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Optimizing Test Performance of Digital Cellular Products With Ultra-High Speed Power Supplies

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Introduction

The power consumption requirements for digital cellular handsets differ dramatically from those for analog handsets. The “bursty” nature of the transmission places rapidly varying transient current requirements on the handset's battery. Simulating the battery's performance accurately during production testing requires a power supply with a wide bandwidth (to minimize voltage drop at the phone during large current transients) as well as circuitry capable of emulating the impedance of the battery. To achieve maximum performance, the impedance of the load, which includes the DUT, cables, and fixturing, must also be kept to a minimum. Voltage and current stability, including freedom from oscillation, overshoot, undershoot, etc., are essential to achieve accurate test results.

AC Model of Electrical Performance

Figure 1 illustrates a typical connection of a power supply to a cellular phone in a production environment.

Each of the components in the figure is represented by an equivalent impedance element. The source and sense leads, each a separate twisted pair cable, have impedance per unit length. The fixture has parasitic impedance and the phone, an active device, will present a widely varying impedance to the power supply, depending on the mode of operation. The circuit shown in ***Figure 2*** depicts an ideal power supply with a resistive load (R_{load}) and remote sense feedback. The power amp stage represents a linear or switching power supply.

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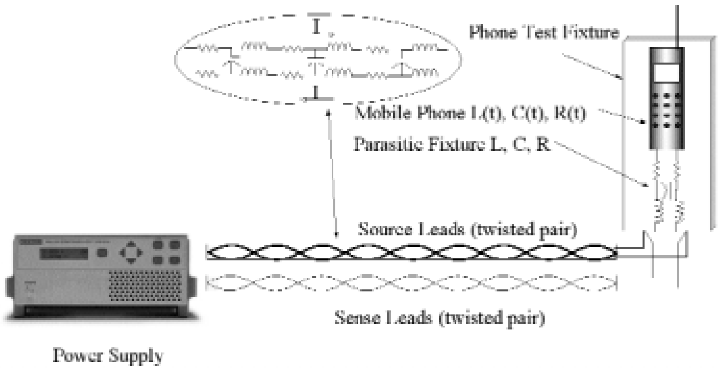

Figure 1. The active and passive impedance elements representing a mobile phone in a test fixture connected to a power supply.

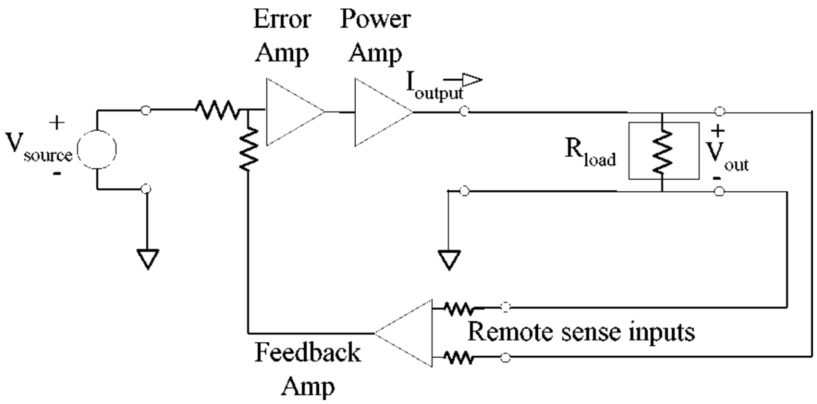

Figure 2. An ideal power supply with a resistive load (R_{load}) and remote sense feedback.

Figure 3 shows the gain and phase performance using Bode plots. Using Bode plots, the performance and stability of a system is determined. The amount of gain will determine the accuracy of the power supply. The gain at high frequencies will determine the amount of voltage drop resulting from a pulsed current load. The point where the gain crosses 0dB is the system bandwidth and the phase at this point determines the system stability. For a system to be stable, the phase should be less than 180°, where 135° defines an optimized system. The system in ***Figure 2*** is a single pole system; the plot in Figure 3 shows that at the location of the pole, the system slope will change by –20dB/decade and the phase will decrease 90°. The maximum phase lag associated with a single pole response is 90°, so this power supply will never achieve the 180° phase shift required for the output to become unstable.

Adding cables and a capacitive load to the output of the power supply adds two more poles to the closed loop response of the system. Therefore, the performance of the system is

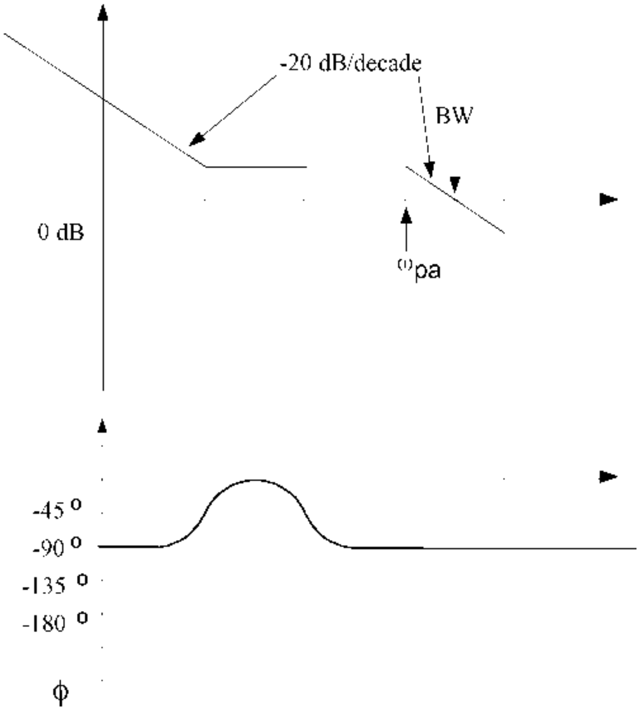

Figure 3. Gain and phase performance an ideal power supply with feedback using Bode plots.

directly affected by the properties of the cabling and load. If sufficient inductance and/or capacitance exists, the possibility for instability is high. ***Figure 4*** shows the power supply with the series cable inductance (L_{cable}) and parallel DUT capacitance (C_{load}).

The location of the two poles in the s-plane forming the second order system can be found from the characteristic equation:

$$s^2 = s\,\frac{\omega_o}{Q} + \omega_o^2 = 0 \qquad (1)$$

where the resonant frequency (ω_o) is referred to as the pole frequency and Q is called the pole Q factor. The Q factor may be expressed as function of L, C, and R where:

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}} \;\text{ and }\; \omega_o = \frac{1}{\sqrt{LC}}\,\text{rad/sec} \;\text{ or }\; f_o = \frac{1}{2\pi\sqrt{LC}}\,\text{Hz} \qquad (2)$$

and the pole locations are given by:

$$\omega_{pl} = \frac{R}{L} \;\text{ and }\; \omega_{pc} = \frac{1}{RC}\,\text{rad/sec} \qquad (3)$$

Figure 5 depicts several possible responses obtained for various values of Q.

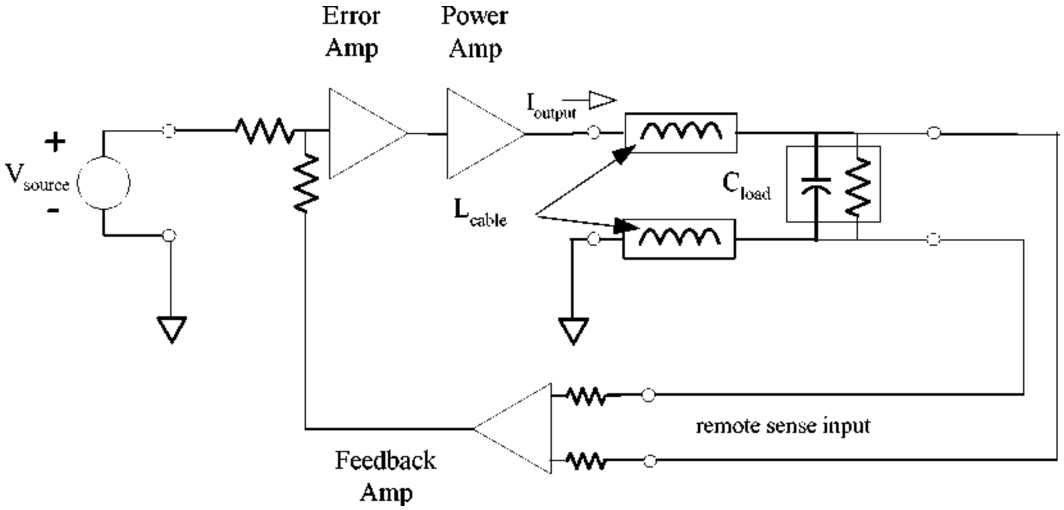

Figure 4. An ideal power supply, with the addition of series inductance (L_{cable}) representing the supply leads and parallel capacitance (C_{load}) in the DUT.

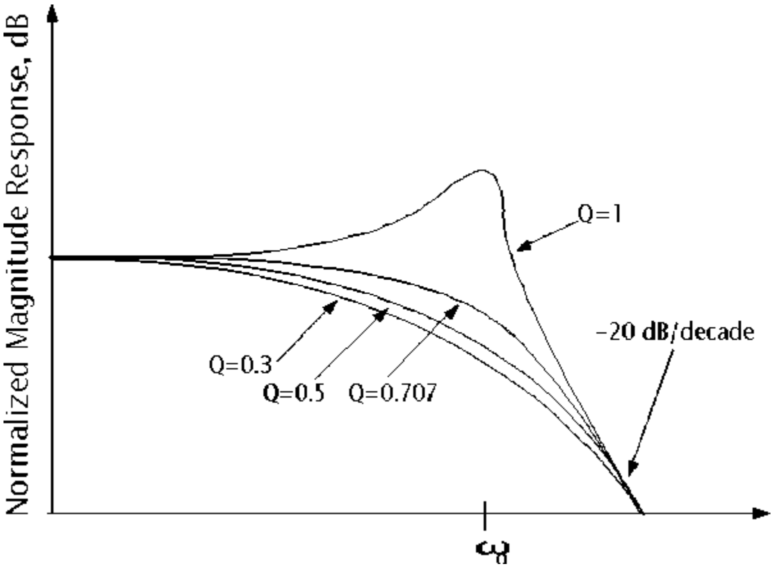

Figure 5. Normalized magnitude response of a second order system for various values of Q.

If L_{cable} and C_{load} are small such that $f_o > BW$, where f_o is the resonant frequency introduced by L_{cable} and C_{load} and BW is the bandwidth of the power supply, then $\phi < 180°$ for all positive values of gain. The transient response with this load will be optimum (i.e., utilize the entire gain of the power amplifier stage). The gain and phase performance of this system is represented in ***Figure 6***. The presence of a zero in the feedback amplifier gives rise to the region of flat gain between ω_1 and ω_{pa}.

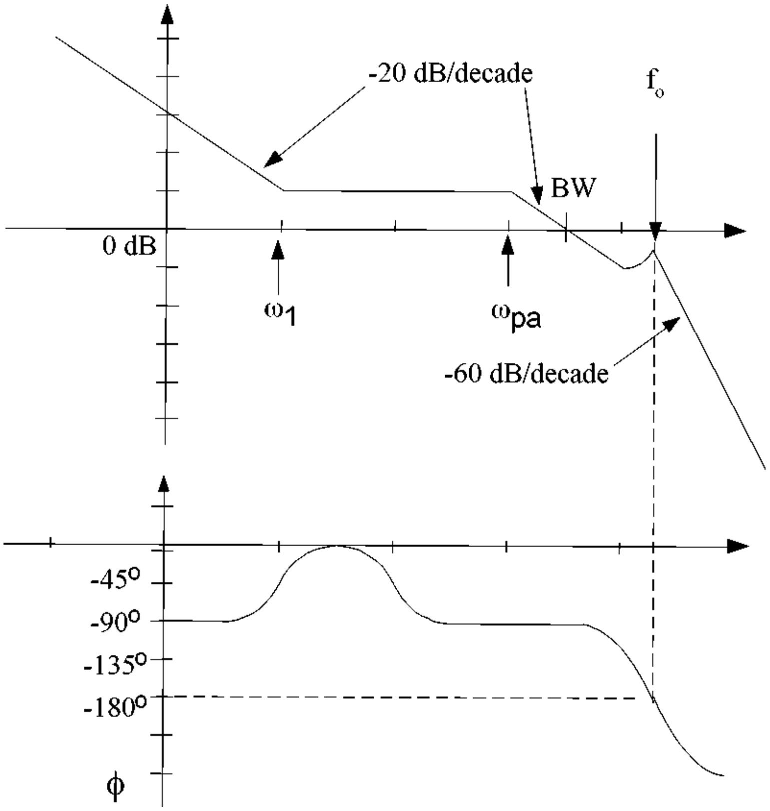

Figure 6. Gain and phase performance of a power supply where the series inductance in the cables and parallel load capacitance are small such that ω_{pL} and $\omega_{pC} > \omega_a$.

If L_{cable} or C_{load} is large such that $f_o \leq BW$, then $\varnothing \geq 180°$ for positive values of gain and the system will be unstable. The gain and phase performance of this system for two different values of Q is shown in ***Figures 7a*** and ***7b***.

Frequency compensation may be used to improve the performance of a power supply with a reactive load. A form of feed forward compensation, the capacitors (C_{comp}) shown in ***Figure 8*** bypass the effects of the poles introduced by L_{cable} and C_{load} when they are in the frequency range where C_{comp} is effective.

The capacitors serve to feed forward the power amplifier signal directly to the inputs of the feedback amplifier and keep the output stable. Consequently, bypassing L_{cable} and C_{load} for $f > f_o$, the system bandwidth is reduced to approximately BW′ and the transient response (speed) of the system is diminished. ***Figure 9*** shows the closed loop gain and phase response of the system with frequency compensation.

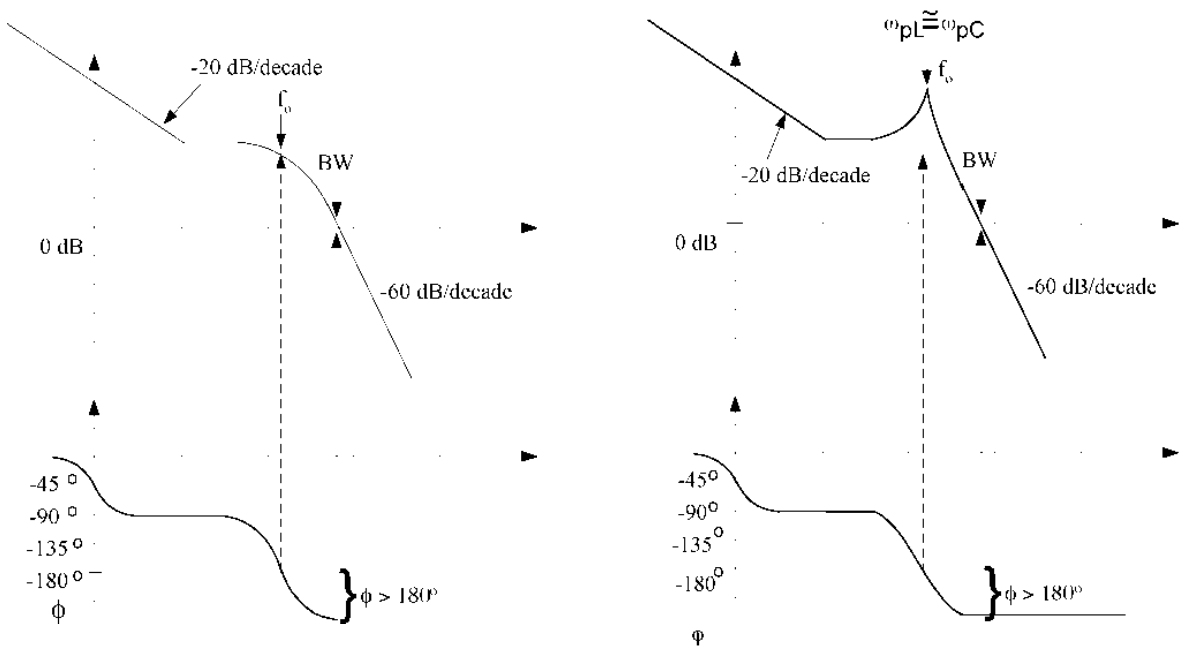

Figure 7. Gain and phase performance of a power supply where $f_o \le$ BW
a) Q < 0.707 ***b)*** Q > 0.707

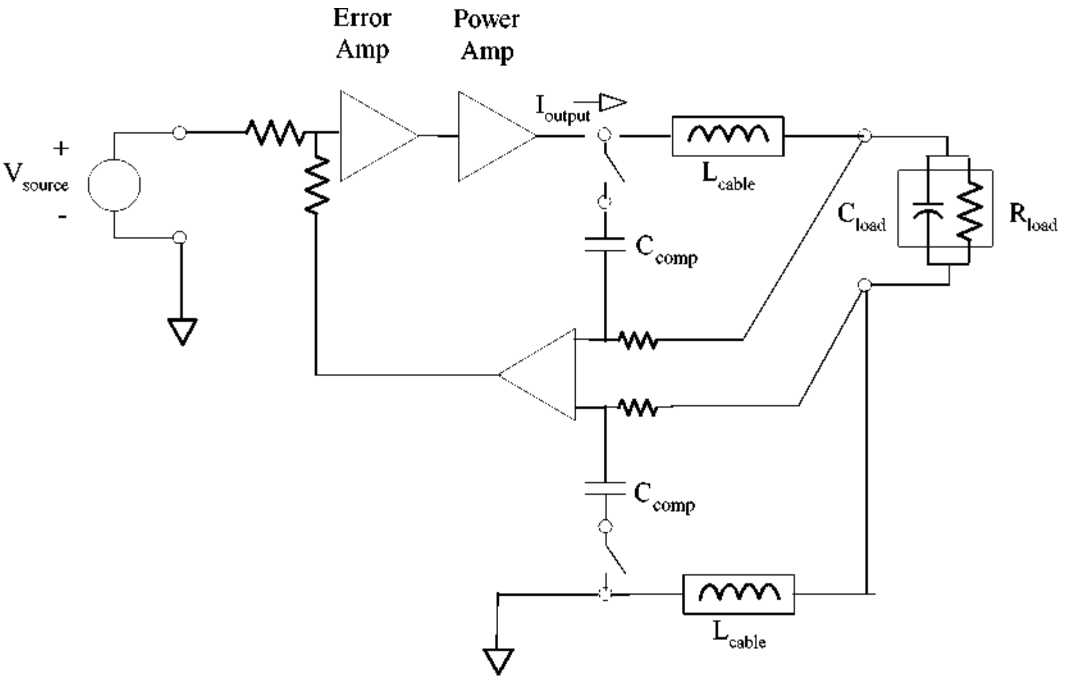

Figure 8. The ideal power supply with the compensation capacitors (C_{comp}) to improve output stability with a reactive load (high inductance in the cables and capacitance in the DUT).

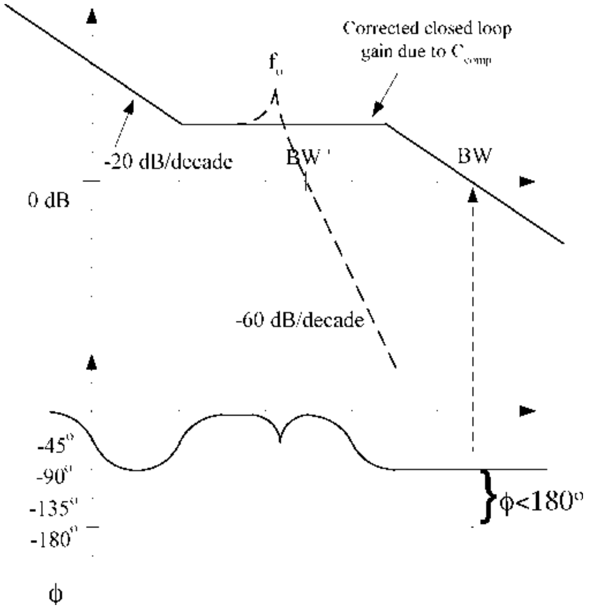

Figure 9. Closed loop gain and phase performance of the compensated power supply circuit.

Techniques to improve transient performance

The information in the previous section can be used to improve the transient performance of a test system in several ways. The best results will be achieved with a new design that seeks to optimize all the components of the test system, including fixturing and cabling. Some of the techniques may be used to improve the performance of an existing system. The characteristics of the DUT are fixed, so the factor over which the test engineer has the least influence is the capacitance of the load ($C_{load)}$. Parameters such R_{load} and L_{cable} may be controlled to varying degrees.

To achieve the best transient performance and thereby utilize the entire bandwidth of the power supply, we have determined that $f_o > BW$. Given that $f_o = 1/[2\pi(LC)^{1/2}]$, minimizing L_{cable} and C_{load} will maximize fo. Unlike C_{load}, the test engineer has some control over the value L_{cable}. To minimize the total inductance in the load, it is important to use low Z cable and minimize the length of the cable between the DUT and the power supply. The characteristic impedance of coaxial cables is given by $Z_{cable} = (L/C)^{1/2}$ and is usually either 50Ω or 75Ω. A 10Ω characteristic impedance coaxial cable has been designed specifically for this application. ***Figure 10*** shows the gain and phase performance of the 10Ω coaxial cable and conventional 20 gauge twisted pair cable.

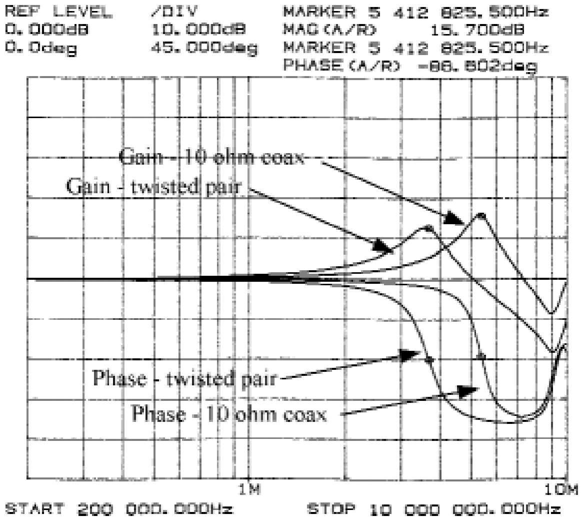

Figure 10. Gain and phase performance of an ultra high-speed power supply with 15 ft. of 10Ω coaxial cable and with 15 ft. of 20 gauge twisted pair cable.

Figure 11 compares the transient current and voltage response of a GSM phone with the 10Ω coaxial and twisted pair cable sets shown in ***Figure 10***. Under the same conditions, the low Z cable provides approximately a 100% improvement in voltage drop and current overshoot while the phone is transmitting.

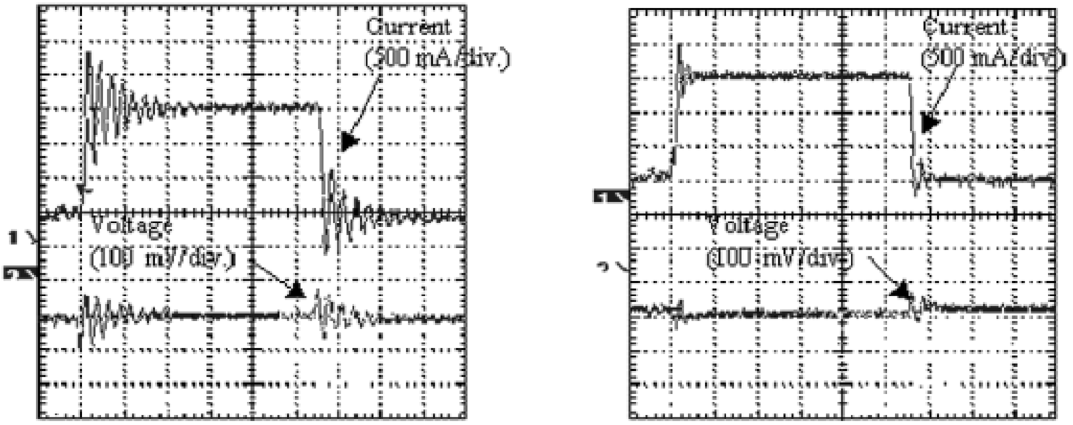

Figure 11. Transient current and voltage response of a GSM phone with an ultra-high speed power supply ***a)*** 15 ft. of 20 gauge shielded twisted pair cable ***b)*** 15 ft. of 10Ω coaxial cable.

Adding resistance to the output cables may improve output stability if $\omega_{pL} \sim \omega_{pC}$ and Q is large. From Equation 2, increasing R reduces Q by separating the values of ω_{pL}, ω_{pC} on the w-axis and reducing the gain peak at f_o. Some experimentation may be necessary to find the appropriate value(s) of R for a particular application. Factors affecting the maximum amount of additional resistance are the type of power supply and the output current and voltage levels. ***Figure 12*** shows the gain and phase performance of the system with additional resistance in the source leads reducing Q at f_o.

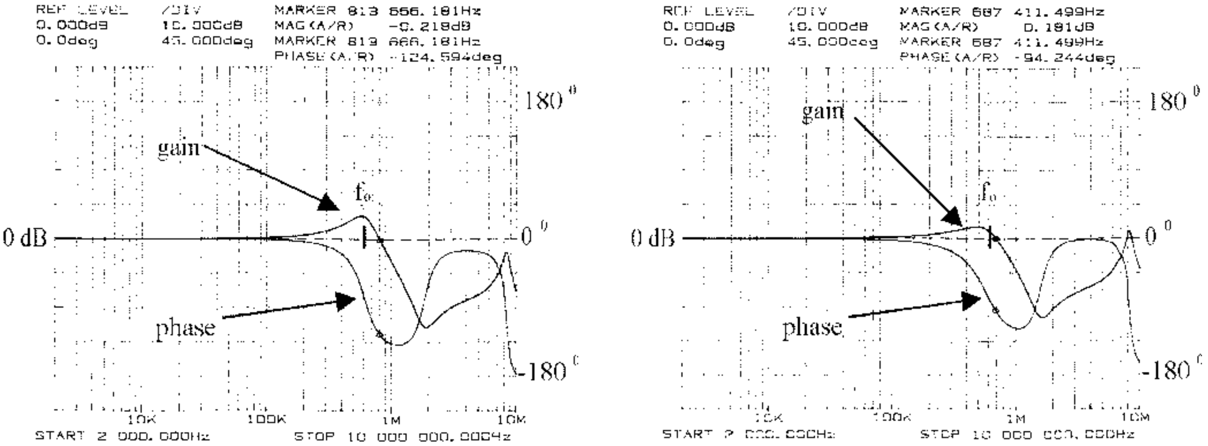

Figure 12. Gain and phase performance of an ultra high speed power supply with 15 ft. of 10Ω coaxial cable and a 0.044µF load ***a)*** without additional resistance ***b)*** with an additional 1Ω in each source lead.

Finally, if the inductance in the cables and fixturing has been minimized and the output is unstable, frequency compensation can used to provide stability with some loss of output bandwidth. ***Figure 13*** shows the gain and phase performance of an ultra high-speed power supply with 15 feet of 10Ω coaxial cable. ***Figure 13a*** shows the response with a 0.022µF capacitor without frequency compensation. The frequencies where the gain is negative and the phase reaches –180° are almost identical and the system is marginally stable. ***Figure 13b*** shows the response with compensation enabled. In this case, Q is reduced, the gain peak is lower, and the phase margin is greatly improved.

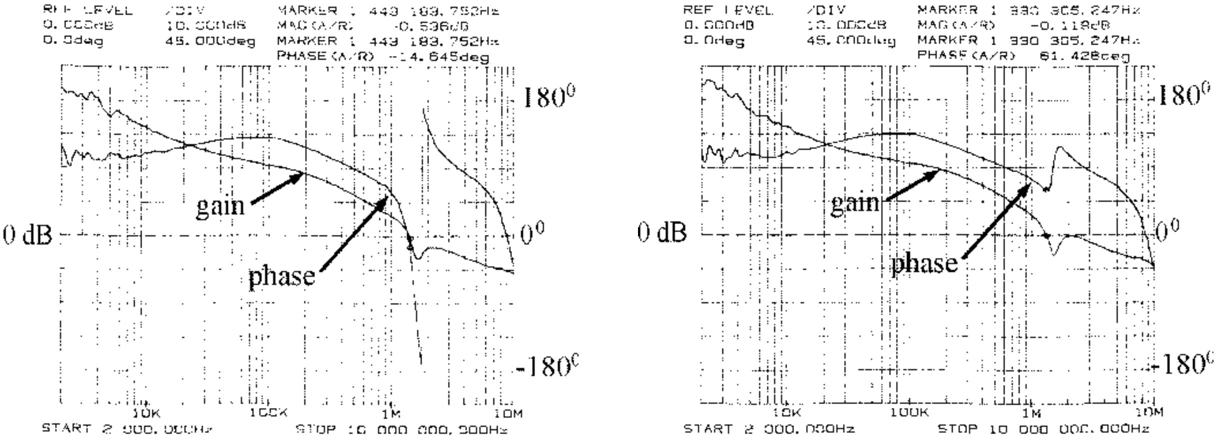

Figure 13. Gain and phase performance of an ultra high-speed power supply with 15 ft. of 10Ω coaxial cable and 0.022µF capacitor ***a)*** without frequency compensation ***b)*** with frequency compensation.

Conclusions

A high-speed power supply with excellent transient performance is required to test digital handsets accurately during the production process. In addition, the transient performance of the test system is affected by the impedance of the load, including cabling, fixturing, and the DUT. Typically, with an ultra-high speed power supply, the output impedance must be minimized to achieve the best performance. Frequency compensation circuitry in the power supply, if available, may be used to improve output stability at the expense of output bandwidth.

Bode plot analysis is used to show the effect of varying the load impedance on the gain and phase of the closed loop response of the system. With a purely resistive load, the power supply output is always stable. For a load consisting of a series inductance in the cables and parallel capacitance and resistance in the DUT, the stability of the output depends on the location of the poles introduced by the inductance and capacitance. In some cases, resistance may be added to the cables to reduce Q, a factor expressing the relative proximity of the poles to each other, and increase stability. Using short cables between the supply and the DUT or low inductance cables may also serve to promote output stability. Finally, if the output remains unstable even after all possible design improvements have been made, frequency compensation circuitry in the supply, if available, will improve stability at the expense of output bandwidth.

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