Measuring closed loop feedback system response

Switching power supplies rely on feedback control loops to ensure the required voltage and current is maintained with varying load conditions. Design of the feedback control loop will influence many factors including regulation, stability and transient response. Derek Luce of Powertek explains how the theoretical loop transfer function can be verified by injecting a disturbance signal from a GP102 FRA (Frequency Response Analyser), determining power supply loop gain and phase margins.

A feedback control loop will oscillate when there is a frequency at which the loop gain is unity and the total phase lag equals 360°. Stability is usually measured by two factors: phase margin, which is the difference between actual phase lag and 360° when the loop gain is unity (usually expressed in degrees). Gain margin, which is the amount the gain has fallen below unity when the total phase lag is 360° (usually expressed in dB).

For most closed loop feedback control systems, these basic rules are applied:-

❑ **Phase margin is greater than 45° (less than 315°) when the loop gain is greater than 0dB.**

❑ **Gain margin is –20dB or lower when the loop phase delay reaches 360°.**

If the above conditions are met, the control loop will have near optimum response; the control loop is unconditionally stable, neither under or over-damped. Usually a frequency response measurement is performed well beyond the control loop operational bandwidth to ensure all likely conditions are revealed.

The Bode Plot plot below shows control loop response curves for a single output switching power supply. Measurements were taken using a GP102 gain phase analyzer, then imported into a spreadsheet.

Gain Phase
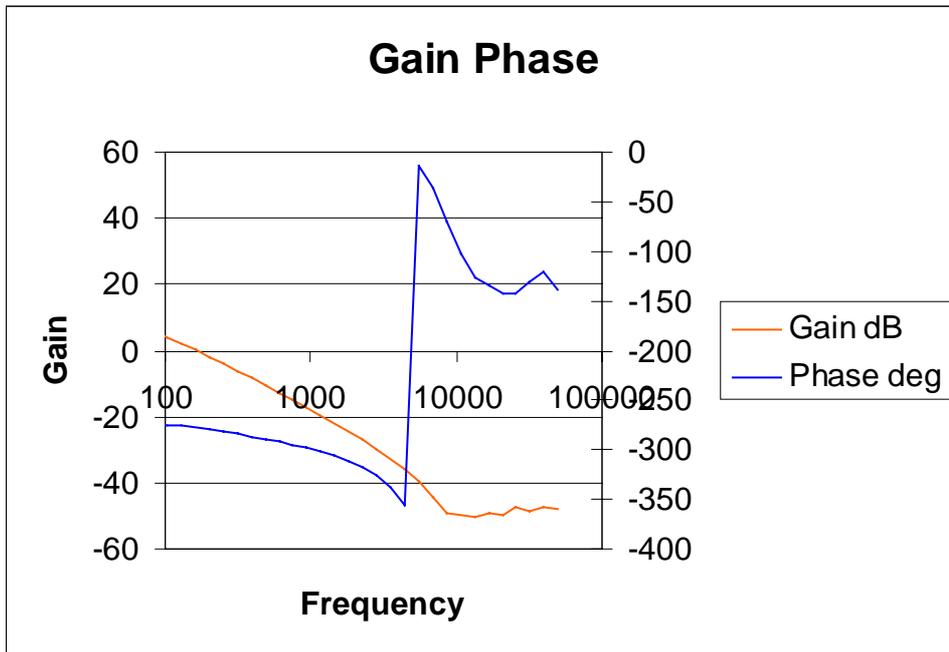
Example of a "sluggish" switching psu loop crossing 0dB at 160Hz
In this case the phase margin is 82 degrees, phase is measured from the 0dB crossover point to 360° (360°-278°). The gain margin is -35dB, measured from 0dB to the point where the phase crosses 360°

Comparing these gain and phase margins to the target values of –20dB gain margin and 60° phase margin, room is available for change without approaching areas of instability. The crossover point is 160Hz, this means that the transient response and regulation of the power supply tested would be over-damped and unacceptable. Ideally a positive loop gain to 1-2 kHz would be required, in this case some small changes to the error amplifier compensation components would resolve this. After a modification the control loop can be re-tested to ensure unconditional stability.

An FRA or Gain Phase Analyser is generally used to perform these measurements, using DFT (Discrete Fourier Transform) techniques, because measured signals are often small and masked in noise and distortion produced by the power supply switching stage. The DFT is used to extract the signal of interest.

Selecting the injection point and setting the best GP102 generator amplitude

In order to make a measurement, a frequency response analyser injects a disturbance at a known frequency (error signal) into the control loop, see injection method 1. Two FRA measurement channels are used to determine how long the disturbance takes from the error amplifier input to the power supply output.

The injection should take place where the control loop feedback signal is confined to a single path and fed from a low impedance source. The feedback path connecting to the power supply output or error amplifier output are both good places to inject a disturbance signal.

The FRA signal generator is used to introduce a small disturbance into the control loop at a particular frequency. Often the signal generator is connected to the circuit under test via an isolation transformer, see injection method 1 below, ensuring there is electrical isolation between the FRA signal generator and circuit under test.
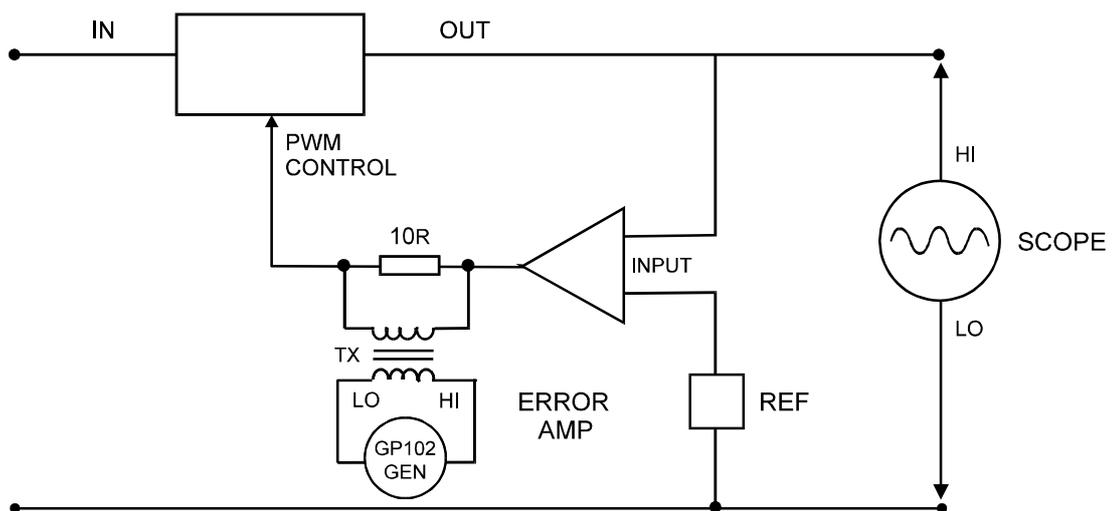
Injection method 1
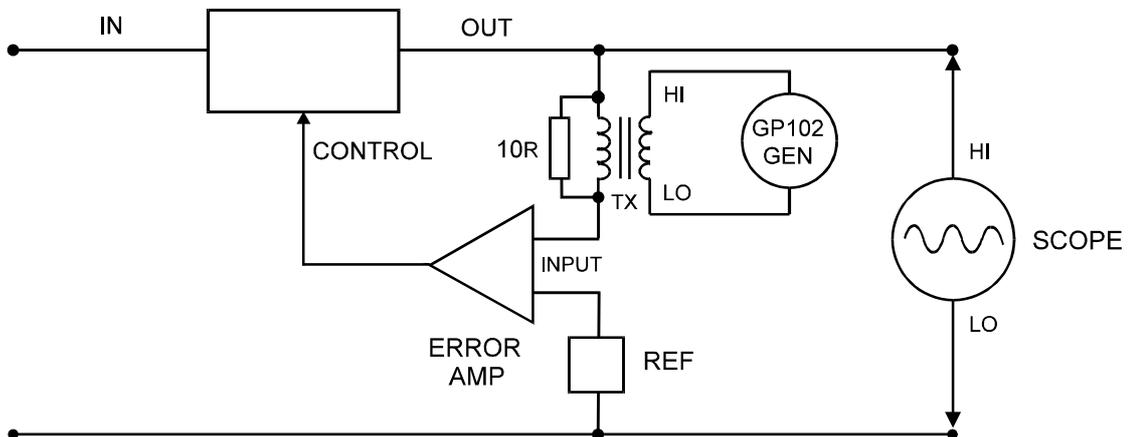
After selecting a suitable injection point, careful selection of injection amplitude is required. This is possible by connecting an oscilloscope across the power supply output. The FRA signal generator amplitude should be set to zero and to a low frequency, usually at the lower part of the control loop bandwidth. Slowly increase the amplitude of the FRA generator. When a small disturbance, around 5% of the nominal psu output voltage, can be seen on the oscilloscope, this will be a good starting point for the FRA signal generator amplitude. Repeat this process at the upper part of the control loop bandwidth to understand if the same drive level can be used over the entire loop bandwidth. A situation must be avoided where the FRA generator is under or over driving the control loop, any measurements made under these conditions are likely to be incorrect.

It is unlikely that the same FRA signal generator setting can be used over the entire control loop bandwidth. Under these circumstances amplitude compression can be used to maintain a steady disturbance signal as the frequency is swept and loop gain changes. This is achieved by controlling the FRA signal generator amplitude to maintain a constant error amplifier input.
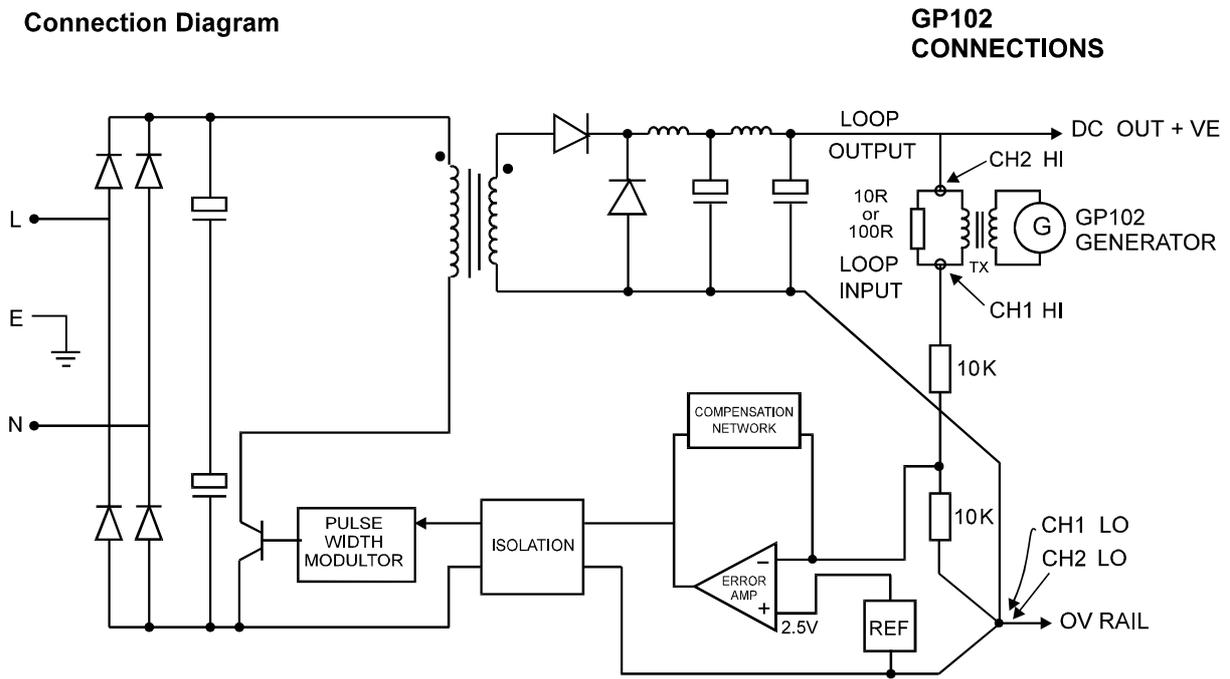
Injection method 2

If the power supply under test produces a high output voltage, then injection method 1 does not apply.

Injection method 2 can be used if the power supply output voltage exceeds the FRA input range (greater than 500Vpk), it allows FRA connections to be made where the control loop voltage to ground (common mode voltages) is low.

Making a measurement of the control loop response using injection method 1

Connect the FRA CH2 to the control loop output and FRA CH1 to the control loop input as shown below:-

Making a measurement of the control loop response using injection method 2

Connection Diagram

GP102 CONNECTIONS
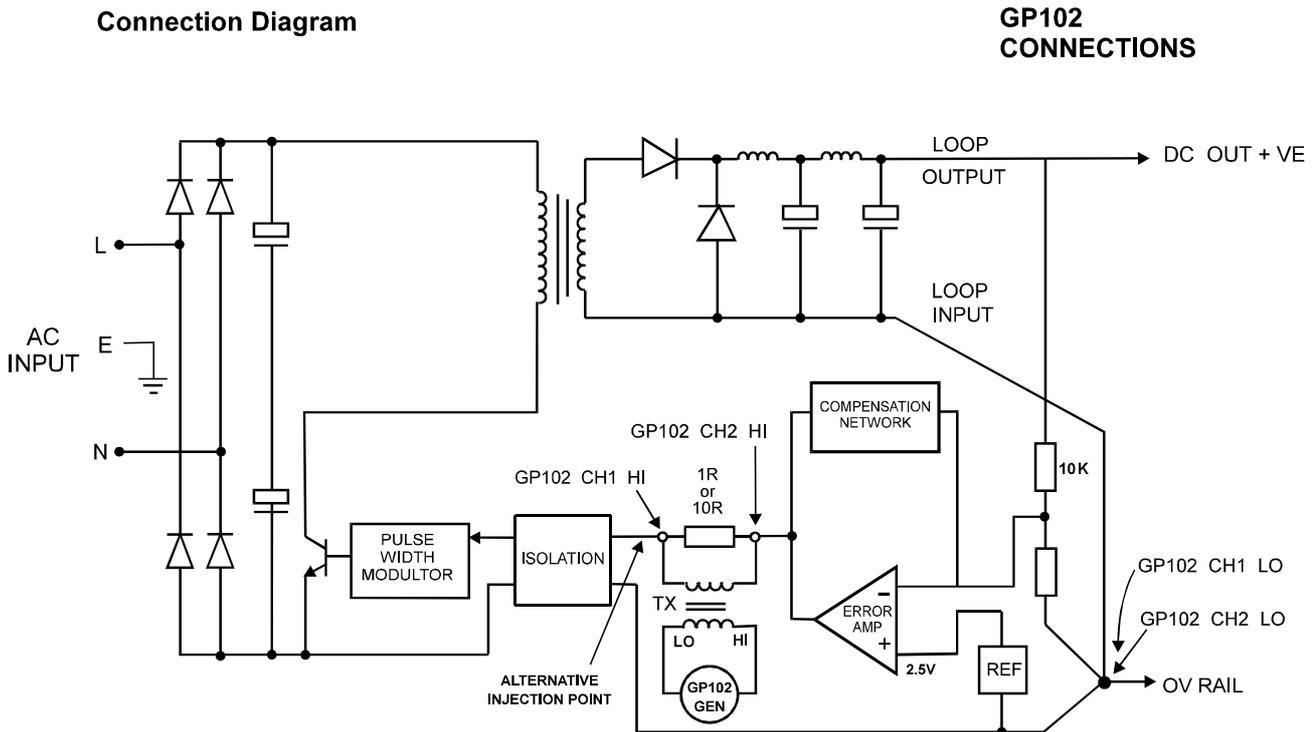
Make a sweep from typically 10Hz to 30kHz and look for gain and phase measurement repeatability as a good indicator that the correct level of injection is applied to the control loop. Assess control loop gain and phase margins, refer to the gain phase guidelines given earlier. Suitable compensation components can be applied to the error amplifier stage, performing a new sweep will show the effect of the new compensation values. The loop gain should ideally roll off at -20dB per decade, particularly where the loop gain passes through unity.

Control loops used in power factor correction PFC circuits

Feedback control loops are not confined to the output regulation of a switching power supply. Active power factor correction, typically used after the bridge rectifier, uses two control loops to achieve a sinusoidal input current, resulting in a load power factor close to 1. PFC circuits are mostly based on a dedicated controller IC, a switching device and a energy storage inductor.

The first loop, the voltage loop, tries to maintain a steady dc voltage at the dc link - the output of the PFC circuit. This loop is relatively slow, crossing 0dB at approximately 10Hz. The second loop, the current control loop, effectively controls the input current waveshape, this PWM chopper circuit has to track the rectified sinusoidal voltage waveform, so in effect the reference for the current control loop is dynamic. Because the current control loop has to track the line frequency, the crossover point may be several kHz.

Testing the slow voltage control loop and the fast current control loop requires a different approach:

Testing the PFC voltage control loop

Voltage loop is straightforward, no circuit modifications are required, in fact the current control loop is left active during the voltage loop test. The usual rules apply, find a place in the loop where the source is a low impedance point and confined to a single path. The value of the injection resistor is likely to be 1000R.

Testing the PFC current control loop

Testing the faster current control loop requires much care and attention as several circuit modifications are required to obtain a true assessment of gain phase margins:-

1. Use a 0-400V dc source to power the input to the PFC circuit, no ac supply is required and should be disconnected

2. Disable the voltage control loop (do not disable the entire IC)

3. If required, provide auxiliary power for the PFC controller IC, typically +18V

4. Use a 0-10V dc supply to control the PFC output current for the corresponding level of input voltage. Effectively the 0-10V dc supply will control gain (within the controller) and replaces the voltage reference, which would normally be changing at 100-120 times a second for 50/60Hz line frequency. The current feedback loop should track the input voltage, hence the use of the 0-10V supply to set different conditions.

5. Apply a variable load to the PFC output

6. Use a 100R injection resistor connected in between the current sense resistor and the PFC sense input. Again follow the standard rules applying to injection

7. Sweep from 50Hz to about half of the switching frequency. The loop response should be checked with different settings and combinations described in points 4 and 5. e.g. tested at zero current, peak current and midway.

Measurements within the PFC area are hazardous. The frequency response analyzer input channels and generator should be isolated from ground and from each other.

The Powertek GP102 Frequency Response Analyser provides a self-contained solution for assessing control loop gain phase margins, along with Bode plot printout and interface capability. Other useful measurements relating to power supply design and testing are power, apparent power, power factor, harmonics, inrush current, complex impedance and wound component testing.

Ends

Word count = 1548 including captions

Backgrounder

Powertek specializes in the design and manufacture of current transducers, power measurement, complex impedance and dynamic waveform analysis, mainly to the power conversion industry. The GP102 Gain Phase Analyser is one of Powertek's in house products, complementing its power analyser and phase angle metrology standards.

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