

Linear Regulator Series, Switching Regulator Series

Measurement Method for Phase Margin with Frequency Response Analyzer (FRA)

To measure the phase margin of a linear regulator IC or switching regulator IC, you can use existing measuring instruments such as oscilloscopes and network analyzers. However, the circuit for injecting a signal into the feedback loop needs its signal source to be floated using a transformer. There are few transformers that have a flat characteristic down to a low frequency. In addition, the switching frequency in the switching regulator must be removed from the output waveform to obtain correct results. This application note introduces a method for easily measuring the phase margin with a Frequency Response Analyzer (FRA) made by NF Corporation.

Measurement method with existing measuring instrument

Figure 1 shows an example of measurement setup with an oscilloscope and a signal generator. To inject a sinusoidal signal into the feedback loop, the signal source is floated using a transformer.

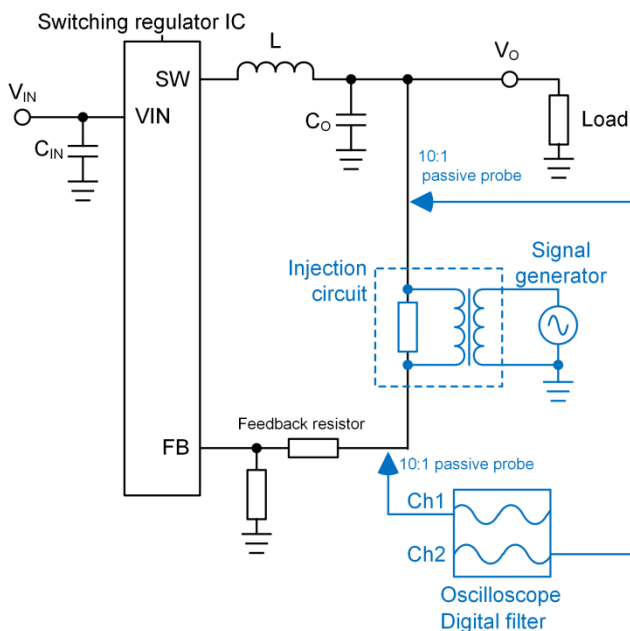


Figure 1. Example of setup with oscilloscope

The input and output of the loop are monitored with Channels 1 and 2 of the oscilloscope, respectively. Since the switching noise generated in

the switching regulator IC is superimposed on the waveform, it is necessary to completely remove the noise by applying a LPF to the waveform with the digital filter of the oscilloscope. The frequency of the signal generator is varied until the amplitudes of the input and output waveforms agree (CH1 – CH2 = 0 dB). The phase difference between Channels 1 and 2 at this frequency is the value of the phase margin. The amplitude and phase of the sine wave is read using the oscilloscope's measurement function.

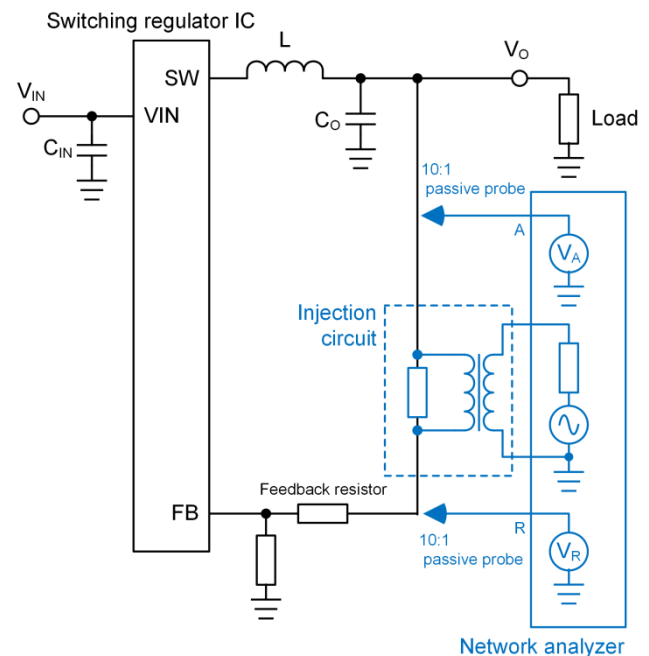


Figure 2. Example of setup with network analyzer

Figure 2 shows an example of a measurement setup with a network analyzer. As in the example of the setup with an oscilloscope, a sinusoidal signal from the signal generator installed on the network analyzer is injected into the feedback loop using a transformer. With inputs R and A of the network analyzer connected to the input and output of the loop, respectively, the phase margin is determined by measuring A/R . Care must be taken when measuring over a wide frequency bandwidth, since the measurement is affected by the frequency characteristics of the transformer.

Measurement method with FRA

Figure 3 shows the external appearance of FRA5087 and Figure 4 shows an example of a measurement setup with the FRA. Since the signal generator installed on the FRA is isolated from the chassis (Figure 5), a sinusoidal signal can be directly injected into the feedback loop. This allows evaluations regardless of the characteristics of the transformer.

1. Choose a point for injecting the signal where input impedance Z_{IN} is high when viewing in the direction of the signal transmission in the loop and where output impedance Z_O is low when viewing in the opposite direction. When using a linear regulator or DC/DC switching regulator, input the signal between the front of the feedback resistor and output V_O .

The method of injection is to connect the signal source output to both sides of injection resistor R_i . By using resistor R_i that satisfies the condition $Z_{IN} \gg R_i \gg Z_O$, you can perform the measurement without disturbing the original loop characteristics. NF Corporation recommends a resistor value between 50Ω and 100Ω.

2. Pick up the signal with shield wires from the both sides of injection resistor R_i and connect the wires to Channels 1 and 2 of the FRA. Channel 1 and 2 of FRA5087 have an input impedance of 1MΩ ($C = 25 \text{ pF} \pm 5 \text{ pF}$), a maximum allowable input of $\pm 350 \text{ V}$ (AC + DC), and a breakdown voltage of 250 Vrms. Therefore, the channels can be directly connected in most cases. FRA5087 can measure voltages and phases up to 10 MHz. However, the cables connected to the inputs of both channels should be of the same type and length to precisely measure the phases at a high frequency. When measuring at a high voltage, also pay attention to the breakdown voltage of the

signal cables to be connected.

In addition, the use of an optional adapter for the loop gain measurement (Figure 6) makes the connection easier (Figure 7).

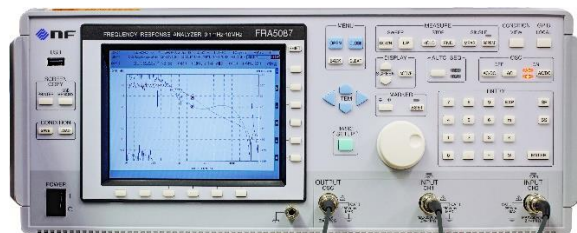


Figure 3. External appearance of FRA5087

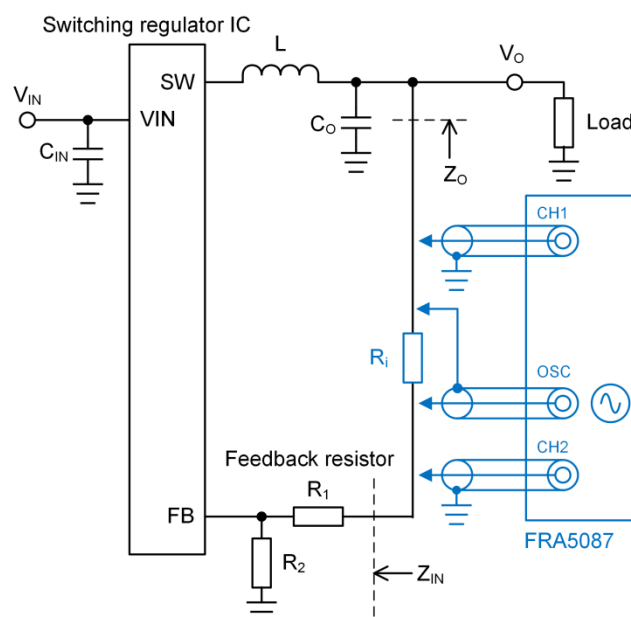


Figure 4. Example of setup with FRA



Figure 5. Each terminal electrically insulated from chassis



(Photograph by NF Corporation)

Figure 6. Adapter for loop gain measurement

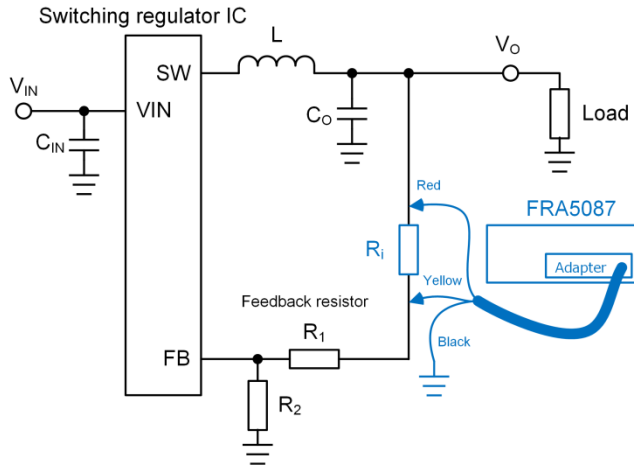


Figure 7. Example of setup with adapter

3. Press the BASIC SETUP key to perform the basic setting.



Figure 8 BASIC SETUP key

4. Set the upper and lower limits of the sweep frequency range.

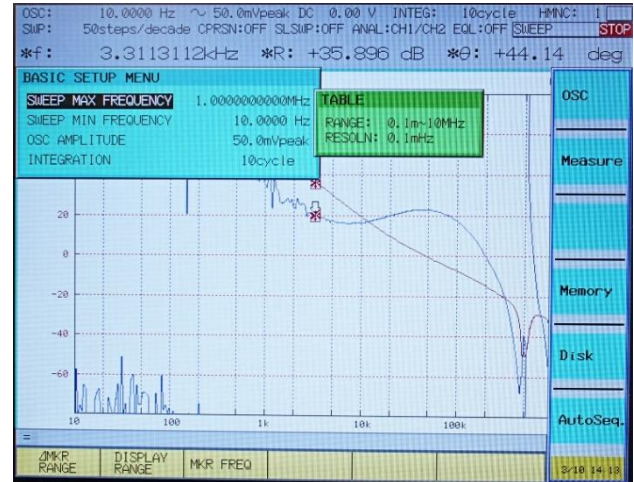


Figure 9. Setting screen for upper limit of frequency

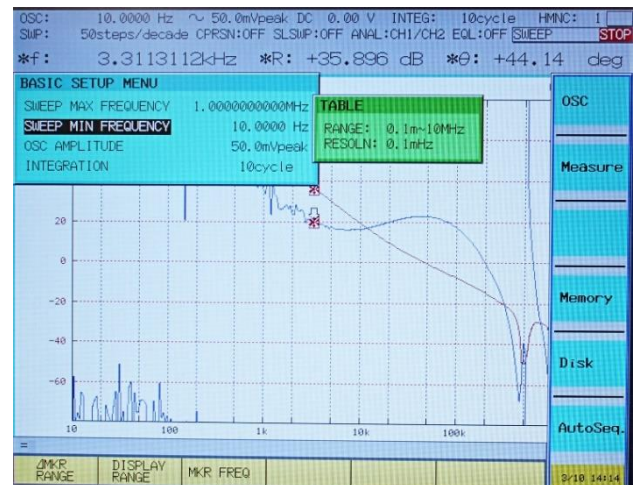


Figure 10. Setting screen for lower limit of frequency

5. Set the output level of the oscillator within the range where the loop operates linearly. Set the output level of the oscillator (Figure 11) and then turn ON the output (Figure 12). It should be noted that, after you change the values in the oscillator output menu, the actual output values will not be updated until you press the AC/DC ON key again. Later, we explain the method for setting the output level of the oscillator.



Figure 11. Setting screen for oscillator output

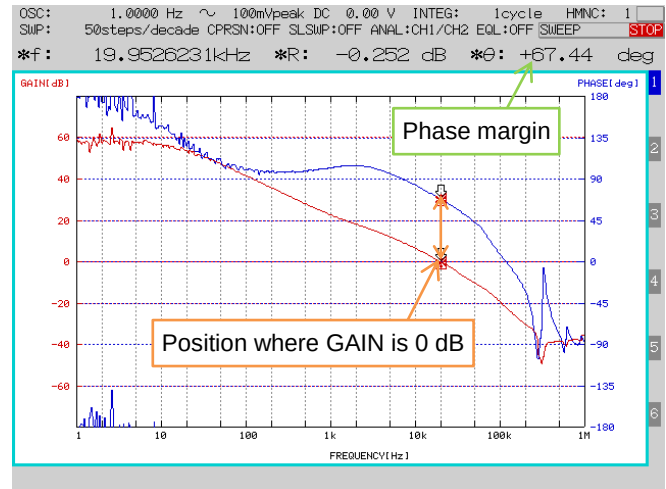


Figure 14. Reading phase margin with marker

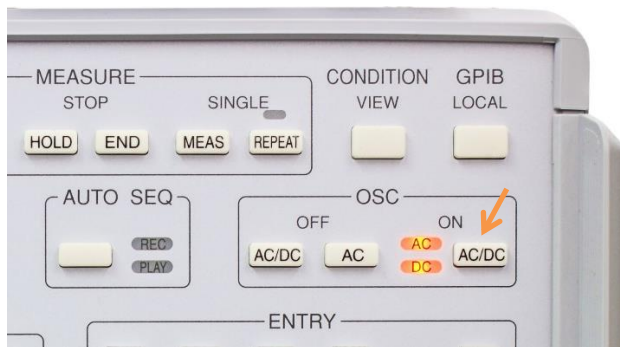


Figure 12. Oscillator output ON key

6. Press the SWEEP DOWN key to start the measurement.



Figure 13. SWEEP DOWN key

7. Move the marker with the marker knob and read the phase margin. Move the marker to the position where GAIN (red line) becomes 0 dB. The “*θ” area of the marker display shows the value of the phase margin.

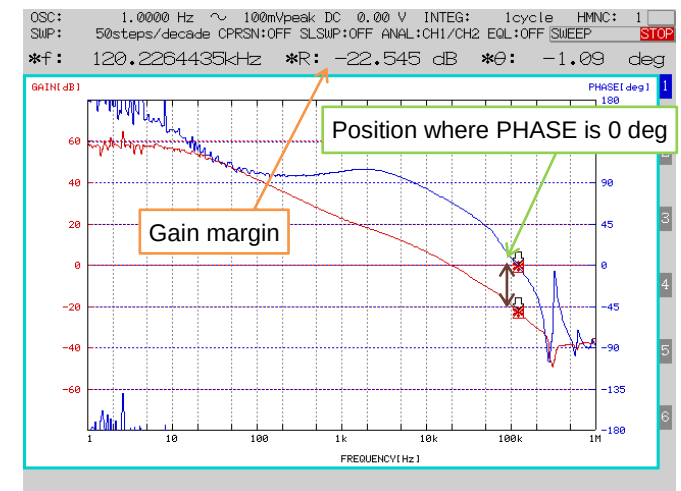


Figure 15. Reading gain margin with marker

9. Method to set the output level of oscillation

It is necessary to set the output level of the oscillation within the range where the loop linearly operates. As shown in Figure 16, monitor output V_O with an oscilloscope. When an appropriate level of injection is injected into the loop, a sine wave is observed as shown in Figure 17. When the injection level is excessive, a distorted waveform is observed as shown in Figure 18. Such distortion prevents the measurement of the correct phase characteristics.

Next, Figures 19 to 28 show the phase characteristics when the oscillation output level is varied from 10 mV peak to 500 mV peak. When the injection level is too low, the signal is buried in noise and cannot be measured. When the injection level is too high, the loop is saturated and its characteristics are altered. In this example, in order to measure just the phase margin, you need only to be able to read data measuring around several tens of kHz. Therefore, the appropriate level for the oscillation output is between 10 mV peak and 100 mV peak. Since the characteristics in the high frequency region are changed at the output level of 200 mV peak, the loop saturation can be deemed to have started. When you want to evaluate the loop characteristics in the low frequency region, the appropriate level for the oscillation output is 60 mV peak to 100 mV peak.

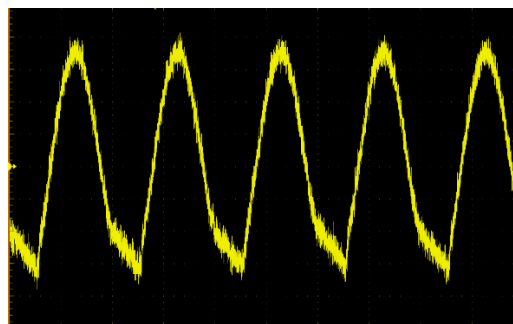


Figure 18. Output waveform with excessive injection level prohibiting linear operation

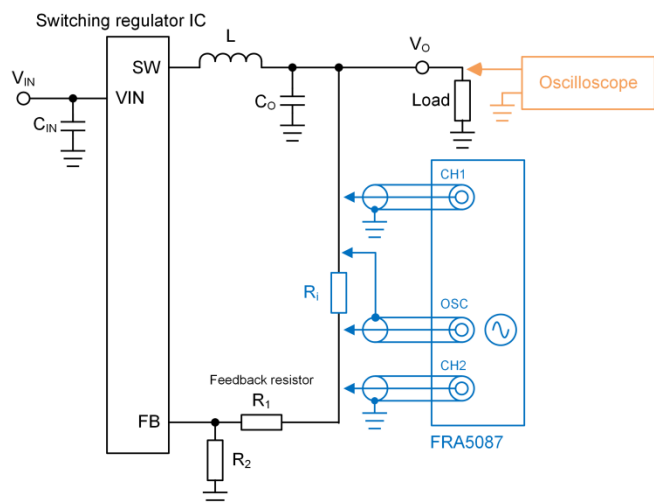


Figure 16. Monitoring output with oscilloscope

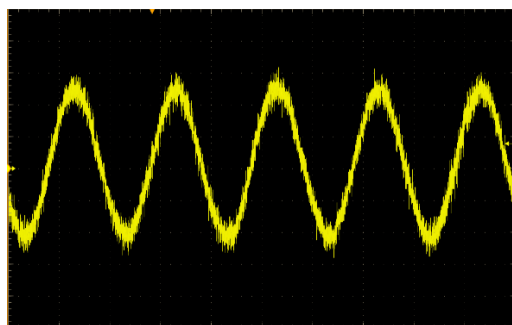


Figure 17. Output waveform with appropriate injection level allowing linear operation

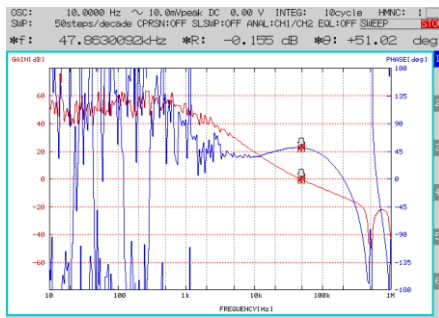


Figure 19. Oscillation output level 10 mV peak

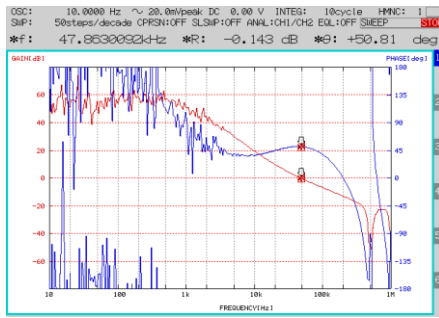


Figure 20. Oscillation output level 20 mV peak

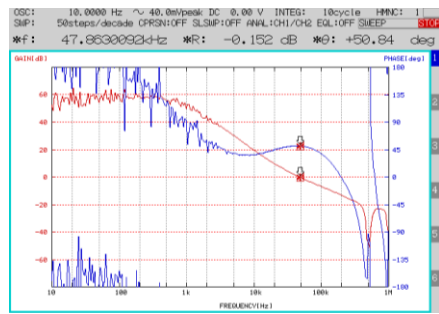


Figure 21. Oscillation output level 40 mV peak

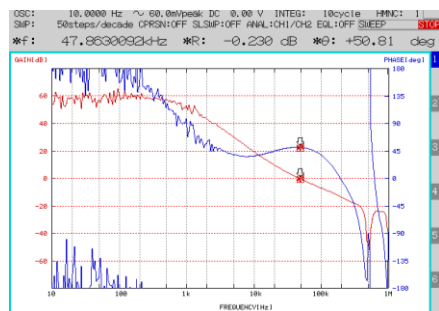


Figure 22. Oscillation output level 60 mV peak

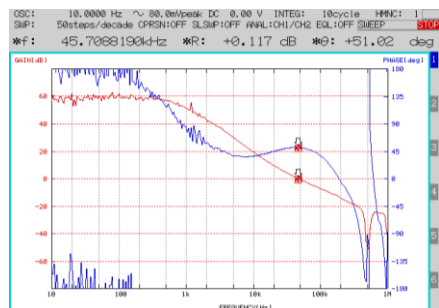


Figure 23. Oscillation output level 80 mV peak

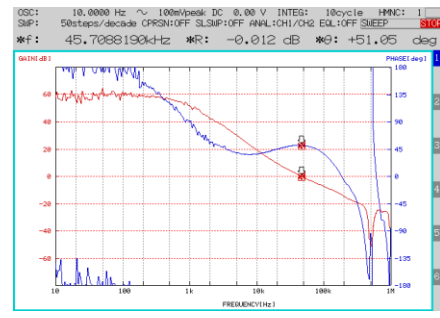


Figure 24. Oscillation output level 100 mV peak

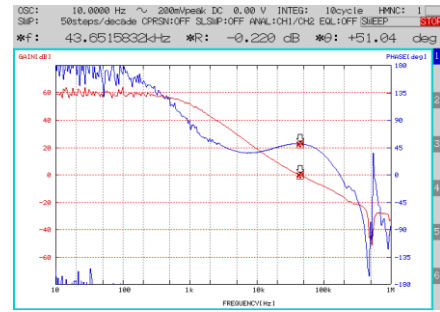


Figure 25. Oscillation output level 200 mV peak

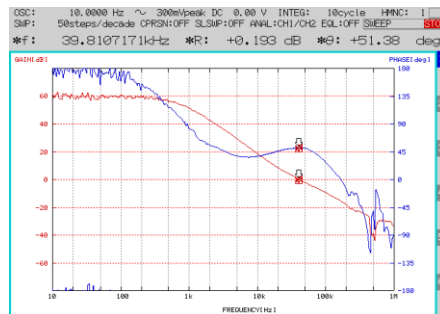


Figure 26. Oscillation output level 300 mV peak

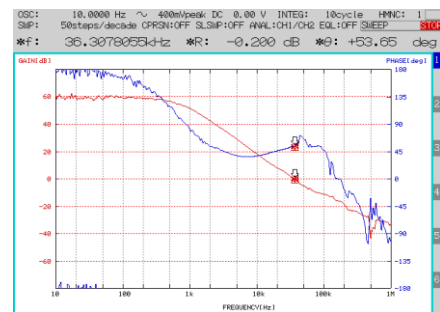


Figure 27. Oscillation output level 400 mV peak

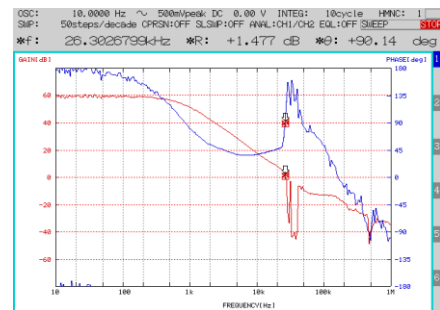


Figure 28. Oscillation output level 500 mV peak

Stability judgment

Table 1 shows the relation between the phase and gain margins and the step response. Since there is a trade-off relation between the phase and gain margins and the step response, the judgment criteria depend on the characteristics required for the power supply.

When a power supply that shows no ringing in the step response is required, it is necessary to adjust the phase of the IC so that the characteristics with a phase margin of 60 deg or larger and a gain margin of 10 dB or larger are obtained. However, the load response characteristics become slow in this case.

Phase margin	Gain margin	Conditions	
		Step response	Ringing
20 deg	3 dB	Fast	Large
30 deg	5 dB	Fast	Somewhat large
45 deg	7 dB	Fast	Some
60 deg	10 dB	Somewhat slow	None
72 deg	12 dB	Slow	None

Table 1. Relation between phase and gain margins and step response

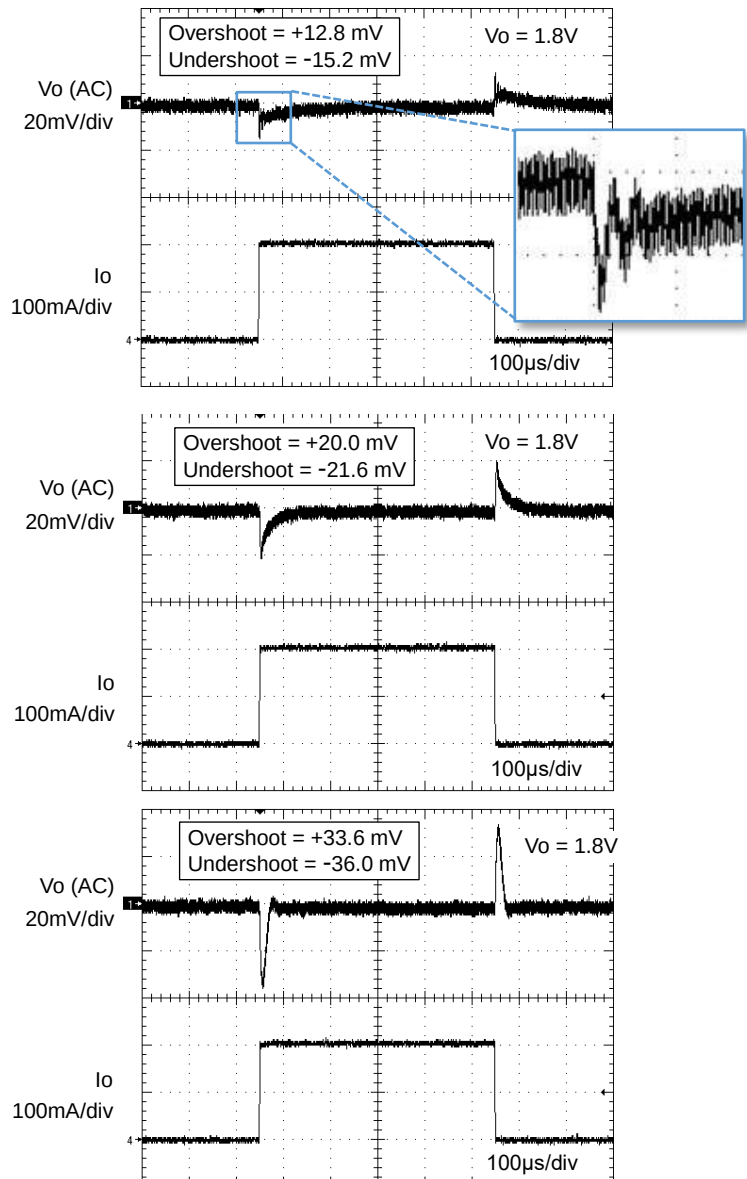
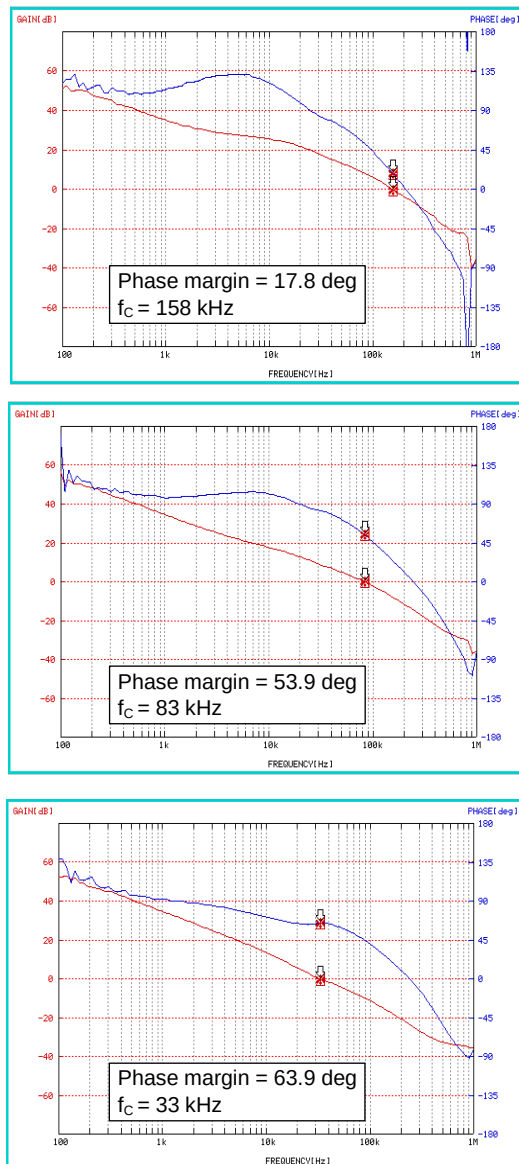


Figure 29. Example of measurement of phase margin and step response characteristic

If you require fast load-response characteristics, adjust the phase of the IC so that a phase margin of approximately 45 deg is obtained. However, in this case it should be noted that a phase margin of 30 deg or larger and a gain margin of 5 dB or larger are obtained as the worst values considering the temperature characteristics and variation. When the margins are smaller than these values, an abnormal oscillation may occur.

Figure 29 shows examples of the measurement of the phase margin and the step response characteristics. The top row shows the waveform when the phase margin is 17.8 deg. Although the load response is good (the output voltage shows little overshoot or undershoot), a ringing is visible. Therefore, a variation may cause an abnormal oscillation. The middle row shows the waveform when the phase margin is 53.9 deg. There is no ringing in the output waveform. The load response characteristics are excellent, giving +1.1% and -1.2% relative to the output voltage. The bottom row shows the waveform when the phase margin is 63.9 deg. Although there is no ringing in the output waveform, the load response characteristics worsen, giving +1.87% and -2.0% relative to the output voltage. When the load response characteristics are not a concern for the power supply, these characteristics can be used without any problem, since the phase characteristics are more stable compared with the characteristics in the middle row.

For more details on the usage of FRA, please refer to the instruction manual by NF Corporation.

References:

- (1) Frequency Response Analyzer FRA5097 Instruction Manual 2010 (NF Corporation)
- (2) Syuhasuu Tokusei Bunsekiki Gizyutsu Kaisetu Syu 2010 (Frequency Response Analyzer Technical Note Collection 2010 in Japanese) NF Corporation
- (3) Syuhasuu Tokusei Sokutei niyoru Suittingu Dengen no Anteisei Hyouka 2011 (Stability Evaluation of Switching Power Supply from Frequency Response Measurement 2011 in Japanese) NF Corporation
- (4) LF Nettowahku Anaraiza niyoru DC-DC Konbahta Tokusei Hyouka 2008 (Characteristic Evaluation of DC-DC Converter Using LF Network Analyzer 2008 in Japanese) Agilent Technologies, currently Keysight Technologies

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