$$Vout = \frac{(-Rfb)}{(R1)} V1 + \frac{(-Rfb)}{(R2)} V2 + \frac{(-Rfb)}{(R3)} V3 \ldots\ldots$$

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TRANSISTORS

1. The direct current in a transistor can be related by using the following formula:

$$I_e = I_b + I_c$$

Where I_e = emitter current

I_b = base current

I_c = collector current

2. The current amplification factor for a common base configuration (alpha) can be determined using the following formula:

$$= \frac{\Delta I_o}{\Delta I_e} \Big| V_c$$

Where (alpha) = current amplication factor in a common base configuration

I_o = collector current

I_e = emitter current

Δ = a change of

V_c = collector voltage

3. The current amplification factor is a common emitter configuration can be determined by the following formula:

$$\beta = \frac{\Delta I_c}{\Delta I_b} \Big| V_c$$

Where β (beta) = current amplification factor in a common emitter configuration

I_c = collector current

I_b = base current

Δ = a change of

V_c = collector voltage

4. The current amplification factor in a common collector configuration can be determined using the following formula:

$$\gamma = \frac{\Delta I_e}{\Delta I_b} \Big|_{V_c}$$

Where γ (gamma) = current amplification factor in a common collector

I_e = emitter current

I_b = base current

Δ = a change of

V_c = collector voltage

5. The percentage of change for a unijunction transistor sweep generator can be determined using the following formula:

$$\% \text{ of change} = \frac{V_p - V_d}{V_1 - V_d} \text{ X } 100$$

Where V_p = Firing potential

V_d = Valley voltage

V_1 = Voltage that capacitor is charging toward

6. The percentage of change for a thyratron (soft tube) sweep generator can be determined using the following formula:

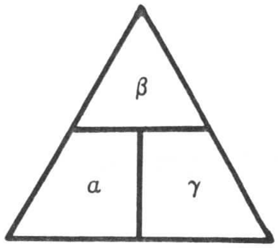
$$\% \text{ of change} = \frac{E_{Pmax} - E_{Pmin}}{E_{app} - E_{Pmin}} \times 100$$

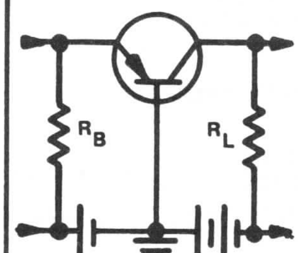
7. The percent of discharge for pulse width calculation for multivibrators can be determined using the following formula:

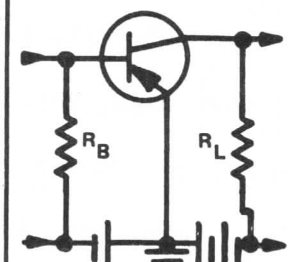
$$\% \text{ of discharge} = \frac{\Delta\, ep - C_o}{\Delta\, ep} \times 100$$

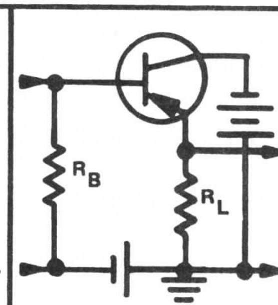
Where $\Delta\, ep = E \text{ applied} - E_{Pmin}$

C_o = Bias necessary for the cutoff.









	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
CURRENT AMPLIFICATION FACTOR	$a = \frac{\Delta I_c}{\Delta I_e}\Big\vert V_C$	$\beta = \frac{\Delta I_c}{\Delta I_b}\Big\vert V_C$	$\gamma = \frac{\Delta I_e}{\Delta I_b}\Big\vert V_C$
INPUT IMPEDANCE	LOW (30 – 150Ω)	MODERATE (500 – 1500Ω)	HIGH (20K – 500K Ω)
OUTPUT IMPEDANCE	HIGH (300K – 500K Ω)	MODERATE (30K – 50K Ω)	LOW (50 – 1K Ω)
VOLTAGE GAIN $A_v = \frac{V_{out}}{V_{in}}$	HIGH (500 – 1500)	MODERATE–HIGH (300 – 1000)	LOW LESS THAN ONE
CURRENT GAIN $A_1 = \frac{I_{out}}{I_{in}}$	LOW LESS THAN ONE	MODERATE–HIGH (25 – 50)	LOW LESS THAN ONE
POWER GAIN $A_p = \frac{P_{out}}{P_{in}}$	MODERATE (20 – 30 db)	HIGH (25 – 40 db)	LOW–MODERATE (10 – 20 db)
PHASE RELATIONSHIP	OUTPUT AND INPUT VOLTAGE IN PHASE	OUTPUT AND INPUT VOLTAGE 180° OUT-OF-PHASE	OUTPUT AND INPUT VOLTAGE IN PHASE
FREQUENCY RESPONSE	50KHz – 1 MHz HIGH	5KHz – 50KHz LOW	20KHz – 500KHz MODERATE
THERMAL STABILITY	GOOD	POOR	FAIR

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Common-base amplifier

Current gain A_1: approximately 1

Voltage again A_v; very high, 100-2500 typical

Power gain A_p: high; 100-2500 typical

Input impedance Z_{ib}: very low; 10 -200 typical

Output impedance Z_{ob}: high; 10 k typical

Phase shift (input to output); 0°

FORMULAS

$$A_v = \frac{v_{out}}{v_{in}}$$

$$A_i = \frac{i_{out}}{i_{in}}$$

$$A_p = \frac{P_{out}}{P_{in}} = A_v \times A_i$$

$$\alpha = \frac{I_C}{I_E} = \frac{i_C}{i_E}$$

$$h_{fb} = \alpha$$

$$h_{ib} = \frac{\Delta V_{BE}}{\Delta I_E} \approx \frac{0.025\ V}{I_E}$$

DEFINITIONS

Input signal-variations in input voltage or current (AC portion of input).

Output signal-variations in output voltage or current (AC portion of output).

Reproduction-duplication of input signal by an amplifier.

Amplification-enlargement of input signal by an amplifier.

Voltage (current, power) gain-ratio of output signal voltage (current, power) to input signal voltage (current, power).

Impedance-effective AC resistance.

Input (output) impedance-impedance seen looking into the input (output) terminals of a circuit.

h_f-transistor's forward AC current gain between input and output, and configuration.

h_i-transistor's AC input resistance, any configuration.

Q point-quiescent operating point; DC bias values of amplifier voltages and currents.

(alpha)-AC current gain between emitter and collector.

h_{fb}-forward AC current gain in common-base common-base configuration; same as

h_{ib}-AC input resistance in common-base configuration.

Z_{ib}-total input impedance of Com.-B amplifier.

Z_{ob}-total output impedance of Com.-B amplifier.

r_{ob}-transistor's AC output resistance in Com-B configuration. Usually can be neglected.

AC load line-load line passing through Q point and with slope determined by R_C R_L.

Clipping-distortion of output waveform when transistor is driven out of active region.

COMMON-EMITTER AMPLIFIER: SUMMARY

The important characteristics of the Com.-E transistor amplifier are summarized:

Current gain A_t: β , much greater than 1

Voltage gain A_v: very high; 100-2500

Power gain A_p: extremely high; 20,000 is typical

Input impedance Z_{ie}: moderately high; 1 k is typical

Output impedance Z_{oe}: moderately high; 2 k is typical

Phase shift: 180° in mid-frequency range

FORMULAS

$$\beta = h_{fe} = \frac{\Delta I_C}{\Delta I_B} = \frac{i_C}{i_B}$$

$$h_{ie} = \frac{V_{BE}}{I_B} \Bigg|_{V_{CE} = \text{constant}}$$

$$h_{ie} \approx h_{fe} h_{ib}$$

$$r_{oe} = \frac{1}{h_{oe}} = \frac{V_{CE}}{I_C} \Bigg|_{I_B = \text{constant}}$$

$$V_B \approx \frac{R_1}{R_1 + R_2} V_{CC} \text{ when } R'_E \geq 20\, R_{TH}$$

$X_C \ll h_{ib}$ for effective bypassing

DEFINITIONS

β (h_{fe})-AC forward current gain in common-emitter configuration.

h_{ie}-transistor AC input resistance in common-emitter configuration.

Z_{ie}-Com.E amplifier input impedance.

Z_{oe}-Com.-E amplifier output impedance.

r_{oe}-transistor's AC output resistance in common-emitter configuration.

h_{oe}-transistor's AC output conductance in common-emitter condiguration.

Q point stability-variation of Q point with changes in temperature and with transistor replacement.

Base-current bias-method of biasing a common-emitter amplifier with a constant base current.

Base-voltage bias-biasing a Com.-E amplifier with a constant base-to-ground voltage.

Emitter bypass capacitor-used in base voltage bias circuit to ground the emitter for AC.

OSCILLATORS

1. The frequency of an LC oscillator is determined by the values of L and C in the frequency determining tank or series resonant circuit.

$$f_o = \frac{1}{2\pi\sqrt{LC}} = \frac{0.159}{\sqrt{LC}}$$

Where f_o = frequency of the oscillator output in hertz

L = inductance in henrys

C = capacitance in farads

2. The output frequency of a phase shift oscillator may be determined by the following formula:

$$f_o = \frac{1}{2\pi RC\sqrt{6}}$$

(3 section only)

$$f_o = \frac{1}{2\pi RC\sqrt{\frac{10}{7}}}$$

(4 section only)

Where f_o = frequency of the oscillator output in hertz

R = value of the phase shift resistor in ohms

C = capacitance of the phase shift capacitor in farads

3. The output frequency of a Wein bridge oscillator is determined by the RC values of the reactive side of the bridge. This is shown by the following formula:

$$f_o = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

Where f_o = frequency of the oscillator output in hertz

R_1 = resistance of the series RC branch in ohms

C_1 = capacitance of the series branch in farads

R_2 = resistance of the parallel RC branch in ohms

C_2 = capacitance of the parallel RC branch in farads

4. When the value of $R_1 C_1$ is equal to $R_2 C_2$ in a Wein Bridge oscillator the following simplified formula may be used.

$$f_0 = \frac{1}{2 \pi R_1 C_1}$$

Where f_0 = frequency of the oscillator output.

R_1 = resistance in ohms of the series RC branch (equal to resistance of the parallel RC branch).

C_1 = capacitance in farads of the series RC branch (equal to capacitance of the parallel RC branch).

PULSES

1. The fundamental sine wave component of a pulse can be determined by using the following formula:

$$F_{fr} = \frac{1}{2\ PW}$$

Where f_{fr} = the fundamental frequency in hertz

PW = pulse width in seconds

2. The highest harmonic content in a pulse, square wave or rectangular wave can be determined using the following formula:

$$f_h = \frac{1}{2\ R_t}$$

Where f_h = highest harmonic of the fundamental sinewave frequency

R_t = rise time of the pulse, square wave or rectangular wave in seconds

3. The relationship between the parameters of a pulse are shown by the following equations:

$$\frac{P_{av}}{P_{pk}} = \frac{PW}{PRT}$$

Where P_{av} = average power in watts

P_{pk} = peak power in watts

PRT = pulse recurrence time in seconds

PW = pulse width in seconds

4. The pulse recurring frequency (PRF) can be determined if the pulse recurring time (PRT) is known, or conversely, the PRT can be determined if the PRF is known.

$$PRF = \frac{1}{PRT}$$

$$PRT = \frac{1}{PRF}$$

Where PRF = pulse recurring frequency in hertz

PRT = pulse recurring time in seconds

5. The duty cycle of a pulse in the ratio of the on time to total time for one pulse. It can be determined from the following formula:

$$\text{Duty cycle} = \frac{PW}{PRT}$$

Where PW = pulse width or "on" time in seconds

PRT = pulse recurring time in seconds

METROLOGY

1. The arithmetic mean of a group of readings can be determined by using the following formula:

$$a_m = \frac{\Sigma R_e}{N}$$

Where a_m = arithmetic mean

ΣR_e = the sum of all readings

N = number of readings

2. The standard deviations of a group of readings can be determined by using the following formula:

$$SD = \sqrt{\frac{\Sigma X^2}{N}}$$

Where SD = standard deviation

Σ = the sum of

X^2 = square of the individual deviations from the arithmetic mean

N = number of readings

3. Small factors of correction or error are often stated in PPM (parts per million) as well as % (percentage). The mathematical relationships, as well as the conversion values, are shown below:

1 ppm (of one unit) $= \frac{1}{1000000}$ or .000001 units.

1% (of one unit) $= \frac{1}{100}$ or .01 units.

To change percentage to parts per million:

ppm = % (10,000).

To change parts per million to percentage:

% = ppm (.0001).

4. Correction, Correction Factors, and Error

a. Definitions;

Nominal: The value specified by the manufacture; the units value an item should be.

Actual: The certified value; the value in units an item is.

Correction: The value in units that, when added algebraically to the nominal, will result in the actual (N + C = A).

Correction Factor: Correction expressed in either percentage or parts per million.

Error: The difference the Actual is from the Nominal (E = N - A). (The error will always carry the same numerical value and opposite polarity of its equivalent correction or correction factor.)

$$C = A - N \qquad E(\%) = \frac{N - A}{A} \times 100$$

$$CF(\%) = \frac{C}{N} \times 10^2 \qquad CF_{ppm} = \frac{C}{N} \times 10^6$$

Where: A = Actual

N = Nominal

C = Correction (in units)

CF(%) = Correction Factor expressed in percentage

CF_{ppm} = Correction Factor expressed in parts per million

E(%) = Error in percentage

b. Remember these simple rules:

(1) N + C = A

(2) Correction and error are always equal in magnitude, but opposite in sign.

(3) Correction factors must be converted to the same units as the nominal before they can be added.

5. $$e_r = \frac{M - T}{T}$$

Where: e_r = relative error

M = measured value

T = True value

$$e_r(\%) = \frac{M - T}{T} \times 100$$

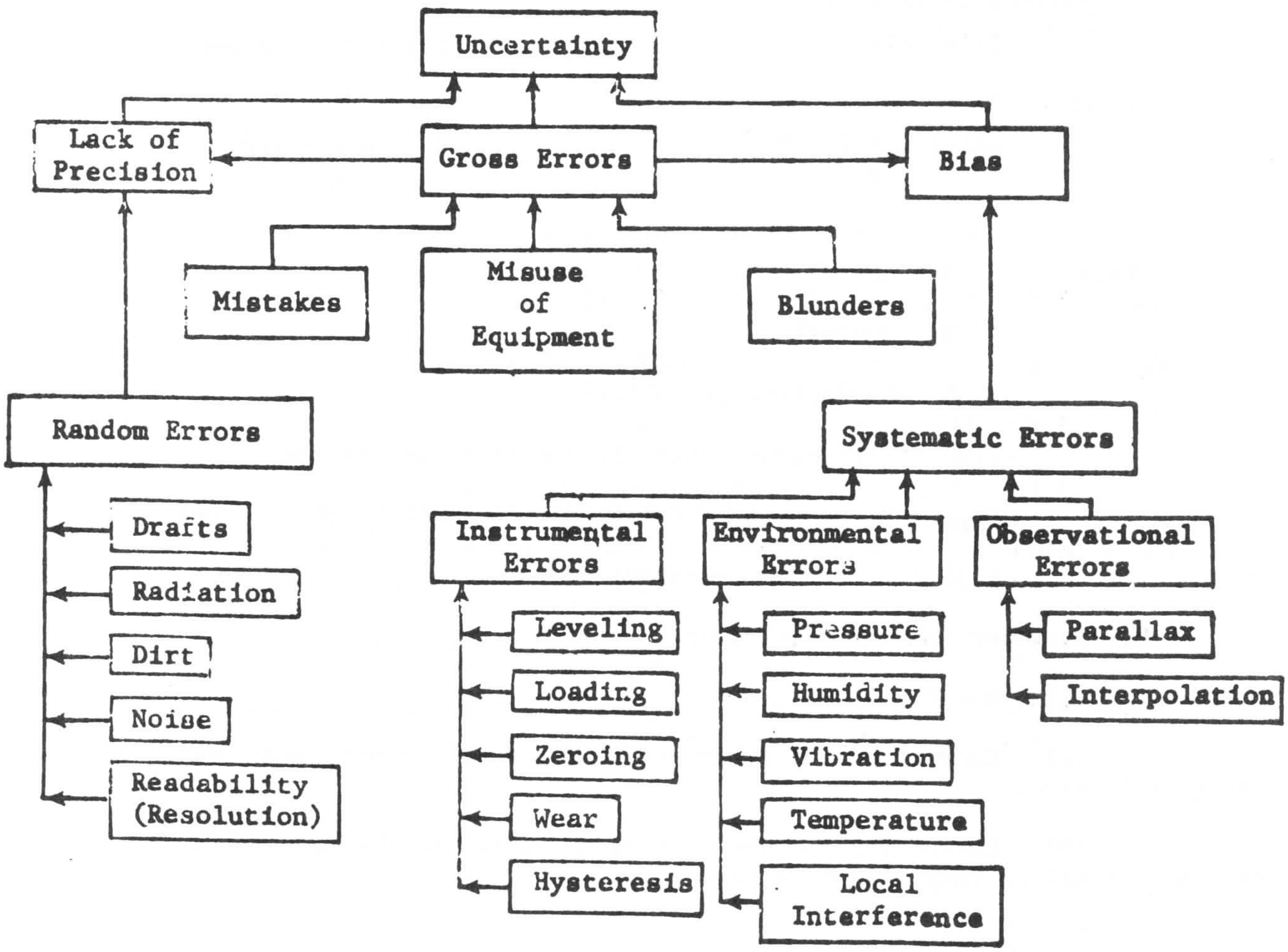
Where: $e_r(\%)$ = percent relative error

M = measured value

T = true value

a. The true value is usually replaced by the accepted or nominal value because the true value is never exactly known.

CLASSIFICATION OF MEASUREMENT ERRORS



TRANSFER RESISTANCE STANDARDS

Formulas for using the SR1010 resistance boxes as transfer standards:

$$R_s = 10R\left(1 + \frac{\Delta ave}{10^6}\right)$$

$$R_p = \frac{R}{10}\left(1 + \frac{\Delta ave}{10^6}\right)$$

$$R_{sp} = R\left(1 + \frac{\Delta sp}{10^6}\right)$$

$$\Delta ave = \frac{\text{total deviation}}{\text{number of units}}$$

$$\Delta d = R_{sp} - R_{10}$$

$$\Delta sp = \Delta ave + \frac{\Delta d}{10}$$

R_s = series resistance of 10 nominally equal resistances

R_p = parallel resistance of 10 nominally equal resistances

R_{sp} = series-parallel resistances of 9 nominally equal resistances

R_{10} = resistance of the 10th resistor

R = the nominal value of one resistor

Δave = the average deviation from nominal of 10 nominally equal resistors in either series or parallel (expressed in ppm)

Δd = the difference between R_{sp} and R_{10} (expressed in ppm)

Δsp = the deviation from nominal of 9 nominally equal resistors in series-parallel (in ppm)

Temperature Correction for Thomas 1-ohm Std:

$Rt = R25 [1 + \alpha (t - 25) + \beta (t - 25)^2]$

Rt = true resistance at ambient temperature

R25 = absolute resistance at 25°C

α = alpha (always positive) in units

β = beta (always negative) in units

t = ambient temperature (in degrees centigrade)

$Ct = C25 + \alpha(t - 25) + \beta (t - 25)^2$

Ct = correction factor in ppm for true resistance

C25 = correction factor in ppm at 25°C

α = alpha (+) in ppm

β = beta (-) in ppm

t = ambient temperature in degrees centigrade

OSCILLOSCOPES

1. The rise time of an oscilloscope can be determined if the rise time of the oscilloscope and the rise time of the preamplifier are known. This is shown by the formula:

$$R_{ts} = \sqrt{R_{tra}^2 + R_{tpa}^2}$$

Where R_{ts} = combined rise time of the oscilloscope vertical amplifiers and preamplifier plug-in

R_{tra} = rise time of the vertical amplifier of the oscilloscope

R_{tpa} = rise time of the preamplifier plug-in

NOTE: The values of R_{tra} and R_{tpa} are indicated on their respective panels.

2. In most applications the measured rise is considered to be the true rise time. However, as the measured rise time begins to approximate the rise time of the oscilloscope (R_{ts}) the following formula is used.

$$R_{tt} = \sqrt{R_{tm}^2 - R_{ts}^2}$$

Where R_{tt} = true rise time

R_{tm} = measured rise time

R_{ts} = combined rise time of the oscilloscope-preamplifier combination

NOTE: It is recommended that this formula be used in this course when the measured rise time is 0.1 micro seconds or less.

3. The upper 3dB limit of frequency response of an oscilloscope or amplifier can be determined by using the following formula:

$$UFR = \frac{.35}{R_t}$$

Where UFR = upper end frequency response (3dB limit) in hertz

R_t = rise time in seconds

.35 = a constant value arrived at as a result of empirical discovery

4. The phase angle between two signals of the same frequency, can be determined by measuring the amplitude of the Lissajou pattern at two points on the Y axis and applying the following formula:

$$\text{Sine } \theta = \frac{Y_1}{Y_2}$$

Where Sine θ = phase angle between the two signals

Y_1 = Y axis intercept 1, taken at the very center of the pattern in centimeters

Y_2 = Y axis intercept 2, which represents the maximum amplitude of the pattern in centimeters

NOTE: Readings made by this method are ambiguous, that is, there are two possible answers for each pattern. The problem can be resolved if the frequencies compared, are low enough so that the direction of rotation of the pattern can be observed.

5. The percentage of amplitude modulation can be determined a number of ways by using an oscilloscope. These methods compare the maximum voltage amplitudes with the minimum voltage amplitudes. The following formula can be used to determine the percentage of amplitude modulation.

$$\% \text{ of AM} = \frac{H_1 - H_2}{H_1 + H_2} \times 100$$

Where % of AM = percentage of amplitude modulation

H_1 = largest dimension in centimeters

H_2 = smallest dimension in centimeters

DISTORTION

The total distortion of a sine wave caused by a number of harmonics can be determined by the following formula:

$$TD = \sqrt{H_2^2 + H_3^2 + H_4^2 + \ldots}$$

Where TD = total distortion in percentage

H_2 = percentage of distortion caused by the second harmonic

H_3 = percentage of distortion caused by the third harmonic

H_4 = percentage of distortion caused by the fourth harmonic

PHASE ANGLE READINGS

1. The phase angle between two signals of the same frequency can be determined using the Phase Unit plug-in of the electronic counter. If the input signal frequency is not 400 Hz ± 4 Hz, the following formula is used to determine the phase angle.

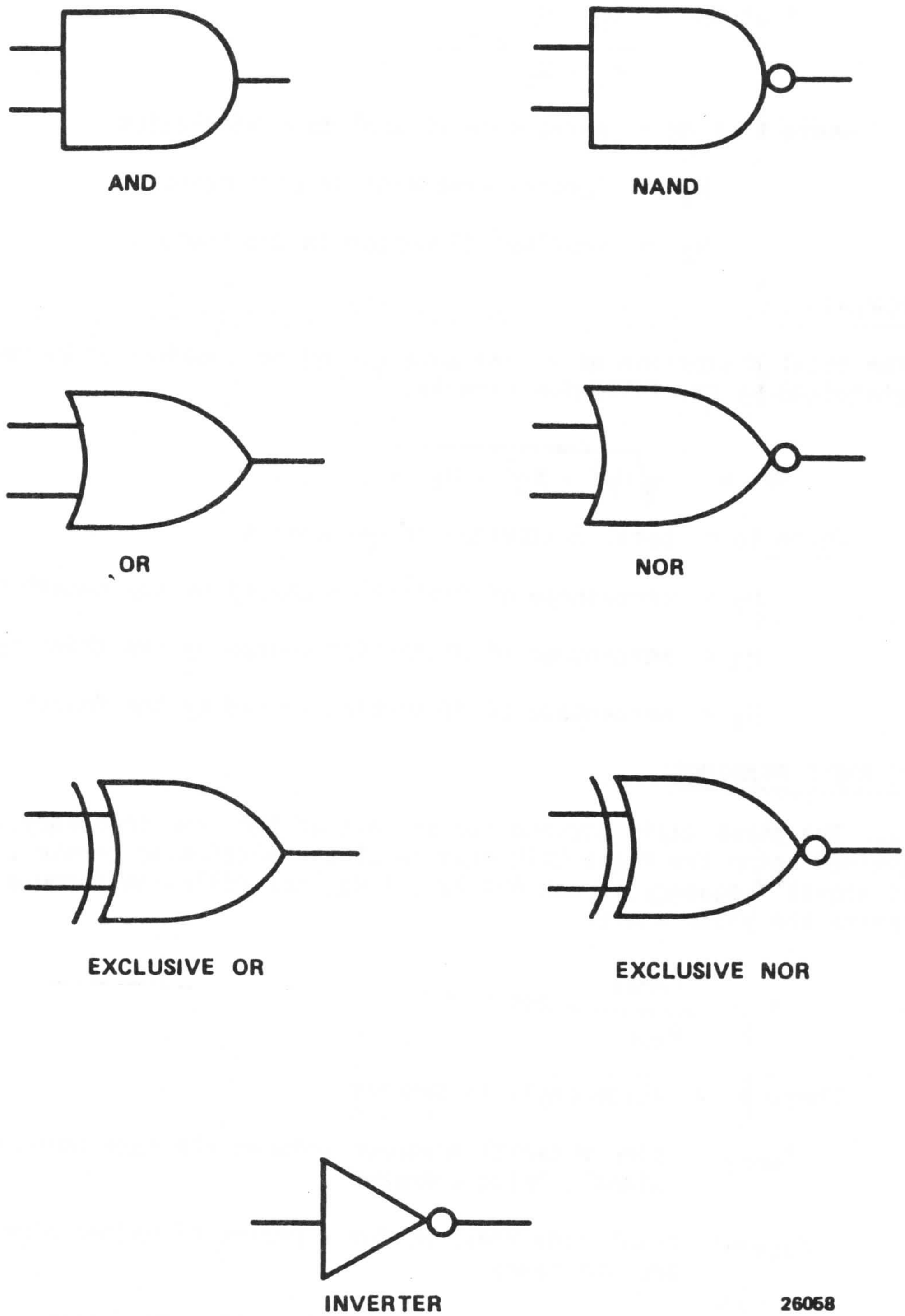
$$\theta = \frac{P_{meas}}{P_{tot}} \times 360$$

Where θ = phase angle in degrees

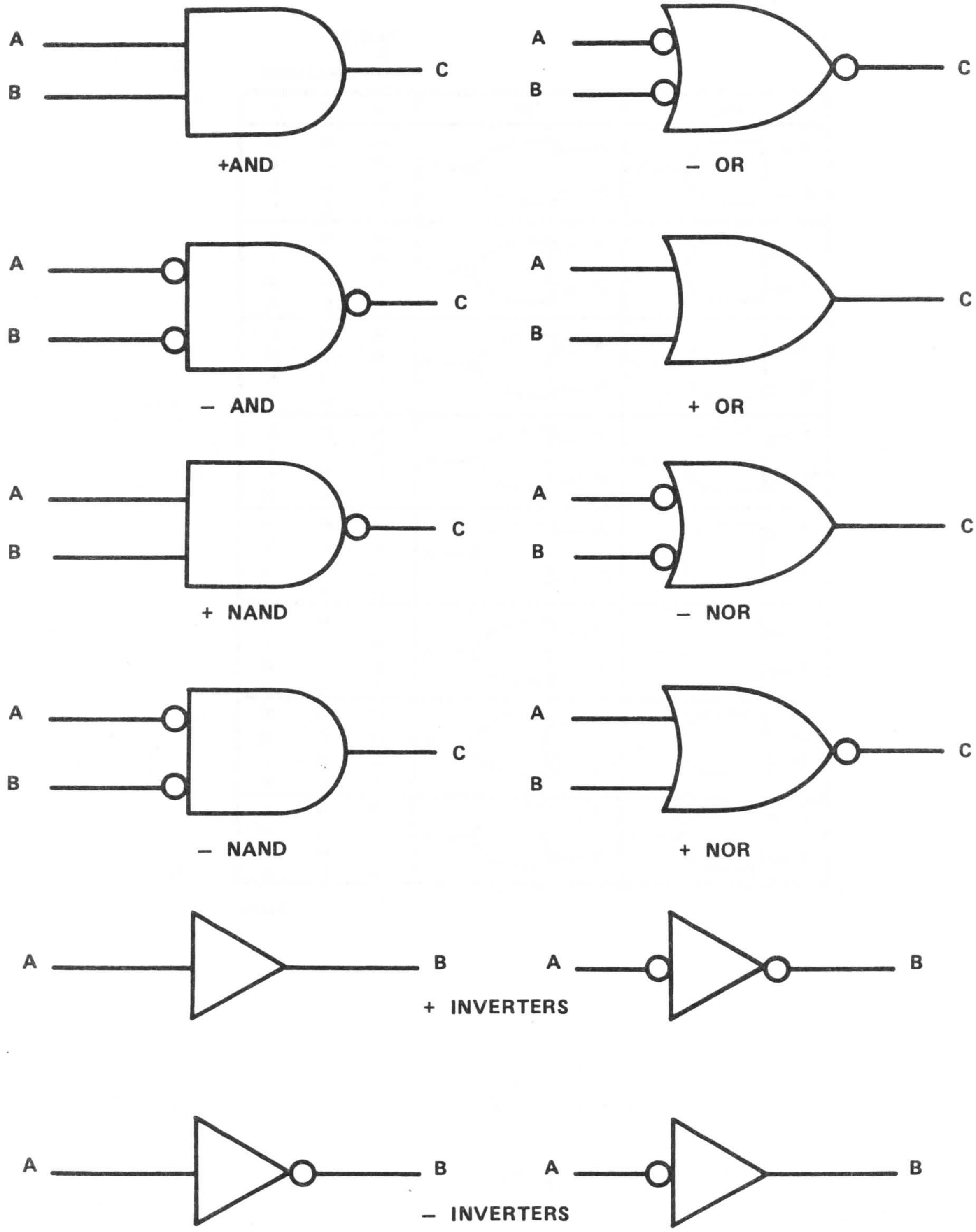
P_{meas} = time interval measured between the same point on two signals being compared

P_{tot} = total time required for a period of either signal (both are the same)

360 = a factor to convert the time ratio to degrees



LOGIC GATES



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EQUIVALENT GATES.

TABLE
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COMBINATIONS

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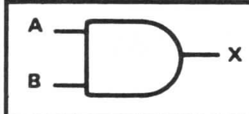
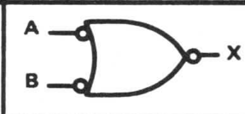
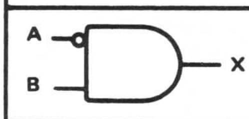
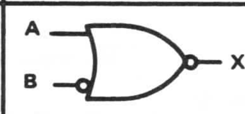
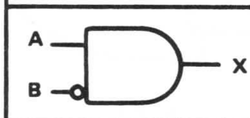
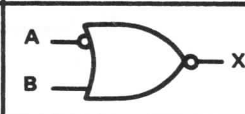
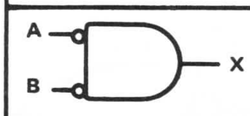
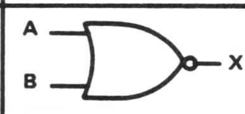
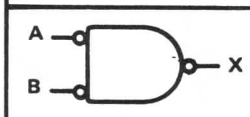
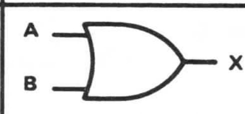
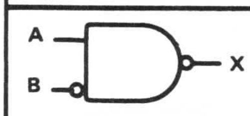
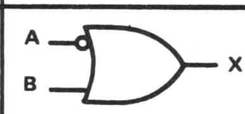
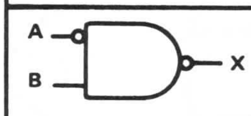
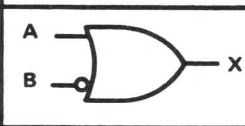
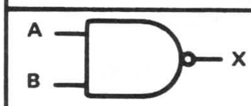
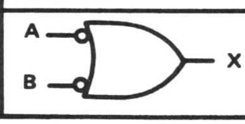
		H H L L	H L H L	H L L L
		H H L L	H L H L	L L H L
		H H L L	H L H L	L H L L
		H H L L	H L H L	L L L H
		H H L L	H L H L	H H H L
		H H L L	H L H L	H L H H
		H H L L	H L H L	H H L H
		H H L L	H L H L	L H H H

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MICROWAVE

1. Wavelength is the distance along the direction of propagation between two points which are in phase, on adjacent waves. It is symbolized by the Greek letter lambda (λ). It can be determined by the following formulas.

$$\lambda\,(\text{meters}) = \frac{300 \times 10^6 \ (\text{meters/seconds})}{f\ (\text{hertz})}$$

$$\lambda\,(\text{cms}) = \frac{300 \times 10^8 \ (\text{cm/second})}{f\ (\text{hertz})}$$

$$\lambda\,(\text{cms}) = \frac{30 \ (\text{cm/seconds})}{f\ (\text{gigahertz})}$$

$$\lambda\,(\text{feet}) = \frac{982.08 \times 10^6 \ (\text{feet/seconds})}{f\ (\text{hertz})}$$

$$\lambda\,(\text{miles} = \frac{186{,}000 \ (\text{miles/seconds})}{f\ (\text{hertz})}$$

Where λ = wavelength in meters, centimeters, feet or miles

f = frequency in hertz

2. The velocity constant (K) is the ratio of the velocity of propagation, along the two wire or coaxial line, to velocity in free space, which is the same as the velocity of light.

$$K = \frac{V_g}{V_o} = \frac{\lambda g}{\lambda o}$$

Where K = velocity constant

V_g = velocity of propagation in meters per second

V_o = velocity of light in meters per second

λo = wavelength in free space

λg = wavelength on a transmission line

3. The wavelength on a two-wire transmission line or coaxial line can be determined if the velocity constant is indicated and the frequency is known.

$$\lambda g = \frac{KV_o}{f}$$

Where λg = wavelength in meters in a transmission line

V_o = velocity of light in meters

f = frequency of operation in hertz

K = velocity constant of the transmission line

4. The characteristic impedance in ohms of a lossless transmission line can be determined by using the following formula:

$$Z_o = \sqrt{\frac{L}{C}}$$

Where Z_o = characteristic impedance of a lossless line in ohms

L = inductance per unit length in henrys

C = capacitance per unit length in farads

5. The characteristic impedance of a coaxial transmission line may be found using the following formula:

$$Z_o = \frac{138}{\sqrt{\epsilon'}} \log \frac{D}{d}$$

Where Z_o = characteristic impedance in ohms

D = inside diameter of the outer conductor

d = outside diameter of the inner conductor

ϵ' = dielectric constant

log = logarithm of the base 10

138 = a constant for coaxial lines

6. The characteristic impedance in ohms of a two-wire transmission line may be found by using the following formula:

$$Z_o = \frac{276}{\sqrt{\epsilon'}} \log \frac{2D}{d}$$

Where Z_0 = characteristic impedance in ohms

D = center to center spacing between conductors

d = diameter of the conductors

log = logarithm of the base 10

276 = a constant for a two-wire line

ϵ' = dielectric constant

7. The voltage maximums and minimums of standing waves, as well as E_i and E_r, can be determined by the following formulas.

$$E_{max} = E_i + E_r$$

$$E_{min} = E_i - E_r$$

$$E_i = \frac{E_{max} + E_{min}}{2}$$

$$E_r = \frac{E_{max} - E_{min}}{2}$$

Where E_{max} = maximum voltge points (loops)

E_{min} = minimum voltage point (node)

E_i = incident voltage

E_r = reflected voltage

8. The standing wave ratio can be determined by the following formula:

$$SWR = \frac{E_{max}}{E_{min}} = \frac{I_{max}}{I_{min}} = \frac{Z_{max}}{Z_{min}} = \frac{E_i + E_r}{E_i - E_r} = \sqrt{\frac{P_{max}}{P_{min}}} = \frac{\sqrt{P_i} + \sqrt{P_r}}{\sqrt{P_i} - \sqrt{P_r}}$$

Where SWR = standing wave ratio

E_{max} = maximum voltage (loop)

E_{min} = minimum voltage (node)

I_{max} = maximum current (loop)

I_{min} = minimum current (node)

Z_{max} = maximum impedance point on a line

Z_{min} = minimum impedance point on a line

E_i = incident voltage

E_r = reflected voltage

P_{max} = maximum power

P_{min} = minimum power

P_i = incident power

P_r = reflected power

9. The voltage standing wave ratio of small discontinuities may be found by sliding load method and using the following formula:

$$VSWR_L \text{ or } VSWR_D = \sqrt{(VSWR_{max})\,(VSWR_{min})}$$

$$\text{or} \quad \sqrt{\frac{VSWR_{max}}{VSWR_{min}}}$$

Where $VSWR_L$ = voltage standing wave ratio of the moving load

$VSWR_D$ = voltage standing wave ratio of the discontinuity

$VSWR_{max}$ = VSWR when the reflections add in phase

$VSWR_{min}$ = VSWR when the reflections are out of phase

NOTE: If the reflection of the moving load is unknown the measurement must be repeated with another load.

10. A VSWR greater than 10:1 can be measured by the double minimum method and its value determined by the following formula:

$$VSWR = \frac{\lambda g}{\pi (d_1 - d_2)}$$

Where VSWR = voltage standing wave ratio

λg = wavelength on the transmission line or waveguide

d_1 = first 3 dB point

d_2 = second 3 dB point

π = 3.14

11. The VSWR of a purely resistive load can be determined in terms of the line characteristic impedance (Z_0) and load resistance.

Where R_L is greater than Z_0, $VSWR = \frac{R_L}{Z_0}$

Where Z_0 is greater than R_L, $VSWR = \frac{Z_0}{R_L}$

Where VSWR = voltage standing wave ratio

Z_0 = characteristic impedance

R_L = Load resistance

12. The reflection coefficient magnitude is the ratio of the voltage of the reflected wave to the voltage of the incident wave. It is symbolized by the Greek lower case letter rho (   ) or by the absolute value of gamma. The following formulas can be used to determine the reflection coefficient magnitude.

$$\rho = |\Gamma| = \frac{E_r}{E_i} = \frac{I_r}{I_i} = \frac{P_r}{P_i}$$

Where $|\Gamma|$ = reflection coefficient magnitude = ρ

E_r = reflected voltage

E_i = incident voltage

I_r = reflected current

P_r = reflected power

P_i = incident power

13. The reflection coefficient magnitude can be determined in terms of the line characteristic impedance and load resistance (for purely resistive loads).

$$\rho = |\Gamma| = \frac{Z_o - R_L}{R_L + Z_o}$$

Where R_L is greater than Z_o

$$\rho = |\Gamma| = \frac{R_L - Z_o}{R_L + Z_o}$$

Where $|\Gamma|$ = reflection coefficient magnitude

Z_o = characteristic impedance of the line

R_L = load resistance

14. The VSWR can be determined if the reflection coefficient magnitude is known, and conversely, the reflection coefficient magnitude can be determined if the VSWR is known. This is shown in the following formula.

$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|} = \frac{1 + \rho}{1 - \rho}$$

$$\rho = |\Gamma| = \frac{\text{VSWR} - 1}{\text{VSWR} + 1}$$

Where VSWR = voltage standing wave ratio

$\rho = |\Gamma|$ = reflection coefficient magnitude

15. The percentage of reflected power (%Pr) can be determined by using the following formulas.

$$\%Pr = 100 \left(\frac{\text{VSWR} - 1}{\text{VSWR} + 1}\right)^2 = |\Gamma|^2 (100) = 100 \left(\frac{E_r}{E_i}\right)^2$$

Where %Pr = percentage of reflected power

VSWR = voltage standing wave ratio

$|\Gamma|$ = reflection coefficient magnitude = ρ

E_r = reflected voltage

E_i = incident voltage

16. A helpful equation of ratio and proportion can be used to determine total power from a source, the power dissipated in the microwave line, or the percentage of the power dissipated.

$$\frac{100\%}{\%Pd} = \frac{P_i}{P_a}$$

Where P_i = total power of the soure in watts

P_a = measured or computed power of the load

%Pd = percentage of total power dissipated.

17. To determine the actual value of impedance from the normalized value the following formula is used:

$$Z_A = Z_0 \tan\theta$$

Where Z_A = actual impedance value at a given point in ohms

Z_0 = characteristic impedance

$\tan\theta$ = tangent of the phase angle which is the normalized value of impedance

NOTE: This formula can only be used where the load is an open, short or pure reactance.

18. To determine Zo in ohms of a quarter wave matching transformer the following formula is used:

$$Z_0 = \sqrt{Z_{in} Z_{out}}$$

Where Z_0 = characteristic impedance of a quarter wave matching transformer

Z_{in} = characteristic impedance of the input transmission line

Z_{out} = characteristic impedance of the output transmission line

19. To determine the effective efficiency of a working bolometer mount the following equation is used.

$$\frac{\eta e^{(std)}}{\eta e^{(ti)}} = \frac{P_{std}}{P_{ti}}$$

Where: $\eta e^{(std)}$ = known efficiency of the standard bolometer

$\eta e^{(ti)}$ = computed efficiency of the test bolometer (test instrument)

P_{std} = absorbed power of the standard

P_{ti} = absorbed power of the test instrument (bolometer)

20. To determine the calibration factor of a bolometer mount, the following formula is used.

$$Kb = \eta e \quad (1 - |\Gamma m|^2)$$

Where Kb = calibration factor of a bolometer mount

$|\Gamma m|$ = reflection coefficient magnitude of the bolometer mount

21. The cutoff wavelength of a rectangular waveguide in its dominant mode may be determined by using the following formula.

$$\lambda co = 2a$$

Where λco = cutoff wavelength for a rectangular waveguide in centimeters

a = width of the inner wide dimension in centimeters

22. The cutoff (f_{co}) of a rectangular waveguide may be determined if the cutoff wavelength is known by using the following formula.

$$f_{co} = \frac{V_o}{\lambda co}$$

Where f_{co} = cutoff frequency of the rectangular waveguide in hertz

V_o = velocity of light in centimeters per second

λco = cutoff wavelength in centimeters

23. Free space wavelength (o) can be computed if the cutoff wavelength of the waveguide and wavelength on the waveguide is known, by using the following formulas.

$$\lambda o = \lambda co\,[\cos\,(\tan^{-1} \frac{\lambda co}{\lambda g})]$$

$$o = \frac{\lambda g}{\sqrt{1 + (\frac{\lambda g}{\lambda co})^2}}$$

Where λo = free space wavelength in centimeters

λco = cutoff wavelength of the waveguide in centimeters

λg = wavelength in centimeters (usually measured)

24. Waveguide wavelength can be computed if the free space, and cutoff wavelength are known. The following formulas can be used to compute waveguide wavelength.

$$\lambda g = \frac{\lambda co}{\tan\left(\cos^{-1} \frac{\lambda o}{\lambda co}\right)}$$

$$\lambda g = \frac{\lambda o}{\sqrt{1 - \left(\frac{\lambda o}{\lambda co}\right)^2}}$$

Where λg = waveguide wavelength

λo = free space wavelength

λco = cutoff wavelength

25. The phase velocity of a waveguide can be determined by using the following formula.

$$V_{ph} = \frac{V_o}{\sqrt{1 - \left(\frac{\lambda o}{\lambda co}\right)^2}}$$

Where V_{ph} = phase velocity on a waveguide in meters per second

V_o = velocity of light in meters per second

λo = free space wavelength in meters

λco = cutoff wavelength in meters

26. The group velocity on a waveguide can be determined by using the following formula.

$$Vg = Vo \sqrt{1 - \frac{\lambda o}{\lambda co}^{2}} = \frac{Vo}{\sqrt{1 + \left(\frac{\lambda g}{\lambda co} \right)^{2}}}$$

Where Vg = group velocity in meters per second

λo = free space wavelength in meters

λco = cutoff wavelength of the waveguide in meters

λg = guide wavelength

Vo = velocity of propagation in free space

27. The velocity of light can be expressed as a function of group and phase velocities as indicated below.

$$Vo = \sqrt{Vg \times Vph}$$

Where Vo = velocity of light in meters per second

Vg = group velocity in meters per second

Vph = phase velocity in meters per second

28. The gain or attenuation of a device may be expressed in decibels using the following formula.

$$dB = 10 \log_{10} \frac{P_L}{P_S}$$

Where dB = gain in decibels

P_L = the larger of the two power levels

P_S = the smaller of the two power levels

$\log_{10}$ = logarithms of the base 10

NOTE: If there was a gain in the device, P_L would represent the output. If there was an attenuation in the device, P_L would represent the input.

29. The attenuation in a "waveguide below cutoff" attenuator (circular TE_{11} mode) is as follows:

$$\alpha = \frac{54.6}{\lambda co} \sqrt{1 - \left(\frac{\lambda co}{\lambda}\right)^2}$$

Where α = attenuation per unit length in dBs

co = cutoff wavelength

λ = free space wavelength

or if λ is much greater than λ co

$$\alpha = \frac{54.6}{\lambda co}$$

Where α = attenuation per unit length in dBs

λ co = cutoff wavelength (3.42 times the guide radius)

30. The coupling factor of a directional coupler can be computed if the input power to the main arm and the output power of the auxiliary arm are known.

$$CF_{dB} = 10 \log \frac{P_i}{P_o}$$

Where CF_{dB} = coupling factor in dB

P_i = power applied to the input of the main arm

P_o = power output at the auxiliary arm

log = logarithm of the base 10

31. The attenuation of a rotary vane attenuator is a function of the angular position of the resistive card. This is shown by the following formula.

$$dB = 40 \log \frac{1}{\cos\theta}$$

Where dB = attenuation in decibels

$\cos\theta$ = cosine of the angular position of the resistive cards

log = logarithm of the base 10

32. The ratio between the standing wave maximum and standing wave minimum may be used to express VSWR.

$$VSWR_{dB} = 20 \log \frac{E_{max}}{E_{min}} = 20 \log VSWR$$

Where $VSWR_{dB}$ = ratio of the standing wave maximum to standing wave minimum in decibels

E_{max} = maximum voltage

E_{min} = minimum voltage

VSWR = voltage standing wave ratio

log = logarithm of the base 10

33. The mismatch loss in decibels can be determined by using the following formula.

$$L_{mm} = 10 \log \frac{1}{(1 - |\Gamma|)^2} = 10 \log \frac{1}{1 - \rho^2}$$

Where L_{mm} = mismatch loss in decibels

$|\Gamma|$ = absolute value of the reflection coefficient = ρ

log = logarithm of the base 10

34. The return loss in decibels may be determined by using the following formula

$$LR_{dB} = 10 \log \frac{P_i}{P_r} = 20 \log \frac{Ei}{Er} = 20 \log \frac{1}{\rho} = 10 \log \frac{1}{\rho^2}$$

Where LR_{dB} = return loss in decibels

log = logarithm of the base 10

P_i = incident power in watts

P_r = reflected power in watts

35. The uncertainty in decibels due to a mismatch between the source and load can be determined by the following formula.

$$dB = 10 \log \frac{1}{(1 \pm |\Gamma 1| \, |\Gamma 2|)^2}$$

Where dB = uncertainty in decibels due to mismatch

$|\Gamma 1|$ = reflection coefficient magnitude at the generator end.

$|\Gamma 2|$ = reflection coefficient magnitude at the load end.

36. The frequency applied to the waveguide can be calculated once the free space wavelength has been found using the following formula.

$$f = \frac{Vo}{\lambda o}$$

Where f = frequency in hertz applied to the waveguide

Vo = velocity of light in meters

λo = free space wavelength in meters

37. The time delay caused by one section of an artificial transmission line, or the total delay caused by a number of sections, can be determined by using the following formulas.

$$T_d = \sqrt{LC}$$

$$T_{dt} = N\sqrt{LC}$$

Where T_d = time delay in seconds

T_{dt} = time delay total in seconds

L = inductance in henrys per section

C = capacitance in farads per section

N = number of sections

38. The following formulas are used for determining an unknown frequency applied to the transfer oscillator. The two adjacent harmonics are designated F_1 and F_2. The highest of the two is F_1.

$$f = H_1F_1, \qquad f = H_2F_2$$

$$H_1 = \frac{F_2}{F_1 - F_2}, \qquad H_2 = \frac{F_1}{F_1 - F_2}$$

Where f = input frequency in hertz

H_1 = harmonic number F_1

H_2 = harmonic number of F_2

F_1 = the highest of the two adjacent beat frequencies in hertz

F_2 = the lower of the two adjacent beat frequencies in hertz

39. The width of the main lobe of a pulse modulated RF spectrum as viewed on the spectrum analyzer may be computed using the following formula.

$$MLW = \frac{2}{PW}$$

Where MLW = main lobe width in hertz

PW = pulse width in seconds, of the modulating signal

40. The general expression for power transfer between a source and a load of reflection coefficients $|\Gamma_g|$ and $|\Gamma_L|$ is:

$$\frac{(1 - |\Gamma_g|^2)(1 - |\Gamma_L|^2)}{(1 \pm |\Gamma_g| \, |\Gamma_L|)^2}$$

MICROWAVE NOISE EQUATIONS

1. The value of the "average noise voltage squared" may be determined using the following formula.

$$\overline{e}_n^{\,2} = 4K\ TRB$$

Where $\overline{e}_n^{\,2}$ = average noise voltage squared

K = Boltzman's constant which relates temperature to energy. It is equal to 1.38×10^{-23} joules per degree Kelvin

T = temperature of the network at toom temperature

R = resistance in ohms

B = frequency bandwidth in hertz

2. The available noise power may be determined by the use of the following formulas.

$$P_n = \frac{\left|\overline{e}_n\right|^2}{4R}$$

$$P_n = KTB$$

Where P_n = noise power in watts

$\left|\overline{e}_n^{\,2}\right|$ = the absolute value of the average voltage

R = resistance in ohms

K = Boltzman's constant which relates temperature to energy. It is equal to 1.38×10^{-23} joules per degree Kelvin

T = temperature of the network at room temperature

B = frequency bandwidth in hertz

3. The noise output of a system, without the noise source turned on, can be determined by using the following formula.

$$N_o = K\ T_o\ B\ G_s$$

Where N_o = noise output in watts of the system under test, without the noise source turned on

K = Boltzman's constant which relates temperature to energy. It is equal to 1.38×10^{-23} joules per degree Kelvin.

T_o = standard temperature of 290° Kelvin

B = frequency bandwidth in hertz

G_s = power gain in watts of the system under test

4. The noise figure rting of a device may be expressed as a ratio of signal to noise. This value may be determined by using the following formulas.

$$F = \frac{N_o}{K\ T_o\ B}$$

$$F = \frac{S_i/N_i}{S_o/N_o}$$

$$F = \frac{N_o}{K\ T_o\ B\ G_s}$$

Where F = the noise figure rating of a device expressed as a ratio of signal to noise

N = noise output in watts of the system under test without the noise source turned on

T_o = standard temperature of 290° Kelvin

B = frequency bandwidth in hertz

S_i = signal at the input of the system under test

S_o = signal at the output of the system under test

N_i = noise input in watts to system under test

K = Boltzman's constant which relates temperature to energy. It is equal to 1.38×10^{-23} joules per degree Kelvin.

G_s = power gain of the system under test

5. The noise figure rating of a device may be expressed in dBs. This can be determined by using the following formula.

$$F_{dB} = 10 \log \left(\frac{T_2 - T_0}{T_0}\right) - 10 \log \left(\frac{N_2}{N_0} - 1\right)$$

Where F_{dB} = noise figure rating in dBs

log = logarithm to the base 10

T_0 = standard temperature of 290° Kelvin

T_2 = the equivalent noise temperature or the ambient temperature for the measurement system

N_2 = noise output with the source generator turned on

N_0 = noise output with source generator turned off

6. To determine the noise power of a noise source, the following formula is used.

$$P_{ns} = K (T_2 - T_0) B$$

Where P_{ns} = noise power of the noise source

K = Boltzman's constant which relates temperature to energy

T_2 = the equivalent noise temperature or the ambient temperature for the measurement system

T_0 = standard temperature of 290° Kelvin

B = frequency bandwidth in hertz

7. The amount of noise power contributed by a receiver to the measured total noise power output is given by Nr.

$$Nr = (f-1) (K\ T_0\ B\ G_s)$$

Where Nr = noise power contributed by the receiver

F = receiver noise figure

K = Boltzman's constant, 1.38×10^{-23} joule/K°

T_0 = reference temperature, 290°K

B = receiver bandwidth

G_s = power gain of receiver

MICROWAVE SIGNAL FLOWGRAPH ANALYSIS

1. The following definitions are directly related to microwave network analysis and are included here to better relate the rules, diagrams and formulas.

A. Signal Flowgraph. A direct picture of signal flow, in which the variables are represented by points and are interrelated by directed lines. Figure 1 shows an example of a signal flowgraph. The arrows indicate the direction of signal flow.

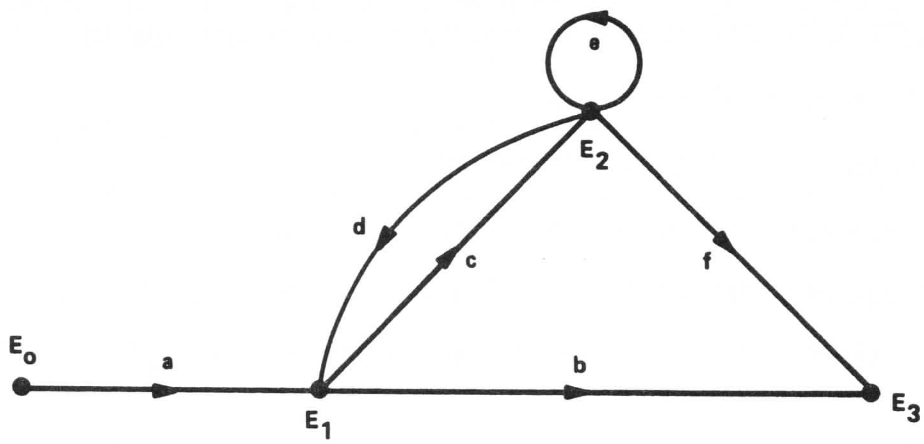


Figure 1. Signal Flowgraph

B. Branch. The direction of signal flow and those operations performed on the signal. In figure 1, "c" is a branch entering "E_2" and "d" is a branch entering "E_1."

C. Node. A node is a point representing an equation variable. In figure 1, "E_1" is a node and depends on "E_0" and "a." ($E_0 \times a = E_1$). "E_2" and "E_3" are also nodes.

D. Source Node. A node with no input branch. In figure 1, "E_0" is the source node.

E. Sink Node. A node with no output branch. In figure 1, "E_3" is the sink node.

F. Intermediate Node. A node with input and output branches. In figure 1, "E_1" and "E_2" are intermediate nodes.

G. Open Path. A path along which a node is encountered only once. In figure 1, "a" to "b" is an open path. "a" to "c" to "f" is also an open path but not "a" to "c" to "d" since "E_1" would be encountered twice.

H. Forward Path. A path between source and sink node, directed toward the sink node. In figure 1, there are five forward paths.

Path #1: "a" to "b" to "E_3"

Path #2: "a" to "c" to "f" to "E_3"

Path #3: "a" to "c" to "d" to "b" to "E_3"

Path #4: "a" to "c" to "e" to "f" to "E_3"

Path #5: "a" to "c" to "e" to "d" to "b" to "E_3"

I. Feedback loop. A path which returns to the starting node while encountering no node twice. In figure 1 "e" and "cd" are both feedback loops.

J. Self-loop. A feedback loop consisting of only one branch. In figure 1, "e" is a self-loop.

K. Branch gain or loss. A linear quantity relating one node to another. In figure 1, "a" relates "E_1" to "E_0."

L. Loop gain. The product of the branch gains in the closed loops. In figure 1, the product "cd" represents a loop gain.

2. The following mathematical rules are illustrated and related to flowgraph analysis.

A. Multiplication: The product of all forward branches. In figure 2, the dependent variable "E_1" is the product of $E_0 \times a$.

Figure 2. "E_1" is the product of $(E_0)(a)$

In figure 3, the variable "E_1" is the product of $(E_0)(\Gamma_L)$, or $E_1 = (E_0)(\Gamma_L)$.

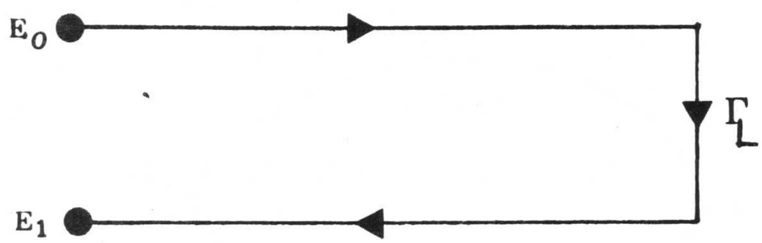


Figure 3. Multiplication and dependent variable

B. Division: Multiplication of a reciprocal quantity accomplishes division. In figure 4, the dependent variable "E_1" is the product of the independent variable "E_0" and $\frac{1}{R}$ (note: $\frac{1}{R} = G$), $E_1 = E_0G$.

$E_1 = E_0G$

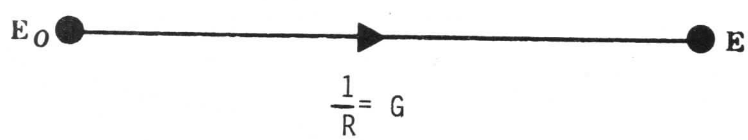


Figure 4. Dependent variable E_1

C. Addition: The sum of all the forward paths. In figure 5, the dependent variable E_3 is the sum of the two forward paths ($E_3 = E_{1a} + E_{2b}$).

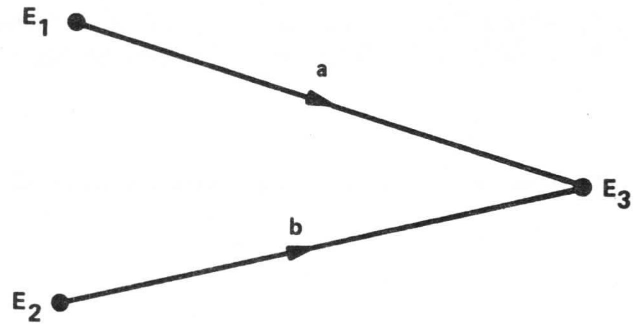


Figure 5. The sum of two forward paths

Figure 6 shows another way of representing addition [$E_1 = E_{oa} + E_{ob} = E_o (a+b)$].

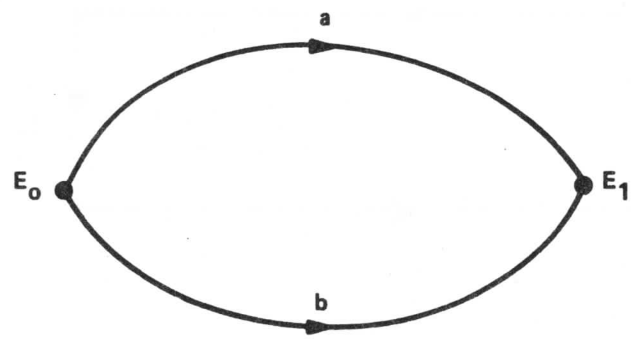


Figure 6. Alternate method of addition

D. Subtraction. A minus sign is used to denote the difference of the forward paths. In figure 7, the dependent variable E_3 is the difference between the forward paths ($E_3 = E_{1a} - E_{2b}$).

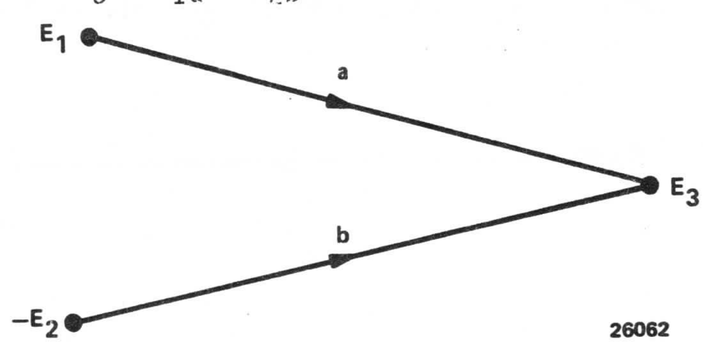


Figure 7. The difference between forward paths

E. Distributed Signals. In figure 8, the independent variable E_0 is distributed through three other branches. The dependent variable E_1 is the product of "$E_0 a$." The dependent variable $E_2 = E_1 b = bE_0 a$. The dependent variable $E_3 = CE_1 = CE_0 a$.

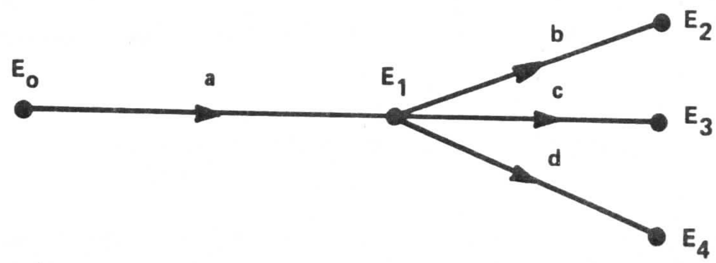


Figure 8. Distribution of the independent variable E_0

F. Self-loop Gain. In figure 9A, "C" is a self-loop. The signal in the self-loop follows an infinite gemetric progression with a common ratio of less than one. (This will be true for our microwave applications.) A geometric progression is a sequence of numbers in which each term, after the first, can be obtained from the preceding by multiplying it by a fixed number called the common ratio. Example: The sequence of numbers, 0.1, 0.01, 0.001, form a geometric progression with the common ratio of 0.1. The self-loop of figure 9A can therefore be expanded as shown in figure 9B.

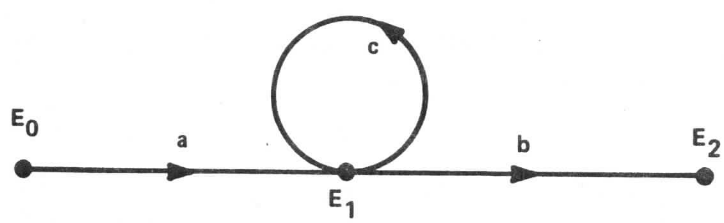


Figure 9A. Self-loop (C)

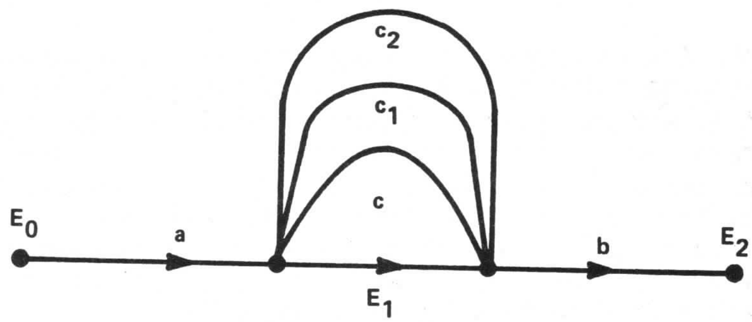


Figure 9B. Expanded self-loop (C)

G. Rule for Self-loop Elimination. To reduce the flowgraph to simpler terms, self-loops are eliminated from the flowgraph and treated mathematically as a node. See figures 9C and 9D.

"To eliminate a self-loop, divide all branches entering the node containing the self-loop by the value of 1 minus the value of the self-loop."

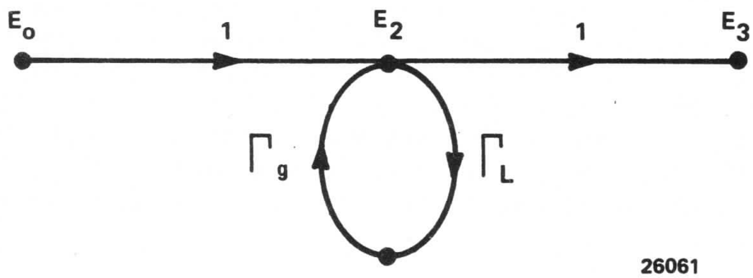
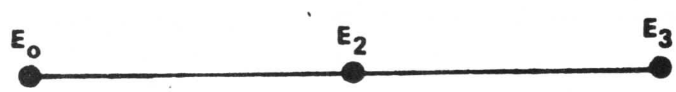


Figure 9C. Flowgraph containing a self-loop



$$E_2 = \frac{1}{1-\Gamma g\ \Gamma L} \qquad E_3 = E_o \frac{1}{(1-\Gamma g\ \Gamma L)}$$

Figure 9D. Flowgraph with self-loop eliminated

3. The "non-touching loop" rule is described in the following explanations and formulas.

When networks are cascaded, it is only necessary to cascade the flowgraphs, since the outgoing wave from one network is the incoming wave to the next. This is demonstrated in figure 10 where a network is placed between a generator and a load. The system now has only one independent variable, the generator amplitude E. The flowgraph contains paths and loops. A "path" is a series of directed lines followed in sequence and in the same direction in such a way that no node is touched more than once. The value of the path is the product of all coefficients encountered en route. There is one path from E to b_2. It has a value S_{21}.

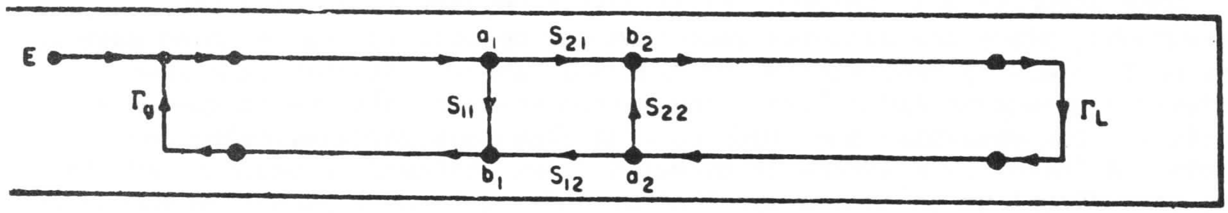


Figure 10. Cascading of a network between load and generator

There are two paths from E to b_1, namely S_{11} and S_{21} L S_{12}. A first order "loop" is a series of directed lines coming to a closure when followed in sequence and in the same direction with no node passed more than once. The value of the loop is the product of all coefficients encountered en route. A second-order loop is the product of any two first-order loops which do not touch at any point. A third-order loop is the product of any three first-order loops, namely, $\Gamma g\ S_{11}$, $S_{22}\ \Gamma L$, and $\Gamma g\ S_{21}\ \Gamma L\ S_{12}$ and there is one second-order loop $\Gamma g\ S_{11}\ S_{22}\ \Gamma L$.

The solution of a flowgraph is accomplished by application of the non-touching loop rule, which written symbolically is

$$T = \frac{\left\{ \begin{aligned} & P_1(1 - \Sigma L(1)^{(1)} + \Sigma L(2)^{(1)} - \Sigma L(3)^{(1)} + \cdots) \\ & \quad + P_2(1 - \Sigma L(1)^{(2)} + \Sigma L(2)^{(2)} \cdots) \\ & \quad\quad + P_3(1 - \cdots) \end{aligned} \right\}}{1 - \Sigma L(1) + \Sigma L(2) - \Sigma L(3) + \cdots}$$

Here $\Sigma L\ (1)$ denotes the sum of all first-order loops. $\Sigma L\ (2)$ denotes the sum of all second-order loops, and so on. P_1, P_2, P_e, etc, are the values of all the various paths which can be followed from the independent-variable node to the node whose value is desired. $\Sigma L\ (1)^{(1)}$ denotes the sum of all first-order loops which do not touch path P1 at any point, and so on.

In other words, each path is multiplied by the factor in brackets which involves all the loops of all orders which that path does not touch. T is a general symbol representing the ratio between the dependent variable or interest and the independent variable. This process is repeated for each independent variable of the system, and the results are summed.

As examples of the application of the rule, the transmission (b_2/E) and the reflection coefficient (b_1/a_1) are written as follows:

$$\frac{b_2}{E} = \frac{S_{21}}{1 - \Gamma_g S_{11} - S_{22}\Gamma_L - \Gamma_g S_{21}\Gamma_L S_{12} + \Gamma_g S_{11} S_{22}\Gamma_L}$$

$$\frac{b_1}{a_1} = \frac{S_{11}(1 - S_{22}\Gamma_L) + S_{21}\Gamma_L S_{12}}{1 - S_{22}\Gamma_L}$$

Note that the generator flowgraph is unnecessary when solving for b_1/a_1 and the loops associated with it are deleted when writing this solution. It is worth mentioning at this point that second and higher-order loops can quite often be neglected while writing down the solution, if one has orders of magnitude for the various coefficient in minds.

4. Various flowgraph diagrams are shown in figures 11 through 17.

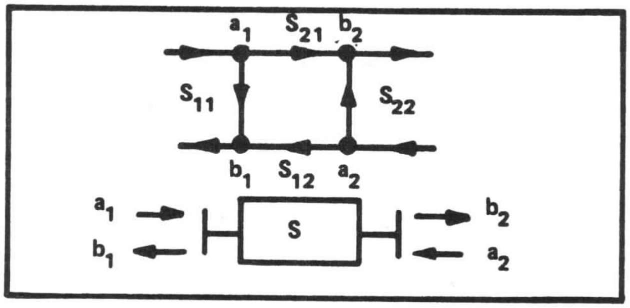


FIGURE 11. TWO-PORT NETWORK

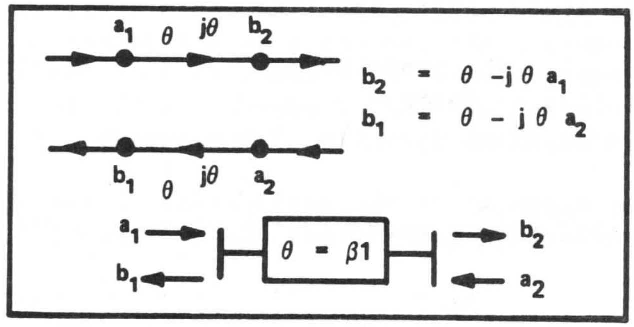


FIGURE 15. LOSSLESS-LINE LENGTH

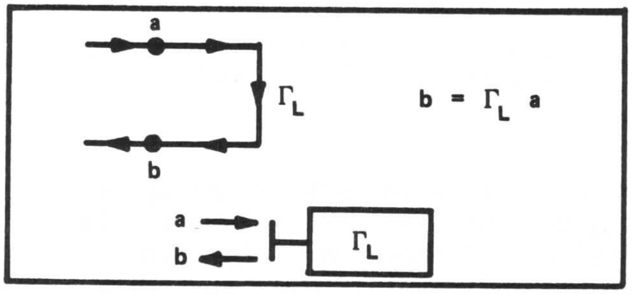


FIGURE 12. LOAD

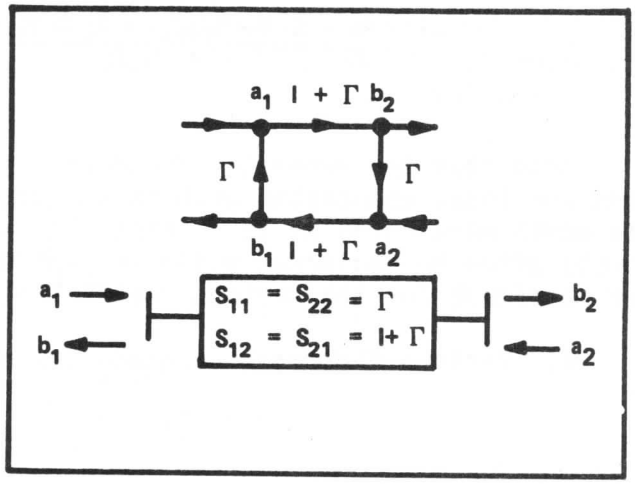


FIGURE 16. SHUNT ADMITTANCE

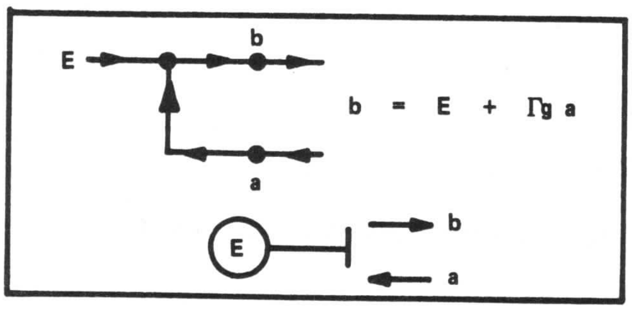


FIGURE 13. GENERATOR

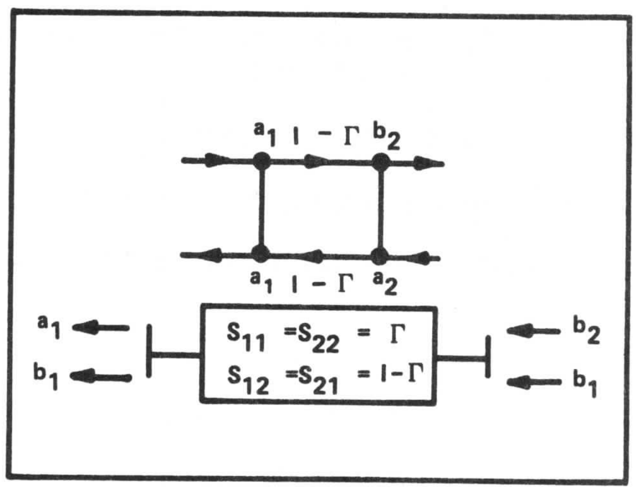


FIGURE 17. SERIES IMPEDANCE

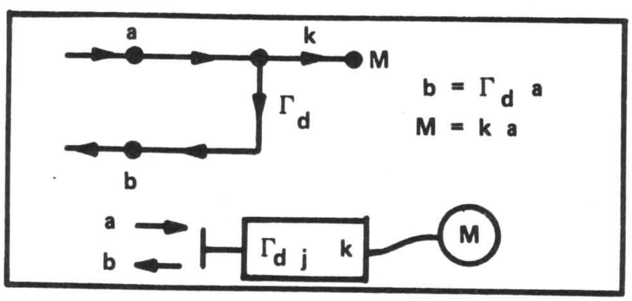


FIGURE 14. VIDEO DETECTOR

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1. The present intensity of radiation can be determined by using the following formula.

$$I_1 = I_0 \times df$$

Where I_1 = present intensity in milliroentgen per hour at one meter

I_0 = original intensity in mr/hr at one meter

df = decay factor

2. The distance that the test instrument must be placed from the source, in order to achieve a desired intensity, can be determined by using the following formulas.

$$d = 39.37 \sqrt{\frac{I_1}{I_2}}$$

$$d = \sqrt{\frac{1550\ I_1}{I_2}}$$

Where d = distance in inches from the source

I_1 = present intensity of the source in milliroentgens per hour, at one meter

I_2 = desired intensity in milliroentgens per hour

39.37 = a factor to convert meters into inches

1550 = the square of 39.37

3. The intensity at a stated distance can be determined by using the following formula.

$$I_d = \frac{1550\ I_1}{d^2}$$

Where I_d = intensity at a given distance in milliroentgens per hour

I_1 = present intensity of the source in milliroentgens per hour at one meter

d = predetermined distance in inches

1550 = the square of 39.37 (inches in a meter)

NOTE: To physically relate the currie to the roentgen, a rule of thumb has been developed. A source of 1 currie will produce a radiation intensity of about 1 roentgen at a distance of 3 feet. This rule of thumb is often referred to as the 3 foot rule.

1. Acceleration is the change of velocity per unit time. This relationship is shown by the following formula.

$$a = \frac{V_2 - V_1}{T}$$

Where a = acceleration

V_1 = initial velocity

V_2 = velocity after acceleration

T = time in seconds

2. Density is the mass per unit volume of a given substance. Density can be determined by one of the following formulas.

$$\rho = \frac{M}{V}$$

Where ρ = mass density

V = volume

M = mass

3. Force is the total push or pull. The basic relationship between force, mass and acceleration is shown in the following formula.

$$F = ma$$

Where F = force

m = mass

a = acceleration

4. True weight is its apparent weight, plus or minus its net buoyant force, when compared to a standard.

$$W_t = W_a \pm \rho air\,(V_x - V_s)\,(\frac{g}{go})$$

Where W_t = true weight

W_a = apparent weight

ρair = density of air

V_x = volume of test weight

V_s = volume of standard

g = local gravity

go = standard gravity

5. Pressure is the amount of force on each unit area of the surface acted upon. The following formula may be used to express this relationship.

$$P = \frac{F}{A}$$

Where P = pressure

F = force

A = area

6. The pressure of a liquid may be determined by the following formulas.

$$P = hD$$

Where P = pressure of the liquid

h = height

D = density

7. Weight is the pull of gravity on a body. The relationship of weight, mass, and gravity is shown in the following formula.

$$W = mg$$

Where W = weight

m = mass

g = acceleration of gravity

8. The total force due to liquid pressure may be determined by the following formula.

$$F = PA$$

$$F = Ah\,D_m$$

$$F = Ah\,D_w$$

Where F = total force due to liquid pressure

A = area over which the force acts

h = height

D_m = mass density

P = pressure

D_w = weight density

9. The specific gravity of a solid or liquid substance is the ratio of the weight of a certain volume of that substance, to the weight of an equal volume of water at 4°C. This is shown by the following formulas.

$$SG = \frac{D_x}{D_w}$$

$$SG = \frac{\text{weight of the substance in air}}{\text{buoyant force of displaced water}} \qquad \frac{W_a}{W_a - W_n} \quad \text{SOLIDS MORE DENSE THAN WATER}$$

$$SG = \frac{\text{buoyant force of liquid}}{\text{buoyant force of water}} \qquad \frac{W_a - W_x}{W_a - W_w} \quad \text{Liquids}$$

Where SG = specific gravity

D_x = density of the substance

D_w = density of water

NOTE: The buoyant force of water is equal to the weight of object in air minus the weight of object in water.

10. The relationship between volume and pressure as indicated by Boyle's Law are shown below. Remember that the law assumes the temperature to be constant.

$$\frac{V_1}{V_2} = \frac{P_2}{P_1} \quad \text{or} \quad V_1P_1 = V_2P_2$$

Where V_1 = original volume

V_2 = new volume

P_1 = original pressure

P_2 = new pressure

11. The relationship between temperature and volume as indicated by Charles' Law is shown below. Remember the law assumes that the pressure remains constant.

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} \quad \text{or} \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Where
V_1 = original volume

V_2 = new volume

T_1 = original absolute temperature

T_2 = new absolute temperature

12. The temperature, volume, and pressure relationship of a gas is shown by the general gas law formula shown below. Note this formula is only valid when absolute units of temperature and pressure are used.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Where
P_1 = original pressure in PSIA

P_2 = new pressure in PSIA

V_1 = original volume

V_2 = new volume

T_1 = original temperature in degrees Kelvin or Rankin

T_2 = new temperature in degrees Kelvin or Rankin

13. The absolute pressure is the sum of the gage pressure and atmospheric pressure as indicated below.

$$P_{ab} = P_G + P_{at}$$

Where
P_{ab} = absolute pressure

P_G = pressure indicated on the gage

P_{at} = atmospheric pressure

14. The local gravity can be calculated using the following formula.

$$g_1 = 980.632 - 2.586 \cos 2\theta + .003 \cos 4\theta - .000094a$$

Where g_1 = local gravity

θ = latitude in degrees

a = elevation in feet above sea level

15. The head pressure correction due to differences in height between the test gage and the pressure tester can be determined by using the following formula.

$$P_g = P_t \pm P_h \quad (P_h = hD)$$

Where P_g = actual gage pressure

P_t = tester pressure

P_h = difference in pressure between the gage and the reference line on the pressure tester.

h = difference in height between gage and tester

D = density of test liquid

16. To calculate true pressure from a pressure tester reading, the following formula can be used.

$$P_t = \frac{\left(M \frac{g_1}{g_s}\right) \left(1 - \frac{\rho a}{\rho B_r}\right)}{A_0(1 + b\,P)(1 + \alpha \triangle T)}$$

Where P_t = true pressure

M = actual mass of weights used, in pounds, as taken from the certification or calibration report plus the piston weight

g_1 = local gravity

g_s = standard gravity, 980.665 cm/sec^2

ρa = (Rho_a) = nominal air density, 0.0012 gm/cm^3

ρB_r = (Rho_{Br}) = nominal brass density, 8.4 gm/cm^3

A_o = area of piston at zero pressure from cal report

b = deformation coefficient from cal report

P = nominal test pressure

α = coefficient of linear expansion from cal report

$\triangle T$ = change in temperature in degrees Celsius from 25°C

17. To determine the unknown candle power of a light source using the photometer method the following formula is used.

$$\frac{I_x}{I_s} = \frac{d_x^{\,2}}{d_s^{\,2}}$$

Where I_x = candle power of the unknown

I_s = candle power of the standard

d_x = distance of the unknown light source from the screen

d_s = distance of the standard light source from the screen

18. The illumination may be determined by the following formula.

$$E = \frac{F}{A}$$

Where E = illumination

F = luminous flux

A = area

19. The illumination in foot candles can be determined by the following formula.

$$E = \frac{I}{d^2}$$

Where E = illumination in foot candles

I = candlepower of source

d = distance from the source

20. The following equation shows the relationship between illumination and distance.

$$\frac{E_1}{E_2} = \frac{d_2^{\,2}}{d_1^{\,2}}$$

Where E_1 = illumination at d_1

E_2 = illumination at d_2

d_1 = distance from E_1

d_2 = distance from E_2

21. The magnification factor can be expressed as the ratio of the size of an image to the size of the object, or the ratio of the image distance to the object distance.

$$MF = \frac{I}{O} = \frac{D_i}{D_o} = \frac{q}{p}$$

Where MF = magnification factor

I = image size

D_i or q = image distance

D_o or p = object distance

22. The relationship between the distance of the object and the focal length for any spherical mirror is shown in the following equation.

$$\frac{1}{f} = \frac{1}{D_o} + \frac{1}{D_i}$$

This equation is often shown as: $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$

Where f = focal length

D_o or p = object distance

D_i or q = image distance

23. The index of refraction is the ratio of velocity of light in a vacuum to the velocity of light in the media as indicated below:

$$n = \frac{V_{LV}}{V_{Lm}}$$

Where n = index of refraction

L_{LV} = velocity of light in a vacuum

L_{Lm} = velocity of light in the media

24. The index of refraction as stated by Snell's Law is shown below:

$$N = \frac{n^1 \text{ sine } \theta^1}{\text{sine } \theta}$$

Where n = index of refractions of the first medium

0 = incident angle

n^1 = index of refraction of the second media

0 = refraction angle

When the first medium is air, the formula is shown below:

$$u = \frac{\text{sine } i}{\text{sine } r^1} = \frac{v^1}{v^2}$$

Where u = index of refraction

sine i = sine of angle of incidence

sine r^1 = sine of angle of refraction

v^1 = speed of light in air

v^2 = speed of light in other medium

25. The change of length due to a temperature change can be computed using the following formula.

$$\Delta l = \alpha l \ (T - T_o)$$

Where Δl = change in length

α = coefficient of linear expansion

l = original length

T = final temperature

T_o = original temperature

NOTE: Algebraically add the total change of length to the total length to obtain the corrected total length.

26. The change of length due to temperature change linear expansion:

$$L_f = L_o \ (1 + \alpha \ \Delta t)$$

Where α = linear coefficient of expansion

Δt = change of temperature

L_o = original length

L_f = final length

27. The relationship between relative humidity, absolute humidity, and capacity of the air is shown by the following formula.

$$\%R_h = \frac{A_h}{C_{ap}} \times 100$$

Where $\%R_h$ = relative humidity in percentage

A_h = absolute humidity in grains per foot

C_{ap} = capacity of air in grains per foot at that temperature

28. The formula for determining the relative humidity is shown below.

$$\%R_h = \frac{P_s \; (t_{dew})}{P_x \; (t_a)} \times 100$$

Where $\%R_h$ = relative humidity in percentage

P_s = pressure of saturated vapor in inches of mercury

t_{dew} = temperature at the dew point

t_a = ambient temperature

29. Torque is a force which produces, or tends to produce, rotation or torsion. It is symbolized by the Greek letter Tau (τ). The amount of torque can be determined by the following formula.

$$\tau = FL$$

Where τ = torque

F = tangential force

L = length of moment arm

30. The angular velocity can be determined by the following formula. Angular velocity is symbolized by the Greek letter omega ( ).

$$\omega = \frac{\theta}{T}$$

Where ω = angular velocity in radians per second

θ = angular displacement

T = time elapsed

31. The relationship between speed (velocity), distance and time is shown in the following formula.

$$V_{av} = \frac{d_t}{T}$$

Where V_{av} = average speed or velocity

T = time

d = distance traveled

32. The frequency of vibration can be determined by the following formulas.

$$f = \frac{1}{T} = \frac{V_{av}}{2DA}$$

Where f = frequency of vibration in hertz

T = time in seconds

V_{av} = average velocity

DA = double amplitude

33. The computation of the acceleration level of a vibration at its maximum displacement can be accomplished by the following formula.

$$g = .0512\ f^2\ DA$$

Where g = acceleration in "g" units

f = frequency in hertz

DA = double amplitude

34. The open circuit sensitivity of a velocity pickup can be determined from the following formula.

$$E_1 = E_2\ \frac{(R_1 + R_2)}{R_2}$$

Where E_1 = open circuit sensitivity

E_2 = sensitivity of the pickup

R_1 = impedance of the pickup

R_2 = input impedance of the readout device

35. The corrected sensitivity of the pickup may be determined by the following formula.

$$E_3 = E_1 \left(\frac{R_2}{R_1 + R_2}\right)$$

Where E_3 = corrected sensitivity

E_1 = open circuit sensitivity

R_2 = input z of the device

R_1 = Z of the pickup

36. If the open circuit sensitivity is known, a sensitivity can be corrected for any load by use of the following formula.

$$Sen_{corr} = Sen_{oc} \left(\frac{R_2}{R_1 + R_2}\right)$$

Where Sen_{corr} = sensitivity corrected for loading effect

Sen_{oc} = open circuit sensitivity

R_1 = Z of the pickup

R_2 = input Z of the device

37. The sensitivity of a velocity pickup can be determined by using the following formula.

$$Sen = \frac{\sqrt{2} \quad RMS_{mv}}{\pi f \ DA}$$

Where Sen = sensitivity in mv/inch/sec

RMS_{mv} = the RMS reading in millivolts

f = frequency in hertz

DA = double amplitude

FORCE MEASUREMENTS

1. Strain: Change in length divided by original length.

$$\epsilon = \frac{\triangle L}{L}$$

Where ϵ = strain

l = length

$\triangle$l = change in length

2. Stress: Force per unit area.

$$\sigma = \frac{F}{A}$$

Where σ = stress

F = force

A = area

3. Young's Modulus: Stress divided by strain.

$$Y = \frac{\sigma}{\epsilon} = \frac{F/A}{L/L} = PSI$$

4. Poisson's Ratio: Transverse strain to axial strain.

$$\mu = \frac{\epsilon T}{\epsilon A}$$

Where μ = Poisson's Ratio

ϵT = transverse strain (right angle to applied force)

ϵA = axial strain (in line with applied force)

SOUND MEASUREMENT

Weber--Fechner Law: An approximate law which states that the magnitude of the sensation of loudness is proportional to the logarithm of the intensity, or:

$$L_{(dB)} = 10 \, \text{Log}_{10} \frac{I}{I_0}$$

Where L = magnitude of the sensation of loudness

I = intensity

I_0 = intensity at the threshold of hearing (10^{-10} microwatts/cm^2)

NOTE: I_0 is also given as 20 Newtons/M^2, the threshold of hearing is 0 dBs; and the threshold of pain of hearing is 120 dBs.

ALPHABETICAL INDEX