Ambertec, P.E., P.C.

Using Recursive Differential Equations

Just two differential equations

$$v = L * di / dt$$

$$i = C * dv / dt$$

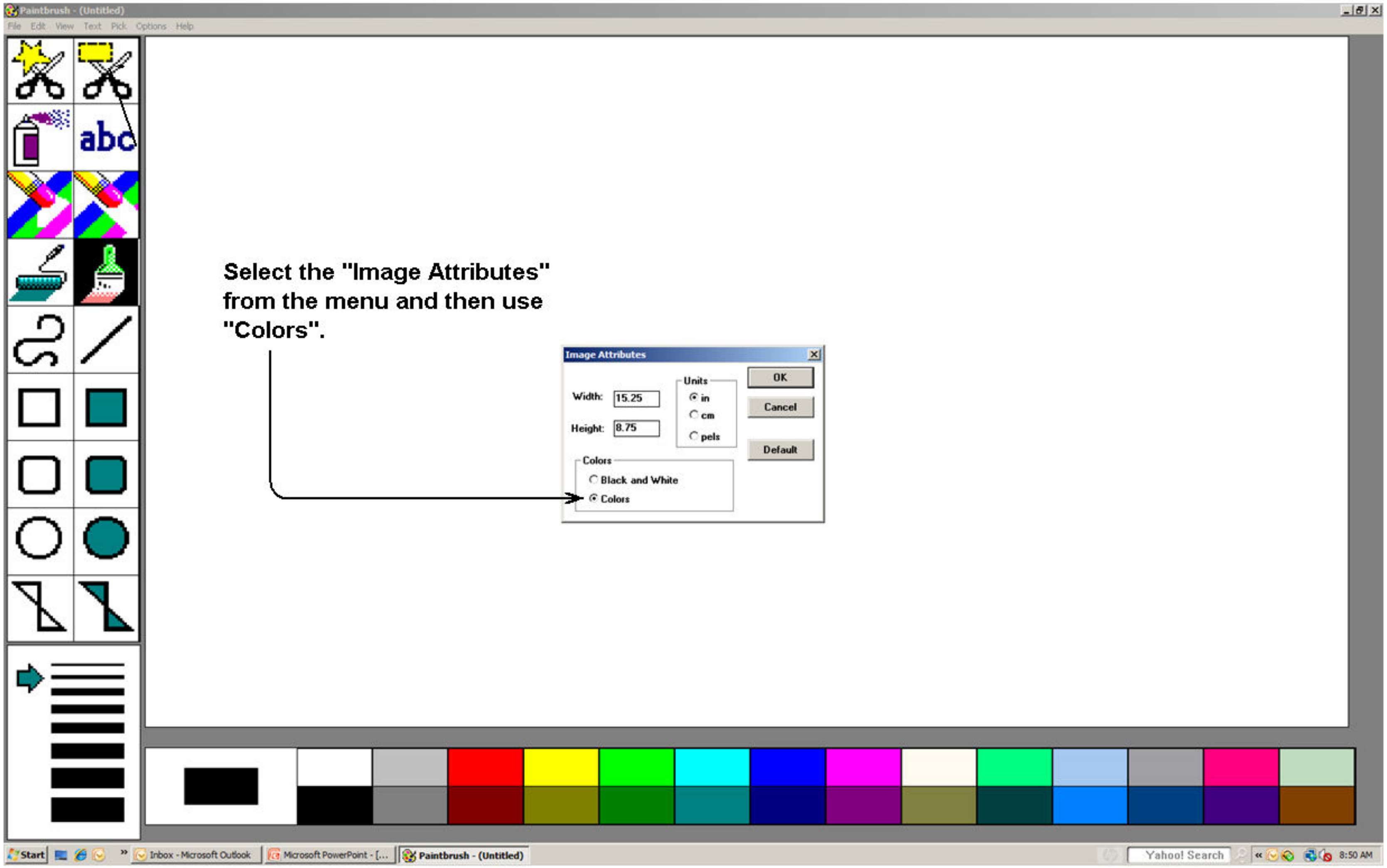
Ambertec, P.E., P.C.

Name	Size	Type	Modified
Gwbasic	78KB	Application	7/7/86 1:00 PM
Pbrush	180KB	Application	12/31/93 2:11 AM
Pbrush	40KB	Help File	12/31/93 2:11 AM
pbrush.dll	7KB	Application Extension	12/31/93 2:11 AM

These four files are old, but while tallying up to only 305 KB, they can be used for analyses that are as varied and versatile as that kind of thing can be.

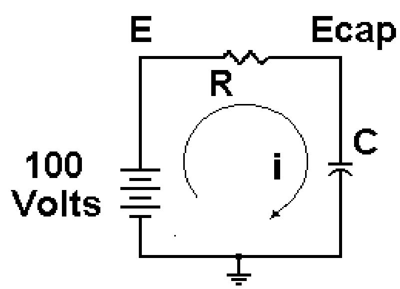
There are even some things you can do with them that some modern software can't do.

Ambertec, P.E., P.C.

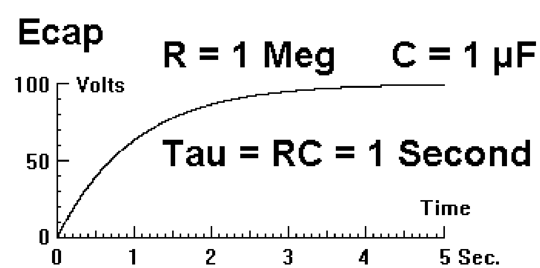


Ambertec, P.E., P.C.

**This is a simple RC network charging from a DC source.
The first order differential equation is put into a loop which simulates in software, the actual process under consideration.**



A capacitor charging from a starting voltage of zero from a 100 volt DC source.



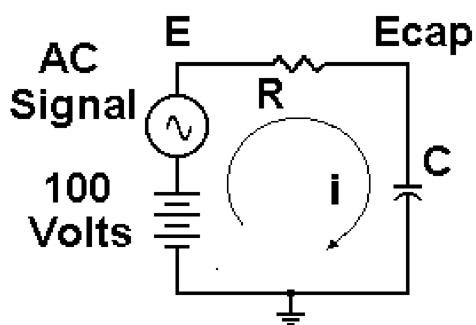
Iterative loop:

i = (E - Ecap) / R
dEcap = i dt / C
Ecap = Ecap + dEcap
t = t + dt

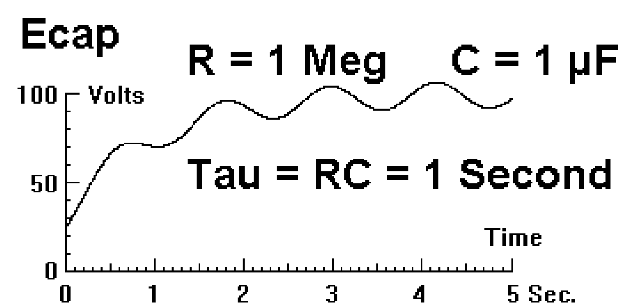
```
150 ECAP=0
160 READ EDC,R,C,DT:DATA 100,1e6,1e-6,.001
170 FOR T=0 TO 5 STEP DT:E=EDC
180 I=(E-ECAP)/R:DV=I*DT/C:ECAP=ECAP+DV:GOSUB 110:NEXT T
```

Ambertec, P.E., P.C.

When we add an AC source in series with the DC source, the output waveform reflects the effects of both of them.



A capacitor charging from a starting voltage of 25 volts from a 100 volt DC source

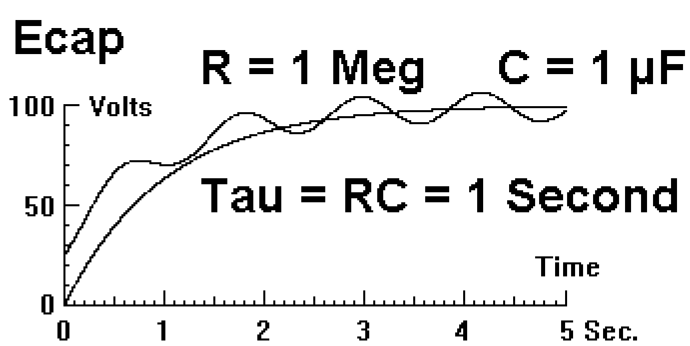


Iterative loop:

i = (E - Ecap) / R
dEcap = i dt / C
Ecap = Ecap + dEcap
t = t + dt

```
150 ECAP=25
160 READ EDC,R,C,DT:DATA 100,1e6,1e-6,.001
170 FOR T=0 TO 5 STEP DT:E=EDC+40*SIN(300*T*PI/180)
180 I=(E-ECAP)/R:DV=I*DT/C:ECAP=ECAP+DV:GOSUB 110:NEXT T
```

Looking at an overlay:

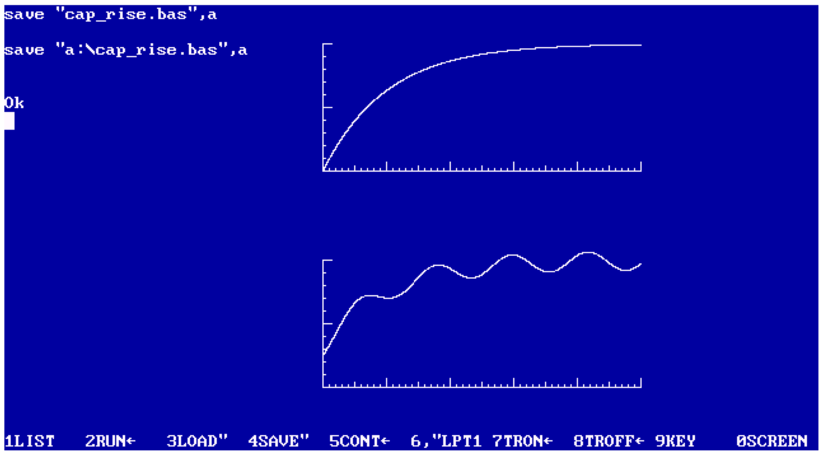


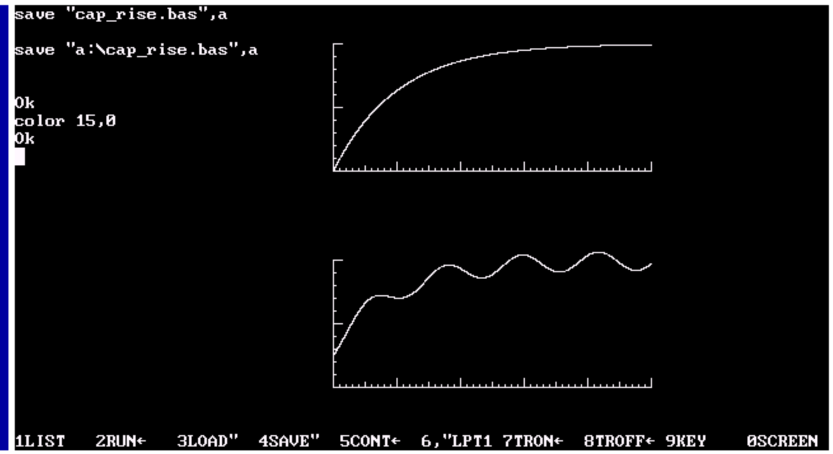
When we overlay the two results, we see that their Ecap values are starting from two different initial values (zero and 25 volts), but are heading to the same average value of 100 volts.

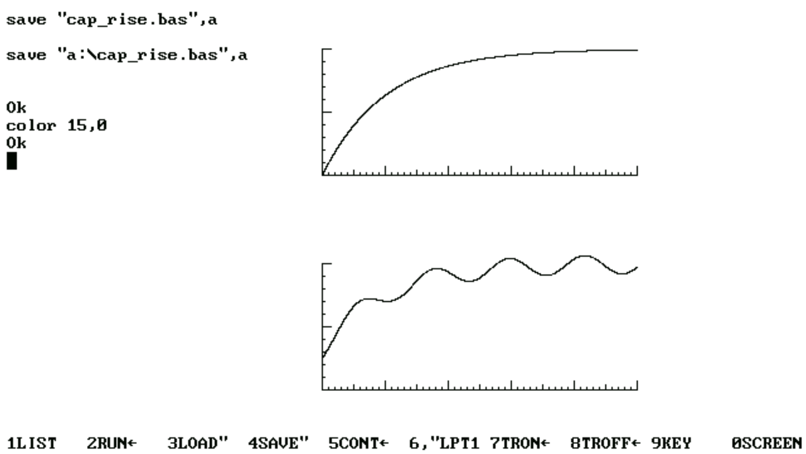
cap_rise.bas

Ambertec, P.E., P.C.

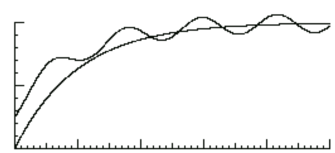
Putting a picture together.



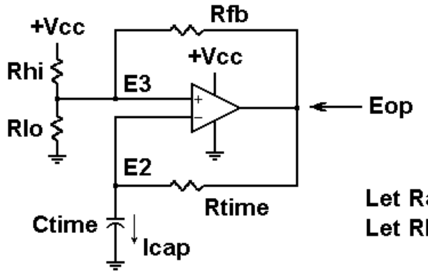




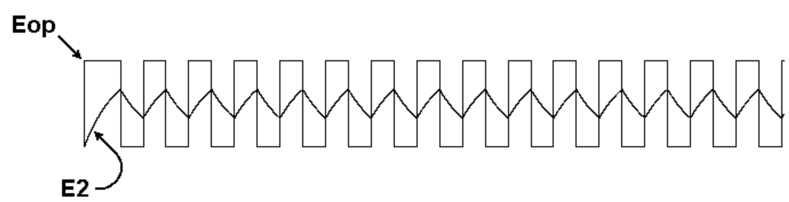
Now move things around and annotate any way you want.



Ambertec, P.E., P.C.



Let Ra = Rfb || Rlo
Let Rb = Rfb || Rhi



Eop = Vcc * 0.5 * (SGN(E3 - E2) + 1)

E3 = Eop * RB / (RB + Rfb) + VCC * RA / (RA + Rhi)

Icap = (Eop - E2) / R time

dE2 = Icap * dt / C time

E2 = E2 + dE2

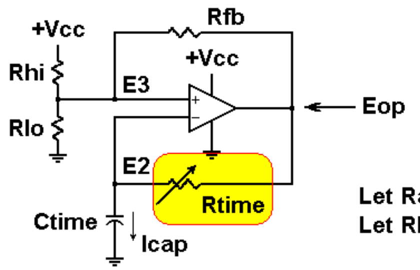
```
10 CLS:SCREEN 9:COLOR 15,1:YSTART=50:XSTART=10:PI=3.14159265#:YS=5:XS=460
20 PRINT "save "+CHR$(34)+"rcosc01.bas"+CHR$(34):PRINT:TMAX=.0002
30 PRINT "save "+CHR$(34)+"a:\rcosc01.bas"+CHR$(34):PRINT:PRINT:GOTO 90
40 Y=YGRIP:X=XGRIP:GOSUB 70
50 Y=EOP*YS:X=XS*T/TMAX:GOSUB 70:XGRIP=X:YGRIP=Y:RETURN
60 Y=E2*YS:X=XS*T/TMAX:GOTO 70
70 CC=XSTART+1.33*X:DD=(320-Y-YSTART):IF KK<>0 THEN LINE (AA,BB)-(CC,DD)
80 AA=CC:BB=DD:KK=1:RETURN
90 READ VCC,DT,RFB,RHI,RLO,RTIME,CTIME
100 DATA 15,1e-8,100e3,100e3,100e3,20e3,470e-12
110 RA=RFB*RLO/(RFB+RLO):RB=RHI*RLO/(RHI+RLO)
120 EOP=.5*(SGN(E3-E2)+1)*VCC
130 E3=EOP*RB/(RB+RFB)+VCC*RA/(RA+RHI)
140 ICAP=(EOP-E2)/RTIME
150 DE2=ICAP*DT/CTIME
160 E2=E2+DE2
170 KK=0:GOSUB 40:GOSUB 40:KK=0:GOSUB 60:GOSUB 60:T=T+DT
180 IF T<TMAX THEN GOTO 120

1LIST   2RUN←   3LOAD"  4SAVE"  5CONT←  6,"LPT1 7TRON←  8TROFF← 9KEY    0SCREEN
```

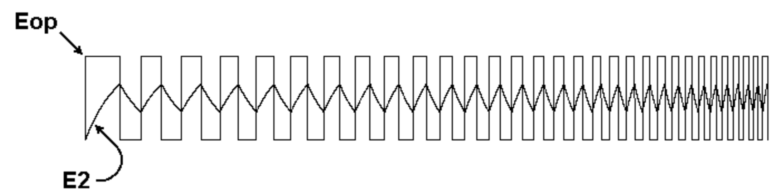
This oscillator simulation uses fixed values of its resistors and capacitors.

rcosc01.bas

Ambertec, P.E., P.C.



Let Ra = Rfb || Rlo
Let Rb = Rfb || Rhi



Eop = Vcc * 0.5 * (SGN(E3 - E2) + 1)

E3 = Eop * RB / (RB + Rfb) + VCC * RA / (RA + Rhi)

Icap = (Eop - E2) / R time

dE2 = Icap * dt / C time

E2 = E2 + dE2

```
10 CLS:SCREEN 9:COLOR 15,1:YSTART=50:XSTART=10:PI=3.14159265#:YS=5:XS=460
20 PRINT "save "+CHR$(34)+"rcosc02.bas"+CHR$(34):PRINT:TMAX=.0002
30 PRINT "save "+CHR$(34)+"a:\rcosc02.bas"+CHR$(34):PRINT:PRINT:GOTO 90
40 Y=YGRIP:X=XGRIP:GOSUB 70
50 Y=EOP*YS:X=XS*T/TMAX:GOSUB 70:XGRIP=X:YGRIP=Y:RETURN
60 Y=E2*YS:X=XS*T/TMAX:GOTO 70
70 CC=XSTART+1.33*X:DD=(320-Y-YSTART):IF KK<>0 THEN LINE (AA,BB)-(CC,DD)
80 AA=CC:BB=DD:KK=1:RETURN
90 READ VCC,DT,RFB,RHI,RLO,RT,CTIME
100 DATA 15,1e-8,100e3,100e3,100e3,20e3,470e-12
110 RA=RFB*RLO/(RFB+RLO):RB=RHI*RLO/(RHI+RLO)
120 EOP=.5*(SGN(E3-E2)+1)*VCC:E3=EOP*RB/(RB+RFB)+VCC*RA/(RA+RHI)
130 REM
140 RTIME=RT*(1-.8*T/TMAX):REM   Here is where the value of Rtime is varied.
150 REM
160 ICAP=(EOP-E2)/RTIME:DE2=ICAP*DT/CTIME:E2=E2+DE2
170 KK=0:GOSUB 40:GOSUB 40:KK=0:GOSUB 60:GOSUB 60:T=T+DT
180 IF T<TMAX THEN GOTO 120

1LIST   2RUN←   3LOAD"   4SAVE"   5CONT←   6,"LPT1 7TRON←   8TROFF← 9KEY    0SCREEN
```

In this simulation, the value of the timing resistance is <u>arbitrarily varied</u> during the time interval under examination.

rcosc02.bas

Ambertec, P.E., P.C.

Drawing pictures in GWBASIC

```
10 CLS:SCREEN 9:COLOR 15,1:YSTART=150:XSTART=100:PI=3.14159254#
20 PRINT "save "+CHR$(34)+"how2draw.bas"+CHR$(34):PRINT
30 PRINT "save "+CHR$(34)+"a:how2draw.bas"+CHR$(34):PRINT:PRINT:GOTO 60
40 CC=XSTART+X:DD=(320-Y-YSTART):IF KK<>0 THEN LINE (AA,BB)-(CC,DD)
50 AA=CC:BB=DD:KK=1:RETURN
60 REM
```

This short program is the basis of drawing pictures. If the variable called "KK" is non-zero, a line will be drawn between two points set by the values of "AA", the previous x-axis coordinate, "CC", the new x-axis coordinate, "BB", the previous y-axis coordinate and "DD", the new y-axis coordinate. (Yes, that is a mouthful.)

If the value of "KK" zero, then no line is drawn, but new x-axis and y-axis coordinates are memorized as the starting point for drawing the next line.

how2draw.bas

Ambertec, P.E., P.C.

Horizontal axis issue:

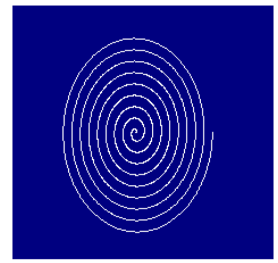
The basic (yes, pun intended) GWBASIC subroutine for doing pictures:

```
10 CLS:SCREEN 9:COLOR 15,1:YSTART=150:XSTART=100:PI=3.14159254#
20 PRINT "save "+CHR$(34)+"how2draw.bas"+CHR$(34):PRINT
30 PRINT "save "+CHR$(34)+"a:how2draw.bas"+CHR$(34):PRINT:PRINT:GOTO 60
40 CC=XSTART+X:DD=(320-Y-YSTART):IF KK<>0 THEN LINE (AA,BB)-(CC,DD)
50 AA=CC:BB=DD:KK=1:RETURN
60 REM
```

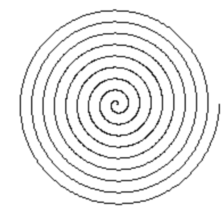
Two lines of code for drawing a spiral.

```
10 CLS:SCREEN 9:COLOR 15,1:YSTART=60:XSTART=100:PI=3.14159254#
20 PRINT "save "+CHR$(34)+"how2dra2.bas"+CHR$(34):PRINT
30 PRINT "save "+CHR$(34)+"a:how2dra2.bas"+CHR$(34):PRINT:PRINT:GOTO 60
40 CC=XSTART+X:DD=(320-Y-YSTART):IF KK<>0 THEN LINE (AA,BB)-(CC,DD)
50 AA=CC:BB=DD:KK=1:RETURN
60 RAD=10:FOR THETA=0 TO 360*9:X=XSTART+RAD*(THETA/360)*COS(THETA*PI/180)
70 Y=YSTART+RAD*(THETA/360)*SIN(THETA*PI/180):GOSUB 40:NEXT THETA
```

The on-screen view in GWBASIC looks like it's crunched in from side to side:



When "Print Screen" takes it to Paintbrush, the vertical to horizontal proportions are okay.



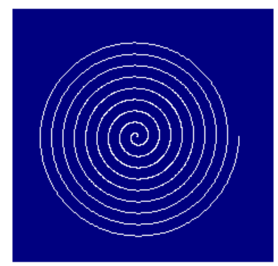
The subroutine with an added coefficient of 1.33 for the x-axis.

```
10 CLS:SCREEN 9:COLOR 15,1:YSTART=150:XSTART=100:PI=3.14159254#
20 PRINT "save "+CHR$(34)+"how2draw.bas"+CHR$(34):PRINT
30 PRINT "save "+CHR$(34)+"a:how2draw.bas"+CHR$(34):PRINT:PRINT:GOTO 60
40 CC=XSTART+X*1.33:DD=(320-Y-YSTART):IF KK<>0 THEN LINE (AA,BB)-(CC,DD)
50 AA=CC:BB=DD:KK=1:RETURN
60 REM
```

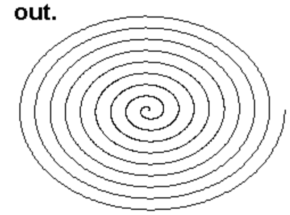
Two lines of code for drawing a spiral.

```
10 CLS:SCREEN 9:COLOR 15,1:YSTART=60:XSTART=100:PI=3.14159254#
20 PRINT "save "+CHR$(34)+"how2dra2.bas"+CHR$(34):PRINT
30 PRINT "save "+CHR$(34)+"a:how2dra2.bas"+CHR$(34):PRINT:PRINT:GOTO 60
40 CC=XSTART+X*1.33:DD=(320-Y-YSTART):IF KK<>0 THEN LINE (AA,BB)-(CC,DD)
50 AA=CC:BB=DD:KK=1:RETURN
60 RAD=10:FOR THETA=0 TO 360*9:X=XSTART+RAD*(THETA/360)*COS(THETA*PI/180)
70 Y=YSTART+RAD*(THETA/360)*SIN(THETA*PI/180):GOSUB 40:NEXT THETA
```

The on-screen view in GWBASIC looks like it's okay:

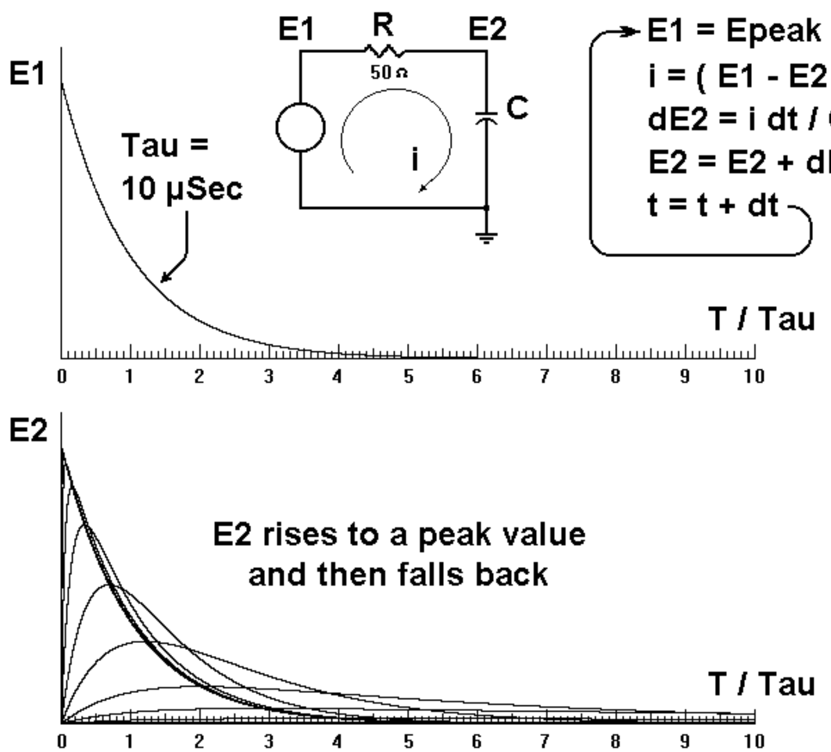


When "Print Screen" takes this image to Paintbrush, the result is horizontally spread out.



Ambertec, P.E., P.C.

We apply an exponentially decaying waveform to the input of a single-pole lowpass filter and calculate the output.



Iterative Loop:

```
→ E1 = Epeak * exp ( - t / Tau )
i = ( E1 - E2 ) / R
dE2 = i dt / C
E2 = E2 + dE2
t = t + dt
```

Max. E2 / E1	C
0.64 %	30 µF
1.85 %	10
5.49 %	3
13.37 %	1
29.96 %	0.3
50.00 %	0.1
71.56 %	0.03
85.43 %	0.01
93.83 %	3000 pF
97.40 %	1000
99.06 %	300
99.66 %	100

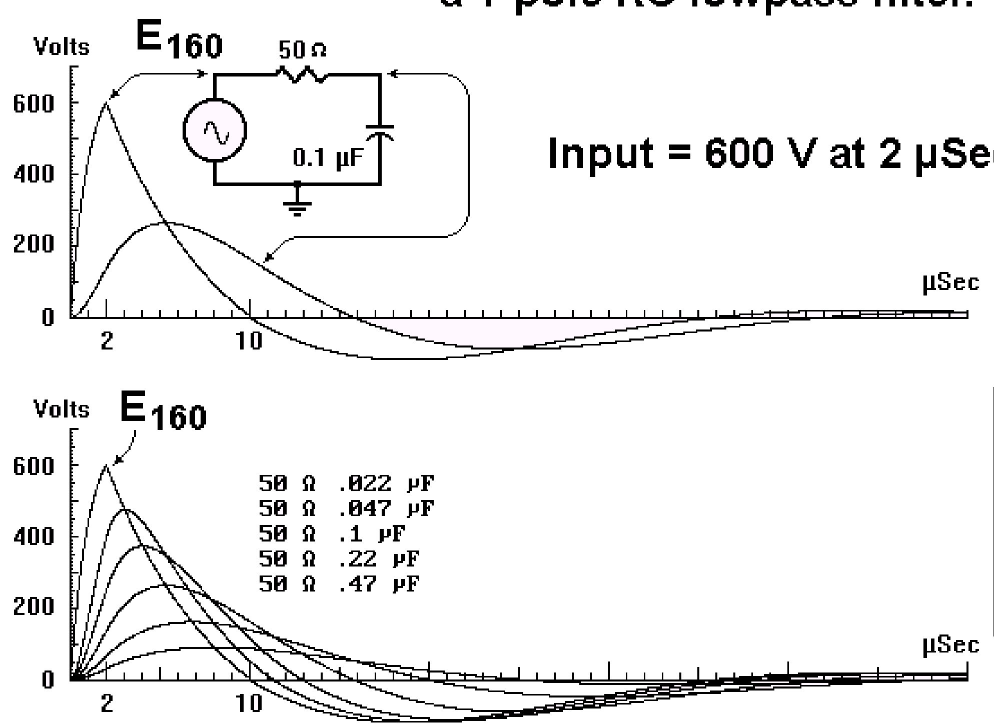
mult_rc.bas

Ambertec, P.E., P.C.

We can apply agency-specified waveforms to circuit inputs:

DO-160C Category A voltage spike input to a 1-pole RC lowpass filter.

Input = 600 V at 2 µSec and zero at 10 µSec.



Iterative Loop:

$E1 = E_{160} * e^{(- t / Tau)}$

$i = (E1 - E2) / R$

$dE2 = i \, dt / C$

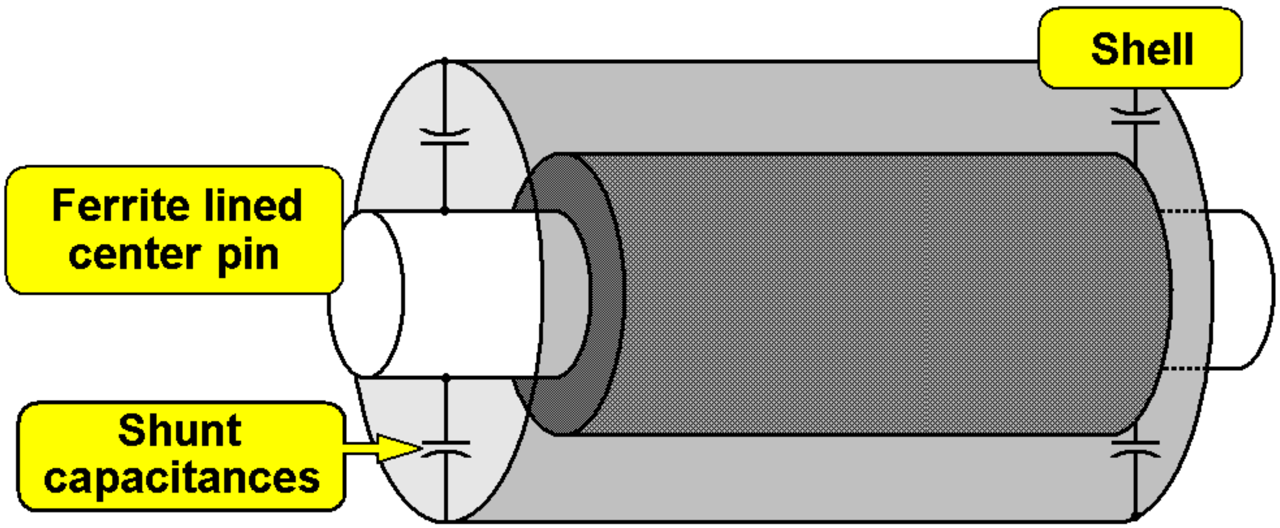
$E2 = E2 + dE2$

$t = t + dt$

catatran.bas

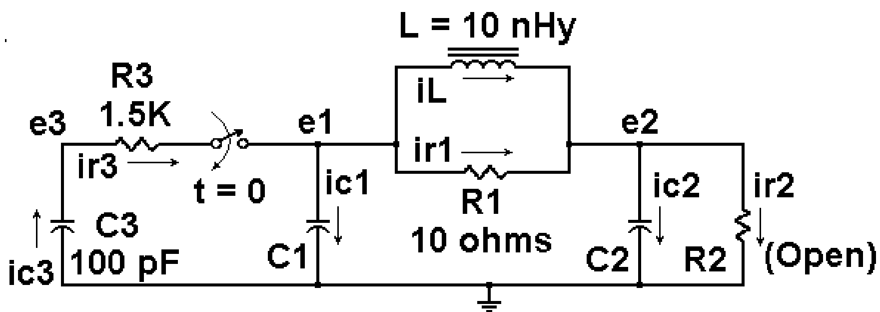
Ambertec, P.E., P.C.

Structure of EMI Filter Pin



Ambertec, P.E., P.C.

The human body model of an electrostatic discharge (ESD) event is applied to a connector's filter-pin.



Mid-frequency pins have C1 = C2 = 4000 pF

Hi-frequency pins have C1 = C2 = 225 pF

Initial conditions are e3 = 4000 volts, e1 = zero, e2 = zero and iL = 0

Iteration loop:

Enter →

```
ir1 = ( e1 - e2 ) / R1
ir2 = e2 / R2
ir3 = ( e3 - e1 ) / R3
ic1 = ir3 - ir1 - iL
ic2 = ir1 - ir2 + iL
de1 = ic1 dt / C1
de2 = ic2 dt / C2
```

→

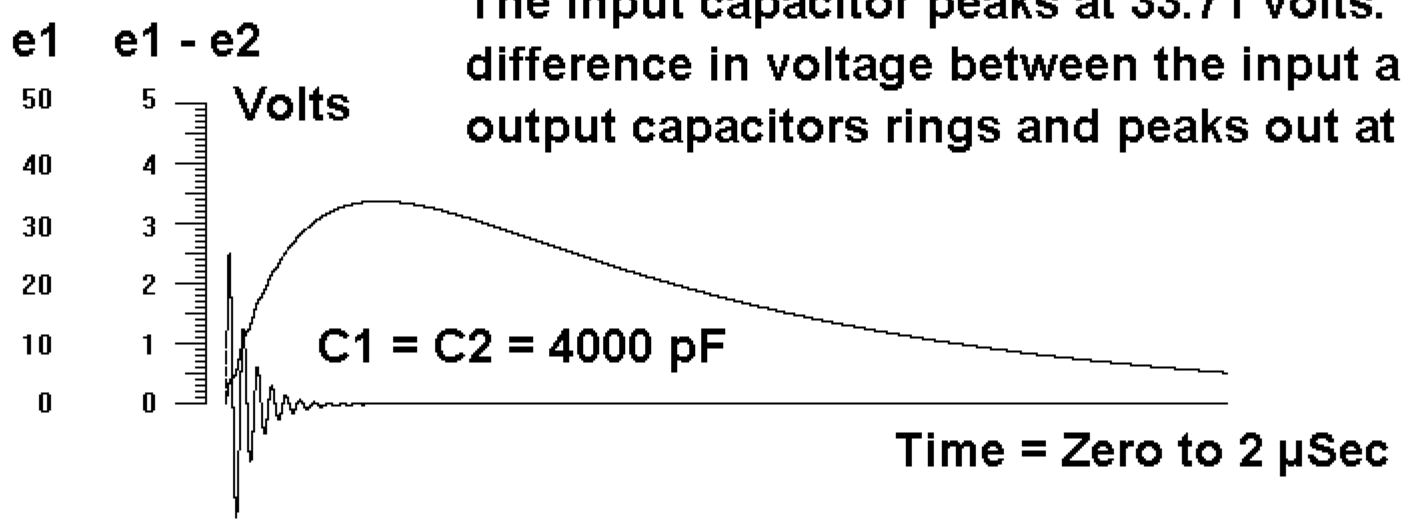
```
de3 = -ir3 dt / C3
diL = ( e1 - e2 ) dt / L
iL = iL + diL
e1 = e1 + de1
e2 = e2 + de2
e3 = e3 + de3
t = t + dt
```

(loop back to Enter)

Ambertec, P.E., P.C.

The human body model of an electrostatic discharge (ESD) event is applied to a connector's filter-pin.

The input capacitor peaks at 33.71 volts. The difference in voltage between the input and the output capacitors rings and peaks out at 2.488 volts.



esdbody.bas

Ambertec, P.E., P.C.

IEEE TRANSACTIONS ON

ELECTROMAGNETIC COMPATIBILITY

MAY 1991 VOLUME 33 NUMBER 2 (ISSN 0018-9375)

A PUBLICATION OF THE IEEE ELECTROMAGNETIC COMPATIBILITY SOCIETY

See: http://www.advansi.com/data/EffectsofSimulElectroMpulseonCA.pdf

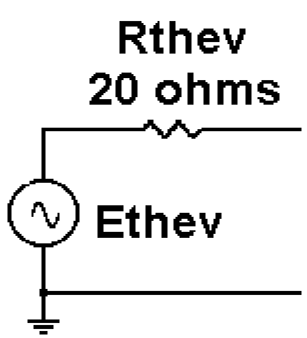
This paper describes a variety of lightning simulations including the Douglas Aircraft BXU7026.

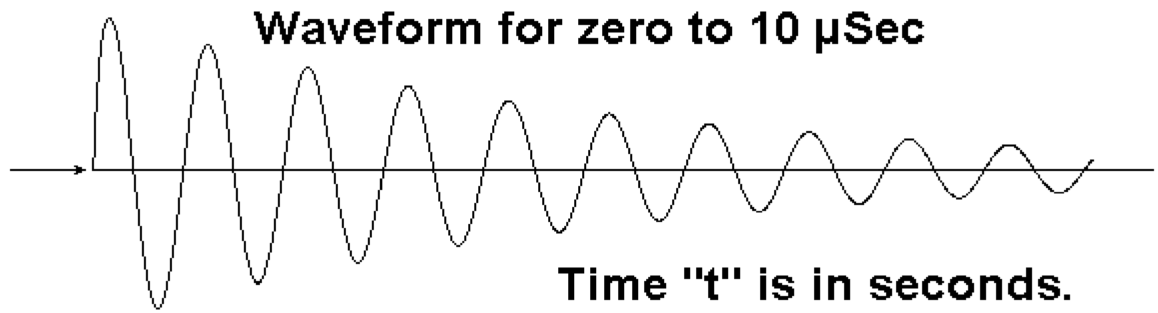
[7] "Requirements for protection of electrical electronics equipment from lightning induced electrical transients," 88277 BXU7026, Douglas Aircraft Co., Long Beach, CA, Apr. 24, 1979.

Ambertec, P.E., P.C.

Lightning strike equivalent circuit of Douglas specification BXU7026.

See: http://www.advansi.com/data/EffectsofSimulElectroMpulseonCA.pdf





Time "t" is in seconds.

$$V_o * (\exp (- a\, t) - \exp (- b\, t)) * \cos ((g\, t - d) * \pi)$$

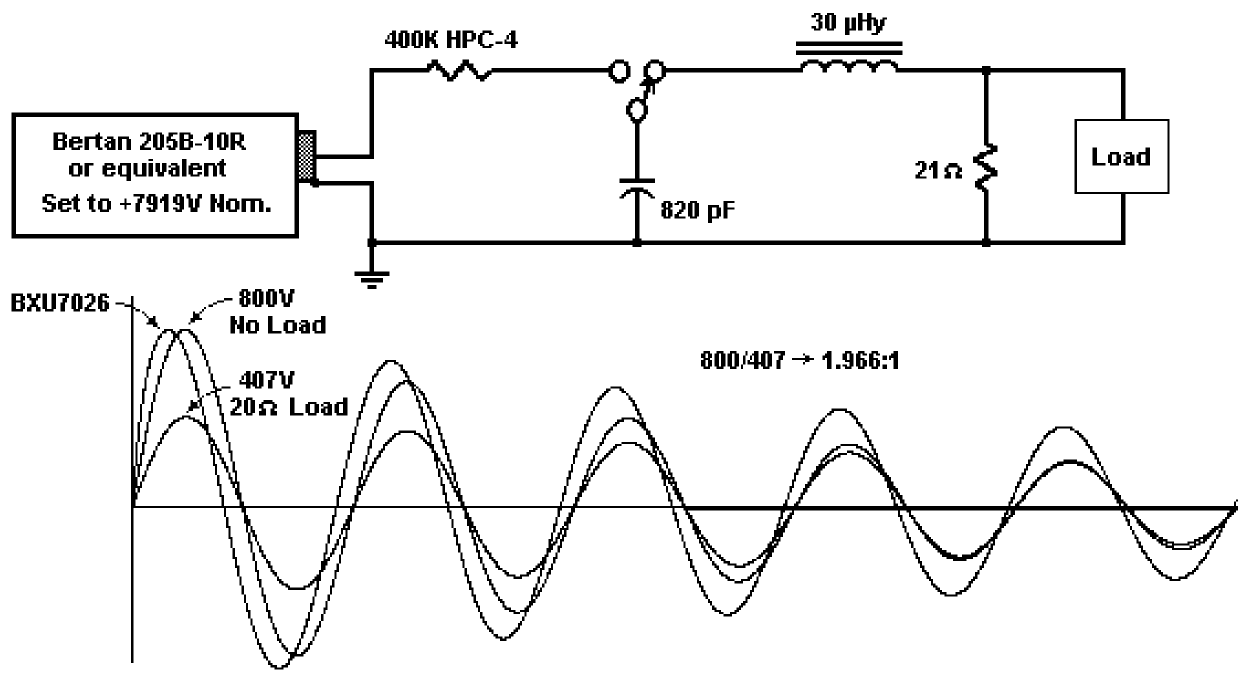
$V0 = 831 \quad a = 200{,}000 \quad b = 32{,}000{,}000$

$g = 2{,}000{,}000 \quad d = 0.32 \quad pi = 3.14159....$

Ambertec, P.E., P.C.

Lightning strike equivalent circuit per Boeing specification BXU7026.

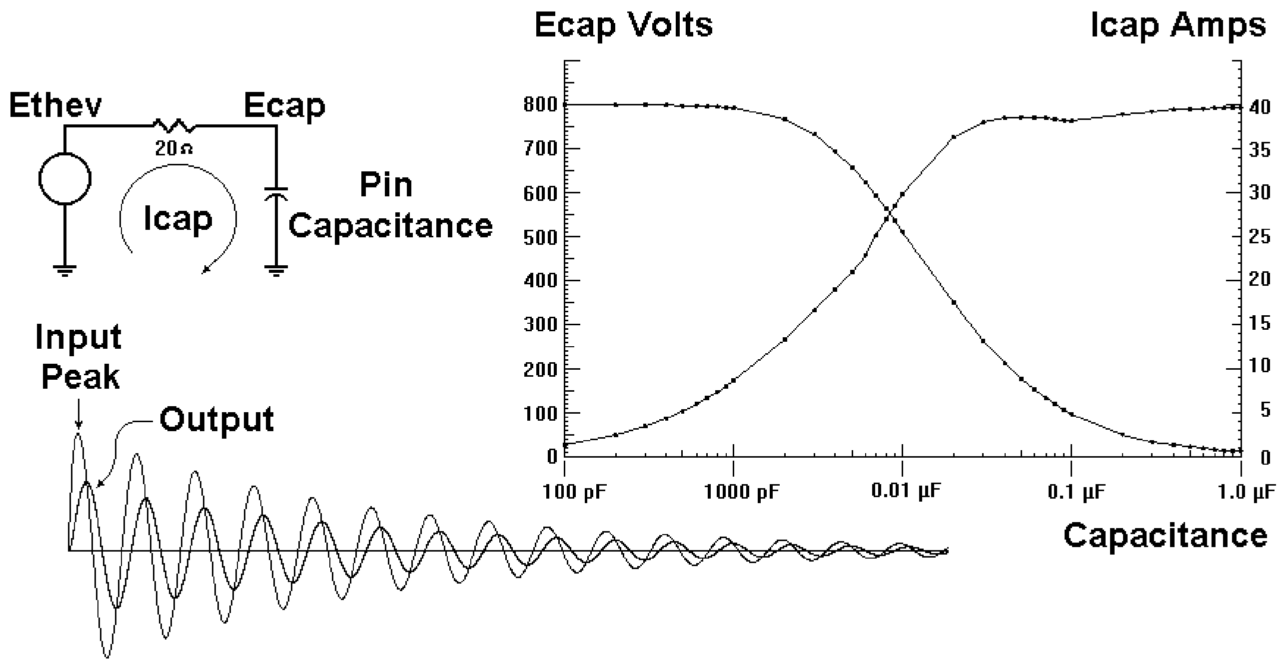
Boeing BXU7026 Waveform Generator for Lighting Simulation (maybe)



bxu_sim1.bas

Ambertec, P.E., P.C.

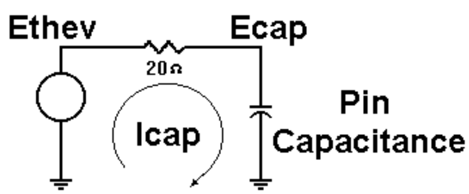
Lightning strike equivalent circuit per Boeing specification BXU7026.

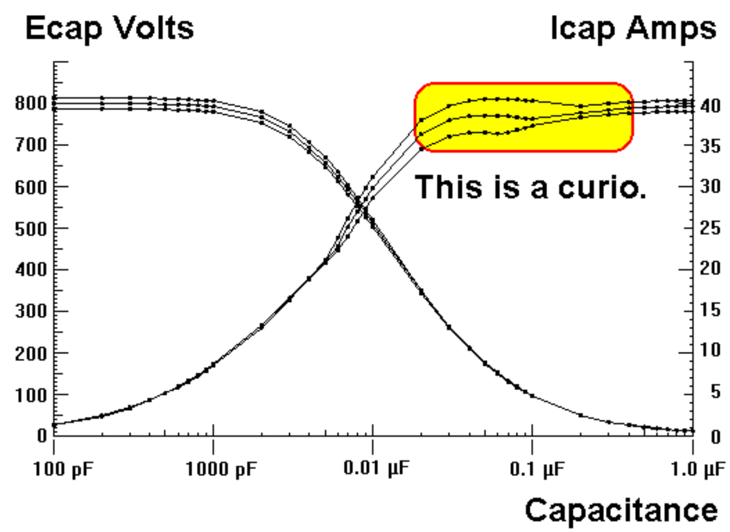


bxu7026a.bas

Ambertec, P.E., P.C.

Examining A Curio



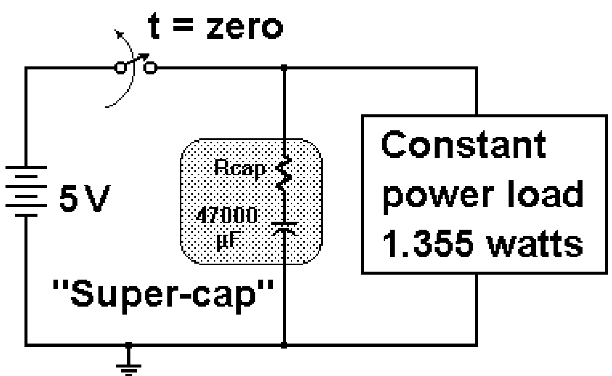


When we alter the Ethev slightly off of BXU7026 coefficients, the ouput changes a little, but the basic result is still the same.

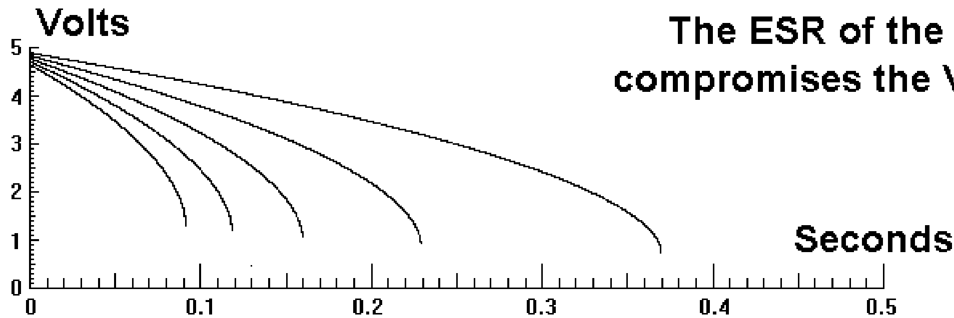
bxu7026b.bas

Ambertec, P.E., P.C.

Constant power decay of the voltage of a charged super-capacitor.



Rcap	Start	Time to 4.5 volts
0.4 ohms	4.889 volts	60.3 mSec
0.6	4.832	50.2
0.8	4.773	40.2
1.0	4.712	30.3
1.2	4.650	20.6



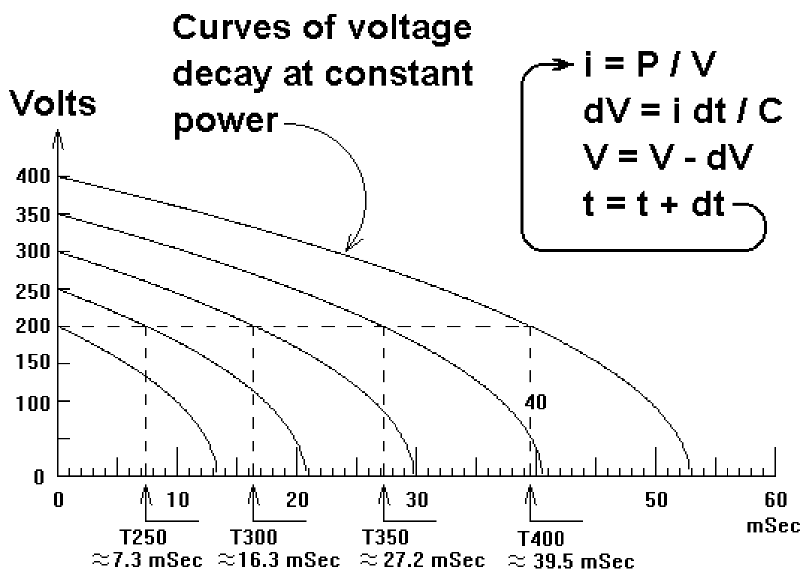
The ESR of the super-cap severely compromises the Vcc hold-up capability.

supercap.bas

Ambertec, P.E., P.C.

Constant power decay of the voltage of a charged capacitor.

Constant power decay of 470 µF capacitor for 714 watt load where the requirement is to sustain the load at 200 volts or more for a specified time.



Tnnn is the decay time from "nnn" volts to 200 volts.

$i = C\, dV/dT$

$i = P/V$

$P/V = C\, dV/dT$

$dT * (P/V) = C\, dV$

$\int dV = (1/ VC) \int P dT$

$\int V\, dV = (1 / C) \int P\, dT$

$0.5 * V^2 \Big|_{Vf}^{Vs} = (P / C) \int dT = (P / C)\, T \Big|_{Tf}^{Ts}$

$(P / C) * \text{Delta } T = 0.5 * Vs^2 - 0.5 * Vf^2$

$\boxed{C = 2 * P * \text{Delta } T / (Vs^2 - Vf^2)}$

C is that capacitance which will hold a voltage starting at Vs above a final or finishing voltage Vf under a constant power load P for a time interval of Delta T.

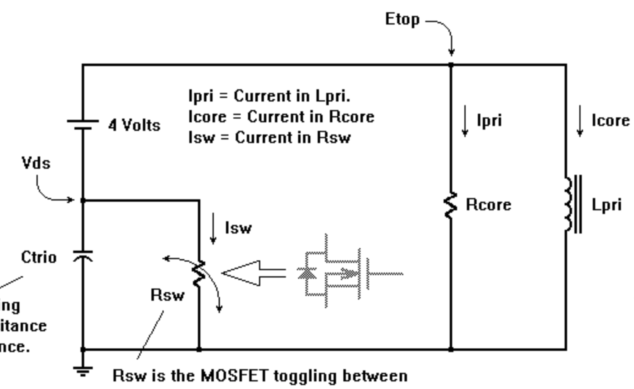
Note that the curve for any particular starting voltage can be slid to the right where it will exactly match a portion of another curve representing a start from a higher initial voltage.

cpwrdcay.bas

Ambertec, P.E., P.C.

Quasi-resonant power inverter

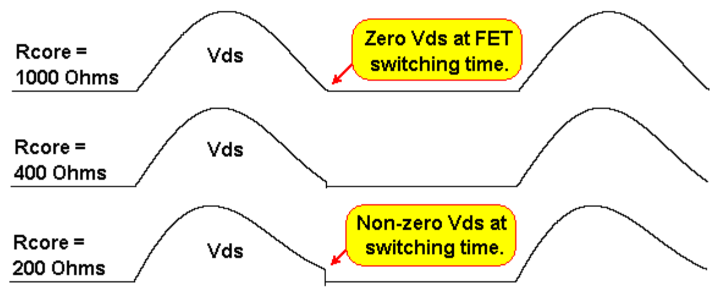
```
dIpri = ( Vtrio + 4 ) * dt / Lpri
Ipri ← Ipri + dIpri
Icore = ( Vtrio + 4 ) / Rcore
Isw = Vtrio / Rsw
Itrio = Ipri + Icore + Isw
dVds = - Itrio * dt / Ctrio
Vds ← Vds + dVds
Etop = Vtrio + 4
t = t + dt
```



Ctrio consists of three ceramic resonating capacitors, the MOSFET's output capacitance and the transformer's winding capacitance.

Rsw is the MOSFET toggling between its Rdson and its essentially open Rds at cut-off. The duty cycle is 50%.

Vds waveforms under the given conditions.



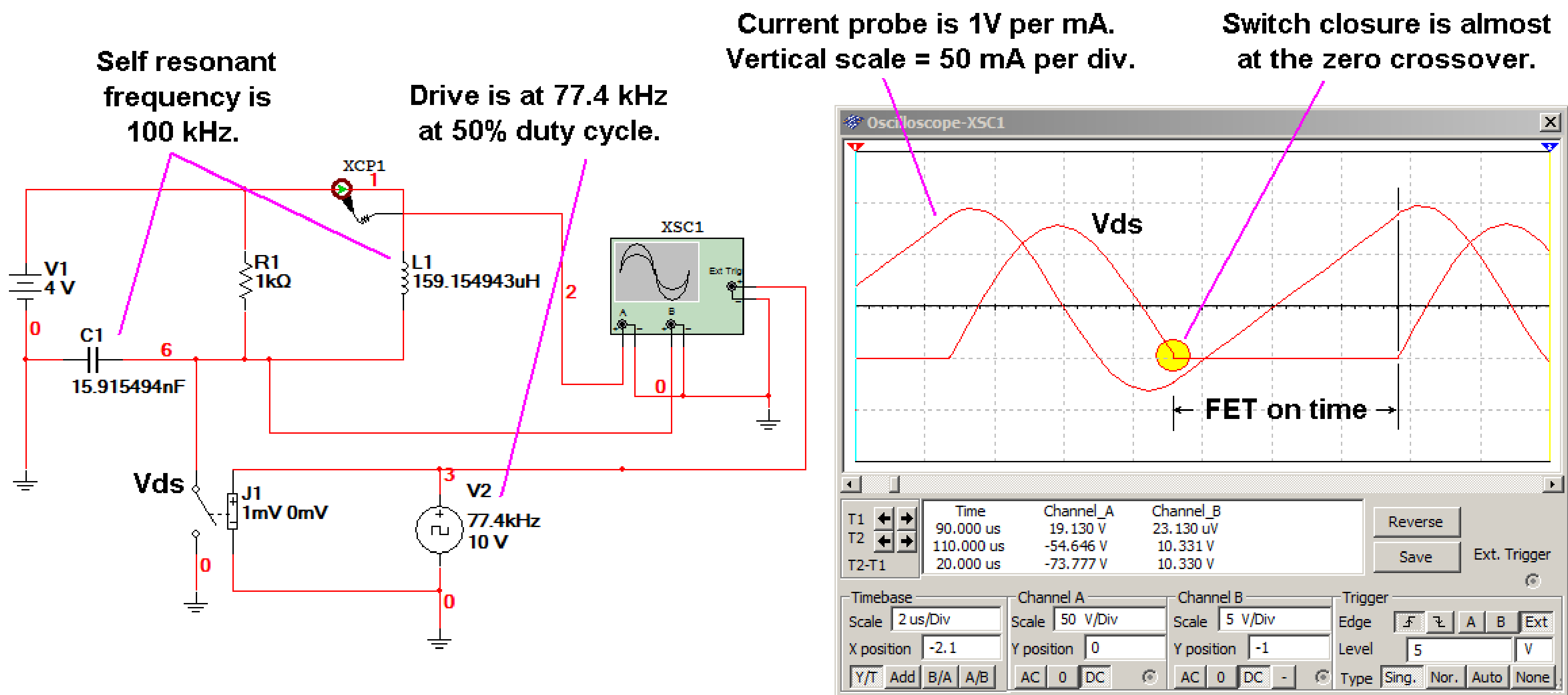
The volts RMS across Rcore and Lpri vary with changes in the values of those two items as follows:

	Rcore = 1000 Ohms	Rcore = 400 Ohms	Rcore = 200 Ohms
Lpri = 200 µHy	4.959 Vrms	4.843 Vrms	4.634 Vrms
175 µHy	4.963 Vrms	4.855 Vrms	4.657 Vrms
150 µHy	4.968 Vrms	4.870 Vrms	4.685 Vrms
100 µHy	4.978 Vrms	4.900 Vrms	4.748 Vrms
85 µHy	4.978 Vrms	4.907 Vrms	4.768 Vrms

These values of Vrms are found when the drive frequency at which the Rsw is toggled is made 77.4% of the nominal self resonance of Lpri and Ctrio (15289 pF).

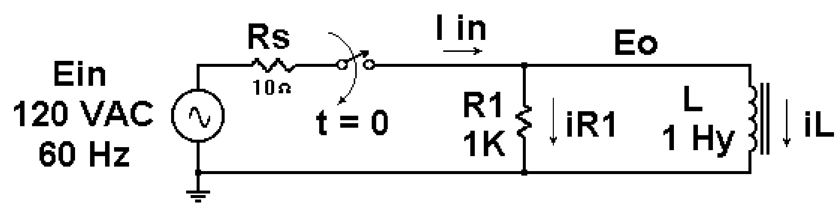
Ambertec, P.E., P.C.

SPICE Simulation



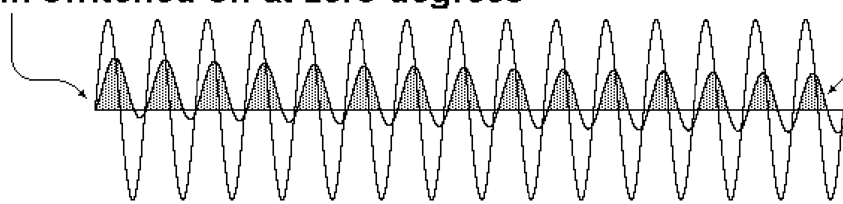
Ambertec, P.E., P.C.

Parallel RL response to AC input switching.
(Think “AC power transformer.”)



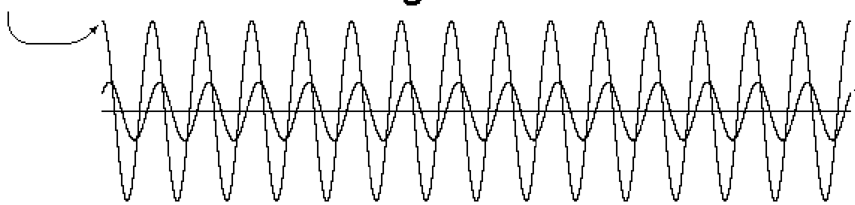
Eo = Ein - I in * Rs
iR1 = Eo / R1
diL = Eo * dt / L
iL = iL + diL
I in = iR1 + iL
t = t + dt

Ein switched on at zero degrees



The input current has a lo-o-o-o-ng duration decaying transient.

Ein switched on at 90 degrees



The input current is transient-free.

transpri.bas

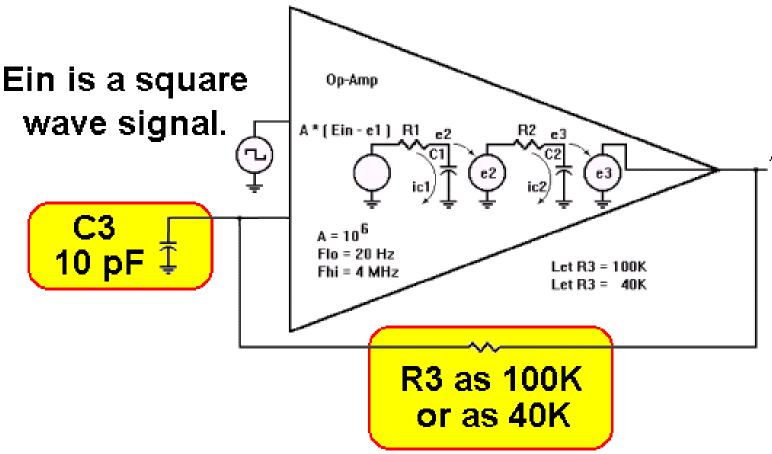
Ambertec, P.E., P.C.

Beware of Loop Gain!

Ambertec, P.E., P.C.

Op-Amp Stability versus Input Capacitance
(This capacitance is spelled "b-a-d")

Ein is a square wave signal.

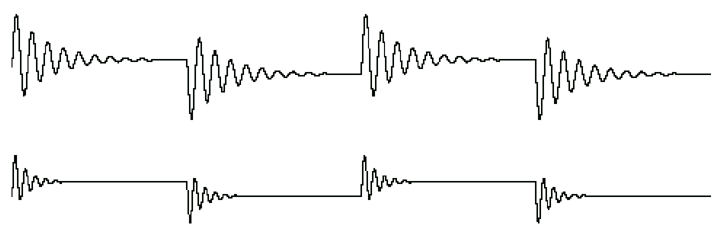


Eout shows just how close to instability this circuit can be.

For time = zero to 160 µSec:

R3 = 100K

R3 = 40K



You ignore this issue at your own peril!

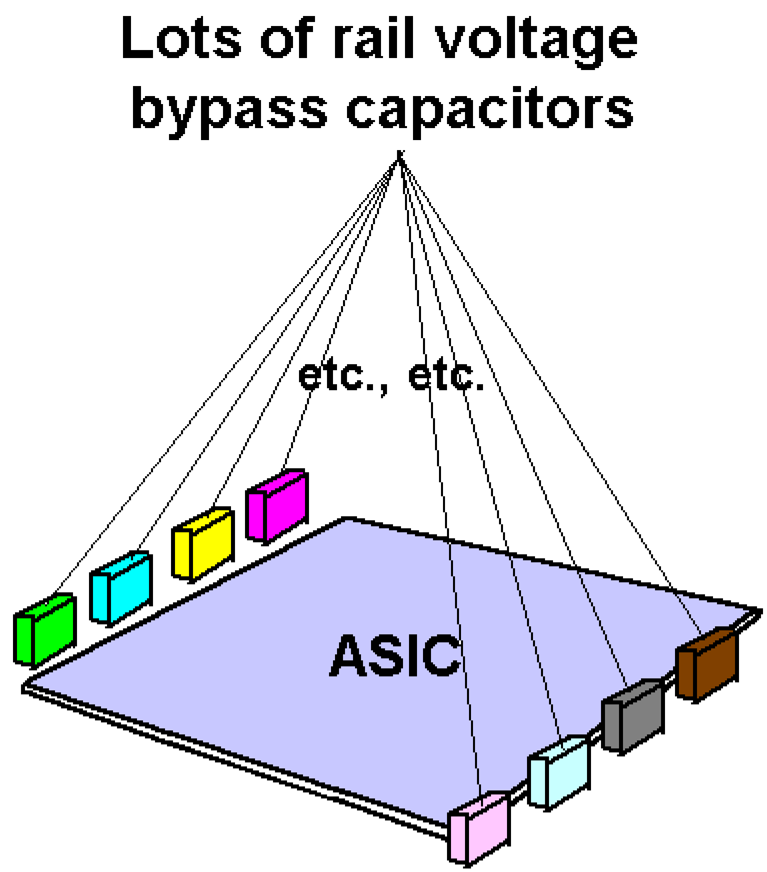
opamposc.bas


Canon a 3

Pieter van Laer
(Dutch, Haarlem 1592/5-1642 (?) Haarlem)

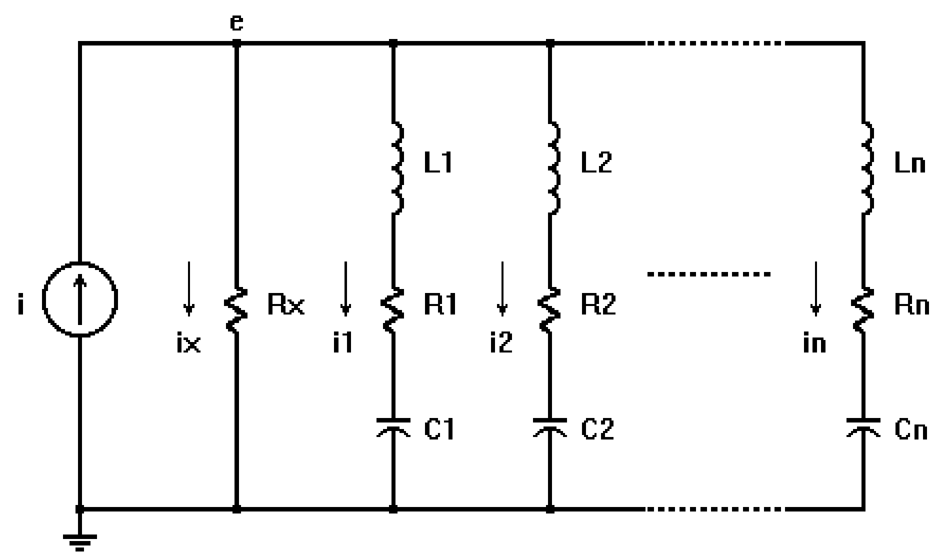
His work is on display at The Metropolitan Museum of Art

A Common Situation



Ambertec, P.E., P.C.

Recursive differential equations for a whole bunch of bypass capacitors across an ASIC's rail voltage to ground.

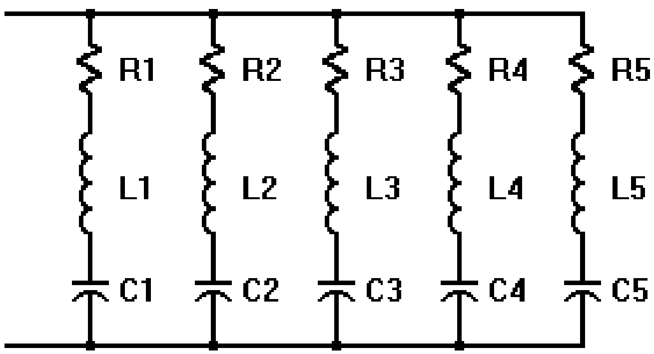



```
ix = i - i1 - i2 - · · · - in
e = ix * Rx
For j = 1 to n:
eLj = e - eCj - ij * Rj
dij = eLj * dt / Lj
deCj = ij * dt / Cj
ij = ij + dij
eCj = eCj + deCj  :  Next j
t = t * t + dt
```

Recursive Differential Equations

Ambertec, P.E., P.C.

Here is the complement of bypass capacitors on the ASIC's rail voltage with respect to ground.



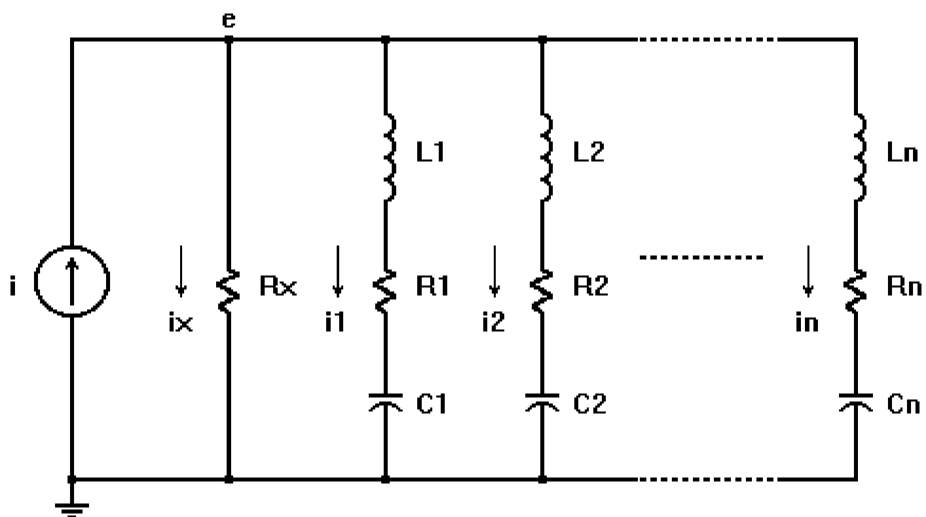
1 = 100 µF capacitor of flyback output.
2 = 10 µF tantalum capacitor.
3 = Ten paralleled 0.1 µF ceramic capacitors.
4 = Twelve paralleled 0.01 µF ceramic capacitors.
5 = Circuit board capacitance of 3000 pF.

We let SRFj be the self resonant frequency of capacitor Cj.
We find each $Lj = 1 / 4 / pi^2 / SRFj^2 / Cj$.

Each Rj is the equivalent series resistance (ESR) of capacitor Cj.

Ambertec, P.E., P.C.

Resistor Rx was added to the paralleled decoupling capacitors to simplify the differential equation derivation. Rx is chosen as 1000 Ohms in these calculations, a value much larger than the capacitor impedances over the frequencies of interest.

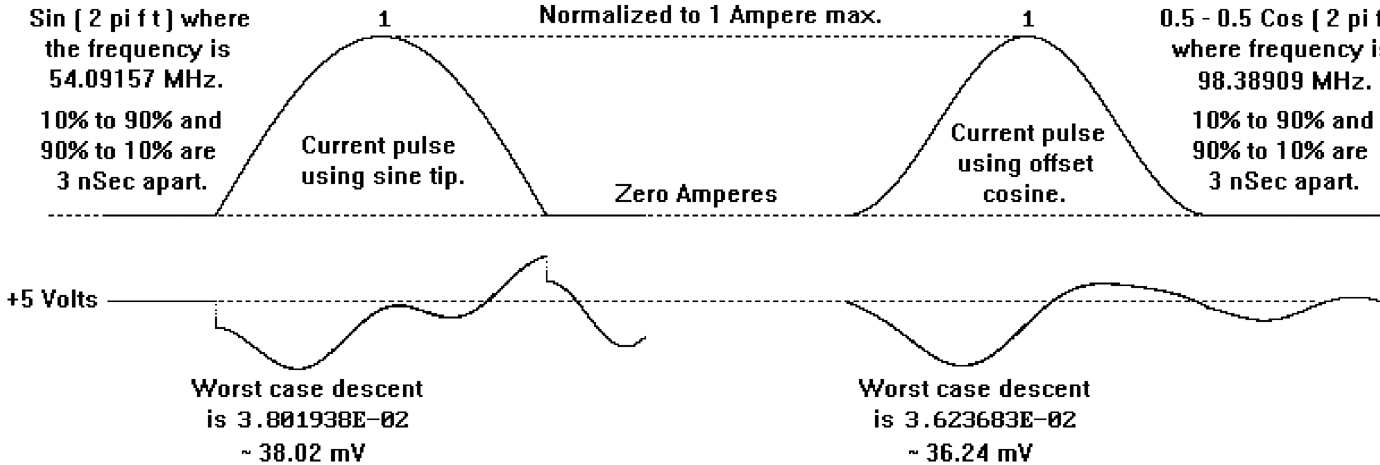


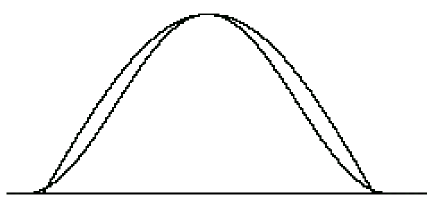

```
ix = i - i1 - i2 - · · · - in
e = ix * Rx
For j = 1 to n:
eLj = e - eCj - ij * Rj
dij = eLj * dt / Lj
deCj = ij * dt / Cj
ij = ij + dij
eCj = eCj + deCj  :   Next j
t = t ‡ t + dt
```

Recursive Differential Equations

Ambertec, P.E., P.C.

We examine two versions of the ASIC's current pulse(s).





Overlay of the two current pulses shows their similarity.

The first derivative of the sine tip current pulse with respect to time is itself non-zero at the zero current points. This results in steps in the rail voltage excursions away from the +5 Volts.

The first derivative of the offset cosine current pulse with respect to time is itself zero at the zero current points. This results in no steps in the rail voltage excursions away from the +5 Volts.

railpuls.bas

The rail voltage departures from +5V are as many mV as shown per ampere of pulse current.

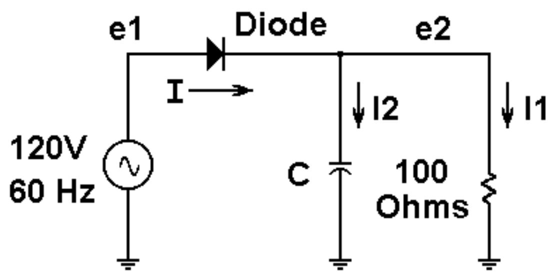
Rounded upward, the rail voltage departures may be taken as 40 mV per Ampere of pulse current.

The actual current pulses turned out to be 150 mA for which the rail voltage ripple came to 6 mV.

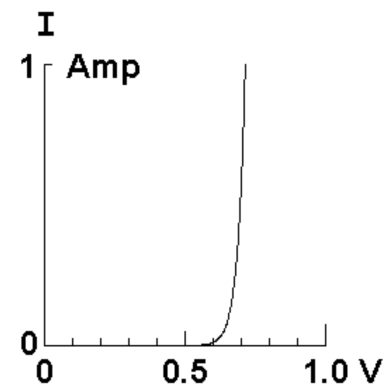
There were smiles.

Ambertec, P.E., P.C.

Half-wave rectifier including a non-linear device, the diode.



q = 1.602 E-19 coul
k = 1.38 E-23 joules per deg K
T = 300 K
Is = 1E-12



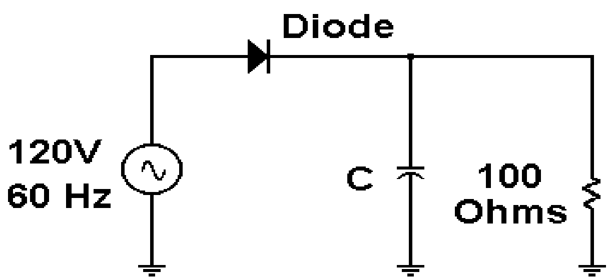
I = Is (exp (qV / kT) -1)
Is = 1E-12

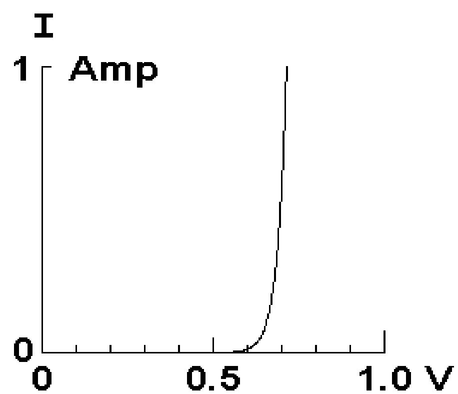
→ I = Is (exp (q (e1 - e2) / kT) -1)
I1 = e2 / R
I2 = I - I1
de2 = I2 dt / C
e2 = e2 + de2
t = t + dt

diodevi.bas

Ambertec, P.E., P.C.

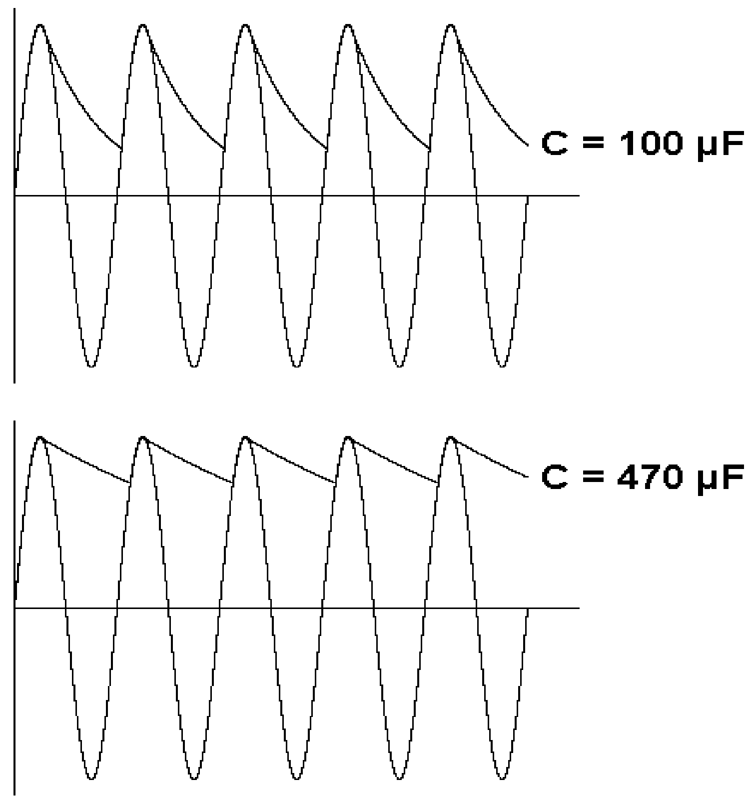
Half-wave rectifier including a non-linear device, the diode.





$I = Is\,(\exp(qV / kT) - 1)$

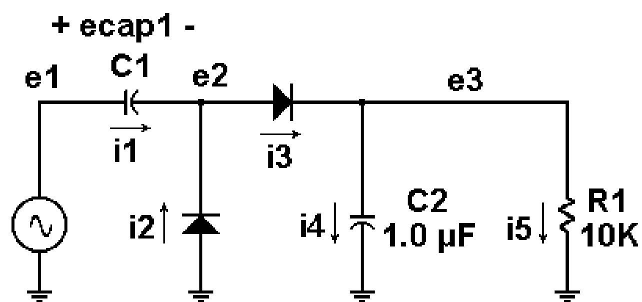
$Is = 1E-12$



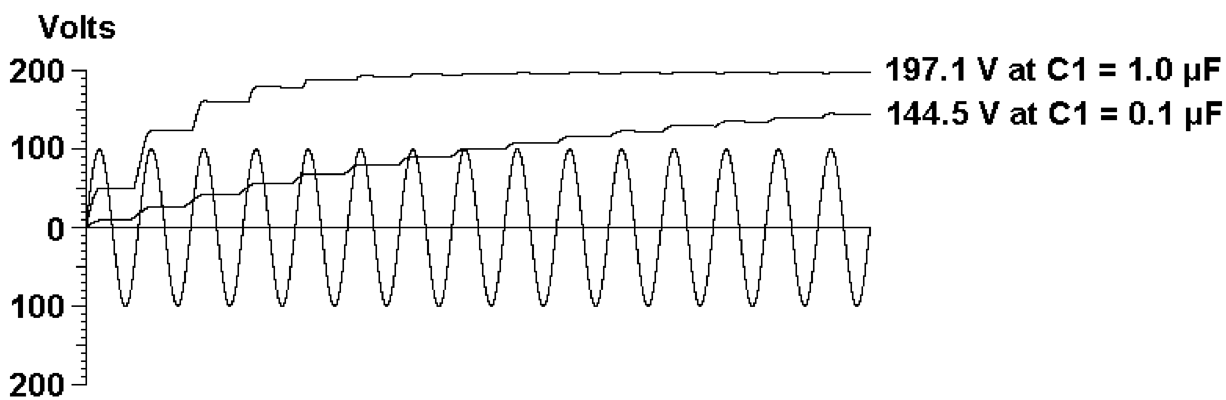
halfwave.bas

Ambertec, P.E., P.C.

Half-wave, Cockroft-Walton voltage doubling rectifier

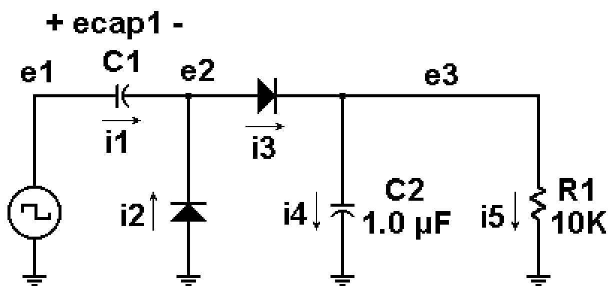



```
e2 = e1 - ecap1
i3 = Is ( exp ( q ( e2 - e3 ) / kT ) -1 )
I2 = Is ( exp ( -q e2 / kT ) -1 )
I1 = i3 - i2
decap1 = i1 dt / C1
ecap1=ecap1 + decap1
i5 = e3 / R1
i4 = i3 - i5
de3 = i4 dt / C2
e3 = e3 + de3
t = t + dt
```

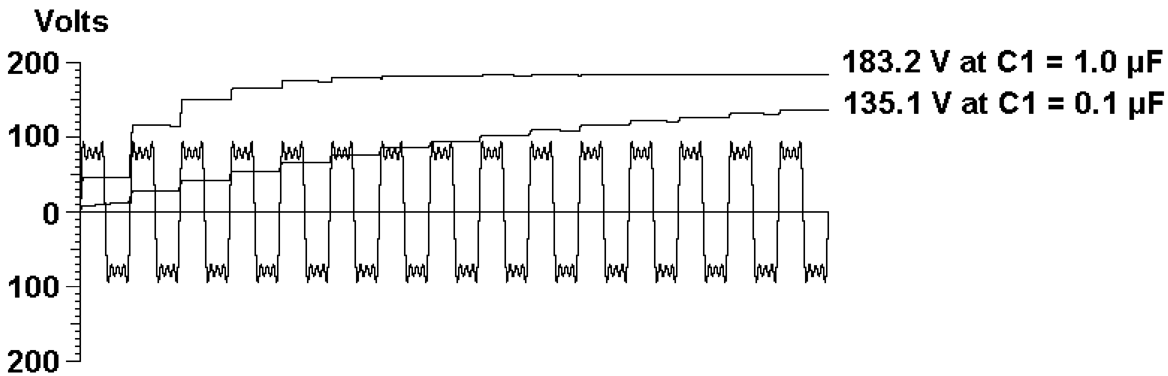


Ambertec, P.E., P.C.

Half-wave, Cockroft-Walton voltage doubling rectifier

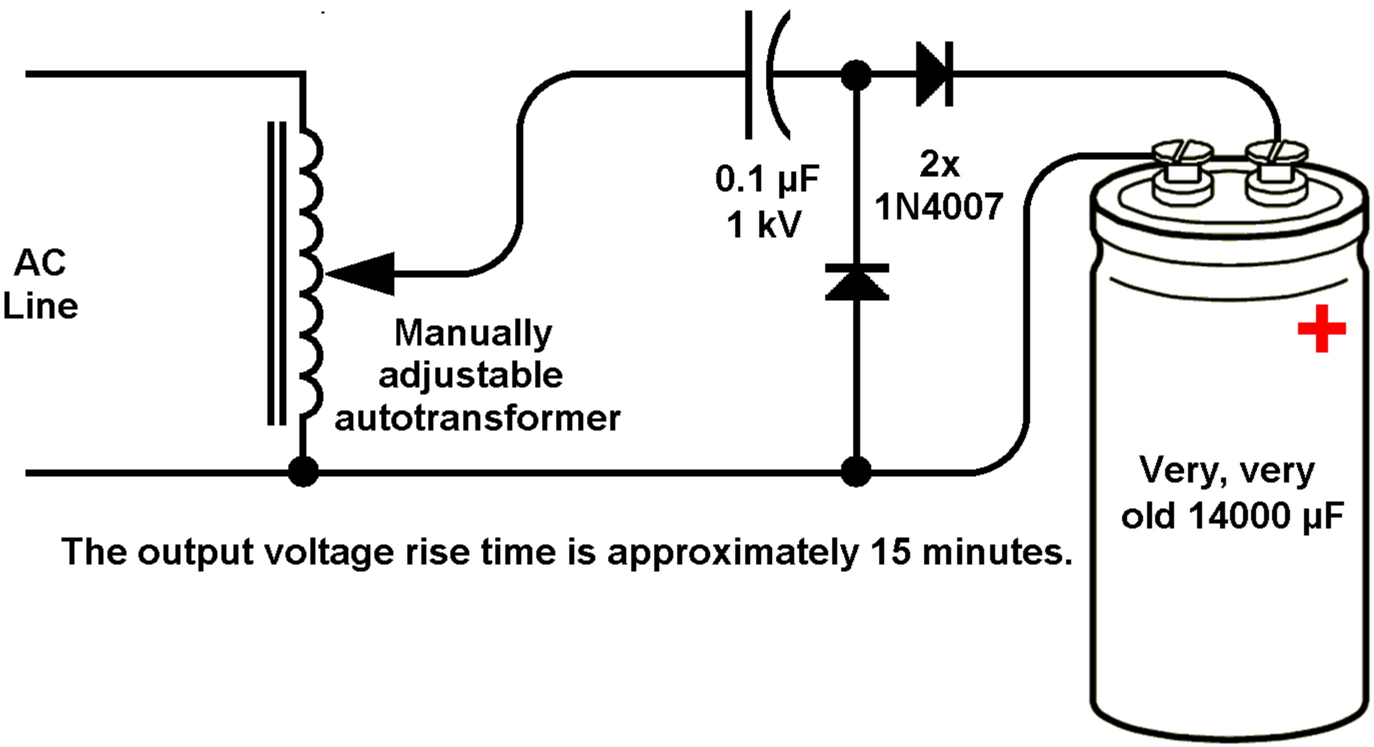



```
e2 = e1 - ecap1
i3 = Is ( exp ( q ( e2 - e3 ) / kT ) -1 )
I2 = Is ( exp ( -q e2 / kT ) -1 )
I1 = i3 - i2
decap1 = i1 dt / C1
ecap1=ecap1 + decap1
i5 = e3 / R1
i4 = i3 - i5
de3 = i4 dt / C2
e3 = e3 + de3
t = t + dt
```



Ambertec, P.E., P.C.

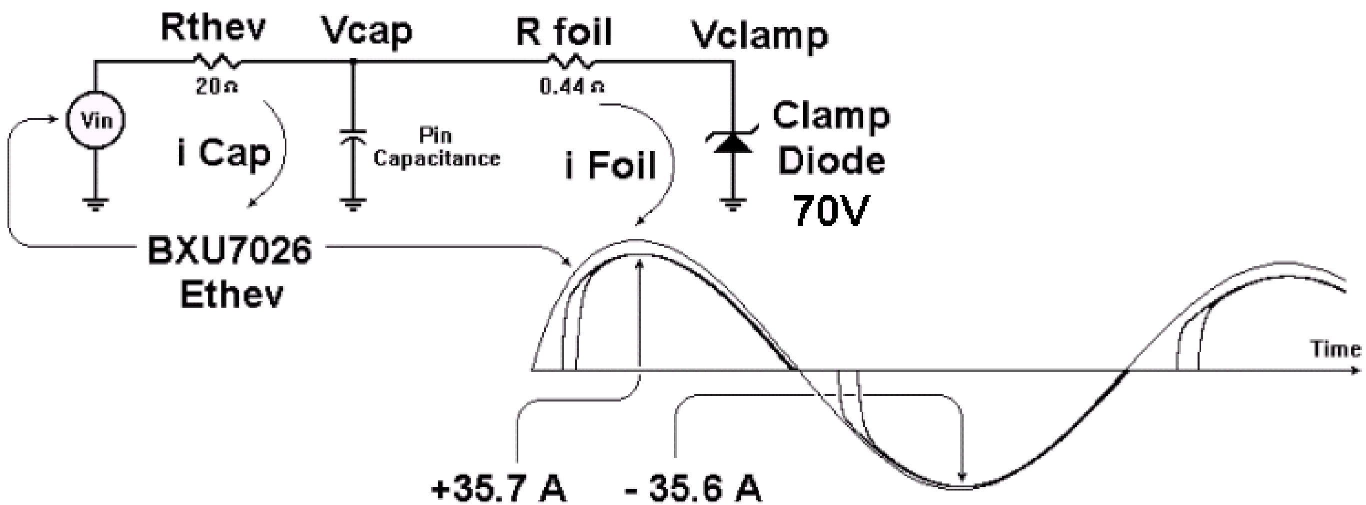
A safe method to rejuvenate an old electrolytic capacitor.



The output voltage rise time is approximately 15 minutes.

Ambertec, P.E., P.C.

Lightning strike protection using a clamp diode.

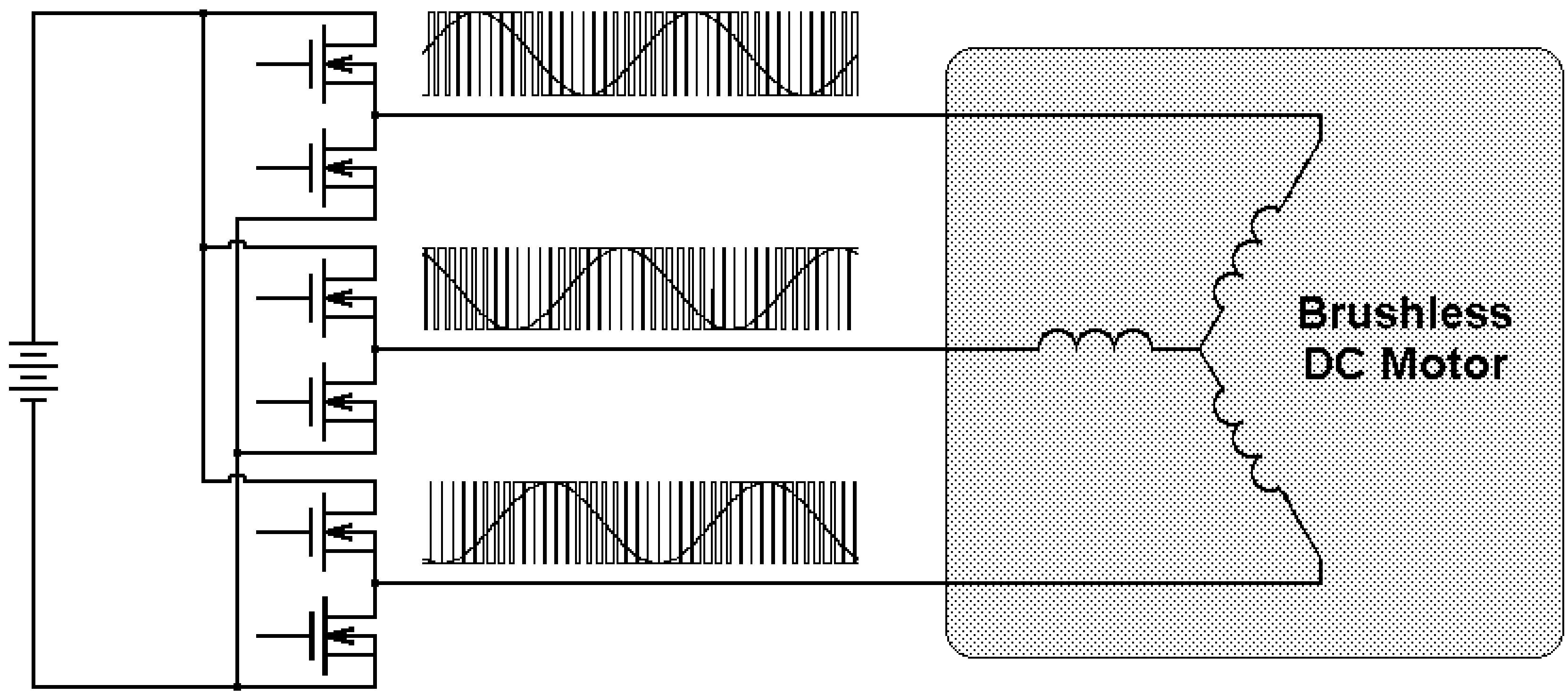


For C pin = 8000 pF, maximum foil current = 35.7A and -35.6A.
If Cpin = 16000 pF, the maxium foil currents are the same, but their onsets are slightly delayed.

zlight.bas

Ambertec, P.E., P.C.

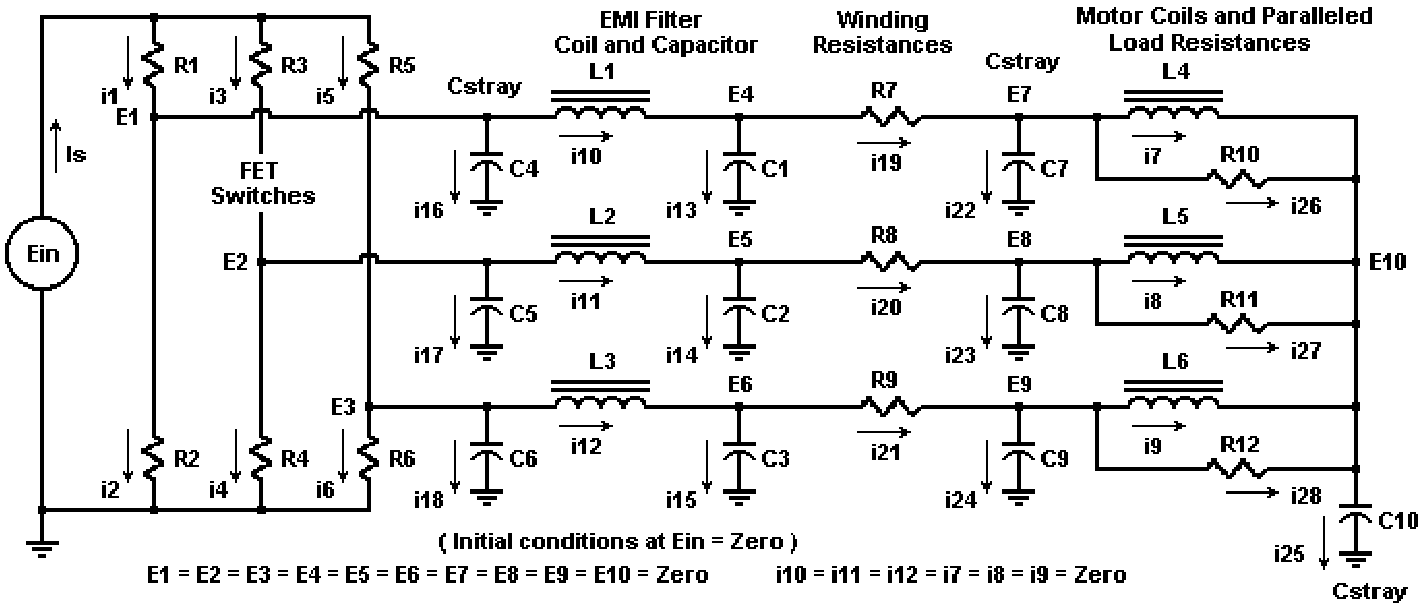
Three-phase PWM excitation of a brushless DC motor.



pwm_sine.bas

Ambertec, P.E., P.C.

Three-phase PWM excitation of a brushless DC motor.

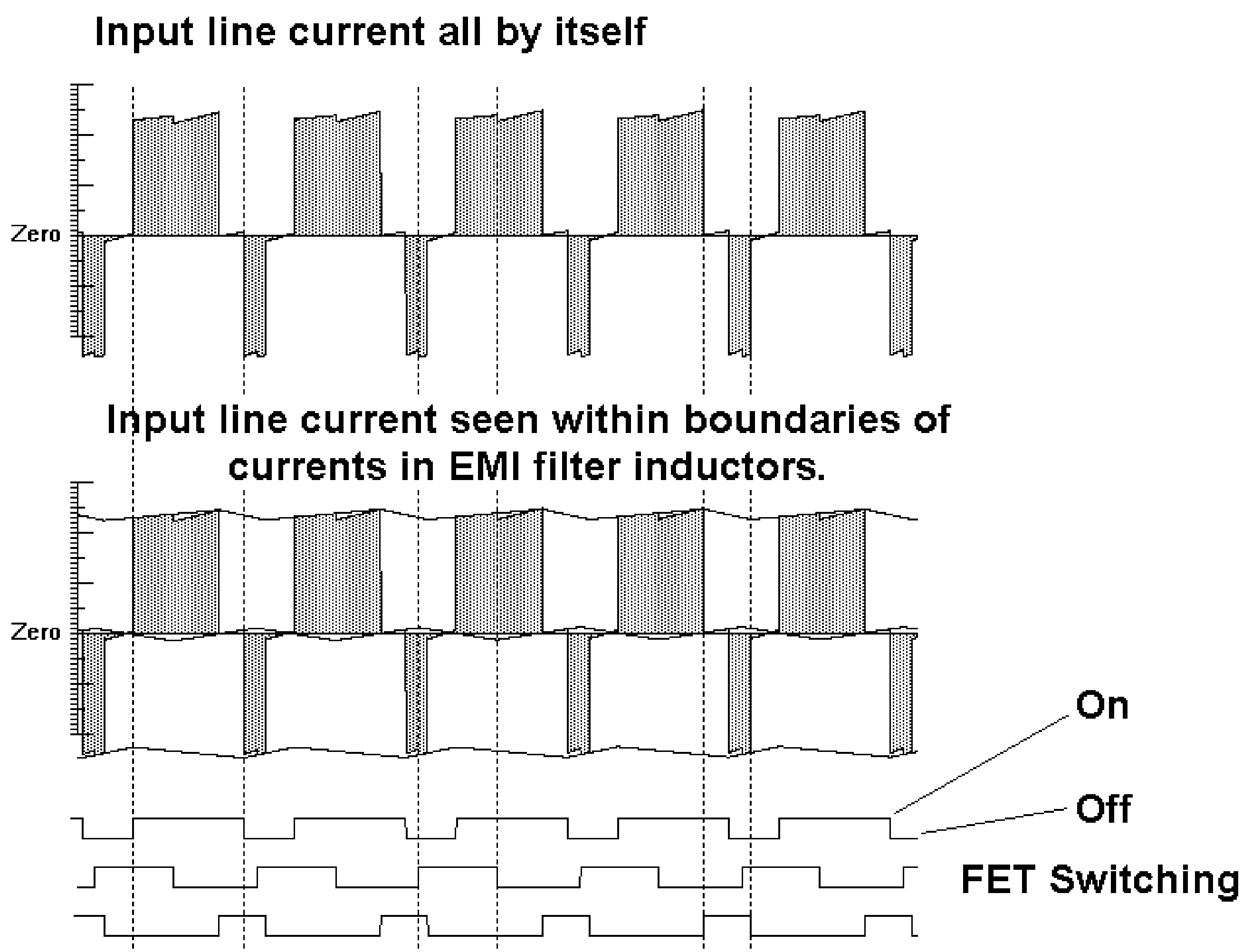


(Initial conditions at Ein = Zero)

E1 = E2 = E3 = E4 = E5 = E6 = E7 = E8 = E9 = E10 = Zero   i10 = i11 = i12 = i7 = i8 = i9 = Zero

i1 = (Ein - E1) * G1 ; i2 = E1 * G2 ; i16 = i1 - i2 - i10 ; dE1 = i16 * dT / C4 ; E1 = E1 + dE1 ; di10 = (E1 - E4) * dT / L1
i10 = i10 + di10 ; i13 = i10 - i19 ; dE4 = i13 * dT / C1 ; E4 = E4 + dE4 ; i19 = (E4 - E7) * G7 ; i22 = i19 - i7- i26
dE7 = i22 * dT / C7 ; E7 = E7 + dE7 ; di7 = (E7 - E10) * dT / L4 ; i7 = i7 + di7 ; i26 = (E7 - E10) * G10
i3 = (Ein - E2) * G3 ; i4 = E2 * G4 ; i17 = i3 - i4 - i11 ; dE2 = i17 * dT / C5 ; E2 = E2 + dE2 ; di11 = (E2 - E5) * dT / L2
i11 = i11 + di11 ; i14 = i11 - i20 ; dE5 = i14 * dT / C2 ; E5 = E5 + dE5 ; i20 = (E5 - E8) * G8 ; i23 = i20 - i8 - i27
dE8 = i23 * dT / C8 ; E8 = E8 + dE8 ; di8 = (E8 - E10) * dT / L5 ; i8 = i8 + di8 ; i27 = (E8 - E10) * G11
i5 = (Ein - E3) * G5 ; i6 = E3 * G6 ; i18 = i5 - i6 - i12 ; dE3 = i18 * dT / C6 ; E3 = E3 + dE3 ; di12 = (E3 - E6) * dT / L3
i12 = i12 + di12 ; i15 = i12 - i21 ; dE6 = i15 * dT / C3 ; E6 = E6 + dE6 ; i21 = (E6 - E9) * G9 ; i24 = i21 - i9 - i28
dE9 = i24 * dT / C9 ; E9 = E9 + dE9 ; di9 = (E9 - E10) * dT / L6 ; i9 = i9 + di9 ; i28 = (E9 - E10) * G12
i25 = i7 + i8 + i9 + i26 + i27 + i28 ; dE10 = i25 * dT / C10 ; E10 = E10 + dE10 ; Is = i1 + i3 + i5

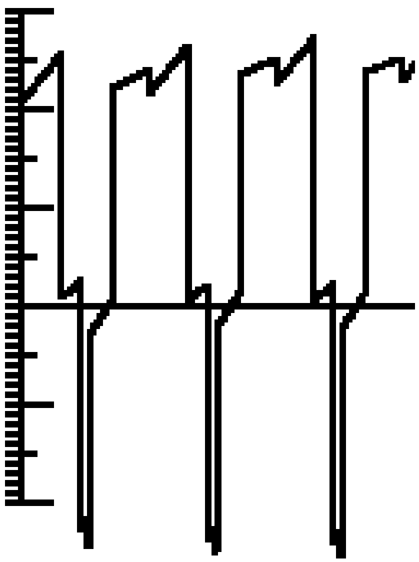
Three-phase PWM excitation of a brushless DC motor.

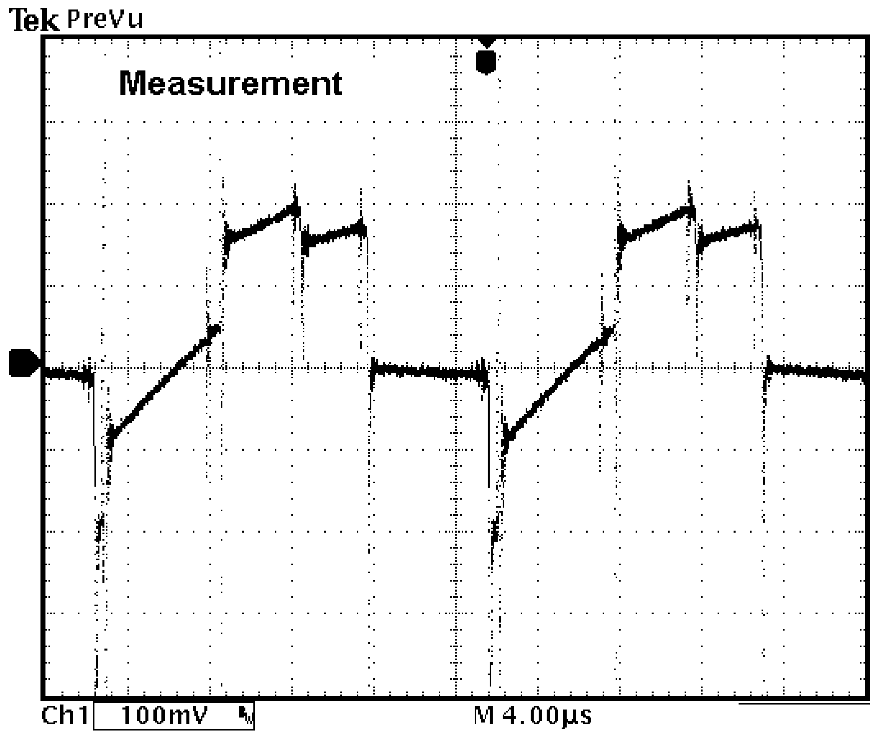


Ambertec, P.E., P.C.

Comparison of Simulation and Measurement

Motor Current Leg Waveform Calculation





motstall.bas

Ambertec, P.E., P.C.

ambertec@ieee.org