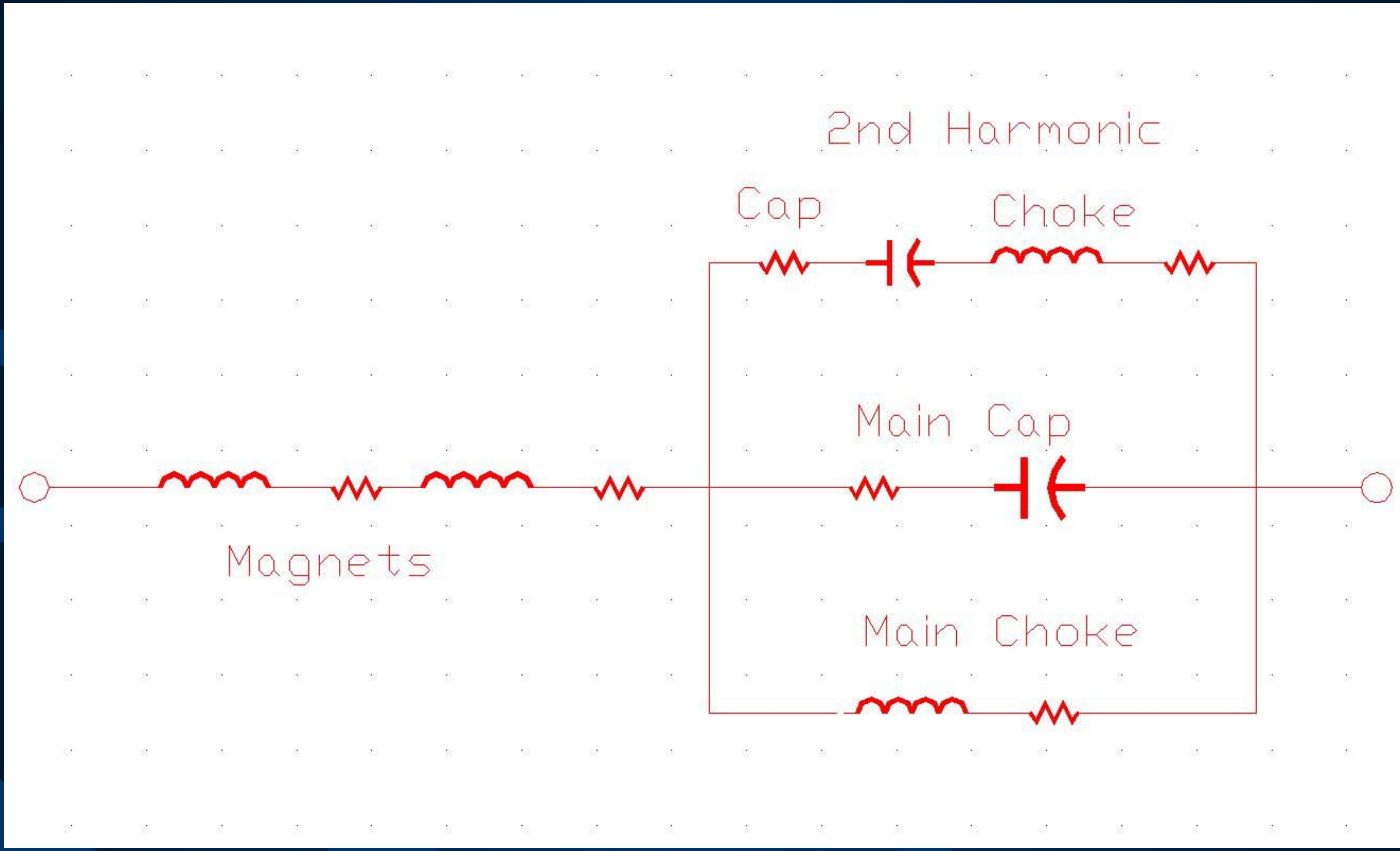
BOOSTER DUAL RESONANCE

- First look at a possible solution for a dual resonant modification to the existing Booster.
- The purpose is to decrease the maximum di/dt in booster magnets and thus free up additional RF capability.
- Goal is to keep present magnets, chokes, and capacitors.
- Add additional components as necessary

Booster Cell With 2nd Harmonic



Mathcad program for calculating component values:

Calculations For A Dual Resonant Booster

DAW 4/5/03

Impedance - neglecting loses:

$$z := \omega \cdot Lm \cdot j + \frac{1}{\left[\frac{1}{\frac{1}{\omega \cdot C \cdot j}} + \frac{1}{\omega \cdot Lch \cdot j} + \frac{1}{\left(\omega \cdot Ls \cdot j + \frac{1}{\omega \cdot Cs \cdot j}\right)}\right]}$$

First some definitions:

The two resonanat frequencies desired (Hz): $fres1 := 15$ $fres2 := 30$

$wres1 := 2 \cdot \pi \cdot fres1$ $wres2 := 2 \cdot \pi \cdot fres2$ $wsum := (wres1)^2 + (wres2)^2$ $wdiff := (wres2)^2 - (wres1)^2$

The magnet inductance (H): $Lm := 0.0204$

The main capacitor bank (F): $C := 0.00611$

Let σ be equal to the ratio of the choke to magnet inductance: $\sigma := 1.96$ $Lch := \sigma \cdot Lm$

The Main Choke Inductance: $Lch = 0.04$

Let υ be equal to the ratio of the res. choke to magnet inductance: $\upsilon := 1.275$ $Lres := \upsilon \cdot Lm$

2nd Harmonic Choke Inductance: $Lres = 0.026$

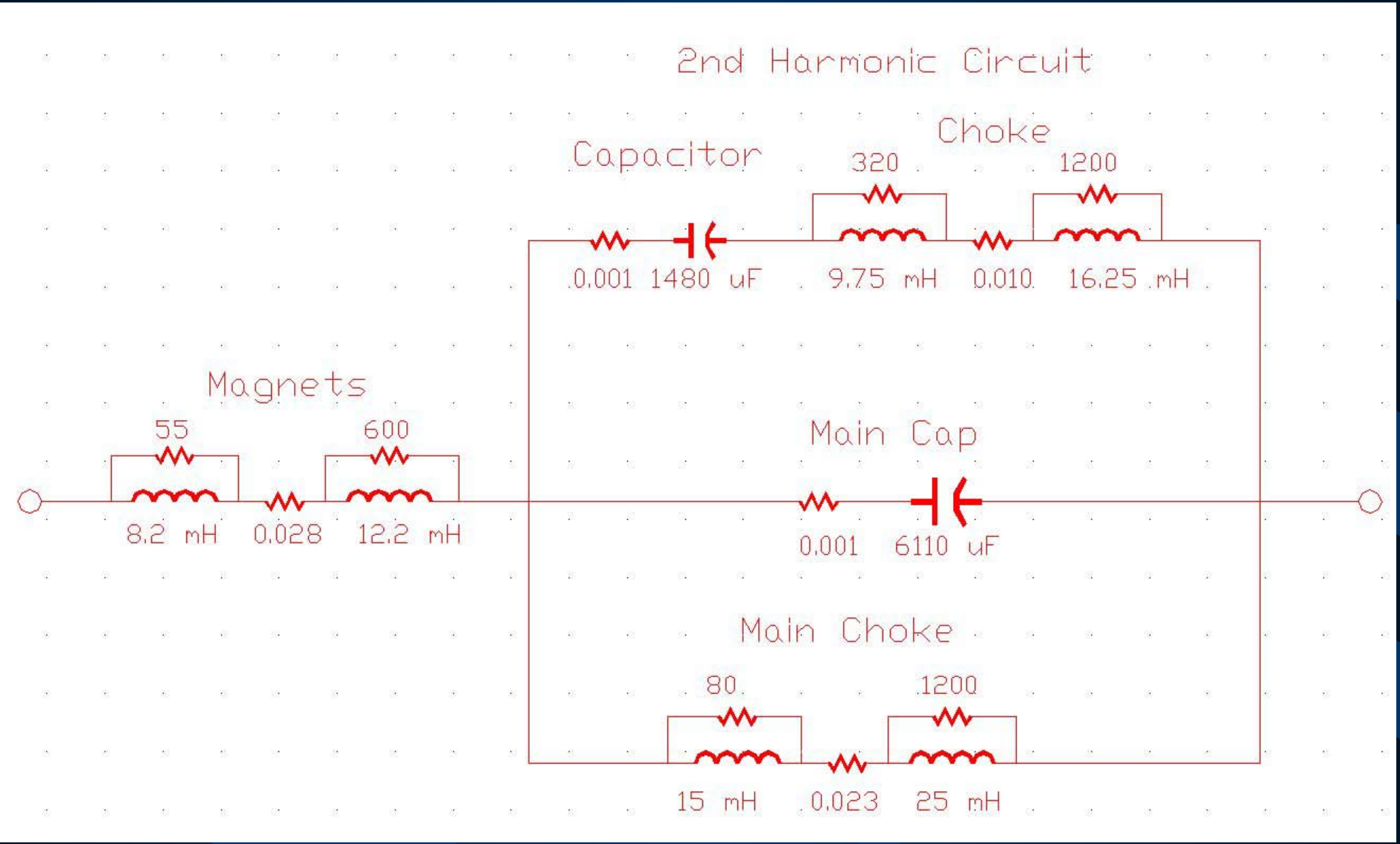
From the analysis below η, the ratio of 2nd harmonic cap bank to main cap bank should be:

$$\eta := \frac{4 \cdot (\sigma + 1)}{\left(wsum^2 - wdiff^2\right) \cdot (Lm \cdot C)^2 \cdot \upsilon \cdot \sigma} \qquad \eta = 0.242 \qquad Cres := \eta \cdot C$$

2nd Harmonic Cap Bank: $Cres = 1.476 \times 10^{-3}$

1st Resonance: $f1 = 14.988$ **2nd Resonance:** $f2 = 30.025$

ATP Computer Model



Mathcad program for investigating component sensitivity:

ADMITTANCE PLOT OF DUAL RESONANT BOOSTER **daw 7/29/03**

THE MAGNET: Rmag1 := 55.0 Rmag := 0.0028 Rmag2 := 500.0

Lmag1 := 0.0082 Lmag2 := 0.0122

THE MAIN CHOKE: Rmck1 := 80.0 Rmck := 0.0023 Rmck2 := 1200.0

Lmck1 := 0.015 Lmck2 := 0.025

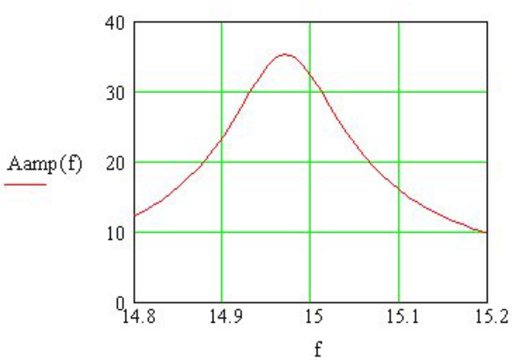
THE 2ND HARMONIC CHOKE: Rmhm1 := 320.0 Rmhm := 0.010 Rmhm2 := 1200.0

Lmhm1 := 0.00975 Lmhm2 := 0.01625

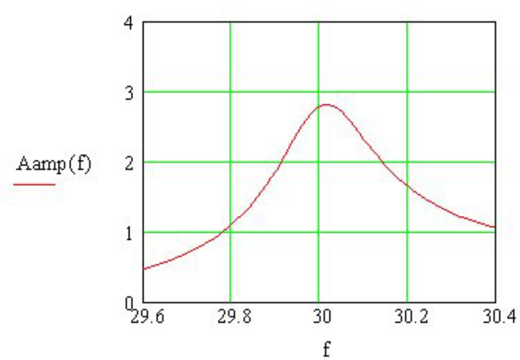
THE MAIN CAP BANK: Cmcap := 0.00611 Rmcap := 0.001

THE 2nd HARMONIC CAP BANK: Cmhm := 0.001480 Rhcap := 0.001

First Resonance:



Second Harmonic:



Mathcad program for calculating the 15 Hz amplitude given required peak current and the relative amplitude of the 2nd harmonic

The following analysis relates to a DUAL RESONANT booster

The purpose is to calculate the required amplitude of the first resonance given the peak current and the relative amplitude of the second resonance.

The current has the form of:

$$Imag := A\cdot\cos(\theta) + B\cdot\sin(2\cdot\theta)$$

The required peak current is: $Iampk := 435.0$

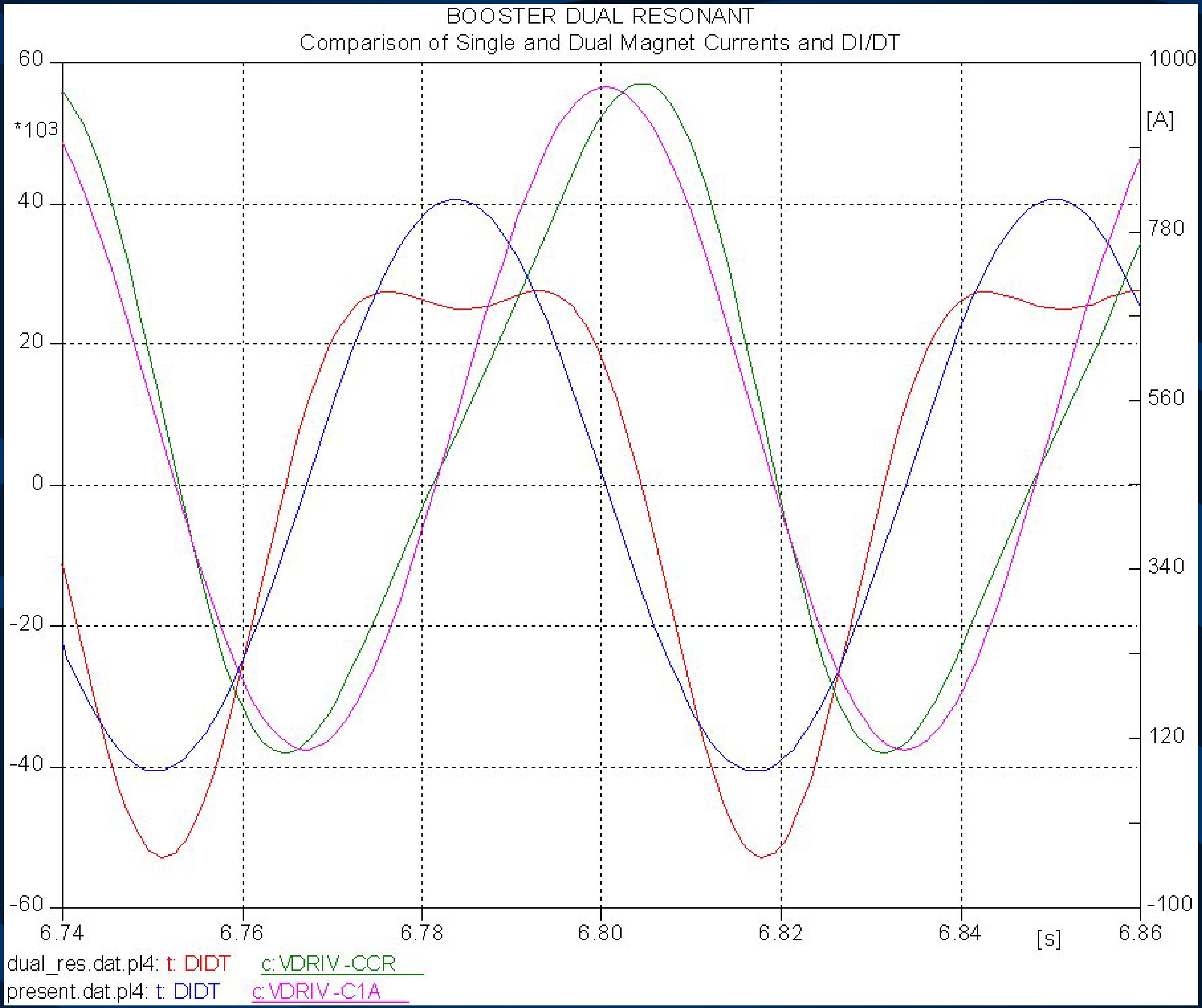
The relative amplitude of the second resonace is (B/A): $\alpha := .125$

$$A := \frac{Iampk}{(\cos(th) + \alpha\cdot\sin(2\cdot th))}$$

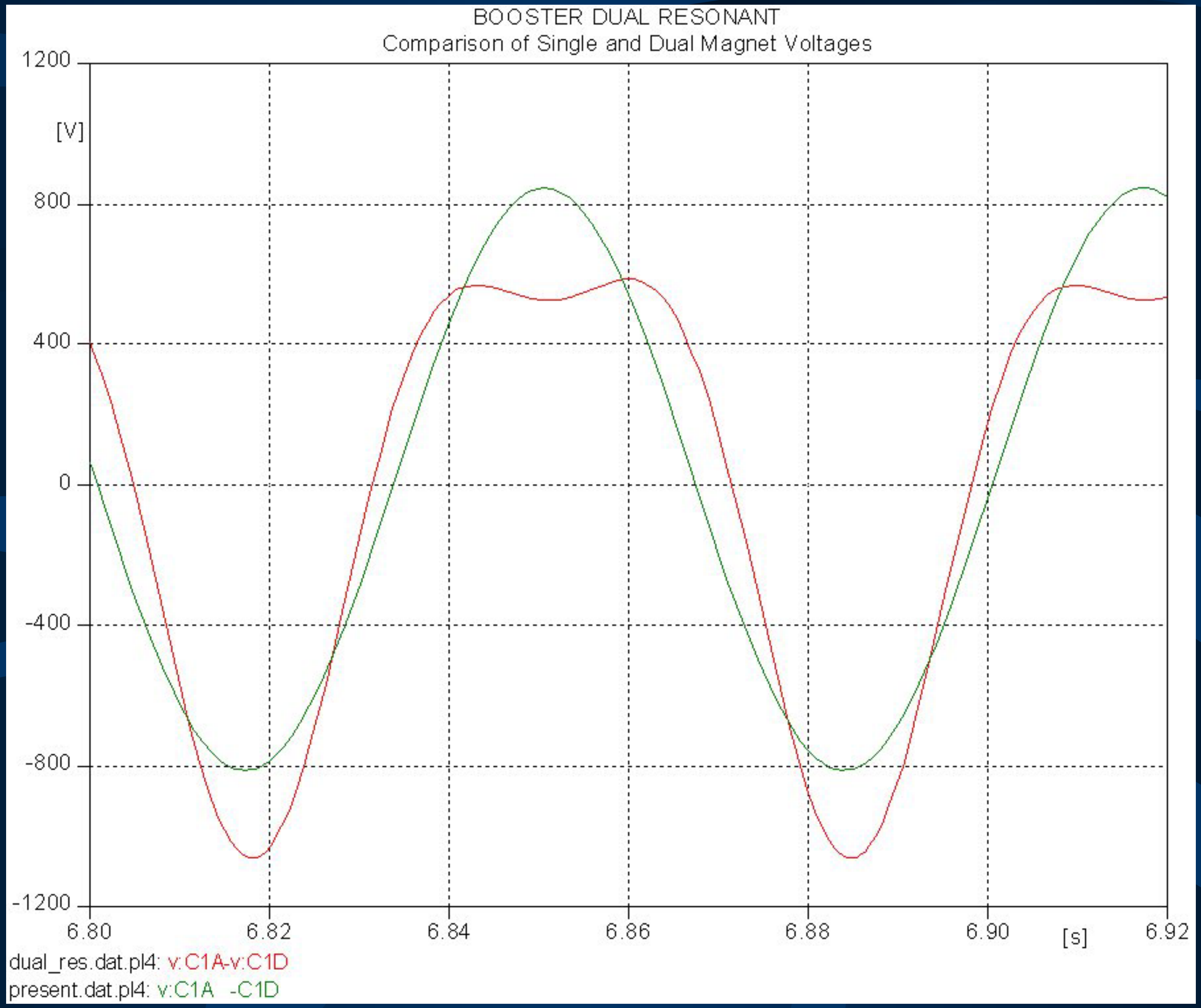
$A = 422.705$

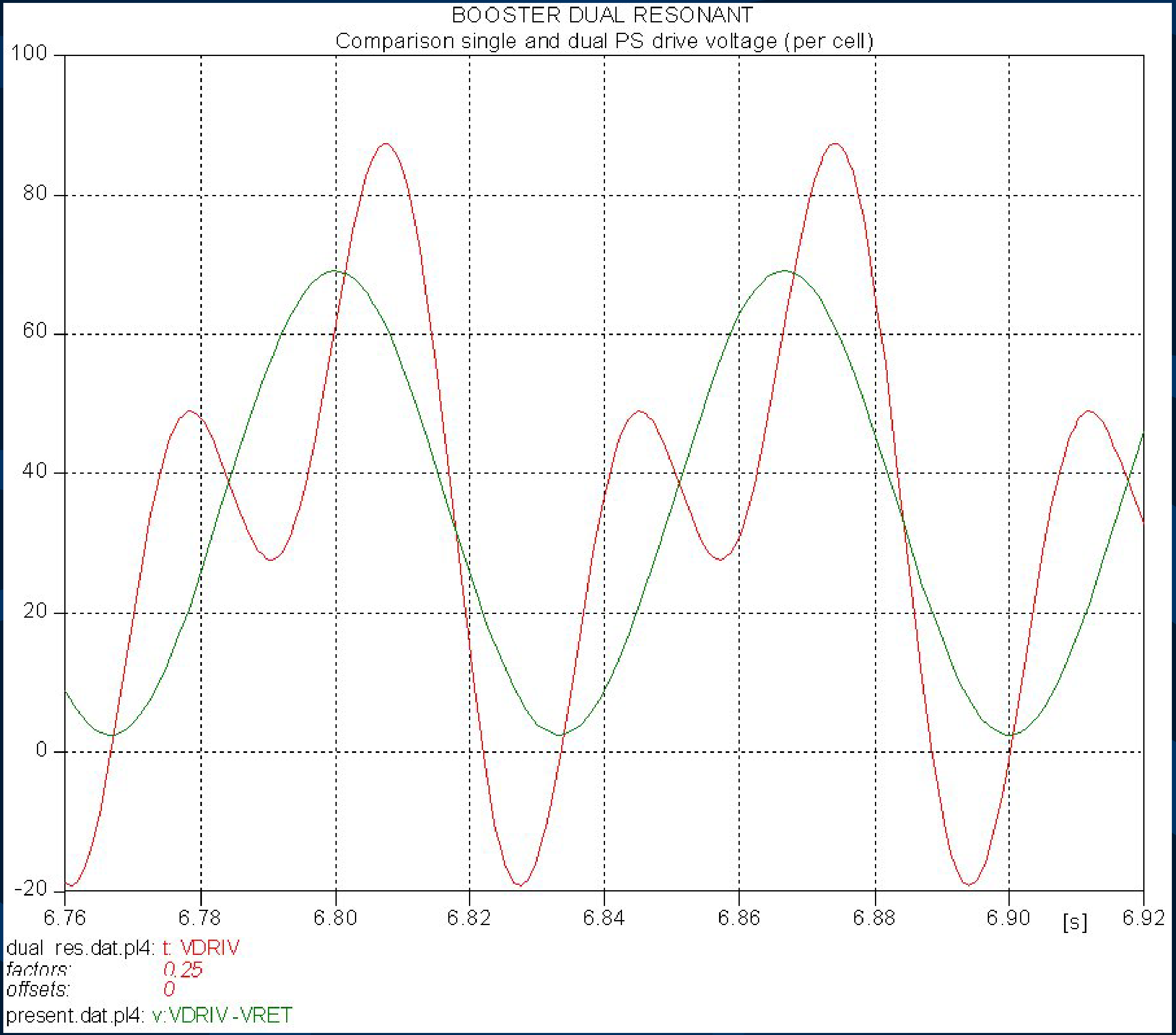
And since $B := \alpha\cdot A$

$B = 52.838$

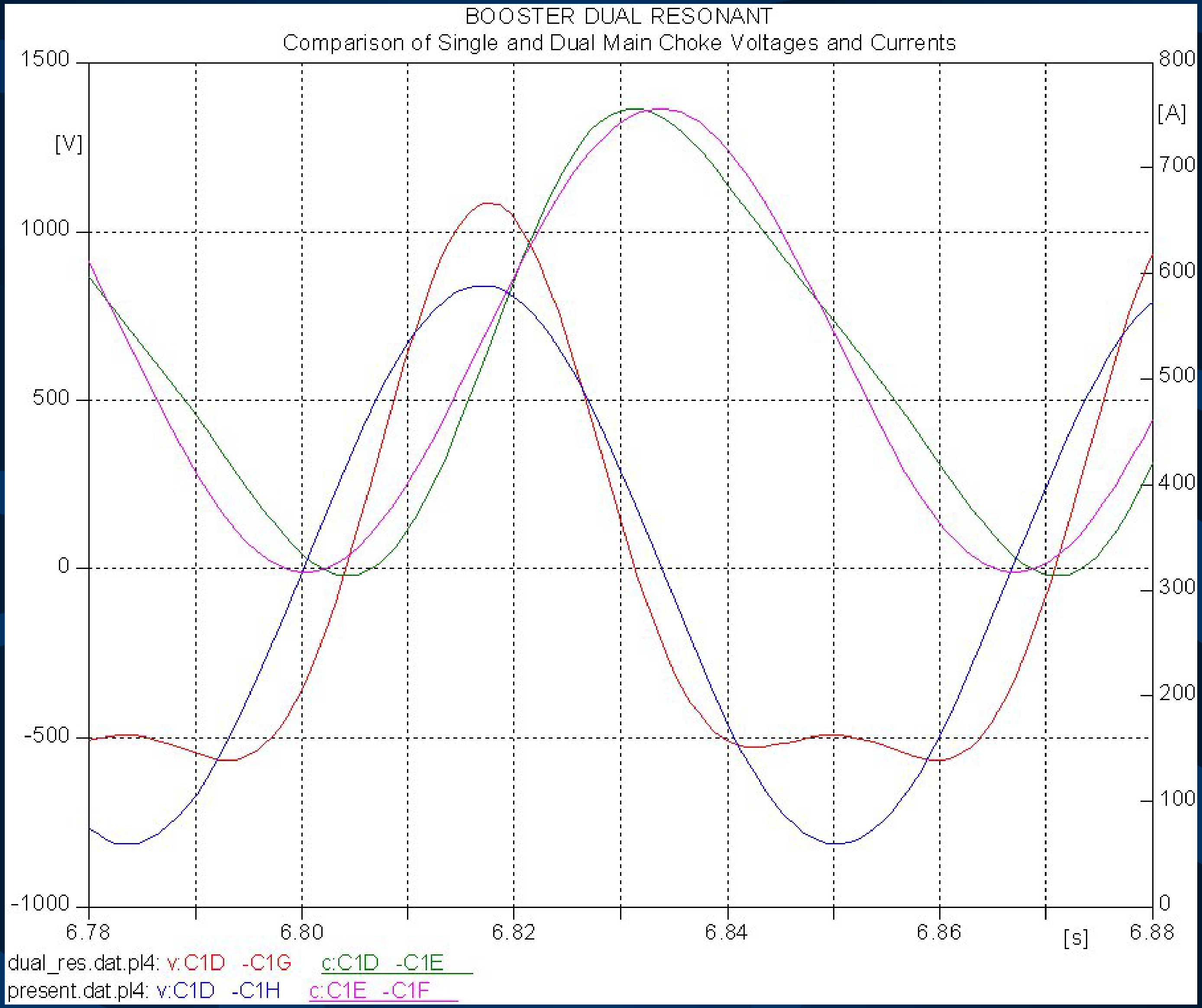


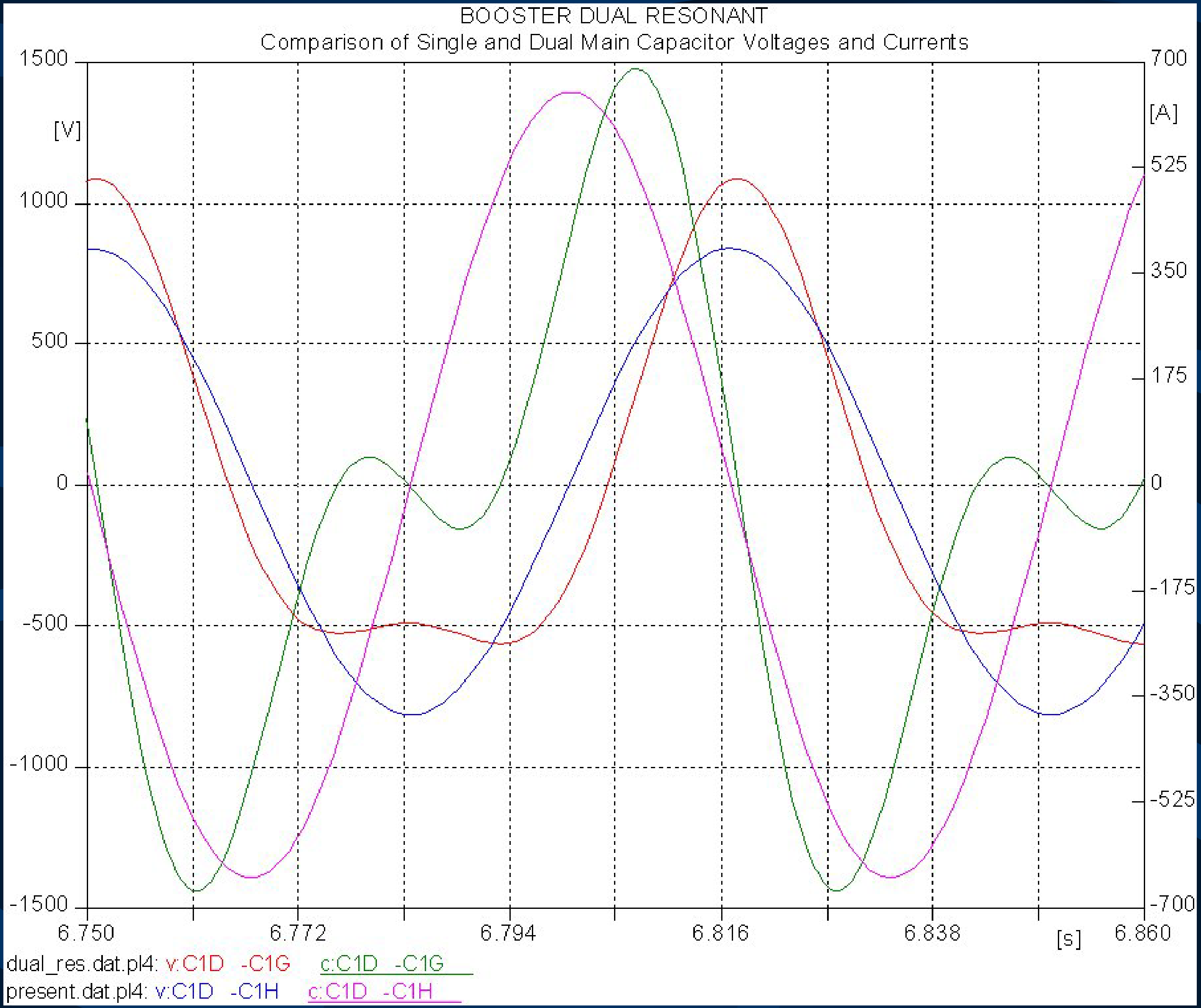
BOOSTER DUAL RESONANT
Comparison of Single and Dual Magnet Currents and DI/DT
60
*103
40
20
0
-20
-40
-60
1000
[A]
780
560
340
120
-100
6.74
6.76
6.78
6.80
6.82
6.84
[s]
6.86
dual_res.dat.pl4: t: DIDT
c:VDRIV-CCR
present.dat.pl4: t: DIDT
c:VDRIV-C1A

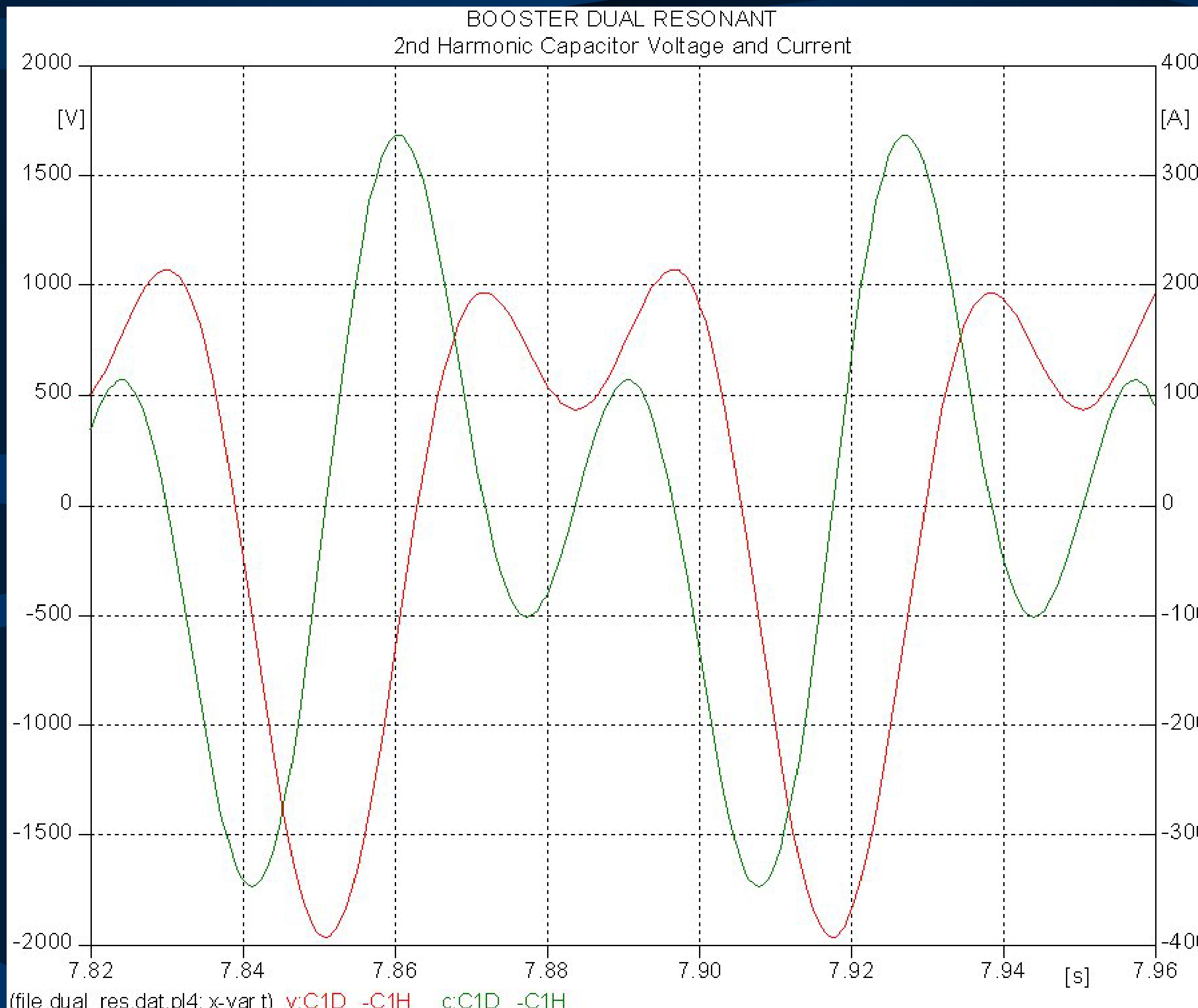

BOOSTER DUAL RESONANT
Comparison of Single and Dual Magnet Voltages
1200
[V]
800
400
0
-400
-800
-1200
6.80
6.82
6.84
6.86
6.88
6.90
[s]
6.92
dual_res.dat.pl4: v:C1A-v:C1D
present.dat.pl4: v:C1A -C1D



BOOSTER DUAL RESONANT
Comparison single and dual PS drive voltage (per cell)
100
80
60
40
20
0
-20
6.76
6.78
6.80
6.82
6.84
6.86
6.88
6.90
[s]
6.92
dual res.dat.pl4: t: VDRIV
factors: 0.25
offsets: 0
present.dat.pl4: v:VDRIV-VRET


BOOSTER DUAL RESONANT
Comparison of Single and Dual Main Choke Voltages and Currents
[V]
1500
1000
500
0
-500
-1000
[A]
800
700
600
500
400
300
200
100
0
6.78
6.80
6.82
6.84
6.86
6.88
[s]
dual_res.dat.pl4: v:C1D -C1G c:C1D -C1E
present.dat.pl4: v:C1D -C1H c:C1E -C1F

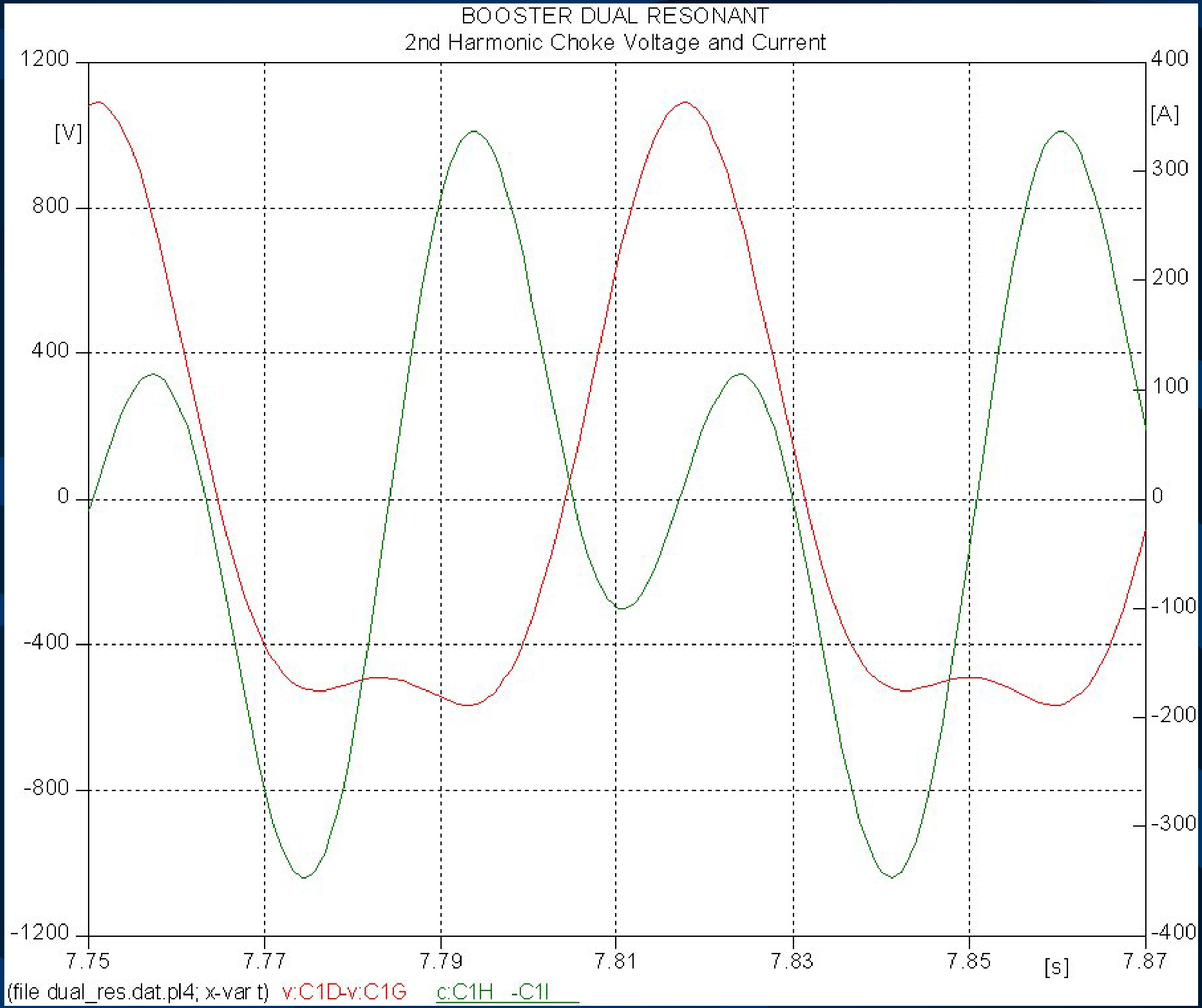

BOOSTER DUAL RESONANT
Comparison of Single and Dual Main Capacitor Voltages and Currents
1500
1000
500
0
-500
-1000
-1500
[V]
700
[A]
525
350
175
0
-175
-350
-525
-700
6.750
6.772
6.794
6.816
6.838
6.860
[s]
dual_res.dat.pl4: v:C1D -C1G c:C1D -C1G
present.dat.pl4: v:C1D -C1H c:C1D -C1H



BOOSTER DUAL RESONANT
2nd Harmonic Capacitor Voltage and Current
[V]
[A]
2000
1500
1000
500
0
-500
-1000
-1500
-2000
400
300
200
100
0
-100
-200
-300
-400
7.82
7.84
7.86
7.88
7.90
7.92
7.94
[s]
7.96
(file dual_res.dat.pl4; x-var t) v:C1D -C1H c:C1D -C1H

2nd Harmonic Capacitor Specifications:

- Capacitance: 1480 uF
- Peak Current: 350 amps
- RMS Current: 200 amps
- Peak Voltage (differential): 2000 volts
- Peak Voltage (common mode): 1500 volts
- Total Loses: < 500 watts


BOOSTER DUAL RESONANT
2nd Harmonic Choke Voltage and Current
1200
800
400
0
-400
-800
-1200
[V]
400
[A]
300
200
100
0
-100
-200
-300
-400
7.75
7.77
7.79
7.81
7.83
7.85
[s]
7.87
(file dual_res.dat.pl4; x-var t) v:C1D-v:C1G c:C1H -C1I

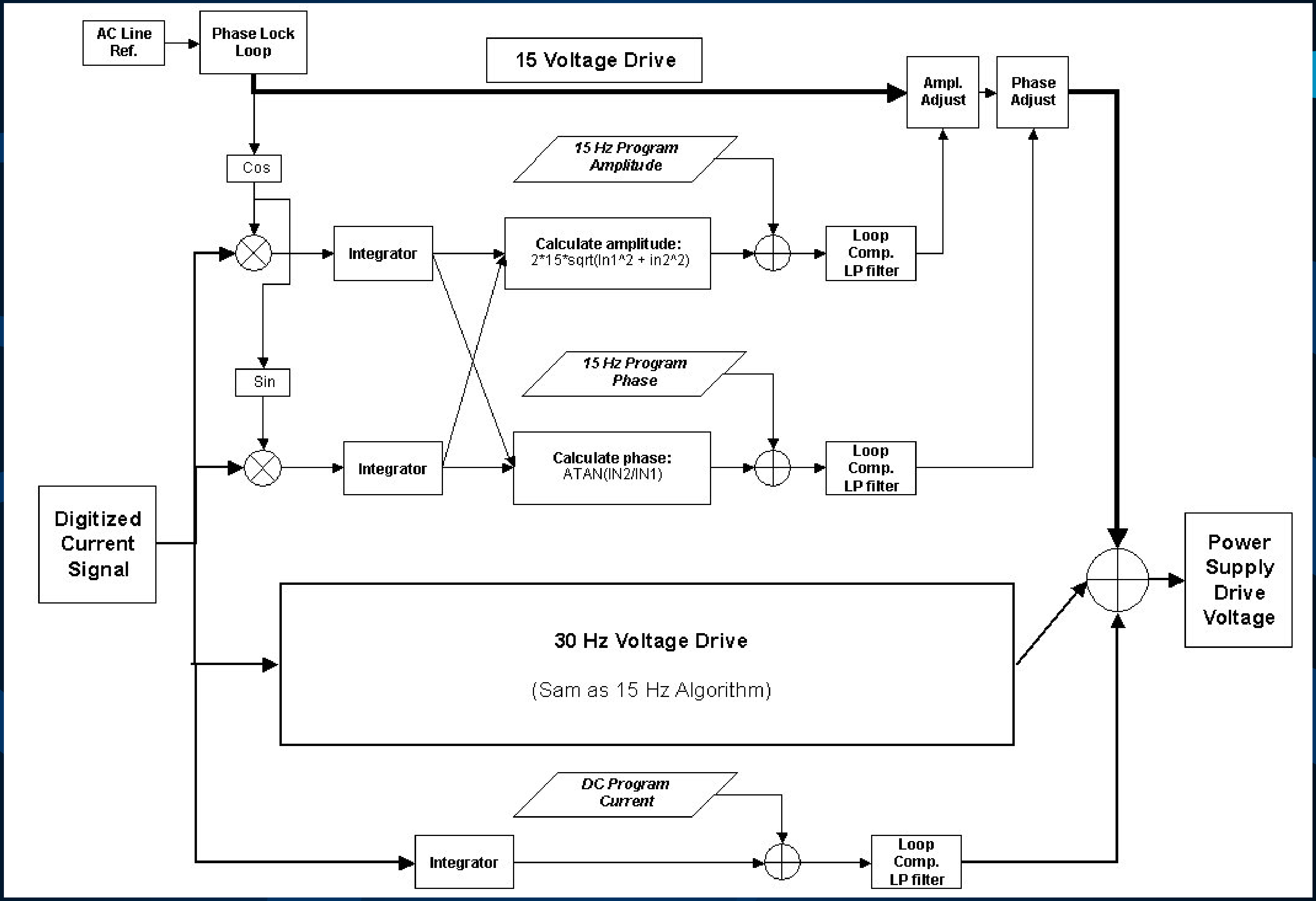
2nd Harmonic Choke Specifications:

• Inductance:	26 mH
• Peak Current:	350 amps
• Total RMS Current:	200 amps
• 15 Hz RMS Current:	120 amps
• 30 Hz RMS Current:	155 amps
• Peak Voltage (differential):	1100 volts
• Peak Voltage (common mode):	1500 volts
• DC Resistance (Rdc):	< 0.010 ohms
• DC Loses (I**2 *Rdc):	400 watts
• AC Loses (Total loss – DC Loses):	< 500 watts

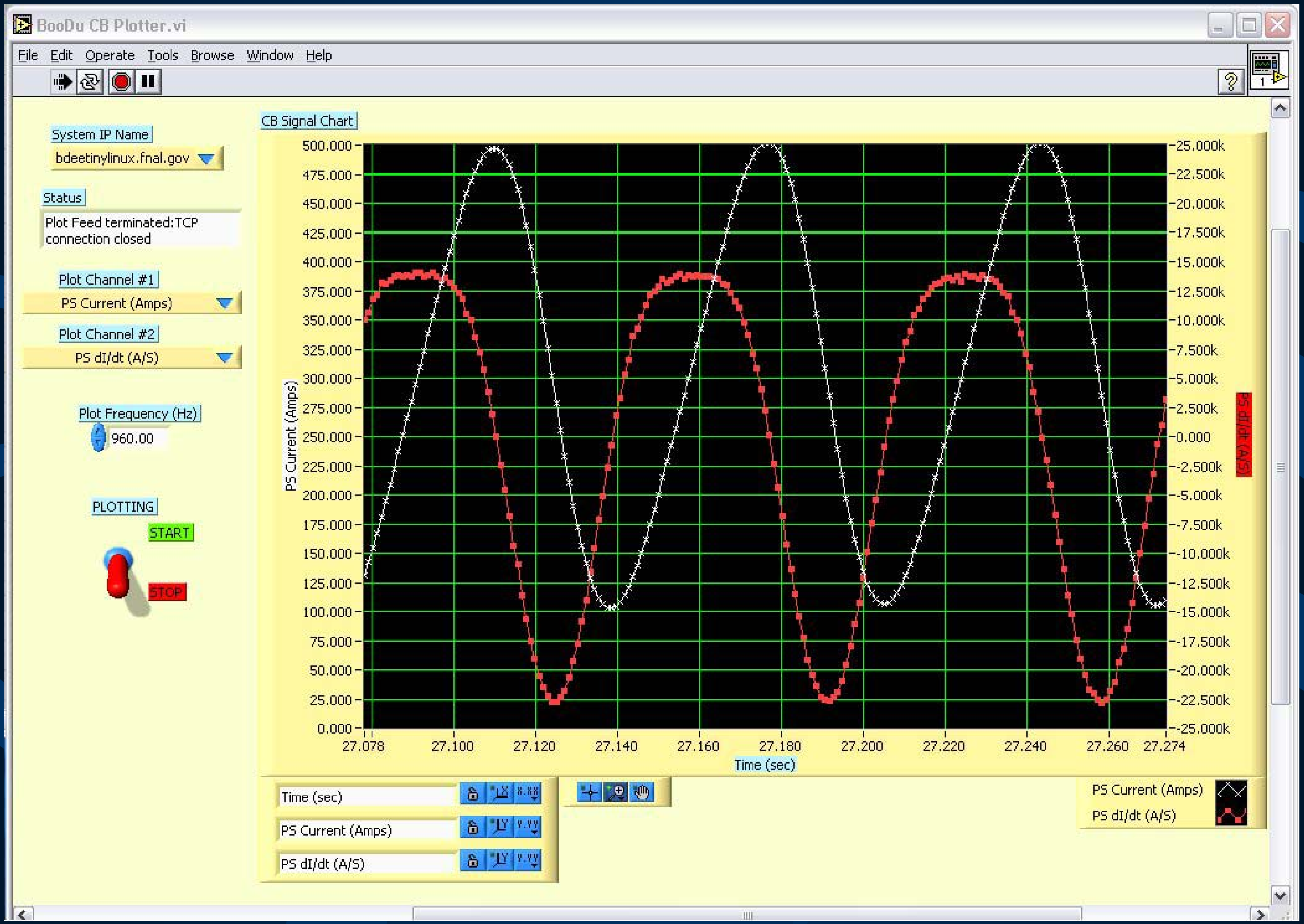
NECESSARY MODIFICATIONS

- Power supplies need to invert
- All power supplies will be needed for normal operation.
- New second harmonic cap bank is needed.
- New second harmonic choke is needed.
- New regulation system needs to be developed.
- Unknown affect on AC line.

REGULATION BLOCK DIAGRAM



Bench-top setup simulating Dual resonant Regulation system using a simple single-card computer



Very crude cost estimate:

- Does not include spares, labor or EDIA.
- New capacitors: $4.5k per cell

  ½*C*V**2 = 3kjoules per cell. Assuming $1.5/joule = $4.5k per cell. (present caps were $1/joule)

- New chokes: $10k per cell

  ½*L*I**2 = 2 kjoules per cell. Assuming $5.0/joule = $10k per cell ($2.5 joule max. for filter choke)

  - largest unknown

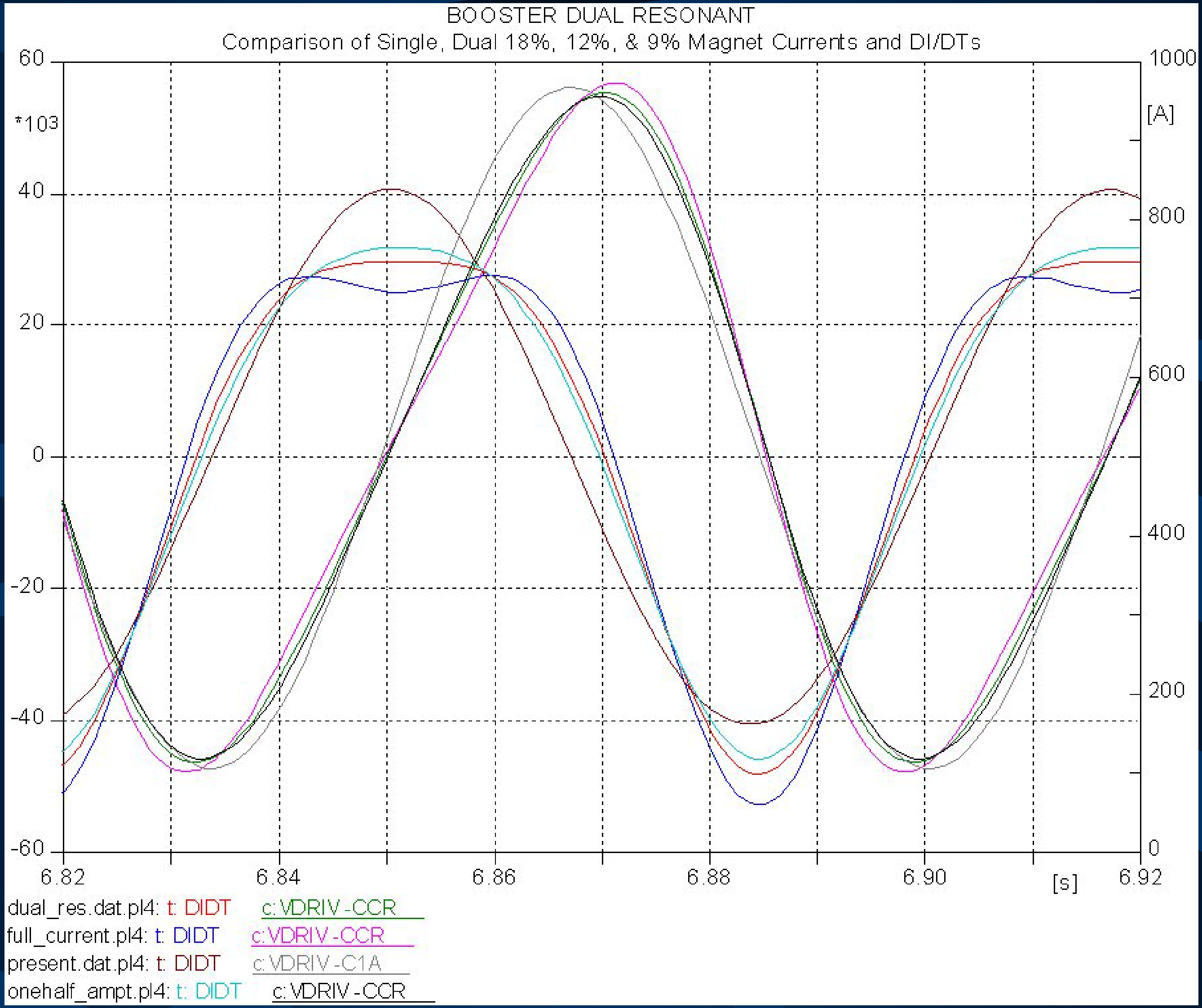
  - excessive losses require additional power supply voltage.

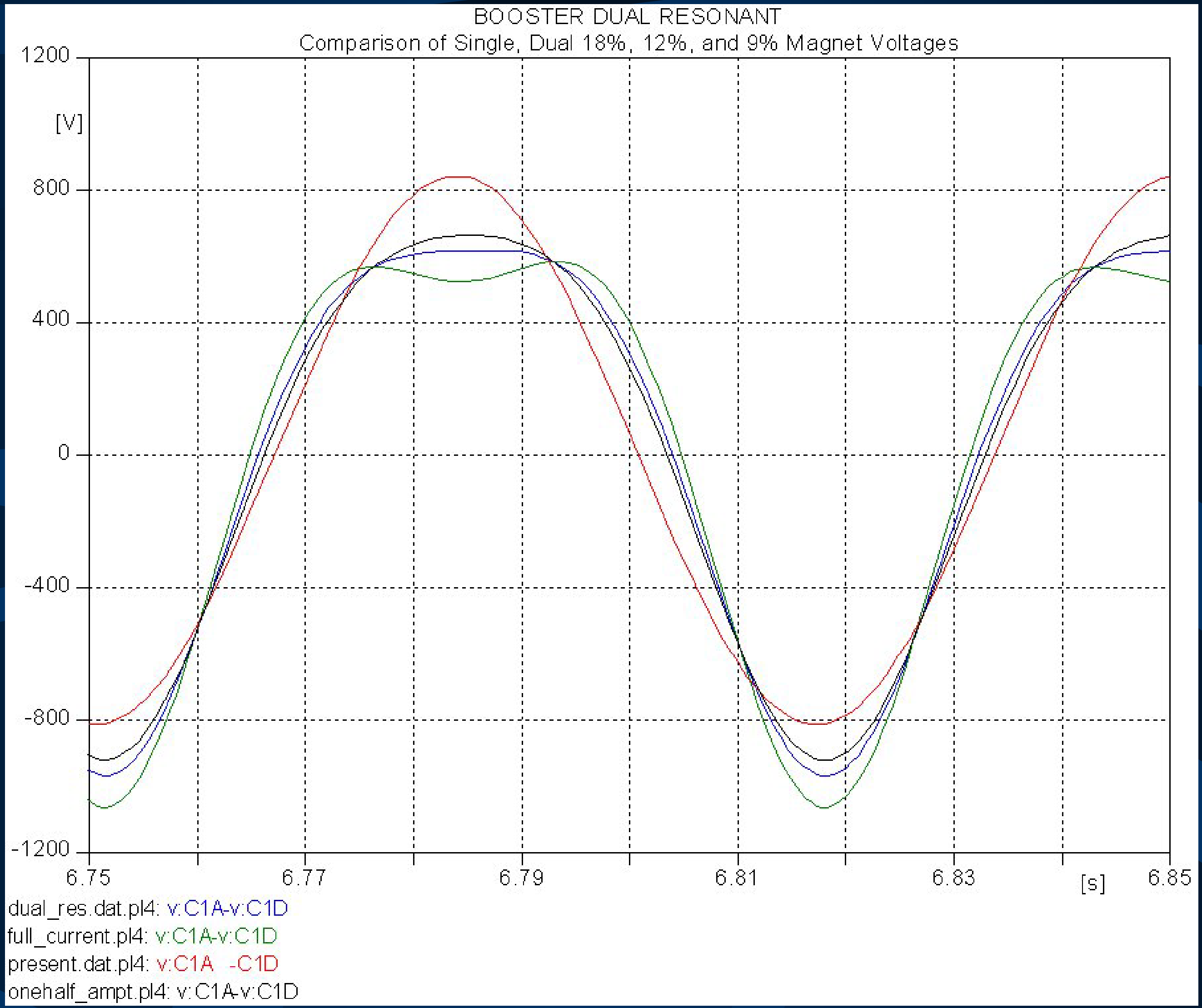
- Unknown costs:

  Current regulation, PS inversion, mitigating potential AC line problems, and booster timing changes.

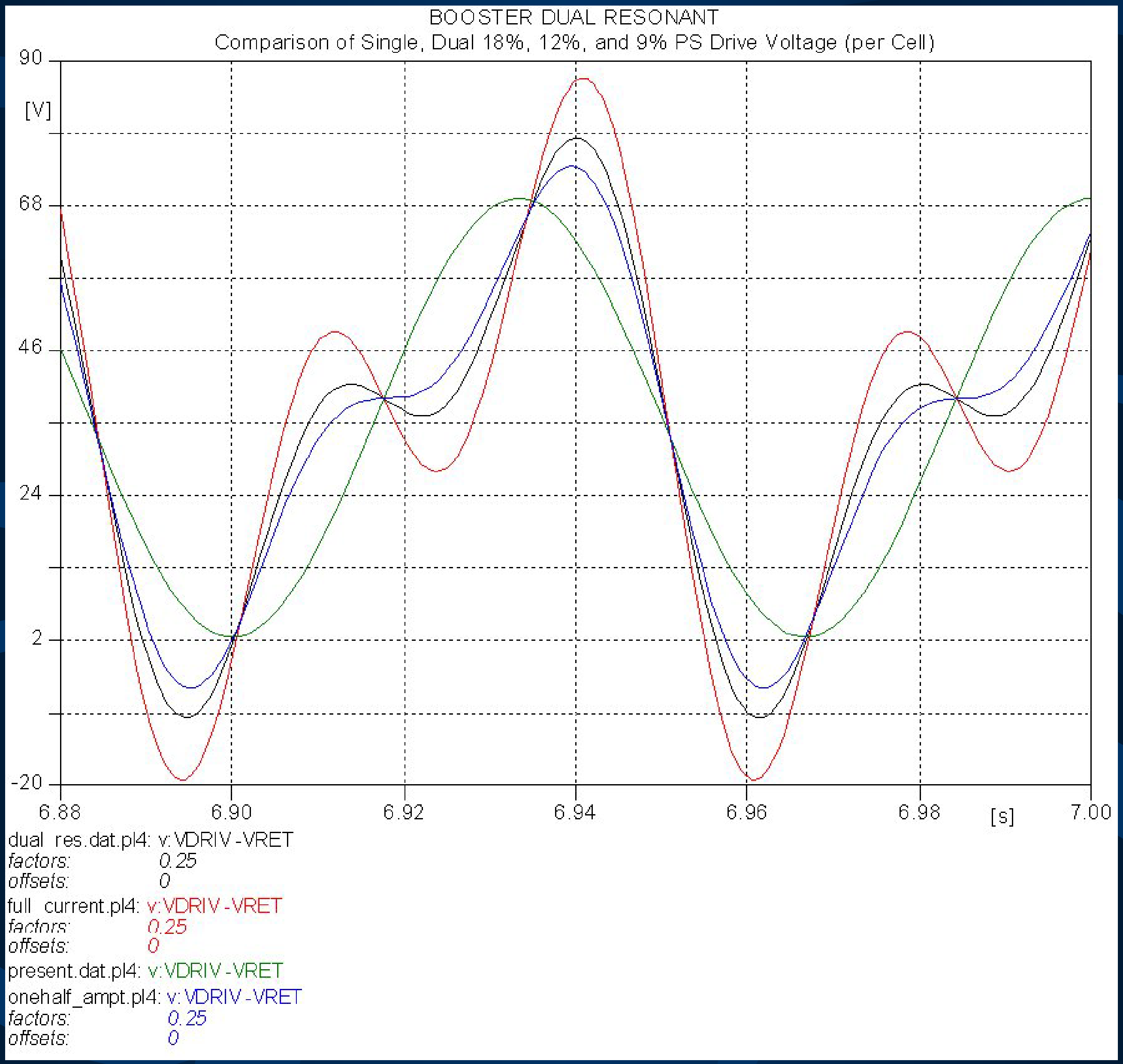
* Total for 48 cells: about $700k

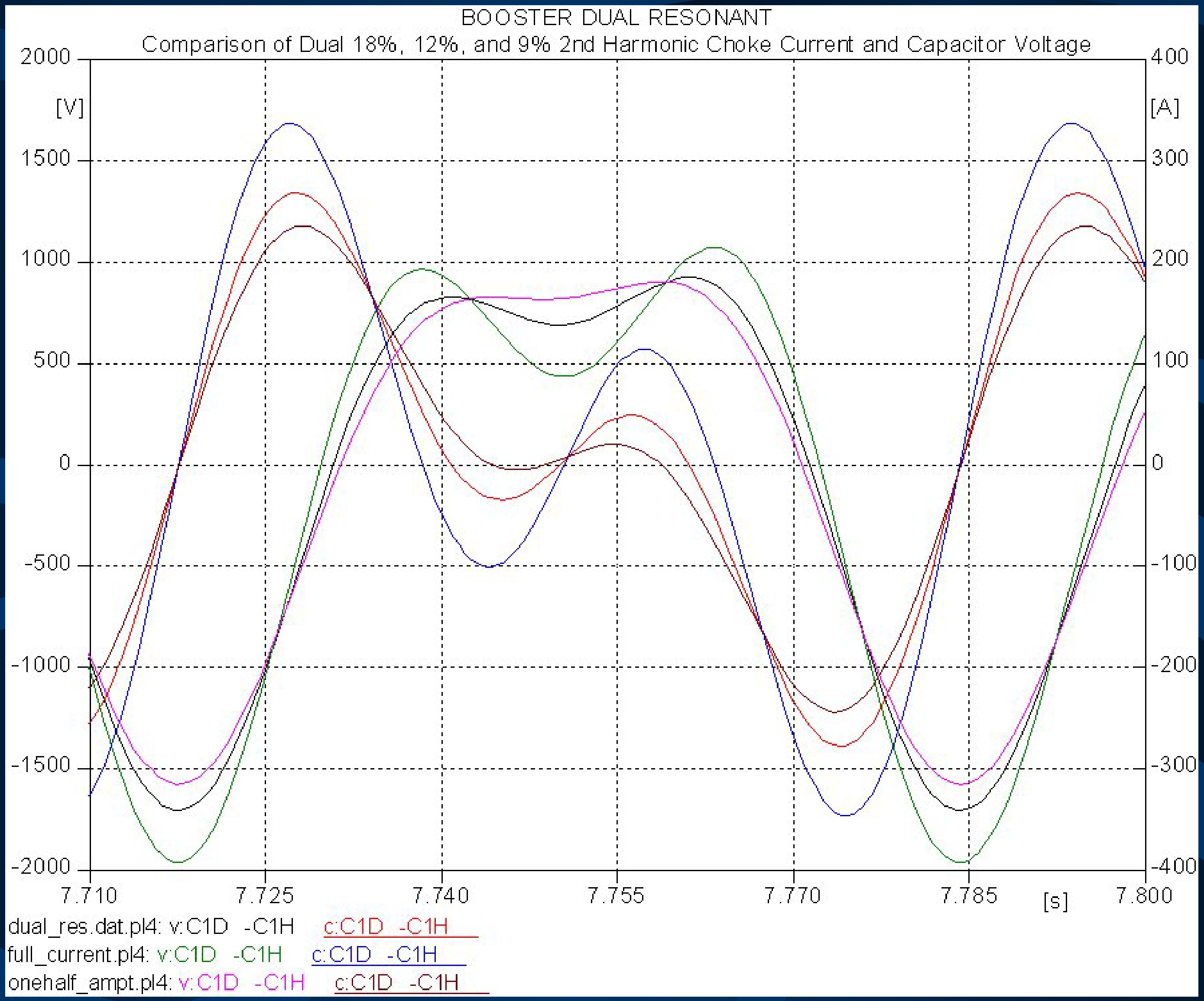
Following Slides Compare the Single Resonant with 18%, 12%, and 9% addition of the 2nd Harmonic


BOOSTER DUAL RESONANT
Comparison of Single, Dual 18%, 12%, & 9% Magnet Currents and DI/DTs
*10³
[A]
[s]
60
40
20
0
-20
-40
-60
1000
800
600
400
200
0
6.82
6.84
6.86
6.88
6.90
6.92
dual_res.dat.pl4: t: DIDT c: VDRIV-CCR
full_current.pl4: t: DIDT c: VDRIV-CCR
present.dat.pl4: t: DIDT c: VDRIV-C1A
onehalf_ampt.pl4: t: DIDT c: VDRIV-CCR



BOOSTER DUAL RESONANT
Comparison of Single, Dual 18%, 12%, and 9% Magnet Voltages
1200
[V]
800
400
0
-400
-800
-1200
6.75
6.77
6.79
6.81
6.83
[s]
6.85
dual_res.dat.pl4: v:C1A-v:C1D
full_current.pl4: v:C1A-v:C1D
present.dat.pl4: v:C1A -C1D
onehalf_ampt.pl4: v:C1A-v:C1D


BOOSTER DUAL RESONANT
Comparison of Single, Dual 18%, 12%, and 9% PS Drive Voltage (per Cell)
90
[V]
68
46
24
2
-20
6.88
6.90
6.92
6.94
6.96
6.98
[s]
7.00
dual_res.dat.pl4: v:VDRIV -VRET
factors: 0.25
offsets: 0
full_current.pl4: v:VDRIV -VRET
factors: 0.25
offsets: 0
present.dat.pl4: v:VDRIV -VRET
onehalf_ampt.pl4: v:VDRIV -VRET
factors: 0.25
offsets: 0


BOOSTER DUAL RESONANT
Comparison of Dual 18%, 12%, and 9% 2nd Harmonic Choke Current and Capacitor Voltage
2000
[V]
1500
1000
500
0
-500
-1000
-1500
-2000
400
[A]
300
200
100
0
-100
-200
-300
-400
7.710
7.725
7.740
7.755
7.770
7.785
[s]
7.800
dual_res.dat.pl4: v:C1D -C1H c:C1D -C1H
full_current.pl4: v:C1D -C1H c:C1D -C1H
onehalf_ampt.pl4: v:C1D -C1H c:C1D -C1H

DANGER: Disadvantages

- The dual resonance mode will increase the voltage stress on them magnets, inductors, and capacitors by as much as 30%.
- According to the manufacturer, the existing capacitors may be nearing the end of their life.
  - 20 years under operating specs
  - Procured in 1985
  - Life time sensitive to operating voltage and current
- Unknown affect on AC line