APPLICATION NOTE U-160

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SAMPLE CIRCUIT MODIFICATIONS ENHANCE OPTOCOUPLER PERFORMANCE

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Simple Circuit Modifications Enhance Optocoupler Performance

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The optocoupler is often used in pulse-width-modulated power converters to transmit an error signal across an isolation boundary. This error signal is used on the primary side to close the control loop. A phototransistor within this optocoupler has a large collector to base area in order to efficiently detect the photons of light emitted from the photodiode. This large area makes a good detector but it increases the collector to base capacitance. Larger capacitance adversely effects the bandwidth of the optocoupler by introducing a phase lag, even at low frequencies, in the small signal model of the compensation circuit. Figure 1 shows a typical optocoupler feedback scheme using a the UC3965 Precision Reference with Low Offset Error Amplifier and a Siemens Optoelectronics IL207 optocoupler. As the output voltage (V_O) drops below its nominal value, due to a sudden increase in load, the photodiode current decreases. This decrease causes the emitter voltage on the phototransistor to decrease which increases the duty cycle of the modulator. The higher duty cycle restores the output voltage to its nominal value. The type of compensation (I, PI, etc) on the UC3965 Error Amplifier is dependent on the PWM control method (i.e., voltage mode or current mode) and the power circuit topology. In all cases the bandwidth and phase of the phototransistor can effect the stability of the power supply. It is the intent of this application note to present test data on circuit configurations which show improvements in the bandwidth performance of a common optocoupler.

A test circuit, shown in Figure 2, was used to measure the gain and phase of an IL207 optocoupler along with the error amplifier of a UC3823AN PWM controller. The integrators in the compensation circuit of Figure 1 were left out and a common ground was used in all of the test circuits in order to simplify the measurements. The negative dc supply voltage (V_{NEG}) was adjusted before each test, with the V_{AC} node grounded, to get about 2 V_{DC} at the output of the error amplifier ($V_{EA,OUT}$). A Ridley Engineering, Inc. AP102A Network Analyzer (produces a swept sine wave source and has two input channels to measure the ac transfer function of a network) was used to measure the frequency response for each test circuit. During the tests an oscilloscope was used to ensure that clipping or

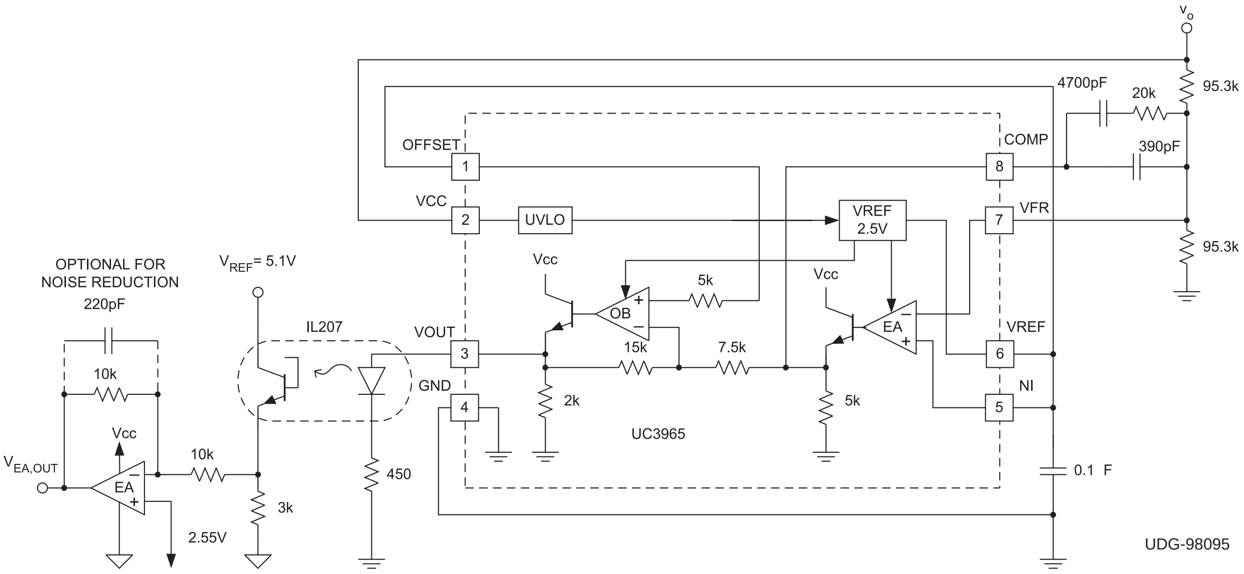

Figure 1. Typical Error Amplifier Feedback with Optocoupler

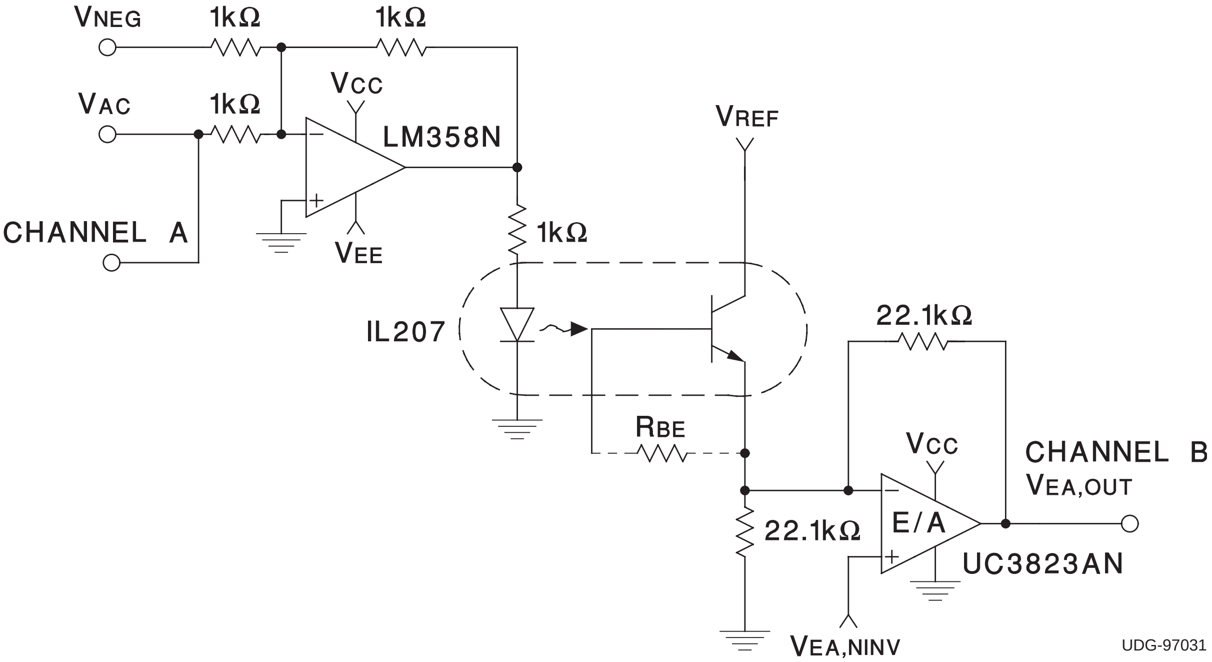

Figure 2. Data Collected for Test 1 with R_{BE} Connected, Data Collected for Test 2 with R_{BE} Not Connected

nonlinearities did not occur at the outputs of the two amplifiers. The results for test 1 are shown in Figure 3. While the noise at 20kHz was later isolated to a power supply used in the testing, its effect on the data is minimum and it was used for all the tests to maintain consistency. The gain in Figure 3 shows a –3dB frequency of about 45.9kHz and a phase of –70.1° at this point. One would expect a single pole –3dB to have a –45° phase shift, therefore this circuit is not modeled accurately by a simple RC filter. Realizing that the phase lag introduced by the optocoupler can steal away phase margin from the overall power supply control loop, it is clear that the optocoupler is phase limited with respect to bandwidth. A goal of this application note is to illustrate the importance of the phase limitations that optocouplers have in power supply feedback loops. To this end other circuit topologies will be presented to improve the effective frequency bandwidth of a given optocoupler. Note that the effective frequency bandwidth can be considered as a figure of merit for an optocoupler and should be less than the phase margin of the power supply control loop. If –15° is arbitrarily selected as this phase it is obvious that the –3dB point on the optocoupler transfer gain curve (Figure 3) will be at a higher frequency.

As mentioned above the designer should keep the control loop crossover frequency below the effective opto bandwidth to ensure enough phase margin and thus power supply stability. For the case of the data shown in Figure 3 the –15° phase point reveals an effective opto bandwidth of 8.56kHz. In contrast the –3dB point yields a much higher frequency value of 45.9kHz. The 8.56kHz frequency may be fine for some designs but others may need up to 30kHz or more of effective opto bandwidth to support a higher crossover frequency. Techniques to improve this effective bandwidth will be introduced shortly.

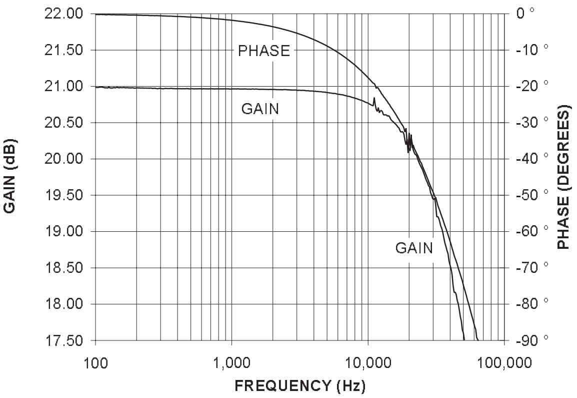

Figure 3. Gain and Phase for Figure 2 Circuit with R_{BE} Not Connected

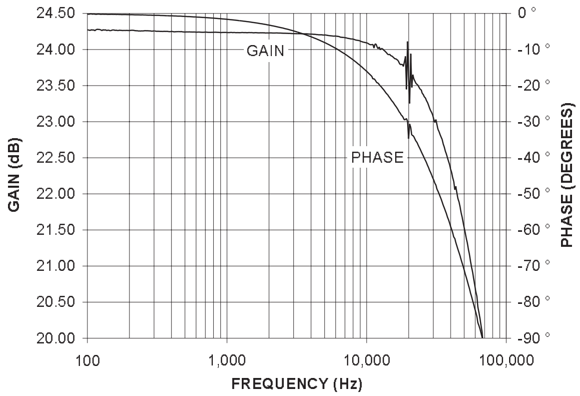

Figure 4. Gain and Phase for Figure 2 Circuit with R_{BE} = 300k

By adding a 300k base-to-emitter resistor in the circuit of Figure 2, test 2 results where obtained and are shown in Figure 4. The added base-to-emitter resistor is often used to reduce noise, typical in optocouplers that have the optotransistor base connection brought out to an IC pin. From the data graphed in Figure 4 it is clear that the R_{BE} resistor also increases the effective bandwidth by about 9% relative to test 1.

The circuit shown in Figure 5 was used to collect data for tests 3 and 4. Graphs of the responses are shown in Figures 6 and 7 respectively. These tests have the inverting input of the error amplifier (E/A) disconnected from the emitter terminal of the phototransistor and a resistor added between these points. The goal is to observe the effects of using the error amplifier in a topology which allows dc gain (however, unity gain was used in the test results presented here). With this configuration the effective opto bandwidth for tests 3 and 4 actually decreased from tests 1 and 2 by a factor of approximately 8, thus implying that the virtual ground at the emitter of the phototransistor was useful in increasing the bandwidth of the system. Note that for isolated power supplies the compensation gain is usually realized on the UC3965 side (secondary side). Therefore, setting up the error amplifier (on the primary side) for nearly unity gain or less is not a problem. For the final test circuit the error amplifier is used with the optotransistor to realize the widest bandwidth from the optocoupler device.

The circuit shown in Figure 8 was used for tests 5 through 9. The base of the phototransistor is connected to the feedback resistor, R_F. An increase in the effective opto bandwidth and the –3dB bandwidth is seen in this optocoupler circuit. The phototransistor has a component of base current

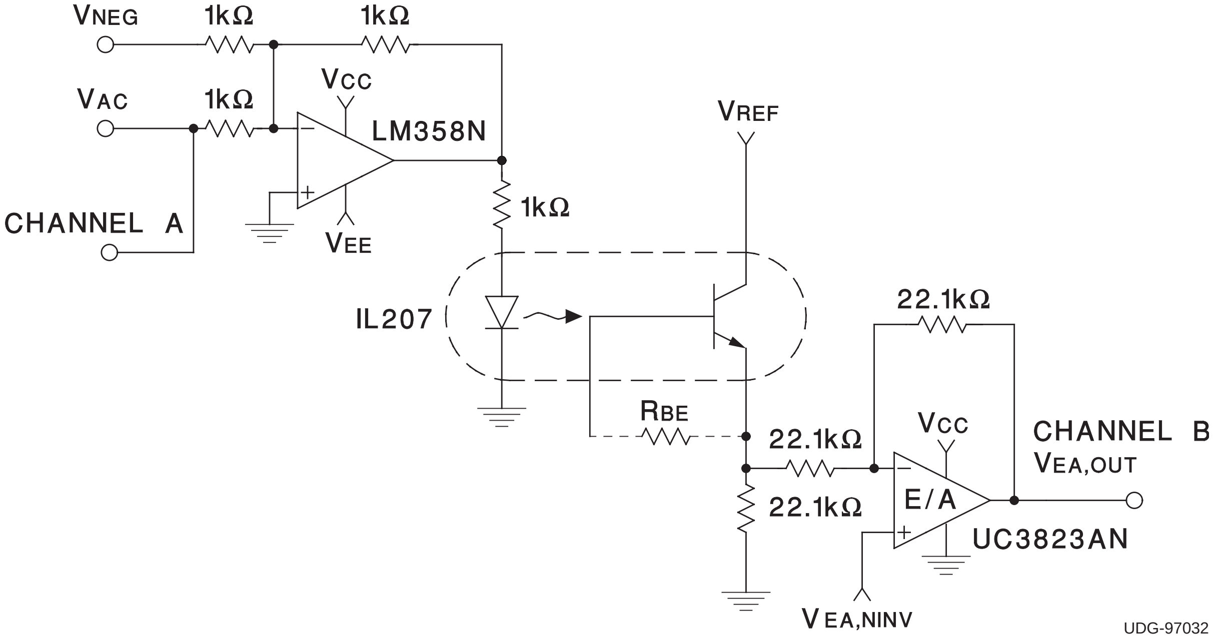

Figure 5. Data Collected for Test 3 with R_{BE} Not Connected, Data Collected for Test 4 with R_{BE} Connected

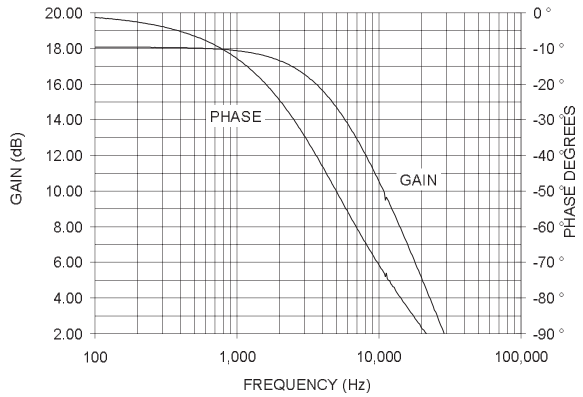

Figure 6. Gain and Phase for Figure 5 with R_{BE} = 300k

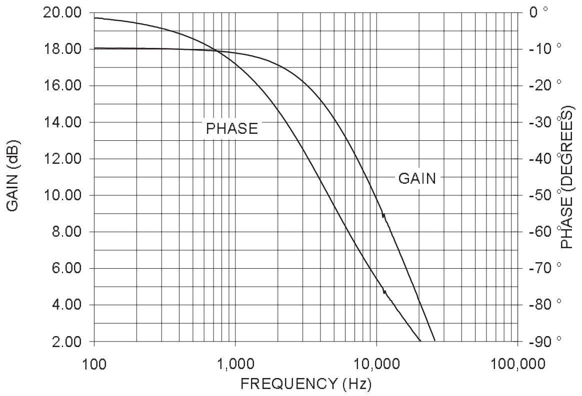

Figure 7. Gain and Phase for Figure 5 with R_{BE} Not Connected

provided by the photodiode and another component of current by the base connection to the feedback resistor. For small signal conditions the base to emitter junction is forward biased. Large signal characteristics, as would be seen under power supply start up or current limit conditions, were not investigated. In tests 5 through 9 different dc gains were achieved by varying the values of R_F and R_E, the feedback and optotransistor emitter resistors. In some cases a 3.3pF capacitor had to be put in parallel with the R_F resistor to prevent oscillation. Depending upon a given power supply design a capacitor of approximately 220pF could be used in parallel with R_F to prevent oscillations.

Test results indicate that the maximum practical overall dc gain of the error amplifier is about 7dB (Test 9). As mentioned above, the dc gain required in the compensation network for the power supply can be realized with the UC3965 so the 7dB limit does not present a system limitation.

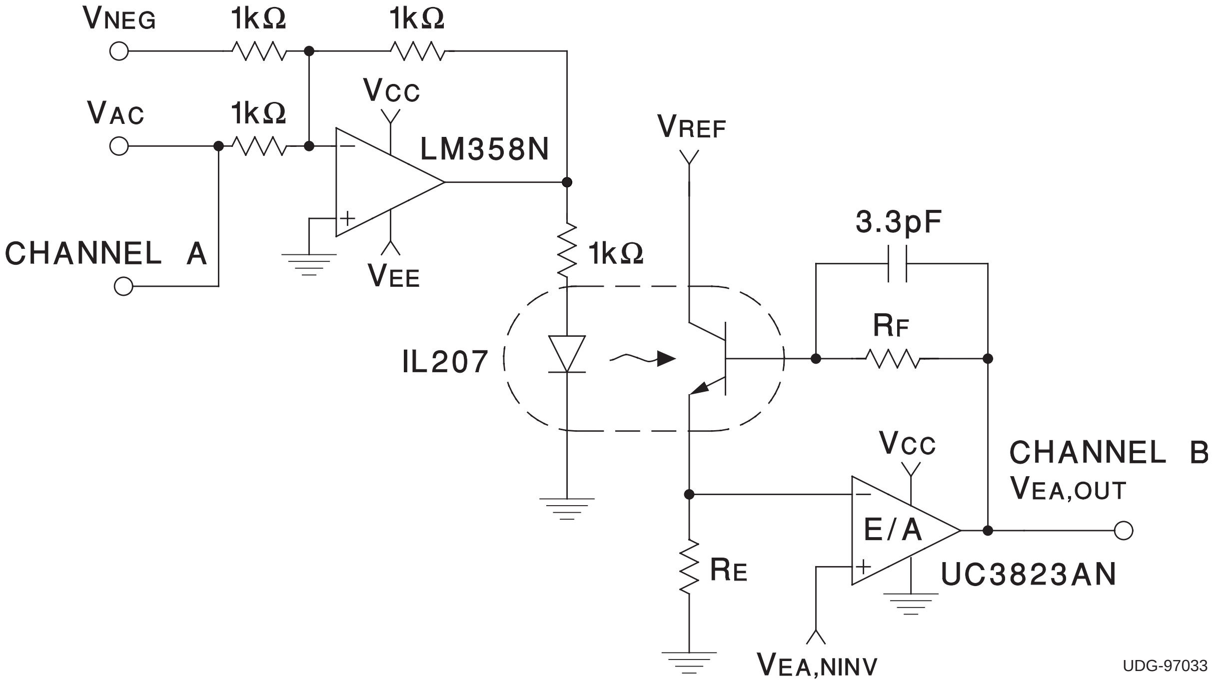

Figure 8. Circuit Used in Tests 5 through 9

(Data results shown in Figures 9 through 13)

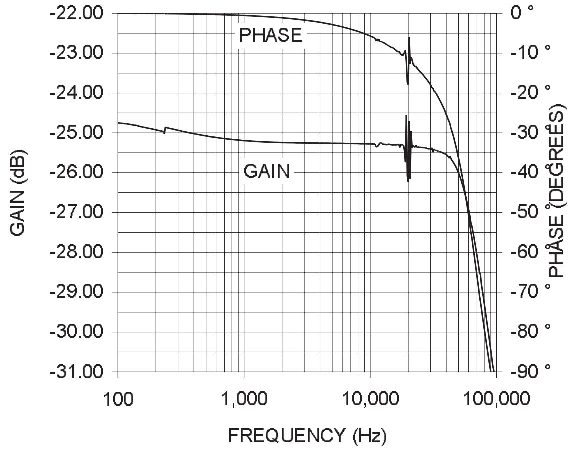

Figure 9. Gain and Phase for Figure 8, R_F = 22.1k and R_E = 22.1k

The maximum measured effective opto band-width of 25.5kHz was achieved for the values of R_F = 22.1k and R_E = 22.1k , as graphically depicted in Figure 9. This is a frequency improvement of about three to one relative to test 1 using the same optocoupler device. All the test results are summarized in Table 1 below.

Summary

The often unknown effective opto bandwidth for a power supply design may cause stability problems. Potential variation in optocoupler parameters from manufacturer to manufacturer in addition to part-to-part variations should be of concern to the designer in terms of closing the loop. The compensation circuit reviewed in this application note can reduce the phase lag effects introduced by the optocoupler by shifting the effective opto bandwidth higher in frequency by a factor of about three. This circuit can be used to help ensure that the variations in optocoupler parameters from lot-to-lot will have less impact on the power supply closed loop performance.

References

[1] Mammano, Bob, "*Isolating the Control Loop*", Unitrode SEM-800, 1991.

[2] Siemens Optoelectronics, 1995-1996 IL207A Datasheet.

[3] Krause, Bob, "*Optoelectronic Feedback Control Techniques for Linear and Switch Mode Power Supplies*", PCIM, Power Quality, 1993.

[4] Blockl, Reinhard, "*Light-Link Components Control High-Frequency Switched-Mode Power Supplies*", Siemens Appnote 41, Optoelectronics 1993 Databook.

Table I. Summary Test Data

Test No.	V_{NEG}= V_{EE} (V)	VAC (mV_{RMS})	–15° Phase Frequency (kHz)	–3dB Frequency (kHz)	R_{BE} (k)	Phase at –3dB Point (deg)	"dc Gain" (dB at 100Hz)	Graph Figure No.	Circuit Figure No.	R_F (k)	R_E (k)
1	–1.44	49.8	8.50	45.9	NC	–70.1	21.0	3	2		
2	–2.28	49.8	9.33	53.6	300	–75.3	24.3	4	2		
3	–2.31	49.8	1.18	4.59	300	–47.3	18.1	6	5		
4	–1.49	49.8	1.07	4.14	NC	–47.0	18.1	7	5		
5	–2.31	994	25.5	64.9	NC	–58.2	–24.7	9	8	22.1*	22.1
6	–2.32	49.8	17.9	>100	NC	<–79.4	–4.39	10	8	221*	22.1
7	–4.07	198	18.5	>100	NC	<–78.3	–2.13	11	8	221*	2.25
8	–2.06	198	24.3	>100	NC	<–59.1	5.54	12	8	750	22.1
9	–1.95	198	21.0	>100	NC	<–68.1	7.56	13	8	1000	22.1

Notes:

V_{EA}, N_{INV}= 2.49V and V_{CC} = 15.0V for all tests
NC = Not Connected
** = R_F with 3.3pF in parallel*

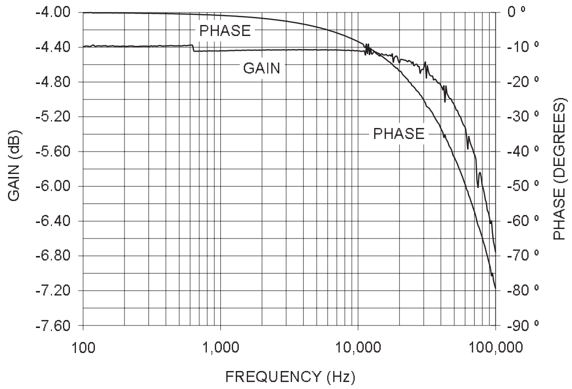

Figure 10. Gain and Phase for Figure 8, R_F = 221k and RE = 22.1k

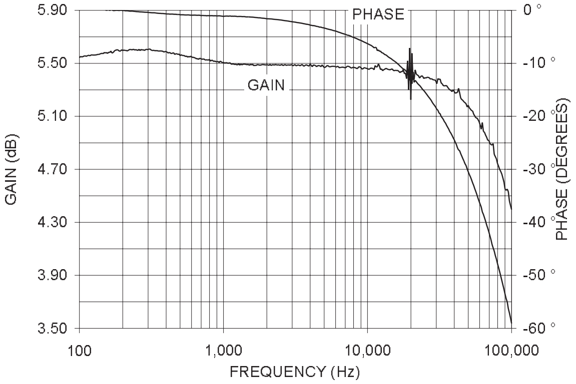

Figure 12. Gain and Phase for Figure 8, R_F = 750k and R_E = 22.1k

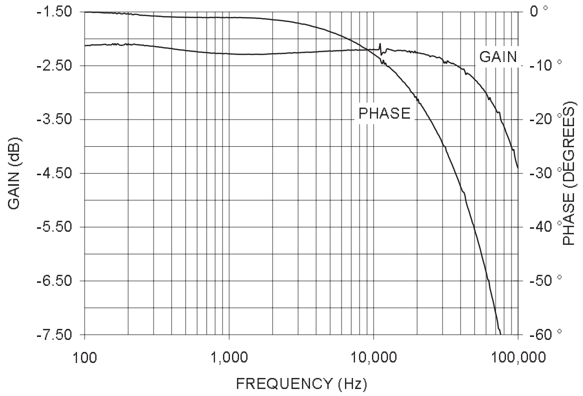

Figure 11. Gain and Phase for Figure 8, R_F = 221k and R_E = 2.25k

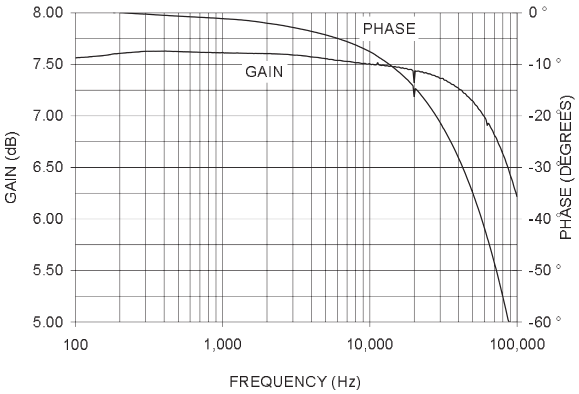

Figure 13. Gain and Phase for Figure 8, R_F = 1M and R_E = 22.1k