

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. 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

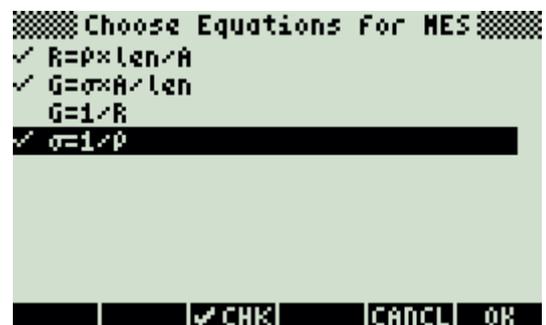
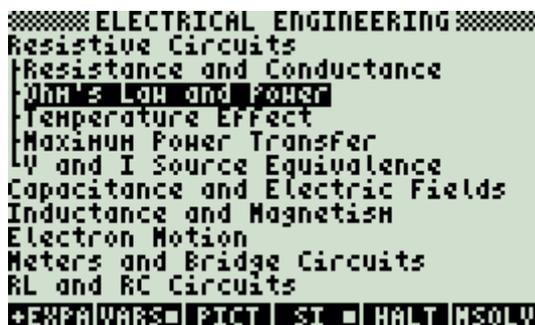


or through the library menu via **LIB**.



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/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/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
  
```

5. Using Equations

Note that there might be more than one mathematical correct solution. Therefore, it is the users responsibility to ensure, that the found solution(s) match reality – and if not repeat the solution process with different guesses for the solver routine. If necessary, consult your calculator manual about the root finding algorithm implemented into the calculator.

5.1. Resistive Circuits

```

ELECTRICAL ENGINEERING
Resistive Circuits
-Resistance and Conductance
-Ohm's Law and Power
-Temperature Effect
-Maximum Power Transfer
-V and I Source Equivalence
-Capacitance and Electric Fields
-Inductance and Magnetic Fields
-EXPA VARS PICT SI HALT HELP
  
```

5.1.1. Resistance and Conductance

Example:

A copper wire 1500_m long has a resistivity of 6.5_Ohm*cm and a cross sectional area of 0.45_cm^2. Compute its resistance and conductance.

Solution:

Upon examining the problem, two choices are noted.

Equations 1, 2 and 4 or equations 1 and 3 can be used to solve the problem.

The second choice was made here.

```

ELECTRICAL ENGINEERING
Resistive Circuits
-Resistance and Conductance
  R=p*len/A
  G=s*A/len
  G=1/R
  s=1/p
-Ohm's Law and Power
-Temperature Effect
-Maximum Power Transfer
-V and I Source Equivalence
-Capacitance and Electric Fields
-EXPA VARS PICT SI HALT MSOLV
  
```

```

Choose Equations for MES
✓ R=p*len/A
G=s*A/len
✓ G=1/R
s=1/p
CHK CANCL OK
  
```

```

ELECTRICAL ENGINEERING
Resistive Circuits
-Resistance and Conductance
  R=p*len/A
  G= Starting
  G= Solver...
  s=
-Ohm's Law and Power
-Temperature Effect
-Maximum Power Transfer
-V and I Source Equivalence
-Capacitance and Electric Fields
-EXPA VARS PICT SI HALT MSOLV
  
```

```

Resistance and Conductance
Eq: ( 'R=p*len/A' 'G=1...
p: 6.5_O*cm
len: 1500._m
A: .45_cm^2
G: 0_S
R: 0_O
Conductance
EDIT VARS VIEW ALL MSOLV
  
```

```

Solving for R
R: 2166666.66667_Ω
Zero

```

EDIT	VARS	VIEW	ALL	MSOLV
------	------	------	-----	-------

```

Resistance and Conductance
Eq: C 'R=ρ*len/A' 'G=1...
ρ 6.5_Ω*cm
len 1500._m
A .45_cm^2
G 4.61588461588E-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: 4.61588461588E-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
  
```

```

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: 0_W
v: 0_V
R: 4.700000_kΩ
g: 0_S
Conductance
EDIT VARS VIEW ALL 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_ Ohm resistor at 75_ °F reads 152.4_ Ohm 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+alpha*(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
```

```
***** ELECTRICAL ENGINEERING *****
Resistive Circuits
Resistance and Conductance
Ohm's Law and Power
Temperature Effect
Starting Solver...
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+alpha*(T2-T1)) *****
Eq: 'R2=R1*(1+alpha*TDELTA...'
R2: 152.400000_Ω
R1: 145_Ω
alpha: 0.1/K
T2: 125_°C
T1: 75_°F
Temperature coefficient
EDIT VARS VIEW INFO SOLVE
```

```
***** R2=R1*(1+alpha*(T2-T1)) *****
Eq: 'R2=R1*(1+alpha*TDELTA...'
R2: 152.400000_Ω
R1: 145_Ω
alpha: 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
V1=Vs*R1/(Rs+R1)
I1=Vs/(Rs+R1)
P=I1*V1
Pmax=Vs^2/(4*Rs)
R1=Rs
V and I Source Equivalence
-EXPA VARS= PICT= SI= HALT MSOLV
  
```

```

##### Choose Equations for MES #####
✓ V1=Vs*R1/(Rs+R1)
✓ I1=Vs/(Rs+R1)
✓ P=I1*V1
✓ Pmax=Vs^2/(4*Rs)
  R1=Rs
#####
##### ✓CHK##### CANCEL OK
  
```

```

##### Maximum Power Transfer #####
Eq: ( 'V1=Vs*R1/(Rs+R1...
R1: 0.5200_Ω P: 0_W
I1: 0_A V1: 0_V
Pmax: 0_W Vsa: 12_V
Rs: 0.0780_Ω

Maximum power in load
EDIT VARS VIEW ALL MSOLV
  
```

```

##### Maximum Power Transfer #####
Eq: ( 'V1=Vs*R1/(Rs+R1...
R1: 0.5200_Ω P: 209.3936...
I1: 20.0669... V1: 10.4348...
Pmax: 461.53... Vsa: 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= EQNS 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
*****
Capacitance and Electric Fields
Inductance and Magnetism
Electron Motion
Meters and Bridge Circuits
EQN VARS PICT SI HALT SOLVE
```

```
***** ELECTRICAL ENGINEERING *****
Resistive Circuits
Resistance and Conductance
Ohm's Law and Power
Temperature Effect
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
```

```
***** Vs=Is*Rs *****
Eq: 'Vs=Is*Rs'
Vs: 5_V
Is: 0_A
Rs: 12.5000_Ω
Current source
EDIT VARS VIEW 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 14.5×10^{-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 ϵ_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, ϵ_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*E0*Er*r^2)
  V=Q/(4*pi*E0*Er*r)
-Long Charged Line
-Charged Disk
-Parallel Plates
-Parallel Wires
-Coaxial Cable
-Sphere
-EXPA VARS PICT SI HALT NSOLV

```

```

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 NSOLV

```

```

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 NSOLV

```

```

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 NSOLV

```

5.2.7. Long Charged Line

Example:

An aluminum wire suspended in air carries a charge density of 2.75E-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
  
```

```

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=ρl/(2*π*ε0*εr*r)
Eq: 'Er=ρl/(2*π*CONST(
Er: 0_V/m
ρl: 2.750000E-15_C/m
εr: 1.040000
r: 50_cm

Radial electric field
EDIT VARS VIEW SOLVE
  
```

```

Er=ρl/(2*π*ε0*εr*r)
Eq: 'Er=ρl/(2*π*CONST(
Er: 0.000095_V/m
ρl: 2.750000E-15_C/m
εr: 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
Capcitanace and Electric Fields
-Point Charge
-Long Charged Line
-Two Parallel Plates
| Ez=ps/(2*E0*Er)*(1-ABS(z)/r(r^2
| Vz=ps/(2*E0*Er)*(r(r^2+z^2)-AB
-Parallel Plates
-Parallel Wires
-Coaxial Cable
-Sphere
-EXPA VARS= PICT SI = HALT MSOLV
  
```

```

##### Choose Equations for MES #####
✓ Ez=ps/(2*E0*Er)*(1-ABS(z)/r(r^2
  Vz=ps/(2*E0*Er)*(r(r^2+z^2)-AB
#####
| ✓CHK | | CANCL | 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_μ² and a thickness of .15_ μ. Use a value of 3.9 for permittivity of SiO₂.

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
-EXPAN VARS PICT SI HALT NSOLV
  
```

```

===== 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
-EXPAN VARS PICT SI HALT NSOLV
  
```

```

===== Parallel Plates =====
Eq: C 'E=V/d' 'C=CONST...'
E: 0_V/m      EQ 3.9000
A: 1250.000... e: 0_C
F: 0_mN      EQ 0.1500_μ
W: 0_J       EQ 5_V
c: 0_F
Capacitance
EDIT VARS VIEW ALL NSOLV
  
```

```

===== Parallel Plates =====
Eq: C 'E=V/d' 'C=CONST...'
E: 33333333... EQ 3.9000
A: 1250.000... e: 1.4388E-...
F: -0.0240... EQ 0.1500_μ
W: 3.5970E-... EQ 5_V
c: 2.8776E-...
Capacitance
EDIT VARS VIEW ALL NSOLV
  
```

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
-ε=π×ε0×εr/ACOSH(d/(2×ra))
-Coaxial Cable
-Sphere
Inductance and Magnetism
EQN VARS= PICT SI = HALT SOLVE
```

```
##### ELECTRICAL ENGINEERING #####
Resistive Circuits
Capacitance and Electric Fields
-Point Charge
-Long Charged Line
-Charged Disk
-Parallel Plates
-Parallel Wires
-ε=π×ε0×εr/ACOSH(d/(2×ra))
-Coaxial Cable
-Sphere
Inductance and Magnetism
EQN VARS= PICT SI = HALT SOLVE
```

```
##### c=π×ε0×εr/ACOSH(d/(2×ra)) #####
Eq: 'c1=π*CONST(ε0)*εr...'
c1: 0_F/m
εr: 1.0400
d: 1.5000_m
ra: 1_cm

Capacitance per unit length
EDIT VARS VIEW SOLVE
```

```
##### c=π×ε0×εr/ACOSH(d/(2×ra)) #####
Eq: 'c1=π*CONST(ε0)*εr...'
c1: 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=PL/(2*pi*E0*Er)*LN(rb/ra)
Er=V/(r*LN(rb/ra))
cl=2*pi*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=PL/(2*pi*E0*Er)*LN(rb/ra)
Er=V/(r*LN(rb/ra))
cl=2*pi*E0*Er*LN(rb/ra)
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

***** Coaxial Cable *****
PL: 3.67000000E-15_C/m
Er: 0_V/m
V: 0_V
ra: 0.30000000_cm
rb: 0.50000000_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 *****
PL: 3.67000000E-15_C/m
Er: 0.01047121_V/m
V: 0.00001605_V
ra: 0.30000000_cm
rb: 0.50000000_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...
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)
  Er=Q/(4*pi*E0*Er*r^2)
  C=4*pi*E0*Er*ra*rb/(rb-ra)
-EXPA VARS= PICT SI = HALT MSOLV
  
```

```

##### Choose Equations for MES #####
✓ V=Q/(4*pi*E0*Er)*(1/ra-1/rb)
  Er=Q/(4*pi*E0*Er*r^2)
✓ C=4*pi*E0*Er*ra*rb/(rb-ra)
#####
  ✓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
EDIT VARS VIEW ALL MSOLV
  
```

```

##### Sphere #####
v: 0.001043_V
Q: 1.450000E-14_C
c: 1.390813E-11_F
Er: 1.250000
rb: 2.500000_cm
ra: 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
  
```

```

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*π*...
B: 0_T
I: 1200.000000_A
r: 10_m

Magnetic field
EDIT VARS VIEW SOLVE
  
```

```

B=μ0*I/(2*π*r)
Eq: 'B=CONST(μ0)*I/(2*π*...
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=-μ0×Is/(2×π)×(ATAN((x+d/2)/y
    By=μ0×Is/(4×π)×LN((y^2+(x+d/2)^
  Parallel Wires
  Loop
  Coaxial Cable
  Skin Effect
-EXPAN VARS= PICT SI = HALT NSOLV

```

```

##### ELECTRICAL ENGINEERING #####
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Long Line
  Long Strip
    Starting Solver...
    Bx=-μ0×Is/(2×π)×(ATAN((x+d/2)/y
    By=μ0×Is/(4×π)×LN((y^2+(x+d/2)^
  Parallel Wires
  Loop
  Coaxial Cable
  Skin Effect
-EXPAN VARS= PICT SI = HALT NSOLV

```

```

##### Long Strip #####
Bx: 0_T
By: 0_T
I: 16025.000000_A/m
R: 2_m
R: 1_m
R: 2_cm
Magnetic field, x axis
EDIT VARS VIEW ALL NSOLV

```

```

##### Long Strip #####
Bx: -0.000026_T
By: 0.000013_T
I: 16025.000000_A/m
R: 2_m
R: 1_m
R: 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= $\mu_0 \times I / (2 \times \pi \times D)$ 
  F= $\mu_0 \times I_1 \times I_2 / (2 \times \pi \times D)$ 
  Bx= $\mu_0 \times (2 \times \pi) \times (I_1 / x - I_2 / (D-x))$ 
  L= $\mu_0 / (4 \times \pi) + \mu_0 / \pi \times \text{ACOSH}(D / (2 \times a))$ 
-Loop
-EXPANVAR= PICT SI = HALT NSOLV
  
```

```

Choose Equations for MES
B= $\mu_0 \times I / (2 \times \pi \times D)$ 
✓ F= $\mu_0 \times I_1 \times I_2 / (2 \times \pi \times D)$ 
✓ Bx= $\mu_0 \times (2 \times \pi) \times (I_1 / x - I_2 / (D-x))$ 
✓ L= $\mu_0 / (4 \times \pi) + \mu_0 / \pi \times \text{ACOSH}(D / (2 \times a))$ 
✓CHK CANCEL OK
  
```

```

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

Inductance per unit length
EDIT VARS VIEW ALL NSOLV
  
```

```

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

Inductance per unit length
EDIT VARS VIEW ALL NSOLV
  
```

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

```

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

VALU= EQNS PRINT EXIT
  
```

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..
✓ T12=μ0×g×SIN(θ)/(2×π)×I1×I2×..
#####
✓CHK CANCL OK
  
```

```

##### Loop #####
Eq: ( 'L12=CONST(μ0)*a...
L12: 0_H T12: 0_N*m
05_5_m 05_5_°
11_30_A 12_50_A
07_7_m 02_2_m

Mutual inductance
EDIT VARS VIEW ALL MSOLV
  
```

```

##### Loop #####
Eq: ( 'L12=CONST(μ0)*a...
L12: 0.000000... T12: 0.00019...
05_5_m 05_5_°
11_30_A 12_50_A
07_7_m 02_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= $\mu_0/(8*\pi)+\mu_0/(2*\pi)*\ln(rb/ra)$ 
-Skin Effect
Electron Motion
EQN VARS PICT SI HALT SOLVE
  
```

```

##### L= $\mu_0/(8*\pi)+\mu_0/(2*\pi)*\ln(rb/ra)$  #####
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 Line
-Long Strip
-Parallel Wires
-Loop
-Coaxial Cable
L= $\mu_0/(8*\pi)+\mu_0/(2*\pi)*\ln(rb/ra)$ 
-Skin Effect
Electron Motion
EQN VARS PICT SI HALT SOLVE
  
```

```

##### L= $\mu_0/(8*\pi)+\mu_0/(2*\pi)*\ln(rb/ra)$  #####
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 6.5E-6 $\Omega\cdot\text{cm}$. 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*u0*mu0)
|Reff=f*(pi*f*u0*u0*mu0)
-EXPAN VARS= PICT SI = HALT NSOLV
  
```

```

ELECTRICAL ENGINEERING
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
|Lon Starting Solver...
|Lon
|Par
|Loop
|Coaxial Cable
|Skin Effect
|s=1/sqrt(pi*f*u0*u0*mu0)
|Reff=f*(pi*f*u0*u0*mu0)
-EXPAN VARS= PICT SI = HALT NSOLV
  
```

```

Skin Effect
Eq: ( 'delta=1/sqrt(pi*f*CONST...
s: 0_m
Reff: 0_ohm
f: 100_MHz
mu0: 1.0200000000
mu: 0.0000065000_ohm*cm
Skin depth
EDIT VARS VIEW ALL NSOLV
  
```

```

Skin Effect
Eq: ( 'delta=1/sqrt(pi*f*CONST...
s: 0.0000127051_m
Reff: 0.0051160718_ohm
f: 100_MHz
mu0: 1.0200000000
mu: 0.0000065000_ohm*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=√(2*(q/He)*Va)
r=He*v/(q*B)
yd=L*Lv/(2*d*Va)*Vd
y=q*Vd/(2*He*d*v^2)*z^2
Thermionic Emission
Photoemission
-EXPA VARS PICT SI HALT NSOLV
  
```

```

Choose Equations for MES
v=√(2*(q/He)*Va)
r=He*v/(q*B)
yd=L*Lv/(2*d*Va)*Vd
y=q*Vd/(2*He*d*v^2)*z^2
-CHK -CANCL OK
  
```

```

Electron Beam Deflection
Eq: ( 'v=√(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 NSOLV
  
```

```

Electron Beam Deflection
Eq: ( 'v=√(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 NSOLV
  
```

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
```


5.4.3. Photoemission

Example:

A red light beam with a frequency of $1.4E14$ _Hz, is influencing an electron beam to overcome a barrier of 0.5 _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*mexu^2
|f0=q*d/h
Meters and Bridge Circuits
RL and RC Circuits
-EXPA VARS= PICT SI = HALT MSOLV
  
```

```

##### ELECTRICAL ENGINEERING #####
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Elec
|Ele Starting
|The Solver...
|The
|The
|The
|h*f=q*d+1/2*mexu^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
f0= 0.5000_V

Vertical velocity
EDIT VARS VIEW ALL MSOLV
  
```

```

##### Photoemission #####
Eq: ( 'CONST(h)*f=CONS...
f= 1.4000E14_Hz
v= 166694.7256_m/s
f0= 1.2090E14_Hz
f0= 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+Rad./2)
-Wheatstone Bridge
-Wien Bridge
EQN VARS PICT SI HALT SOLVE

```

```

ELECTRICAL ENGINEERING
Resistive Circuits
Capacitance and Electric Fields
Inductance and Magnetism
Elec
Mete
Starting
Solver...
-Rs
-Rse=(Vmax-Vsen)/Isen
-Isen=Vs/(Rs+Rh+Rad./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

```

```

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
✓CHK CANCL OK
  
```

```

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

```

Wheatstone Bridge
Eq: C 'Vm=GALV(Rx, R2, R...
Rx: 99_Ω R2: 100_Ω
R3: 1000._Ω R4: 1000._Ω
R5: 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
VALU= EQNS PRINT EXIT
  
```

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/(w^2*Rs*Rx)
R3/R1-Rs/Rx=1/(w^2*Rs*Rx*Cs^2)
f=1/(2*pi*Cs*Rs)
w=2*pi*f
-EXPAND VARS PICT SI HALT NSOLV
  
```

```

Choose Equations for MES
Cx/Cs=R3/R1-Rs/Rx
Cs*Cx=1/(w^2*Rs*Rx)
R3/R1-Rs/Rx=1/(w^2*Rs*Rx*Cs^2)
f=1/(2*pi*Cs*Rs)
w=2*pi*f
CHK CANCL OK
  
```

```

Wien Bridge
Eq: Cx/Cs=R3/R1-Rs/Rx
Cx: 0_μF R3: 100_Ω
R1: 100_Ω R2: 200_Ω
Rx: 0_Ω C3: 1.2_μF
w: 0_r/s F: 1_kHz
Unknown capacitor
EDIT VARS VIEW ALL NSOLV
  
```

```

Wien Bridge
Eq: Cx/Cs=R3/R1-Rs/Rx
Cx: 0.36652... R3: 100_Ω
R1: 100_Ω R2: 200_Ω
Rx: 287.952... C3: 1.20000...
w: 6283.185... F: 1_kHz
Unknown capacitor
EDIT VARS VIEW ALL NSOLV
  
```

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

```

Wien Bridge
w: 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_Ω each with a 0.22_μF capacitor and 470_Ω parallel resistance. Compute Lx and Rx.

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
-Maxwell Bridge
  -Lx=R2*R3*Cs
  -Rx=R2*R3/Rs
  -Q=ω*(Lx/Rx)
  -Q=ω*Cs*Rs
  -ω=2*π*f
-EXPA VARS= PICT= SI= HALT MSOLV
  
```

```

Choose Equations for MES
✓ Lx=R2*R3*Cs
✓ Rx=R2*R3/Rs
Q=ω*(Lx/Rx)
Q=ω*Cs*Rs
ω=2*π*f
✓CHK CANCL OK
  
```

```

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

Unknown inductance
EDIT VARS VIEW ALL MSOLV
  
```

```

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

VALU= EQNS PRINT EXIT
  
```

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
-UNSYN. RESISTIVE ATTENUATOR
  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
-UNSYN. RESISTIVE ATTENUATOR
  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 040 125_Ω
Rx: 0_Ω 030 2.25_μF
R1: 1000._Ω 040 1.25_μF
R2: 1000._Ω
Unknown inductance
EDIT VARS VIEW ALL MSOLV
  
```

```

Owen Bridge
Eq: ( 'Lx=C3*R1*R4' 'R...
Lx: .28125_H 040 125_Ω
Rx: 800_Ω 030 2.25_μF
R1: 1000._Ω 040 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
Ohm 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
Max
Max Solver...
Ohm
Ohm
SYN
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*Rp/(Rk+Rp)
  Rk=I(Rl*Rp^2/(Rl-Rp))
  DB=20*LOG(I((Rl-Rp)/Rp)+I(Rl/Rp)
-EXPA VARS= PICT= SI = HALT NSOLV
  
```

```

##### Choose Equations for MES #####
Rj=Rl-Rk*Rp/(Rk+Rp)
Rk=I(Rl*Rp^2/(Rl-Rp))
-DB=20*LOG(I((Rl-Rp)/Rp)+I(Rl/Rp)
#####
CHK CANCL OK
  
```

```

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

Attenuator loss
EDIT VARS VIEW   SOLVE
  
```

```

DB=20*LOG(I((Rl-Rp)/Rp)+I(Rl/Rp)
Eq: 'DB=20*LOG(I((Rl-Rp)/Rp)+I(Rl/Rp)
DB: 4.179752805
Rl: 125_Ω
Rp: 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
  τ=L/R
  uL=I0*R*e^(-t/τ)
  iL=I0*e^(-t/τ)
  W=1/2*L*I0^2*(1-e^(-2*t/τ))
-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
✓ uL=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' 'uL=I0*R...
L 400_mH    uL: 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' 'uL=I0*R...
L 400_mH    uL: 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 NSOLV

```

```

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 NSOLV

```

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

```

RL Natural Response
τ: 0.00320000_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
47_Ω W: 0_J
1.2_μF W0: 18_V
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...
47_Ω W: 1.887941...
1.2_μF W0: 18_V
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      I0: 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 I0: 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
-EXP VARS PICT SI HALT NSOLV

```

```

ELECTRICAL ENGINEERING
RL and RC Circuits
RL Natural Response
RC Natural Response
RL
RC
Starting Solver...
τ=
vC=
iC=(Vs-V0)/R*e^(-t/τ)
RL Series to Parallel
RC Series to Parallel
RLC Circuits
-EXP 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
- $\omega = 2\pi \times f$ 
- $Q_s = \omega L_s / R_s$ 
- $R_p = (R_s^2 + \omega^2 L_s^2) / R_s$ 
- $L_p = (R_s^2 + \omega^2 L_s^2) / (\omega^2 L_s)$ 
- $R_p = R_s \times (1 + Q_s^2)$ 
- $L_p = L_s \times (1 + 1/Q_s^2)$ 
- $Q_p = R_p / (\omega L_p)$ 
- $R_s = \omega^2 L_p^2 R_p / (R_p^2 + \omega^2 L_p^2)$ 
- $L_s = R_p^2 L_p / (R_p^2 + \omega^2 L_p^2)$ 
- $R_s = R_p / (1 + Q_p^2)$ 
- $L_s = Q_p^2 L_p / (1 + Q_p^2)$ 
  
```

```

Choose Equations for MES
✓  $\omega = 2\pi \times f$ 
✓  $Q_s = \omega L_s / R_s$ 
✓  $R_p = (R_s^2 + \omega^2 L_s^2) / R_s$ 
✓  $L_p = (R_s^2 + \omega^2 L_s^2) / (\omega^2 L_s)$ 
✓  $R_p = R_s \times (1 + Q_s^2)$ 
✓  $L_p = L_s \times (1 + 1/Q_s^2)$ 
  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)
  +
  [OK] [CANCL] [CHK]
  
```

```

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_μF and 150_kΩ at 120_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
RC Series to Parallel
w=2*pi*f
Qs=1/(w*Rs*Cp)
Rp=Rs*(1+1/(w^2*Rs^2*Cp^2))
Cp=Cp/(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=Cp/(1+1/Qs^2)
Rs=Rp/(1+Qp^2)
Cs=Cp*(1+Qp^2)/Qp^2
  
```

```

Choose Equations for MES
w=2*pi*f
Qs=1/(w*Rs*Cp)
Rp=Rs*(1+1/(w^2*Rs^2*Cp^2))
Cp=Cp/(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=Cp/(1+1/Qs^2)
  
```

```

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

Series resistance
EDIT VARS VIEW ALL MSOLV
  
```

```

RC Series to Parallel
Eq: C 'w=2*pi*f' 'Rp=Rs...'
w: 120_kHz Rs: 5.30873...
Cs: .000047... w: 753982.2...
Rp: 150_kΩ Cp: 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: 5.3087319364E-9_Ω
Cs: .000047_F

VALU= EQNS PRINT EXIT
  
```

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^2
-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
50_Ω X: 0_Ω
XL: 0_Ω 20_mH
XC: 0_Ω 47_μF
ω: 0_r/s 1000._Hz
Reactance
EDIT VARS VIEW ALL NSOLV
  
```

```

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

```

Series Impedance
m: 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 kΩ resistor, 67 μH and 0.01 μF. 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
-θ=ATAN(G/B)
-G=1/R
-B=BL+BC
-BL=-1/(ωL)
-BC=ωC
-ω=2πF
RLC Natural Response
-EXPA VARS= PICT SI = HALT NSOLV
  
```

```

ELECTRICAL ENGINEERING
RLC Circuits
Series Impedance
Parallel Admittance
-ABS(Ym)^2=G^2+B^2
-θ=ATAN(G/B)
-G=1/R
-B=BL+BC
-BL=-1/(ωL)
-BC=ωC
-ω=2πF
RLC Natural Response
-EXPA VARS= PICT SI = HALT NSOLV
  
```

```

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

```

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

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

```

Parallel Admittance
G: 0.000100000000_S
ω: 62831853.0718_r/s
BL: -0.00023754469_S
BC: 0.62831853072_S
B: 0.62808098603_S
Ym: 0.62808099399_S
θ: 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 NSOLV

```

```

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

```

```

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

```

```

RLC Natural Response
Eq: ( 's1r=RE(UVAL(-α)...
s1r: -212.76... s1i: 1,009.2...
s2r: -212.76... s2i: -1,009...
ω0: 1031.42... 20_mH
α: 212.7659... 50_Ω
47_μF
Characteristic Frequency
EDIT VARS VIEW ALL NSOLV

```

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_kΩ resistor, a 40_mH inductor and a 2_μF 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_μs 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=sqrt(1/(L*C))
-a=1/(2*R*C)
-wd=sqrt(w0^2-a^2)
-u=B1*e^(-a*t)*cos(wd*t)+B2*e^(-a*t)*sin(wd*t)
-B1=V0
-B2=-(a/wd)*(V0-2*I0*R)
-EXPA VARS PICT SI HALT NSOLV

```

```

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

```

```

Underdamped Transient
Eq: ( 'w0=sqrt(1/(L*C))' ...
L: 40_mH C: 2_μF w0: 0_r/s
v: 0_V t: 1_μs B1: 0_V
B2: 0_V a: 0_r/s wd: 0_r/s
V0: 2.5_V I0: 10_mA R: 1_kΩ

Classical radian frequency
EDIT VARS VIEW ALL NSOLV

```

```

Underdamped Transient
Eq: ( 'w0=sqrt(1/(L*C))' ...
L: 40_mH C: 2_μF w0: 3535...
v: 2.50... t: 1_μs B1: 2.5_V
B2: 1.24... a: 250... wd: 3526...
V0: 2.5_V I0: 10_mA R: 1_kΩ

Classical radian frequency
EDIT VARS VIEW ALL NSOLV

```

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
Critically-Damped Transient
α=1/(2*R*C)
ω0=1/(L*C)
v=D1*t*e^(-α*t)+D2*e^(-α*t)
D1=I0/C+α*V0
D2=V0
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

ELECTRICAL ENGINEERING
RLC Circuits
Series Impedance
Parallel Admittance
RLC Und
Starting Solver...
α=
ω0=1/(L*C)
v=D1*t*e^(-α*t)+D2*e^(-α*t)
D1=I0/C+α*V0
D2=V0
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

Critically-Damped Transient
Eq: ( 'α=1/(2*R*C)' 'ω0=
100_Ω ω0: 0_r/s 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 NSOLV
  
```

```

Critically-Damped Transient
Eq: ( 'α=1/(2*R*C)' 'ω0=
100_Ω ω0: 5000... 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 NSOLV
  
```

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

```

Critically-Damped Transient
α: 5000.000000_r/s
ω0: 5000.000000_r/s
D1: 5100.000000_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...
ω0=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... 40_mH α: 5000...
v: -0.0... 1_ms A1: -0.0...
A2: 5.01... 1_μF V0: 5_V
R: 10_Ω I0: 0_A s2: -997...
s1: -250...
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...
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=Zr*Im*SIN(w*t)*COS(θ)
VL=ZL*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 EQS 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(w*t)
ABS(Zm)^2=R^2+1/(w*C)^2
VR=Zm*Im*SIN(w*t)*COS(θ)
VC=Zm*Im*COS(w*t)*SIN(θ)
V=VR+VC
Vm=Im*Zm
θ=ATAN(-1/(w*C*R))
w=2*pi*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/(w*C*R))
w=2*pi*f
-EXPA VARS= PICT= SI= HALT NSOLV

```

```

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

```

```

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

```

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

```

RC Series Impedance
w: 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
|YH=1/ZH
|G=YH×COS(θy)
|B=YH×SIN(θy)
|ABS(YH)^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...
|YH
|G=YH×COS(θy)
|B=YH×SIN(θy)
|ABS(YH)^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      X: -475_Ω
θz: 0_r      ZH: 0_Ω
YH: 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      X: -475_Ω
θz: -1.3134... ZH: 491.172...
YH: 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_Ω and 75_Ω and reactive components 75_Ω and -145_Ω 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
-EXPA VARS PICT SI HALT NSOLV
  
```

```

ELECTRICAL ENGINEERING
Impedance ↔ Admittance
Two Impedances in Series
ABS(ZM)^2=R^2+X^2
θ=
R= Starting
X= Solver...
ABS(Z2M)^2=R2^2+X2^2
θ1=ATAN(X1/R1)
θ2=ATAN(X2/R2)
Two Impedances in Parallel
-EXPA 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 θ2: 75_Ω θ3: 100_Ω
θ4: 0_r θ5: -145... θ6: 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... θ2: 75_Ω θ3: 100_Ω
θ4: -1.0... θ5: -145... θ6: 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 EQS 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)
-EXPA 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)
-EXPA 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 θ2: 75_Ω θ3: 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: 108.0... X: -7.5... ZM: 108.0...
θ: -0.0... Z1M: 125... Z2M: 163...
θ1: 0.64... θ2: 75_Ω θ3: 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 EQS 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: 0_W Wp: 110_V
Ip: 0_A PT: 0_W
VL: 0_V IL: 25_A
0.1250_r
Power per phase
EDIT VARS VIEW ALL 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
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 Δ 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= $\sqrt{3}$ *Vp*Ip*cos( $\theta$ )
PT= $\sqrt{3}$ *VL*IL*cos( $\theta$ )
Power Measurements
Electrical Resonance
OpAmp Circuits
-EXPA VARS= PICT SI = HALT NSOLV
  
```

```

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

```

##### Balanced Wye Network #####
Eq: C '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
  
```

```

##### Balanced Wye Network #####
Eq: C 'VL= $\sqrt{3}$ *Vp' 'IL=I...
P: 2728.543... 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 3 Network
|Balanced Wye Network
|Power Measurements
|W1=VL*IL*COS(theta+pi/6)
|W2=VL*IL*COS(theta-pi/6)
|PT=sqrt(3)*VL*IL*COS(theta)
Electrical Resonance
OpAmp Circuits
Solid State Devices
Linear Amplifiers
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

ELECTRICAL ENGINEERING
Polyphase Circuits
|Balanced 3 Network
|Balanced Wye Network
|W1 Starting
|W2 Solver...
|PT
Electrical Resonance
OpAmp Circuits
Solid State Devices
Linear Amplifiers
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

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

Wattmeter 1
EDIT VARS VIEW ALL NSOLV
  
```

```

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

Wattmeter 1
EDIT VARS VIEW ALL NSOLV
  
```

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: 1000... ωc: 0_r/s ωl: 0_r/s
β: 0_r/s Q: 3.90... Q: 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: 1000... ωc: 1035... ωl: 1031...
β: 41.6... Q: 3.90... Q: 248...
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/b
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-omega^2)
w=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 (0+1)
w2 Solver... (0+1)
Q=
w0=j(w0^2-omega^2)
w=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: C 'Q=w0/b' 'w1=w0*...
b: 0_r/s w1: 0_r/s
w0: 0_r/s 1_kΩ
2.4000_μF w1: 0_r/s
omega: 0_r/s w0: 0_r/s
24.8069
Bandwidth
EDIT VARS VIEW ALL NSOLV
  
```

```

##### Parallel Resonance II #####
Eq: C 'Q=w0/b' 'w1=w0*...
b: 416.6667... w1: 10129.9...
w0: 10546.6... 1_kΩ
2.4000_μF w1: 10334.1...
omega: 208.3333... w0: 10336.2...
24.8069
Bandwidth
EDIT VARS VIEW ALL NSOLV
  
```

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

```

##### Parallel Resonance II #####
omega: 208.3333_r/s
w0: 10336.2083_r/s
b: 416.6667_r/s
w1: 10129.9743_r/s
w2: 10546.6410_r/s
wd: 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
-EXPAN VARS= PICT= SI= HALT NSOLV
  
```

```

##### ELECTRICAL ENGINEERING #####
Electrical Resonance
-Parallel Resonance I
-Parallel Resonance II
-Resonance in Lossy Inductor
-w0 Starting Solver...
-Yr
-Zr
-wm=f(f(1/(L*C))^2*(1+2*R/Rg)+C)
-Series Resonance
OpAMP Circuits
Solid State Devices
-EXPAN 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: 82214.714872_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*C))
Z=√(R^2+(w*L-1/(w*C))^2)
θ=ATAN((w*L-1/(w*C))/R)
w1=-R/(2*L)+√((R/(2*L))^2+1/(L*C))
w2=R/(2*L)+√((R/(2*L))^2+1/(L*C))
β=w2-w1
β=R/L
Q=w0*L/R
Q=1/R*√(L/C)
-EXPA VARS PICT SI HALT NSOLV
  
```

```

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

```

Series Resonance
Eq: ( 'w0=1/√(L*C)' 'Z...'
z: 0_Ω θ: 0_r w 1250...
w2: 0_r/s w1: 0_r/s β: 0_r/s
w0: 0_r/s θ: 0 25_Ω
69_μH 0.01...
Impedance
EDIT VARS VIEW ALL NSOLV
  
```

```

Series Resonance
Eq: ( 'w0=1/√(L*C)' 'Z...'
z: 791... θ: -1.5... w 1250...
w2: 1398... w1: 1036... β: 3623...
w0: 1203... θ: 3.32... 25_Ω
69_μH 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_Ω
θ: -1.539216_r
w1: 1036253.45047_r/s
w2: 1398572.29105_r/s
β: 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
-EXPAN 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
-EXPAN 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_kΩ and a feedback resistance of 20_kΩ.

Solution:

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

```

ELECTRICAL ENGINEERING
OpAmp Circuits
- Basic Inverter
- Non-Inverting Amplifier
- Current Amplifier
- Transconductance Amplifier
- Level Detector (Inverting)
- Level Detector (Non-Inverting)
-EXPAN 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 CANCL 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_MΩ and a resistance to the load of 18_kΩ .

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
  
```

```

##### 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: C 'Av=1+Rf/R1' 'Rp...'
Av: 0
Rp: 0_Ω
R1: 18_kΩ
Rf: 1_MΩ

Voltage gain
EDIT VARS VIEW ALL NSOLV
  
```

```

##### Non-Inverting Amplifier #####
Eq: C '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_kΩ feedback resistance has a voltage gain of 42. If the source resistance is 1_kΩ, the load resistance is 10_kΩ and the output resistance of the OpAmp is 100_Ω.

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: 10_kΩ
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
```

```
##### ELECTRICAL ENGINEERING #####
OpAMP Circuits
- Basic Inverter
- Non-Inverting Amplifier
- Cur
- Starting Solver...
  -  $R_s$ 
  -  $R_o$ 
- 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
```

```
##### 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
OpAmp Comparator (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
Tra
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
  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: C '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: C '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 CANCL OK
  
```

```

Differentiator
Eq: C '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: C '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
  
```


5.12. 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 (Depletio
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: $1.45 \times 10^{10} / \text{cm}^3$)

```

ELECTRICAL ENGINEERING
Solid State Devices
Semiconductor Basics
Pn=1/(q*un*nd)
Pp=1/(q*up*no)
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))*e^(-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*no)
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))*e^(-x^2/(4*D*t))
-EXPA VARS PICT SI HALT HSOLV
  
```

```

Semiconductor Basics
Eq: ( 'EF=Ei+CONST(k)*...
EF: 0_eV      Nd: 8.E-17_...
ni: 1450000... Ei: 0_eV
Ec: 1.12_eV   E0: 0_J
T: 300_K      Wp: .85
mns: .5
Fermi level
EDIT VARS VIEW ALL MSOLV

```

```

Semiconductor Basics
Eq: ( 'EF=Ei+CONST(k)*...
EF: -.99278... Nd: 8.E-17_...
ni: 1450000... Ei: .570288...
Ec: 1.12_eV   E0: 0_J
T: 300_K      Wp: .85
mns: .5
Fermi level
EDIT VARS VIEW ALL MSOLV

```

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)
ni=1450000
n=no*(A*(n*D*t)) * exp(-x^2/(4*D*t))
EQN VARS PICT SI HALT SOLVE

```

```

ELECTRICAL ENGINEERING
Solid State Devices
Semiconductor Basics
Pn=1/(q*un*Nd)
Pp
Dn
Dp
Ei
EF=Ei+k*T*Ln(Nd/ni)
Ei=(Ec+Ev)/2+3/4*(k*T)*Ln(hp/hn)
ni=1450000
n=no*(A*(n*D*t)) * exp(-x^2/(4*D*t))
EQN VARS PICT SI HALT SOLVE

```

```

n=no*ERFC(x/(2*sqrt(D*t)))
Eq: 'UVAL(UBASE(N))=UV...
n: 8.E17_1/cm^3
no: 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

```

```

n=no*ERFC(x/(2*sqrt(D*t)))
Eq: 'UVAL(UBASE(N))=UV...
n: 8.E17_1/cm^3
no: 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 ni.

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 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*E0*ABS(Vbi-Va)/q*Na)
xp=(Nd/Na)*xn
xd=xn+xp
Cj=Es*E0*Aj/xd
Vbi=2*k*T/q*Ln(a*LGJ*xd/(2*ni))
xd=(12*Es*E0/(q*a*LGJ))*ABS(Vbi-V
PN Junction Currents
-EXPA 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(a*LGJ*xd/(2*ni))
xd=(12*Es*E0/(q*a*LGJ))*ABS(Vb..
CHK CANCL OK
  
```

```

PN Junctions
Eq: ( 'Vbi=CONST(k)*T/...
T: 300_K na: 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 a: 100... xd: 0_m
Depletion layer width
EDIT VARS VIEW ALL NSOLV
  
```

```

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

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 V and an applied voltage of -5 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(Vb..
PN Junction Currents
-EXPA 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 CANCEL OK
```

```
##### PN Junctions #####
Eq: ( 'Cj=es*CONST(e0)...
Cj: 0_F A: 100_μ^2
xd: 0.31800... E: 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... E: 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 $100\text{ }\mu\text{m}^2$, an applied voltage of 0.5 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 $25\text{ }\mu\text{m}$ and $15\text{ }\mu\text{m}$. The minority carrier densities are $5 \times 10^{16}\text{ cm}^{-3}$ (electrons) and 25 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*V0/(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*V0/
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*np0+Dp/Lp*pn0)..
I=I0*(e^(q*V0/(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*..
Go=q/(k*T)*(I+I0)
ts=tp*LH(1+IF/Ir)
ERF(I/(ts/tp))=1/(1+Ir/IF)
CHK CANCL 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
V0: .5_V T: 300_K

Junction current
EDIT VARS VIEW ALL NSOLV
  
```

```

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...
V0: 0.50... T: 300_K

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
  
```

```

ELECTRICAL ENGINEERING
Semiconductor Basics
PN Junctions
PN Junction Currents
I=q*Aj*(Dn/Ln*np0+Dp/Lp*pn0)*(e
I=I0*(e^(q*Va/(k*T))-1)
I0=q*Aj*(Dn/Ln*np0+Dp/Lp*pn0)
IR0=-q*Aj*ni*xd/(2*to)
IR0=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*np0+Dp/Lp*pn0)..
I=I0*(e^(q*Va/(k*T))-1)
I0=q*Aj*(Dn/Ln*np0+Dp/Lp*pn0)
IR0=-q*Aj*ni*xd/(2*to)
IR0=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 CANCL OK

```

```

ELECTRICAL ENGINEERING
Semiconductor Basics
PN Junctions
PN Junction Currents
Starting Solver...
I=
I=
I0=
IR=
IR0=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 Val: 0.50... T: 300_K
I0: 0_A An: 100... Dn: 35_c...
Ln: 25_μ nnp0: 500... Dp: 10_c...
Lp: 15_μ pnp0: 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... Val: 0.50... T: 300_K
I0: 1.12... An: 100... Dn: 35_c...
Ln: 25_μ nnp0: 500... Dp: 10_c...
Lp: 15_μ pnp0: 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: α 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 β , 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=IC/IE
  beta=alpha/(1-alpha)
  IE=IB+IC
  IC=alpha*IE+ICBO
  IC=alpha/(1-alpha)*IB+ICBO/(1-alpha)
  IC=beta*IB+ICEO
  ICEO=ICBO*(beta+1)
-EXPA VARS= PICT SI = HALT NSOLV
  
```

```

Choose Equations for MES
alpha=IC/IE
beta=alpha/(1-alpha)
IE=IB+IC
IC=alpha*IE+ICBO
IC=alpha/(1-alpha)*IB+ICBO/(1-alpha)
ICEO=ICBO*(beta+1)
  
```

```

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

CE current gain
EDIT VARS VIEW ALL NSOLV
  
```

```

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

CE current gain
EDIT VARS VIEW ALL NSOLV
  
```

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 α 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 β .

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)*Ic0
ICE0=ICB0*(bf+1)
ICE0=Ic0*(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)*Ic0
ICE0=ICB0*(bf+1)
+
✓CHK CANCL OK
  
```

```

Ebers-Moll Equations
Eq: ( 'IC=of*If-Ir' 'I...
IC: 10.8_mA IB: 0_A
Ir: 0_A bf: 0
br: 0 of: .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... of: .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: .11111111111111
Is: .01225_A
VALU= EQNS PRINT EXIT
  
```

5.12.6. Ideal Currents - pnp

Example:

Find the emitter current gain α 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 cm^{-3} and the base density is 500000 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)/kT)
IC=q*A1*DB*pB/WB*(e^(q*VBE)/kT)
IB=q*A1*DE/LE*nE*(e^(q*VBE)/kT)
alpha=(DB*pB/WB)/(DB*pB/WB+DE*nE/LE)
END VARS=PICT SI HALT SOLVE
  
```

```

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

```

alpha=(DB*pB/WB)/(DB*pB/WB+DE*nE/LE)
Eq: 'alpha=DB*pB/WB/(DB*pB/WB+DE*nE/LE)
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/WB+DE*nE/LE)
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
  
```

```

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

CB current gain
OK
  
```

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 α '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
Icsat=ICsat*rt
ICsat=VCC/RL
tr=rtB*Ln(1/(1-(ICsat*rt)/(IB*rtB)))
tsd1=rtB*Ln(1/(1-(ICsat*rt)/(IB*rtB)))
tsd2=rtB*Ln(2*IB*rtB/(ICsat*rt*(1-af)))
VCEsat=k*T/q*Ln(1+(1+IC/IB*(1-af)))
EQN VARS= PICT SI = HALT SOLVE
  
```

```

VCEsat=k*T/q*Ln(1+(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+(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
OK
  
```

```

ELECTRICAL ENGINEERING
PN Junction Currents
Transistor Currents
Ebers-Moll Equations
Ideal Currents - pnp
Switching Transients
Icsat=ICsat*rt
ICsat=VCC/RL
tr=rtB*Ln(1/(1-(ICsat*rt)/(IB*rtB)))
tsd1=rtB*Ln(1/(1-(ICsat*rt)/(IB*rtB)))
tsd2=rtB*Ln(2*IB*rtB/(ICsat*rt*(1-af)))
VCEsat=k*T/q*Ln(1+(1+IC/IB*(1-af)))
EQN VARS= PICT SI = HALT SOLVE
  
```

```

VCEsat=k*T/q*Ln(1+(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 V bias is applied to the substrate which has a Fermi potential of 0.35 V . Assume the relative permittivity of silicon and silicon dioxide is 11.8 and 3.9, respectively, and the work function is 0.2 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=√(2*es*E0*(2*PF)/(q*Ng))
Qb0=-√(2*q*Ng*es*E0*ABS(2*PF))
Qb=-√(2*q*Ng*es*E0*ABS(-2*PF+Vb))
Cox=Es*E0/tox
γ=1/Cox*√(2*q*Ng*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=√(2*es*E0*(2*PF)/(q*Ng))
✓ Qb0=-√(2*q*Ng*es*E0*ABS(2*PF..
✓ Qb=-√(2*q*Ng*es*E0*ABS(-2*PF..
✓ Cox=Es*E0/tox
✓ γ=1/Cox*√(2*q*Ng*es*E0)
✓ VT0=PGC-2*PF-Qb0/Cox-Qox/Cox
  
```

```

MOS Transistor I
Eq: ( 'xd=√(2*es*CONST...
xd: 0_μ eb: 0_C/...Vb: -5_V
Es: 3.9 tox: .01... γ: 0_V^...
Ng: 5.E1...Es: 11.8 VT0: 0_V
PGC: .2_V PF: .35_Veb0: 0_C...
Qox: .00... Cox: 0_F...
Oxide capacitance per unit
EDIT VARS VIEW ALL NSOLV
  
```

```

MOS Transistor I
Eq: ( 'xd=√(2*es*CONST...
xd: .427... eb: -9.7...Vb: -5_V
Es: 3.9 tox: .01... γ: .118...
Ng: 5.E1...Es: 11.8 VT0: -.4...
PGC: .2_V PF: .35_Veb0: -3...
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 V . The bias factor is $1.1\text{ V}^{1/2}$. The drain and gate voltages are 5 V and the substrate bias voltage is -5 V . Assuming that λ is 0.05 1/V and Φ_F is 0.35 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*M/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*M*L)
gd=kn*(VGS-VT)
-EXPA VARS PICT SI HALT NSOLV
  
```

```

Box: 3.9   tox: .01... kn1: 0_A...
ID: 0_A   lambda: .05... ID: 0_A
VGS: 5_V   VTO: .75... PF: 1.1...
VSB: -5_V  BFA: .35_V Ttr: 0_s
mu: 500... fmax: 0... gm: 0_S
Cox: 0_F... M: 6_mu   L: 1.25...
gd: 0_S   kn: 0_A/... VGS: 5_V
VT: 0_V
EDIT VARS VIEW ALL NSOLV
  
```

```

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

```

Box: 3.9   tox: .01... kn1: 1.7...
ID: 3.3... lambda: .05... ID: 1.82...
VGS: 5_V   VTO: .75... PF: 1.1...
VSB: -5_V  BFA: .35_V Ttr: 1.6...
mu: 500... fmax: 12... gm: 2.10...
Cox: 3.4... M: 6_mu   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 NSOLV
  
```

```

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 NSOLV
  
```

```

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 NSOLV
  
```

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

```



```

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...  Wn= 3.10...  CF= 0.35...
VIH= 2.5...  VDD= 5_V  VTL= 1.3...
KR= 3  VTDD= 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.
VOH: 3.6281229487_V
VTL: 1.30634942122_V
VIH: 2.59682528939_V
VALU= EQNS PRINT EXIT

```

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

5.12.13. CMOS Transistor Pair

Example:

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

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

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

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

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)
MOS 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)/C1
  kN/2*(Vin-VTN)^2=kP/2*(VDD-Vin-
Junction FET
-EXPA VARS= PICT= SI= HALT 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)/C1
  kN/2*(Vin-VTN)^2=kP/2*(VDD-Vin-
  [X] CHK [ ] CANCL [ ] OK
  
```

```

mu_p: 200_cm^...  kN: 10_μ
LP: 2_μ           WN: 1250._c...
Cox: 34530._...  HN: 4_μ
LN: 2_μ          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
  
```

```

Solving for kP
kP: .00003453_A/V^2
Zero
EDIT VARS VIEW [ ] ALL MSOLV
  
```

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

```

mu_p: 200_cm^...  kN: 10_μ
LP: 2_μ           WN: 1250._c...
Cox: 34530._...  HN: 4_μ
LN: 2_μ          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
  
```

```

CMOS Transistor Pair
kP: .00003453_A/V^2
kN: .000086325_A/V^2
Vo: 1.85714285714_V
VIL: 1.48979591837_V
VALU= EQNS PRINT [ ] EXIT
  
```

5.12.14. Junction FET

Example:

Find the saturation current when the drain current at zero bias is $12.5\ \mu\text{A}$, the gate voltage is $5\ \text{V}$ and the pinch off voltage is $12\ \text{V}$. The channel width is $3\ \mu\text{m}$, 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 $0.85\ \text{V}$ and the gate voltage is $-8\ \text{V}$

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/
-
-ID=ID0*(1-VG/Vp)^2
-VDSat=VG-Vp
-IDsat=ID0*(1-VG/Vp)^2
EQN VARS= PICT= SI= HALT 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/
-
-ID=ID0*(1-VG/Vp)^2
-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
  
```

```

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
-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 α₀ is 0.93, find β₀ 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)
β0=α0/(1-α0)
Rin=re+rb/β0
Ro=rc
Ai=α0
Av=α0*β0/(re+rb/β0)
Aov=(α0*rc)*(Rin/(Rin+Rs))/(re+rb/β0)
-BJT (Common Emitter)
-BJT (Common Collector)
-FET (Common Gate)
-EXPA VARS PICT SI HALT MSOLV

```

```

ELECTRICAL ENGINEERING
Linear Amplifiers
-BJT (Common Base)
β0=α0/(1-α0)
Rin
Ro Starting Solver...
Ai
Av
Aov=(α0*rc)*(Rin/(Rin+Rs))/(re+rb/β0)
-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 α0: 0.93
rc: 1_MΩ Rin: 0_Ω
Rs: 50_Ω re: 35_Ω
rb: 1.2_kΩ β0: 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: 1000000.0 Ai: .93
Av: 74.2084... Ri: 10_kΩ
Aov: 5304.50... Ai: .93
r0: 1_MΩ Rin: 125.322...
R3: 50_Ω r3: 35_Ω
r0: 1.2_kΩ β0: 13.2857...
Output resistance
EDIT VARS VIEW ALL MSOLV

```

```

BJT (Common Base)
β0: 13.2857142857
Rin: 125.322580645_Ω
Ro: 1000000.0_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 α_0 is 0.93, find β_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)
  beta0=alpha0/(1-alpha0)
  Rin=rb+beta0*re
  Ro=rc
  Ai=-beta0
  Av=-beta0*RL/(beta0*re+rb)
  Aou=-beta0*RL/(Rs+Rin)
BJT (Common Collector)
FET (Common Gate)
-EXPAN VARS PICT SI HALT NSOLV
  
```

```

ELECTRICAL ENGINEERING
Linear Amplifiers
BJT (Common Base)
BJT (Common Emitter)
  beta0
  Ri
  Ro
  Ai
  Av=-beta0*RL/(beta0*re+rb)
  Aou=-beta0*RL/(Rs+Rin)
BJT (Common Collector)
FET (Common Gate)
-EXPAN VARS PICT SI HALT NSOLV
  
```

```

BJT (Common Emitter)
alpha0: .93      Ro: 1_MΩ
rc: 1_MΩ        Ai: 0
Av: 0           re: 35_Ω
rb: 1.2_kΩ      Aou: 0
beta0: 0        RL: 1_kΩ
Rs: 50_Ω       Rin: 0_Ω

Input resistance
EDIT VARS VIEW ALL NSOLV
  
```

```

Solving for Rin
Rin: 1665._Ω
Zero

EDIT VARS VIEW ALL NSOLV
  
```

```

BJT (Common Emitter)
alpha0: .93      Ro: 1_MΩ
rc: 1_MΩ        Ai: -13.285...
Av: -7.9794...  re: 35_Ω
rb: 1.2_kΩ      Aou: -7.7467...
beta0: 13.2857... RL: 1_kΩ
Rs: 50_Ω       Rin: 1665._Ω

Input resistance
EDIT VARS VIEW ALL NSOLV
  
```

```

BJT (Common Emitter)
beta0: 13.2857142857
Rin: 1665._Ω
Ai: -13.2857142857
Av: -7.9794079794
Aou: -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 α_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)
  β0=α0/(1-α0)
  Rin=rb+β0*re+(β0+1)*Rl
  Ro=re+(Rs+rb)/β0
  Ai=rc/(rc*(1-α0)+Rl+re)
  Au=α0*Rl/(re+Rl)
  Aou=(β0+1)*Rl/(Rs+Rin+(β0+1)*Rl)
FET (Common Gate)
-EXPA VARS= PICT SI = HALT NSOLV
  
```

```

ELECTRICAL ENGINEERING
Linear Amplifiers
BJT (Common Base)
BJT (Common Emitter)
BJT (Common Collector)
  β0
  Rin
  Ro
  Ai=rc/(rc*(1-α0)+Rl+re)
  Au=α0*Rl/(re+Rl)
  Aou=(β0+1)*Rl/(Rs+Rin+(β0+1)*Rl)
FET (Common Gate)
-EXPA VARS= PICT SI = HALT NSOLV
  
```

```

BJT (Common Collector)
Ro: 0_Ω      β0: 1000._kΩ
Ai: 0        rc: 100000...
Av: 0        α0: .99
rc: 25_Ω     Aou: 0
Rs: 25_Ω     Rin: 0_Ω
β0: 0        RL: 100_Ω
Output resistance
EDIT VARS VIEW ALL NSOLV
  
```

```

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

```

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

```

BJT (Common Collector)
β0: 99.00000000
Rin: 1012475.00000_Ω
Ro: 10126.2626263_Ω
Ai: 99.99998750
Av: 0.792000000
Aou: 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_kΩ. The external gate resistance is 1_MΩ and the drain resistance is 125_kΩ. The transconductance is 1.6 x 10⁻³_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 Drain)
-μ=gm*rd
-Rin=(Rl+rd)/(μ+1)
-Av=(μ+1)*Rl/(rd+Rl)
-Ro=rd+(μ+1)*RG
-FET (Common Source)
-FET (Common Drain)
-EXPA VARS= PICT SI = HALT NSOLV
  
```

```

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

```

FET (Common Gate)
Eq: ( 'μ=gm*rd' 'Rin=(Rl+rd)/(μ+1)'
-μ: 0.0016_S Rin: 0_Ω
Av: 0 RL: 10_kΩ
Ro: 0_Ω RD: 125_kΩ
μ: 0 RG: 1_MΩ

Input resistance
EDIT VARS VIEW ALL NSOLV
  
```

```

Starting Solver...
Solving for Rin
Rin: 671.641791045_Ω
Zero
EDIT VARS VIEW ALL NSOLV
  
```

```

FET (Common Gate)
Eq: ( 'μ=gm*rd' 'Rin=(Rl+rd)/(μ+1)'
-μ: 0.0016_S Rin: 671.641791045_Ω
Av: 14.8888888888889 RL: 10_kΩ
Ro: 201125000_Ω RD: 125_kΩ
μ: 200 RG: 1_MΩ

Input resistance
EDIT VARS VIEW ALL NSOLV
  
```

```

FET (Common Gate)
μ: 200
Rin: 671.641791045_Ω
Av: 14.8888888888889
Ro: 201125000_Ω
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 2.5×10^{-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)
  - $\mu = g_m \times r_d$ 
  - $R_{in} = (R_L + r_d) / (\mu + 1)$ 
  - $A_v = -g_m \times (r_d \times R_L / (r_d + R_L))$ 
  - $R_o = r_d$ 
-FET (Common Drain)
-EXPA VARS= PICT SI = HALT MSOLV
  
```

```

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

```

FET (Common Source)
Eq: ( ' $\mu = g_m \times r_d$ ' ' $R_{in} = (...$ '
Rin: 0_Ω  $\mu$ : 0
Av: 0  $R_{in}$ : .0025_S
RL: 100_kΩ Ro: 0_Ω
rd: 18_kΩ

Input resistance
EDIT VARS VIEW ALL MSOLV
  
```

```

Solving for Av
Av: -38.1355932202
Zero

EDIT VARS VIEW ALL MSOLV
  
```

```

FET (Common Source)
Eq: ( ' $\mu = g_m \times r_d$ ' ' $R_{in} = (...$ '
Rin: 2565.21_Ω  $\mu$ : 45
Av: -38.135...  $R_{in}$ : .0025_S
RL: 100_kΩ Ro: 18000._Ω
rd: 18_kΩ

Input resistance
EDIT VARS VIEW ALL MSOLV
  
```

```

FET (Common Source)
 $\mu$ : 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 5×10^{-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)
-EXPA VARS= PICT SI = HALT 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)
-EXPA VARS= PICT SI = HALT NSOLV
  
```

```

FET (Common Drain)
Eq: ( 'μ=gm*rd' 'Rin=(...
μ: .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
  
```

```

Starting Solver...
Solving for Av
Av: .990099009901
Zero
EDIT VARS VIEW ALL NSOLV
  
```

```

FET (Common Drain)
Eq: ( 'μ=gm*rd' 'Rin=(...
μ: .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
  
```

```

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 β_0 value of 100 are connected to a load of 10_k Ω . The emitter, base and source resistances are 25_ Ω , 1500_k Ω and 1_k Ω , respectively. The external base resistance is 27_k Ω .

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= $\beta_0 \times (r_e + \beta_0 \times (r_e + R_L))$ 
  Ro= $r_e + (\beta_0 \times (r_e + r_b) + R_s) / \beta_0^2$ 
  Ai= $\beta_0^2 \times R_{BA} / (R_{BA} + \beta_0 \times (R_L + r_e))$ 
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

***** 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= $\beta_0 \times (r_e + \beta_0 \times (r_e + R_L))$ 
  Ro= $r_e + (\beta_0 \times (r_e + r_b) + R_s) / \beta_0^2$ 
  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= $\beta_0 \times (r_e + \beta_0 \times (r_e + R_L))$ 
Rin: 0_ $\Omega$  Ro: 0_ $\Omega$ 
Rb: 1500._k $\Omega$  R3: 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
  
```

```

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

```

***** Darlington (CC-CC) *****
Eq: ( 'Rin= $\beta_0 \times (r_e + \beta_0 \times (r_e + R_L))$ 
Rin: 1002525... Ro: 15025.3...
Rb: 1500._k $\Omega$  R3: 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
  
```

```

***** 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 Ω , 25_ Ω , and 10_k Ω , respectively. The configuration has a value of β_0 equal to 100. The source and collector resistances are 1_k Ω and 100_k Ω . 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=rc/ $\beta_0$ 
  Av=-Rl/rexre/(re+Rs/ $\beta_0$ ^2)
-Emitter-Coupled Amplifier
-Differential Amplifier
-Source-Coupled JFET Pair
-EXPA VARS PICT SI HALT NSOLV
  
```

```

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

```

Darlington (CC-CE)
Eq: ( 'Rin=rb+ $\beta_0$ *re' ' ...
Rin: 0_ $\Omega$  rb: 1.5_k $\Omega$ 
Ro: 0_ $\Omega$  rc: 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 NSOLV
  
```

```

Starting Solver...
Solving for Ro
Ro: 1000._ $\Omega$ 
Zero
EDIT VARS VIEW ALL NSOLV
  
```

```

Darlington (CC-CE)
Eq: ( 'Rin=rb+ $\beta_0$ *re' ' ...
Rin: 4000._ $\Omega$  rb: 1.5_k $\Omega$ 
Ro: 1000._ $\Omega$  rc: 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 NSOLV
  
```

```

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
β0=α0/(1-α0)
Ro=re+(β0*(re+rb)+Rs)/β0^2
Av=Rl/re*(β0*re/(2*β0*re+Rl))
Ai=-α0*β0
Rin=β0*re+rb
Ro=rc
Differential Amplifier
Source-Coupled JFET Pair
-EXPA VARS PICT SI HALT NSOLV

```

```

ELECTRICAL ENGINEERING
Darlington (CC-CC)
Darlington (CC-CE)
Emitter-Coupled Amplifier
β0
Ro Starting Solver...
Av
Ai
Rin=β0*re+rb
Ro=rc
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
α0: .98 Rin: 0_Ω
β0: 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
α0: .98 Rin: 3225._Ω
β0: 49 Re: 25_Ω
rb: 2_kΩ Ro: 56000._Ω
rc: 56_kΩ
Current gain, CB
EDIT VARS VIEW ALL NSOLV

```

```

Emitter-Coupled Amplifier
β0: 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 Ω and 10_k Ω respectively. If the emitter resistance is 25_ Ω and the base resistance is 2_k Ω , 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*RCA
-Ac=-alpha*RCA/(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 NSOLV
  
```

```

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

```

Differential Amplifier
Ad: 0 AD .005_S
Ac: 0 AC .98
RCA: 18_kΩ Rid: 0_Ω
rb: 2_kΩ re: 25_Ω
Ric: 0_Ω beta: 49
REA: 10_kΩ
Differential mode gain
EDIT VARS VIEW ALL NSOLV
  
```

```

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

```

Differential Amplifier
Ad: -45 AD .005_S
Ac: -.88089... AC .98
RCA: 18_kΩ Rid: 6450._Ω
rb: 2_kΩ re: 25_Ω
Ric: 490000... beta: 49
REA: 10_kΩ
Differential mode gain
EDIT VARS VIEW ALL NSOLV
  
```

```

Differential Amplifier
Ad: -45.
Ac: -.880898876404
Rid: 6450._Ω
Ric: 490000._Ω
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 Ω , and the source resistance is 100_ Ω . The drain resistance is 12_k Ω and the transconductance is 6.8 x 10⁻³_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=-mu*RDA/((mu+1)*2*Rs+rd+RDA)
mu=gm*rd
CMRR=gm*Rs
Class A, B, and C Amplifiers
Transformers
-EXPA VARS= PICT= SI= HALT NSOLV
  
```

```

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

```

Source-Coupled JFET Pair
Eq: ( 'Ad=-1/2*gm*(rd*...
Ad: 0 Ac: 0
RDA: 25_kOhm mu: 0
rd: 12_kOhm CMRR: 0
gm: .0068_S R3: 100_ohm

Differential mode gain
EDIT VARS VIEW ALL NSOLV
  
```

```

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

```

Source-Coupled JFET Pair
Eq: ( 'Ad=-1/2*gm*(rd*...
Ad: -27.567... Ac: -38.116...
RDA: 25_kOhm mu: 81.6
rd: 12_kOhm CMRR: .68
gm: .0068_S R3: 100_ohm

Differential mode gain
EDIT VARS VIEW ALL NSOLV
  
```

```

Source-Coupled JFET Pair
Ad: -27.5675675675
mu: 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
  
```

```

ELECTRICAL ENGINEERING
Class A, B, and C Amplifiers
-Class A Amplifier
-R=n^2*Rl
-IC
-Imax
-Pd
-PP
-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
  
```

```

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

```

R= 50_Ω      ΔVCE= 10_V
Imax= 110_mA  VCC= 15_V
IQ= 60_mA    VCEmax= 12_V
VCEmin= 6_V   VPP= 12_V
n= 2         PP= 6_V
IQ= 50_mA    R= 200_Ω
η= 6.94444... Po= .0625_W
Pdc= .9_W

```

EDIT VARS VIEW ALL NSOLV

```

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
- Choose 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×θTj)
Push-Pull Principle
- Class B Amplifier
-EXPAN VARS PICT SI HALT NSOLV
  
```

```

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×θTj)
  ✓CHK CANCL 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 NSOLV
  
```

```

Solving for Tj
Tj: 422.038888889_K
Zero
EDIT VARS VIEW ALL NSOLV
  
```

```

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 NSOLV
  
```

```

Power Transistor
Tj: 422.03888889_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 Solver...
- Pus
  | 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: 8.515625_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)
-Vi=gm*R*(VH/(2*√2))/(1+h0E*R/2)
-IC=gm*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)
  Vi=gm*R*(VH/(2*√2))/(1+h0E*R/2)
  IC=gm*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
Pdc: 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...
Pdc: 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*Rc/(I^2*(Rc+R0))
V0=V0^2/(Q*Po)
XL=Xc*Q^2/(Q^2+1)
XC1=-R1/Q
XL=1/Q*(R1+J(R1*R2))
XC2=-R2/Q
Transformers
Motors and Generators
EQN VARS= PICT SI = HALT SOLVE
  
```

```

ELECTRICAL ENGINEERING
Push-Pull Principle
Class B Amplifier
Class C Amplifier
Starting Solver...
XL=1/Q*(R1+J(R1*R2))
XC2=-R2/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 Ampl
Transformers
Ideal Transformer
Linear Equivalent Circ
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*N1=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...
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: C '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: C 'V1/V2=N1/N2' 'I...
V1 110_V      I1 500_mA
v2 396_V      I2 .138888...
zin 13.5030... N1 10
N2 36         RL 175_Ω

Secondary voltage
EDIT VARS VIEW ALL MSOLV

```

```

Ideal Transformer
V2: 396_V
I2: .1388888888889_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_Ω and 5_Ω, 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_Ω and 2.5_Ω. The secondary side is loaded with an impedance of 12.5_kΩ. The reactive part of load is 10_Ω. 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+Rl)
Xin=X1+(N1/N2)^2*(X2+Xl)
Motors and Generators
-EXPA VARS= PICT SI = HALT MSOLV
  
```

```

ELECTRICAL ENGINEERING
Solid State Devices
Linear Amplifiers
Class A, B, and C Amplifiers
Transformers
Ideal Transformer
Starting Solver...
I1=I2*N2/N1
Rin=R1+(N1/N2)^2*(R2+Rl)
Xin=X1+(N1/N2)^2*(X2+Xl)
Motors and Generators
-EXPA VARS= PICT SI = HALT MSOLV
  
```

```

V1: 110_V      V2: 0_V
I1: 500_mA     I2: 0_A
Rin: 0_Ω       RL: 18_Ω
R2: 5_Ω        RL: 12.5_kΩ
Xin: 0_Ω       XL: 6_Ω
N1: 10         N2: 36
R2: 2.5_Ω      RL: 10_Ω
Secondary voltage
EDIT VARS VIEW ALL MSOLV
  
```

```

Solving for I2
I2: .138888888889_A
Zero
EDIT VARS VIEW ALL MSOLV
  
```

```

V1: 110_V      V2: 396_V
I1: 500_mA     I2: .138888...
Rin: 982.891... RL: 18_Ω
R2: 5_Ω        RL: 12.5_kΩ
Xin: 6.96450... XL: 6_Ω
N1: 10         N2: 36
R2: 2.5_Ω      RL: 10_Ω
Secondary voltage
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_cm² 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*I*B*L*A
- MF=1/2*Rel*I*d^2
- F=1/2*B^2/μ0
- Es=Ns*ω*d/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*I*B*L*A
- MF
- 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        ω: 62_r/s
φ: 0_Wb
Flux
EDIT VARS VIEW ALL NSOLV

```

```

Solving for Es
Es: 12.7172630362_V
Zero
EDIT VARS VIEW ALL NSOLV

```

```

Energy Conversion
R0 2.8_A/m      L0 15_cm
R1 .5_cm^2      Wf .000018...
R2 .46_A/Wb    F 1289155.0...
R3 1.8_T        Es 12.7172...
R4 32           Ws 62_r/s
R5 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_r/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 / pi * Wm * p
- Ea = pi / ap * p / pi * Wm * p
- Ea = K * Wm * p
- K = pi * p / (ap * pi)
- T * Wm = Ea * Ia + Ef * If
- T = K * p * Ia
- Ra = rho * pi / ap ^ 2 * L / A
-EXPA VARS= PICT SI HALT NSOLV
  
```

```

##### Choose Equations for MES #####
✓ Wme = p/2 * Wm
✓ Eta = p / pi * Wm * p
✓ Ea = pi / ap * p / pi * Wm * p
✓ Ea = K * Wm * p
✓ K = pi * p / (ap * pi)
✓ T * Wm = Ea * Ia + Ef * If
  T = K * p * Ia
  Ra = rho * pi / ap ^ 2 * L / A
  Vf = Rf * If
+
##### ✓CHK CANCEL OK #####
  
```

```

Wme: 0_r/s      Eta: 0_V
p: 6.65_Wb      K: 0
pi: 64          pi: 6
ap: 8           T: 0_N*m
Wm: 31_r/s     Ea: 0_V
Ia: 12_A       Ef: 25_V
If: .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...
p: .65_Wb      K: 15.27887...
pi: 64         pi: 6
ap: 8          T: 119.1757...
Wm: 31_r/s    Ea: 307.869...
Ia: 12_A      Ef: 25_V
If: .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_kΩ 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_Ω. The armature resistance is 13_Ω in series with an external resistance of 55_Ω.

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*ω*φ
Vt=IL*RL
Vt=Ea-Ra*IL
IL=K*φ*ω/(Ra+RL)
DC Shunt Generator
DC Series Generator
-EXPAN VARS= PICT SI = HALT NSOLV

```

```

===== ELECTRICAL ENGINEERING =====
Motors and Generators
Energy Conversion
DC Generator
Starting Solver...
If
Ea
Vt
Vt=Ea-Ra*IL
IL=K*φ*ω/(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_Ω      Rf: 10_Ω
Vt: 0_V      Ea: 0_V
IL: 0_A      K: 3.8
φ: 1.6_Wb    ω: 31_r/s
Ra: 13_Ω     RL: 46_kΩ
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_Ω      Rf: 10_Ω
Vt: 188.426... Ea: 188.48_V
IL: 4.09623... K: 3.8
φ: 1.6_Wb    ω: 31_r/s
Ra: 13_Ω     RL: 46_kΩ
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
Ea=Ra*Ia
Vt=(Re+Rf)*If
Vt=IL*RI
Vt=Ea-Ra*Ia
Ia=IL+If
Ea=Ra*Ia+(Re+Rf)*If
EQN VARS= PICT SI = HALT SOLVE
  
```

```

ELECTRICAL ENGINEERING
Motors and Generators
Energy Conversion
DC Generator
Sep
DC Starting
Solver...
Vt=IL*RI
Vt=Ea-Ra*Ia
Ia=IL+If
Ea=Ra*Ia+(Re+Rf)*If
EQN VARS= PICT SI = HALT SOLVE
  
```

```

Ea=R*W*p
Ea: 125_V
R: 0
W: 31_r/s
p: 1.80000000_Wb
Machine constant
EDIT VARS VIEW SOLVE
  
```

```

Ea=R*W*p
Ea: 125_V
R: 2.24014337
W: 31_r/s
p: 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-A load current from a generated voltage of 17-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=0-(0.068+0.40)*15
Separately-Excited DC Motor
DC Shunt Motor
DC Series Motor
EQN VARS= PICT SI = HALT SOLVE

```

```

***** ELECTRICAL ENGINEERING *****
Motors and Generators
Energy Conversion
DC Generator
Sep
DC Starting Solver...
DC
Ia
Vt=0-(0.068+0.40)*15
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

```

```

***** 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
-DC Separately-Excited DC Motor
  VF=RF*IF
  Vt=K*d*W+Ra*Ia
  TL=K*d*Ia-Tloss
  Eg=K*W*d
  T=K*Ia*d
  W=Vt/(K*d)-Ra*T/(K*d)^2
  T=Tloss+TL
  P=T*W
-EXPA VARS= PICT SI = HALT MSOLV
  
```

```

Choose Equations for MES
✓ VF=RF*IF
✓ Vt=K*d*W+Ra*Ia
  TL=K*d*Ia-Tloss
✓ Eg=K*W*d
✓ T=K*Ia*d
  W=Vt/(K*d)-Ra*T/(K*d)^2
  T=Tloss+TL
  P=T*W
  ✓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
W: 31_r/s   T: 0_N*m
K: 0        Ia: 0.5_A
E: 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
W: 31_r/s   T: .4677419...
K: .3897849... Ia: 0.5_A
E: 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
  
```

```

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
  
```

```

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)
T=Tloss+TL
K*p=KF*IL
T=KF*IL^2
EXPANSION 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)
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 R3: 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 R3: 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
-  $E_a = K \cdot \phi \cdot \omega_m$ 
-  $T = R_a \cdot I_a$ 
-  $V_t = E_a + R_a \cdot I_a$ 
-  $T = T_{loss} + T_L$ 
-  $\omega_m = V_t / (R_a \cdot p) - R_a \cdot I_a / (R_a \cdot p)^2$ 
- Induction Motor I
- Induction Motor II
EQN VARS PICT SI HALT SOLVE
  
```

```

ELECTRICAL ENGINEERING
- Separately-Excited DC Motor
- DC Shunt Motor
- DC Series Motor
- Per
- Starting Solver...
-  $E_a = K \cdot \phi \cdot \omega_m$ 
-  $T = R_a \cdot I_a$ 
-  $V_t = E_a + R_a \cdot I_a$ 
-  $T = T_{loss} + T_L$ 
-  $\omega_m = V_t / (R_a \cdot p) - R_a \cdot I_a / (R_a \cdot p)^2$ 
- Induction Motor I
- Induction Motor II
EQN VARS PICT SI HALT SOLVE
  
```

```

ELECTRICAL ENGINEERING
Eq:  $E_a = K \cdot \phi \cdot \omega_m$ 
Eq: 110_V
K: 0
p: 1.26_Wb
 $\omega_m$ : 62.5_r/s
Machine constant
EDIT VARS VIEW SOLVE
  
```

```

ELECTRICAL ENGINEERING
Eq:  $E_a = K \cdot \phi \cdot \omega_m$ 
Eq: 110_V
K: 1.39682539682
p: 1.26_Wb
 $\omega_m$ : 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
-wr=ws-p/2*wn
-s=(ws-(p/2)*wn)/ws
-Pr/Pna=s
-wr=s*ws
-Pna=3*Ir*Ema
-Pne=3*(p/2)*(wn/ws)*Pna
-Pne=T*wn
-T=3*(p/2)*(Pna/ws)
-Pna=Rr*Ir^2+(1-s)/s*Rr*Ir^2
-Pa=(1-s)/s*Rr*Ir^2
Rr=R1/RN^2
  
```

```

ELECTRICAL ENGINEERING
Induction Motor I
-wr=ws-p/2*wn
-s=(ws-(p/2)*wn)/ws
-Pr
-wr Starting
-Pn Solver...
-Pn
-Pne=T*wn
-T=3*(p/2)*(Pna/ws)
-Pna=Rr*Ir^2+(1-s)/s*Rr*Ir^2
-Pa=(1-s)/s*Rr*Ir^2
Rr=R1/RN^2
  
```

```

Pa=(1-s)/s*Rr*Ir^2
Eq: 'Pa=(1-s)/s*Rr*Ir^...'
Pa: 0_W
s: .95
Rr: 1.8_Ω
Ir: 75_A

Mechanical power
EDIT VARS VIEW SOLVE
  
```

```

Pa=(1-s)/s*Rr*Ir^2
Eq: 'Pa=(1-s)/s*Rr*Ir^...'
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/ωs
T=3/ωs*p/2*Rs/s*Va^2/(Rst+Rs/s)
Tmax=3/ωs*p/4*Va^2/(Rs^2+XL^2)
sH=Rs/s/(Rs^2+XL^2)
Tmax=-3/ωs*p/4*Va^2/(Rs^2+XL^2)
Rr=R1/KM^2
Single-Phase Induction Motor
Synchronous Machines
EQN VARS= PICT SI = HALT SOLVE
  
```

```

***** ELECTRICAL ENGINEERING *****
Induction Motor I
Induction Motor II
Pm=Rs/s*Ir^2
T=
T= Starting Solver...
Tmax=3/ωs*p/4*Va^2/(Rs^2+XL^2)
sH=Rs/s/(Rs^2+XL^2)
Tmax=-3/ωs*p/4*Va^2/(Rs^2+XL^2)
Rr=R1/KM^2
Single-Phase Induction Motor
Synchronous Machines
EQN VARS= PICT SI = HALT SOLVE
  
```

```

Eq: 'Tmax=3/ωs*p/4*Va...
Tmax: 0_N*m
ωs: 245_r/s
p: 8
Va: 125_V
Rst: 8_Ω
XL: 12_Ω
Maximum positive torque
EDIT VARS VIEW SOLVE
  
```

```

Eq: 'Tmax=3/ωs*p/4*Va...
Tmax: 17.0658086252_N*m
ωs: 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_r/s and a mechanical radian frequency of 62.5_r/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

```

```

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...
sf: 0
p: 8
ws: 245_r/s
wm: 62.5_r/s

Slip For Forward Flux
EDIT VARS VIEW SOLVE

```

```

sf=(2/p)*ws-wm/(2/p*ws)
Eq: 'sf=(2/p*ws-wm)/(2...
sf: -0.02040816
p: 8
ws: 245_r/s
wm: 62.50000000_r/s

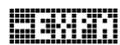
Slip For Forward Flux
EDIT VARS VIEW INFO SOLVE

```


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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