



TESTING POWER SOURCES FOR STABILITY

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Testing Power Sources for Stability

Abstract:

Recent advances in measurement technology have made it not only possible to measure stability margins, but made it a quick and simple process. On power sources with remote voltage sensing terminals, gain and phase margins can usually be determined in a few seconds without even removing the cover. These measurements can be made while the source is operating normally, supplying power to the real load. In this way, the effects of the real load on stability margins and power source performance can easily be determined. This paper will explore the causes of problems when the power source is connected to the real load — as opposed to the resistive load normally used by the power source manufacturers — and how to specify and test the power source to avoid those problems.

How a Power Source Regulates Voltage

In order to understand how to effectively test power sources for stability, one needs to understand what stability means and where the feedback loop is in a power source. Figure 1 shows a simplified block diagram of a typical power source. The power source may have several outputs, but prime consideration is given to the one around which the loop is closed.

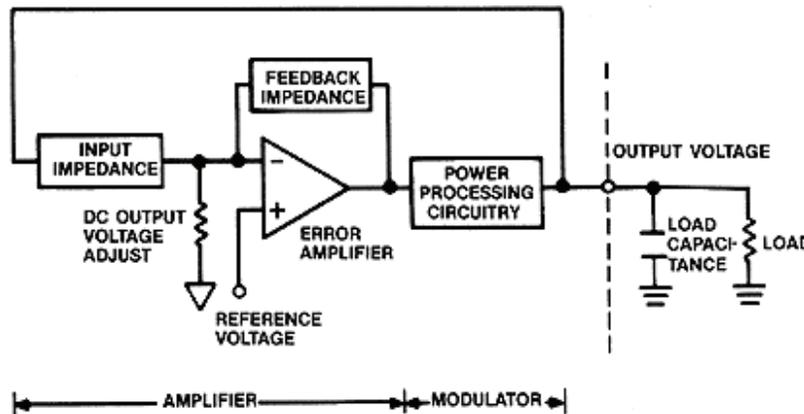


Figure 1. Block Diagram of Power Source Feedback Loop

The POWER PROCESSING CIRCUITRY is the power-handling portion of the power source, typically from the PWM terminal of a control IC to the regulated output. On one popular control IC, the SG1524, this is from pin 9 of the IC to the output of the power source that is being regulated. We call this portion the MODULATOR.

The ERROR AMPLIFIER is the op-amp which senses the value of the controlled output and compares it to the reference voltage, together with its associated input network, feedback network, and bias components. We call this the AMPLIFIER. Typically, the output voltage is scaled by a divider network consisting of a resistor in the input impedance block and a bias resistor, and then compared to a constant reference voltage. If the output voltage is too high, the inverting input of the op-amp will be more positive than the non-inverting input, and the output of the op-amp will swing negative, reducing the output of the modulator. The opposite happens if the output voltage is too low. For all reasonable frequencies above DC, the gain of the amplifier is the ratio of the FEEDBACK IMPEDANCE to the INPUT IMPEDANCE. The bias resistor does not enter into the AC gain calculation, since it carries no AC current.

The FEEDBACK LOOP is the path through the input impedance, the error amplifier, the power processing circuit, and back around to the input impedance. The gain around this loop is the product of the gain of the amplifier and the gain of the modulator. If the gains are expressed in dB, the gain around the loop is simply the sum of the gain of the amplifier (in dB) and the gain of the modulator (also in dB), since dB is a log scale and you multiply by adding logarithms. When multiplying two quantities that have magnitude and phase components, the magnitudes are multiplied and the phases are added, so the phase shift around the loop is simply the sum of the phase shift of the amplifier and the phase shift of the modulator. As you might have guessed, by expressing gain in dB we have made graphic analysis very easy. When gain is expressed in dB, the gain around a feedback loop is simply the sum of the gains of all the pieces of the loop, and the phase shift around a loop is simply the sum of the phase shifts of all the pieces of the loop.

TRANSFER FUNCTION is another way of expressing the gain and phase shift of a block as a function of frequency. A typical method of displaying a transfer function is the BODE PLOT, which is a plot of log gain and linear phase versus log frequency.

How Remote Sensing Works

With remote sensing, an extra pair of wires is included in the cable between the power source and the load, as shown in Figure 2. These wires are connected to the controlled output voltage at the load, then routed back to the error amplifier inside the power source so that the voltage can be sensed by the wires that carry negligible current. If the cable is long, there can be a substantial voltage drop in the power-carrying wires.

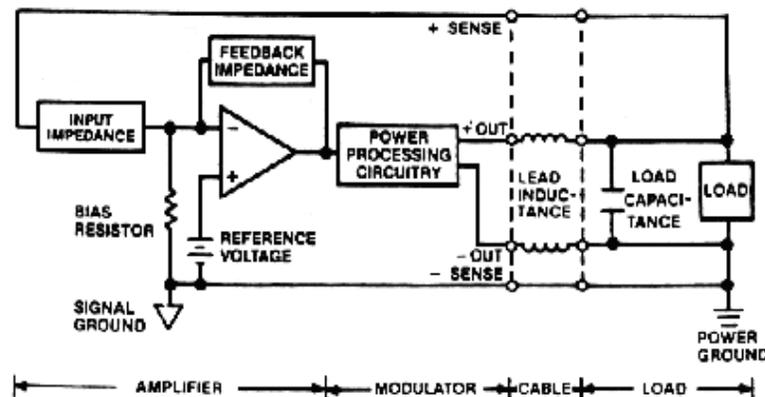


Figure 2. Power Source Feedback Loop with Remote Sensing of Output Voltage

The problem is that the power-carrying wires also have resistance and inductance. To make matters worse, most of the time there is a substantial amount of capacitance across each output at the load. The resistance and inductance of the leads, coupled with the capacitance of the load, cause additional phase shift that affects the stability of the feedback loop. This phase shift is not present during testing of the power source, which is typically tested with resistive loads and short cables, and the extra phase shift causes degradation of the stability margins. Oscillation of the feedback loop is a common occurrence when remote loads are first connected.

Review of the Basics

What Phase Is

To understand how oscillation occurs, it is necessary to understand phase and amplitude of sine waves. Figure 3a shows a sine wave of voltage, and Figures 3b through 3e show the same waveform lagging 90° , 180° , 270° , and 360° respectively.

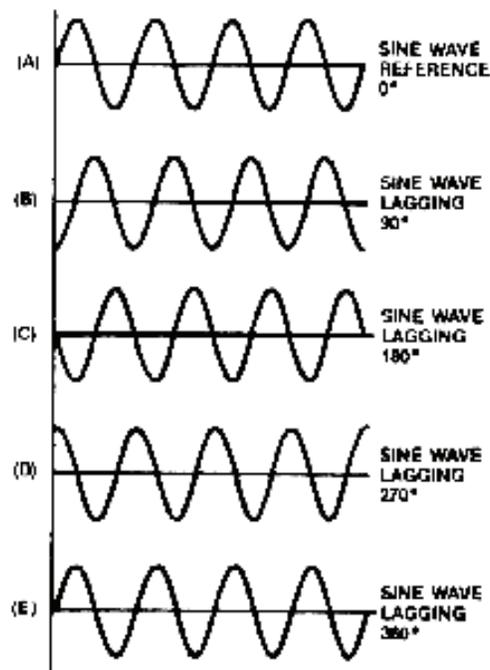


Figure 3. Phase

Notice that when the waveform lags by 360° , it is impossible to distinguish it from the original.

What Amplitude Is

Amplitude is the size of the sine wave. Figure 4a shows a sine wave with larger amplitude, and Figure 4c shows a sine wave with smaller amplitude.

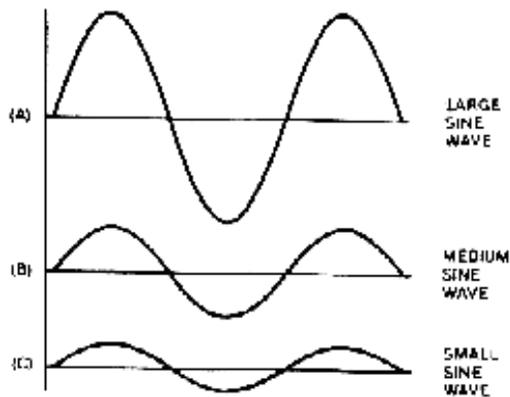


Figure 4. Amplitude

If a feedback loop is broken, and a sine wave signal is applied to the input of the loop, the signal will come back multiplied by the loop gain. At low frequency there is gain around the loop, and the signal will come back with a larger amplitude. At high frequency there is loss around the loop and a sine wave will come back with smaller amplitude. There is some frequency at which a sine wave will come back with exactly the same amplitude, and this frequency is known as the UNITY GAIN FREQUENCY, or GAIN CROSSOVER.

What Frequency Is

Frequency is the number of cycles of a voltage waveform in a given period of time, usually one second. Figure 5b shows a sine wave. Figure 5c shows a higher frequency sine wave, that is, one with more cycles per second. Figure 5a shows a lower frequency sine wave, that is, one with fewer cycles per second. The important aspect of frequency is that reactive elements change impedance with frequency. It is this change of impedance with frequency which makes the various slopes of the Bode gain curve.

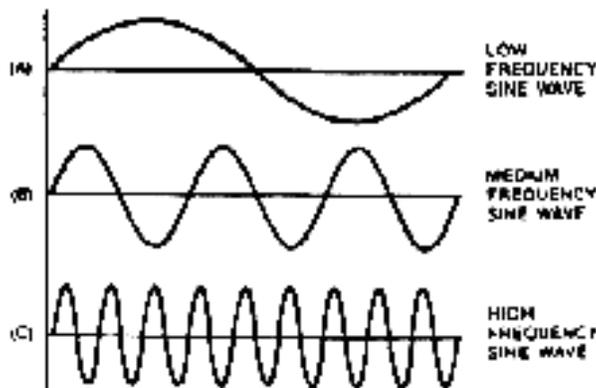


Figure 5. Frequency

Stability Criteria

Bode Stability Criteria

Unconditionally Stable Systems. < > As noted earlier, when a signal is shifted 360° in phase, it cannot be distinguished from the original signal. The phase shift around a feedback loop typically increases with increasing frequency. At some frequency, there will be a point where the total phase shift around the loop equals 360° . The gain around a feedback loop typically decreases with increasing frequency. There will be some frequency at which the gain is 1, that is, a signal injected in a feedback loop will return with exactly the same amplitude. If the phase shift around the loop is 360° at the same frequency at which the gain is 1, the signal coming back around the loop will look exactly like the signal injected into the loop initially. If this condition exists, and the feedback loop is closed, any disturbance will progress around the loop and come back exactly in phase with unity gain, and the feedback loop will oscillate.

In order to make a feedback loop stable, the gain must be less than unity when the phase shift is a total of 360° , and the phase shift must be less than 360° when the gain around the loop is unity. Figure 6a is a Bode plot of a feedback loop which is unconditionally stable.

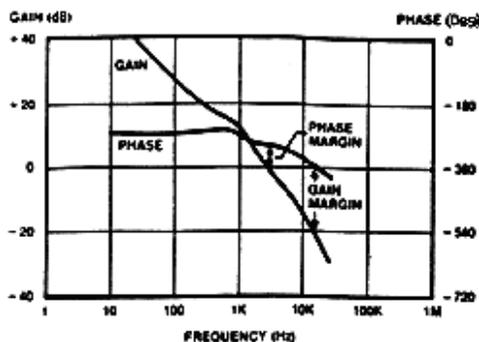


Figure 6a. Unconditionally Stable Loop

Phase lag is increasing in the negative direction. When the loop gain is unity, the phase has not quite reached 360° . The difference between the actual phase lag and 360° at the point in frequency where the gain is 1, is called the PHASE MARGIN.

At a higher frequency, the total phase shift finally reaches 360° . At this point the gain has fallen below unity, and the amount the gain has fallen below unity at the point in frequency where the phase shift is 360° is called the GAIN MARGIN. Notice that the phase margin and gain margin are related, and both go to zero when the gain curve and phase curve cross at the same point. Oscillation will occur when the phase margin and gain margin are zero. Phase margin and gain margin are a measure of how stable a system is, how far it is away from oscillation.

Conditionally Stable Systems. In order for a feedback loop to oscillate, the phase lag has to be 360° at the frequency where the gain is unity. If the total phase shift exceeds 360° at some frequency lower than unity gain, but is reduced to less than 360° at the unity gain frequency, this is known as a conditionally stable system. Conditionally stable systems will not oscillate. The primary difference between an unconditionally stable system and a conditionally stable system is that in an unconditionally stable system the gain must increase to cause oscillation. In a conditionally stable system, the gain may increase or decrease to cause oscillation. The problem with a conditionally stable system is that something may cause a gain decrease, for example increased load or decreased line voltage, and this could cause the system to go unstable. This is why conditionally stable systems are

generally to be avoided, although there are advantages to conditionally stable systems, and their use may be advantageous in some circumstances if analysis shows that they can never become unstable.

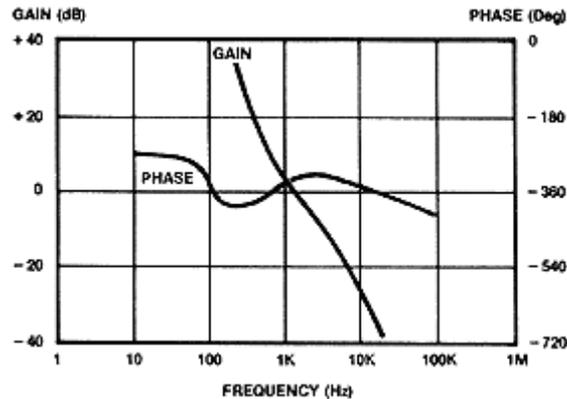


Figure 6b. Conditionally Stable Loop

Nyquist Stability Criteria

Unconditionally Stable Systems. A Nyquist plot is another method of presenting the same information as a Bode plot. Whereas a Bode plot is made on rectangular coordinate paper, a Nyquist diagram is made on polar paper. Figure 7a shows a Nyquist diagram of an unconditionally stable system. V1 represents the output voltage after going around the gain of the loop. Notice that at DC a signal V1 comes back amplified and inverted, or in other words, 180° out of phase. At higher frequencies the amplitude of V2 decreases and the phase lag increases. The track that the head of vector V2 would make with increasing frequency is shown in the figure. Amplitude is proportional to the length of the vectors, and phase shift is proportional to the angle of the vectors. A unity gain circle is shown, which is a circle of all vectors that have the same amplitude as V1. When the amplitude of V2 is the same as the amplitude of V1, the difference between the actual phase shift and 360° is the phase margin, and at a higher frequency when V2 is in phase with V1, the ratio of V2 to V1 represents the gain margin.

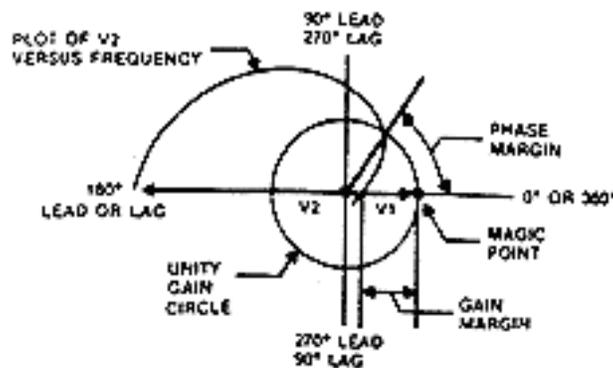


Figure 7a. Unconditionally Stable Loop

Conditionally Stable Systems. Figure 7b is a Nyquist diagram of a conditionally stable system. The figure is similar to Figure 7a, except that the track of the head of vector V2 swings completely around through 360° and then back to less than 360° before it crosses the unity gain circle. The "magic point" in this figure is the point where the unity gain circle crosses the 360° axis. Nyquist put the magic point at what he called "-1" and stated that stability was based on 180° of phase shift. He chose to neglect the 180° of additional phase shift due to the inversion. Many people were confused by this, and still

think that oscillation is caused by 180° of loop phase shift, even though it is obvious that 360° is the amount of phase shift that causes the return signal to look exactly like the injected signal. As Nyquist proved, if the track of the head of vector V2 goes around the magic point in the counterclockwise direction, even if it exceeded 360° of total phase shift at some point, the system is stable.

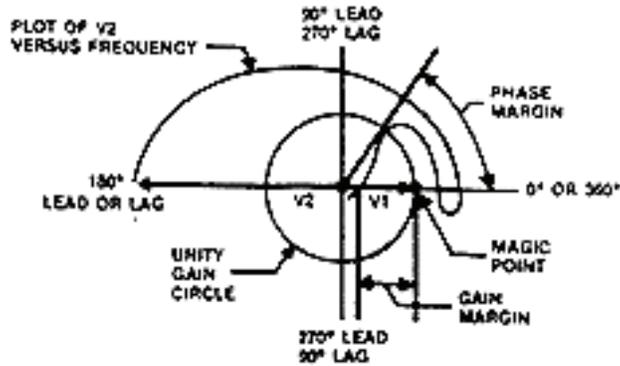


Figure 7b. Conditionally Stable Loop

Measurement Techniques

Description of the Method

Now to answer the burning question: how to put all this newfound knowledge to use? Figure 8 again shows a block diagram of a typical power source. It is the same as the block diagrams previously shown, except that a small resistor has been inserted in series with the feedback loop. This resistor is known as the INJECTION RESISTOR.

The value of the injection resistor is not critical. A typical value is 100 ohms, but a lower value of resistance can be used if 100 ohms affects the circuit under test. The value of the injection resistor should be small compared to the value of the resistors in the block labeled input impedance.

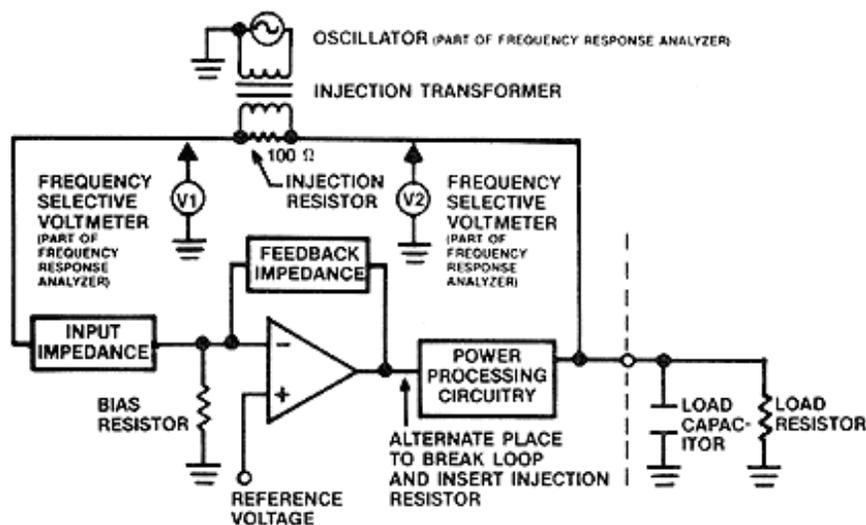


Figure 8. Technique for Making Bode Plot Measurements

A transformer with low primary-to-secondary capacitance and flat frequency response is connected across the 100-ohm resistor. Venable Industries manufactures a complete line of these transformers. The primary of this transformer is driven by an oscillator. The purpose of this combination is to create a floating sinusoidal voltage in series with the feedback loop, but with low capacitance to ground or any other part of the circuit.

The sinusoidal voltage, which is impressed across the 100-ohm resistor, creates a disturbance in all parts of the feedback loop. The voltage with respect to ground at any point around the feedback loop can be measured. In this case, the voltage labeled V1 would be the voltage with respect to ground, which would be considered the input to the feedback loop. This signal would be amplified or attenuated by the error amplifier, then amplified or attenuated by the power processing circuitry, and come back as V2, which is V1 multiplied by the gain of the loop. The ratio of V2 to V1, therefore, is loop gain.

A Frequency Response Analyzer is an instrument that has an oscillator output that can be used to inject the error voltage into a circuit, and two frequency-selective voltmeter inputs that measure the component of voltage at the frequency of the oscillator. These instruments also have the capability of displaying the ratio of the two input voltages in both magnitude and phase. The magnitude of the ratio is the gain around the loop, and the phase between the two voltages is the total phase shift around the loop. In most frequency response analyzers, the frequency of the oscillator can be swept over a wide range the gain and phase shift plotted as a function of frequency. There is no restriction as to where V1 and V2 are connected. For example, if V1 is connected as shown, and V2 were moved to the junction between the output of the error amplifier and the input to the power processing circuitry, the resulting Bode plot would be the gain and phase characteristics of the error amplifier versus frequency. If V1 were moved to the point between the output of the error amplifier and the power processing circuit input, and V2 were left connected as shown, the resulting Bode plot would be the gain and phase shift versus frequency characteristics of the power-processing portion of the circuitry. In this way, simply by moving the probes around, Bode plots of the overall loop or any portion of the loop may be obtained.

Often there are other gain blocks within a feedback loop. For example, in a power source it is not unusual to have a voltage isolation circuit, such as an opto-isolator, or additional gain or filter stages. The transfer function, that is, the plot of gain and phase shift of each block as a function of frequency, can easily be plotted simply by moving the connection of the V1 and V2 voltmeter channels which are part of the frequency response analyzer. IN order to measure the gain all the way around the loop, it is necessary to use the injection resistor technique that effectively breaks the loop while maintaining normal operation and normal DC bias points of the system.

Selecting an Injection Point

The injection resistor should be inserted in the loop at some point where the signal is confined to a single path. The point shown meets this criterion, as well as the path into the power processing circuitry. The output of the op-amp at the point before the feedback impedance is connected is not a valid point, since the signal is not confined to a single path.

The injection point shown is the one that is most frequently available in a power source. This point gives the best data at high frequency. An alternate injection point is in series with the input to the power processing circuitry. This point gives better low frequency data.

If the error amplifier used is the one inside the PWM chip, the connection from the error amplifier to the power processing circuitry is made inside the IC, and is not available to be broken. For this reason,

it is not always possible to inject in series with the input to the power processing circuitry. Either injection point gives adequate results when measuring gain and phase margin.

Accuracy Criteria

In addition to having the signal confined to a single path, it is also necessary that the input impedance, the impedance looking into the input of the feedback loop, be high relative to the output impedance, the signal looking back into the output of the feedback loop. The injection point shown in Figure 8 usually meets these criteria. The output of the modulator is usually a large filter capacitor with low impedance, and the input impedance to the op-amp is normally high.

The input to the power processing circuitry also meets these criteria in most cases. The output impedance of an op-amp at all reasonable frequencies is low, and the power processing circuitry input is typically the input of a comparator, normally a high impedance.

The injection techniques shown in Figure 8 give very accurate results if the two accuracy criteria are met, that is, the signal is confined to a single path and the input impedance is large compared to the output impedance.

Typical Bode Plots

Modulator (Power Processing Block)

The Bode plot of a typical modulator, or power-processing block, is shown in Figure 9. At low frequency the gain is typically flat with a gain of 10 to 30 dB for low voltage supplies using most commercial PWM chips. At the L-C corner frequency of the output filter, the gain curve breaks from flat to a -2 slope, usually with some peaking at the corner. The term -2 slope means that the gain is falling at 40 dB per decade. A slope of -1 means that the gain is falling at 20 dB per decade.

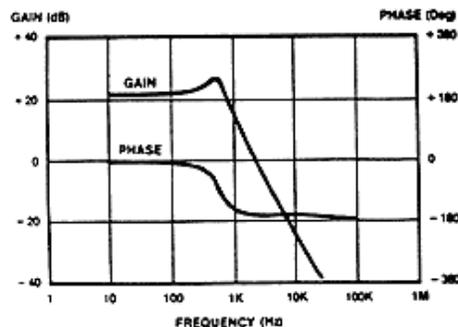


Figure 9. Typical Modulator Bode Plot

The phase shift through the modulator is small at low frequency, and makes a transition toward 180° at the L-C corner. At high frequency, parasitic effects such as the ESR of the filter capacitor and time delays affect the gain and phase shift. This is discussed in detail in the section on effects of parasitics.

Amplifier (Error Amplifier) Bode Plot

The Bode plot of a typical error amplifier is shown in Figure 10. The gain falls at a -1 slope at low frequency and at high frequency, and there is a small intermediate range of frequencies for which the gain is a $+1$ slope. This $+1$ slope region causes a reduction in phase lag through the error amplifier, which appears as a phase bump which peaks at the center of the $+1$ slope region. Both the gain and

frequency of the +1 slope region can be adjusted by choosing components in the error amplifier such that the peak of the phase boost curve occurs exactly at loop gain crossover.

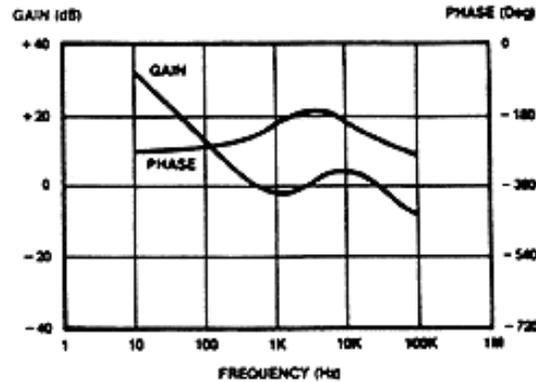


Figure 10. Typical Amplifier Bode Plot

Overall Feedback Loop

Figure 11 shows the overall loop plot of a power source. The gain of the overall loop is the sum of the gains of the amplifier and the modulator. The phase shift is the sum of the phase shifts of the amplifier and modulator. The difference between the phase lag and 360° when the gain is unity is the phase margin, and the amount the gain has fallen below unity when the phase is 360° is the gain margin. Both of these points are clearly labeled on Figure 11.

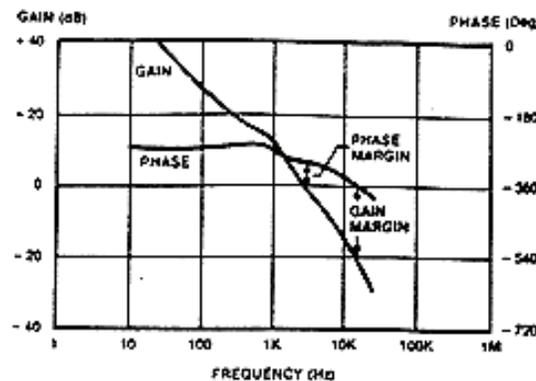


Figure 11. Typical Overall Loop Plot

Please note that the point at which the gain is unity for the modulator, as shown in Figure 9, and for the amplifier, as shown in Figure 10, are not meaningful since these are only portions of the overall feedback loop. The only plot where unity gain or 360° phase shift has any significance is the overall loop plot.

Effects of Parasitics

Filter Capacitor ESR

A schematic diagram of the output filter section of a typical switching regulator is shown in Figure 12a, and the resulting Bode plot is shown in Figure 12b. The filter capacitor impedance decreases as the frequency increases.

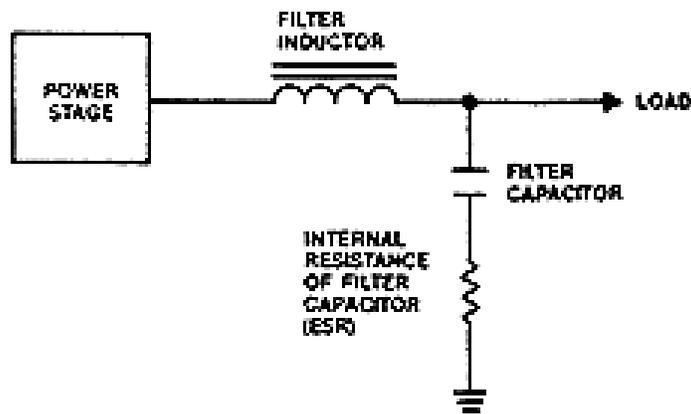


Figure 12a. Conditionally Stable Loop

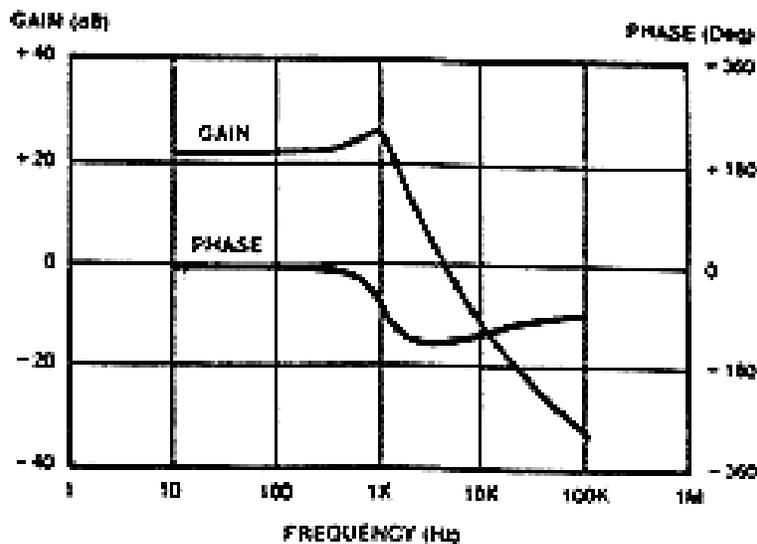


Figure 12b. Effect of Capacitor ESR

All capacitors have parasitic internal resistance. There is some frequency at which the filter capacitor reactance decreases below the internal parasitic resistance. At this point, the capacitor effectively becomes a resistor, and the filter that previously was an L-C filter becomes an L-R filter. The L-C filter caused the gain to fall at a -2 slope, but with an L-R filter, the gain falls at a -1 slope. The frequency at which the reactance of the filter capacitor is equal to the resistance of its internal resistor is known as the ESR zero, where ESR stands for Equivalent Series Resistance, and zero means it causes a zero in the transfer function of the feedback loop. It is beyond the scope of this paper to explain zeroes and poles. All you really need to know is that zeroes are places where the Bode gain plot bends upward, for example from a -2 to a -1 , and are normally accompanied by 90° of phase lead. Poles are places where the Bode gain plot bends downward, and are normally accompanied by 90° of phase lag. Each reactive component (L or C) normally creates a zero or pole, and two reactive components together generate two zeroes or two poles. In an L-C filter for example, the L and C create two poles, cause the gain to break from a 0 slope to -2 , and cause an extra 180° of phase lag.

As can be seen from Figure 12b, the ESR zero causes a reduction in phase lag through the modulator. This resistance helps the stability of the power source feedback loop, although it increases the output ripple voltage that is applied to the load. A problem can occur when the stability of the power source depends on the ESR zero of the output filter capacitor, as discussed in the next section.

Capacitance of the Load

Figure 13 shows the effect of paralleling the output of a power source with a good capacitor with low ESR. This often happens in computer power systems, where the load power bus may be filtered with thousands of ceramic bypass capacitors. The additional capacitance causes the corner frequency of the modulator gain curve to shift lower, but more importantly it reduces the benefit gained from the ESR of the power source output capacitor.

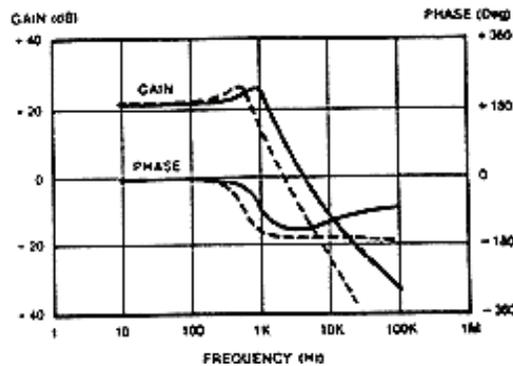


Figure 13. Effect of Parallel Capacitor

The ESR corner frequency is not as high as you might expect. For large electrolytic capacitors, the frequency of the ESR zero is typically in the range of 300 to 3,000 Hz. This is often lower than the loop crossover frequency, and many power source loops depend on the ESR zero of the output filter capacitors for stability.

Remote Sense Leads

Power sources that furnish a large amount of current to the load, and are not necessarily physically close to the load, often have sense leads to compensate for the DC drop in the power cables. The inductance of the sense leads, together with the capacitance in the load, can cause an extra L-C corner in the feedback loop. If the modulator curve was falling at a -1 slope, then it will fall at a -3 slope above the corner frequency of the second L-C circuit with 180° more phase lag as shown in Figure 14. Even without remote sense leads, manufacturers frequently put in second-stage L-C filters to reduce the output voltage ripple. It is virtually impossible to stabilize a feedback loop with a loop crossover frequency above the corner frequency of the second-stage L-C filter. For this reason, the loop crossover frequency must be reduced below the second-stage L-C corner frequency, normally causing a loop performance penalty to trade off against the improvement in output ripple.

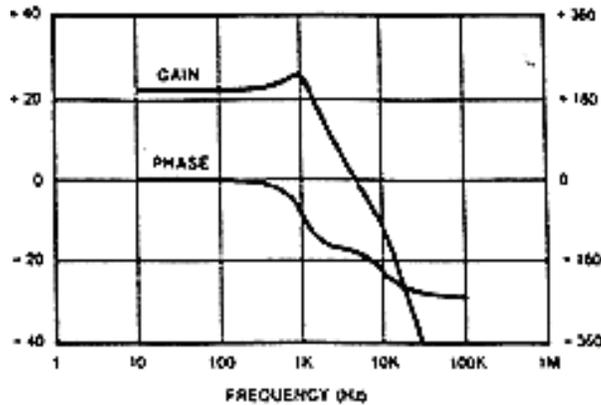


Figure 14. Effect of Remote Sense Leads

Op-amp Output Impedance

Another parasitic whose impact is frequently underestimated is the output impedance of the transconductance amplifiers used in most popular PWM IC chips. For example, the output impedance of the popular SG1524 chip is 5 megohms, paralleled by 100 picofarads. This high output impedance makes it difficult to drive a feedback network, although this fact is often overlooked. When calculating the performance of the error amplifier, the output impedance of the op-amp must be considered.

Time Delays

Another parasitic not frequently considered is time delay. Time delays cause a phase shift that increases linearly with frequency, without attendant change in gain. A time delay of one microsecond causes a 360-degree phase lag at 1 MHz. While most PWM chips do not contribute any significant time delay, a few do, and magamp regulators almost always do, contributing up to a half-cycle delay. In addition, the storage time of bipolar switching transistors frequently shows up as a time delay in the feedback loop. A five-microsecond time delay, which is not uncommon in bipolar transistors, would cause an additional 18° of phase lag at 10 kHz. Rapid increase in phase lag due to time delays frequently contributes to low gain margins in power source feedback loops, since the phase lag increases much faster than the gain decreases.

Specifying to Avoid Problems

Know Your Load

Whether you are a power source user or a power source manufacturer, it is important to know the nature of the load that will be connected to the output of the power source. It may be enough just to estimate the total value of all the bus capacitors inside the load. If this is not adequate, the actual impedance versus frequency plot of a load can be made with a frequency response analyzer, simply by driving the load with a small amount of AC superimposed on the DC source voltage, and then measuring the ratio of the input voltage and input current as the frequency of the small AC voltage is swept. Any good frequency response analyzer system, such as the Venable Industries Model 350, can plot impedance versus frequency.

Communicate with your Vendor

If you are purchasing a power source, let your power source vendor know the nature of the load he is to supply. This will allow him to test his power source with a load as close as possible to the one with

which it will actually be used. It will save you a lot of grief when the power sources are finally delivered and connected to your equipment.

Specify Acceptable Margins

The safest way to avoid problems when buying is to let your vendor know the nature of the load, and then to specify acceptable gain and phase margins with the actual load. If the power source vendor knows what specifications must be met, and has the necessary test equipment to verify his design, it is much more likely that he will deliver an acceptable product.

Test for Compliance

To have the best assurance that everything will work when the system is finally integrated, specify acceptable gain and phase margins, and test the power source and system to make sure that they do, in fact, meet the criteria. As a minimum, Bode plots should be run on acceptance units to make sure there are adequate margins of stability under all line, load, and temperature conditions. The Bode plot makes a good incoming inspection test. Almost anything that affects the normal operation of a power source will have some effect on the Bode plot. By running a Bode plot test on 100% of all incoming power sources, you can easily weed out the ones that are "out of family." By singling out these bad or unusual power sources before they get into your customer's hands, you will save money and avoid potential ill will with your customers.

Developing Worst Case Criteria

The Purpose of Margins

Theoretically, a feedback system is stable if the loop phase margin is only 1 degree and the gain margin 0.1 dB. You would probably not want to go into production with these margins, however. The reason for specifying margins is that there is unit-to-unit variation in production. The goal is to specify adequate margins so that even with the worst-case unit-to-unit variation, the power source will still be stable.

Causes of Variations

Variations from unit-to-unit are caused both by choice of circuit topology and choice of components. There is some slight amount of variation due to tolerances of capacitors, resistors, and the PWM IC. There are, however, components frequently used in power sources that are much worse offenders in terms of causing variations. The two components, which give the most unit-to-unit variation, are opto-couplers and transconductance op-amps. Opto-couplers are used for voltage isolation between primary and secondary. The transconductance op-amps frequently found in PWM ICs are tempting because they are available and free, but the variation in output impedance from unit-to-unit can be a major source of loop problems, and they are best bypassed and replaced with a real op-amp. Total variation in loop gain due to these sources over a production run can be as high as 10 to 20 dB.

Typical Acceptable Margins

The minimal acceptable phase margin in qualification units should be in the range of 20° to 30°. If good circuit design techniques are used, opto-isolators avoided, and internal transconductance amplifiers bypassed, as little as 20° of phase margin may be acceptable since there is little likelihood that the phase margin will get much worse over a production run. If, on the other hand, components were selected whose parameters vary greatly, minimum phase margin of 30° or more in the worst case

may be required in initial qualification units in order to assure that there will be adequate phase margin in all units of the production run. Nominal phase margin of 60 to 70° is normally required to have 20° to 30° in worst-case conditions. This same reasoning applies to gain margins. Typical worst-case gain margins should be 6 to 10 dB. As with phase margin, if causes of variations in the circuit have been minimized, a relatively small amount of gain margin may be required. If opto-couplers or other similar devices which cause unit-to-unit variation were used, gain margins of 10 dB or more are required in order to assure that in the worst case all power sources will be stable.

Summary

Power source feedback loops have many parasitic elements, and not all of them are confined within the power source. Especially with remote sensing, the cables and nature of the load have a dramatic effect on the nature of the power source feedback loop. It is best to test the products you buy or manufacture so that you really know the nature and magnitude of the parasitic effects. It is also important to know the nature of the load and for the user to communicate that information to the power source vendor. Impedance of simple loads may be able to be calculated; more complex loads should be measured. By understanding the effects of load capacitance, remote sensing and other parasitics that affect power source loop gain, plans can be made for these effects so that system integration problems can be minimized.