

# Library 1666: Electrical Engineering

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## **1. Disclaimer & Copyright**

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This program has been tested but may contain errors. I'm making no warranty of any kind with regard to this software, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose. I shall not be liable for any errors or for incidental or consequential damages in connection with the furnishing, performance, or use of this software. Suggestions, criticism and/or improvement suggestions can be send to the author at [Software49g@gmx.de](mailto:Software49g@gmx.de). All rights reserved.

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## **2. Credits**

Thanks to ACO for the HP 49G, Wolfgang Rautenberg for OT49, Eduardo M. Kalinowski for "Programming in System RPL", Mika Heiskanen for BZ and various post from different authors in comp.sys.hp48. Without them this program couldn't been written.

### **3. System Requirements & Installation**

#### **3.1. System Requirements**

Library 1666: Electrical Engineering has been coded and compiled with Debug4x and is written in System RPL. It is designed for the HP 49G+ and HP 50G.

Electrical Engineering requires TreeBrowser and GUISLV/GUIMES is recommended as the default solver for it.

If you are not familiar about TreeBrowser and GUISLV/GUIMES then please read the documentations that comes with it.

#### **3.2. Installation & Deinstallation**

Use the installation program EEI on the SD card to install / update / modify / delete the Electrical Engineering library.

Insert the SD card into the turned off calculator and then power up the calculator. Now start the installation program EEI from the SD card.

-> in RPN mode key in :3:EEI [ENTER] [EVAL]

-> in ALG mode key in EVAL(:3:EEI) [ENTER]

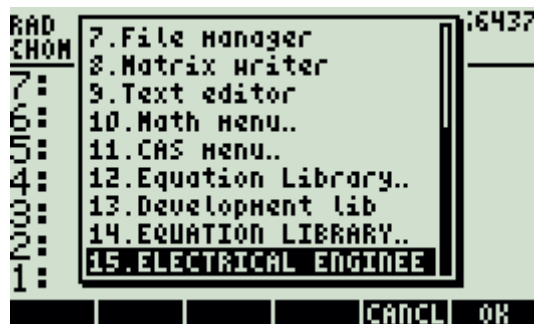
The installation program will guide you through the installation process.

## 4. Using the library

### 4.1. Starting Electrical Engineering

Electrical Engineering can be started in two different ways.

Through the **APPS** key

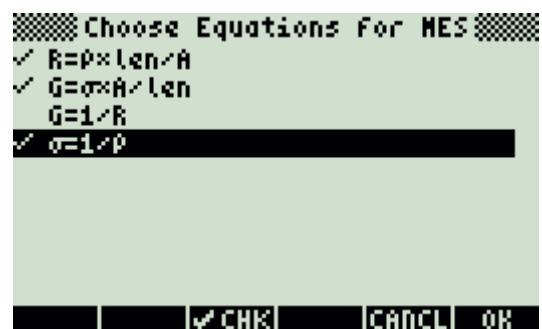
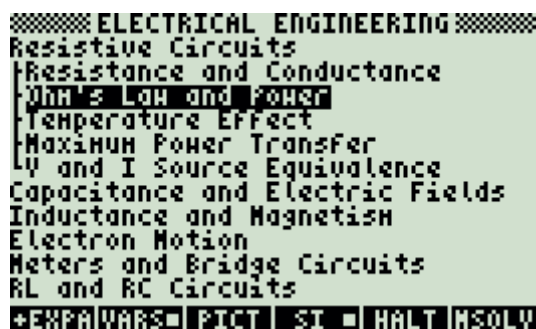


or through the library menu via **LIB**.



### 4.2. Choosing a set of equations of a subtopic

Move the cursor to a subtopic and then press **TOOL** to open a choose box to select the equations which will be passed to the Multiple Equation Solver.



### 4.3. Choosing all equations of a subtopic

Move the cursor to a subtopic and then press **APPS** to start the Multiple Equation Solver with all equations of that subtopic.

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Point Charge
Long Charged Line
Charged Disk
Parallel Plates
Parallel Wires
Coaxial Cable
Sphere
Inductance and Magnetism
Electron Motion
+EXPA VARS= PICT= SI = HALT MSOLV
```

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Point Charge
Long Charged Line
Charged Disk
Parallel Plates
Parallel Wires
Coaxial Cable
Sphere
Inductance and Magnetism
Electron Motion
+EXPA VARS= PICT= SI = HALT MSOLV
```

```
===== Parallel Plates =====
Eq: ( 'E=V/d' 'C=CONST...'
E: 0_V/m Er: 0
A: 0_cm^2 e: 0_C
F: 0_N d: 0_m
W: 0_J v: 0_V
c: 0_F
Electric Field
EDIT VARS= PICT= SI = HALT MSOLV
```

### 4.4. Choosing a single equation of a subtopic

Move the cursor to the equation of a subtopic and then press **APPS**

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Resistance and Conductance
Ohm's Law and Power
V=I*R
P=V*I
P=I^2*R
P=V^2/R
P=V^2*G
R=1/G
Temperature Effect
Maximum Power Transfer
EQN VARS= PICT SI = HALT SOLVE
```

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Resistance and Conductance
Ohm's Law and Power
V=I*R
P=V*I
P=I^2*R
P=V^2/R
P=V^2*G
R=1/G
Temperature Effect
Maximum Power Transfer
EQN VARS= PICT SI = HALT SOLVE
```

```
===== P=I^2*R =====
Eq: 'P=I^2*R'
P: 0_W
I: 0_A
R: 0_Ω
Power
EDIT VARS= PICT SI = HALT SOLVE
```





```

Solving for R
R: 2166666.66667_Ω
Zero

EDIT VARS VIEW ALL MSOLV

```

```

Resistance and Conductance
Eq: ( 'R=p*len/A' 'G=1...
p 6.5_Ω*cm
len 1500._m
A .45_cm^2
G 4.61538461538E-7_S
R 2166666.66667_Ω
Conductance
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

Resistance and Conductance
R: 2166666.66667_Ω
G: 4.61538461538E-7_S

VALU EQNS PRINT EXIT

```

### 5.1.2. Ohm's Law and Power

#### Example:

A 4.7\_kΩ load carries a current of 275\_mA. Calculate the voltage across the load, power dissipated and load conductance.

#### Solution:

Upon examining the problem, several choices are noted. Either equations 1, 2 and 6 or 2, 3 and 5 or 2, 3 and 6 or 1, 2 and 5 or **all** the equations.

The last choice was made here.

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Resistance and Conductance
Ohm's Law and Power
V=I*R
P=V*I
P=I^2*R
P=V^2/R
P=V^2*G
R=1/G
Temperature Effect
Maximum Power Transfer
-EXPA VARS= PICT SI = HALT MSOLV
```

```
===== Ohm's Law and Power =====
Eq: ( 'V=I*R' 'P=V*I' ...
I: 275_mA
P: 0_W
V: 0_V
R: 4.700000_kΩ
G: 0_S
Conductance
EDIT VARS VIEW ALL MSOLV
```

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Resistance and Conductance
Ohm's Law and Power
V=
P= Starting
P= Solver...
P=
P=V^2*G
R=1/G
Temperature Effect
Maximum Power Transfer
-EXPA VARS= PICT SI = HALT MSOLV
```

```
===== Ohm's Law and Power =====
Eq: ( 'V=I*R' 'P=V*I' ...
I: 275_mA
P: 355.437500_W
V: 1292.500000_V
R: 4.700000_kΩ
G: 0.000213_S
Conductance
EDIT VARS VIEW ALL MSOLV
```

### 5.1.3. Temperature Effect

#### Example:

A 145\_Ω resistor at 75\_°F reads 152.4\_Ω at 125\_°C. Find the temperature coefficient of the resistance.

#### Solution:

Since there is only one equation in this topic, there is no need to make a choice of equations.

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Resistance and Conductance
Ohm's Law and Power
Temperature Effect
R2=R1*(1+α*(T2-T1))
Maximum Power Transfer
V and I Source Equivalence
Capacitance and Electric Fields
Inductance and Magnetism
Electron Motion
Meters and Bridge Circuits
EQN VARS PICT SI HALT SOLVE
```

```
===== R2=R1*(1+α*(T2-T1)) =====
Eq: 'R2=R1*(1+α*TDELTA...'
R2: 152.400000_Ω
R1: 145_Ω
α: 0.1/K
T2: 125_°C
T1: 75_°F
Temperature coefficient
EDIT VARS VIEW INFO SOLVE
```

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Resistance and Conductance
Ohm's Law and Power
Teh
Max
V a
Starting
Solver...
Capacitance and Electric Fields
Inductance and Magnetism
Electron Motion
Meters and Bridge Circuits
EQN VARS PICT SI HALT SOLVE
```

```
===== R2=R1*(1+α*(T2-T1)) =====
Eq: 'R2=R1*(1+α*TDELTA...'
R2: 152.400000_Ω
R1: 145_Ω
α: 0.000505_1/K
T2: 125_°C
T1: 75_°F
Temperature coefficient
EDIT VARS VIEW INFO SOLVE
```

#### 5.1.4. Maximum DC Power Transfer

### Example:

A 12\_V car battery has a resistive load of 0.52\_Ohm. The battery has a source impedance of 0.078\_Ohm. Find the maximum power deliverable from this battery and the power delivered to this resistive load.

**Solution:**

Upon examining the problem, equation 1, 2, 3 and 4 are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Resistive Circuits
Resistance and Conductance
Ohm's Law and Power
Temperature Effect
Maximum Power Transfer
 $V_I = V_S \times R_L / (R_S + R_L)$ 
 $I_I = V_S / (R_S + R_L)$ 
 $P = I_I \times V_I$ 
 $P_{max} = V_S^2 / (4 \times R_S)$ 
 $R_{th} = R_S$ 
V and I Source Equivalence
-ENPA VARS= PICT= SI= HALT NSOLV

```

☒ Choose Equations For MES

- ☒  $V_L = V_S \times R_L / (R_S + R_L)$
- ☒  $I_L = V_S / (R_S + R_L)$
- ☒  $P = I_L \times V_L$
- ☒  $P_{max} = V_S^2 / (4 \times R_S)$
- $R_L = R_S$

☐ ☒ CHK ☐ CANCEL ☐ OK

```

Maximum Power Transfer
Eq: ( 'V1=VS*R1/(RS+R1...'
RL: 0.5200_Ω P: 0_W
IL: 0_A VL: 0_V
Pmax: 0_W VS: 12_V
RS: 0.0780_Ω

Maximum power in load
EDIT VARS VIEW ALL MSOLV

```

```

Maximum Power Transfer
Eq: C 'V1=VS*R1/(RS+R1...
RL=0.5200_Ω P=209.3936...
IL=20.0669... VL=10.4348...
Pmax=461.53... Ws=12_V
Rs=0.0780_Ω

Maximum power in load
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

Maximum Power Transfer
V1: 10.4348_V
I1: 20.0669_A
P: 209.3936_W
Pmax: 461.5385_W

VALU= ENDS PRINT      EXIT

```

### 5.1.5. V and I Source Equivalence

#### Example:

Find the short circuit current equivalent for a 5\_V source with a 12.5\_Ohm source resistance.

#### Solution:

Since there is only one equation in this topic, there is no need to make a choice of equations.

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Resistance and Conductance
Ohm's Law and Power
Temperature Effect
Maximum Power Transfer
V and I Source Equivalence
Vs=Is*Rs
Capacitance and Electric Fields
Inductance and Magnetism
Electron Motion
Meters and Bridge Circuits
EQN VARS=PICT= SI = HALT SOLVE
```

```
===== Vs=Is*Rs =====
Eq: 'Vs=Is*Rs'
Vs: 5_V
Is: 0_A
Rs: 12.5000_Ω

Current source
EDIT VARS VIEW SOLVE
```

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Resistance and Conductance
Ohm's Law and Power
Temperature Effect
Maximum Power Transfer
V and I Source Equivalence
Vs=Is*Rs
Capacitance and Electric Fields
Inductance and Magnetism
Electron Motion
Meters and Bridge Circuits
EQN VARS=PICT= SI = HALT SOLVE
```

```
===== Vs=Is*Rs =====
Eq: 'Vs=Is*Rs'
Vs: 5_V
Is: 0.4000_A
Rs: 12.5000_Ω

Current source
EDIT VARS VIEW INFO SOLVE
```

## 5.2. Capacitance and Electric Fields

```

ELECTRICAL ENGINEERING
Capacitance and Electric Fields
Point Charge
Long Charged Line
Charged Disk
Parallel Plates
Parallel Wires
Coaxial Cable
Sphere
-EXPA VARS PICT SI HALT HELP

```

### 5.2.6. Point Charge

#### Example:

A point charge of  $14.5 \times 10^{-14}$  coulomb is located 2.4\_m away from an instrument measuring electric field and absolute potential. The permittivity of air is 1.08. Compute the electric field and potential.

#### Solution:

Upon examining the problem, both equations are needed to solve this problem. Note that  $\epsilon_0$ , the permittivity of free space does not appear as one of the variables that needs to be entered. It is entered automatically by the software, as it is a built in constant. However,  $\epsilon_r$ , the relative permittivity must be entered as a known value.

```

ELECTRICAL ENGINEERING
Resistive Circuits
Capacitance and Electric Fields
Point Charge
Er=Q/(4*pi*epsilon0*Er*r^2)
V=Q/(4*pi*epsilon0*Er*r)
Long Charged Line
Charged Disk
Parallel Plates
Parallel Wires
Coaxial Cable
Sphere
-EXPA VARS PICT SI HALT MSOLV

```

```

ELECTRICAL ENGINEERING
Resistive Circuits
Capacitance and Electric Fields
Point Charge
Er= Starting
V= Solver...
Long Charged Line
Charged Disk
Parallel Plates
Parallel Wires
Coaxial Cable
Sphere
-EXPA VARS PICT SI HALT MSOLV

```

```

Point Charge
Eq: ( 'Er=Q/(4*pi*CONST...
Er: 0_V/m
V: 0_V
Q: 1.450000E-13_C
Er: 1.080000
r: 2.400000_m
Radial electric field
EDIT VARS VIEW ALL MSOLV

```

```

Point Charge
Eq: ( 'Er=Q/(4*pi*CONST...
Er: 0.00020948994_V/m
V: 0.00050277585_V
Q: 1.45000000000E-13_C
Er: 1.08000000000
r: 2.40000000000_m
Radial electric field
EDIT VARS VIEW ALL MSOLV

```

### 5.2.7. Long Charged Line

#### Example:

An aluminum wire suspended in air carries a charge density of  $2.75\text{E-}15$  coulombs/m. Find the electric field  $50$ \_cm away. Assume the relative permittivity of air to be  $1.04$ .

#### Solution:

Since there is only one equation in this topic, there is no need to make a choice of equations.

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Point Charge
Long Charged Line
Charged Disk
Parallel Plates
Parallel Wires
Coaxial Cable
Sphere
Inductance and Magnetism
EQN VARS= PICT SI = HALT SOLVE
```

```
Er=p1/(2*pi*E0*Er*r)
Eq: 'Er=p1/(2*pi*CONST(
Er: 0_V/m
p1: 2.750000E-15_C/m
er: 1.040000
r: 50_cm

Radial electric field
EDIT VARS VIEW SOLVE
```

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Point Charge
Long Charged Line
Charged Disk
Parallel Plates
Parallel Wires
Coaxial Cable
Sphere
Inductance and Magnetism
EQN VARS= PICT SI = HALT SOLVE
```

```
Er=p1/(2*pi*E0*Er*r)
Eq: 'Er=p1/(2*pi*CONST(
Er: 0.000095_V/m
p1: 2.750000E-15_C/m
er: 1.040000
r: 50_cm

Radial electric field
EDIT VARS VIEW INFO SOLVE
```

### 5.2.8. Charged Disk

#### Example:

A charged disc 5.5\_cm in radius produces an electric field of .2\_V/cm at a distance of 50\_cm away from the surface of the disc. Assuming that relative permittivity of air is 1.04, what is the charge density on the surface of the disc?

#### Solution:

Upon examining the problem, select the first equation to solve for the unknown variable.

```
##### ELECTRICAL ENGINEERING #####
Resistive Circuits
Capacitance and Electric Fields
-Point Charge
-Long Charged Line
-Charged Disk
  Ez=ps/(2*E0*Er)*(1-ABS(z)/f(ra^
  Vz=ps/(2*E0*Er)*(f(ra^2+z^2)-AB
-Parallel Plates
-Parallel Wires
-Coaxial Cable
-Sphere
-EXPR VARS= PICT SI = HALT MSOLV
```

```
##### Choose Equations for MES #####
✓ Ez=ps/(2*E0*Er)*(1-ABS(z)/f(..
  Vz=ps/(2*E0*Er)*(f(ra^2+z^2)..
#####
✓CHK CANCEL OK
```

```
##### Charged Disk #####
Eq: 'Ez=ps/(2*CONST(ε0...
Ez: 0.200000_V/cm
ps: 0_C/m^2
Er: 1.040000
z: 50_cm
ra: 5.500000_cm
Charge density
EDIT VARS VIEW SOLVE
```

```
##### Charged Disk #####
Eq: 'Ez=ps/(2*CONST(ε0...
Ez: 0.200000_V/cm
ps: 6.143364E-8_C/m^2
Er: 1.040000
z: 50_cm
ra: 5.500000_cm
Charge density
EDIT VARS VIEW INFO SOLVE
```



### 5.2.9. Parallel Plates

#### Example:

A silicon dioxide insulator forms the insulator for the gate of a MOS transistor. Calculate the charge, electric field and mechanical force on the plates of a 5\_V MOS capacitor with an area of 1250\_μ<sup>2</sup> and a thickness of .15\_ μ. Use a value of 3.9 for permittivity of SiO<sub>2</sub>.

#### Solution:

Upon examining the problem, all of the equations are needed to compute the solution to this problem.

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Point Charge
Long Charged Line
Charged Disk
Parallel Plates
E=V/d
C=ε0×εr×A/d
Q=C×V
F=-1/2×V^2×C/d
W=1/2×V^2×C
-EXPN VARS= PICT= SI= HALT MSOLV
```

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Point Charge
Long Charged Line
Charged Disk
Parallel Plates
E=V/d
C=ε0×εr×A/d
Q=C×V
F=-1/2×V^2×C/d
W=1/2×V^2×C
-EXPN VARS= PICT= SI= HALT MSOLV
```

```
===== Parallel Plates =====
Eq: ( 'E=V/d' 'C=CONST...'
E: 0_V/m      Er: 3.9000
A: 1250.000... ε: 0_C
F: 0_mN       Q: 0.1500_μ
W: 0_J        V: 5_V
C: 0_F
Capacitance
EDIT VARS VIEW ALL MSOLV
```

```
===== Parallel Plates =====
Eq: ( 'E=V/d' 'C=CONST...'
E: 33333333... Er: 3.9000
A: 1250.000... ε: 1.4388E-...
F: -0.0240_... Q: 0.1500_μ
W: 3.5970E-... V: 5_V
C: 2.8776E-...
Capacitance
EDIT VARS VIEW ALL MSOLV
```

Press **TOOL** to view all calculated results.

```
===== Parallel Plates =====
E: 33333333.3333_V/m
C: 2.8776E-13_F
Q: 1.4388E-12_C
F: -0.0240_mN
W: 3.5970E-12_J
VALU= EQNS PRINT EXIT
```

### 5.2.10. Parallel Wires

#### Example:

Compute the capacitance per unit length of a set of power lines 1\_cm radius and 1.5\_m apart. The dielectric medium separating the wires is air with a relative permittivity of 1.04.

#### Solution:

Since there is only one equation in this topic, there is no need to make a choice of equations.

```
##### ELECTRICAL ENGINEERING #####
Resistive Circuits
Capacitance and Electric Fields
-Point Charge
-Long Charged Line
-Charged Disk
-Parallel Plates
-Parallel Wires
- $c = \pi \times \epsilon_0 \times \epsilon_r / \text{ACOSH}(d / (2 \times r_a))$ 
-Coaxial Cable
-Sphere
Inductance and Magnetism
EQN VARS= PICT SI = HALT SOLVE
```

```
#####  $c = \pi \times \epsilon_0 \times \epsilon_r / \text{ACOSH}(d / (2 \times r_a))$  #####
Eq: 'c1=π*CONST(ε0)*εr...'
cl: 0_F/m
εr: 1.0400
d: 1.5000_m
ra: 1_cm

Capacitance per unit length
EDIT VARS VIEW SOLVE
```

```
##### ELECTRICAL ENGINEERING #####
Resistive Circuits
Capacitance and Electric Fields
-Point Charge
-Long Charged Line
-Charged Disk
-Parallel Plates
-Parallel Wires
- $c = \pi \times \epsilon_0 \times \epsilon_r / \text{ACOSH}(d / (2 \times r_a))$ 
-Coaxial Cable
-Sphere
Inductance and Magnetism
EQN VARS= PICT SI = HALT SOLVE
```

```
#####  $c = \pi \times \epsilon_0 \times \epsilon_r / \text{ACOSH}(d / (2 \times r_a))$  #####
Eq: 'c1=π*CONST(ε0)*εr...'
cl: 5.7736E-12_F/m
εr: 1.0400
d: 1.5000_m
ra: 1_cm

Capacitance per unit length
EDIT VARS VIEW INFO SOLVE
```

### 5.2.11. Coaxial Cable

#### Example:

A coaxial cable with an inner cable radius of 0.3\_cm and an outer conductor with an inside radius of 0.5\_cm has a mica filled insulator with a permittivity of 2.1.

If the inner conductor carries a linear charge of 3.67E-15\_coulombs/m, find the electric field at the outer edge of the inner conductor and potential between the two conductors. Compute the capacitance per m of the cable.

#### Solution:

Upon examining the problem, all of the equations are needed to compute the solution to this problem.

```

===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Point Charge
Long Charged Line
Charged Disk
Parallel Plates
Parallel Wires
Coaxial Cable
V=PI/(2*x*E0*Er)*LN(rb/ra)
Er=V/(r*LN(rb/ra))
cl=2*x*E0*Er/LN(rb/ra)
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Point Charge
Long Charged Line
Charged Disk
Parallel Plates
Parallel Wires
Coaxial Cable
V=PI/(2*x*E0*Er)*LN(rb/ra)
Er=V/(r*LN(rb/ra))
cl=2*x*E0*Er/LN(rb/ra)
-EXPA VARS= PICT= SI= HALT NSOLV

```

Starting Solver...

```

===== Coaxial Cable =====
PI: 3.67000000E-15_C/m
Er: 0_V/m
V: 0_V
r: 0.30000000_cm
cl: 0_F/m
Er: 2.10000000
rb: 0.50000000_cm
ra: 0.30000000_cm
Radial electric field
EDIT VARS VIEW ALL NSOLV

```

```

===== Coaxial Cable =====
PI: 3.67000000E-15_C/m
Er: 0.01047121_V/m
V: 0.00001605_V
r: 0.30000000_cm
cl: 2.28704768E-10_F/m
Er: 2.10000000
rb: 0.50000000_cm
ra: 0.30000000_cm
Radial electric field
EDIT VARS VIEW ALL NSOLV

```

Press TOOL to view all calculated results.

```

===== Coaxial Cable =====
V: 0.00001605_V
Er: 0.01047121_V/m
cl: 2.28704768E-10_F/m
VALU= EQNS PRINT EXIT

```

### 5.2.12. Sphere

**Example:**

Two concentric spheres 2\_cm and 2.5\_cm radius, are separated with a dielectric with a relative permittivity of 1.25. The inner sphere has a charge of 1.45E-14\_coulombs. Find the potential difference between the two spherical plates of the capacitor as well as the capacitance.

**Solution:**

Upon examining the problem, equations 1 and 3 are needed to compute a solution.

```

===== ELECTRICAL ENGINEERING =====
Capacitance and Electric Fields
Point Charge
Long Charged Line
Charged Disk
Parallel Plates
Parallel Wires
Coaxial Cable
Sphere
V=Q/(4*pi*E0*Er)*(1/ra-1/rb)
E=Q/(4*pi*E0*Er*r^2)
C=4*pi*E0*Er*ra*rb/(rb-ra)
-EXPA VARS= PICT SI= HALT NSOLV

```

Choose Equations For MES

✓  $V = Q / (4 \times \pi \times \epsilon_0 \times \epsilon_r) \times (1/r_a - 1/r_b)$   
 $E_r = Q / (4 \times \pi \times \epsilon_0 \times \epsilon_r \times r^2)$   
 ✓  $C = 4 \times \pi \times \epsilon_0 \times \epsilon_r \times r_a \times r_b / (r_b - r_a)$

✓CHK CANCEL OK

```

Sphere
v: 0_V
q: 1.450000E-14_C
c: 0_F
Er: 1.250000
rb: 2.500000_cm
ra: 2_cm
Potential

```

```

Sphere
v=0.001043_V
q=1.450000E-14_C
c=1.390813E-11_F
E=1.250000
r=2.500000_cm
rho=2_cm
Potential
EDIT VARS VIEW ALL MSOLV

```

### 5.3. Inductors and Magnetism

```

ELECTRICAL ENGINEERING
Inductance and Magnetism
Long Line
Long Strip
Parallel Wires
Loop
Coaxial Cable
Skin Effect
Electron Motion
-EXPA VARS PICT SI = HALT HELP

```

#### 5.3.1. Long Line

##### Example:

An overhead transmission line carries a current of 1200\_A at 10\_m away from the surface of the earth. Find the magnetic field at the surface of the earth.

##### Solution:

Since there is only one equation in this topic, there is no need to make a choice of equations.

```

ELECTRICAL ENGINEERING
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Long Line
Long Strip
Parallel Wires
Loop
Coaxial Cable
Skin Effect
Electron Motion
EQN VARS= PICT SI = HALT SOLVE

```

```

B=μ0×I/(2×π×r)
Eq: 'B=CONST(μ0)*I/(2*...
B: 0_T
I: 1200.000000_A
r: 10_m

Magnetic field
EDIT VARS VIEW SOLVE

```

```

ELECTRICAL ENGINEERING
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Long Line
Long Strip
Parallel Wires
Loop
Coaxial Cable
Skin Effect
Electron Motion
EQN VARS= PICT SI = HALT SOLVE

```

```

B=μ0×I/(2×π×r)
Eq: 'B=CONST(μ0)*I/(2*...
B: 0.000024_T
I: 1200.000000_A
r: 10_m

Magnetic field
EDIT VARS VIEW INFO SOLVE

```

### 5.3.2. Long Strip

#### Example:

A strip transmission line 2\_cm wide carries a current of 16025\_A/m. Find the magnetic field values 1\_m away and 2\_m from the surface of the strip.

#### Solution:

Upon examining the problem, both equations need to be used to compute the solution.

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Long Line
Long Strip
Bx=-mu*Is/(2*pi)*(ATAN((x+d/2)/y
By=mu*Is/(4*pi)*LN((y^2+(x+d/2)^
Parallel Wires
Loop
Coaxial Cable
Skin Effect
-EXPA VARS= PICT SI = HALT NSOLV
```

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Long Line
Long Strip
Starting Solver...
Bx=-mu*Is/(2*pi)*(ATAN((x+d/2)/y
By=mu*Is/(4*pi)*LN((y^2+(x+d/2)^
Parallel Wires
Loop
Coaxial Cable
Skin Effect
-EXPA VARS= PICT SI = HALT NSOLV
```

```
===== Long Strip =====
Bx: 0_T
By: 0_T
Is: 16025.000000_A/m
x: 2_m
x: 1_m
d: 2_cm
Magnetic Field, x axis
EDIT VARS VIEW ALL NSOLV
```

```
===== Long Strip =====
Bx: -0.000026_T
By: 0.000013_T
Is: 16025.000000_A/m
x: 2_m
x: 1_m
d: 2_cm
Magnetic Field, x axis
EDIT VARS VIEW ALL NSOLV
```

### 5.3.3. Parallel Wires

### Example:

A pair of aluminum wires 1.5\_cm in diameter are separated by 1\_m and carry currents of 1200\_A and 1600\_A in opposite directions. Find the force of attraction, the magnetic field generated midway between the wires and the inductance per unit length resulting from their proximity.

**Solution:**

Upon examining the problem, equations 1 and 2 and 3 are needed to compute a solution.

```

===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Long Line
Long Strip
Parallel Wires
B=mu0*I/(2*pi*a)
F=mu0*I1*I2/(2*pi*a)
Bx=mu0*(2*pi)*(I1/x-I2/(D-x))
L=mu0/(4*pi)+mu0/pi*ACOSH(D/(2*a))
Loop
-EXPA VARS= PICT SI = HALL MSOLV

```

Choose Equations for MES

$B = \mu_0 \times I / (2 \times \pi \times D)$

✓  $F_H = \mu_0 \times I_1 \times I_2 / (2 \times \pi \times D)$

✓  $B_x = \mu_0 \times (2 \times \pi) \times (I_1 / x - I_2 / (D - x))$

✓  $L = \mu_0 / (4 \times \pi) + \mu_0 / \pi \times \text{ACOSH}(D / (2 \times a..$

✓CHK CANCEL ON

Eq: { 'Fw=CONST( $\mu_0$ )\*I1...  
 Fw: 0\_N/m      Bx: 0\_T  
 I1: 1200.00...    I2: -1600.0...  
 x: 50\_cm      L: 0\_H/m  
 d: 1\_m      a: 1.500000...

Inductance per unit length

EDIT VARS VIEW ALL MSOLV

```

Parallel Wires
Eq: { 'FW=CONST( $\mu_0$ )*I1...
FW=-0.3840... Bx=0.00112...
I1=1200.00... I2=-1600.0...
x=50_cm L=0.000002...
D=1_m D=1.500000...

Inductance per unit length
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

Parallel Wires
Fw: -0.38400000_N/m
Bx: 0.00112000_T
L: 0.00000178_H/m

```

### 5.3.4. Loop

#### Example:

Calculate the torque and inductance for a rectangular loop of width 7\_m and length 5\_m, carrying a current of 50\_A, separated by a distance of 2\_m from a wire of infinite length carrying a current of 30\_A. The loop angle of incidence is 5 degrees relative to the parallel plane intersecting the infinite wire.

#### Solution:

Upon examining the problem, the last two equations are needed.

```

===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
-Long Line
-Long Strip
-Parallel Wires
-Loop
  B=μ0×I×a^2/(2×f(a^2+z^2)^3)
  Ls=μ0×g×(Ln(2×a/r0)-2)
  L12=-μ0×g×COS(θ)/(2×π)×Ln((b+d)
  T12=μ0×g×SIN(θ)/(2×π)×I1×I2×Ln(
-EXPA VARS= PICT= SI= HALT MSOLV
  
```

```

===== Choose Equations for MES =====
B=μ0×I×a^2/(2×f(a^2+z^2)^3)
Ls=μ0×g×(Ln(2×a/r0)-2)
✓ L12=-μ0×g×COS(θ)/(2×π)×Ln((b+d)
✓ T12=μ0×g×SIN(θ)/(2×π)×I1×I2×Ln(
===== ✓CHK===== CANCEL OK
  
```

```

===== Loop =====
Eq: ( 'L12=CONST(μ0)*a...
L12: 0_H T12: 0_N*m
0: 5_m 0: 5_°
I1: 30_A I2: 50_A
0: 7_m 0: 2_m

Mutual inductance
EDIT VARS VIEW ALL MSOLV
  
```

```

===== Loop =====
Eq: ( 'L12=CONST(μ0)*a...
L12: 0.000000... T12: 0.00019...
0: 5_m 0: 5_°
I1: 30_A I2: 50_A
0: 7_m 0: 2_m

Mutual inductance
EDIT VARS VIEW ALL MSOLV
  
```

Press **TOOL** to view all calculated results.

```

===== Loop =====
L12: 0.000001_H
T12: 0.000197_N*m

===== VALU= EQNS PRINT===== EXIT
  
```



### 5.3.5. Coaxial Cable

#### Example:

A coaxial cable has an inner conductor radius of 3\_mm and the outer conductor radius of 0.15\_in. Find its inductance per meter.

#### Solution:

Since there is only one equation in this topic, there is no need to make a choice of equations.

```
##### ELECTRICAL ENGINEERING #####
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
-Long Line
-Long Strip
-Parallel Wires
-Loop
-Coaxial Cable
  L= $\mu_0/(8\pi)+\mu_0/(2\pi)\times\ln(r_b/r_a)$ 
-Skin Effect
Electron Motion
EQN VARS=PICT= SI = HALT SOLVE
```

```
##### L= $\mu_0/(8\pi)+\mu_0/(2\pi)\times\ln(r_b/r_a)$  #####
Eq: 'L=CONST( $\mu_0$ )/(8* $\pi$ )...'
L: 0_H/m
rb: 3_mm
ra: 0.1500000000_in

Inductance per unit length
EDIT VARS VIEW INFO SOLVE
```

```
##### ELECTRICAL ENGINEERING #####
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
-Long
-Long Starting
-Par Solver...
-Loop
-Coaxial Cable
  L= $\mu_0/(8\pi)+\mu_0/(2\pi)\times\ln(r_b/r_a)$ 
-Skin Effect
Electron Motion
EQN VARS=PICT= SI = HALT SOLVE
```

```
##### L= $\mu_0/(8\pi)+\mu_0/(2\pi)\times\ln(r_b/r_a)$  #####
Eq: 'L=CONST( $\mu_0$ )/(8* $\pi$ )...'
L: 0.0000000022_H/m
rb: 3_mm
ra: 0.1500000000_in

Inductance per unit length
EDIT VARS VIEW INFO SOLVE
```

### 5.3.6. Skin Effect

#### Example:

Find the effect on depth of signal penetration for a 100 MHz signal in copper with a resistivity of  $6.5 \times 10^{-6} \text{ } \Omega \cdot \text{cm}$ . The relative permeability of copper is 1.02.

#### Solution:

Upon examining the problem, both equations need to be used to compute the solution.

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
-Long Line
-Long Strip
-Parallel Wires
-Loop
-Coaxial Cable
-Skin Effect
  %s=1/sqrt(pi*f*u0*mu*r/rho)
  %Reff=f*(pi*f*u0*mu*r*rho)
-EXPA VARS= PICT SI = HALT NSOLV
```

```
===== Skin Effect =====
Eq: ( '%s=1/sqrt(pi*f*CONST...
%: 0_m
Reff: 0_Ω
f: 100_MHz
u0: 1.0200000000
rho: 0.0000065000_Ω*cm
Skin depth
EDIT VARS VIEW ALL NSOLV
```

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
-Long
-Long Starting
-Long Solver...
-Parallel
-Loop
-Coaxial Cable
-Skin Effect
  %s=1/sqrt(pi*f*u0*mu*r/rho)
  %Reff=f*(pi*f*u0*mu*r*rho)
-EXPA VARS= PICT SI = HALT NSOLV
```

```
===== Skin Effect =====
Eq: ( '%s=1/sqrt(pi*f*CONST...
%: 0.0000127051_m
Reff: 0.0051160718_Ω
f: 100_MHz
u0: 1.0200000000
rho: 0.0000065000_Ω*cm
Skin depth
EDIT VARS VIEW ALL NSOLV
```

## 5.4. Inductors and Magnetism

```

ELECTRICAL ENGINEERING
Electron Motion
Electron Beam Deflect
Thermionic Emission
Photoemission
Meters and Bridge Circ
RL and RC Circuits
RLC Circuits
AC Circuits
-EXPA VARS PICT SI HALT HELP

```

### 5.4.1. Electron Beam Deflection

#### Example:

An electron beam in a CRT is subjected an accelerating voltage of 1250\_V. The screen target is 40\_cm away from the center of the deflection section. The plate separation is 0.75\_cm and the horizontal path length through the deflection region is 0.35 cm. The deflection region is controlled by a 100\_V voltage. A magnetic field of 0.456\_T puts the electrons in the beam in a circular orbit. What is the vertical deflection distance of the beam when it reaches the CRT screen?

#### Solution:

Upon examining the problem, the first three equations are needed to solve this problem.

```

ELECTRICAL ENGINEERING
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Electron Motion
Electron Beam Deflection
v=J(2*(q/me)*Va)
r=me*v/(q*B)
yd=L*Ls/(2*d*Va)*Vd
y=q*Vd/(2*me*d*v^2)*z^2
Thermionic Emission
Photoemission
-EXPA VARS PICT SI HALT MSOLV

```

```

Choose Equations for MES
v=J(2*(q/me)*Va)
r=me*v/(q*B)
yd=L*Ls/(2*d*Va)*Vd
y=q*Vd/(2*me*d*v^2)*z^2
CHK CANCEL OK

```

```

Electron Beam Deflection
Eq: { 'v=J(2*(CONST(q)...
r: 0_cm v: 0_m/s
B: 0.4560_T yd: 0_cm
L: 0.3500_cm Ls: 40_cm
d: 0.7500_cm Va: 1250.00...
Vd: 100_V
Radius of circular path
EDIT VARS VIEW ALL MSOLV

```

```

Electron Beam Deflection
Eq: { 'v=J(2*(CONST(q)...
r: 0.0261_cm v: 20969141...
B: 0.4560_T yd: 0.7467...
L: 0.3500_cm Ls: 40_cm
d: 0.7500_cm Va: 1250.00...
Vd: 100_V
Radius of circular path
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```
Electron Beam Deflection
v: 20969141.7125_m/s
r: 0.0261_cm
yd: 0.7467_cm

VALU= EQNS PRINT  EXIT
```

### 5.4.2. Thermionic Emission

#### Example:

A cathode consists of a cesium coated tungsten with a surface area of  $2.45\text{ cm}^2$ . It is heated to  $1200\text{ K}$  in a power vacuum tube. If the Richardson's constant is  $120\text{ A}/(\text{m}^2\text{K}^2)$  and the work function is  $1.22\text{ V}$ , find the current available from such the cathode.

#### Solution:

Since there is only one equation in this topic, there is no need to make a choice of equations.

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Electron Motion
Electron Beam Deflection
Thermionic Emission
Photoemission
Meters and Bridge Circuits
RL and RC Circuits
RLC Circuits
EQN VARS PICT SI HALT SOLVE
```

```
===== I=A0*S*T^2*e^(-q*d/(k*T)) =====
Eq: 'I=A0*S*T^2*e^(-CO...'
I: 0_A
A0: 120_A/(m^2*K^2)
s: 2.4500_cm^2
T: 1200.0000_K
d: 1.2200_V
Thermionic current
EDIT VARS VIEW SOLVE
```

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Elec
Ele Starting
The Solver...
The
Photoemission
Meters and Bridge Circuits
RL and RC Circuits
RLC Circuits
EQN VARS PICT SI HALT SOLVE
```

```
===== I=A0*S*T^2*e^(-q*d/(k*T)) =====
Eq: 'I=A0*S*T^2*e^(-CO...'
I: 0.3184_A
A0: 120_A/(m^2*K^2)
s: 2.4500_cm^2
T: 1200.0000_K
d: 1.2200_V
Thermionic current
EDIT VARS VIEW INFO SOLVE
```

### 5.4.3. Photoemission

#### Example:

A red light beam with a frequency of  $1.4\text{E}14\text{ Hz}$ , is influencing an electron beam to overcome a barrier of  $0.5\text{ V}$ . What is the electron velocity and find the threshold frequency of the light.

#### Solution:

Upon examining the problem, both equations need to be used to compute the solution.

```
##### ELECTRICAL ENGINEERING #####
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Electron Motion
|Electron Beam Deflection
|Thermionic Emission
|Photoemission
|  h*f=q*d+1/2*mexv^2
|  f0=q*d/h
Meters and Bridge Circuits
RL and RC Circuits
-EXPA VARS= PICT SI = HALT MSOLV
```

```
##### Photoemission #####
Eq: ( 'CONST(h)*f=CONS...
F 1.4000E14_Hz
v: 0_m/s
f0: 0_Hz
P 0.5000_V

Vertical velocity
EDIT VARS VIEW ALL MSOLV
```

```
##### ELECTRICAL ENGINEERING #####
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Elec
|Ele Starting
|The Solver...
|The
|  h*f=q*d+1/2*mexv^2
|  f0=q*d/h
Meters and Bridge Circuits
RL and RC Circuits
-EXPA VARS= PICT SI = HALT MSOLV
```

```
##### Photoemission #####
Eq: ( 'CONST(h)*f=CONS...
F 1.4000E14_Hz
v: 166694.7256_m/s
f0: 1.2090E14_Hz
P 0.5000_V

Vertical velocity
EDIT VARS VIEW ALL MSOLV
```

## 5.5. Meters and Bridge Circuits

```
===== ELECTRICAL ENGINEERING =====
Meters and Bridge Circuits
-Amp, Volt, Ohmmeter
-Wheatstone Bridge
-Wien Bridge
-Maxwell Bridge
-Owen Bridge
-Sym. Resistive Attenu.
-Unsym. Resistive Attenu.
-EXPA VARS PICT SI HALT HELP
```

### 5.5.1. Amp, Volt, Ohmmeter

#### Example:

What resistance can be added to a voltmeter with a current sensitivity of 10 mA and a voltage sensitivity of 5 V to read 120 V?

#### Solution:

Upon examining the problem, the second equation needs to be selected to solve this problem.

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Electron Motion
Meters and Bridge Circuits
-Amp, Volt, Ohmmeter
-Rsh=Rh*Isen/(Imax-Isen)
-Rse=(Vmax-Vsen)/Isen
-Isen=Vs/(Rs+Rh+Radj/2)
-Wheatstone Bridge
-Wien Bridge
EQN VARS PICT SI HALT SOLVE
```

```
===== Rse=(Vmax-Vsen)/Isen =====
Eq: 'Rse=(Vmax-Vsen)/I...
Rse: 0_Ω
Vmax: 120_V
Vsen: 5_V
Isen: 10_mA

Series resistance
EDIT VARS VIEW INFO SOLVE
```

```
===== ELECTRICAL ENGINEERING =====
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Elec
Mete Starting
Solver...
-Amp
-Rs
-Rse=(Vmax-Vsen)/Isen
-Isen=Vs/(Rs+Rh+Radj/2)
-Wheatstone Bridge
-Wien Bridge
EQN VARS PICT SI HALT SOLVE
```

```
===== Rse=(Vmax-Vsen)/Isen =====
Eq: 'Rse=(Vmax-Vsen)/I...
Rse: 11500.0000_Ω
Vmax: 120_V
Vsen: 5_V
Isen: 10_mA

Series resistance
EDIT VARS VIEW INFO SOLVE
```

### 5.5.2. Wheatstone Bridge

#### Example:

A Wheatstone bridge circuit has a resistor  $R_2$  of  $100\ \Omega$  on the unknown side of the bridge and two  $1000\ \Omega$  resistors connected on the known side of the bridge. A resistor of  $99\ \Omega$  was connected to the bridge in the location where the unknown resistor would normally be present. The bridge is supplied by a  $10\text{ V}$  source with a resistance of  $2.5\ \Omega$ . The galvanometric resistance is  $1\text{ M}\Omega$ . Find the voltage across the meter and the galvanometric current.

#### Solution:

Upon examining the problem, the second and third equations are needed to solve the problem.

```

ELECTRICAL ENGINEERING
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Electron Motion
Meters and Bridge Circuits
  Amp, Volt, and Ohmmeter
  Wheatstone Bridge
    Rx/R2=R3/R4
    Vm=GALV(Rx,R2,R3,R4,Rg,Rs,Vs)
    Ig=Vm/Rg
    Wien Bridge
-EXPA VARS= PICT= SI= HALT MSOLV

```

```

Choose Equations for MES
Rx/R2=R3/R4
✓ Vm=GALV(Rx,R2,R3,R4,Rg,Rs,Vs)
✓ Ig=Vm/Rg

```

```

Choose Equations for MES
Rx/R2=R3/R4
✓ Vm=GALV(Rx,R2,R3,R4,Rg,Rs,Vs)
✓ Ig=Vm/Rg

```

```

Wheatstone Bridge
Eq: ( 'Vm=GALV(Rx,R2,R...
Rx: 99_Ω      R2: 100_Ω
R3: 1000._Ω   R4: 1000._Ω
Rs: 2.5_Ω     Vs: 10_V
Ig: 0_A       Vm: 0_V
Rg: 1000000...
Voltage across meter
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

Wheatstone Bridge
Vm: -.008233045949_V
Ig: -8.233045949E-9_A

```



### 5.5.3. Wien Bridge

#### Example:

A set of measurements obtained using a Wien bridge is based on the following input. All measurements are carried out at 1000\_Hz. The known resistors R1 and R3 are 100\_Ω each, the series resistance is 200\_Ω and Cs is 1.2\_μF. Find the values of the unknown RC circuit components and the radian frequency.

#### Solution:

Upon examining the problem, the first, third and fifth equations are needed to solve the problem.

```

===== ELECTRICAL ENGINEERING =====
Inductance and Magnetism
Electron Motion
Meters and Bridge Circuits
Amp, Volt, and Ohmmeter
Wheatstone Bridge
Wien Bridge
Cx/Cs=R3/R1-Rs/Rx
Cs×Cx=1/(ω²×Rs×Rx)
R3/R1-Rs/Rx=1/(ω²×Rs×Rx×Cs²)
F=1/(2×π×Cs×Rs)
ω=2×π×F
-EXP WARS= PICT= SI= HALT MSOLV
  
```

```

===== Choose Equations for MES =====
✓ Cx/Cs=R3/R1-Rs/Rx
Cs×Cx=1/(ω²×Rs×Rx)
✓ R3/R1-Rs/Rx=1/(ω²×Rs×Rx×Cs²)
F=1/(2×π×Cs×Rs)
✓ ω=2×π×F
=====
✓CHK CANCEL OK
  
```

```

===== Wien Bridge =====
Eq: ( 'Cx/Cs=R3/R1-Rs/...
Cx: 0_μF R3: 100_Ω
R1: 100_Ω R2: 200_Ω
Rx: 0_Ω C3: 1.2_μF
ω: 0_r/s F: 1_kHz

Unknown capacitor
EDIT VARS VIEW ALL MSOLV
  
```

```

===== Wien Bridge =====
Eq: ( 'Cx/Cs=R3/R1-Rs/...
Cx: 0.36652... R3: 100_Ω
R1: 100_Ω R2: 200_Ω
Rx: 287.952... C3: 1.20000...
ω: 6283.185... F: 1_kHz

Unknown capacitor
EDIT VARS VIEW ALL MSOLV
  
```

Press **TOOL** to view all calculated results.

```

===== Wien Bridge =====
ω: 6283.185307_r/s
Rx: 287.952416_Ω
Cx: 0.366529_μF

=====
VALU= EQNS PRINT EXIT
  
```

#### 5.5.4. Maxwell Bridge

### Example:

Find the inductance and resistance of an inductive element using the Maxwell bridge. The bridge resistors are  $1000\ \Omega$  each with a  $0.22\ \mu\text{F}$  capacitor and  $470\ \Omega$  parallel resistance. Compute  $L_x$  and  $R_x$ .

**Solution:**

Upon examining the problem, the first two equations are needed to solve the problem.

```

ELECTRICAL ENGINEERING
Electron Motion
Meters and Bridge Circuits
Amp, Volt, and Ohmmeter
Wheatstone Bridge
Wien Bridge
-ORNL- 8-6-88
Lx=R2*R3*Cs
Rx=R2*R3/Rs
Q=w*(Lx/Rx)
Q=w*Cs/Rs
w=2*pi*f
-ENPA VARS= PICT= SI= HALT NSOLV

```

Choose Equations For MES

☒  $Lx = R2 \times R3 \times Cs$

☒  $Rx = R2 \times R3 / Rs$

☐  $Q = \omega \times (Lx / Rx)$

☐  $Q = \omega \times Cs \times Rs$

☐  $\omega = 2 \times \pi \times f$

☒ CHK ☐ CANCEL ☐ OK

```

Maxwell Bridge
Eq: C 'Lx=R2*R3*Cs' 'R...
Lx: 0_H  C3: 0.22_μF
Rx: 0_Ω  R2: 1_kΩ
R3: 1_kΩ  R3: 470_Ω

Unknown inductance
EDIT VARS VIEW ALL MSOLV

```

```

Maxwell Bridge
Eq: C 'Lx=R2*R3*Cs' 'R...
Lx=0.22_H Cs=0.22_μF
Rx=2127.66... R2=1_kΩ
R3=1_kΩ R4=470_Ω

Unknown inductance
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

Maxwell Bridge
Lx: 0.22_H
Rx: 2127.66_0

```

### 5.5.5. Owen Bridge

#### Example:

A lossy inductor is plugged into an Owen bridge to measure its properties. The resistance branch has 1000\_Ω resistors and a capacitor of 2.25\_μF on the non-resistor leg and 1.25\_μF capacitor on the resistor leg of the bridge. A series resistance of 125\_Ω connects the C4 leg to balance the inductive element.

#### Solution:

Both equations are needed for solving the problem.

```
===== ELECTRICAL ENGINEERING =====
Electron Motion
Meters and Bridge Circuits
-AMP, Volt, and Ohmmeter
-Wheatstone Bridge
-Wien Bridge
-Maxwell Bridge
-UNKN BRIDGE
  Lx=C3*R1*R4
  Rx=C3*R1/C4-R2
-Sym. Resistive Attenuator
-Unsym. Resistive Attenuator
-EXPA VARS= PICT= SI= HALT MSOLV
```

```
===== ELECTRICAL ENGINEERING =====
Electron Motion
Meters and Bridge Circuits
-AMP, Volt, and Ohmmeter
-Whe Starting
-Wie Solver...
-Max
-UNKN
  Lx=C3*R1*R4
  Rx=C3*R1/C4-R2
-Sym. Resistive Attenuator
-Unsym. Resistive Attenuator
-EXPA VARS= PICT= SI= HALT MSOLV
```

```
===== Owen Bridge =====
Eq: ( 'Lx=C3*R1*R4' 'R...
Lx: 0_H R4: 125_Ω
Rx: 0_Ω C3: 2.25_μF
R1: 1000._Ω C4: 1.25_μF
R2: 1000._Ω

Unknown inductance
EDIT VARS VIEW ALL MSOLV
```

```
===== Owen Bridge =====
Eq: ( 'Lx=C3*R1*R4' 'R...
Lx: .28125_H R4: 125_Ω
Rx: 800_Ω C3: 2.25_μF
R1: 1000._Ω C4: 1.25_μF
R2: 1000._Ω

Unknown inductance
EDIT VARS VIEW ALL MSOLV
```

Press **TOOL** to view all calculated results.

```
===== Owen Bridge =====
Lx: .28125_H
Rx: 800_Ω

VALU= EQNS PRINT EXIT
```

### 5.5.6. Symmetrical Resistive Attenuator

#### Example:

Design a symmetrical and Bridges Tee attenuator for a 50\_Ω load and a 6 DB loss.

#### Solution:

All three equations are needed.

```
##### ELECTRICAL ENGINEERING #####
Meters and Bridge Circuits
Amp, Volt, and Ohmmeter
Wheatstone Bridge
Wien Bridge
Maxwell Bridge
Owen Bridge
SYN. Resistive Attenuator
Ra=Ro*(10^(DB/20)-1)/(10^(DB/20)+1)
Rb=Ro*2*10^(DB/20)/(10^(DB/10)+1)
Rc=Ro*(10^(DB/20)-1)
Unsyn. Resistive Attenuator
-EXPA VARS= PICT= SI= HALT MSOLV
```

```
##### ELECTRICAL ENGINEERING #####
Meters and Bridge Circuits
Amp, Volt, and Ohmmeter
Wheatstone Bridge
Wien Bridge
Maxwell Bridge
Owen Bridge
SYN. Resistive Attenuator
Ra=Ro*(10^(DB/20)-1)/(10^(DB/20)+1)
Rb=Ro*2*10^(DB/20)/(10^(DB/10)+1)
Rc=Ro*(10^(DB/20)-1)
Unsyn. Resistive Attenuator
-EXPA VARS= PICT= SI= HALT MSOLV
```

```
##### SYN. Resistive Attenuator #####
Eq: ( 'Ra=Ro*(10^(DB/20)-1)/(10^(DB/20)+1)
Ra: 0_Ω
Rb: 0_Ω
Rc: 0_Ω
Ro: 50_Ω
DB: 6
Resistance Multiplier
EDIT VARS VIEW ALL MSOLV
```

```
##### SYN. Resistive Attenuator #####
Eq: ( 'Ra=Ro*(10^(DB/20)-1)/(10^(DB/20)+1)
Ra: 16.6139424583_Ω
Rb: 66.9310406479_Ω
Rc: 49.7631157485_Ω
Ro: 50_Ω
DB: 6
Resistance Multiplier
EDIT VARS VIEW ALL MSOLV
```

Press **TOOL** to view all calculated results.

```
##### SYN. Resistive Attenuator #####
Ra: 16.6139424583_Ω
Rb: 66.9310406479_Ω
Rc: 49.7631157485_Ω
VALU= EQNS PRINT EXIT
```

### 5.5.7. Unsymmetrical Resistive Attenuator

#### Example:

A network needs to be patched by an unsymmetrical attenuator. The network to the right of the attenuator presents a resistive load of 125\_Ω, while the network to the left of the attenuator possesses an impedance of 100\_Ω. What is the expected loss in DB?

#### Solution:

The last equation is needed to compute the signal attenuation.

```
===== ELECTRICAL ENGINEERING =====
Meters and Bridge Circuits
-Amp, Volt, and Ohmmeter
-Wheatstone Bridge
-Wien Bridge
-Maxwell Bridge
-Owen Bridge
-Sym. Resistive Attenuator
-Unsym. Resistive Attenuator
  Rj=Rl-Rk*Rx/(Rk+Rx)
  Rk=I(Rl*Rx^2/(Rl-Rx))
  DB=20*LOG(I((Rl-Rx)/Rx)+I(Rl/Rx)
-EXPA VARS= PICT= SI = HALT MSOLV
```

```
DB=20*LOG(I((Rl-Rx)/Rx)+I(Rl/Rx)
Eq: 'DB=20*LOG(I((Rl-Rx)/Rx)+I(Rl/Rx)
DB: 0
Rl: 125_Ω
Rx: 100_Ω

Attenuator loss
EDIT VARS VIEW SOLVE
```

```
===== Choose Equations for MES =====
Rj=Rl-Rk*Rx/(Rk+Rx)
Rk=I(Rl*Rx^2/(Rl-Rx))
✓ DB=20*LOG(I((Rl-Rx)/Rx)+I(Rl/Rx)
=====
✓CHK CANCEL OK
```

```
DB=20*LOG(I((Rl-Rx)/Rx)+I(Rl/Rx)
Eq: 'DB=20*LOG(I((Rl-Rx)/Rx)+I(Rl/Rx)
DB: 4.179752805
Rl: 125_Ω
Rx: 100_Ω

Attenuator loss
EDIT VARS VIEW INFO SOLVE
```

Rj and Rk can be computed from the first two equations above.

## 5.6. RL and RC Circuits

```

ELECTRICAL ENGINEERING
RL and RC Circuits
-RL Natural Response
-RC Natural Response
-RL Step Response
-RC Step Response
-RL Series to Parallel
-RC Series to Parallel
RLC Circuits
-EXPA VARS PICT SI HALT HELP

```

### 5.6.1. RL Natural Response

#### Example:

An RL circuit consists of a 400\_mH inductor and a 125\_Ω resistor. With an initial current of 100\_mA, find the inductor current and voltage across the inductor 1\_ms and 10\_ms after the switch has been closed.

#### Solution:

Upon examining the problem, the first three equations are needed to solve the problem.

Solution after 1\_ms

```

ELECTRICAL ENGINEERING
RL and RC Circuits
-RL Natural Response
-RC Natural Response
-RL Step Response
-RC Step Response
-RL Series to Parallel
-RC Series to Parallel
-EXPA VARS PICT SI HALT MSOLV

```

```

Choose Equations for MES
✓ τ=L/R
✓ vL=I0*R*e^(-t/τ)
✓ iL=I0*e^(-t/τ)
W=1/2*L*I0^2*(1-e^(-2*t/τ))
✓CHK CANCL OK

```

```

RL Natural Response
Eq: ( 'τ=L/R' 'vL=I0*R...'
L: 400_mH vL: 0_V
R: 125_Ω iL: 0_A
I0: 100_mA t: 1_ms
τ: 0_s
Time constant
EDIT VARS VIEW ALL MSOLV

```

```

RL Natural Response
Eq: ( 'τ=L/R' 'vL=I0*R...'
L: 400_mH vL: 9.1452_V
R: 125_Ω iL: 0.0732_A
I0: 100_mA t: 1_ms
τ: 0.0032_s
Time constant
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

RL Natural Response
τ: 0.003200_s
VL: 9.145195_V
iL: 0.073162_A

VALU= EQNS PRINT EXIT

```

Solution after 10\_ms

```

RL Natural Response
Eq: { 'τ=L/R' 'VL=I0*R...'
L: 400_mH    VL: 0_V
R: 125_Ω     iL: 0_A
I0: 100_mA   t: 10_ms
τ: 0_s

Time constant
EDIT VARS VIEW ALL MSOLV

```

```

RL Natural Response
Eq: { 'τ=L/R' 'VL=I0*R...'
L: 400_mH    VL: 0.5492_V
R: 125_Ω     iL: 0.0044_A
I0: 100_mA   t: 10_ms
τ: 0.0032_s

Time constant
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

RL Natural Response
τ: 0.003200000_s
VL: 0.54921167_V
iL: 0.00439369_A

VALU= EQNS PRINT EXIT

```

### 5.6.2. RC Natural Response

#### Example:

An RC circuit consists of a 1.2\_μF capacitor and a 47\_Ω resistor. The capacitor has been charged to 18\_V. A switch disconnects the energy source. Find the voltage across the capacitor 100\_ms later. How much energy is left in the capacitor?

#### Solution:

Upon examining the problem, all of the equations are needed to solve the problem.

```

ELECTRICAL ENGINEERING
RL and RC Circuits
RL Natural Response
RC Natural Response
τ=R*C
vC=V0*e^(-t/τ)
iC=V0/R*e^(-t/τ)
W=1/2*C*V0^2*(1-e^(-2*t/τ))
RL Step Response
RC Step Response
RL Series to Parallel
RC Series to Parallel
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

ELECTRICAL ENGINEERING
RL and RC Circuits
RL Natural Response
RC Natural Response
τ=
vC Starting
iC Solver...
W=
RL Step Response
RC Step Response
RL Series to Parallel
RC Series to Parallel
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

RC Natural Response
Eq: ( 'τ=R*C' 'vC=V0*e...'
vC: 0_V ic: 0_A
R: 47_Ω W: 0_J
C: 1.2_μF V0: 18_V
t: 100_μs τ: 0_s

Capacitor voltage
EDIT VARS VIEW ALL NSOLV

```

```

RC Natural Response
Eq: ( 'τ=R*C' 'vC=V0*e...'
vC: 3.05665... ic: 6.50352...
R: 47_Ω W: 1.887941...
C: 1.2_μF V0: 18_V
t: 100_μs τ: .0000564...

Capacitor voltage
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

RC Natural Response
τ: 0.00005640000_s
vC: 3.05665784791_V
iC: 0.06503527336_A
W: 0.00018879411_J

VALU= EQNS PRINT EXIT

```



### 5.6.3. RL Step Response

#### Example:

An inductor circuit consisting of 25\_mH inductance and 22.5\_Ω resistance. Prior to applying a 100\_V stimulus, the inductor carries a current of 100\_mA. Find the current in and the voltage across the inductor after 0.01\_s.

#### Solution:

Upon examining the problem, all three equations are need to be solve the problem.

```

ELECTRICAL ENGINEERING
RL and RC Circuits
RL Natural Response
RC Natural Response
RL Step Response
  τ=L/R
  vL=(Vs-ID×R)×e^(-t/τ)
  iL=Vs/R+(ID-Vs/R)×e^(-t/τ)
RC Step Response
RL Series to Parallel
RC Series to Parallel
RLC Circuits
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

ELECTRICAL ENGINEERING
RL and RC Circuits
RL Natural Response
RC Natural Response
RL Step Response
  τ= Starting
  vL= Solver...
  iL=
RC Step Response
RL Series to Parallel
RC Series to Parallel
RLC Circuits
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

RL Step Response
Eq: ( 'τ=L/R' 'vL=(Vs-...
L: 25_mH      vL: 0_V
iL: 0_A      ID: 100_mA
Vs: 100_V    R: 22.5000_Ω
t: 0.0100_s  τ: 0_s

Time constant
EDIT VARS VIEW ALL NSOLV
  
```

```

RL Step Response
Eq: ( 'τ=L/R' 'vL=(Vs-...
L: 25_mH      vL: 0.0121_V
iL: 4.4439_A  ID: 100_mA
Vs: 100_V    R: 22.5000_Ω
t: 0.0100_s  τ: 0.0011_s

Time constant
EDIT VARS VIEW ALL NSOLV
  
```

Press **TOOL** to view all calculated results.

```

RL Step Response
τ: 0.001111111111_s
vL: 0.01206330835_V
iL: 4.44390829740_A

VALU= EQNS PRINT EXIT
  
```

#### 5.6.4. RC Step Response

##### Example:

A 10\_V step function is applied to an RC circuit with a 7.5\_Ω resistor and a 67\_nF capacitor. The capacitor was charged to an initial potential of -10\_V.

What is the voltage across the 0.1\_ms after the step function has been applied?

##### Solution:

All three equations are needed to compute the solution for this problem.

```
===== ELECTRICAL ENGINEERING =====
RL and RC Circuits
-RL Natural Response
-RC Natural Response
-RL Step Response
-RC Step Response
  τ=R*C
  vC=Vs+(V0-Vs)*e^(-t/τ)
  iC=(Vs-V0)/R*e^(-t/τ)
-RL Series to Parallel
-RC Series to Parallel
RLC Circuits
-EXPA VARS= PICT= SI= HALT NSOLV
```

```
===== ELECTRICAL ENGINEERING =====
RL and RC Circuits
-RL Natural Response
-RC Natural Response
-RL Step Response
-RC Step Response
  τ=
  vC=
  iC=(Vs-V0)/R*e^(-t/τ)
-RL Series to Parallel
-RC Series to Parallel
RLC Circuits
-EXPA VARS= PICT= SI= HALT NSOLV
```

```
===== RC Step Response =====
Eq: ( 'τ=R*C' 'vC=Vs+(...
67_nF vC: 0_V
iC: 0_A Vs: 10_V
V0: -10_V R: 7.5000_Ω
t: 0.1000_μs τ: 0_s

Time constant
EDIT VARS VIEW ALL NSOLV
```

```
===== RC Step Response =====
Eq: ( 'τ=R*C' 'vC=Vs+(...
67_nF vC: -6.3909...
iC: 2.1855_A Vs: 10_V
V0: -10_V R: 7.5000_Ω
t: 0.1000_μs τ: 5.0250E-...

Time constant
EDIT VARS VIEW ALL NSOLV
```

Press **TOOL** to view all calculated results.

```
===== RC Step Response =====
τ: 0.00000050250_s
vC: -6.39091631960_V
iC: 2.18545550929_A

VALU= EQNS PRINT EXIT
```

### 5.6.5. RL Series to Parallel

#### Example:

A 24\_mH inductor has a quality factor of 5 at 10000\_Hz.

Find its series resistance and the parallel equivalent circuit parameters.

#### Solution:

Upon examining the problem, the first six equations need to be solved as a set.

```

ELECTRICAL ENGINEERING
RL Series to Parallel
w=2*pi*f
Qs=w*Ls/Rs
Rp=(Rs^2+w^2*Ls^2)/Rs
Lp=(Rs^2+w^2*Ls^2)/(w^2*Ls)
Rp=Rs*(1+Qs^2)
Lp=Ls*(1+1/Qs^2)
Qp=Rp/(w*Lp)
Rs=w^2*Lp^2*Rp/(Rp^2+w^2*Lp^2)
Ls=Rp^2*Lp/(Rp^2+w^2*Lp^2)
Rs=Rp/(1+Qp^2)
Ls=Qp^2*Lp/(1+Qp^2)

```

```

Choose Equations for MES
w=2*pi*f
Qs=w*Ls/Rs
Rp=(Rs^2+w^2*Ls^2)/Rs
Lp=(Rs^2+w^2*Ls^2)/(w^2*Ls)
Rp=Rs*(1+Qs^2)
Lp=Ls*(1+1/Qs^2)
Qp=Rp/(w*Lp)
Rs=w^2*Lp^2*Rp/(Rp^2+w^2*Lp^2)
Ls=Rp^2*Lp/(Rp^2+w^2*Lp^2)
Rs=Rp/(1+Qp^2)
Ls=Qp^2*Lp/(1+Qp^2)

```

```

RL Series to Parallel
Eq: ( 'w=2*pi*f' 'Qs=w*...
F: 10000._Hz w: 0_r/s
Rp: 0_Ω Rs: 0_Ω
Lp: 0_H Ls: 24_mH
Qs: 5
Radian Frequency
EDIT VARS VIEW ALL NSOLV

```

```

RL Series to Parallel
Eq: ( 'w=2*pi*f' 'Qs=w*...
F: 10000.00... w: 62831.85...
Rp: 7841.41... Rs: 301.592...
Lp: 0.0250_H Ls: 24_mH
Qs: 5
Radian Frequency
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

RL Series to Parallel
w: 62831.853072_r/s
Rs: 301.592895_Ω
Rp: 7841.415263_Ω
Lp: 0.024960_H
VALU EQNS PRINT EXIT

```

### 5.6.6. RC Series to Parallel

### Example:

A parallel RC Circuit consists of a  $47\text{ }\mu\text{F}$  and  $150\text{ k}\Omega$  at  $120\text{ kHz}$ . Find its series equivalent.

**Solution:**

Upon examining the problem, equations 1, 3, 4, 6 and 7 are needed to solve the problem.

```

ELECTRICAL ENGINEERING
1. Series to Parallel
w2=w*f
qs=1/(w*Rs*Cs)
Rp=Rs*(1+1/(w^2*Rs^2*Cs^2))
Cp=Cs/(1+w^2*Cs^2*Rs^2)
qp=w*Rp*Cp
Rs=Rp/(1+w^2*Rp^2*Cp^2)
Cs=(1+w^2*Rp^2*Cp^2)/(w^2*Rp^2)
Rp=Rs*(1+qs^2)
Cp=Cs/(1+1/qs^2)
Rs=Rp/(1+qp^2)
Cs=Cp*(1+qp^2)/qp^2

```

Choose Equations For MES

☒  $w = 2 \times \pi \times f$

$Q_s = 1 / (w \times R_s \times C_s)$

☒  $R_p = R_s \times (1 + 1 / (w^2 \times R_s^2 \times C_s^2))$

☒  $C_p = C_s / (1 + w^2 \times C_s^2 \times R_s^2)$

$Q_p = w \times R_p \times C_p$

$R_s = R_p / (1 + w^2 \times R_p^2 \times C_p^2)$

☒  $C_s = (1 + w^2 \times R_p^2 \times C_p^2) / (w^2 \times R_p)$

$R_p = R_s \times (1 + Q_s^2)$

$C_p = C_s / (1 + 1 / Q_s^2)$

☒ CHK

☐ CANCEL

☐ OK

```
RC Series to Parallel
Eq: ( 'w=2*pi*f' 'Rp=Rs...'
F 120_kHz      Rs: 0_Ω
Cs: 0_F        w: 0_r/s
R 150_kΩ       47_μF

Series resistance
EDIT VARS VIEW ALL MSOLV
```

```

RC Series to Parallel
Eq: { 'w=2*pi*f' 'Rp=R_s...
F 120_kHz      Rs= 5.30873...
Cs= .000047... w= 753982.2...
R 150_kΩ       C 47_μF

Series resistance
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

RC Series to Parallel:
w: 753982.236862_r/s
Rs: 5.30087319364E-9_W
Cs: .000047_F

VALU= EQDS PRINT

```

## 5.7. RLC Circuits

```

ELECTRICAL ENGINEERING
RLC Circuits
Series Impedance
Parallel Admittance
RLC Natural Response
Underdamped Transient
Critically-Damped Trai
Overdamped Transient
AC Circuits
-EXPA VARS PICT SI HALT HELP

```

### 5.7.1. Series Impedance

#### Example:

A circuit consists of a 50\_Ω resistor in series with a 20\_mH inductor and 47\_μF capacitor.

At a frequency of 1000\_Hz calculate the impedance and phase angle of impedance.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
RLC Circuits
Series Impedance
ABS(Zm)^2=R^2+X...
θ=ATAN(X/R)
X=XL+XC
XL=ωL
XC=-1/(ωC)
ω=2πF
Parallel Admittance
RLC Natural Response
Underdamped Transient
-EXPA VARS PICT SI HALT NSOLV

```

```

Series Impedance
Eq: ( 'ABS(Zm)^2=R^2+X...
Zm: 0_Ω θ: 0_r
R: 50_Ω X: 0_Ω
XL: 0_Ω L: 20_mH
XC: 0_Ω C: 47_μF
ω: 0_r/s F: 1000._Hz
Reactance
EDIT VARS VIEW ALL NSOLV

```

```

Series Impedance
Eq: ( 'ABS(Zm)^2=R^2+X...
Zm: 132.105... θ: 1.182635...
R: 50_Ω X: 122.2774...
XL: 125.663... L: 20_mH
XC: -3.3862... C: 47_μF
ω: 6283.185... F: 1000._Hz
Reactance
EDIT VARS VIEW ALL NSOLV

```

```

Series Impedance
ω: 6283.18530718_r/s
XL: 125.663706144_Ω
XC: -3.38627538494_Ω
X: 122.277430759_Ω
Zm: 132.105147791_Ω
θ: 1.18263584444_r
VALU EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

## 5.7.2. Parallel Admittance

### Example:

A parallel RLC Circuit consists of a 10 k $\Omega$  resistor, 67  $\mu$ H and 0.01  $\mu$ F.  
Find the circuit admittance parameters at a frequency of 10 MHz.

### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
RLC Circuits
Series Impedance
Parallel Admittance
-ABS(Ym)^2=G^2+B^2
-0=ATAN(G/B)
-G=1/R
-B=BL+BC
-BL=-1/(w*L)
-BC=w*C
-w=2*pi*F
RLC Natural Response
-EXPA VARS= PICT SI = HALT NSOLV

```

```

ELECTRICAL ENGINEERING
RLC Circuits
Series Impedance
Parallel Admittance
-ABS(Ym)^2=G^2+B^2
-0=ATAN(G/B)
-G=1/R
-B=BL+BC
-BL=-1/(w*L)
-BC=w*C
-w=2*pi*F
RLC Natural Response
-EXPA VARS= PICT SI = HALT NSOLV

```

```

Parallel Admittance
Eq: ( 'ABS(Ym)^2=G^2+B...
Ym: 0_S 0: 0_r G: 0_S
R: 10_kΩ B: 0_S BL: 0_S
L: 67_μH BC: 0_S 0: 0.01...
w: 0_r/s F: 10_M...
Admittance & Magnitude
EDIT VARS VIEW ALL NSOLV

```

```

Parallel Admittance
Eq: ( 'ABS(Ym)^2=G^2+B...
Ym: 0.62... 0: 0.00... G: 0.00...
R: 10_kΩ B: 0.62... BL: -0.0...
L: 67_μH BC: 0.62... 0: 0.01...
w: 6283... F: 10_M...
Admittance & Magnitude
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

Parallel Admittance
G: 0.000100000000_S
w: 62831853.0718_r/s
BL: -0.00023754469_S
BC: 0.62831853072_S
B: 0.62808098603_S
Ym: 0.62808099399_S
0: 0.00015921514_r
VALU= EQNS PRINT EXIT

```

### 5.7.3. RLC Natural Response

#### Example:

A RLC circuit consists of a 50\_Ω resistor in series with a 20\_mH inductor and 47\_μF capacitor.

Calculate the circuit parameters.

#### Solution:

All of the equations are needed to solve the parameters from these given set of variables.

```

ELECTRICAL ENGINEERING
RLC Circuits
Series Impedance
Parallel Admittance
RLC Natural Response
s1r=RE(-α+√(α^2-ω0^2))
s1i=IM(-α+√(α^2-ω0^2))
s2r=RE(-α-√(α^2-ω0^2))
s2i=IM(-α-√(α^2-ω0^2))
ω0=1/(L×C)
α=1/(2×R×C)
Underdamped Transient
-EXPA VARS= PICT= SI= HALT MSOLV

```

```

ELECTRICAL ENGINEERING
RLC Circuits
Series Impedance
Parallel Admittance
Starting Solver...
s1r=RE(-α+√(α^2-ω0^2))
s1i=IM(-α+√(α^2-ω0^2))
s2r=RE(-α-√(α^2-ω0^2))
s2i=IM(-α-√(α^2-ω0^2))
ω0=1/(L×C)
α=1/(2×R×C)
Underdamped Transient
-EXPA VARS= PICT= SI= HALT MSOLV

```

```

RLC Natural Response
Eq: ( 's1r=RE(UVAL(-α)...
s1r: 0 s1i: 0
s2r: 0 s2i: 0
ω0: 0_r/s L: 20_mH
α: 0_r/s R: 50_Ω
47_μF
Characteristic Frequency
EDIT VARS VIEW ALL MSOLV

```

```

RLC Natural Response
Eq: ( 's1r=RE(UVAL(-α)...
s1r: -212.76... s1i: 1,009.2...
s2r: -212.76... s2i: -1,009.2...
ω0: 1031.42... L: 20_mH
α: 212.7659... R: 50_Ω
47_μF
Characteristic Frequency
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

RLC Natural Response
ω0: 1031.42124626_r/s
α: 212.765957447_r/s
s1r: -212.765957447
s1i: 1009.23755112
s2r: -212.765957447
s2i: -1009.23755112
VALU= EQNS PRINT EXIT

```

#### 5.7.4. Underdamped Transient

##### Example:

A parallel RLC circuit is designed with a 1\_k $\Omega$  resistor, a 40\_mH inductor and a 2\_ $\mu$ F capacitor. The initial current in the inductor is 10\_mA and the initial charge in the capacitor is 2.5\_V.

Calculate the resonant frequency and the voltage across the capacitor 1\_ $\mu$ s after the input stimulus has been applied.

##### Solution:

All of the equations need to be selected to solve this problem.

```
~~~~~ ELECTRICAL ENGINEERING ~~~~~
RLC Circuits
+Series Impedance
+Parallel Admittance
+RLC Natural Response
+Underdamped Transient
  w0=1/(L*C)
  a=1/(2*R*C)
  wd=1(w0^2-a^2)
  u=B1*e^(-a*t)*COS(wd*t)+B2*e^(-
  B1=V0
  B2=-(a/wd)*(V0-2*I0*R)
-EXPA VARS= PICT= SI= HALT HSOLV
```

```
~~~~~ ELECTRICAL ENGINEERING ~~~~~
RLC Circuits
+Series Impedance
+Parallel Admittance
+RLC Natural Response
+Underdamped Transient
  w0=1/(L*C)
  a=1/(2*R*C)
  wd=1(w0^2-a^2)
  u=B1*e^(-a*t)*COS(wd*t)+B2*e^(-
  B1=V0
  B2=-(a/wd)*(V0-2*I0*R)
-EXPA VARS= PICT= SI= HALT HSOLV
```

```
~~~~~ Underdamped Transient ~~~~~
Eq: ( 'w0=1/(L*C)' ...
L: 40_mH C: 2_uF w0: 0_r/s
v: 0_V t: 1_us B1: 0_V
B2: 0_V a: 0_r/s wd: 0_r/s
V0: 2.5_V I0: 10_mA R: 1_kOhm
Classical radian frequency
EDIT VARS VIEW ALL HSOLV
```

```
~~~~~ Underdamped Transient ~~~~~
Eq: ( 'w0=1/(L*C)' ...
L: 40_mH C: 2_uF w0: 3535...
v: 2.50... t: 1_us B1: 2.5_V
B2: 1.24... a: 250... wd: 3526...
V0: 2.5_V I0: 10_mA R: 1_kOhm
Classical radian frequency
EDIT VARS VIEW ALL HSOLV
```

Press **TOOL** to view all calculated results.

```
~~~~~ Underdamped Transient ~~~~~
w0: 3535.53390593_r/s
a: 250_r/s
wd: 3526.68399492_r/s
B1: 2.5_V
B2: 1.24054210876_V
v: 2.50373343246_V
VALU= EQNS PRINT EXIT
```



### 5.7.5. Critical-Damped Transient

#### Example:

A critically damped RLC circuit consists of a 100\_Ω resistor in series with a 40\_mH inductor and a 1\_μF capacitor. The initial inductor current is 1\_mA and the initial capacitor charge is 10\_V.

Find the voltage across the capacitor after 10\_μs.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
RLC Circuits
+Series Impedance
+Parallel Admittance
+RLC Natural Response
+Underdamped Transient
+Critical-Damped Transient
  α=1/(2*R*C)
  ω0=1/(L*C)
  v=D1*t*x^(-α*t)+D2*x^(-α*t)
  D1=I0/C+α*V0
  D2=V0
-EXPA VARS= PICT= SI= HALT MSOLV

```

```

ELECTRICAL ENGINEERING
RLC Circuits
+Series Impedance
+Parallel Admittance
+RLC Natural Response
+Underdamped Transient
+Critical-Damped Transient
  α=1/(2*R*C)
  ω0=1/(L*C)
  v=D1*t*x^(-α*t)+D2*x^(-α*t)
  D1=I0/C+α*V0
  D2=V0
-EXPA VARS= PICT= SI= HALT MSOLV

```

```

Critically-Damped Transient
Eq: ( 'α=1/(2*R*C)' 'ω0=1/(L*C)'
R: 100_Ω ω0: 0_r/s L: 40_mH
v: 0_V t: 10_μs D1: 0_V/s
I0: 1_mA C: 1_μF α: 0_r/s
D2: 0_V V0: 10_V

Capacitor voltage
EDIT VARS VIEW ALL MSOLV

```

```

Critically-Damped Transient
Eq: ( 'α=1/(2*R*C)' 'ω0=1/(L*C)'
R: 100_Ω ω0: 5000... L: 40_mH
v: 9.99... t: 10_μs D1: 5100...
I0: 1_mA C: 1_μF α: 5000...
D2: 10_V V0: 10_V

Capacitor voltage
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

Critically-Damped Transient
α: 5000.0000000_r/s
ω0: 5000.0000000_r/s
D1: 51000.0000000_V/s
D2: 10_V
v: 9.9974213_V

VALU= EQNS PRINT EXIT

```

### 5.7.6. Overdamped Transient

#### Example:

An overdamped RLC circuit consists of a 10\_Ω resistor in series with a 40\_mH inductor and a 1\_μF capacitor. If the initial inductor current is 0\_mA and the capacitor is charged to a potential of 5\_V, find the voltage across the capacitor after 1\_ms.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
RLC Natural Response
Underdamped Transient
Critically-Damped Transient
Overdamped Transient
s1=-α+√(α^2-ω0^2)
s2=-α-√(α^2-ω0^2)
ω0=1/√(L×C)
α=1/(2×R×C)
v=A1×e^(s1×t)+A2×e^(s2×t)
A1=(V0×s2+1/C×(V0/R+I0))/(s2-s1)
A2=-(V0×s1+1/C×(V0/R+I0))/(s2-s1)
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

ELECTRICAL ENGINEERING
RLC Natural Response
Underdamped Transient
Critically-Damped Transient
Overdamped Transient
Starting Solver...
s1
s2
ω0
α=1/(2×R×C)
v=A1×e^(s1×t)+A2×e^(s2×t)
A1=(V0×s2+1/C×(V0/R+I0))/(s2-s1)
A2=-(V0×s1+1/C×(V0/R+I0))/(s2-s1)
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

Overdamped Transient
Eq: { 's1=-α+√(α^2-ω0^2)
ω0: 0_r/s 40_mH α: 0_r/s
v: 0_V 1_ms A1: 0_V
A2: 0_V 1_μF V0: 5_V
R: 10_Ω I0: 0_A s2: 0_r/s
s1: 0_r/s
Characteristic Frequency
EDIT VARS VIEW ALL NSOLV

```

```

Overdamped Transient
Eq: { 's1=-α+√(α^2-ω0^2)
ω0: 5000_r/s 40_mH α: 5000_r/s
v: -0.0_V 1_ms A1: -0.0_V
A2: 5.01_V 1_μF V0: 5_V
R: 10_Ω I0: 0_A s2: -997_r/s
s1: -250_r/s
Characteristic Frequency
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

Overdamped Transient
ω0: 5000.000000_r/s
α: 50000.000000_r/s
s1: -250.6281447_r/s
s2: -99749.3718553_r/s
A1: -0.0125945_V
A2: 5.0125945_V
v: -0.0098025_V
VALU= EQNS PRINT EXIT

```

## 5.8. AC Circuits

```

ELECTRICAL ENGINEERING
AC Circuits
RL Series Impedance
RC Series Impedance
Impedance ↔ Admittance
Two Impedances in Series
Two Impedances in Parallel
Polyphase Circuits
Electrical Resonance
-EXPA VARS PICT SI HALT HELP

```

### 5.8.1. RL Series Impedance

#### Example:

An RL circuit consists of a 50\_Ω resistor and a 0.025\_H inductor. At a frequency of 400 Hz, the current amplitude is 24\_mA.

Find the impedance of the circuit and the voltage drops across the resistor and inductor after 100 ms.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
AC Circuits
RL Series Impedance
I=Im*SIN(w*t)
ABS(ZH)^2=R^2+w^2*L^2
VR=2H*Im*SIN(w*t)*COS(θ)
VL=2H*Im*COS(w*t)*SIN(θ)
V=VR+VL
VH=Im*ZH
θ=ATAN(w*L/R)
w=2*pi*f
RC Series Impedance
-EXPA VARS PICT SI HALT NSOLV

```

```

RL Series Impedance
Eq: ( 'I=Im*SIN(w*t)' ...
I: 0_A t: 100_... v: 0_V
VR: 0_V VL: 0_V VH: 0_V
Im: 24_mA ZH: 0_Ω θ: 0_r
L: 0.025_... R: 50_Ω w: 0_r/s
f: 400_...
Instantaneous current
EDIT VARS VIEW ALL NSOLV

```

```

RL Series Impedance
Eq: ( 'I=Im*SIN(w*t)' ...
I: 0.00_... t: 100_... v: 1.75_...
VR: 0.29_... VL: 1.46_... VH: 1.92_...
Im: 24_mA ZH: 80.2_... θ: 0.89_...
L: 0.02_... R: 50_Ω w: 2513_...
f: 400_...
Instantaneous current
EDIT VARS VIEW ALL NSOLV

```

```

RL Series Impedance
w: 2513.2741229_r/s
I: 0.0059686_A
Zm: 80.2984543_Ω
Vm: 1.9271629_V
θ: 0.8986371_r
VR: 0.2984279_V
VL: 1.4605890_V
V: 1.7590169_V
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

### 5.8.2. RC Series Impedance

#### Example:

An RC circuit consists of a 100\_Ω resistor in series with a 47\_μF capacitor. At a frequency of 1500\_Hz, the current peaks at an amplitude of 72\_mA.

Find all the parameters of the RC circuit and the voltage drop after 150\_μs.

#### Solution:

Use all of the equations to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
AC Circuits
RL Series Impedance
RC Series Impedance
I=Im*SIN(ω*t)
ABS(Zm)^2=R^2+1/(ω*C)^2
VR=Zm*Im*SIN(ω*t)*COS(θ)
VC=Zm*Im*COS(ω*t)*SIN(θ)
V=VR+VC
Vm=Im*Zm
θ=ATAN(-1/(ω*C*R))
ω=2*π*f
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

===== ELECTRICAL ENGINEERING =====
AC Circuits
RL Series Impedance
RC Series Impedance
I=
AB Starting
VR Solver...
VC
V=VR+VC
Vm=Im*Zm
θ=ATAN(-1/(ω*C*R))
ω=2*π*f
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

===== RC Series Impedance =====
Eq: ( 'I=Im*SIN(ω*t)' ...
I: 0_A t: 150_μs v: 0_V
VR: 0_V VC: 0_V Vm: 0_V
Im: 72_mA Zm: 0_Ω θ: 0_r
C: 47_μF R: 100_Ω ω: 0_r/s
f: 1500...
Total voltage
EDIT VARS VIEW ALL NSOLV

```

```

===== RC Series Impedance =====
Eq: ( 'I=Im*SIN(ω*t)' ...
I: 0.07... t: 150_μs v: 7.08...
VR: 7.11... VC: -0.0... Vm: 7.20...
Im: 72_mA Zm: 100... θ: -0.0...
C: 47_μF R: 100_Ω ω: 9424...
f: 1500...
Total voltage
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

===== RC Series Impedance =====
ω: 9424.77796077_r/s
I: 0.07111356_A
Zm: 100.02547867_Ω
Vm: 7.20183446_V
θ: -0.02257134_r
VR: 7.11135605_V
VC: -0.02542705_V
V: 7.08592900_V
VALU= EQNS PRINT EXIT

```

### 5.8.3. Impedance ↔ Admittance

#### Example:

Find the admittance of an impedance consisting of a resistive part of 125\_Ω and a reactance part of 475\_Ω.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Impedance ↔ Admittance
-ABS(ZM)^2=R^2+X^2
-θz=ATAN(X/R)
-R=ZM×COS(θz)
-X=ZM×SIN(θz)
-θy=-θz
-YM=1/ZM
-G=YM×COS(θy)
-B=YM×SIN(θy)
-ABS(YM)^2=G^2+B^2
-θy=ATAN(B/G)
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

ELECTRICAL ENGINEERING
Impedance ↔ Admittance
-ABS(ZM)^2=R^2+X^2
-θz=ATAN(X/R)
-R=
-X= Starting
-θy= Solver...
-YM
-G=YM×COS(θy)
-B=YM×SIN(θy)
-ABS(YM)^2=G^2+B^2
-θy=ATAN(B/G)
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

Impedance ↔ Admittance
Eq: ( 'ABS(Zm)^2=R^2+X...
R: 125_Ω      B: -475_Ω
θz: 0_r      ZM: 0_Ω
YM: 0_S      θy: 0_r
B: 0_S      G: 0_S

Impedance phase angle
EDIT VARS VIEW ALL NSOLV

```

```

Impedance ↔ Admittance
Eq: ( 'ABS(Zm)^2=R^2+X...
R: 125_Ω      B: -475_Ω
θz: -1.3134... ZM: 491.172...
YM: 0.00203... θy: 1.31347...
B: 0.001968... G: 0.000518...

Impedance phase angle
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

Impedance ↔ Admittance
Zm: 491.17206761_Ω
θz: -1.31347261_r
θy: 1.31347261_r
YM: 0.00203595_S
G: 0.00051813_S
B: 0.00196891_S

VALU= EQNS PRINT EXIT

```

#### 5.8.4. Two Impedances in Series

##### Example:

Two impedances, consisting of resistances of  $100\ \Omega$  and  $75\ \Omega$  and reactive components  $75\ \Omega$  and  $-145\ \Omega$  respectively, are connected in series.

Find the magnitude and phase angle of the combination.

##### Solution:

All of the equations are needed to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
Impedance ↔ Admittance
Two Impedances in Series
-ABS(Zm)^2=R^2+X^2
-θ=ATAN(X/R)
-R=R1+R2
-X=X1+X2
-ABS(Z1m)^2=R1^2+X1^2
-ABS(Z2m)^2=R2^2+X2^2
-θ1=ATAN(X1/R1)
-θ2=ATAN(X2/R2)
Two Impedances in Parallel
-EXP(VARS)=PICT=SI=HALT=NSOLV

```

```

===== ELECTRICAL ENGINEERING =====
Impedance ↔ Admittance
Two Impedances in Series
-ABS(Zm)^2=R^2+X^2
-θ=
-R=
-X=
-ABS(Z2m)^2=R2^2+X2^2
-θ1=ATAN(X1/R1)
-θ2=ATAN(X2/R2)
Two Impedances in Parallel
-EXP(VARS)=PICT=SI=HALT=NSOLV

```

```

===== Two Impedances in Series =====
Eq: ( 'ABS(Zm)^2=R^2+X...
Zm: 0_Ω θ: 0_r R: 0_Ω
X: 0_Ω Z1m: 0_Ω Z2m: 0_Ω
θ1: 0_r θ1: 75_Ω θ1: 100_Ω
θ2: 0_r θ2: -145_Ω θ2: 75_Ω

Impedance Magnitude
EDIT VARS VIEW ALL NSOLV

```

```

===== Two Impedances in Series =====
Eq: ( 'ABS(Zm)^2=R^2+X...
Zm: 188... θ: -0.3... R: 175_Ω
X: -70_Ω Z1m: 125... Z2m: 163...
θ1: 0.64... θ1: 75_Ω θ1: 100_Ω
θ2: -1.0... θ2: -145_Ω θ2: 75_Ω

Impedance Magnitude
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

===== Two Impedances in Series =====
R: 175_Ω
X: -70_Ω
Z1m: 125_Ω
Z2m: 163.24827717_Ω
θ1: 0.64350111_r
θ2: -1.09345094_r
Zm: 188.48076825_Ω
θ: -0.38050638_r
VALU=EQNS PRINT EXIT

```

### 5.8.5. Two Impedances in Parallel

#### Example:

For two impedances in parallel possessing values identical to the previous example, calculate the magnitude and phase of the combination (resistances of 100\_Ω and 75\_Ω and reactive components 75\_Ω and -145\_Ω respectively).

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
Impedance ↔ Admittance
Two Impedances in Series
Two Impedances in Parallel
ABS(ZM)^2=((R1*R2-X1*X2)^2+(R1*
θ=ATAN((X1*R2+R1*X2)/(R1*R2-X1*
R=ZM*COS(θ)
X=ZM*SIN(θ)
ABS(Z1M)^2=R1^2+X1^2
ABS(Z2M)^2=R2^2+X2^2
θ1=ATAN(X1/R1)
θ2=ATAN(X2/R2)
-EXPAN VARS= PICT= SI= HALT NSOLV

```

```

===== ELECTRICAL ENGINEERING =====
Impedance ↔ Admittance
Two Impedances in Series
Two Impedances in Parallel
ABS(ZM)^2=((R1*R2-X1*X2)^2+(R1*
θ= Starting
R= Solver...
X=
ABS(Z1M)^2=R1^2+X1^2
ABS(Z2M)^2=R2^2+X2^2
θ1=ATAN(X1/R1)
θ2=ATAN(X2/R2)
-EXPAN VARS= PICT= SI= HALT NSOLV

```

```

===== Two Impedances in Parallel =====
Eq: ( 'ABS(Zm)^2=((R1*...
R: 0_Ω X: 0_Ω ZM: 0_Ω
θ: 0_r Z1M: 0_Ω Z2M: 0_Ω
θ1: 0_r θ1: 75_Ω θ1: 100_Ω
θ2: 0_r θ2: -145_Ω θ2: 75_Ω

Resistance
EDIT VARS VIEW ALL NSOLV

```

```

===== Two Impedances in Parallel =====
Eq: ( 'ABS(Zm)^2=((R1*...
R: 108... X: -7.5... ZM: 108...
θ: -0.0... Z1M: 125... Z2M: 163...
θ1: 0.64... θ1: 75_Ω θ1: 100_Ω
θ2: -1.0... θ2: -145_Ω θ2: 75_Ω

Resistance
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

===== Two Impedances in Parallel =====
Zm: 108.26587156_Ω
θ: -0.06944346_r
R: 108.00492611_Ω
X: -7.51231527_Ω
Z1m: 125_Ω
Z2m: 163.24827717_Ω
θ1: 0.64350111_r
θ2: -1.09345094_r
VALU= EQNS PRINT EXIT

```

## 5.9. Polyphase Circuits

```

ELECTRICAL ENGINEERING
Polyphase Circuits
  Balanced Δ Network
  Balanced Wye Network
  Power Measurements
  Electrical Resonance
  OpAmp Circuits
  Solid State Devices
  Linear Amplifiers
-EXPA VARS PICT SI HALT HELP

```

### 5.9.1. Balanced Δ Network

#### Example:

Given a line current of 25\_A, a phase voltage of 110 V and a phase angle of 0.125\_rad, find the phase current, power, total power and line voltage.

#### Solution:

Upon examining the problem, all equations are needed.

```

ELECTRICAL ENGINEERING
Polyphase Circuits
  Balanced Δ Network
    VL=Vp
    IL=√3*Ip
    P=Vp*Ip*cos(θ)
    PT=3*Vp*Ip*cos(θ)
    PT=√3*VL*IL*cos(θ)
  Balanced Wye Network
  Power Measurements
  Electrical Resonance
  OpAmp Circuits
-EXPA VARS PICT SI HALT NSOLV

```

```

Balanced Δ Network
Eq: ( 'VL=Vp' 'IL=√3*I...
P: 1575.325... Wp 110_V
Ip: 14.4338... PT: 4725.97...
VL: 110_V IL: 25_A
θ: 0.1250_r

Power per phase
EDIT VARS VIEW ALL NSOLV

```

```

Balanced Δ Network
Eq: ( 'VL=Vp' 'IL=√3*I...
P: 0_W Wp: 110_V
Ip: 0_A PT: 0_W
VL: 0_V IL: 25_A
θ: 0.1250_r

Power per phase
EDIT VARS VIEW ALL NSOLV

```

```

Balanced Δ Network
VL: 110_V
Ip: 14.4338_A
P: 1575.3254_W
PT: 4725.9761_W

VALU EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.



### 5.9.2. Balanced Wye Network

#### Example:

Using the known parameters in the previous example for the Balanced  $\Delta$  Network, find the phase current, power, total power and line voltage (current of 25\_A, a phase voltage of 110\_V and a phase angle of 0.125\_rad).

#### Solution:

All of the equations are needed to compute the solution for this problem.

```
===== ELECTRICAL ENGINEERING =====
Polyphase Circuits
-Balanced  $\Delta$  Network
-Balanced Wye Network
  VL= $\sqrt{3}$ *Vp
  IL=Ip
  P=Vp*Ip*cos( $\theta$ )
  PT=3*Vp*Ip*cos( $\theta$ )
  PT= $\sqrt{3}$ *VL*IL*cos( $\theta$ )
Power Measurements
Electrical Resonance
OpAmp Circuits
-EXPAND VARS= PICT SI= HALT NSOLV
```

```
===== Balanced Wye Network =====
Eq: ( 'VL= $\sqrt{3}$ *Vp' 'IL=I...'
P: 0_W Wp 110_V
Ip: 0_A PT: 0_W
VL: 0_V IL: 25_A
 $\theta$ : 0.1250_r

Power per phase
EDIT VARS VIEW ALL NSOLV
```

```
===== ELECTRICAL ENGINEERING =====
Polyphase Circuits
-Balanced  $\Delta$  Network
-Balanced Wye Network
  VL= $\sqrt{3}$ *Vp
  IL=Ip
  P=Vp*Ip*cos( $\theta$ )
  PT=3*Vp*Ip*cos( $\theta$ )
  PT= $\sqrt{3}$ *VL*IL*cos( $\theta$ )
Power Measurements
Electrical Resonance
OpAmp Circuits
-EXPAND VARS= PICT SI= HALT NSOLV
```

```
===== Balanced Wye Network =====
Eq: ( 'VL= $\sqrt{3}$ *Vp' 'IL=I...'
P: 2728.543_W Wp 110_V
Ip: 25_A PT: 8185.63...
VL: 190.525... IL: 25_A
 $\theta$ : 0.1250_r

Power per phase
EDIT VARS VIEW ALL NSOLV
```

Press **TOOL** to view all calculated results.

```
===== Balanced Wye Network =====
VL: 190.5256_V
Ip: 25_A
P: 2728.5436_W
PT: 8185.6308_W

VALU= EQNS PRINT EXIT
```

### 5.9.3. Power Measurements

#### Example:

Given a line voltage of 110\_V and a line current of 25\_A and a phase angle of 0.1\_rad, find the wattmeter readings in a 2 wattmeter meter system.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```
##### ELECTRICAL ENGINEERING #####
Polyphase Circuits
| Balanced 4 Network
| Balanced Wye Network
| Power Measurements
| W1=VL*IL*COS(θ+π/6)
| W2=VL*IL*COS(θ-π/6)
| PT=√3*VL*IL*COS(θ)
Electrical Resonance
OpAmp Circuits
Solid State Devices
Linear Amplifiers
-EXPA VARS= PICT= SI= HALT MSOLV
```

```
##### ELECTRICAL ENGINEERING #####
Polyphase Circuits
| Balanced 4 Network
| Balanced Wye Network
| W1 Starting
| W2 Solver...
| PT
Electrical Resonance
OpAmp Circuits
Solid State Devices
Linear Amplifiers
-EXPA VARS= PICT= SI= HALT MSOLV
```

```
##### Power Measurements #####
Eq: ( 'W1=VL*IL*COS(θ+...
W1: 0_W W2: 0_W
PT: 0_W VL: 110_V
IL: 25_A θ: 0.1000_r

Wattmeter 1
EDIT VARS VIEW ALL MSOLV
```

```
##### Power Measurements #####
Eq: ( 'W1=VL*IL*COS(θ+...
W1: 2232.40... W2: 2506.94...
PT: 4739.34... VL: 110_V
IL: 25_A θ: 0.1000_r

Wattmeter 1
EDIT VARS VIEW ALL MSOLV
```

Press **TOOL** to view all calculated results.

```
##### Power Measurements #####
W1: 2232.4010_W
W2: 2506.9429_W
PT: 4739.3439_W

VALU= EQNS PRINT EXIT
```

## 5.10. Electrical Resonance

```

ELECTRICAL ENGINEERING
Electrical Resonance
Parallel Resonance I
Parallel Resonance II
Resonance in Lossy Inductor
Series Resonance
OpAmp Circuits
Solid State Devices
Linear Amplifiers
-EXPA VARS PICT SI HALT HELP

```

```

ELECTRICAL ENGINEERING
Electrical Resonance
Parallel Resonance I
Parallel Resonance II
Resonance in Lossy Inductor
Series Resonance
OpAmp Circuits
Solid State Devices
Linear Amplifiers
-EXPA VARS PICT SI HALT HELP

```

### 5.10.1. Parallel Resonance I

#### Example:

Calculate the resonance parameters of a parallel resonant circuit containing a 10,000\_Ω resistor, a 2.4\_μF capacitor and a 3.9\_mH inductor. The amplitude of the current is 10\_mA at a radian frequency of 10,000 rad/s.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Electrical Resonance
Parallel Resonance I
Vm=Im/√(1/R^2+(ωC-1/(ωL))^2)
θ=ATAN((ωC-1/(ωL))/R)
ω0=1/√(L×C)
ω1=-1/(2×R×C)+√(1/(2×R×C)^2+1/L)
ω2=+1/(2×R×C)+√(1/(2×R×C)^2+1/L)
β=ω2-ω1
Q=ω0/β
Q=R×√(C/L)
Q=ω0×R×C
-EXPA VARS PICT SI HALT NSOLV

```

```

Parallel Resonance I
Eq: { 'Vm=Im/√(1/R^2+(ωC-1/(ωL))^2)
Vm: 0_V IM: 10_mA θ: 0_r
ω: 10000... ω2: 0_r/s ω1: 0_r/s
β: 0_r/s L: 3.90... C: 0
ω0: 0_r/s R: 10_kΩ C: 2.40...
Phase angle
EDIT VARS VIEW ALL NSOLV

```

```

Parallel Resonance I
Eq: { 'Vm=Im/√(1/R^2+(ωC-1/(ωL))^2)
Vm: 6.08... IM: 10_mA θ: -1.5...
ω: 10000... ω2: 1035... ω1: 1031...
β: 41.6... L: 3.90... C: 2.40...
ω0: 1033... R: 10_kΩ C: 2.40...
Phase angle
EDIT VARS VIEW ALL NSOLV

```

```

Parallel Resonance I
Vm: 6.08246721_V
θ: -1.50993409_r
ω0: 10336.2278824_r/s
ω1: 10315.4155446_r/s
ω2: 10357.0822112_r/s
β: 41.66666660_r/s
Q: 248.06946958
VALU EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

### 5.10.2. Parallel Resonance II

#### Example:

A parallel resonant circuit has a 1000\_Ω resistor and a 2.4\_μF capacitor. The Quality Factor for this circuit is 24.8069.

Find the band-width, damped and resonant frequencies.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
Electrical Resonance
Parallel Resonance I
Parallel Resonance II
Q=w0/p
w1=w0*(-1/(2*Q)+j(1/(2*Q)^2)+1)
w2=w0*(+1/(2*Q)+j(1/(2*Q)^2)+1)
Q=1/(2*R*C)
w0=j(w0^2-Q^2)
w0=w0*j(1-1/(4*Q^2))
Q=w0/(2*Q)
Resonance in Lossy Inductor
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

===== ELECTRICAL ENGINEERING =====
Electrical Resonance
Parallel Resonance I
Parallel Resonance II
Q=
w1 Starting
w2 Solver...
Q=
w0=j(w0^2-Q^2)
w0=w0*j(1-1/(4*Q^2))
Q=w0/(2*Q)
Resonance in Lossy Inductor
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

===== Parallel Resonance II =====
Eq: ( 'Q=w0/p' 'w1=w0*...
p: 0_r/s w1: 0_r/s
w0: 0_r/s 1_kΩ
2.4000_μF w0: 0_r/s
w0: 0_r/s w0: 0_r/s
24.8069
Bandwidth
EDIT VARS VIEW ALL NSOLV
  
```

```

===== Parallel Resonance II =====
Eq: ( 'Q=w0/p' 'w1=w0*...
p: 416.6667_r/s w1: 10129.9...
w0: 10546.6... 1_kΩ
2.4000_μF w0: 10334.1...
w0: 208.3333_r/s w0: 10336.2...
24.8069
Bandwidth
EDIT VARS VIEW ALL NSOLV
  
```

Press **TOOL** to view all calculated results.

```

===== Parallel Resonance II =====
w0: 208.3333_r/s
w0: 10336.2083_r/s
p: 416.6667_r/s
w1: 10129.9743_r/s
w2: 10546.6410_r/s
w0: 10334.1086_r/s
VALU= EQNS PRINT EXIT
  
```

### 5.10.3. Resonance in Lossy Inductor

#### Example:

A power source with an impedance  $R_g$  of  $5\ \Omega$  is driving a parallel combination of a lossy  $40\ \mu\text{H}$  inductor with a  $2\ \Omega$  loss resistance, and a capacitor of  $2.7\ \mu\text{F}$ . Find the frequency of resonance and the frequency for maximum amplitude.

#### Solution:

Upon examining the problem, all equations are needed to solve for a solution.

```

##### ELECTRICAL ENGINEERING #####
Electrical Resonance
Parallel Resonance I
Parallel Resonance II
Resonance in Lossy Inductor
w0=f(1/(L*C)-(R/L)^2)
Yres=(L+Rg*R*C)/(L*Rg)
Zres=1/Yres
wm=f(f((1/(L*C))^2*(1+2*R/Rg))+C)
Series Resonance
OpAmp Circuits
Solid State Devices
-EXPA VARS=PICT= SI = HALT NSOLV

```

```

##### ELECTRICAL ENGINEERING #####
Electrical Resonance
Parallel Resonance I
Parallel Resonance II
333 Starting
w0 Solver...
Yr
Zr
wm=f(f((1/(L*C))^2*(1+2*R/Rg))+C)
Series Resonance
OpAmp Circuits
Solid State Devices
-EXPA VARS=PICT= SI = HALT NSOLV

```

```

##### Resonance in Lossy Inductor #####
Eq: ( 'w0=f(1/(L*C)-(R...
w0: 0_r/s      Zres: 0_Ω
Yres: 0_S      wm: 0_r/s
Rg: 5_Ω        C: 2.7000_μF
R: 2_Ω         L: 40_μH

Resonant Frequency
EDIT VARS VIEW  ALL NSOLV

```

```

##### Resonance in Lossy Inductor #####
Eq: ( 'w0=f(1/(L*C)-(R...
w0: 82214.7... Zres: 2.9851...
Yres: 0.3350... wm: 107999...
Rg: 5_Ω        C: 2.7000_μF
R: 2_Ω         L: 40_μH

Resonant Frequency
EDIT VARS VIEW  ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

##### Resonance in Lossy Inductor #####
w0: 82214.714372_r/s
Yres: 0.335000_S
Zres: 2.985075_Ω
wm: 107999.736543_r/s

VALU= EQNS PRINT  EXIT

```

#### 5.10.4. Series Resonance

##### Example:

Find the characteristic parameters of a series-resonant circuit with  $R = 25\ \Omega$ ,  $L = 69\ \mu\text{H}$ ,  $C = 0.01\ \mu\text{F}$  and a radian frequency of 125000 rad/s.

##### Solution:

Upon examining the problem, all equations are needed to solve the problem.

```

ELECTRICAL ENGINEERING
Resonance in Lossy Inductor
Series Resonance
w0=(1/L*(L*C))
Z=sqrt(R^2+(w*L-1/(w*C))^2)
theta=ATAN((w*L-1/(w*C))/R)
w1=-R/(2*L)+sqrt((R/(2*L))^2+1/(L*C))
w2=R/(2*L)+sqrt((R/(2*L))^2+1/(L*C))
beta=w2-w1
beta=R/L
Q=w0*L/R
Q=1/R*sqrt(L/C)
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

ELECTRICAL ENGINEERING
Resonance in Lossy Inductor
Series Resonance
w0=(1/L*(L*C))
Z=
theta= Starting
w1= Solver...
w2=
beta=w2-w1
beta=R/L
Q=w0*L/R
Q=1/R*sqrt(L/C)
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

Series Resonance
Eq: ( 'w0=1/sqrt(L*C)' 'Z...'
z: 0_0 theta: 0_r w: 1250...
w2: 0_r/s w1: 0_r/s beta: 0_r/s
w0: 0_r/s q: 0 Q: 25_0
L: 69_uH C: 0.01...
Impedance
EDIT VARS VIEW ALL NSOLV

```

```

Series Resonance
Eq: ( 'w0=1/sqrt(L*C)' 'Z...'
z: 791... theta: -1.5... w: 1250...
w2: 1398... w1: 1036... beta: 3623...
w0: 1203... q: 3.32... Q: 25_0
L: 69_uH C: 0.01...
Impedance
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

Series Resonance
w0: 1203858.53086_r/s
z: 791.769784_0
theta: -1.539216_r
w1: 1036253.45047_r/s
w2: 1398572.29105_r/s
beta: 362318.840580_r/s
Q: 3.322650
VALU= EQNS PRINT EXIT

```

## 5.11. OpAmp Circuits

```

ELECTRICAL ENGINEERING
OpAmp Circuits
- Basic Inverter
- Non-Inverting Amplifier
- Current Amplifier
- Transconductance Amplifier
- Level Detector (Inverting)
- Level Detector (Non-Inverting)
- Differentiator
-EXPA VARS PICT SI HALT HELP

```

```

ELECTRICAL ENGINEERING
- Basic Inverter
- Non-Inverting Amplifier
- Current Amplifier
- Transconductance Amplifier
- Level Detector (Inverting)
- Level Detector (Non-Inverting)
- Differentiator
- Differential Amplifier
-EXPA VARS PICT SI HALT NSOLV

```

### 5.11.1. Basic Inverter

#### Example:

Find the gain of an inverter and its optimum value for bias resistance given an input resistance of 1\_k $\Omega$  and a feedback resistance of 20\_k $\Omega$ .

#### Solution:

Use the first and second equations to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
OpAmp Circuits
- Basic Inverter
- AV=-Rf/R1
- Rp=R1*Rf/(R1+Rf)
- Fcp=Fop*(-Av)*(R1/Rf)
- tr=0.35*Rf/(Fop*(-Av)*R1)
- Non-Inverting Amplifier
- Current Amplifier
- Transconductance Amplifier
- Level Detector (Inverting)
- Level Detector (Non-Inverting)
-EXPA VARS PICT SI HALT NSOLV

```

```

Choose Equations for MES
✓ AV=-Rf/R1
✓ Rp=R1*Rf/(R1+Rf)
Fcp=Fop*(-Av)*(R1/Rf)
tr=0.35*Rf/(Fop*(-Av)*R1)
✓CHK CANCEL OK

```

```

Basic Inverter
Eq: ('AV=-Rf/R1' 'Rp=...'
Av: 0
Rp: 0_Ω
R1: 1_kΩ
Rf: 20_kΩ

Voltage gain
EDIT VARS VIEW ALL NSOLV

```

```

Basic Inverter
Eq: ('AV=-Rf/R1' 'Rp=...'
Av: -20
Rp: 952.380952_Ω
R1: 1_kΩ
Rf: 20_kΩ

Voltage gain
EDIT VARS VIEW ALL NSOLV

```

### 5.11.2. Non-Inverting Amplifier

#### Example:

Find the DC gain of a non-inverting amplifier with a feedback resistance of 1\_M $\Omega$  and a resistance to the load of 18\_k $\Omega$ .

Find the gain and the optimum value for a bias resistor.

#### Solution:

Use the first and second equations to compute the solution for this problem.

```
===== ELECTRICAL ENGINEERING =====
OpAmp Circuits
- Basic Inverter
- Non-Inverting Amplifier
  - Av=1+Rf/R1
  - Rp=R1*Rf/(R1+Rf)
  - Fcp=Fop*(-Av)*R1/(R1+Rf)
  - tr=0.35*(R1+Rf)/(Fop*(-Av)*R1)
- Current Amplifier
- Transconductance Amplifier
- Level Detector (Inverting)
- Level Detector (Non-Inverting)
-EXPA VARS= PICT= SI= HALT NSOLV
```

```
===== Non-Inverting Amplifier =====
Eq: ( 'Av=1+Rf/R1' 'Rp...'
Av: 0
Rp: 0_Ω
R1: 18_kΩ
Rf: 1_MΩ

Voltage gain
EDIT VARS VIEW ALL NSOLV
```

```
===== Choose Equations for MES =====
✓ Av=1+Rf/R1
✓ Rp=R1*Rf/(R1+Rf)
  Fcp=Fop*(-Av)*R1/(R1+Rf)
  tr=0.35*(R1+Rf)/(Fop*(-Av)*R1)

✓CHK CANCEL OK
```

```
===== Non-Inverting Amplifier =====
Eq: ( 'Av=1+Rf/R1' 'Rp...'
Av: 56.55555556
Rp: 17681.7288802_Ω
R1: 18_kΩ
Rf: 1_MΩ

Voltage gain
EDIT VARS VIEW ALL NSOLV
```



### 5.11.3. Current Amplifier

#### Example:

A current amplifier with a 200\_k $\Omega$  feedback resistance has a voltage gain of 42. If the source resistance is 1\_k $\Omega$ , the load resistance is 10\_k $\Omega$  and the output resistance of the OpAmp is 100\_ $\Omega$ .

Find the current gain, input and output resistances.

#### Solution:

Use all of the equations to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
OpAmp Circuits
Basic Inverter
Non-Inverting Amplifier
Current Amplifier
  Aic=(Rs+Rf)*Av/(Rl+Ro+Rs*(1+Av))
  Rin=Rf/(1+Av)
  Rout=Rs*(1+Av)
Transconductance Amplifier
Level Detector (Inverting)
Level Detector (Non-Inverting)
Differentiator
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

===== ELECTRICAL ENGINEERING =====
OpAmp Circuits
Basic Inverter
Non-Inverting Amplifier
Current Amplifier
  Aic=(Rs+Rf)*Av/(Rl+Ro+Rs*(1+Av))
  Rin=Rf/(1+Av)
  Rout=Rs*(1+Av)
Transconductance Amplifier
Level Detector (Inverting)
Level Detector (Non-Inverting)
Differentiator
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

===== Current Amplifier =====
Eq: ( 'Aic=(Rs+Rf)*Av/...
Aic: 0 Rin: 0_Ω
Ro: 100_Ω Rin: 0_Ω
Rf: 200_kΩ Rout: 0_Ω
Rs: 1_kΩ Av: 42

Current gain
EDIT VARS VIEW ALL NSOLV

```

```

===== Current Amplifier =====
Eq: ( 'Aic=(Rs+Rf)*Av/...
Aic: 158.983... Rin: 4651.16...
Ro: 100_Ω Rin: 4651.16...
Rf: 200_kΩ Rout: 43000.0...
Rs: 1_kΩ Av: 42

Current gain
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

===== Current Amplifier =====
Aic: 158.98305085
Rin: 4651.16279070_Ω
Rout: 43000.0000000_Ω

VALU= EQNS PRINT EXIT

```

#### 5.11.4. Transconductance Amplifier

##### Example:

Find the transconductance and output resistance for a transconductance amplifier with a voltage gain of 48 and an external resistance of 125\_Ω.

##### Solution:

Upon examining the problem, all equations are needed to solve the problem.

```
##### ELECTRICAL ENGINEERING #####
OpAmp Circuits
- Basic Inverter
- Non-Inverting Amplifier
- Current Amplifier
- Transconductance Amplifier
-  $A_{gc}=1/R_s$ 
-  $R_{out}=R_s \times (1+A_v)$ 
- Level Detector (Inverting)
- Level Detector (Non-Inverting)
- Differentiator
- Differential Amplifier
-EXPAN VARS= PICT= SI = HALT MSOLV
```

```
##### Transconductance Amplifier #####
Eq: ( 'Agc=1/Rs' 'Rout...'
Agc: 0_S
Rout: 0_Ω
Rs: 125_Ω
Av: 48

Transconductance
EDIT VARS VIEW ALL MSOLV
```

```
##### ELECTRICAL ENGINEERING #####
OpAmp Circuits
- Basic Inverter
- Non-Inverting Amplifier
- Cur
- Starting Solver...
- Rs
- Ro
- Level Detector (Inverting)
- Level Detector (Non-Inverting)
- Differentiator
- Differential Amplifier
-EXPAN VARS= PICT= SI = HALT MSOLV
```

```
##### Transconductance Amplifier #####
Eq: ( 'Agc=1/Rs' 'Rout...'
Agc: 0.008000000_S
Rout: 6125.00000000_Ω
Rs: 125_Ω
Av: 48

Transconductance
EDIT VARS VIEW ALL MSOLV
```

### 5.11.5. Level Detector (Inverting)

#### Example:

An inverting level detector possesses two zener diodes to set the trip level. The setting levels are 4\_V and 3\_V, respectively, for the first and second diodes. The reference voltage is 5\_V, the OpAmp is supported by a 10\_kΩ bias resistor and a 1\_MΩ feedback resistor. Find the hysteresis, the upper and lower detection thresholds, and the input resistance.

#### Solution:

Upon examining the problem, all equations are needed to solve the problem.

```

===== ELECTRICAL ENGINEERING =====
OpAmp Circuits
Basic Inverter
Non-Inverting Amplifier
Current Amplifier
Transconductance Amplifier
Level Detector (Inverting)
R1=Rp*Rf/(Rp+Rf)
ΔVH=(Vz1+Vz2)*Rp/(Rp+Rf)
VU=(VR*Rf+Rp*Vz1)/(Rf+Rp)
VL=(VR*Rf-Rp*Vz2)/(Rf+Rp)
Level Detector (Non-Inverting)
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

===== ELECTRICAL ENGINEERING =====
OpAmp Circuits
Basic Inverter
Non-Inverting Amplifier
Cur
Trg
30
Starting
Solver...
R1
ΔVH=(Vz1+Vz2)*Rp/(Rp+Rf)
VU=(VR*Rf+Rp*Vz1)/(Rf+Rp)
VL=(VR*Rf-Rp*Vz2)/(Rf+Rp)
Level Detector (Non-Inverting)
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

===== Level Detector (Inverting) =====
Eq: ( 'R1=Rp*Rf/(Rp+Rf...'
R1: 0_Ω ΔVH: 0_V
VU: 0_V Vz1: 4_V
VL: 0_V VR: 5_V
Vz2: 3_V Rf: 1_MΩ
Rp: 10_kΩ
Input resistor
EDIT VARS VIEW ALL NSOLV

```

```

===== Level Detector (Inverting) =====
Eq: ( 'R1=Rp*Rf/(Rp+Rf...'
R1: 9900.99... ΔVH: 0.06930...
VU: 4.99009... Vz1: 4_V
VL: 4.92079... VR: 5_V
Vz2: 3_V Rf: 1_MΩ
Rp: 10_kΩ
Input resistor
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

===== Level Detector (Inverting) =====
R1: 9900.99009901_Ω
ΔVH: 0.06930693_V
VU: 4.99009901_V
VL: 4.92079208_V
VALU= EQNS PRINT EXIT

```

### 5.11.6. Level Detector (Non-Inverting)

#### Example:

For a non-inverting level detector with the same specifications as the inverting level detector in the previous example, compute the hysteresis, the upper and lower detection thresholds, and the input resistance.

#### Solution:

Upon examining the problem, all equations are needed to solve the problem.

```

***** ELECTRICAL ENGINEERING *****
OpAmp Circuits
Basic Inverter
Non-Inverting Amplifier
Current Amplifier
Transconductance Amplifier
Level Detector (Inverting)
Level Detector (Non-Inverting)
R1=Rp*Rf/(Rp+Rf)
ΔVH=(Vz1+Vz2)*Rp/(Rp+Rf)
VU=(VR*(Rf+Rp)+Rp*Vz1)/Rf
VL=(VR*(Rp+Rf)-Rp*Vz2)/Rf
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

***** ELECTRICAL ENGINEERING *****
OpAmp Circuits
Basic Inverter
Non-Inverting Amplifier
Cur
Trd
Lev
Lev
Starting
Solver...
R1=Rp*Rf/(Rp+Rf)
ΔVH=(Vz1+Vz2)*Rp/(Rp+Rf)
VU=(VR*(Rf+Rp)+Rp*Vz1)/Rf
VL=(VR*(Rp+Rf)-Rp*Vz2)/Rf
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

***** Level Detector (Non-Inverting) *****
Eq: ( 'R1=Rp*Rf/(Rp+Rf)...
R1: 0_Ω ΔVH: 0_V
VU: 0_V Vz1: 4_V
VL: 0_V VR: 5_V
Rp: 10_kΩ Vz2: 3_V
Rf: 1_MΩ
Input resistor
EDIT VARS VIEW ALL NSOLV

```

```

***** Level Detector (Non-Inverting) *****
Eq: ( 'R1=Rp*Rf/(Rp+Rf)...
R1: 9900.99... ΔVH: 0.06930...
VU: 5.09000... Vz1: 4_V
VL: 5.02000... VR: 5_V
Rp: 10_kΩ Vz2: 3_V
Rf: 1_MΩ
Input resistor
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

***** Level Detector (Non-Inverting) *****
R1: 9900.99009901_Ω
ΔVH: 0.06930693_V
VU: 5.09000000_V
VL: 5.02000000_V
VALU= EQNS PRINT EXIT

```

### 5.11.7. Differentiator

#### Example:

A differentiator circuit designed with an OpAmp has a slew rate of 1.5\_V/μs. If the maximum output voltage is 5\_V, and the feedback resistor is 39\_kΩ, what input capacitor and resistor are needed for the amplifier with a characteristic frequency of 50\_kHz?

#### Solution:

Use the third and fourth equations to compute the solution for this problem.

```
===== ELECTRICAL ENGINEERING =====
-Transconductance Amplifier
-Level Detector (Inverting)
-Level Detector (Non-Inverting)
-Differentiator
  Rf=Vomax/If
  Rp=Rf
  C1=Vomax/(Rf*Vrate)
  R1=1/(2*pi*Fd*C1)
  Fd=1/(2*pi*Rf*C1)
  Cp=10/(2*pi*Fd*Rp)
  Cf=1/(4*pi*Fd*Rf)
-EXPA VARS= PICT= SI= HALT MSOLV
```

```
===== Choose Equations for MES =====
  Rf=Vomax/If
  Rp=Rf
  ✓ C1=Vomax/(Rf*Vrate)
  ✓ R1=1/(2*pi*Fd*C1)
  Fd=1/(2*pi*Rf*C1)
  Cp=10/(2*pi*Fd*Rp)
  Cf=1/(4*pi*Fd*Rf)
===== ✓CHK===== CANCEL OK
```

```
===== Differentiator =====
Eq: { 'C1=Vomax/(Rf*Vr...
Vomax: 5_V      Rf: 39_kΩ
Vrate: 1.500... R1: 0_Ω
Fd: 50_kHz     c1: 0_F

Input capacitor
EDIT VARS VIEW ALL MSOLV
```

```
===== Differentiator =====
Eq: { 'C1=Vomax/(Rf*Vr...
Vomax: 5_V      Rf: 39_kΩ
Vrate: 1.500... R1: 37242.2...
Fd: 50_kHz     c1: 8.54700...

Input capacitor
EDIT VARS VIEW ALL MSOLV
```

Press **TOOL** to view all calculated results.

```
===== Differentiator =====
C1: 8.54700855E-11_F
R1: 37242.2566835_Ω

VALU= EQNS PRINT EXIT
```

### 5.11.8. Differential Amplifier

#### Example:

Find the differential mode gain and the current gain for a differential amplifier with bridge resistors R1, R2, R3 and R4 of 10\_kΩ, 3.9\_kΩ, 10.2\_kΩ and 4.1\_kΩ, respectively. Assume a voltage gain of 90.

#### Solution:

Use the third and fourth equations to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
Non-Inverting Amplifier
Current Amplifier
Transconductance Amplifier
Level Detector (Inverting)
Level Detector (Non-Inverting)
Differentiator
Differential Amplifier
Ad=R3/R1
Aco=R3^2/(R3*(R1+R3)*CMRR)
Ad=(Av*R3)/sqrt(R1^2*Av^2+R3^2)
Acc=(R4*R1-R2*R3)/(R1*(R2+R4))
-EXPA VARS=PICT= SI = HALT NSOLV

```

```

===== Choose Equations for MES =====
Ad=R3/R1
Aco=R3^2/(R3*(R1+R3)*CMRR)
✓ Ad=(Av*R3)/sqrt(R1^2*Av^2+R3^2)
✓ Acc=(R4*R1-R2*R3)/(R1*(R2+R4))
=====
✓CHK CANCEL OK

```

```

===== Differential Amplifier =====
Eq: ( 'Ad=Av*R3/sqrt(R1^2...
Ad: 0 Au: 90
Acc: 0 R3: 10.2000...
R1: 10_kΩ R2: 3.90000...
R4: 4.10000...

Differential Mode gain
EDIT VARS VIEW ALL NSOLV

```

```

===== Differential Amplifier =====
Eq: ( 'Ad=Av*R3/sqrt(R1^2...
Ad: 1.01993... Au: 90
Acc: 0.01525... R3: 10.2000...
R1: 10_kΩ R2: 3.90000...
R4: 4.10000...

Differential Mode gain
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

===== Differential Amplifier =====
Ad: 1.01993450
Acc: 0.01525000

VALU= EQNS PRINT EXIT

```

## 5.12. Solid State Devices

```

ELECTRICAL ENGINEERING
Solid State Devices
Semiconductor Basics
PN Junctions
PN Junction Currents
Transistor Currents
Ebers-Moll Equations
Ideal Currents - pnp
Switching Transients
-EXPA VARS PICT SI HALT HELP

```

```

ELECTRICAL ENGINEERING
Switching Transients
MOS Transistor I
MOS Transistor II
MOS Inverter (Resistiv
MOS Inverter (Saturat
MOS Inverter (Depleti
CMOS Transistor Pair
Junction FEI
-EXPA VARS PICT SI HALT HSOLV

```

**Note:** The equations in this section are grouped under topics which describe general properties of semiconductors or devices. Equations for a variety of specific cases and are listed together under a sub-topic heading and are not necessarily a set of consistent equations which can be solved together. Choosing equations in a subtopic without regard as to whether the equations represent actual relationships could generate erroneous results or no solution at all.

### 5.12.1. Semiconductor Basics

Remember that the result of equation five and six depends on the constant chosen for  $n_i$ .

#### Example 1:

Find the intrinsic and actual Fermi levels for Silicon at 300\_K if the conduction band is 1.12\_eV above the valence band. The donor density is  $8 \times 10^{17} \text{ cm}^{-3}$ . The effective masses for electrons and holes are 0.5 and 0.85.

#### Solution:

Since the dopant is a donor, use equations 6 and 7 to compute a solution.

(Intrinsic Density Carrier Concentration of Silicon at 300\_K:  $1.45 \times 10^{10} \text{ 1/cm}^3$ )

```

ELECTRICAL ENGINEERING
Solid State Devices
Semiconductor Basics
Pn=1/(q*un*nd)
Pp=1/(q*up*na)
Dn/un=(k*T)/q
Dp/up=(k*T)/q
Ei=EF+k*T*Ln(na/ni)
EF=Ei+k*T*Ln(nd/ni)
Ei=(Ec+Ev)/2+3/4*(k*T)*Ln(mp/mn)
n=q/(A*sqrt(n*D*t))*exp(-x^2/(4*D*t))
PN Junctions
-EXPA VARS PICT SI HALT HSOLV

```

```

Choose Equations For MES
Pn=1/(q*un*nd)
Pp=1/(q*up*na)
Dn/un=(k*T)/q
Dp/up=(k*T)/q
Ei=EF+k*T*Ln(na/ni)
✓ EF=Ei+k*T*Ln(nd/ni)
✓ Ei=(Ec+Ev)/2+3/4*(k*T)*Ln(mp/mn)
n=nd*ERFC(x/(2*sqrt(D*t)))
n=q/(A*sqrt(n*D*t))*exp(-x^2/(4*D*t))
✓CHK CANCL OK

```

```

Semiconductor Basics
Eq: ( 'EF=Ei+CONST(k)*...
EF: 0_eV Nd: 8.E-17_...
ni: 1450000... Ei: 0_eV
Ec: 1.12_eV Ev: 0_J
T: 300_K q: .85
h: .5
Fermi level
EDIT VARS VIEW ALL HSOLV

```

```

Semiconductor Basics
Eq: ( 'EF=Ei+CONST(k)*...
EF: -.99278... Nd: 8.E-17_...
ni: 1450000... Ei: .570288...
Ec: 1.12_eV Ev: 0_J
T: 300_K q: .85
h: .5
Fermi level
EDIT VARS VIEW ALL HSOLV

```

Press **TOOL** to view all calculated results.

```

Semiconductor Basics
Ei: .570288413672_eV
EF: -.992782627064_eV
VALU EQNS PRINT EXIT

```

### Example 2:

Find the diffusion penetration depth after one hour for phosphorus atoms with a diffusion coefficient of  $1.8 \times 10^{-14} \text{ cm}^2/\text{s}$ . The carrier density at the desired depth is  $8 \times 10^{17} \text{ 1/cm}^3$  while the surface density is  $4 \times 10^{19} \text{ 1/cm}^3$ .

### Solution:

Equation 8 is needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Solid State Devices
Semiconductor Basics
Pn=1/(q*un*Nd)
Pp=1/(q*up*Na)
Dn/un=(k*T)/q
Dp/up=(k*T)/q
Ei=EF+k*T*Ln(Nd/ni)
EF=Ei+k*T*Ln(Nd/ni)
Ei=(Ec+Ev)/2+3/4*(k*T)*Ln(hp/hn)
Ei=.084870627064_eV
n=Nd*ERFC(x/(2*sqrt(D*t)))
n=0/(A*(n*D*t))*exp(-x^2/(4*D*t))
EQN VARS PICT SI HALT SOLVE

```

```

n=Nd*ERFC(x/(2*sqrt(D*t)))
Eq: 'UVAL(UBASE(N))=UV...
n: 8.E17_1/cm^3
Nd: 4.E19_1/cm^3
x: 0_μ
D: 1.8E-14_cm^2/s
t: 3600._s
Depth from surface
EDIT VARS VIEW SOLVE

```

```

ELECTRICAL ENGINEERING
Solid State Devices
Semiconductor Basics
Pn=1/(q*un*Nd)
Pp=1/(q*up*Na)
Dn/un=(k*T)/q
Dp/up=(k*T)/q
Ei=EF+k*T*Ln(Nd/ni)
EF=Ei+k*T*Ln(Nd/ni)
Ei=(Ec+Ev)/2+3/4*(k*T)*Ln(hp/hn)
Ei=.084870627064_eV
n=Nd*ERFC(x/(2*sqrt(D*t)))
n=0/(A*(n*D*t))*exp(-x^2/(4*D*t))
EQN VARS PICT SI HALT SOLVE

```

```

n=Nd*ERFC(x/(2*sqrt(D*t)))
Eq: 'UVAL(UBASE(N))=UV...
n: 8.E17_1/cm^3
Nd: 4.E19_1/cm^3
x: .264836084827_μ
D: 1.8E-14_cm^2/s
t: 3600._s
Depth from surface
EDIT VARS VIEW INFO SOLVE

```



### 5.12.2. PN Junctions

Remember that the result of equation one and six depends on the constant chosen for  $n_i$ .

#### Example 1:

A PN step junction is characterized by an acceptor doping density of  $6 \times 10^{16} \text{ 1/cm}^3$  and a donor doping density of  $9 \times 10^{17} \text{ 1/cm}^3$ . The junction area is  $100 \text{ } \mu\text{m}^2$  at room temperature. For an applied voltage of  $-5 \text{ V}$ , find the built-in potential and junction capacitance. Use a value of 11.8 for the relative permittivity of silicon.

#### Solution:

Use the first five equations to compute the solution for this problem.

(Intrinsic Density Carrier Concentration of Silicon at 300\_K:  $1.45 \times 10^{10} \text{ 1/cm}^3$ )

```

ELECTRICAL ENGINEERING
Solid State Devices
Semiconductor Basics
PN Junctions
Vbi=k*T/q*Ln(Nd*Na/ni^2)
xn=f(2*Es*EO*ABS(Vbi-Va)/q*Na/
xp=(Nd/Na)*xn
xd=xn+xp
Cj=Es*EO*Aj/xd
Vbi=2*k*T/q*Ln(aLGJ*xd/(2*ni..
xd=(12*Es*EO/(q*aLGJ)*ABS(Vb..
PN Junction Currents
-EXPAN VARS= PICT= SI= HALT MSOLV

```

```

Choose Equations for MES
✓ Vbi=k*T/q*Ln(Nd*Na/ni^2)
✓ xn=f(2*Es*EO*ABS(Vbi-Va)/q*Na..
✓ xp=(Nd/Na)*xn
✓ xd=xn+xp
✓ Cj=Es*EO*Aj/xd
Vbi=2*k*T/q*Ln(aLGJ*xd/(2*ni..
xd=(12*Es*EO/(q*aLGJ)*ABS(Vb..
✓CHK CANCEL OK

```

```

PN Junctions
Eq: ( 'Vbi=CONST(k)*T/...
T: 300_K ni: 1450... Vbi: 0_V
Va: -5_V Nd: 9.E1... Na: 6.E1...
xn: 0_m xp: 0_m Cj: 0_F
Es: 11.8 EO: 100... xd: 0_m
Depletion layer width
EDIT VARS VIEW ALL MSOLV

```

```

PN Junctions
Eq: ( 'Vbi=CONST(k)*T/...
T: 300_K ni: 1450... Vbi: .85...
Va: -5_V Nd: 9.E1... Na: 6.E1...
xn: 2.30... xp: 3.45... Cj: 2.83...
Es: 11.8 EO: 100... xd: 3.68...
Depletion layer width
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

PN Junctions
Vbi: .857760692886_V
xn: 2.30334844544E-8...
xp: 3.45502266816E-7...
xd: 3.6853575127E-7_m
Cj: 2.83498726753E-1...
VALU= EQNS PRINT EXIT

```

```

PN Junctions
Vbi: 8.577607E-1_V
xn: 2.303348E-8_m
xp: 3.455023E-7_m
xd: 3.685358E-7_m
Cj: 2.834987E-14_F
VALU= EQNS PRINT EXIT

```

### Example 2:

A linearly graded junction has an area of  $100\text{ }\mu^2$ , a depletion layer width of  $0.318005\text{ }\mu$ , a built-in voltage of  $0.8578\text{ V}$  and an applied voltage of  $-5\text{ V}$ . The relative permittivity of silicon is  $11.8$ . Under room temperature conditions, what is the junction capacitance and the linear-graded junction parameter?

### Solution:

Use the equations five and seven to compute the solution for this problem.

```
===== ELECTRICAL ENGINEERING =====
Solid State Devices
Semiconductor Basics
PN Junctions
Vbi=k*T/q*Ln(Nd*Na/ni^2)
xn=f(2*Es*E0*ABS(Vbi-Va)/q*Na/
xp=(Nd/Na)*xn
xd=xn+xp
Cj=Es*E0*Aj/xd
Vbi=2*k*T/q*Ln(aLGJ*xd/(2*ni))
xd=(12*Es*E0/(q*aLGJ)*ABS(Vbi-V
PN Junction Currents
-EXPAN VARS= PICT= SI= HALT NSOLV
```

```
===== Choose Equations for MES =====
Vbi=k*T/q*Ln(Nd*Na/ni^2)
xn=f(2*Es*E0*ABS(Vbi-Va)/q*Na..
xp=(Nd/Na)*xn
xd=xn+xp
✓ Cj=Es*E0*Aj/xd
Vbi=2*k*T/q*Ln(aLGJ*xd/(2*ni..
✓ xd=(12*Es*E0/(q*aLGJ)*ABS(Vb..
=====
✓CHK= CANCL= OK=
```

```
===== PN Junctions =====
Eq: ( 'Cj=es*CONST(e0)...
Cj: 0_F A: 100_μ^2
xd: 0.31800... Es: 11.8000...
aLGJ: 0_1/m^4 Vbi: 0.85780...
Va: -5_V

Junction capacitance
EDIT VARS VIEW ALL NSOLV
```

```
===== PN Junctions =====
Eq: ( 'Cj=es*CONST(e0)...
Cj: 3.28546... A: 100_μ^2
xd: 0.31800... Es: 11.8000...
aLGJ: 1.4253... Vbi: 0.85780...
Va: -5_V

Junction capacitance
EDIT VARS VIEW ALL NSOLV
```

Press **TOOL** to view all calculated results.

```
===== PN Junctions =====
Cj: 3.2855E-14_F
aLGJ: 1.4254E30_1/m^4

VALU= EQNS PRINT EXIT
```

### 5.12.3. PN Junction Currents

#### Example:

A PN Junction is characterized as having a junction area of  $100\text{ }\mu^2$ , an applied voltage of  $0.5\text{ V}$ , and diffusion coefficients for electrons and holes of  $35\text{ cm}^2/\text{s}$  and  $10\text{ cm}^2/\text{s}$ , respectively. The diffusion lengths for electrons and holes are  $25\text{ }\mu$  and  $15\text{ }\mu$ . The minority carrier densities are  $5 \times 10^6\text{ 1/cm}^3$  (electrons) and  $25\text{ 1/cm}^3$  (holes).

Find the junction current and the saturation current for room temperature conditions.

#### Solution:

Use the equations one and two or one and three to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Semiconductor Basics
PN Junctions
PN Junction Currents
I=q*Aj*(Dn/Ln*np0+Dp/Lp*pn0)*(e
I=I0*(e^(q*Vd/(k*T))-1)
I0=q*Aj*(Dn/Ln*np0+Dp/Lp*pn0)
IR0=-q*Aj*ni*xd/(2*to)
IRG=q*Aj*ni*xd/(2*to)*(e^(q*Vd/
Go=q/(k*T)*(I+I0)
ts=tp*Ln(1+IF/IR)
ERF(I/(ts/tp))=1/(1+IR/IF)
-EXPA VARS= PICT SI = HALT MSOLV

```

```

Choose Equations For MES
✓ I=q*Aj*(Dn/Ln*np0+Dp/Lp*pn0)..
✓ I=I0*(e^(q*Vd/(k*T))-1)
I0=q*Aj*(Dn/Ln*np0+Dp/Lp*pn0)
IR0=-q*Aj*ni*xd/(2*to)
IRG=q*Aj*ni*xd/(2*to)*(e^(q*Vd/
Go=q/(k*T)*(I+I0)
ts=tp*Ln(1+IF/IR)
ERF(I/(ts/tp))=1/(1+IR/IF)
✓CHK CANCEL OK

```

```

PN Junction Currents
Eq: ( ' I=CONST(q)*Aj*(...
A: 100... Dn: 35_c... Ln: 25_μ
np0: 500... Dp: 10_c... Lp: 15_μ
pn0: 25... I: 0_A I0: 0_A
Vd: .5_V T: 300_K

Junction current
EDIT VARS VIEW ALL MSOLV

```

```

PN Junction Currents
Eq: ( ' I=CONST(q)*Aj*(...
A: 100... Dn: 35_c... Ln: 25_μ
np0: 500... Dp: 10_c... Lp: 15_μ
pn0: 25... I: 0.00... I0: 1.12...
Vd: 0.50... T: 300_K

Junction current
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

PN Junction Currents
I: 0.000002814_A
I0: 1.121526801E-14_A

VALU= EQNS PRINT EXIT

```

```

##### ELECTRICAL ENGINEERING #####
Semiconductor Basics
PN Junctions
PN Junction Currents
I=q*Aj*(Dn/Ln*npo+Dp/Lp*pno)*(e
I=I0*(e^(q*Va/(k*T))-1)
I0=q*Aj*(Dn/Ln*npo+Dp/Lp*pno)
IR0=-q*Aj*ni*xd/(2*to)
IRG=q*Aj*ni*xd/(2*to)*(e^(q*Va/
Go=q/(k*T)*(I+I0)
ts=tp*Lh(1+If/Ir)
ERF(I(ts/tp))=1/(1+Ir/If)
-EXPA VARS= PICT SI = HALT NSOLV

```

```

##### Choose Equations for MES #####
✓ I=q*Aj*(Dn/Ln*npo+Dp/Lp*pno)..
I=I0*(e^(q*Va/(k*T))-1)
✓ I0=q*Aj*(Dn/Ln*npo+Dp/Lp*pno)
IR0=-q*Aj*ni*xd/(2*to)
IRG=q*Aj*ni*xd/(2*to)*(e^(q*..
Go=q/(k*T)*(I+I0)
ts=tp*Lh(1+If/Ir)
ERF(I(ts/tp))=1/(1+Ir/If)
✓CHK CANCEL OK

```

```

##### ELECTRICAL ENGINEERING #####
Semiconductor Basics
PN Junctions
PN Junction Currents
I= Starting
I= Solver...
I0=
IR=
IRG=q*Aj*ni*xd/(2*to)*(e^(q*Va/
Go=q/(k*T)*(I+I0)
ts=tp*Lh(1+If/Ir)
ERF(I(ts/tp))=1/(1+Ir/If)
-EXPA VARS= PICT SI = HALT NSOLV

```

```

##### PN Junction Currents #####
Eq: ( 'I=CONST(q)*Aj*(...
I: 0_A Va: 0.50... T: 300_K
I0: 0_A A0: 100... Dn: 35_c...
Ln: 25_μ npo: 500... Dp: 10_c...
Lp: 15_μ pno: 25_...
Junction current
EDIT VARS VIEW ALL NSOLV

```

```

Solving for I0
I0: 1.121526801E-14_A
Zero
EDIT VARS VIEW ALL NSOLV

```

```

##### PN Junction Currents #####
Eq: ( 'I=CONST(q)*Aj*(...
I: 0.00... Va: 0.50... T: 300_K
I0: 1.12... A0: 100... Dn: 35_c...
Ln: 25_μ npo: 500... Dp: 10_c...
Lp: 15_μ pno: 25_...
Junction current
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

##### PN Junction Currents #####
I: 0.000002814_A
I0: 1.121526801E-14_A
VALU= EQNS PRINT EXIT

```

#### 5.12.4. Transistor Currents

##### Example:

A junction transistor has the following parameters:  $\alpha$  is 0.98, the base current is  $1.2\text{ }\mu\text{A}$  while  $I_{CBO}$  is  $1.8\text{ }\mu\text{A}$ .

Find the  $\beta$ , emitter and collector currents.

##### Solution:

A few different choices are available, however the results might differ slightly due to the combination of equations used. The second, third and fifth equations can be used to solve this problem.

```

ELECTRICAL ENGINEERING
Semiconductor Basics
PN Junctions
PN Junction Currents
Transistor Currents
   $\alpha = I_C / I_E$ 
   $\beta = \alpha / (1 - \alpha)$ 
   $I_E = I_B + I_C$ 
   $I_C = \alpha I_E + I_{CBO}$ 
   $I_C = \alpha / (1 - \alpha) \times I_B + I_{CBO} / (1 - \alpha)$ 
   $I_C = \beta I_B + I_{CEO}$ 
   $I_{CEO} = I_{CBO} \times (\beta + 1)$ 
-EXPAND VARS= PICT SI = HALT MSOLV
  
```

```

Choose Equations for MES
 $\alpha = I_C / I_E$ 
✓  $\beta = \alpha / (1 - \alpha)$ 
✓  $I_E = I_B + I_C$ 
   $I_C = \alpha I_E + I_{CBO}$ 
✓  $I_C = \alpha / (1 - \alpha) \times I_B + I_{CBO} / (1 - \alpha)$ 
   $I_C = \beta I_B + I_{CEO}$ 
   $I_{CEO} = I_{CBO} \times (\beta + 1)$ 
  ✓CHK CANCEL OK
  
```

```

Transistor Currents
Eq: ( ' $\beta = \alpha / (1 - \alpha)$ ' 'IE=...'
 $\beta$ : 0 IE: 0_A
IC: 0_A IB: 1.2_μA
ICBO: 1.8_μA α: .98

CE current gain
EDIT VARS VIEW ALL MSOLV
  
```

```

Transistor Currents
Eq: ( ' $\beta = \alpha / (1 - \alpha)$ ' 'IE=...'
 $\beta$ : 49 IE: .000060...
IC: .000058... IB: 1.2_μA
ICBO: 1.8_μA α: .98

CE current gain
EDIT VARS VIEW ALL MSOLV
  
```

Press **TOOL** to view all calculated results.

```

Transistor Currents
 $\beta$ : 49.
IC: .000058800009_A
IE: .000060000009_A

VALU= EQNS PRINT EXIT
  
```

### 5.12.5. Ebers-Moll Equations

#### Example:

A junction transistor has a forward and reverse  $\alpha$  of 0.98 and 0.10 respectively. The collector current is 10.8\_mA while the forward current is 12.5\_mA. respectively. Compute the base, saturation and reverse currents, in addition to the forward and the reverse b.

#### Solution:

The second through sixth equations are needed to solve this problem.

```

ELECTRICAL ENGINEERING
Ebers-Moll Equations
IE=IF-or*Ir
IC=of*IF-Ir
IB=(1-of)*IF+(1-or)*Ir
bf=of/(1-of)
br=or/(1-or)
of*IF=Is
or*Ir=Is
ICB0=(1-or*of)*Ir0
ICE0=ICB0*(bf+1)
ICE0=Ir0*(1-of*or)/(1-of)
-EXPA VARS= PICT= SI= HALT MSOLV

```

```

Choose Equations for MES
IE=IF-or*Ir
✓ IC=of*IF-Ir
✓ IB=(1-of)*IF+(1-or)*Ir
✓ bf=of/(1-of)
✓ br=or/(1-or)
✓ of*IF=Is
or*Ir=Is
ICB0=(1-or*of)*Ir0
ICE0=ICB0*(bf+1)
+
✓CHK CANCEL OK

```

```

Ebers-Moll Equations
Eq: ( 'IC=of*If-Ir' 'I...
IC: 10.8_mA IB: 0_A
Ir: 0_A bf: 0
br: 0 or: .1
of: .98 IF: 12.5_mA
Is: 0_A
Saturation current
EDIT VARS VIEW ALL MSOLV

```

```

Ebers-Moll Equations
Eq: ( 'IC=of*If-Ir' 'I...
IC: 10.8_mA IB: .001555...
Ir: .00145_A bf: 49
br: .111111... or: .1
of: .98 IF: 12.5_mA
Is: .01225_A
Saturation current
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

Ebers-Moll Equations
Ir: .00145_A
IB: .001555_A
bf: 49
br: .111111111111
Is: .01225_A
VALU= EQNS PRINT EXIT

```

### 5.12.6. Ideal Currents - pnp

#### Example:

Find the emitter current gain  $\alpha$  for a transistor with the following properties: base width of  $0.75\text{ }\mu\text{m}$ , base diffusion coefficient of  $35\text{ cm}^2/\text{s}$ , emitter diffusion coefficient of  $12\text{ cm}^2/\text{s}$ , and emitter diffusion length of  $0.35\text{ }\mu\text{m}$ . The emitter electron density is  $30000\text{ cm}^{-3}$  and the base density is  $500000\text{ cm}^{-3}$ .

#### Solution:

Use the last equation to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Solid State Devices
Semiconductor Basics
PN Junctions
PN Junction Currents
Transistor Currents
Ebers-Moll Equations
Ideal Currents - pnp
IE=q*A1*(DE*nE/LE+DB*pB/WB)*(e^(q*VBE)/k
IC=q*A1*DB*pB/WB*(e^(q*VBE)/k
IB=q*A1*DE/LE*nE*(e^(q*VBE)/k
alpha=((DB*pB)/WB)/((DB*pB)/WB+DE*nE/LE)
EQN VARS=PICT=SI=HALT SOLVE

```

```

alpha=((DB*pB)/WB)/((DB*pB)/WB+DE*nE/LE)
Eq: 'alpha=DB*pB/WB/(DB*pB/...
alpha: 0 DB: 35_cm^2...
pB: 500000... WB: .75_μ
DE: 12_cm^2... nE: 30000...
LE: .35_μ

```

CB current gain

EDIT VARS VIEW SOLVE

```

alpha=((DB*pB)/WB)/((DB*pB)/WB+DE*nE/LE)
Eq: 'alpha=DB*pB/WB/(DB*pB/...
alpha: 957779515245 DB: 35_cm^2...
pB: 500000... WB: .75_μ
DE: 12_cm^2... nE: 30000...
LE: .35_μ

```

CB current gain

OK

```

ELECTRICAL ENGINEERING
Solid State Devices
Semiconductor Basics
PN Junctions
PN Starting Solver...
Trd
Ebe
Ide
IE=q*A1*(DE*nE/LE+DB*pB/WB)*(e^(q*VBE)/k
IC=q*A1*DB*pB/WB*(e^(q*VBE)/k
IB=q*A1*DE/LE*nE*(e^(q*VBE)/k
alpha=((DB*pB)/WB)/((DB*pB)/WB+DE*nE/LE)
EQN VARS=PICT=SI=HALT SOLVE

```

```

alpha=((DB*pB)/WB)/((DB*pB)/WB+DE*nE/LE)
Eq: 'alpha=DB*pB/WB/(DB*pB/...
alpha: .9577795... DB: 35_cm^2...
pB: 500000... WB: .75_μ
DE: 12_cm^2... nE: 30000...
LE: .35_μ

```

CB current gain

EDIT VARS VIEW INFO SOLVE

### 5.12.7. Switching Transients

#### Example:

Find the saturation voltage for a switching transistor at room temperature when a base current of 5.1\_mA is used to control a collector current of 20\_mA. The forward and reverse  $\alpha$ 's are 0.99 and 0.1 respectively.

#### Solution:

Use the last equation to solve this problem.

```

===== ELECTRICAL ENGINEERING =====
PN Junction Currents
Transistor Currents
Ebers-Moll Equations
Ideal Currents - pnp
Switching Transients
Vcesat=VCC/RI
ICsat=VCC/RI
tr=tauB*LN(1/(1-(ICsat*tau)/(IB*tauB)))
tsd1=tauB*LN(1/(1-(ICsat*tau)/(IB*tauB)))
tsd2=tauB*LN(2*IB*tauB/(ICsat*tau*(1-
Vcesat=k*T/q*LN((1+IC/IB*(1-af))..
EQN VARS= PICT SI = HALT SOLVE

```

```

Vcesat=k*T/q*LN((1+IC/IB*(1-af))..
Eq: 'Vcesat=CONST(k)*T...
Vcesat: 0_V T: 300_K
IC: 20_mA IB: 5.1_mA
af: .1 af: .99

```

CE saturation voltage

EDIT VARS VIEW SOLVE

```

Vcesat=k*T/q*LN((1+IC/IB*(1-af))..
Eq: 'Vcesat=CONST(k)*T...
Vcesat: 0.093869_V T: 300_K
IC: 20_mA IB: 5.1_mA
af: .1 af: .99
Vcesat:
0.093869_V
Zero

```

CE saturation voltage

OK

```

===== ELECTRICAL ENGINEERING =====
PN Junction Currents
Transistor Currents
Ebers-Moll Equations
Ideal Currents - pnp
Switching Transients
Vcesat=VCC/RI
ICsat=VCC/RI
tr=tauB*LN(1/(1-(ICsat*tau)/(IB*tauB)))
tsd1=tauB*LN(1/(1-(ICsat*tau)/(IB*tauB)))
tsd2=tauB*LN(2*IB*tauB/(ICsat*tau*(1-
Vcesat=k*T/q*LN((1+IC/IB*(1-af))..
EQN VARS= PICT SI = HALT SOLVE

```

```

Vcesat=k*T/q*LN((1+IC/IB*(1-af))..
Eq: 'Vcesat=CONST(k)*T...
Vcesat: 0.093869_V T: 300_K
IC: 20_mA IB: 5.100000...
af: 0.100000 af: 0.990000

```

CE saturation voltage

EDIT VARS VIEW INFO SOLVE



### 5.12.8. MOS Transistor I

Remember that the result of equation one depends on the constant chosen for ni.

#### Example:

A p-type silicon with a doping level of  $5 \times 10^{15} \text{ 1/cm}^3$  has an oxide thickness of  $0.01 \text{ }\mu$  and oxide charge density of  $1.8 \times 10^{-10} \text{ C/cm}^2$ . A  $-5 \text{ V}$  bias is applied to the substrate which has a Fermi potential of  $0.35 \text{ V}$ . Assume the relative permittivity of silicon and silicon dioxide is 11.8 and 3.9, respectively, and the work function is  $0.2 \text{ V}$ .

#### Solution:

Use the second through last equations to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Ebers-Moll Equations
Ideal Currents - pnp
Switching Transients
MOS Transistor I
PF=k*T/q*Ln(ni/p)
xd=f(2*es*E0*(2*PF)/(q*Na))
Qb0=-f(2*q*Na*es*E0*ABS(2*PF))
Qb=-f(2*q*Na*es*E0*ABS(-2*PF+VS))
Cox=Eox*E0/tox
gamma=1/Cox*f(2*q*Na*es*E0)
VT0=PGC-2*PF-Qb0/Cox-Qox/Cox
-EXPA VARS= PICT SI = HALT NSOLV

```

```

Choose Equations For MES
PF=k*T/q*Ln(ni/p)
✓ xd=f(2*es*E0*(2*PF)/(q*Na))
✓ Qb0=-f(2*q*Na*es*E0*ABS(2*PF))
✓ Qb=-f(2*q*Na*es*E0*ABS(-2*PF+VS))
✓ Cox=Eox*E0/tox
✓ gamma=1/Cox*f(2*q*Na*es*E0)
✓ VT0=PGC-2*PF-Qb0/Cox-Qox/Cox
✓CHK CANCEL OK

```

```

MOS Transistor I
Eq: ( 'xd=f(2*es*CONST...
xd: 0_μ Qb: 0_C/...VS: -5_V
Eox: 3.9 tox: .01_ γ: 0_V^...
Na: 5.E1_ es: 11.8 VT0: 0_V
PGC: .2_V PF: .35_V Qb0: 0_C...
Qox: .00_ Cox: 0_F...
Oxide capacitance per unit
EDIT VARS VIEW ALL NSOLV

```

```

MOS Transistor I
Eq: ( 'xd=f(2*es*CONST...
xd: .427_ Qb: -9.7_...VS: -5_V
Eox: 3.9 tox: .01_ γ: .118_...
Na: 5.E1_ es: 11.8 VT0: -.4_...
PGC: .2_V PF: .35_V Qb0: -3.7_...
Qox: .00_ Cox: 3.4_...
Oxide capacitance per unit
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

MOS Transistor I
xd: 0.427306_μ
Qb0: -0.000342_C/m^2
Qb: -0.000977_C/m^2
Cox: 0.003453_F/m^2
γ: 0.118483_V^0.5000_...
VT0: -0.401391_V
VALU= EQNS PRINT EXIT

```

### 5.12.9. MOS Transistor II

#### Example:

An nMOS transistor has a  $6\text{ }\mu\text{m}$  width and  $1.25\text{ }\mu\text{m}$  gate length. The electron mobility is  $500\text{ cm}^2/(\text{V}\cdot\text{s})$ . The gate oxide thickness is  $0.01\text{ }\mu\text{m}$ . The oxide permittivity is 3.9. The zero bias threshold voltage is  $0.75\text{ V}$ . The bias factor is  $1.1\text{ V}^{1/2}$ . The drain and gate voltages are  $5\text{ V}$  and the substrate bias voltage is  $-5\text{ V}$ .

Assuming that  $\lambda$  is  $0.05\text{ 1/V}$  and  $\Phi_F$  is  $0.35\text{ V}$ , find all the relevant performance parameters.

#### Solution:

Use all of the equations to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
MOS Transistor II
kn1=mu*Cox
kn1=mu*Eox*E0/tox
kn=kn1*W/L
ID=kn/2*(VGS-VT)^2*(1+lambda*VDS)
ID=IFTE(VGS-VT<VDS, kn/2*(2*(VGS
VT=VT0+gamma*(1+(ABS(-2*PF+VSB))-1/2
gm=kn*(VGS-VT)
Ttr=4/3*L^2/(mu*(VGS-VT))
fMax=gm/(2*pi*Cox*W*L)
gd=kn*(VGS-VT)
-EXPA VARS=PICT= SI = HALT NSOLV

```

```

Solving for VT
VT: 2.4558879758_V
Zero
EDIT VARS VIEW ALL NSOLV

```

```

Eox: 3.9   tox: .01... kn1: 0_A...
ID: 0_A   lambda: .05... ID: 0_A
VGS: 5_V   VT0: .75... PF: 1.1...
VSB: -5_V   BFA: .35_V Ttr: 0_s
mu: 500... fMax: 0... gm: 0_S
Cox: 0_F... W: 6_μ   L: 1.25...
gd: 0_S   kn: 0_A/... VGS: 5_V
VT: 0_V
EDIT VARS VIEW ALL NSOLV

```

```

Eox: 3.9   tox: .01... kn1: 1.7...
ID: 3.3... lambda: .05... ID: 1.82...
VGS: 5_V   VT0: .75... PF: 1.1...
VSB: -5_V   BFA: .35_V Ttr: 1.6...
mu: 500... fMax: 12... gm: 2.10...
Cox: 3.4... W: 6_μ   L: 1.25...
gd: 2.10... kn: 8.28... VGS: 5_V
VT: 2.45...
EDIT VARS VIEW ALL NSOLV

```

Press **TOOL** to view all calculated results.

```

===== MOS Transistor II =====
kn1: 0.0001727_A/V^2
kn: 0.0008288_A/V^2
VT: 2.4558880_V
gm: 0.0021084_S
Ttr: 1.6377686E-11_s
gd: 0.0021084_S
Cox: 0.0034531_F/m^2
ID: 0.0033526_A
VALU= EQNS PRINT EXIT

```

```

===== MOS Transistor II =====
VT: 2.4558880_V
gm: 0.0021084_S
Ttr: 1.6377686E-11_s
gd: 0.0021084_S
Cox: 0.0034531_F/m^2
ID: 0.0033526_A
ID: 0.0001828_A
fmax: 12957056141.9...
VALU= EQNS PRINT EXIT

```

### 5.12.10. MOS Inverter (Resistive Load)

#### Example:

Find the driver device constant, output and mid-point voltages for a MOS inverter driving a 100\_kΩ resistive load. Driver properties include a 3\_μ wide gate, a length of 0.8\_μ, Cox of 345313 pF/cm². The electron mobility is 500 cm²/(V\*s), VIH = 2.8\_V, VT = 1\_V and VDD = 5\_V.

#### Solution:

Use all of the equations to compute the solution for this problem.

By examining the equations, it is clear that there is more than one solution.

However, the root finding algorithm stops, after the first solution has been found.

In this example VOH, VOL, VIH, Vo and VM have to be positive and between 0 and VDD.

```

ELECTRICAL ENGINEERING
MOS Transistor II
MOS Inverter (Resistive)
kD=μn*Cox*WD/LD
VOH=VDD
VOL^2-2*(1/(kD*RL)+VDD-VT)*VOL+
kD/2*(2*(VIH-VT)*Vo-Vo^2)=(VDD-
kD/2*(VM-VT))^2=(VDD-VM)/RL
MOS Inverter (Saturated)
MOS Inverter (Depletion)
CMOS Transistor Pair
Junction FET
-EXPAN VARS= PICT SI= HALT MSOLV

```

```

MOS Inverter (Resistive)
Eq: ( 'kD=μn*Cox*WD/LD...
μn: 500... Cox: 345... WD: 3_μ
LD: 0.8_μ VOH: 0_V VOL: 0_V
VIH: 2.8... Vo: 0_V kD: 0_A/...
VT: 1_V VDD: 5_V VM: 0_V
RL: 100...
Midpoint voltage
EDIT VARS VIEW ALL MSOLV

```

```

MOS Inverter (Resistive)
Eq: ( 'kD=μn*Cox*WD/LD...
μn: 500... Cox: 345... WD: 3_μ
LD: 0.80... VOH: 5_V VOL: 0.0...
VIH: 2.8... Vo: 0.04... kD: 0.00...
VT: 1_V VDD: 5_V VM: 0.63...
RL: 100...
Midpoint voltage
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

MOS Inverter (Resistive)
kD: 0.00064746_A/V^2
VOH: 5_V
VOL: 0.01927817_V
Vo: 0.04304795_V
VM: 0.63270575_V
VALU= EQNS PRINT EXIT

```

In total, there are eight solutions for this example.

Calculate the other solutions by providing adequate guess(es) through the variables for the root finding algorithm.

Computed results:

Solution 1

```
##### MOS Inverter (Resistive) #####
kD: 0.00064746_A/V^2
VOH: 5_V
VOL: 0.01927817_V
Vo: 0.04304795_V
VM: 0.63270575_V

VALU= EQNS PRINT      EXIT
```

Solution 2

```
##### MOS Inverter (Resistive) #####
kD: 0.00064746_A/V^2
VOH: 5_V
VOL: 8.01161168_V
Vo: 0.04304795_V
VM: 0.63270575_V

VALU= EQNS PRINT      EXIT
```

Solution 3

```
##### MOS Inverter (Resistive) #####
kD: 0.00064746_A/V^2
VOH: 5_V
VOL: 0.01927817_V
Vo: 3.58784190_V
VM: 0.63270575_V

VALU= EQNS PRINT      EXIT
```

Solution 4

```
##### MOS Inverter (Resistive) #####
kD: 0.00064746_A/V^2
VOH: 5_V
VOL: 8.01161168_V
Vo: 3.58784190_V
VM: 0.63270575_V

VALU= EQNS PRINT      EXIT
```

Solution 5

```
##### MOS Inverter (Resistive) #####
kD: 0.00064746_A/V^2
VOH: 5_V
VOL: 0.01927817_V
Vo: 0.04304795_V
VM: 1.33640440_V

VALU= EQNS PRINT      EXIT
```

Solution 6

```
##### MOS Inverter (Resistive) #####
kD: 0.00064746_A/V^2
VOH: 5_V
VOL: 8.01161168_V
Vo: 0.04304795_V
VM: 1.33640440_V

VALU= EQNS PRINT      EXIT
```

Solution 7

```
##### MOS Inverter (Resistive) #####
kD: 0.00064746_A/V^2
VOH: 5_V
VOL: 0.01927817_V
Vo: 3.58784190_V
VM: 1.33640440_V

VALU= EQNS PRINT      EXIT
```

Solution 8

```
##### MOS Inverter (Resistive) #####
kD: 0.00064746_A/V^2
VOH: 5_V
VOL: 8.01161168_V
Vo: 3.58784190_V
VM: 1.33640440_V

VALU= EQNS PRINT      EXIT
```

### 5.12.11. MOS Inverter (Saturated Load)

#### Example:

A MOS inverter with a saturated MOS transistor as its load. The driver has a length of  $1\text{ }\mu\text{m}$  and a width of  $6\text{ }\mu\text{m}$  while the load has a length of  $3\text{ }\mu\text{m}$  and a width of  $6\text{ }\mu\text{m}$ . The Fermi level for the substrate material is  $0.35\text{ V}$ , a zero-bias threshold of  $0.75\text{ V}$ . Assume a drain supply voltage of  $5\text{ V}$  and an output voltage of  $3.1\text{ V}$ . The electron mobility is  $500\text{ cm}^2/(\text{V}\cdot\text{s})$ , the oxide capacitance per unit area is  $345313\text{ pF/cm}^2$  and the bias factor is  $0.5\text{ V}^{1/2}$ . Find the output high voltage, the input high voltage, and the threshold of the load device.

#### Solution:

Use equations one, two, three, four, six and seven in order to get a complete solution for the problem

```

ELECTRICAL ENGINEERING
MOS Inverter (Saturated)
KL=mu*Cox*WL/LL
KD=mu*Cox*WD/LD
KR=KD/KL
VOH=VDD-(VT0+gamma*(I(VOH+2*pF)-I(2
KR*(2*(Vin-VT0)*Vo-Vo^2)=(VDD-V
VTL=VT0+gamma*(I(Vo+2*pF)-I(2*pF))
VIH=(2*(VDD-VTL))/(I(3*KR)+1)+V
Vo=(VDD-VTL+VT0+VT0*I(KR))/(1+I(KR
gHL=KL*(VDD-VTL)
tauL=CL/gHL
-EXPA VARS= PICT SI = HALT NSOLV

```

```

ELECTRICAL ENGINEERING
KR=KD/KL
VOH=VDD-(VT0+gamma*(I(VOH+2*pF)-I(2
KR*(2*(Vin-VT0)*Vo-Vo^2)=(VDD-V
VTL=VT0+gamma*(I(Vo+2*pF)-I(2*pF))
VIH=(2*(VDD-VTL))/(I(3*KR)+1)+V
Vo=(VDD-VTL+VT0+VT0*I(KR))/(1+I(KR
gHL=KL*(VDD-VTL)
tauL=CL/gHL
tch=tauL*(VI/Vo-1)
tauD=CL/(KD*(VI-VT0))
VDS=VDS0+8*VDD/(VTL-VT0)+LIT0/8
EQN VARS= PICT SI = HALT SOLVE

```

```

Choose Equations for NES
✓ KL=mu*Cox*WL/LL
✓ KD=mu*Cox*WD/LD
✓ KR=KD/KL
✓ VOH=VDD-(VT0+gamma*(I(VOH+2*pF)-..
KR*(2*(Vin-VT0)*Vo-Vo^2)=(VD..
✓ VTL=VT0+gamma*(I(Vo+2*pF)-I(2*pF..
✓ VIH=(2*(VDD-VTL))/(I(3*KR)+1..
Vo=(VDD-VTL+VT0+VT0*I(KR))/(1+..
gHL=KL*(VDD-VTL)
+
✓CHK CANCEL OK

```

```

ELECTRICAL ENGINEERING
MOS Inverter (Saturated)
KL=mu*Cox*WL/LL
KD=mu*Cox*WD/LD
KR=KD/KL
Vo Starting Solver... -I(2
KR*(2*(Vin-VT0)*Vo-Vo^2)=(VDD-V
VTL=VT0+gamma*(I(Vo+2*pF)-I(2*pF))
VIH=(2*(VDD-VTL))/(I(3*KR)+1)+V
Vo=(VDD-VTL+VT0+VT0*I(KR))/(1+I(KR
gHL=KL*(VDD-VTL)
tauL=CL/gHL
-EXPA VARS= PICT SI = HALT NSOLV

```

```

MOS Inverter (Saturated)
WL: 6_μ LL: 3_μ mu: 500_...
Cox: 345... WD: 6_μ LD: 1_μ
KD: 0_A/_... KL: 0_A/_... VOH: 0_V
VDD: 5_V... VTL: 3.1_V VT0: .35_V
VIH: 0_V VDD: 5_V VTL: 0_V
KR: 0 VT0: .75...
Load transistor threshold
EDIT VARS VIEW ALL NSOLV

```

```

Solving for VOH
VOH: 3.6281229487_V
Zero
EDIT VARS VIEW ALL NSOLV

```

```

MOS Inverter (Saturated)
KL= 6_μ LL= 3_μ Wn= 500_...
Cox= 345... NDD= 6_μ LDD= 1_μ
KD= 0.00... KL= 0.00... VDH= 3.6...
Vn= 0.50... VDD= 5_V VTL= 1.3...
KR= 3 VTD= 0.7...
Load transistor threshold
EDIT VARS VIEW ALL NSOLV

```

```

MOS Inverter (Saturated)
kL: .000345313_A/V^2
kD: .001035939_A/V^2
KR: 3.
VDH: 3.6281229487_V
VTL: 1.30634942122_V
VIH: 2.59682528939_V
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

### 5.12.12. MOS Inverter (Depletion Load)

#### Example:

A MOS inverter with a depletion mode transistor as the load has a driver transistor  $5\text{ }\mu$  wide and  $1\text{ }\mu$  long while the load is a depletion mode device with a zero-bias threshold of  $-4\text{ V}$ ,  $3\text{ }\mu$  long and  $3\text{ }\mu$  wide. The Fermi level for the substrate material is  $0.35\text{ V}$ , a zero-bias threshold of  $1\text{ V}$ .

Given an electron mobility of  $500\text{ cm}^2/(\text{V}\cdot\text{s})$  and a depletion threshold of  $-4\text{ V}$ ; for the load device, compute  $V_{OL}$  and  $V_{TL}$  when the output voltage is  $2.5\text{ V}$ . Assume  $V_{OH}$  to be  $4\text{ V}$  and  $0.5$  for  $\gamma$ , the oxide capacitance per unit area is  $34500\text{ pF/cm}^2$ .

#### Solution:

The problem can be solved with the equations one, two, three and four.

```

ELECTRICAL ENGINEERING
MOS Inverter (Saturated)
MOS Inverter (Depletion)
kL=mu*Cox*WL/LL
kD=mu*Cox*WD/LD
kD/2*(2*(VOH-VTD)*VOL-VOL^2)=kL
VTL=VTLD+gamma*(I(Vo+2*PF)-I(2*PF))
tch=CL*VL/I0
I0=kL*VTL^2
CMOS Transistor Pair
Junction FET
Linear Amplifiers
-EXPA VARS= PICT SI = HALT MSOLV

```

```

Choose Equations For MES
✓ kL=mu*Cox*WL/LL
✓ kD=mu*Cox*WD/LD
✓ kD/2*(2*(VOH-VTD)*VOL-VOL^2)=kL
✓ VTL=VTLD+gamma*(I(Vo+2*PF)-I(2*PF))
tch=CL*VL/I0
I0=kL*VTL^2
✓CHK CANCEL OK

```

```

WL: 3_μ      LL: 3_μ
mu: 500_cm^... Cox: 34500. ...
WD: 5_μ      LD: 1_μ
kD: 0_A/V^2   VOH: 4_V
VTD: 1_V      VOL: 0_V
kL: 0_A/V^2   VTL: 0_V
VTLD: -4_V    gamma: .5_V^2
Vo: 2.5_V     PF: .35_V
EDIT VARS VIEW ALL MSOLV

```

```

WL: 3_μ      LL: 3_μ
mu: 500_cm^... Cox: 34500. ...
WD: 5_μ      LD: 1_μ
kD: .000086... VOH: 4_V
VTD: 1_V      VOL: .447271...
kL: .000017... VTL: -3.5239...
VTLD: -4_V    gamma: .5_V^2
Vo: 2.5_V     PF: .35_V
EDIT VARS VIEW ALL MSOLV

```

Press **TOOL** to view all calculated results.

```

MOS Inverter (Depletion)
kL: .00001725_A/V^2
kD: .00008625_A/V^2
VTL: -3.52390282227_V
VOL: .447271698782_V
VALU= EQNS PRINT EXIT

```

Solution 1

```

MOS Inverter (Depletion)
kL: .00001725_A/V^2
kD: .00008625_A/V^2
VTL: -3.52390282227_V
VOL: 5.55272830121_V
VALU= EQNS PRINT EXIT

```

Solution 2

### 5.12.13. CMOS Transistor Pair

#### Example:

Find the transistor constants for an N and P MOS transistor pair given:

*N transistor:*  $W_N=4_\mu$ ,  $L_N=2_\mu$ ,  $\mu_n=1250_\text{cm}^2/(\text{V}\cdot\text{s})$ ,  $C_{ox}=34530_\text{pF}/\text{cm}^2$ ,  $V_{TN}=1_\text{V}$

*P transistor:*  $V_{TP}= -1_\text{V}$ ,  $W_p=10_\mu$ ,  $\mu_p=200_\text{cm}^2/(\text{V}\cdot\text{s})$ ,  $I_P=2_\mu$

$V_{DD}=2_\text{V}$ ,  $V_{IH}=5_\text{V}$

#### Solution:

The solution can be calculated by selecting the first four equations.

```

ELECTRICAL ENGINEERING
MOS Transistor II
MOS Inverter (Resistive)
MOS Inverter (Saturated)
MOS Inverter (Depletion)
CMOS Transistor Pair
  KP=mu_n*Cox*WP/LP
  KN=mu_p*Cox*WN/LN
  VIH=(2*Vo+VTN+(KP/KN)*(VDD-ABS(
  VIL=(2*Vo-VDD-VTP+KN/KP*VTN)/(1
  KN/2*(Vin-VTN)^2=KP/2*(VDD-Vin-
Junction FET
-EXPA VARS= PICT= SI= HALT MSOLV
  
```

```

mu_p: 200_cm^...  WP: 10_mu
LP: 2_mu          mu_n: 1250._c...
Cox: 34530._...  WN: 4_mu
LN: 2_mu          VIH: 5_V
VIL: 0_V         Vo: 0_V
VDD: 2_V         VTP: -1_V
VTN: 1_V         KN: 0_A/V^2
KP: 0_A/V^2
EDIT VARS VIEW ALL MSOLV
  
```

```

mu_p: 200_cm^...  WP: 10_mu
LP: 2_mu          mu_n: 1250._c...
Cox: 34530._...  WN: 4_mu
LN: 2_mu          VIH: 5_V
VIL: 1.48979...  Vo: 1.85714...
VDD: 2_V         VTP: -1_V
VTN: 1_V         KN: .000086...
KP: .000034...
EDIT VARS VIEW ALL MSOLV
  
```

```

Choose Equations for MES
✓ KP=mu_n*Cox*WP/LP
✓ KN=mu_p*Cox*WN/LN
✓ VIH=(2*Vo+VTN+(KP/KN)*(VDD-ABS(
✓ VIL=(2*Vo-VDD-VTP+KN/KP*VTN)...
  KN/2*(Vin-VTN)^2=KP/2*(VDD-V...
  
```

```

Solving for kP
kP: .00003453_A/V^2
Zero
  
```

Press **TOOL** to view all calculated results.

```

CMOS Transistor Pair
kP: .00003453_A/V^2
kN: .000086325_A/V^2
Vo: 1.85714285714_V
VIL: 1.48979591837_V
  
```



#### 5.12.14. Junction FET

##### Example:

Find the saturation current when the drain current at zero bias is 12.5\_μA, the gate voltage is 5\_V and the pinch off voltage is 12 V. The channel width is 3\_μ, use a value of 11.8 for the relative permittivity of silicon, for the donor density use a value of  $1 \times 10^{16} \text{ cm}^{-3}$ . The built-in voltage is 0,85\_V and the gate voltage is -8\_V

##### Solution:

Use the third equation to solve this problem.

```

ELECTRICAL ENGINEERING
MOS Transistor II
MOS Inverter (Resistive)
MOS Inverter (Saturated)
MOS Inverter (Depletion)
CMOS Transistor Pair
Junction FET
ID=2*q*x2*un*nd*b/L*(VDD-2/3*(Vb
IDsat=2*q*x2*un*nd*b/L*(VDSat-2/
x=0.85_V
VDSat=VG-Vp
IDsat=ID0*(1-VG/Vp)^2
EQN VARS=PICT= SI = HALT SOLVE

```

```

b=f(2*E0*Es/(q*nd)*(Vbi+VDSat-V..
b: 3_μ
es: 11.8
nd: 1.E16_1/cm^3
vbi: .85_V
VDSat: 0_V
VG: -8_V
Drain saturation current
EDIT VARS VIEW SOLVE

```

```

ELECTRICAL ENGINEERING
MOS Transistor II
MOS Inverter (Resistive)
MOS Inverter (Saturated)
MOS Inverter (Depletion)
CMOS Transistor Pair
Junction FET
ID=2*q*x2*un*nd*b/L*(VDD-2/3*(Vb
IDsat=2*q*x2*un*nd*b/L*(VDSat-2/
x=0.85_V
VDSat=VG-Vp
IDsat=ID0*(1-VG/Vp)^2
EQN VARS=PICT= SI = HALT SOLVE

```

```

b=f(2*E0*Es/(q*nd)*(Vbi+VDSat-V..
b: 3_μ
es: 11.8
nd: 1.E16_1/cm^3
vbi: .85_V
VDSat: 60.1568746932_V
VG: -8_V
Drain saturation current
EDIT VARS VIEW INFO SOLVE

```

### 5.13. Linear Amplifiers

```

ELECTRICAL ENGINEERING
Linear Amplifiers
BJT (Common Base)
BJT (Common Emitter)
BJT (Common Collector)
FET (Common Gate)
FET (Common Source)
FET (Common Drain)
Darlington (CC-CC)
-EXPA VARS PICT SI HALT MSOLV

```

```

ELECTRICAL ENGINEERING
FET (Common Gate)
FET (Common Source)
FET (Common Drain)
Darlington (CC-CC)
Darlington (CC-CE)
Emitter-Coupled Amplifier
Differential Amplifier
Source-Coupled JFET Pair
-EXPA VARS PICT SI HALT MSOLV

```

#### 5.13.1. BJT (Common Base)

##### Example:

A common base configuration of a linear amplifier has an emitter resistance of 35\_Ω, collector and base resistances of 1\_MΩ and 1.2\_kΩ resistances, respectively. The load resistor is 10\_kΩ. If the source resistance is 50\_Ω and  $\alpha_0$  is 0.93, find  $\beta_0$  and the gains for this amplifier.

##### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Linear Amplifiers
BJT (Common Base)
 $\beta_0 = \alpha_0 / (1 - \alpha_0)$ 
 $R_{in} = r_e + r_b / \beta_0$ 
 $R_o = r_c$ 
 $A_i = \alpha_0$ 
 $A_v = \alpha_0 \times R_L / (r_e + r_b / \beta_0)$ 
 $A_{ov} = (\alpha_0 \times r_c) \times (R_{in} / (R_{in} + R_s)) / (r_e + r_b / \beta_0)$ 
BJT (Common Emitter)
BJT (Common Collector)
FET (Common Gate)
-EXPA VARS PICT SI HALT MSOLV

```

```

ELECTRICAL ENGINEERING
Linear Amplifiers
BJT (Common Base)
 $\beta_0 = \alpha_0 / (1 - \alpha_0)$ 
 $R_{in} = r_e + r_b / \beta_0$ 
 $R_o = r_c$ 
 $A_i = \alpha_0$ 
 $A_v = \alpha_0 \times R_L / (r_e + r_b / \beta_0)$ 
 $A_{ov} = (\alpha_0 \times r_c) \times (R_{in} / (R_{in} + R_s)) / (r_e + r_b / \beta_0)$ 
BJT (Common Emitter)
BJT (Common Collector)
FET (Common Gate)
-EXPA VARS PICT SI HALT MSOLV

```

```

BJT (Common Base)
Ro: 0_Ω Ai: 0
Av: 0 RL: 10_kΩ
Aov: 0  $\alpha_0$ : .93
rc: 1_MΩ Rin: 0_Ω
Rs: 50_Ω re: 35_Ω
rb: 1.2_kΩ  $\beta_0$ : 0
Output resistance
EDIT VARS VIEW ALL MSOLV

```

```

Solving for Rin
Rin: 125.322580645_Ω
Zero
EDIT VARS VIEW ALL MSOLV

```

```

BJT (Common Base)
Ro: 1000000... Ai: .93
Av: 74.2084... Ri: 10_kΩ
Aov: 5304.50... .93
rc: 1_MΩ Rin: 125.322...
Rsi: 50_Ω Rci: 35_Ω
Rbi: 1.2_kΩ β0: 13.2857...
Output resistance
EDIT VARS VIEW ALL MSOLV

```

```

BJT (Common Base)
β0: 13.2857142857
Rin: 125.322580645_Ω
Ro: 1000000._Ω
Ai: .93
Av: 74.2084942086
Aov: 5304.50781969
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

### 5.13.2. BJT (Common Emitter)

#### Example:

A common base configuration of a linear amplifier has an emitter resistance of 35\_Ω, collector and base resistances of 1\_MΩ and 1.2\_kΩ resistances, respectively. The load resistor is 1\_kΩ and the output resistance is 1\_MΩ. If the source resistance is 50\_Ω and  $\alpha_0$  is 0.93, find  $\beta_0$  and the gains for this amplifier.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Linear Amplifiers
BJT (Common Base)
BJT (Common Emitter)
   $\beta_0 = \alpha_0 / (1 - \alpha_0)$ 
   $R_{in} = r_b + \beta_0 \times r_e$ 
   $R_o = r_c$ 
   $A_i = -\beta_0$ 
   $A_v = -\beta_0 \times R_L / (\beta_0 \times r_e + r_b)$ 
   $A_{ov} = -\beta_0 \times R_L / (R_s + R_{in})$ 
BJT (Common Collector)
FET (Common Gate)
-EXPAND VARS= PICT SI = HALT MSOLV
  
```

```

BJT (Common Emitter)
 $\alpha_0$ : 0.93       $R_o$ : 1_MΩ
 $r_c$ : 1_MΩ       $A_i$ : 0
 $A_v$ : 0         $r_e$ : 35_Ω
 $r_b$ : 1.2_kΩ    $A_{ov}$ : 0
 $\beta_0$ : 0        $R_L$ : 1_kΩ
 $R_s$ : 50_Ω      $R_{in}$ : 0_Ω

Input resistance
EDIT VARS VIEW ALL MSOLV
  
```

```

BJT (Common Emitter)
 $\alpha_0$ : 0.93       $R_o$ : 1_MΩ
 $r_c$ : 1_MΩ       $A_i$ : -13.285...
 $A_v$ : -7.9794...  $r_e$ : 35_Ω
 $r_b$ : 1.2_kΩ    $A_{ov}$ : -7.7467...
 $\beta_0$ : 13.2857...  $R_L$ : 1_kΩ
 $R_s$ : 50_Ω      $R_{in}$ : 1665._Ω

Input resistance
EDIT VARS VIEW ALL MSOLV
  
```

```

ELECTRICAL ENGINEERING
Linear Amplifiers
BJT (Common Base)
BJT (Common Emitter)
  Starting Solver...
   $\beta_0$ 
   $R_i$ 
   $R_o$ 
   $A_i$ 
   $A_v = -\beta_0 \times R_L / (\beta_0 \times r_e + r_b)$ 
   $A_{ov} = -\beta_0 \times R_L / (R_s + R_{in})$ 
BJT (Common Collector)
FET (Common Gate)
-EXPAND VARS= PICT SI = HALT MSOLV
  
```

```

Solving for Rin
Rin: 1665._Ω
Zero

EDIT VARS VIEW ALL MSOLV
  
```

```

BJT (Common Emitter)
 $\beta_0$ : 13.2857142857
 $R_{in}$ : 1665._Ω
 $A_i$ : -13.2857142857
 $A_v$ : -7.9794079794
 $A_{ov}$ : -7.74677217825

VALU= EQNS PRINT EXIT
  
```

Press **TOOL** to view all calculated results.

### 5.13.3. BJT (Common Collector)

#### Example:

An amplifier in a common collector configuration has a gain  $\alpha_0$  of 0.99. The emitter, base and collector resistances are 25\_Ω, 1000\_kΩ, and 100000\_MΩ respectively. The load resistor is 100\_Ω. If the source resistance is 25\_Ω find all the mid-band characteristics.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Linear Amplifiers
BJT (Common Base)
BJT (Common Emitter)
BJT (Common Collector)
  -  $\beta_0 = \alpha_0 / (1 - \alpha_0)$ 
  -  $R_{in} = r_b + \beta_0 r_e + (\beta_0 + 1) R_L$ 
  -  $R_o = r_e + (R_s + r_b) / \beta_0$ 
  -  $A_i = r_e / (r_e \times (1 - \alpha_0) + R_L + r_e)$ 
  -  $A_v = \alpha_0 R_L / (r_e + R_L)$ 
  -  $A_{ov} = (\beta_0 + 1) R_L / (R_s + R_{in} + (\beta_0 + 1) R_L)$ 
FET (Common Gate)
-EXPA VARS= PICT SI = HALT MSOLV

```

```

ELECTRICAL ENGINEERING
Linear Amplifiers
BJT (Common Base)
BJT (Common Emitter)
BJT (Common Collector)
  - Starting Solver...
  -  $\beta_0 = \alpha_0 / (1 - \alpha_0)$ 
  -  $R_{in} = r_b + \beta_0 r_e + (\beta_0 + 1) R_L$ 
  -  $R_o = r_e + (R_s + r_b) / \beta_0$ 
  -  $A_i = r_e / (r_e \times (1 - \alpha_0) + R_L + r_e)$ 
  -  $A_v = \alpha_0 R_L / (r_e + R_L)$ 
  -  $A_{ov} = (\beta_0 + 1) R_L / (R_s + R_{in} + (\beta_0 + 1) R_L)$ 
FET (Common Gate)
-EXPA VARS= PICT SI = HALT MSOLV

```

```

BJT (Common Collector)
Ro: 0_Ω      Rb: 1000._kΩ
Ai: 0        re: 100000...
Av: 0        α0: .99
re: 25_Ω     Aov: 0
Rs: 25_Ω     Rin: 0_Ω
β0: 0        RL: 100_Ω
Output resistance
EDIT VARS VIEW ALL MSOLV

```

```

Solving for Rin
Rin: 1012475._Ω
Zero
EDIT VARS VIEW ALL MSOLV

```

```

BJT (Common Collector)
Ro: 10126.2... Rb: 1000.00...
Ai: 99.9999... re: 100000...
Av: 0.79200... α0: 0.99000...
re: 25_Ω     Aov: 0.00977...
Rs: 25_Ω     Rin: 1012475...
β0: 99       RL: 100_Ω
Output resistance
EDIT VARS VIEW ALL MSOLV

```

```

BJT (Common Collector)
β0: 99.000000000
Rin: 1012475.000000_Ω
Ro: 10126.2626263_Ω
Ai: 99.99998750
Av: 0.792000000
Aov: 0.00977995
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

#### 5.13.4. FET (Common Gate)

##### Example:

A FET amplifier connected in a common gate mode has a load of 10\_k $\Omega$ . The external gate resistance is 1\_M $\Omega$  and the drain resistance is 125\_k $\Omega$ . The transconductance is 1.6 x 10<sup>-3</sup>\_Siemens. Find the midband parameters.

##### Solution:

All of the equations are needed to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
Linear Amplifiers
-BJT (Common Base)
-BJT (Common Emitter)
-BJT (Common Collector)
-FET (Common Gate)
   $\mu = g_m \times r_d$ 
   $R_{in} = (R_L + r_d) / (\mu + 1)$ 
   $A_v = (\mu + 1) \times R_L / (r_d + R_L)$ 
   $R_o = r_d + (\mu + 1) \times R_G$ 
-FET (Common Source)
-FET (Common Drain)
-EXPA VARS= PICT SI = HALT MSOLV
  
```

```

===== FET (Common Gate) =====
Eq: { ' $\mu = g_m \times r_d$ ' ' $R_{in} = (...$ '
AM: .0016_S Rin: 0_ $\Omega$ 
Av: 0 RL: 10_k $\Omega$ 
Ro: 0_ $\Omega$  rd: 125_k $\Omega$ 
 $\mu$ : 0 RG: 1_M $\Omega$ 

Input resistance
EDIT VARS VIEW ALL MSOLV
  
```

```

===== FET (Common Gate) =====
Eq: { ' $\mu = g_m \times r_d$ ' ' $R_{in} = (...$ '
AM: .0016_S Rin: 671.641...
Av: 14.8888... RL: 10_k $\Omega$ 
Ro: 2011250... rd: 125_k $\Omega$ 
 $\mu$ : 200 RG: 1_M $\Omega$ 

Input resistance
EDIT VARS VIEW ALL MSOLV
  
```

```

===== ELECTRICAL ENGINEERING =====
Linear Amplifiers
-BJT (Common Base)
-BJT (Common Emitter)
-BJT (Common Collector)
-FET (Common Gate)
  Starting Solver...
   $\mu = g_m \times r_d$ 
   $R_{in} = (R_L + r_d) / (\mu + 1)$ 
   $A_v = (\mu + 1) \times R_L / (r_d + R_L)$ 
   $R_o = r_d + (\mu + 1) \times R_G$ 
-FET (Common Source)
-FET (Common Drain)
-EXPA VARS= PICT SI = HALT MSOLV
  
```

```

Solving for Rin
Rin: 671.641791045_ $\Omega$ 
Zero

EDIT VARS VIEW ALL MSOLV
  
```

```

===== FET (Common Gate) =====
 $\mu$ : 200
Rin: 671.641791045_ $\Omega$ 
Av: 14.8888888889
Ro: 201125000._ $\Omega$ 

VALU= EQNS PRINT EXIT
  
```

Press **TOOL** to view all calculated results.

### 5.13.5. FET (Common Source)

#### Example:

Find the voltage gain of a FET configured as a common-source based amplifier. The transconductance is  $2.5 \times 10^{-3}$  Siemens, a drain resistance of  $18\text{ k}\Omega$  and a load resistance of  $100\text{ k}\Omega$ .

Find all the parameters for this amplifier circuit.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Linear Amplifiers
-BJT (Common Base)
-BJT (Common Emitter)
-BJT (Common Collector)
-FET (Common Gate)
-FET (Common Source)
  -u=gm*rd
  -Rin=(Rl+rd)/(u+1)
  -Av=-gm*(rd*Rl/(rd+Rl))
  -Ro=rd
-FET (Common Drain)
-EXPA VARS= PICT SI = HALT MSOLV

```

```

FET (Common Source)
Eq: { 'u=gm*rd' 'Rin=(...
Rin: 0_Ω u: 0
Av: 0 AM: .0025_S
RL: 100_kΩ Ro: 0_Ω
rd: 18_kΩ

Input resistance
EDIT VARS VIEW ALL MSOLV

```

```

FET (Common Source)
Eq: { 'u=gm*rd' 'Rin=(...
Rin: 2565.21_Ω u: 45
Av: -38.135... AM: .0025_S
RL: 100_kΩ Ro: 18000._Ω
rd: 18_kΩ

Input resistance
EDIT VARS VIEW ALL MSOLV

```

```

ELECTRICAL ENGINEERING
Linear Amplifiers
-BJT (Common Base)
-BJT (Common Emitter)
-BJT (Common Collector)
-FET (Common Gate)
-FET (Common Source)
  -u=gm*rd
  -Rin=(Rl+rd)/(u+1)
  -Av=-gm*(rd*Rl/(rd+Rl))
  -Ro=rd
-FET (Common Drain)
-EXPA VARS= PICT SI = HALT MSOLV

```

```

Solving for Av
Av: -38.1355932202
Zero

EDIT VARS VIEW ALL MSOLV

```

```

FET (Common Source)
u: 45.
Rin: 2565.2173913_Ω
Av: -38.1355932202
Ro: 18000._Ω

VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

### 5.13.6. FET (Common Drain)

#### Example:

Compute the voltage gain for a common-drain FET amplifier. The transconductance is  $5 \times 10^{-3}$  Siemens, a drain resistance of  $25\text{ k}\Omega$  and a load resistance of  $100\text{ k}\Omega$ . Find all the parameters for this amplifier circuit.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
Linear Amplifiers
-BJT (Common Base)
-BJT (Common Emitter)
-BJT (Common Collector)
-FET (Common Gate)
-FET (Common Source)
-FET (Common Drain)
-μ=gm*rd
-Rin=(Rl+rd)/(μ+1)
-Av=μ*Rl/((μ+1)*Rl+rd)
-Ro=rd/(μ+1)
-EXP VARS= PICT SI= HALT NSOLV

```

```

===== FET (Common Drain) =====
Eq: ( 'μ=gm*rd' 'Rin=(...
AM: .005_S Rin: 0_Ω
Av: 0 RL: 100_kΩ
Ro: 0_Ω rd: 25_kΩ
μ: 0

Amplification Factor
EDIT VARS VIEW ALL NSOLV

```

```

===== FET (Common Drain) =====
Eq: ( 'μ=gm*rd' 'Rin=(...
AM: .005_S Rin: 992.063...
Av: .990099... RL: 100_kΩ
Ro: 198.412... rd: 25_kΩ
μ: 125

Amplification Factor
EDIT VARS VIEW ALL NSOLV

```

```

===== ELECTRICAL ENGINEERING =====
Linear Amplifiers
-BJT (Common Base)
-BJT (Common Emitter)
-BJT (Common Collector)
-FET (Common Gate)
-FET (Common Source)
-FET (Common Drain)
-μ=gm*rd
-Rin=(Rl+rd)/(μ+1)
-Av=μ*Rl/((μ+1)*Rl+rd)
-Ro=rd/(μ+1)
-EXP VARS= PICT SI= HALT NSOLV

```

```

Solving for Av
Av: .990099009901
Zero

EDIT VARS VIEW ALL NSOLV

```

```

===== FET (Common Drain) =====
μ: 125.
Rin: 992.063492063_Ω
Av: .990099009901
Ro: 198.412698413_Ω

VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.



### 5.13.7. Darlington (CC-CC)

#### Example:

Transistors in a Darlington pair having a  $\beta_0$  value of 100 are connected to a load of 10\_k $\Omega$ . The emitter, base and source resistances are 25\_ $\Omega$ , 1500\_k $\Omega$  and 1\_k $\Omega$ , respectively. The external base resistance is 27\_k $\Omega$ .

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
Linear Amplifiers
-BJT (Common Base)
-BJT (Common Emitter)
-BJT (Common Collector)
-FET (Common Gate)
-FET (Common Source)
-FET (Common Drain)
-Darlington (CC-CC)
  Rin= $\beta_0 \times (r_e + \beta_0 \times (r_b + R_L))$ 
  Ro= $r_e + (\beta_0 \times (r_b + R_L) + R_s) / \beta_0^2$ 
  Ai= $\beta_0^2 \times R_{BA} / (R_{BA} + \beta_0 \times (R_L + r_e))$ 
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

===== Darlington (CC-CC) =====
Eq: ( 'Rin= $\beta_0 \times (r_e + \beta_0 \times (r_b + R_L))$ 
Rin: 0_ $\Omega$  Ro: 0_ $\Omega$ 
rb: 1500._k $\Omega$  Rs: 1_k $\Omega$ 
Ai: 0 RBA: 27_k $\Omega$ 
 $\beta_0$ : 100 RL: 10_k $\Omega$ 
re: 25_ $\Omega$ 
Input resistance
EDIT VARS VIEW ALL NSOLV
  
```

```

===== Darlington (CC-CC) =====
Eq: ( 'Rin= $\beta_0 \times (r_e + \beta_0 \times (r_b + R_L))$ 
Rin: 1002525... Ro: 15025.3...
rb: 1500._k $\Omega$  Rs: 1_k $\Omega$ 
Ai: 262.263... RBA: 27_k $\Omega$ 
 $\beta_0$ : 100 RL: 10_k $\Omega$ 
re: 25_ $\Omega$ 
Input resistance
EDIT VARS VIEW ALL NSOLV
  
```

```

===== ELECTRICAL ENGINEERING =====
Linear Amplifiers
-BJT (Common Base)
-BJT (Common Emitter)
-BJT (Common Collector)
-FET (Common Gate)
-FET (Common Source)
-FET (Common Drain)
-Darlington (CC-CC)
  Rin= $\beta_0 \times (r_e + \beta_0 \times (r_b + R_L))$ 
  Ro= $r_e + (\beta_0 \times (r_b + R_L) + R_s) / \beta_0^2$ 
  Ai= $\beta_0^2 \times R_{BA} / (R_{BA} + \beta_0 \times (R_L + r_e))$ 
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

Solving for Rin
Rin: 100252500._ $\Omega$ 
Zero
EDIT VARS VIEW ALL NSOLV
  
```

```

===== Darlington (CC-CC) =====
Rin: 100252500._ $\Omega$ 
Ro: 15025.35_ $\Omega$ 
Ai: 262.26323458
VALU= EQNS PRINT EXIT
  
```

Press **TOOL** to view all calculated results.

### 5.13.8. Darlington (CC-CE)

#### Example:

An amplifier circuit has a base, emitter, and load resistance of 1.5\_k $\Omega$ , 25\_ $\Omega$ , and 10\_k $\Omega$ , respectively. The configuration has a value of  $\beta_0$  equal to 100. The source and collector resistances are 1\_k $\Omega$  and 100\_k $\Omega$ . Find the voltage gain, input and output resistances.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
FET (Common Gate)
FET (Common Source)
FET (Common Drain)
Darlington (CC-CC)
Darlington (CC-CE)
Rin=rb+ $\beta_0$ *re
Ro=re/ $\beta_0$ 
Av=-RL/rexre/(re+Rs/ $\beta_0$ ^2)
Emitter-Coupled Amplifier
Differential Amplifier
Source-Coupled JFET Pair
-EXPA VARS= PICT= SI= HALT MSOLV

```

```

Darlington (CC-CE)
Eq: ( 'Rin=rb+ $\beta_0$ *re' '...
Rin: 0_ $\Omega$  rb: 1.5_k $\Omega$ 
Ro: 0_ $\Omega$  re: 100_k $\Omega$ 
Av: 0 RL: 10_k $\Omega$ 
re: 25_ $\Omega$  Rs: 1_k $\Omega$ 
 $\beta_0$ : 100
Input resistance
EDIT VARS VIEW ALL MSOLV

```

```

Darlington (CC-CE)
Eq: ( 'Rin=rb+ $\beta_0$ *re' '...
Rin: 4000._ $\Omega$  rb: 1.5_k $\Omega$ 
Ro: 1000._ $\Omega$  re: 100_k $\Omega$ 
Av: -398.40... RL: 10_k $\Omega$ 
re: 25_ $\Omega$  Rs: 1_k $\Omega$ 
 $\beta_0$ : 100
Input resistance
EDIT VARS VIEW ALL MSOLV

```

```

ELECTRICAL ENGINEERING
FET (Common Gate)
FET (Common Source)
FET (Common Drain)
Darlington (CC-CC)
Darlington (CC-CE)
Starting Solver...
Rin=rb+ $\beta_0$ *re
Ro=re/ $\beta_0$ 
Av=-RL/rexre/(re+Rs/ $\beta_0$ ^2)
Emitter-Coupled Amplifier
Differential Amplifier
Source-Coupled JFET Pair
-EXPA VARS= PICT= SI= HALT MSOLV

```

```

Solving for Ro
Ro: 1000._ $\Omega$ 
Zero
EDIT VARS VIEW ALL MSOLV

```

```

Darlington (CC-CE)
Rin: 4000._ $\Omega$ 
Ro: 1000._ $\Omega$ 
Av: -398.406374502
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

### 5.13.9. Emitter-Coupled Amplifier

#### Example:

An emitter coupled pair amplifier is constructed from transistors with  $\alpha_0=0.98$ . The emitter, base and collector resistances are 25\_Ω, 2\_kΩ and 56\_kΩ, respectively. If the load resistance is 10\_kΩ, find the mid-band performance factors.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Darlington (CC-CC)
Darlington (CC-CE)
Emitter-Coupled Amplifier
 $\beta_0 = \alpha_0 / (1 - \alpha_0)$ 
 $R_o = r_e + (\beta_0 \times (r_e + r_b) + R_s) / \beta_0^2$ 
 $A_v = R_L / r_e \times (\beta_0 \times r_e / (2 \times \beta_0 \times r_e + R_L))$ 
 $A_i = -\alpha_0 \times \beta_0$ 
 $R_{in} = \beta_0 \times r_e + r_b$ 
 $R_o = r_c$ 
Differential Amplifier
Source-Coupled JFET Pair
-EXPA VARS PICT SI HALT NSOLV

```

```

ELECTRICAL ENGINEERING
Darlington (CC-CC)
Darlington (CC-CE)
Emitter-Coupled Amplifier
 $\beta_0$  Starting Solver...
 $A_v$ 
 $A_i$ 
 $R_{in} = \beta_0 \times r_e + r_b$ 
 $R_o = r_c$ 
Differential Amplifier
Source-Coupled JFET Pair
-EXPA VARS PICT SI HALT NSOLV

```

```

Emitter-Coupled Amplifier
Rs: 0_Ω Av: 0
RL: 10_kΩ Ai: 0
 $\alpha_0$ : .98 Rin: 0_Ω
 $\beta_0$ : 0 Re: 25_Ω
rb: 2_kΩ Ro: 0_Ω
rc: 56_kΩ
Current gain, CB
EDIT VARS VIEW ALL NSOLV

```

```

Solving for Av
Av: 39.3574297189
Zero
EDIT VARS VIEW ALL NSOLV

```

```

Emitter-Coupled Amplifier
Rs: 1342967... Av: 39.3574...
RL: 10_kΩ Ai: -48.02
 $\alpha_0$ : .98 Rin: 3225._Ω
 $\beta_0$ : 49 Re: 25_Ω
rb: 2_kΩ Ro: 56000._Ω
rc: 56_kΩ
Current gain, CB
EDIT VARS VIEW ALL NSOLV

```

```

Emitter-Coupled Amplifier
 $\beta_0$ : 49.
Av: 39.3574297189
Ai: -48.02
Rin: 3225._Ω
Ro: 56000._Ω
Rs: 134296750._Ω
VALU EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

### 5.13.10. Differential Amplifier

#### Example:

A differential amplifier pair has a transconductance of 0.005\_Siemens,  $\alpha_0=0.98$ ,  $\beta_0=49$ . The external collector and external emitter resistances are 18\_k $\Omega$  and 10\_k $\Omega$  respectively. If the emitter resistance is 25\_ $\Omega$  and the base resistance is 2\_k $\Omega$ , find the common mode, differential resistance and gains.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
Darlington (CC-CC)
Darlington (CC-CE)
Emitter-Coupled Amplifier
Differential Amplifier
Ad=-1/2*gm*RCR
Ac=-gm*RCR/(2*REA+re)
Rid=2*(rb+beta*re)
Ric=beta*REA
Source-Coupled JFET Pair
Class A, B, and C Amplifiers
Transformers
-EXPA VARS= PICT SI = HALT MSOLV

```

```

===== Differential Amplifier =====
Ad: 0 Ad: .005_S
Ac: 0 gm: .98
RCR: 18_kOhm Rid: 0_ohm
rb: 2_kOhm re: 25_ohm
Ric: 0_ohm beta: 49
REA: 10_kOhm
Differential Mode gain
EDIT VARS VIEW ALL MSOLV

```

```

===== Differential Amplifier =====
Ad: -45 Ad: .005_S
Ac: -.88089... gm: .98
RCR: 18_kOhm Rid: 6450._ohm
rb: 2_kOhm re: 25_ohm
Ric: 490000... beta: 49
REA: 10_kOhm
Differential Mode gain
EDIT VARS VIEW ALL MSOLV

```

```

===== ELECTRICAL ENGINEERING =====
Darlington (CC-CC)
Darlington (CC-CE)
Emitter-Coupled Amplifier
Differential Amplifier
Starting Solver...
Ad:
Ac:
Rid:
Ric: beta*REA
Source-Coupled JFET Pair
Class A, B, and C Amplifiers
Transformers
-EXPA VARS= PICT SI = HALT MSOLV

```

```

Solving for Ac
Ac: -.880898876404
Zero
EDIT VARS VIEW ALL MSOLV

```

```

===== Differential Amplifier =====
Ad: -45.
Ac: -.880898876404
Rid: 6450._ohm
Ric: 490000._ohm
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

### 5.13.11. Source-Coupled JFET Pair

#### Example:

Find the gain parameters of a source-coupled JFET pair amplifier if the external drain resistance is 25\_k $\Omega$ , and the source resistance is 100\_ $\Omega$ . The drain resistance is 12\_k $\Omega$  and the transconductance is 6.8 x 10<sup>-3</sup>\_Siemens.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

##### ELECTRICAL ENGINEERING #####
Darlington (CC-CC)
Darlington (CC-CE)
Emitter-Coupled Amplifier
Differential Amplifier
Source-Coupled JFET Pair
Ad=-1/2*gm*(rd*RDA)/(rd+RDA)
Ac=-u*RDA/((u+1)*2*Rs+rd+RDA)
u=gm*rd
CMRR=gm*Rs
Class A, B, and C Amplifiers
Transformers
-EXPAN VARS= PICT= SI= HALT NSOLV

```

```

##### Source-Coupled JFET Pair #####
Eq: ( 'Ad=-1/2*gm*(rd*...
Ad: 0 Ac: 0
RDA: 25_k $\Omega$  u: 0
rd: 12_k $\Omega$  CMRR: 0
gm: .0068_S Rs: 100_ $\Omega$ 

Differential Mode gain
EDIT VARS VIEW ALL NSOLV

```

```

##### Source-Coupled JFET Pair #####
Eq: ( 'Ad=-1/2*gm*(rd*...
Ad: -27.567... Ac: -38.116...
RDA: 25_k $\Omega$  u: 81.6
rd: 12_k $\Omega$  CMRR: .68
gm: .0068_S Rs: 100_ $\Omega$ 

Differential Mode gain
EDIT VARS VIEW ALL NSOLV

```

```

##### ELECTRICAL ENGINEERING #####
Darlington (CC-CC)
Darlington (CC-CE)
Emitter-Coupled Amplifier
Dif
Sol Starting Solver...
Ad
Ac
u=gm*rd
CMRR=gm*Rs
Class A, B, and C Amplifiers
Transformers
-EXPAN VARS= PICT= SI= HALT NSOLV

```

```

Solving for Ac
Ac: -38.1165919283
Zero
EDIT VARS VIEW ALL NSOLV

```

```

##### Source-Coupled JFET Pair #####
Ad: -27.5675675675
u: 81.6
CMRR: .68
Ac: -38.1165919283
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

## 5.14. Class A, B and C Amplifiers

```

ELECTRICAL ENGINEERING
Class A, B, and C Amplifiers
Class A Amplifier
Power Transistor
Push-Pull Principle
Class B Amplifier
Class C Amplifier
Transformers
Motors and Generators
-EXPA VARS PICT SI HALT HELP

```

**Note:** The equations in this section are grouped under topics which describe general properties of semiconductors or devices. Equations for a variety of specific cases and are listed together under a sub-topic heading and are not necessarily a set of consistent equations which can be solved together. Choosing equations in a subtopic without regard as to whether the equations represent actual relationships could generate erroneous results or no solution at all.

### 5.14.1. Class A Amplifier

#### Example:

A Class A power amplifier is coupled to a 50\_Ω load through the output of a transformer with a turn ratio of 2. The quiescent operating current is 60\_mA, and the incremental collector current is 50\_mA. The collector-to-admitter voltage swings from 6\_V to 12\_V. The supply collector voltage is 15\_V. The maximum current is 110\_mA. Find the power delivered and the efficiency of power conversion.

#### Solution:

All of the equations are needed to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Class A, B, and C Amplifiers
Class A Amplifier
R=n^2*Rl
IC=VCE/R
Imax=IC+IC
Pdc=VCC*IC
PP=VCEmax-VCEmin
VPP=n*PP
Po=(IC)^2*R/8
η=Po/Pdc
Power Transistor
-EXPA VARS PICT SI HALT NSOLV

```

```

Rl: 50_Ω      VCE: 0_V
Imax: 110_mA  VCC: 15_V
IC: 60_mA     VCEmax: 12_V
VCEmin: 6_V   VPP: 0_V
n: 2          PP: 0_V
IC: 50_mA     R: 0_Ω
η: 0          Po: 0_W
Pdc: 0_W
EDIT VARS VIEW ALL NSOLV

```

```

ELECTRICAL ENGINEERING
Class A, B, and C Amplifiers
Class A Amplifier
R=n^2*Rl
IC=VCE/R
Imax=IC+IC
Pdc=VCC*IC
PP=VCEmax-VCEmin
VPP=n*PP
Po=(IC)^2*R/8
η=Po/Pdc
Power Transistor
-EXPA VARS PICT SI HALT NSOLV

```

```

Solving for R
R: 200_Ω
Zero
EDIT VARS VIEW ALL NSOLV

```

```

R= 50_Ω      ΔVCE= 10_V
IHX= 110_mA  VCC= 15_V
ICQ= 60_mA   VCEHX= 12_V
VCEHX= 6_V   VPP= 12_V
n= 2         PP= 6_V
QIC= 50_mA   R= 200_Ω
η= 6.944444... Po= .0625_W
Pdc= .9_W
EDIT VARS VIEW ALL MSOLV

```

```

Class A Amplifier
R= 200_Ω
ΔVCE= 10_V
Pdc= 0.900000_W
PP= 6_V
VPP= 12_V
Po= 0.062500_W
η= 0.069444
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

### 5.14.2. Power Transistor

#### Example:

A power transistor has a common emitter current gain of 125. A 750\_Ω base resistance is coupled to an external emitter resistance of 10\_kΩ. The ambient temperature is 75\_°F and the thermal resistance of the unit is 10\_°C/W. The power that needs to be dissipated is 12.5\_W. The base emitter voltage is 1.25\_V while ICBO is 1\_mA.

Find the junction temperature, collector current and the instability factor.

#### Solution:

We note from the equation set that IC is computed in three different ways. To make the calculations consistent given the data, we use equations 1, 2, 4 and 5 to solve for this problem.

```

ELECTRICAL ENGINEERING
Class A, B, and C Amplifiers
- Class A Amplifier
- Power Transistor
  Tj=Ta+θJA×Pd
  IC=hFE×IB+(1+hFE)×ICBO
  IB=-(IC×Re-VBE)/(Re+RB)
  IC=-hFE×VBE/(hFE×Re+RB)+hFE×..
  S=(1+RB/Re)×hFE/(hFE+RB/Re)
  IC=-hFE×IB+S×ICBO×(1+H×Tj)
Push-Pull Principle
- Class B Amplifier
-EXPANVAR= PICT SI = HALT MSOLV

```

```

Choose Equations for MES
✓ Tj=Ta+θJA×Pd
✓ IC=hFE×IB+(1+hFE)×ICBO
  IB=-(IC×Re-VBE)/(Re+RB)
✓ IC=-hFE×VBE/(hFE×Re+RB)+hFE×..
✓ S=(1+RB/Re)×hFE/(hFE+RB/Re)
  IC=-hFE×IB+S×ICBO×(1+H×Tj)
✓CHK CANCEL OK

```

```

Power Transistor
Tj: 0_K Ta: 75_°F
θJA: 10_°C/W Pd: 12.5_W
IB: 0_μA IC: 0_A
VBE: 1.25_V ICBO: 1_mA
s: 0 hFE: 125
RB: 750_Ω Re: 10_kΩ
Junction temperature
EDIT VARS VIEW ALL MSOLV

```

```

Solving for Tj
Tj: 422.038888889_K
Zero
EDIT VARS VIEW ALL MSOLV

```

```

Power Transistor
Tj: 422.038... Ta: 75_°F
θJA: 10_°C/W Pd: 12.5_W
IB: -1000.4... IC: 9.49430...
VBE: 1.25_V ICBO: 1_mA
s: 1.074355... hFE: 125
RB: 750_Ω Re: 10_kΩ
Junction temperature
EDIT VARS VIEW ALL MSOLV

```

```

Power Transistor
Tj: 422.038888889_K
IC: 0.00094943_A
S: 1.07435539
IB: -1000.40455726_μA
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.



### 5.14.3. Push-Pull Principle

#### Example:

Find the output power for a push-pull circuit with a collector voltage of 15\_V and a load resistance of 50\_Ω. The push-pull transformer secondary winding amplifies voltage by a factor of 2.5.

#### Solution:

Use the third equation to compute the solution for this problem.

```
##### ELECTRICAL ENGINEERING #####
Class A, B, and C Amplifiers
- Class A Amplifier
- Power Transistor
- Push-Pull Principle
  R=VCC/Imax
  Po=VCC^2/(2*R)
  Po=(n2/(2*n1))^2*VCC^2/(2*R2)
- Class B Amplifier
- Class C Amplifier
Transformers
Motors and Generators
EQN VARS= PICT= SI= HALT SOLVE
```

```
##### Po=(n2/(2*n1))^2*VCC^2/(2*R2) #####
Po: 0_W
n2: 2.5
n1: 1
VCC: 15_V
R2: 50_Ω

Power output
EDIT VARS VIEW SOLVE
```

```
##### ELECTRICAL ENGINEERING #####
Solid State Devices
Linear Amplifiers
Class A, B, and C Amplifiers
- Cla
- Pow Starting
- Pus Solver...
  R=
  Po=VCC^2/(2*R)
  Po=(n2/(2*n1))^2*VCC^2/(2*R2)
- Class B Amplifier
- Class C Amplifier
EQN VARS= PICT= SI= HALT SOLVE
```

```
##### Po=(n2/(2*n1))^2*VCC^2/(2*R2) #####
Po: 3.515625_W
n2: 2.5
n1: 1
VCC: 15_V
R2: 50_Ω

Power output
EDIT VARS VIEW INFO SOLVE
```

#### 5.14.4. Class B Amplifier

##### Example:

A Class B amplifier provides 5\_W to an effective load of 50\_Ω. The collector voltage is 25\_V. If the peak current is 500\_mA, find the average DC current and the efficiency of power conversion.

##### Solution:

Use the first, second, fourth and fifth equations to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Class B Amplifier
Po=K^2*VCC^2/(2*R)
Idc=2*K*Imax/n
Pdc=2*K*Imax*VCC/n
Pdc=2*K*VCC^2/(n*R)
η=Po/Pdc
η=n*K/4
Pd=2*VCC^2/(n*R)*(K-K^2*n/4)
V1=gH*R*(VH/(2*I2))/(1+h0E*R/2)
IC=gH*VH/n/(1+h0E*R/2)
Class C Amplifier
-EXPA VARS= PICT SI = HALT MSOLV

```

```

Choose Equations for MES
✓ Po=K^2*VCC^2/(2*R)
✓ Idc=2*K*Imax/n
Pdc=2*K*Imax*VCC/n
✓ Pdc=2*K*VCC^2/(n*R)
✓ η=Po/Pdc
η=n*K/4
Pd=2*VCC^2/(n*R)*(K-K^2*n/4)
V1=gH*R*(VH/(2*I2))/(1+h0E*R/2)
IC=gH*VH/n/(1+h0E*R/2)
✓CHK CANCEL OK

```

```

Class B Amplifier
Eq: { 'Po=K^2*VCC^2/(2*...
Idc: 0_A Imax: 500_mA
K: 0 VCC: 25_V
R: 50_Ω η: 0
Po: 5_W Pdc: 0_W

DC current
EDIT VARS VIEW ALL MSOLV

```

```

Solving for Idc
Idc: .284705017367_A
Zero

EDIT VARS VIEW ALL MSOLV

```

```

Class B Amplifier
Eq: { 'Po=K^2*VCC^2/(2*...
Idc: .284705... Imax: 500_mA
K: .8944271... VCC: 25_V
R: 50_Ω η: .7024814...
Po: 5_W Pdc: 7.11762...

DC current
EDIT VARS VIEW ALL MSOLV

```

```

Class B Amplifier
K: .894427191
Idc: .284705017367_A
Pdc: 7.11762543418_W
η: .702481473103

VALU= EQNS PRINT EXIT

```

### 5.14.5. Class C Amplifier

#### Example:

A Class C amplifier is supplying a tuned circuit, with a quality factor of 5. If the output voltage is 15\_V and the power delivered is 75\_W.

Find the capacitive reactance of the circuit needed in the tank circuit.

#### Solution:

Use the second equation to compute the solution for this problem.

```
***** ELECTRICAL ENGINEERING *****
|Push-Pull Principle
|Class B Amplifier
|Class C Amplifier
|   $I = I^2 \times R_c / (I^2 \times (R_c + R_D))$ 
|   $X_C = V_0^2 / (Q \times P_o)$ 
|   $X_L = X_C \times Q^2 / (Q^2 + 1)$ 
|   $X_{C1} = -R_1 / Q$ 
|   $X_L = 1 / Q \times (R_1 + j(R_1 \times R_2))$ 
|   $X_{C2} = -R_2 / Q$ 
Transformers
Motors and Generators
EQN VARS= PICT SI = HALT SOLVE
```

```
***** ELECTRICAL ENGINEERING *****
|Push-Pull Principle
|Class B Amplifier
|Class C Amplifier
|   $I = I^2 \times R_c / (I^2 \times (R_c + R_D))$ 
|   $X_C = V_0^2 / (Q \times P_o)$ 
|   $X_L = X_C \times Q^2 / (Q^2 + 1)$ 
|   $X_{C1} = -R_1 / Q$ 
|   $X_L = 1 / Q \times (R_1 + j(R_1 \times R_2))$ 
|   $X_{C2} = -R_2 / Q$ 
Transformers
Motors and Generators
EQN VARS= PICT SI = HALT SOLVE
```

```
***** XC=V0^2/(Q*Po) *****
Eq: 'XC=V0^2/(Q*Po)'
XC: 0_Ω
V0: 15_V
Q: 5
Po: 75_W

Tuned circuit parameter
EDIT VARS VIEW SOLVE
```

```
***** XC=V0^2/(Q*Po) *****
Eq: 'XC=V0^2/(Q*Po)'
XC: .6_Ω
V0: 15_V
Q: 5
Po: 75_W

Tuned circuit parameter
EDIT VARS VIEW INFO SOLVE
```

## 5.15. Transformers

```

ELECTRICAL ENGINEERING
OpAmp Circuits
Solid State Devices
Linear Amplifiers
Class A, B, and C Amplifiers
Transformers
Ideal Transformer
Linear Equivalent Circuit
Motors and Generators
-EXPA VARS PICT SI HALT HELP

```

### 5.15.6. Ideal Transformer

#### Example:

An ideal transformer has 10 primary turns and 36 secondary turns. The primary side draws 500\_mA when subjected to a 110\_V input. If the load impedance is 175\_Ω, find the input impedance at the primary side of the transformer in addition to the voltage and current on the secondary end.

#### Solution:

Use all of the equations to compute the solution for this problem.

```

ELECTRICAL ENGINEERING
Solid State Devices
Linear Amplifiers
Class A, B, and C Amplifiers
Transformers
Ideal Transformer
V1/V2=N1/N2
I1*I1=I2*N2
V1*I1=V2*I2
Zin=(N1/N2)^2*ZL
Linear Equivalent Circuit
Motors and Generators
-EXPA VARS PICT SI HALT MSOLV

```

```

ELECTRICAL ENGINEERING
Solid State Devices
Linear Amplifiers
Class A, B, and C Amplifiers
Transformers
Starting
Solver...
V1
I1
V1*I1=V2*I2
Zin=(N1/N2)^2*ZL
Linear Equivalent Circuit
Motors and Generators
-EXPA VARS PICT SI HALT MSOLV

```

```

Ideal Transformer
Eq: { 'V1/V2=N1/N2' 'I...
V1: 110_V I1: 500_mA
V2: 0_V I2: 0_A
Zin: 0_Ω N1: 10
N2: 36 ZL: 175_Ω

Secondary voltage
EDIT VARS VIEW ALL MSOLV

```

```

Solving for V2
V2: 396_V
Zero
EDIT VARS VIEW ALL MSOLV

```

```

Ideal Transformer
Eq: { 'V1/V2=N1/N2' 'I...
V1: 110_V      I1: 500_mA
V2: 396_V      I2: .138888...
Zin: 13.5030... N1: 10
N2: 36         ZL: 175_Ω

Secondary voltage
EDIT VARS VIEW ALL MSOLV

```

```

Ideal Transformer
V2: 396_V
I2: .138888888889_A
Zin: 13.5030864198_Ω

VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

### 5.15.7. Linear Equivalent Circuit

#### Example:

The transformer in the above problem has a primary and secondary resistance of  $18\ \Omega$  and  $5\ \Omega$ , respectively. Therefore, the ideal transformer has 10 primary turns and 36 secondary turns. The primary side draws 500\_mA when subjected to a 110\_V input. The corresponding coils have a reactance of  $6\ \Omega$  and  $2.5\ \Omega$ . The secondary side is loaded with an impedance of  $12.5\ \text{k}\Omega$ . The reactive part of load is  $10\ \Omega$ . Find the voltage and current on the secondary side in addition to the equivalent impedance on the primary side.

#### Solution:

Upon examining the problem, all of the equations are needed to compute the solution to this problem.

```

ELECTRICAL ENGINEERING
Solid State Devices
Linear Amplifiers
Class A, B, and C Amplifiers
Transformers
Ideal Transformer
Linear Equivalent Circuit
V1=N1/N2*V2
I1=I2*N2/N1
Rin=R1+(N1/N2)^2*(R2+R0)
Xin=X1+(N1/N2)^2*(X2+X0)
Motors and Generators
-EXPA VARS= PICT SI = HALT MSOLV

```

```

V1: 110_V      V2: 0_V
I1: 500_mA     I2: 0_A
Rin: 0_Ω       R1: 18_Ω
R2: 5_Ω        R0: 12.5_kΩ
Xin: 0_Ω       X1: 6_Ω
N1: 10         N2: 36
R2: 2.5_Ω      X0: 10_Ω
Secondary voltage
EDIT VARS VIEW ALL MSOLV

```

```

V1: 110_V      V2: 396_V
I1: 500_mA     I2: .138888...
Rin: 982.891... R1: 18_Ω
R2: 5_Ω        R0: 12.5_kΩ
Xin: 6.96450... X1: 6_Ω
N1: 10         N2: 36
R2: 2.5_Ω      X0: 10_Ω
Secondary voltage
EDIT VARS VIEW ALL MSOLV

```

```

ELECTRICAL ENGINEERING
Solid State Devices
Linear Amplifiers
Class A, B, and C Amplifiers
Transformers
Ideal Transformer
Linear Equivalent Circuit
V1=N1/N2*V2
I1=I2*N2/N1
Rin=R1+(N1/N2)^2*(R2+R0)
Xin=X1+(N1/N2)^2*(X2+X0)
Motors and Generators
-EXPA VARS= PICT SI = HALT MSOLV

```

```

Solving for I2
I2: .138888888889_A
Zero
EDIT VARS VIEW ALL MSOLV

```

```

Linear Equivalent Circuit
V2: 396_V
I2: .138888888889_A
Rin: 982.89197531_Ω
Xin: 6.96450617284_Ω
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

## 5.16. Transformers

```

ELECTRICAL ENGINEERING
Motors and Generators
Energy Conversion
DC Generator
Separately-Excited DC
DC Shunt Generator
DC Series Generator
Separately-Excited DC
DC Shunt Motor
-EXPA VARS PICT SI HALT HELP

```

```

ELECTRICAL ENGINEERING
Separately-Excited DC
DC Shunt Motor
DC Series Motor
Permanent Magnet Motor
Induction Motor I
Induction Motor II
Single-Phase Induction
Synchronous Machines
-EXPA VARS PICT SI HALT NSOLV

```

**Note:** The equations in this section are grouped under topics which describe general properties of semiconductors or devices. Equations for a variety of specific cases and are listed together under a sub-topic heading and are not necessarily a set of consistent equations which can be solved together. Choosing equations in a subtopic without regard as to whether the equations represent actual relationships could generate erroneous results or no solution at all.

### 5.16.1. Energy Conversion

#### Example:

A conductor having a length of 15\_cm and a cross sectional area of 0.5\_cm<sup>2</sup> is subjected to a magnetic induction of 1.8\_T and a field intensity of 2.8\_A/m. The magnetic reluctance is 0.46\_A/Wb. The conductor has 32 turns and is moving at a rotational speed of 62\_rad/s. Find the magnetic flux, the magnetic energy, the induced electric field and the mechanical pressure on the coil.

#### Solution:

All of the equations are needed to solve this problem.

```

ELECTRICAL ENGINEERING
Motors and Generators
Energy Conversion
MF=1/2*H*B*L*A
WF=1/2*Rel*pd^2
F=1/2*B^2/μ0
Es=Ns*ws*pd/12
DC Generator
Separately-Excited DC Genr.
DC Shunt Generator
DC Series Generator
Separately-Excited DC Motor
-EXPA VARS PICT SI HALT NSOLV

```

```

ELECTRICAL ENGINEERING
Motors and Generators
Energy Conversion
MF=1/2*H*B*L*A
WF=
F= Starting
Es= Solver...
DC
Separately-Excited DC Genr.
DC Shunt Generator
DC Series Generator
Separately-Excited DC Motor
-EXPA VARS PICT SI HALT NSOLV

```

```

Energy Conversion
H: 2.8_A/m    L: 15_cm
A: 0.5_cm^2   MF: 0_J
Rel: 0.46_A/Wb F: 0_Pa
B: 1.8_T      Es: 0_V
Ns: 32        ws: 62_r/s
p: 0_Wb
Flux
EDIT VARS VIEW ALL NSOLV

```

```

Solving for Es
Es: 12.7172630362_V
Zero
EDIT VARS VIEW ALL NSOLV

```

```

Energy Conversion
H= 2.8_A/m    L= 15_cm
A= .5_cm^2    Wf= .000018...
B= .46_A/Wb   F= 1289155.03904_Pa
E= 1.8_T      Es= 12.71726304_V
n= 32          v= 62_r/s
p= 9.064982...
Flux
EDIT VARS VIEW ALL MSOLV

```

```

Energy Conversion
Wf= 0.00001890_J
Ø= 0.00906498_Wb
F= 1289155.03904_Pa
Es= 12.71726304_V
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.



### 5.16.2. DC Generator

#### Example:

A six-pole DC generator rotates at a mechanical speed of 31\_rad/s. The armature sweeps across a flux of 0.65\_Wb. There are eight parallel paths and 64 coils in the armature. The armature current is 12\_A. The field is supplied by a 25\_V source delivering a current of 0.69\_A.

Find the torque and the voltages generated in the armature.

#### Solution:

Upon examining the problem, equation one to six are needed to compute the solution for this problem.

```

=====ELECTRICAL ENGINEERING=====
Motors and Generators
Energy Conversion
DC Generator
  Wme=p/2*Wm
  Eta=p/π*Wm*d
  Ea=φ/ap*p/π*Wm*d
  Ea=K*Wm*d
  K=φ*p/(ap*π)
  T*Wm=Ea*Ia+Ef*If
  T=K*d*Ia
  Ra=φ*π/ap^2*L/A
-EXPA VARS= PICT SI = HALT NSOLV
  
```

```

===== Choose Equations for MES =====
✓ Wme=p/2*Wm
✓ Eta=p/π*Wm*d
✓ Ea=φ/ap*p/π*Wm*d
✓ Ea=K*Wm*d
✓ K=φ*p/(ap*π)
✓ T*Wm=Ea*Ia+Ef*If
  T=K*d*Ia
  Ra=φ*π/ap^2*L/A
  Vf=Rf*If
+
===== ✓CHK===== CANCEL OK
  
```

```

Wme: 0_r/s      Eta: 0_V
φ: 0.65_Wb      K: 0
π: 64           π: 6
ap: 8           T: 0_N*m
Wm: 31_r/s      Ea: 0_V
Ia: 12_A         Ef: 25_V
If: 0.69_mA
Electrical radian frequency
EDIT VARS VIEW ALL NSOLV
  
```

```

Solving for T
T: 119.175777839_N*m
Sign Reversal
EDIT VARS VIEW ALL NSOLV
  
```

```

Wme: 93_r/s      Eta: 38.4836...
φ: 0.65_Wb      K: 15.27887...
π: 64           π: 6
ap: 8           T: 119.1757...
Wm: 31_r/s      Ea: 307.869...
Ia: 12_A         Ef: 25_V
If: 0.69_mA
Electrical radian frequency
EDIT VARS VIEW ALL NSOLV
  
```

```

===== DC Generator =====
Wme: 93_r/s
Eta: 38.4836652396_V
Ea: 307.869321917_V
K: 15.2788745368
T: 119.175777839_N*m
VALU= EQNS PRINT EXIT
  
```

Press **TOOL** to view all calculated results.

### 5.16.3. Separately-Excited DC Generator

#### Example:

A DC generator with a machine constant of 3.8 is driving a load of 46\_k $\Omega$  and rotates at a speed of 31\_rad/s. The magnetic flux is 1.6\_Wb. The field is driven by a 24\_V source. The field coil resistance is 10\_ $\Omega$ . The armature resistance is 13\_ $\Omega$  in series with an external resistance of 55\_ $\Omega$ .

Find the field current, armature induced voltage and the terminal voltage.

#### Solution:

Use all the equations to compute the solution for this problem.

```

===== ELECTRICAL ENGINEERING =====
Motors and Generators
Energy Conversion
DC Generator
  Separately-Excited DC Genr.
    If=Vfs/(Rf+Rl)
    Ea=K* $\omega$ * $\phi$ 
    Vt=IL*RL
    Vt=Ea-Ra*IL
    IL=K* $\phi$ * $\omega$ /(Ra+RL)
  DC Shunt Generator
  DC Series Generator
-EXPAN VARS= PICT SI = HALT NSOLV

```

```

===== ELECTRICAL ENGINEERING =====
Motors and Generators
Energy Conversion
DC Generator
  Separately-Excited DC Genr.
    Starting Solver...
    If=
    Ea=
    Vt=
    Vt=Ea-Ra*IL
    IL=K* $\phi$ * $\omega$ /(Ra+RL)
  DC Shunt Generator
  DC Series Generator
-EXPAN VARS= PICT SI = HALT NSOLV

```

```

===== Separately-Excited DC Genr. =====
If: 0_mA Vfs: 24_V
Ra: 55_ $\Omega$  Rf: 10_ $\Omega$ 
Vt: 0_V Ea: 0_V
IL: 0_A K: 3.8
 $\phi$ : 1.6_Wb  $\omega$ : 31_r/s
Ra: 13_ $\Omega$  RL: 46_k $\Omega$ 
Field current
EDIT VARS VIEW ALL NSOLV

```

```

Solving for Vt
Vt: 188.426748962_V
Zero
EDIT VARS VIEW ALL NSOLV

```

```

===== Separately-Excited DC Genr. =====
If: 369.230... Vfs: 24_V
Ra: 55_ $\Omega$  Rf: 10_ $\Omega$ 
Vt: 188.426... Ea: 188.48_V
IL: 4.09623... K: 3.8
 $\phi$ : 1.6_Wb  $\omega$ : 31_r/s
Ra: 13_ $\Omega$  RL: 46_k $\Omega$ 
Field current
EDIT VARS VIEW ALL NSOLV

```

```

===== Separately-Excited DC Genr. =====
If: 369.23076923_mA
Ea: 188.480000000_V
IL: 0.00409623_A
Vt: 188.42674896_V
VALU= EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

#### 5.16.4. DC Shunt Generator

##### Example:

Find the machine constant of a shunt generator running at 31\_rad/s and producing 125\_V with a 1.8\_Wb flux.

##### Solution:

Use the first equation to solve this problem.

```
===== ELECTRICAL ENGINEERING =====
Motors and Generators
- Energy Conversion
- DC Generator
- Separately-Excited DC Genr.
- DC Shunt Generator
-  $E_a = K \times \omega_m \times \phi$ 
-  $V_t = (R_a + R_f) \times I_f$ 
-  $V_t = I_L \times R_L$ 
-  $V_t = E_a - R_a \times I_a$ 
-  $I_a = I_L + I_f$ 
-  $E_a = R_a \times I_a + (R_a + R_f) \times I_f$ 
EQN  VARS=  PICT  SI  HALT  SOLVE
```

```
=====  $E_a = K \times \omega_m \times \phi$  =====
Ea: 125_V
K: 0
 $\omega_m$ : 31_r/s
 $\phi$ : 1.80000000_Wb

Machine constant
EDIT  VARS  VIEW  SOLVE
```

```
===== ELECTRICAL ENGINEERING =====
Motors and Generators
- Energy Conversion
- DC Generator
- Sep
- DC
- Starting Solver...
-  $V_t = I_L \times R_L$ 
-  $V_t = E_a - R_a \times I_a$ 
-  $I_a = I_L + I_f$ 
-  $E_a = R_a \times I_a + (R_a + R_f) \times I_f$ 
EQN  VARS=  PICT  SI  HALT  SOLVE
```

```
=====  $E_a = K \times \omega_m \times \phi$  =====
Ea: 125_V
K: 2.24014337
 $\omega_m$ : 31_r/s
 $\phi$ : 1.80000000_Wb

Machine constant
EDIT  VARS  VIEW  INFO  SOLVE
```

### 5.16.5. DC Series Generator

#### Example:

Find the terminal voltage of a series generator with an armature resistance of  $0.068\ \Omega$  and a series resistance of  $0.40\ \Omega$ . The generator delivers a  $15\text{ A}$  load current from a generated voltage of  $17\text{ V}$ .

#### Solution:

Use the second equation to solve this problem.

```
***** ELECTRICAL ENGINEERING *****
Motors and Generators
Energy Conversion
DC Generator
Separately-Excited DC Genr.
DC Shunt Generator
DC Series Generator
Ia=If
Vt=Ea-(Ra+Rs)*IL
Separately-Excited DC Motor
DC Shunt Motor
DC Series Motor
EQN VARS= PICT SI = HALT SOLVE
```

```
***** Vt=Ea-(Ra+Rs)*IL *****
Eq: 'Vt=Ea-(Ra+Rs)*IL'
Vt: 0_V
Ea: 17_V
Ra: 0.068000000_Ω
Rs: 0.400000000_Ω
IL: 15_A
Terminal voltage
EDIT VARS VIEW SOLVE
```

```
***** ELECTRICAL ENGINEERING *****
Motors and Generators
Energy Conversion
DC Generator
Sep
DC Starting
DC Solver...
Ia
Vt=Ea-(Ra+Rs)*IL
Separately-Excited DC Motor
DC Shunt Motor
DC Series Motor
EQN VARS= PICT SI = HALT SOLVE
```

```
***** Vt=Ea-(Ra+Rs)*IL *****
Eq: 'Vt=Ea-(Ra+Rs)*IL'
Vt: 9.980000000_V
Ea: 17_V
Ra: 0.068000000_Ω
Rs: 0.400000000_Ω
IL: 15_A
Terminal voltage
EDIT VARS VIEW INFO SOLVE
```

### 5.16.6. Separately-Excited DC Motor

#### Example:

Find the terminal voltage, field current and machine constant for a motor with an armature current 0.5\_A and resistance of 100\_Ω rotating at an angular velocity of 31\_rad/s. The back emf is 29\_V. The field is driven by a 15\_V source driving a 50\_Ω load. The flux available in the armature is 2.4\_Wb.

#### Solution:

Solve the first, second, fourth and fifth equations to solve this problem.

```

ELECTRICAL ENGINEERING
-DC Shunt Generator
-DC Series Generator
-SEPARATELY-EXCITED DC MOTOR
  VF=RF*IF
  VT=K*d*WM+R*A*IA
  TL=K*d*IA-Tloss
  Ea=K*WM*d
  T=K*IA*d
  WM=VT/(K*d)-R*A*T/(K*d)^2
  T=Tloss+TL
  P=T*WM
-EXPA VARS= PICT SI = HALT MSOLV
  
```

```

Choose Equations for MES
✓ VF=RF*IF
✓ VT=K*d*WM+R*A*IA
  TL=K*d*IA-Tloss
✓ Ea=K*WM*d
✓ T=K*IA*d
  WM=VT/(K*d)-R*A*T/(K*d)^2
  T=Tloss+TL
  P=T*WM
  ✓CHK  CANCEL  OK
  
```

```

SEPARATELY-EXCITED DC MOTOR
VF: 15_V      RF: 50_Ω
IF: 0_mA      VT: 0_V
Ra: 100_Ω     Ea: 29_V
WM: 31_r/s    T: 0_N*m
K: 0          Ia: .5_A
Φ: 2.4_Wb
Machine constant
EDIT VARS VIEW  ALL MSOLV
  
```

```

Solving for K
K: .389784946237
Zero
EDIT VARS VIEW  ALL MSOLV
  
```

```

SEPARATELY-EXCITED DC MOTOR
VF: 15_V      RF: 50_Ω
IF: 300_mA    VT: 79_V
Ra: 100_Ω     Ea: 29_V
WM: 31_r/s    T: .4677419...
K: .3897849... Ia: .5_A
Φ: 2.4_Wb
Machine constant
EDIT VARS VIEW  ALL MSOLV
  
```

```

SEPARATELY-EXCITED DC MOTOR
If: 300_mA
K: .389784946237
T: .467741935483_N*m
Vt: 79_V
VALU= EQNS PRINT  EXIT
  
```

Press **TOOL** to view all calculated results.

### 5.16.7. DC Shunt Motor

#### Example:

Find the back emf for a motor with a machine constant of 2.1, rotating at 62\_rad/s in a flux of 2.4\_Wb.

#### Solution:

Use the fourth equation to solve this problem.

```
~~~~~ ELECTRICAL ENGINEERING ~~~~~
-DC Shunt Generator
-DC Series Generator
-Separately-Excited DC Motor
-DC Shunt Motor
-Vt=(Re+Rf)*If
-Vt=K*p*wm+Ra*Ia
-TL=K*p*Ia-Tloss
-Ea=K*p*wm
wm=(Vt/(K*p)-(Ra+Rd)*T/(K*p)^2
T=Tloss+TL
T=K*p*Ia
EQN VARS= PICT SI = HALT SOLVE
```

```
~~~~~ Ea=K*p*wm ~~~~~
Ea: 0_V
K: 2.1
wm: 62_r/s
p: 2.4_Wb

Avg. emf induced in armatur
EDIT VARS VIEW SOLVE
```

```
~~~~~ ELECTRICAL ENGINEERING ~~~~~
-DC Shunt Generator
-DC Series Generator
-Separately-Excited DC Motor
-DC Shunt Motor
-Vt= Starting
-Vt= Solver...
-TL
-Ea=K*p*wm
wm=(Vt/(K*p)-(Ra+Rd)*T/(K*p)^2
T=Tloss+TL
T=K*p*Ia
EQN VARS= PICT SI = HALT SOLVE
```

```
~~~~~ Ea=K*p*wm ~~~~~
Ea: 312.48_V
K: 2.1
wm: 62_r/s
p: 2.4_Wb

Avg. emf induced in armatur
EDIT VARS VIEW INFO SOLVE
```

### 5.16.8. DC Series Motor

#### Example:

A series motor, with a machine constant of 2.4, rotating at 62\_rad/s, is supplied with a terminal voltage of 110\_V and produces a torque of 3\_N\*m. The armature resistance is 10\_Ω, the series resistance is 5\_Ω, and the adjustable resistance is 0.001\_Ω.

Find the average voltage induced in the armature, the flux, and the load current.

#### Solution:

The first, third and fifth equations are needed to compute a solution.

```

ELECTRICAL ENGINEERING
Separately-Excited DC Motor
DC Shunt Motor
DC Series Motor
Vt=K*p*wm+(Ra+Rs+Rd)*IL
TL=K*p*IL-Tloss
Ea=K*wm*p
T=K*p*IL
wm=Vt/(K*p)-(Ra+Rs+Rd)*T/(K*p)^2
T=Tloss+TL
K*p=KF*IL
T=KF*IL^2
-EXPAN VARS PICT SI HALT NSOLV

```

```

Choose Equations For MES
✓ Vt=K*p*wm+(Ra+Rs+Rd)*IL
  TL=K*p*IL-Tloss
✓ Ea=K*wm*p
  T=K*p*IL
✓ wm=Vt/(K*p)-(Ra+Rs+Rd)*T/(K*p)^2
  T=Tloss+TL
  K*p=KF*IL
  T=KF*IL^2
✓CHK CANCEL OK

```

```

DC Series Motor
Eq: { 'Vt=K*ø*wm+(Ra+R...
IL: 0_A Vt: 110_V
Ra: 10_Ω R: 5_Ω
Rd: .001_Ω T: 3_N*m
Ea: 0_V K: 2.4
wm: 62_r/s ø: 0_Wb
Load current
EDIT VARS VIEW ALL NSOLV

```

```

Solving for ø
ø: .472605120055_Wb
Zero
EDIT VARS VIEW ALL NSOLV

```

```

DC Series Motor
Eq: { 'Vt=K*ø*wm+(Ra+R...
IL: 2.64491... Vt: 110_V
Ra: 10_Ω R: 5_Ω
Rd: .001_Ω T: 3_N*m
Ea: 70.3236... K: 2.4
wm: 62_r/s ø: .4726051...
Load current
EDIT VARS VIEW ALL NSOLV

```

```

DC Series Motor
ø: .472605120055_Wb
Ea: 70.3236418642_V
IL: 2.64491421478_A
VALU EQNS PRINT EXIT

```

Press **TOOL** to view all calculated results.

### 5.16.9. Permanent Magnet Motor

#### Example:

Find the machine constant for a permanent motor rotating at 62.5\_rad/s in a magnetic flux field of 1.26\_Wb. Assume a 110\_V back emf.

#### Solution:

The first equation is needed to compute the solution.

```
===== ELECTRICAL ENGINEERING =====
Separately-Excited DC Motor
DC Shunt Motor
DC Series Motor
Permanent Magnet Motor
Ea=K*ø*ωm
T=K*p*Ia
Vt=Ea+Ra*Ia
T=Tloss+TL
ωm=Vt/(K*p)-Ra*I/(K*p)^2
Induction Motor I
Induction Motor II
EQN VARS= PICT SI = HALT SOLVE
```

```
===== Ea=K*ø*ωm =====
Eq: 'Ea=K*ø*ωm'
Ea: 110_V
K: 0
p: 1.26_Wb
ωm: 62.5_r/s

Machine constant
EDIT VARS VIEW SOLVE
```

```
===== ELECTRICAL ENGINEERING =====
Separately-Excited DC Motor
DC Shunt Motor
DC Series Motor
Per Starting Solver...
Ea=K*ø*ωm
T=K*p*Ia
Vt=Ea+Ra*Ia
T=Tloss+TL
ωm=Vt/(K*p)-Ra*I/(K*p)^2
Induction Motor I
Induction Motor II
EQN VARS= PICT SI = HALT SOLVE
```

```
===== Ea=K*ø*ωm =====
Eq: 'Ea=K*ø*ωm'
Ea: 110_V
K: 1.39682539682
p: 1.26_Wb
ωm: 62.5_r/s

Machine constant
EDIT VARS VIEW INFO SOLVE
```



### 5.16.10. Induction Motor I

#### Example:

Find the mechanical power for an induction motor with a slip of 0.95, a rotor current of 75\_A and a resistance of 1.8\_Ω.

#### Solution:

Upon examining the problem, equation ten is needed to compute a solution.

```

ELECTRICAL ENGINEERING
Induction Motor I
- $\omega_r = \omega_s - p/2 \times \omega_m$ 
- $s = (\omega_s - (p/2) \times \omega_m) / \omega_s$ 
- $P_r / P_{ha} = s$ 
- $\omega_r = s \times \omega_s$ 
- $P_{ha} = 3 \times I_r \times E_{ha}$ 
- $P_{he} = 3 \times (p/2) \times (\omega_m / \omega_s) \times P_{ha}$ 
- $P_{he} = T \times \omega_m$ 
- $T = 3 \times (p/2) \times (P_{ha} / \omega_s)$ 
- $P_{ha} = R_r \times I_r^2 + (1-s) / s \times R_r \times I_r^2$ 
- $P_a = (1-s) / s \times R_r \times I_r^2$ 
- $R_r = R_1 / K^2$ 

```

```

ELECTRICAL ENGINEERING
Induction Motor I
- $\omega_r = \omega_s - p/2 \times \omega_m$ 
- $s = (\omega_s - (p/2) \times \omega_m) / \omega_s$ 
-Pr
- $\omega_r$  Starting
-PH Solver...
-PH
-Phe=T* $\omega_m$ 
-T=3*(p/2)*(Pha/ωs)
-Pha=Rr×Ir2+(1-s)/s×Rr×Ir2
-Pa=(1-s)/s×Rr×Ir2
-Rr=R1/K2

```

```

Pa=(1-s)/s×Rr×Ir2
Eq: 'Pa=(1-s)/s×Rr×Ir2...'
Pa: 0_W
s: .95
Rr: 1.8_Ω
Ir: 75_A

Mechanical power
EDIT VARS VIEW SOLVE

```

```

Pa=(1-s)/s×Rr×Ir2
Eq: 'Pa=(1-s)/s×Rr×Ir2...'
Pa: 532.894736842_W
s: .95
Rr: 1.8_Ω
Ir: 75_A

Mechanical power
EDIT VARS VIEW INFO SOLVE

```

### 5.16.11. Induction Motor II

#### Example:

An applied voltage of 125\_V is applied to an eight pole motor rotating at 245\_rad/s. The stator resistance and reactance is 8\_Ω and 12\_Ω respectively. Find the maximum torque.

#### Solution:

Use the fourth equation to compute the solution.

```

===== ELECTRICAL ENGINEERING =====
Induction Motor I
Induction Motor II
Pm=Rs/s*Ir^2
T=3*(p/2)*Pm/ws
T=3/ws*p/2*Rs/s*Va^2/((Rst+Rs/s
Tmmax=3/ws*p/4*Va^2/(Rs^2+XL
sH=Rs/(Rs^2+XL^2)
Tgmax=-3/ws*p/4*Va^2/(Rs^2+XL
Rr=R1/KM^2
Single-Phase Induction Motor
Synchronous Machines
EQN VARS= PICT SI = HALT SOLVE

```

```

Eq: 'Tmmax=3/ws*p/4*Va...
Tmmax: 0_N*m
ws: 245_r/s
p: 8
Va: 125_V
Rst: 8_Ω
XL: 12_Ω
Maximum positive torque
EDIT VARS VIEW SOLVE

```

```

===== ELECTRICAL ENGINEERING =====
Induction Motor I
Induction Motor II
Pm=Rs/s*Ir^2
T= Starting
T= Solver...
T=
Tmmax=3/ws*p/4*Va^2/(Rs^2+XL
sH=Rs/(Rs^2+XL^2)
Tgmax=-3/ws*p/4*Va^2/(Rs^2+XL
Rr=R1/KM^2
Single-Phase Induction Motor
Synchronous Machines
EQN VARS= PICT SI = HALT SOLVE

```

```

Eq: 'Tmmax=3/ws*p/4*Va...
Tmmax: 17.0658086252_N*m
ws: 245_r/s
p: 8
Va: 125_V
Rst: 8_Ω
XL: 12_Ω
Maximum positive torque
EDIT VARS VIEW INFO SOLVE

```

### 5.16.12. Single-Phase Induction Motor

#### Example:

Find the forward slip for an eight pole induction motor with a stator frequency of 245\_rad/s and a mechanical radian frequency of 62.5\_rad/s.

#### Solution:

The first equation is needed to compute the solution.

```
##### ELECTRICAL ENGINEERING #####
Separately-Excited DC Motor
DC Shunt Motor
DC Series Motor
Permanent Magnet Motor
Induction Motor I
Induction Motor II
Single-Phase Induction Motor
sf=((2/p)*ws-wm)/((2/p)*ws)
If=p/2*1/ws*Isf^2*Rr/(2*sf)
Tb=-p/2*1/ws*Isb^2*Rr/(2*(2-sf))
Synchronous Machines
EQN VARS= PICT SI = HALT SOLVE
```

```
##### sf=((2/p)*ws-wm)/((2/p)*ws) #####
Eq: 'sf=((2/p)*ws-wm)/((2/p)*ws)'
sf: 0
p: 8
ws: 245_r/s
wm: 62.5_r/s

Slip For Forward Flux
EDIT VARS VIEW SOLVE
```

```
##### ELECTRICAL ENGINEERING #####
Separately-Excited DC Motor
DC Shunt Motor
DC Series Motor
Per
Ind Starting
Ind Solver...
Sin
sf=((2/p)*ws-wm)/((2/p)*ws)
If=p/2*1/ws*Isf^2*Rr/(2*sf)
Tb=-p/2*1/ws*Isb^2*Rr/(2*(2-sf))
Synchronous Machines
EQN VARS= PICT SI = HALT SOLVE
```

```
##### sf=((2/p)*ws-wm)/((2/p)*ws) #####
Eq: 'sf=((2/p)*ws-wm)/((2/p)*ws)'
sf: -0.02040816
p: 8
ws: 245_r/s
wm: 62.50000000_r/s

Slip For Forward Flux
EDIT VARS VIEW INFO SOLVE
```

### 5.16.13. Synchronous Machines

#### Example:

Find the stator radian frequency and the maximum torque for a synchronous machine with a mechanical rotational velocity of 31\_rad/s. The motor has eight poles, a field current of 1.8\_A and experiences an applied voltage of 130\_V.

#### Solution:

The first and second equations are needed to compute the solution.

```

ELECTRICAL ENGINEERING
DC Series Motor
Permanent Magnet Motor
Induction Motor I
Induction Motor II
Single-Phase Induction Motor
Synchronous Machines
  WM=2/p*ws
  Tmax=p/2*3/ws*If*Va
  Pma=Va*Ia*cos(0)
  T=Pme/WM
  T=3*Pma/((2/p)*ws)
-EXPA VARS= PICT SI = HALT NSOLV

```

```

Choose Equations for MES
✓ WM=2/p*ws
✓ Tmax=p/2*3/ws*If*Va
Pma=Va*Ia*cos(0)
T=Pme/WM
T=3*Pma/((2/p)*ws)
✓CHK CANCEL OK

```

```

Synchronous Machines
WM: 31_r/s
Tmax: 0_N*m
p: 8
ws: 0_r/s
If: 1.80000000_A
Va: 130_V
Pullout torque
EDIT VARS VIEW ALL NSOLV

```

```

Solving for ws
ws: 124_r/s
Zero
EDIT VARS VIEW ALL NSOLV

```

```

Synchronous Machines
WM: 31_r/s
Tmax: 22.64516129_N*m
p: 8
ws: 124_r/s
If: 1.80000000_A
Va: 130_V
Pullout torque
EDIT VARS VIEW ALL NSOLV

```

```

Synchronous Machines
ws: 124_r/s
Tmax: 22.64516129_N*m
VALU= EQNS PRINT EXIT

```






















Press **TOOL** to view all calculated results.









## 6. Used Keys



The following keys are used by the TreeBrowser application, which provides the environment for Electrical Engineering.

Keys while the TreeBrowser is active:



-  : opens a tree
-  : closes a tree
-  : shows the equation if there is something to show and if one is on the lowest level
-  : shows variables (if there are any)
-  : shows picture (if there is any)
-  : sets or clears the user flag for using units with SI units (user flag 60 and 61)
-  : sets or clears the user flag for using units with English units (user flag 60 and 61)
-  : shows help for TreeBrowser
-  : temporary stops the TreeBrowser and gives access to the normal user stack. One has complete control over the calculator at this point. If an error happens by another program, for example, which is not covered by TreeBrowser your calculator may crash. The purpose of these functions is to allow simple calculations so that it is not necessary to leave TreeBrowser for this.  CONT brings you back to the TreeBrowser.
-  : starts the solver if one is on the lowest level and the equation contains =. System flag 30 controls if the solver of the HP 48SX or the solver of the HP 48GX is used.
-  : starts the Multiple Equation Solver, all equations of the lowest level are grouped together. The equations should be related by topic to each other if you want usable results (also see user guide of the HP 48GX).  
 CONT brings you back to the TreeBrowser.
-  : double click opens or closes a tree
-  : starts the solver if the equation contains =
-  : toggles between the way equations are shown, if you provide a program which tests system flag 13 it is possible to have two different appearances of the equation.
-  : opens a choose box to select the equations which will be passed to the Multiple Equation Solver.
-  : shows variables (if there are any)
-  : shows picture (if there is any)
-  : ends TreeBrowser
-  : opens or closes a tree



    : arrow keys to navigate or to move the screen



  : one page up


  : one page down


  : first entry


  : last entry

  : move screen to the right


  : move screen to the left

 : choose font

 : toggle fonts

 : hide / show title


 : hide / show menu


 : integrated help


Keys while an equation is shown:

 : previous equation


 : copies the current equation to the stack





 : next equation

 : toggles between big and small appearance of the equation (changes system flag 80)

 : leaves the equation view and jumps back to the TreeBrowser

 : previous equation

 : next equation

    : arrow keys to navigate or to move the screen

## 7. Things To Do

In principle, it would be possible to extend Electrical Engineering with more equations and/or more functionality.

Contact me directly in this case to examine what would be needed for this.

<mailto:Software49G@gmx.de>

Suggestions, criticism and/or improvements are welcome.

## 8. Version History

09.04.2012	Version 1.0	First public version.
01.01.2014	Version 1.01	Revised all equations.

## 9. Known Bugs

Version 1.01	Revised all equations, added some missing equations, fixed some bugs in some equations.
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