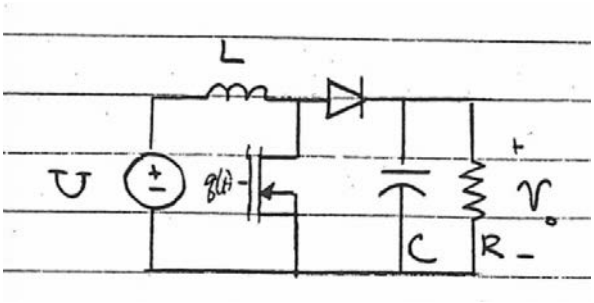
6.622 Power Electronics *Prof. David Perreault*

Lecture 26 - Control 2

1 Control Design Example

Boost converter
L = $10\mu H$, C = $50\mu F$
$f_s w = 100kHz, V_{0,ref} = 24V$
$U_{nom} = 9V, 8V < U < 10V$
$2\Omega < R < 10\Omega 1$



Start with switched equations of state:

$$\begin{cases} \frac{di_L}{dt} = \frac{u}{L}q(t) + \frac{(u-v_0)}{L}(1-q(t)) \\ \frac{dv_0}{dt} = -\frac{1}{RC}v_0 q(t) + (\frac{1}{C}i_L - \frac{1}{RC}v_0)(1-q(t)) \end{cases}$$

State space averaging with $\overline{x} = \frac{1}{T}\int_{t-T}^{t} x(\tau)d\tau$ results in nonlinear averaged model

$$\begin{cases} \frac{d\overline{i_L}}{dt} = \frac{\overline{u}}{L} + \frac{\overline{v}}{L}d' \\ \frac{d\overline{v_0}}{dt} = -\frac{1}{RC}\overline{v_0} + \frac{1}{C}\overline{i_L}d' \end{cases}$$

Linearization about op. point. U, I_L, V_0, D yields LTI linearized model of incremental dynamics

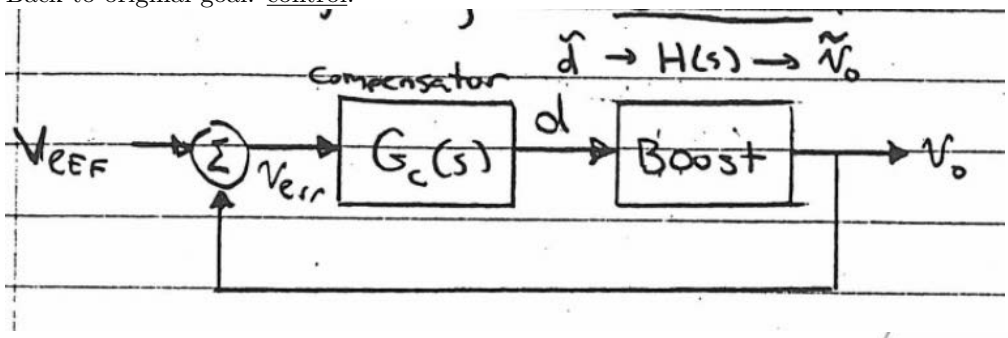
$$\begin{cases} \frac{d\tilde{i_L}}{dt} = \frac{\tilde{u}}{L} - \frac{D'\tilde{v_0}}{L} + \frac{V_0}{L}\tilde{d} \\ \frac{d\tilde{v_0}}{dt} = -\frac{1}{RC}\tilde{v_0} + \frac{D'}{C}\tilde{i_L} - \frac{I_L}{C}\tilde{d} \end{cases}$$

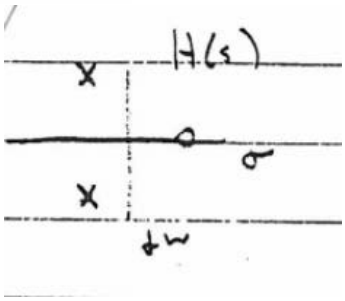
Using Laplace transform and identity $\frac{V_0}{R} = D'I_L$

$$H(s) = \frac{\tilde{v_0(s)}}{\tilde{d(s)}} = \frac{-s\frac{V_0}{RCD'} + \frac{V_0 D'}{LC}}{s^2 + \frac{1}{RC}s + \frac{D'^2}{LC}}$$

Transfer fucntion depends on op. point.
@ u = 9, V = 24, D = 0.625
$I_L \approx 25.6A, R = 2.5\Omega, C = 50\mu F, L = 50\mu H$
$\frac{\tilde{v_0}}{\tilde{d}} = \frac{-512000s+1.8\times10^{10}}{s^2+8000s+2.81\times10^8}$
zero at s = 35,156
Poles at s = $-4000 \pm j16279$
period$\approx 0.4ms$

Back to original goal: control!

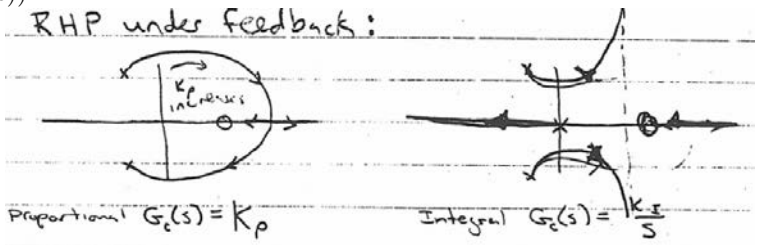




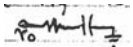
Looking at our transfer function, we have

1. 2 lightly-damped poles in LHP
2. 1 RHP zero

This is tricky, because the poles tend to move to the RHP under feedback: (Note sign in numerator of H(s))



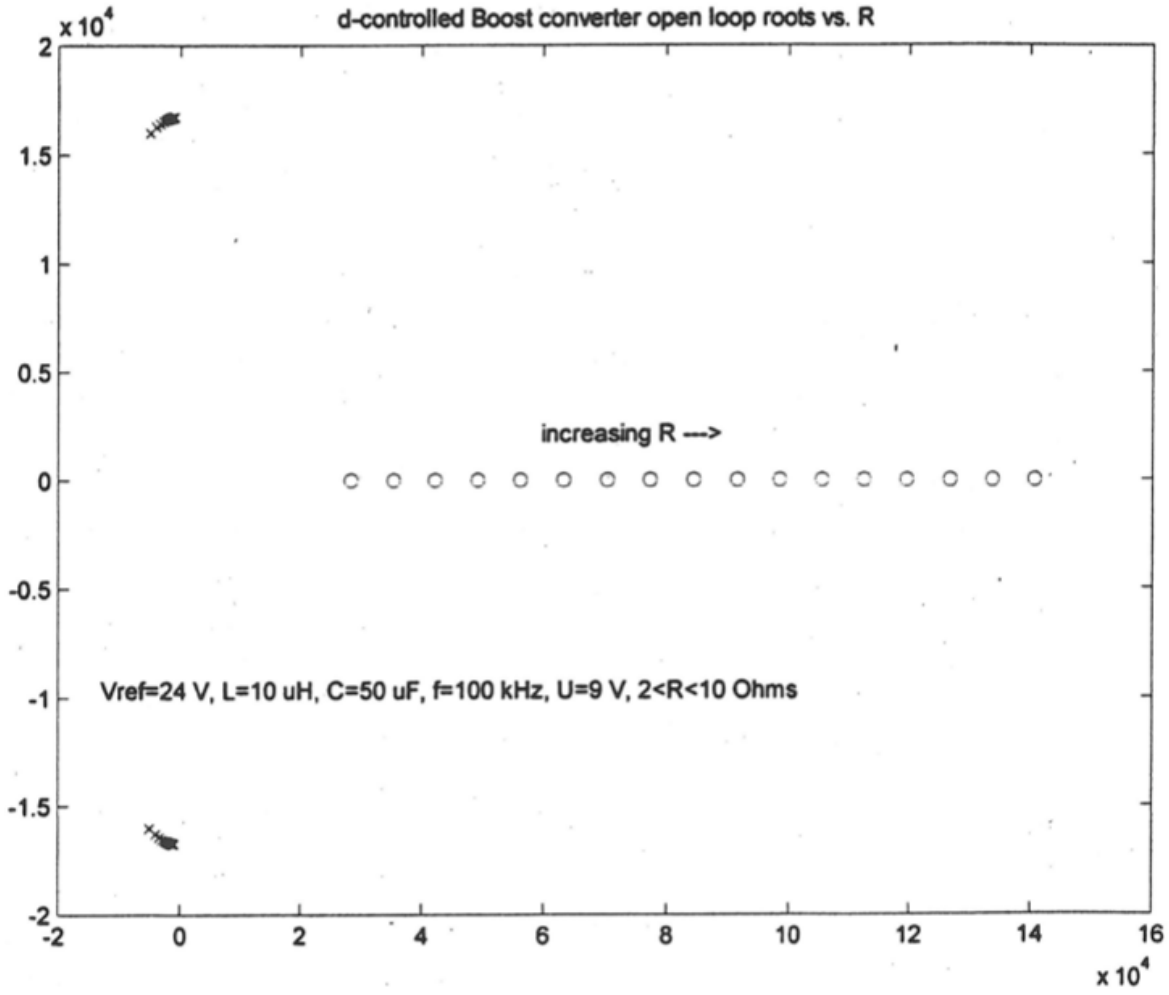
→ So, we must pick control gains that are not too high for stability.
Also, the poles move with operating point! (variations in U, R for example)

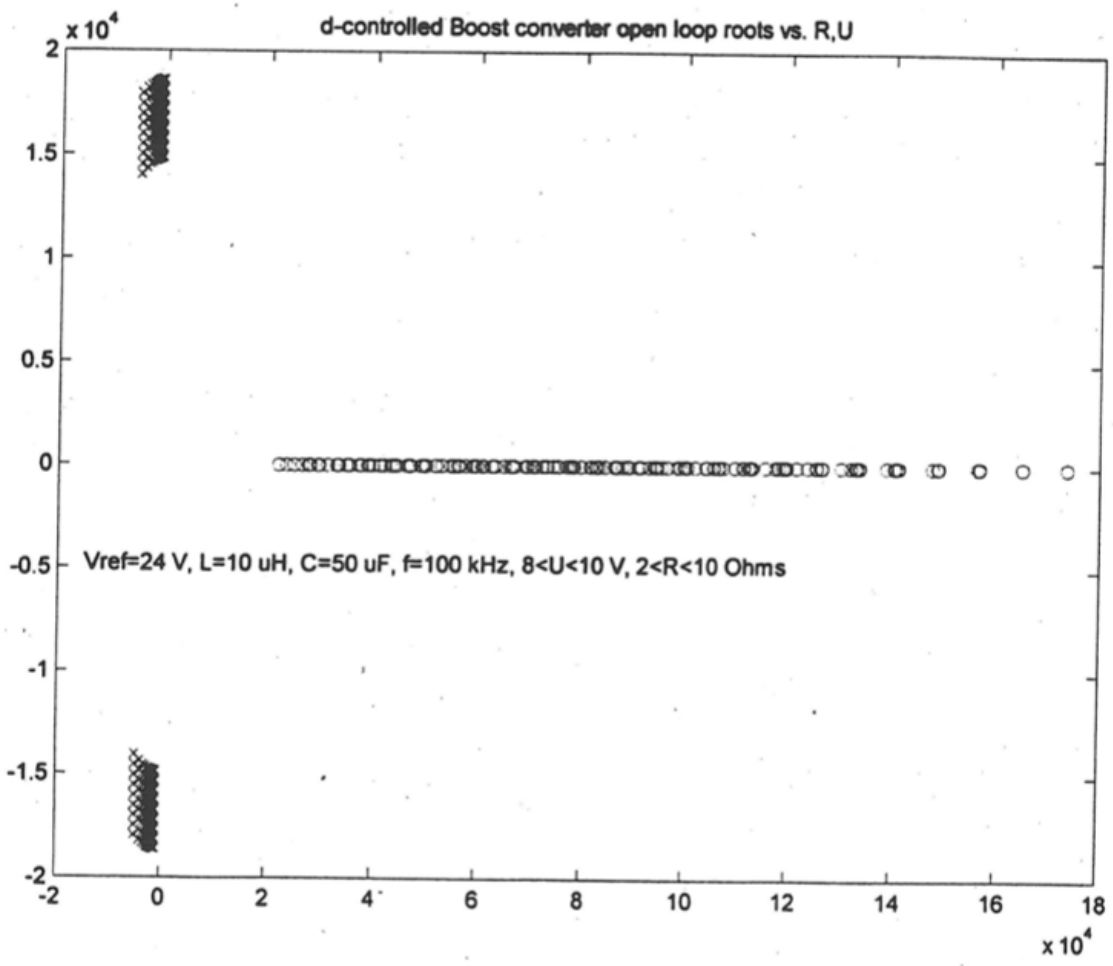
- Look at slide for variations of poles with R (problem becomes more difficult at light load...)
- Could use a damping leg  !! (neat trick)

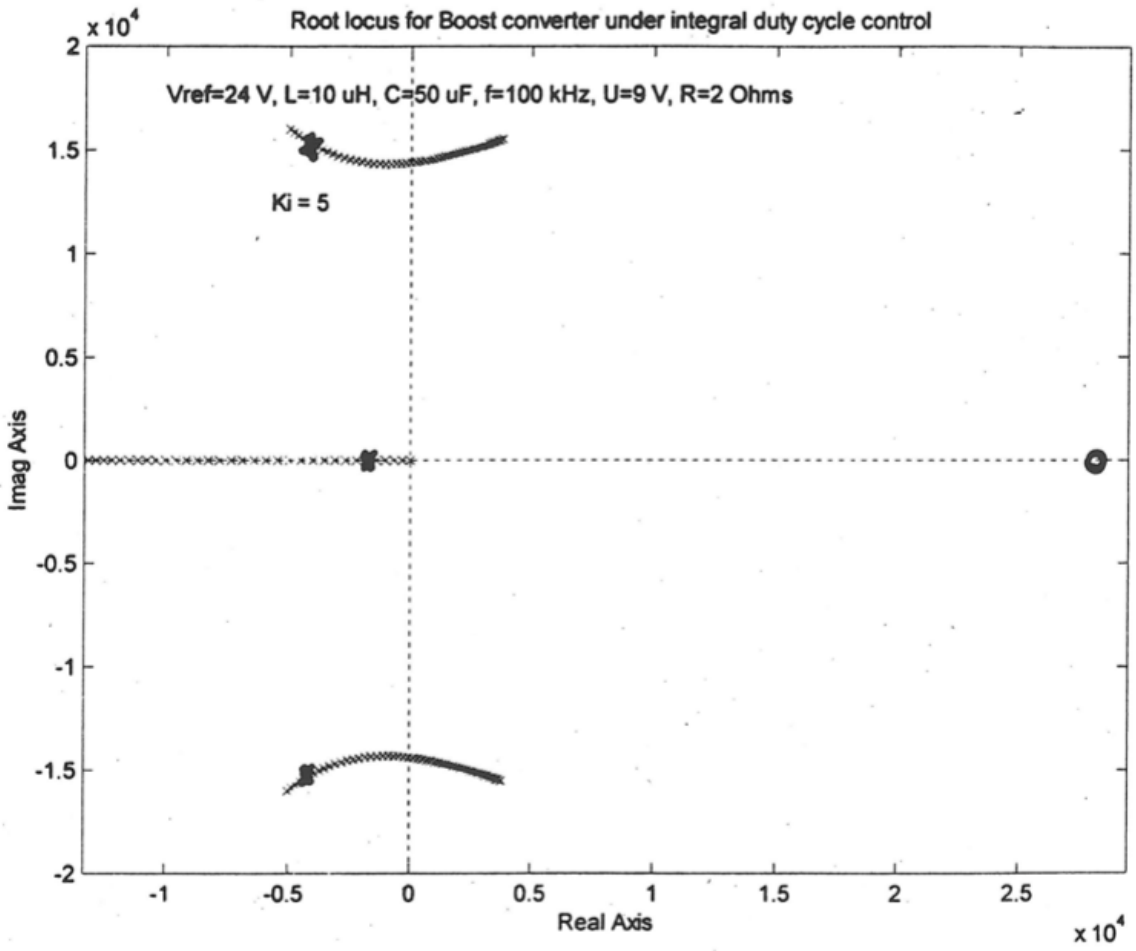
Must design controller valid over all operating points

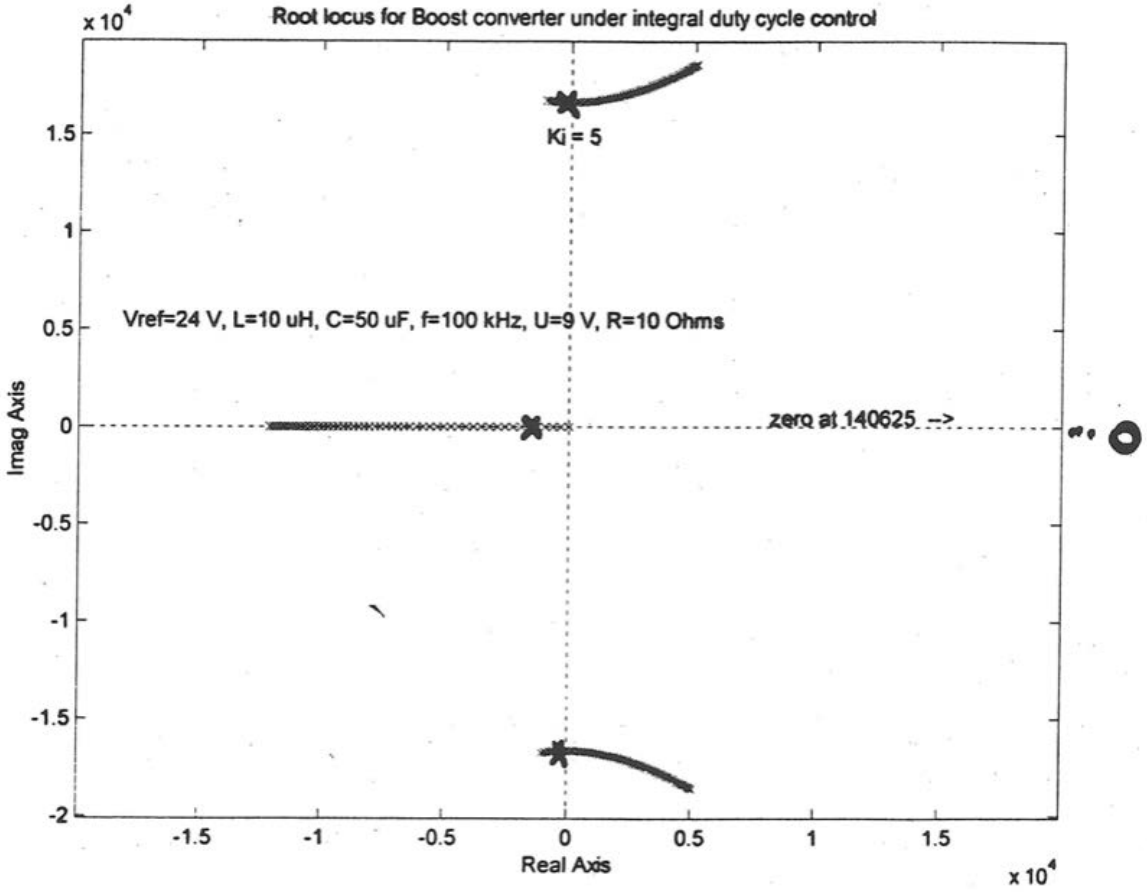
- Look at simple integral controller design
- Note: technically only small signal dynamics are determined, but power converters are forgiving in this respect.

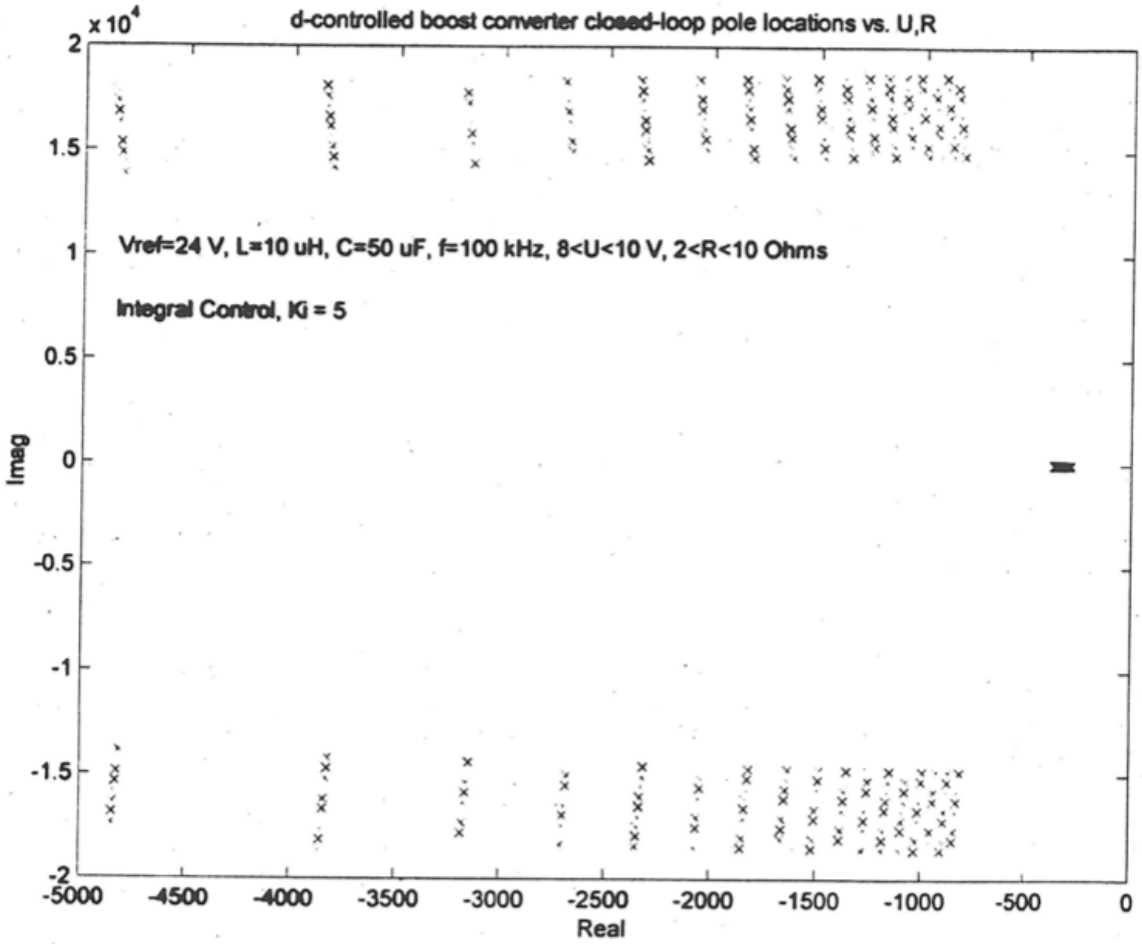
Note: This controller may not be ok in practice due to lightly-damped poles (noise sensitive, transient perf, etc), main pro is RHP zero!! → go to the current-mode control!!

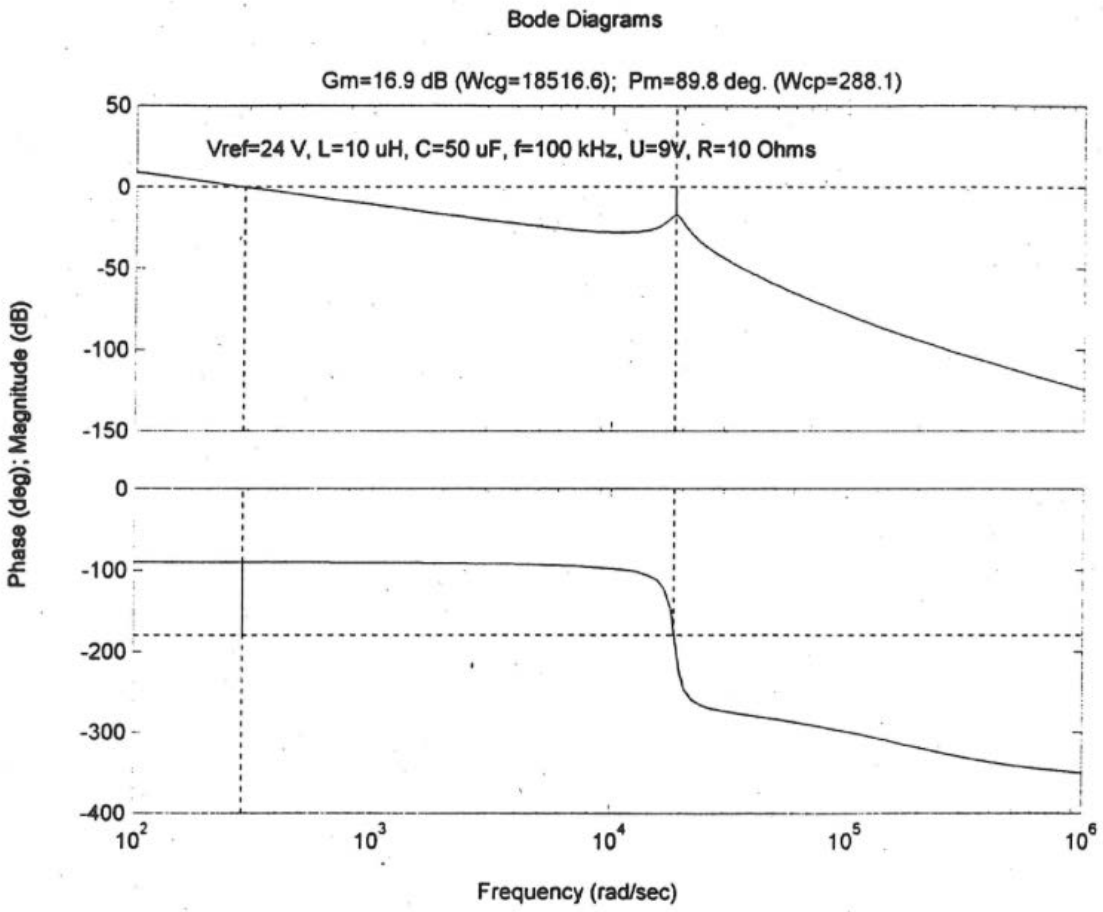

d-controlled Boost converter open loop roots vs. R
x 10^4
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
increasing R --->
Vref=24 V, L=10 uH, C=50 uF, f=100 kHz, U=9 V, 2<R<10 Ohms
-2
0
2
4
6
8
10
12
14
16
x 10^4

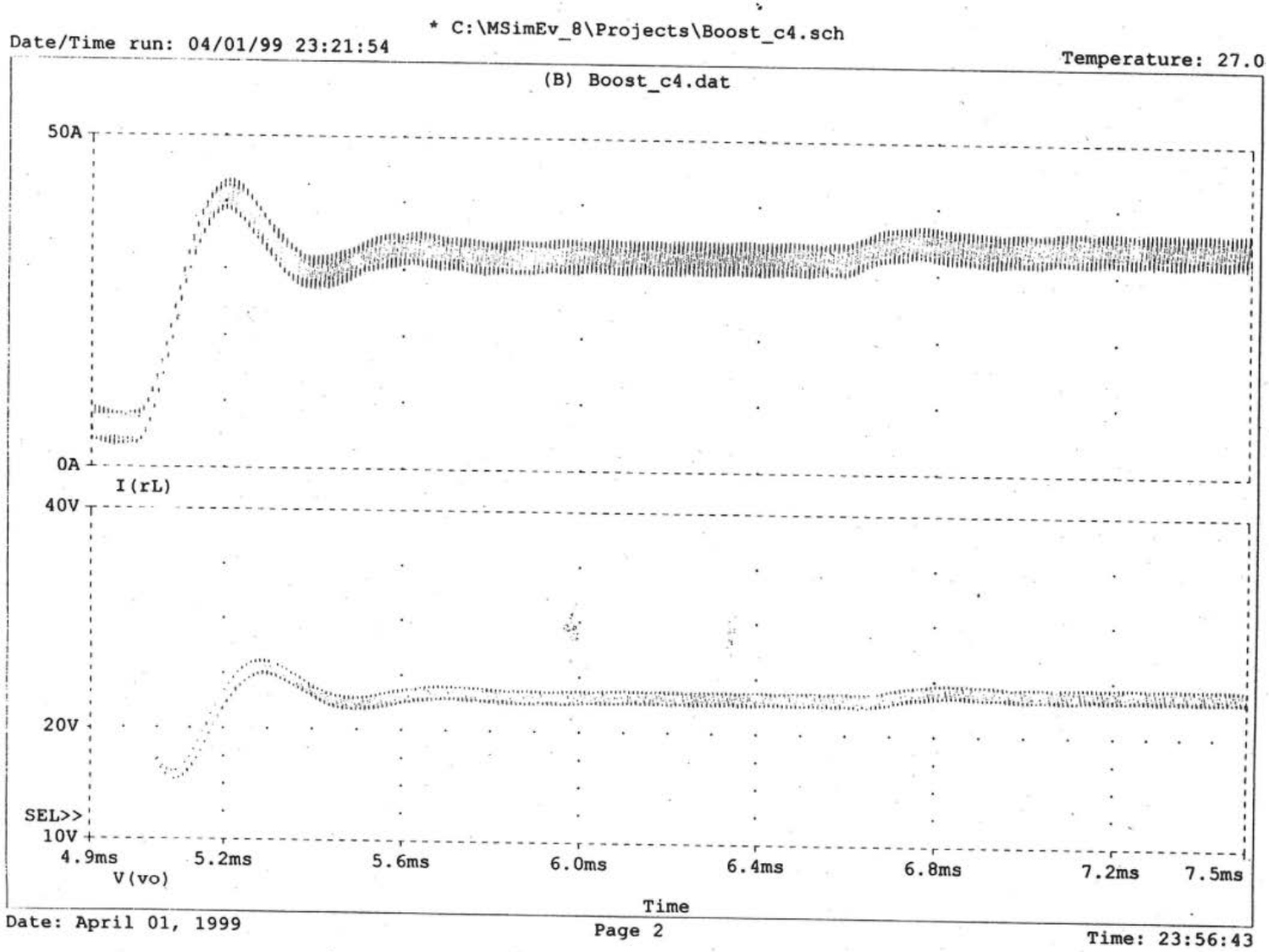

d-controlled Boost converter open loop roots vs. R,U
x 10^4
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2
0
2
4
6
8
10
12
14
16
18
x 10^4
Vref=24 V, L=10 uH, C=50 uF, f=100 kHz, 8<U<10 V, 2<R<10 Ohms

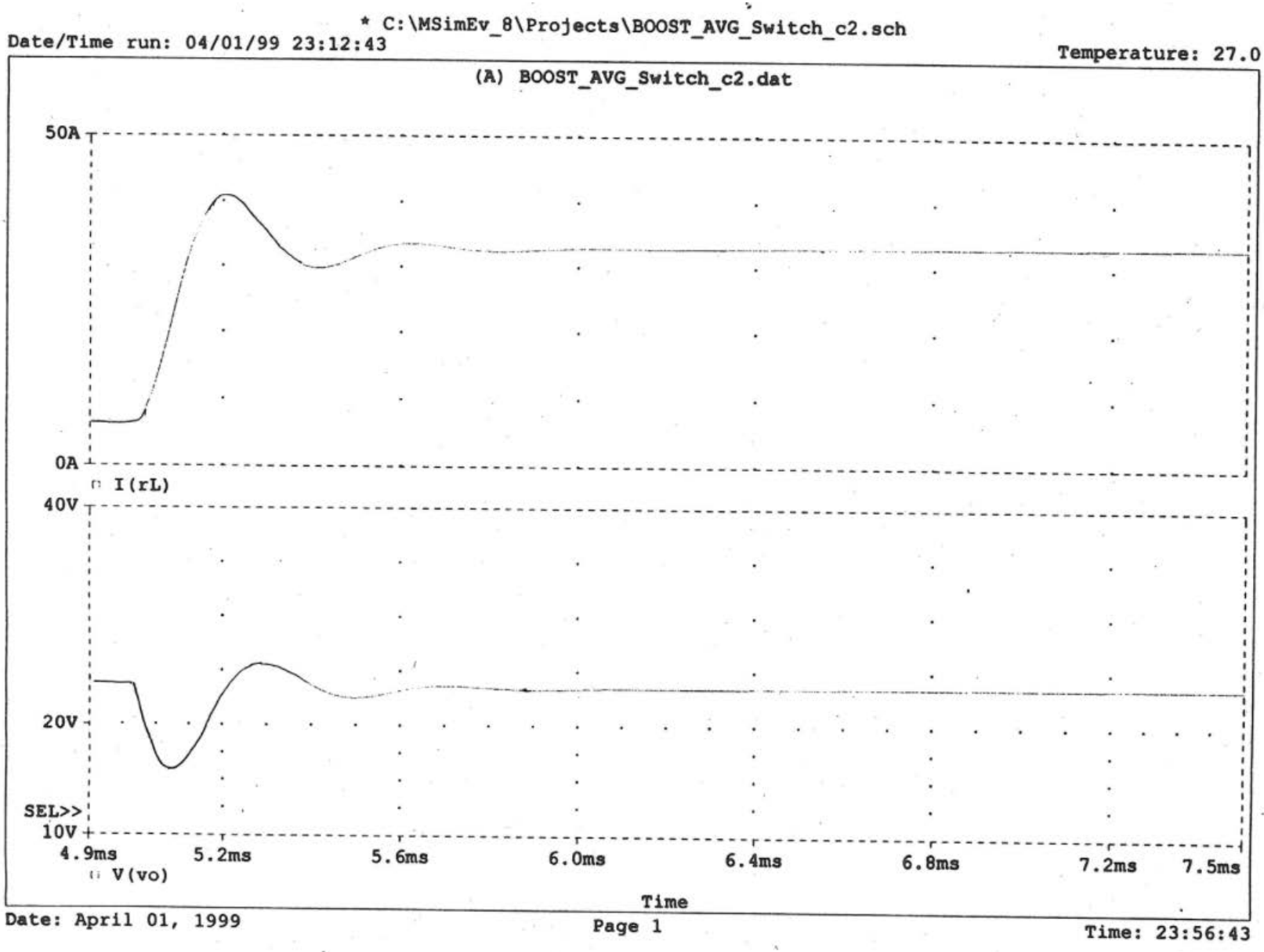

Root locus for Boost converter under integral duty cycle control
x 10^4
Vref=24 V, L=10 uH, C=50 uF, f=100 kHz, U=9 V, R=2 Ohms
Ki = 5
Imag Axis
Real Axis
x 10^4
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
-0.5
0
0.5
1
1.5
2
2.5

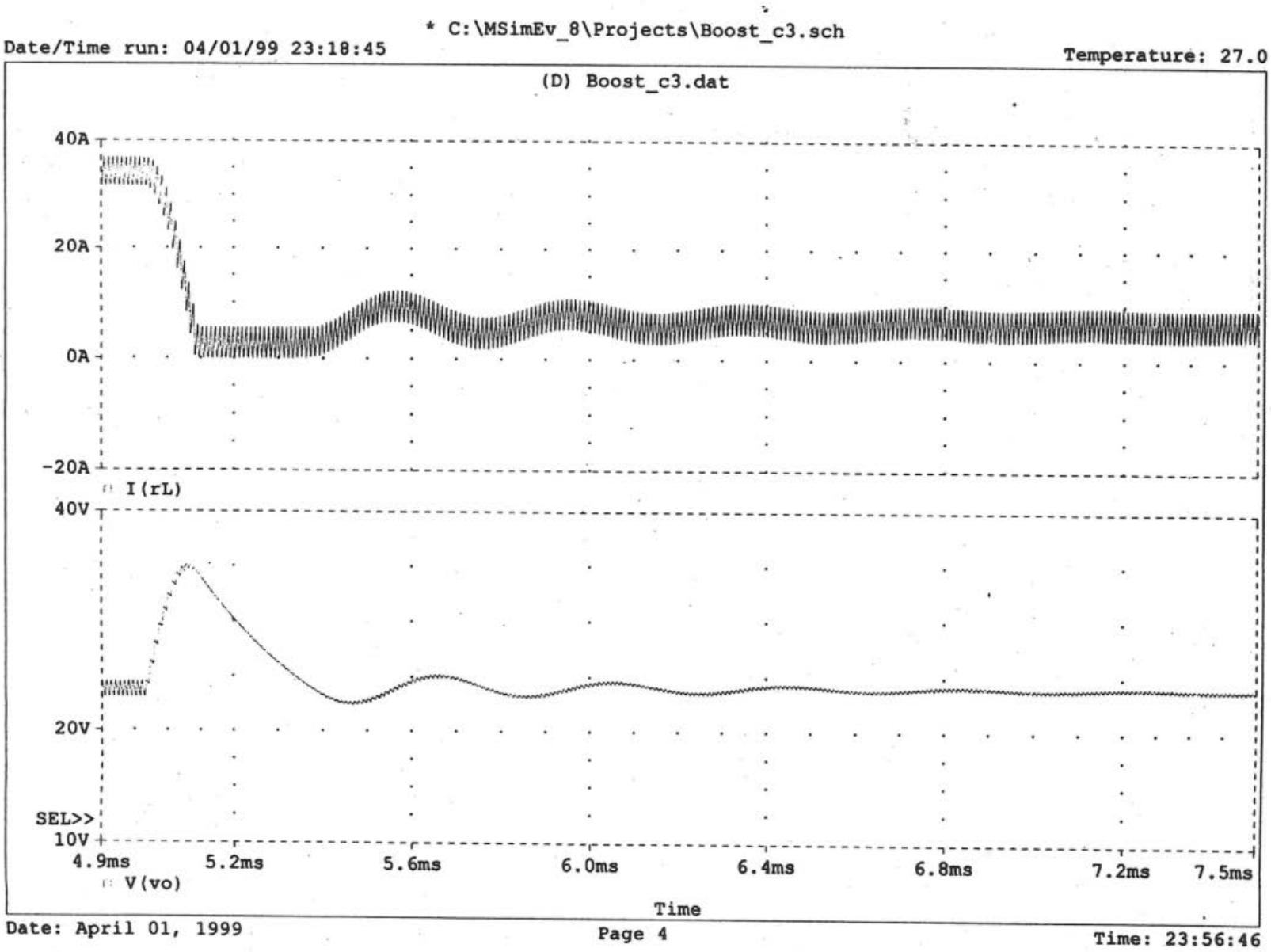

Root locus for Boost converter under integral duty cycle control
x 10^4
Ki = 5
Vref=24 V, L=10 uH, C=50 uF, f=100 kHz, U=9 V, R=10 Ohms
zero at 140625 -->
Imag Axis
Real Axis
x 10^4
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5

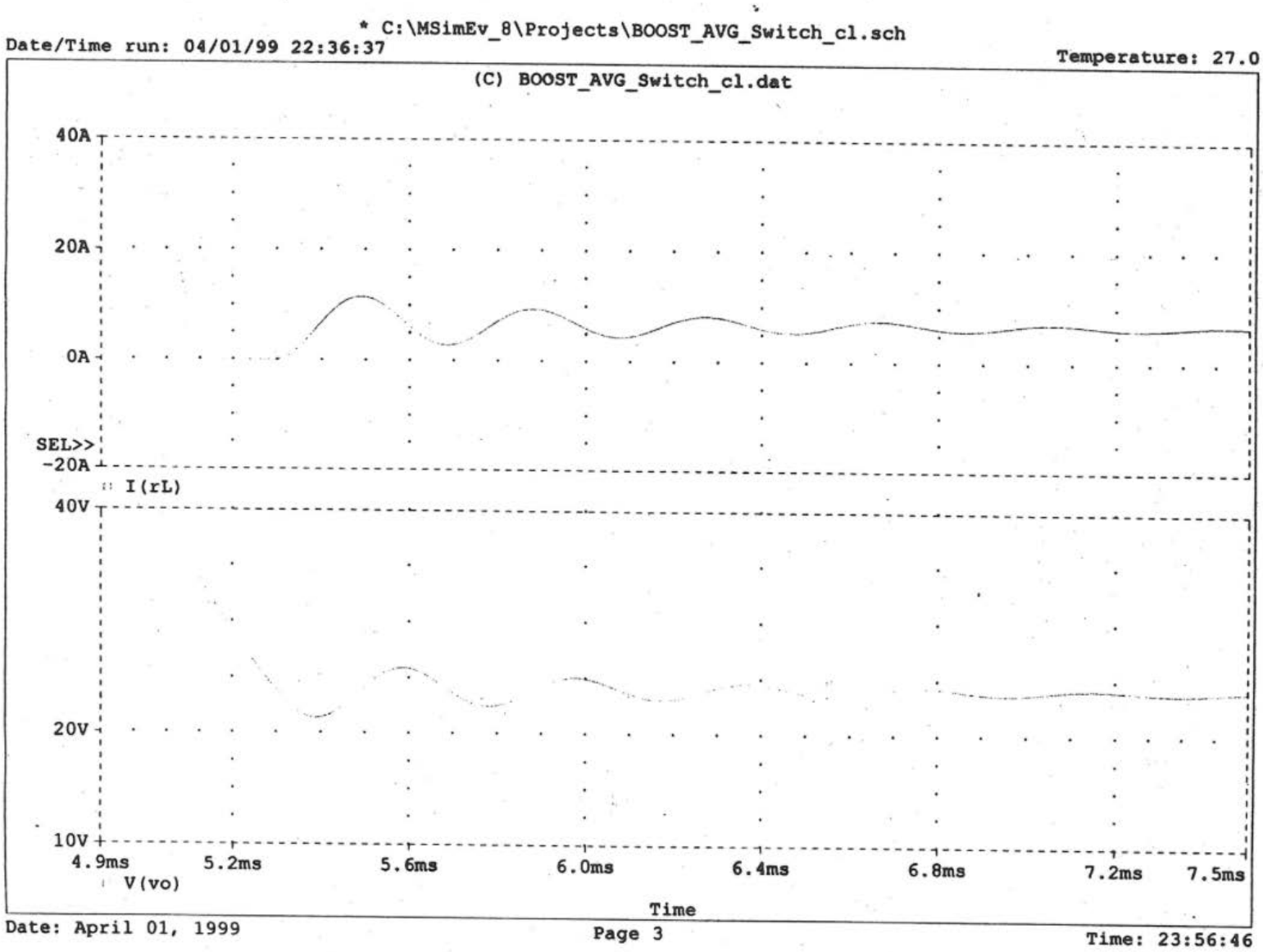

d-controlled boost converter closed-loop pole locations vs. U,R
x 10^4
Vref=24 V, L=10 uH, C=50 uF, f=100 kHz, 8<U<10 V, 2<R<10 Ohms
Integral Control, Ki = 5
Imag
Real
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-5000
-4500
-4000
-3500
-3000
-2500
-2000
-1500
-1000
-500
0


Bode Diagrams
Gm=16.9 dB (Wcg=18516.6); Pm=89.8 deg. (Wcp=288.1)
Vref=24 V, L=10 uH, C=50 uF, f=100 kHz, U=9V, R=10 Ohms
Phase (deg); Magnitude (dB)
Frequency (rad/sec)
50
0
-50
-100
-150
0
-100
-200
-300
-400
10^2
10^3
10^4
10^5
10^6


* C:\MSimEv_8\Projects\Boost_c4.sch
Date/Time run: 04/01/99 23:21:54
Temperature: 27.0
(B) Boost_c4.dat
50A
0A
I(rL)
40V
20V
SEL>>
10V
4.9ms
5.2ms
5.6ms
6.0ms
6.4ms
6.8ms
7.2ms
7.5ms
V(vo)
Time
Date: April 01, 1999
Page 2
Time: 23:56:43


* C:\MSimEv_8\Projects\BOOST_AVG_Switch_c2.sch
Date/Time run: 04/01/99 23:12:43
Temperature: 27.0
(A) BOOST_AVG_Switch_c2.dat
50A
0A
I(rL)
40V
20V
SEL>>
10V
4.9ms
5.2ms
5.6ms
6.0ms
6.4ms
6.8ms
7.2ms
7.5ms
V(vo)
Time
Date: April 01, 1999
Page 1
Time: 23:56:43


* C:\MSimEv_8\Projects\Boost_c3.sch
Date/Time run: 04/01/99 23:18:45
Temperature: 27.0
(D) Boost_c3.dat
40A
20A
0A
-20A
I(rL)
40V
20V
SEL>>
10V
4.9ms
5.2ms
5.6ms
6.0ms
6.4ms
6.8ms
7.2ms
7.5ms
V(vo)
Time
Date: April 01, 1999
Page 4
Time: 23:56:46


* C:\MSimEv_8\Projects\BOOST_AVG_Switch_cl.sch
Date/Time run: 04/01/99 22:36:37
Temperature: 27.0
(C) BOOST_AVG_Switch_cl.dat
40A
20A
0A
SEL>>
-20A
I(rL)
40V
20V
10V
4.9ms
5.2ms
5.6ms
6.0ms
6.4ms
6.8ms
7.2ms
7.5ms
V(vo)
Time
Date: April 01, 1999
Page 3
Time: 23:56:46

6.622 Power Electronics

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