

ELECTRICAL AND ELECTRONICS ENGINEERING DEPARTMENT

EE464 POWER ELECTRONICS – II

Homework III

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Table of Contents

[A. Plant Characteristics 3](#_Toc73883608)

[1. Examination of Transfer Function 3](#_Toc73883609)

[2. Bode Plot of the Plant 3](#_Toc73883610)

[B. Controller Design 3](#_Toc73883611)

[3. Identification of Poles and Zeros 3](#_Toc73883612)

[4. Crossover Frequency 4](#_Toc73883613)

[5. Compensator Selection 4](#_Toc73883614)

[6. Component Selection of Compensator 5](#_Toc73883615)

[7. Bode Plot of Loop Transfer Function 6](#_Toc73883616)

[C. Simulation 7](#_Toc73883617)

[8. Full Load to Half Load 7](#_Toc73883618)

# Plant Characteristics

## Examination of Transfer Function

Transfer function is mathemetical function that represent the relation between output and input theoretically. In other words, transfer function models the plant.

## Bode Plot of the Plant

Figure 1 shows the bode diagram for control-to-output transfer function of buck converter with and without ESR of the capacitor. Both system are similar up to a point where the zero is located due to the ESR of the capacitor. Since the ideal system doesn’t have zero, phase of ideal system continues to decrease and slope of gain decreases with -40dB. On the other hand, non-ideal system gain reduces with -20dB after the zero of the non-ideal plant.

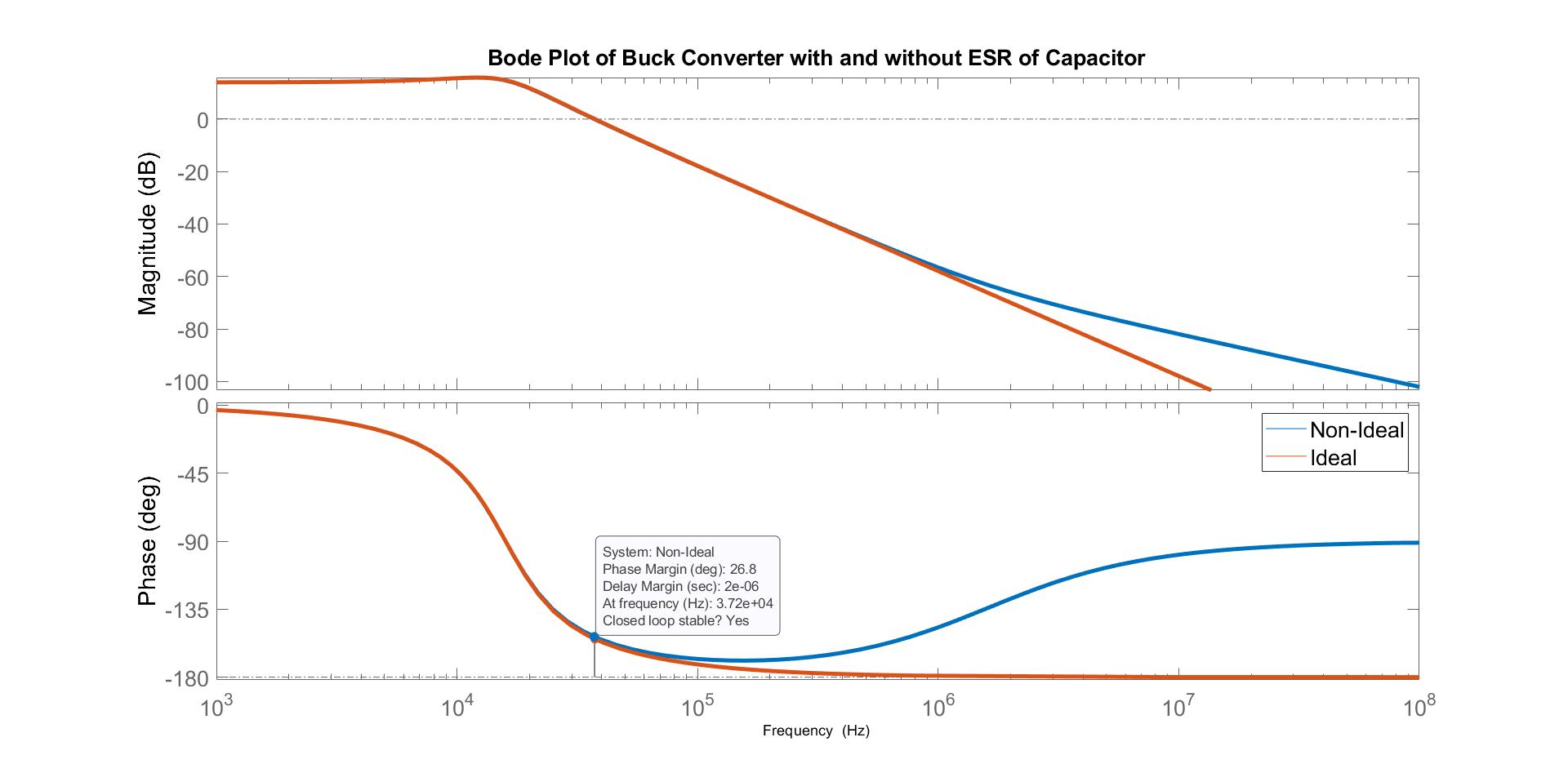


Figure 1 Bode diagram for control-to-output transfer function of buck converter with and without ESR of the capacitor

Theoretically, both ideal and non-ideal plant does not have gain margin since their phases does not reach -180°. Ideal system, however, is very close to the -180° so that gain margin of ideal plant can be calculate at 106 Hz as 58.2 dB. On the other hand, their phase margins are calculated at 37.2 kHz which is also named crossover frequency. The phase margins are 25.3° and 26.8° for ideal and non-ideal plants, respectively. That the difference in phase margins is small is because zero of the non-ideal plant is far away from the cross-over frequency.

# Controller Design

## Identification of Poles and Zeros

According to given control-to-output transfer function zeros and poles are found in Equation (1). The non-ideal plant has one zero and one double pole. The calculations for poles are not exact poles theoretically, since the ESR affects the poles location in neglible amount. Hence, the pole is approximated as purely resonanance frequency.

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## Crossover Frequency

*‘...F0 is the zero crossover frequency defined as the frequency when loop gain equals unity. F0 is also called “the bandwidth of the loop” or “the bandwidth of the system*”’. (Alıntı-infinion AN)

Typical limitation is done based on switching frequency. Crossover frequency is selected as 1/10~1/5 of switching frequency to attenuate switching noise sufficiently. The phase margin is also defined at the crossover frequency and typical phase margin is 45°.

Besides, there is a relation between crossover frequency and transient response. The gain of the loop is positive before the crossover frequency and negative after the crossover frequency. As the crossover frequency gets higher, gain becomes positive and high for wide range of frequency. Error signal amplified for wide range in great amount, which makes the system fast.

The crossover frequency is selected as 20kHz in order to make high attenuation of switching noise. There is no need further reduction in crossover frequency. Also, selection of crossover frequency lower than the resonance frequency since there is an amplification at resonance frequency.

The crossover frequency for other compensator is selected as 40kHz for the sake of comparison of two compansator having different crossover frequencies.

## Compensator Selection

The double pole at resonance frequency makes the gain slope -40dB, which makes placing a zero before crossover frequency is compulsary in order to get higher crossover frequency. The constraint on crossover frequency affects the gain at high frequencies which are desired to be attenuated. Therefore, some poles should be placed after the crossover frequency.

The phase of frequency response should be also considered. Phase margin is compansated with double pole at resonance frequency and zeros that should be placed for the sake of desired crossover frequency. However, number of the poles and zeros should not be so unbalanced before the crossover frequency that the phase margin gets closer to the -180°.

Figure 2 is taken from the application note by infinion (alıntı). Type 3-B compensator is selected. Other types of compensators are not appropriate for the plant. Therefore, the type-3B compensators with different crossover frequencies and phase margins are compared.

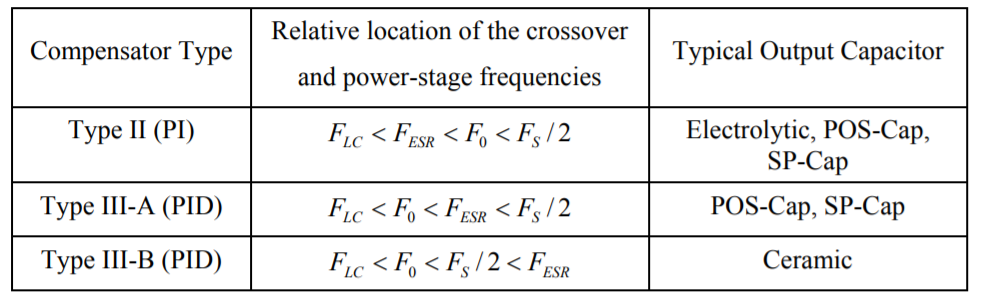


Figure 2 Selection parameters of compansator types based on significant frequency values

## Component Selection of Compensator

The circuit schematic of type III-B compensator is shown in Figure 3.

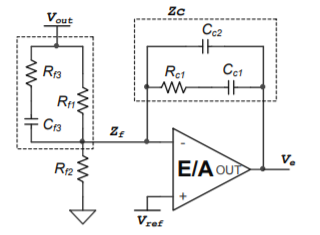


Figure 3 Circuit schematic of type III-B compensator

The tranfer function of compensator is given in Equation (2).

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| --- | --- | --- |
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The calculation of poles and zeros of type III-B compensator is done in Equation (3).

|  |  |  |
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The selection of poles and zeros are done according to application note xxx (alıntı). The angle, theta, in selection 2nd zero and pole represents the maximum phase lead at crossover frequency. Typical value of phase lead is 70°. Selection of poles and zeros are shown in Equation (4).

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Table 1 shows the calculated zeros, poles and component values. Practical values of components are verified from Digikey.

Table 1 Calculated zeros, poles and component values of the plant at 40kHz and 20kHz crossover frequency

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Description** | **40kHz Crossover Frequency** | | **20kHz Crossover Frequency** | |
| **FP1** | 0 Hz | | 0 Hz | |
| **FP2** | 226.85 kHz | | 113.43 kHz | |
| **FP3** | 100 kHz | | 100 kHz | |
| **FZ1** | 3.527 kHz | | 1.763 kHz | |
| **FZ2** | 7.053 kHz | | 3.527 kHz | |
|  | **Theoretical** | **Practical** | **Theoretical** | **Practical** |
| **Cf3** | 2.2 nF | 2.2 nF | 2.2 nF | 2.2 nF |
| **Rf3** | 318.9 Ω | 320 Ω | 637.8 | 634 |
| **Rf1** | 9.937 kΩ | 10 kΩ | 19.88 k | 20 k |
| **Rf2** | 5.714 kΩ | 5.69 kΩ | 11.43 k | 11.5 k |
| **RC1** | 4.113 kΩ | 4.12 kΩ | 2.06 k | 2.05 k |
| **CC1** | 10.95 nF | 12 nF | 44.03 nF | 47 nF |
| **CC2** | 386.3 pF | 390 pF | 776.4 pF | 750 pF |

## Bode Plot of Loop Transfer Function

Figure 4 shows the bode plot of loop transfer function for 40kHz crossover frequency. 20.5dB and 67° are gain and phase margins for 41.1 kHz crossover frequency. System is stable. COMMENT on PHASE MARGINS

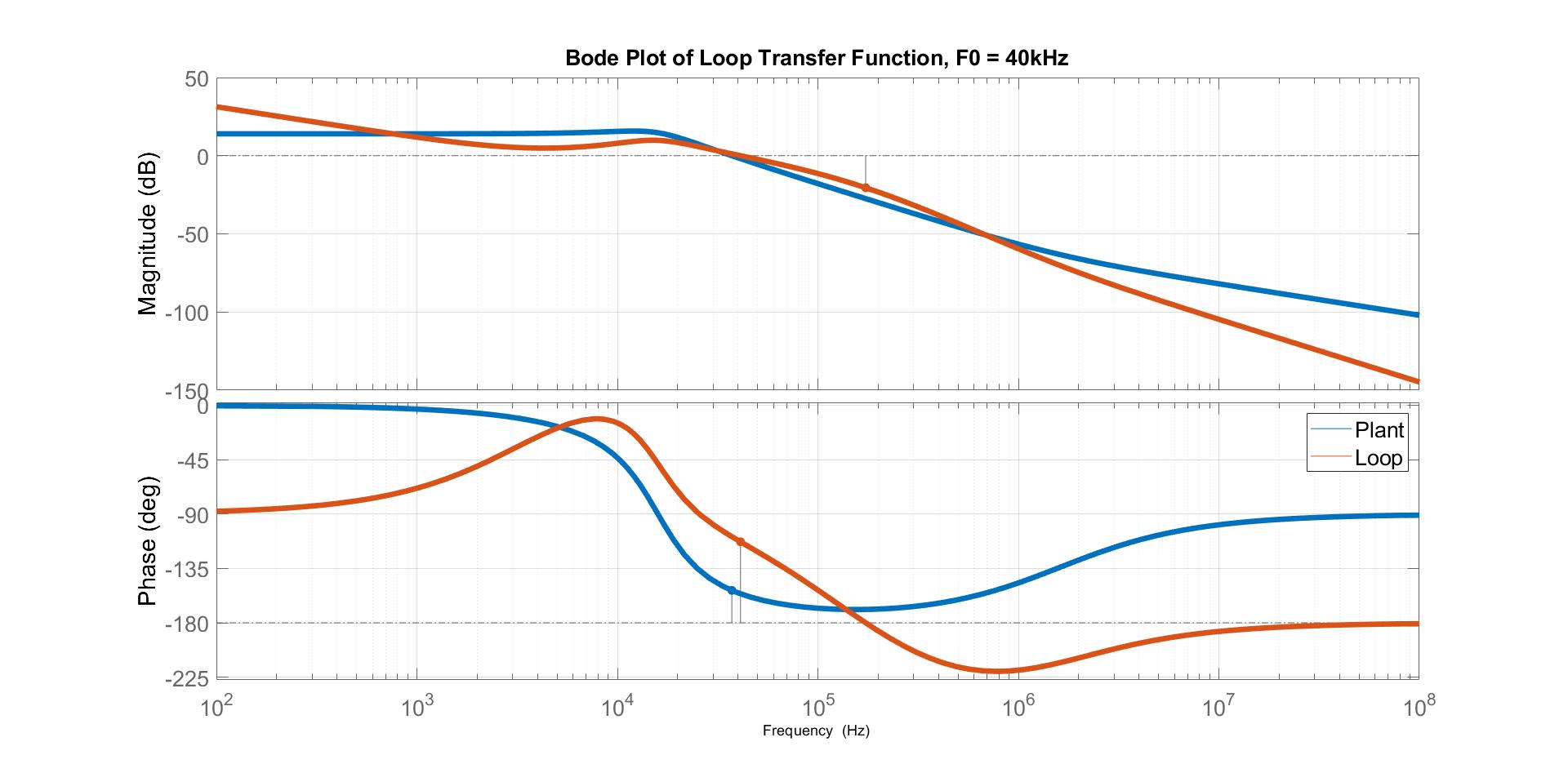


Figure 4 Bode plot of loop transfer function for 40kHz crossover frequency

Figure 5 shows the bode plot of loop transfer function for 20kHz crossover frequency. 23.3dB and 101° are gain and phase margins for 23.9 kHz crossover frequency. System has 3 phase crossover point at 496Hz, 9.66kHz and 23.9kHz. System is stable. COMMENT on PHASE MARGINS

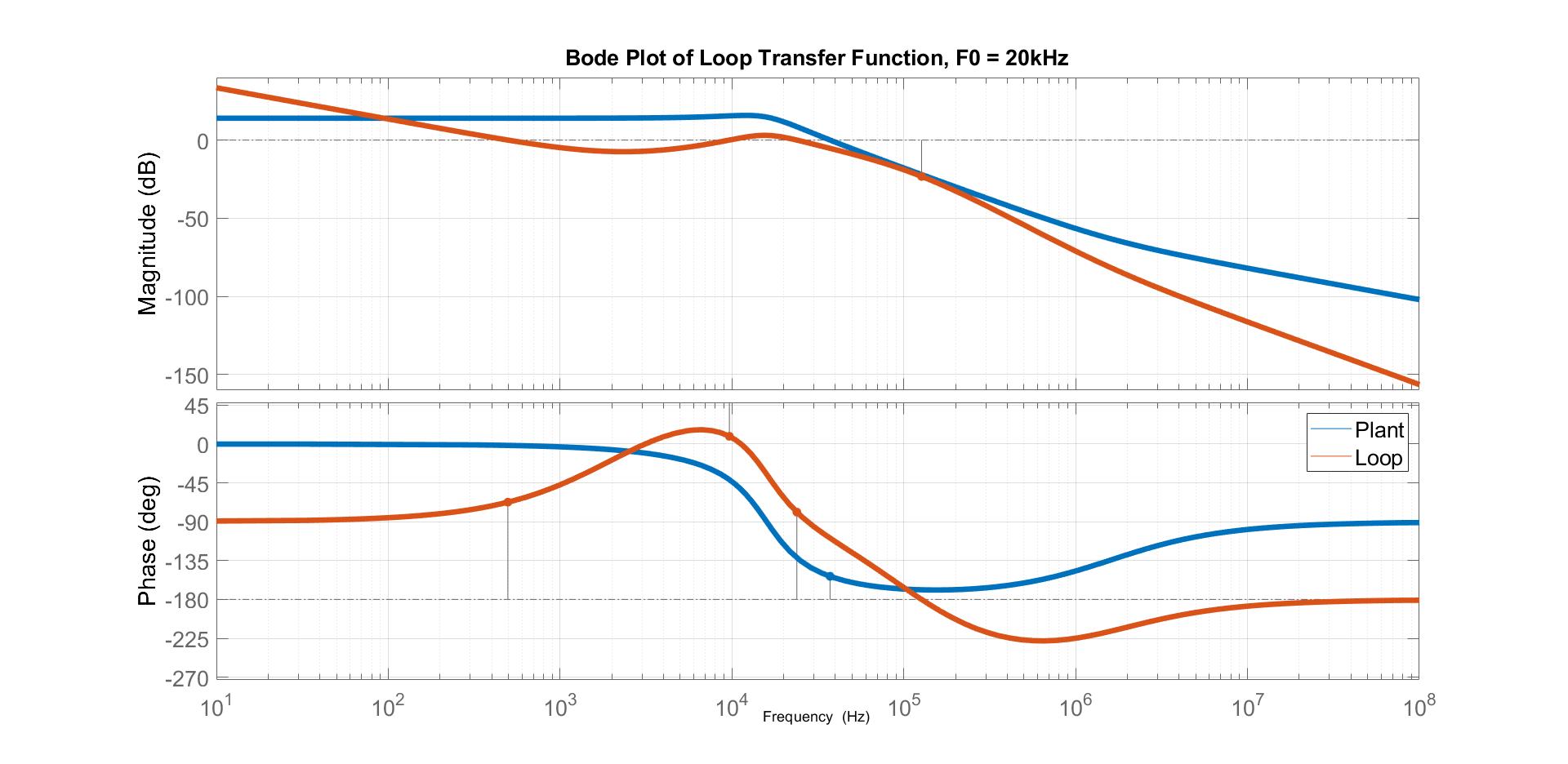


Figure 5 Bode plot of loop transfer function for 20kHz crossover frequency

# Simulation

## Full Load to Half Load

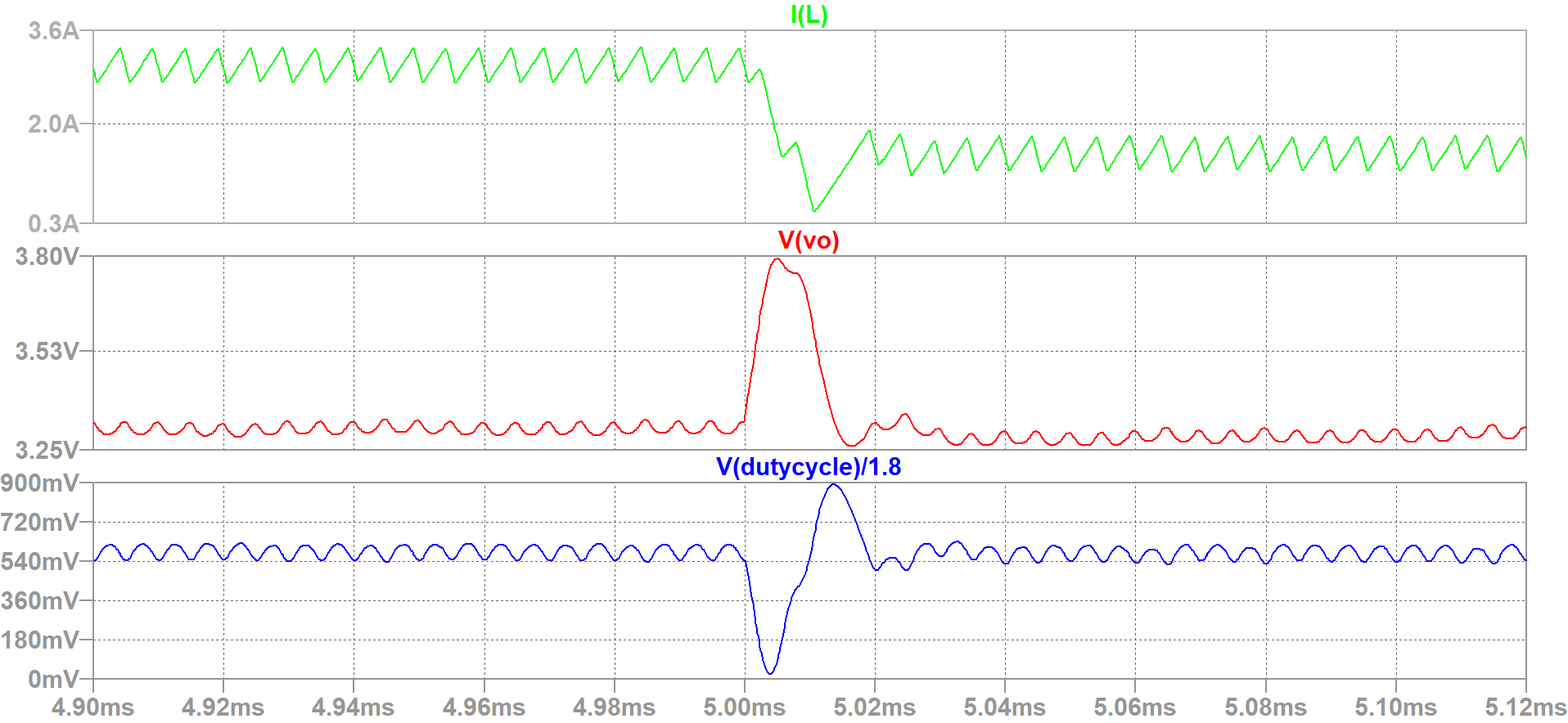


Figure 6 Full-to-half load, transient waveforms of Vo, IL and D for compensator with 40kHz crossover frequency

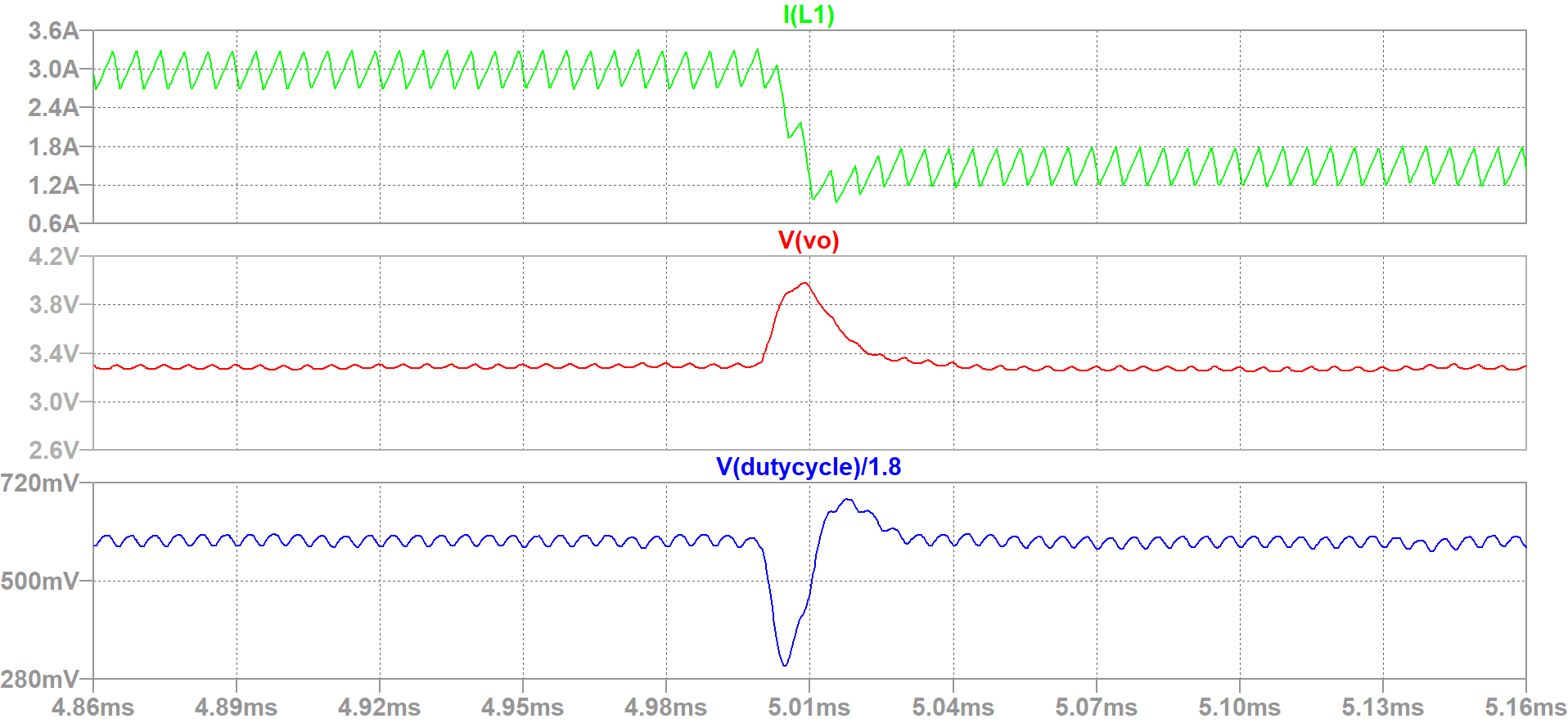


Figure 7 Full-to-half load, transient waveforms of Vo, IL and D for compensator with 20kHz crossover frequency

## Half Load to Full Load

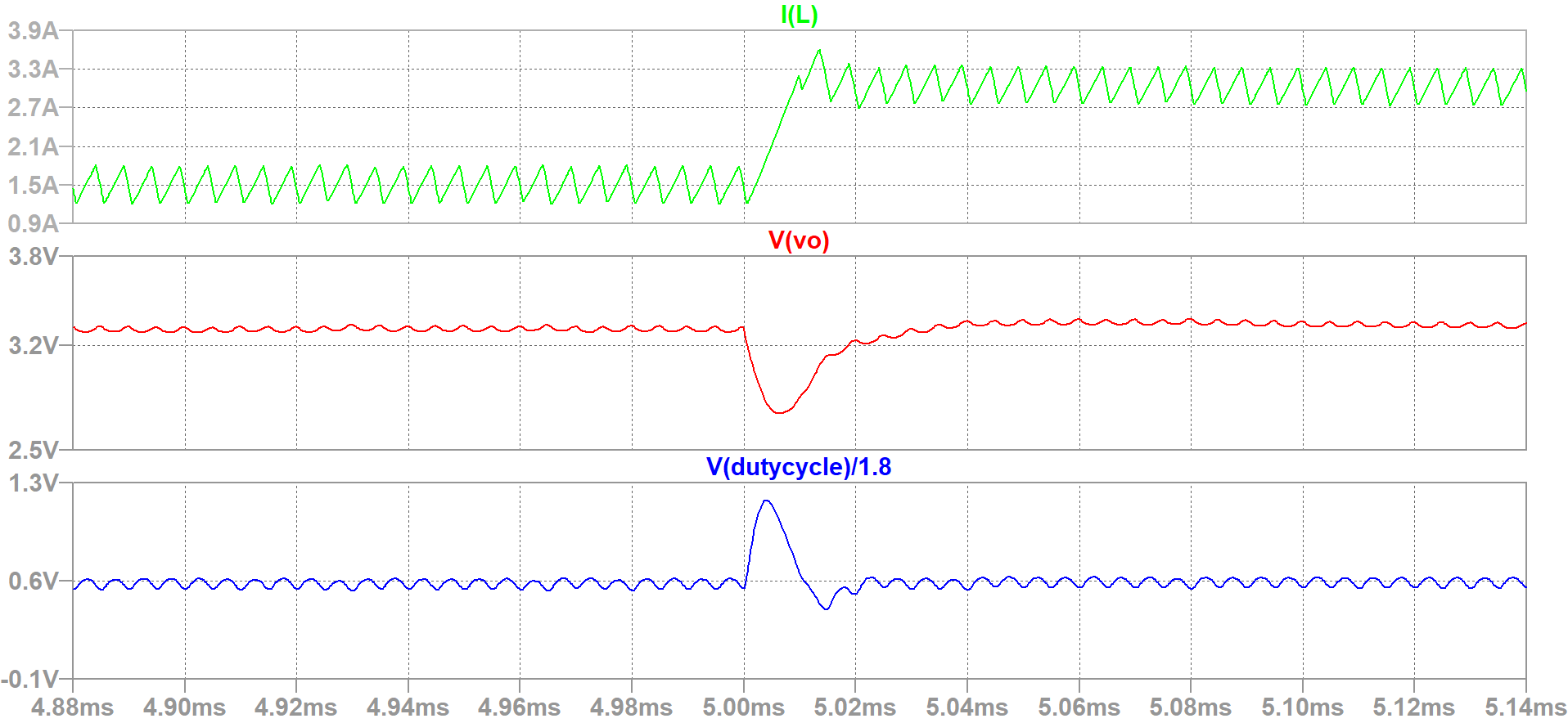


Figure 8 Half-to-full load, transient waveforms of Vo, IL and D for compensator with 40kHz crossover frequency

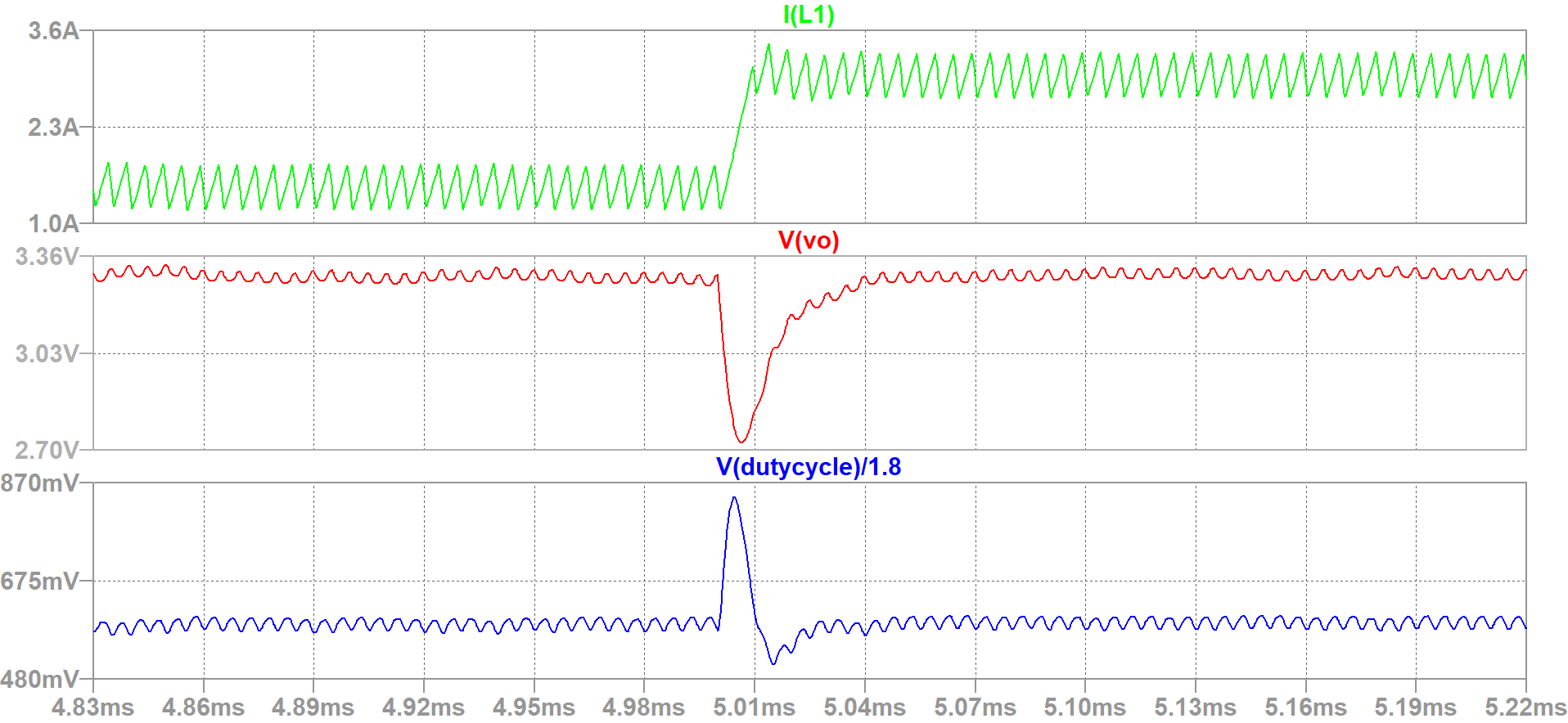


Figure 9 Half-to-full load, transient waveforms of Vo, IL and D for compensator with 20kHz crossover frequency

## Drop in Input Voltage

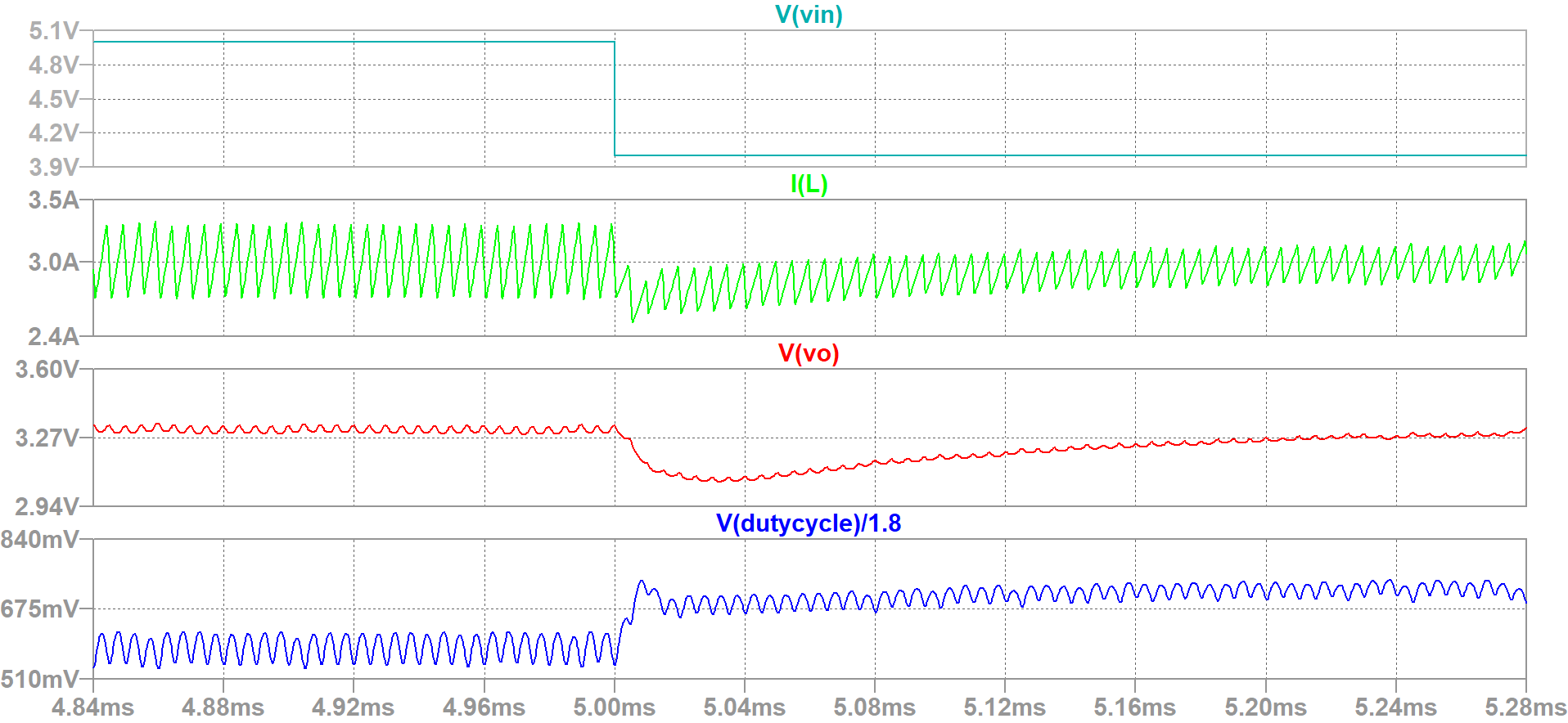


Figure 10 Step change in input voltage 5V-to-4V, transient waveforms of Vo, Vin, IL and D for compensator with 40kHz crossover frequency

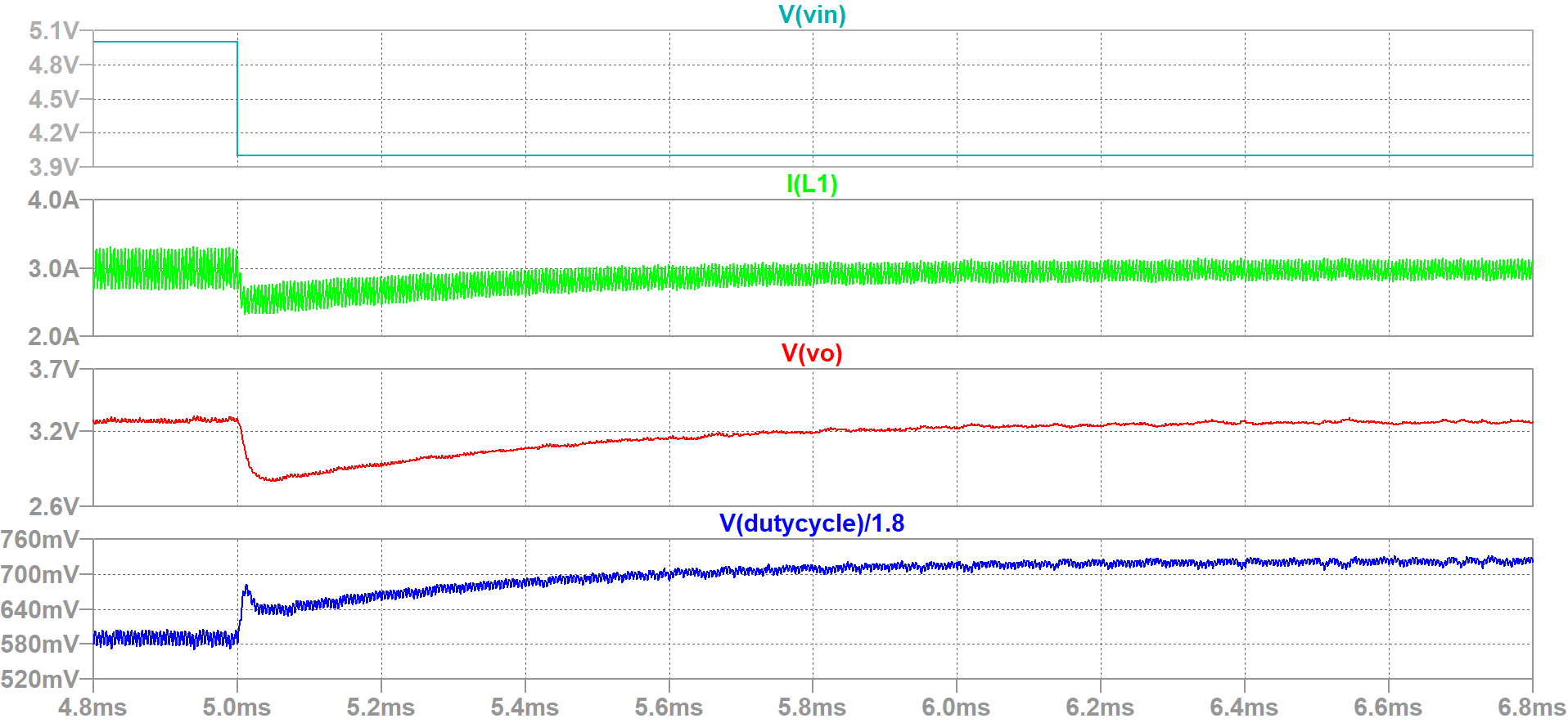


Figure 11 Step change in input voltage 5V-to-4V, transient waveforms of Vo, Vin, IL and D for compensator with 20kHz crossover frequency