Minimizing Power Supply Transient Voltage at a Digital Wireless Telecommunications Products' Test Fixture

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Abstract

This paper addresses the problem of maintaining a stable, transient-free voltage at a DUT (device under test) when:

1. *The DUT draws current in pulses, as is the case with digital wireless products.*
2. *The DUT is remotely located from the power source, thus introducing significant path impedance and voltage drop.*

The resulting transient voltage drop can disrupt the testing. The cause of these transient drops are explained and alternative solutions to minimize them are suggested.

Introduction

The market trend in wireless telecommunications is clearly headed towards digital products. The consumer advantages are significant; transmission quality, accessibility, and battery operating times are all improved.

Digital wireless telecommunications products transmit in short bursts and conserve power between transmissions, thus improving battery operating time. The resulting load on the battery is current drawn in pulses.

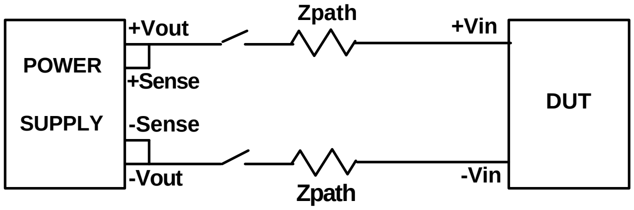
Another trend in digital wireless is towards lower operating voltages, allowing for more efficient circuitry and smaller batteries. As the transmit power remains the same, the current level increases with the lower voltage.

The high volume production test of wireless products often dictate that the programmable power source and other test equipment be remotely located from the highly automated test fixturing. Cabling may be several meters in length. Connectors, contacts, and relays may be required. The result is that the path can have a few ohms resistance and microhenries of inductance and thus is no longer negligible.

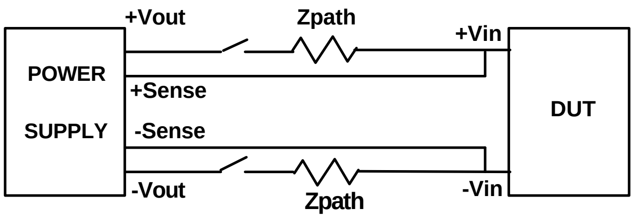
These three factors, pulsed current loading, higher current levels, and significant path impedance to the remote test fixture make it increasingly difficult for the test system engineer to maintain a stable, transient-free voltage at the DUT. Most battery-powered products have low battery voltage shutdown circuits. If the resulting voltage drop at the DUT is large enough, the DUT may shut down and disrupt the test.

Modeling the Power Source and Remote DUT as a System

For the current generation of digital products operating around 6 volts, a typical requirement is that, during transient pulse currents, the voltage at the DUT remain within 300 millivolts of the set value. Figure 1 below shows two possible test system configurations, figure "a" being local voltage sensing and figure "b" remote voltage sensing. .



a) Local Sense Mode



b) Remote Sense Mode

Figure 1: Test System Configurations

Power Supply Performance In Local Sense Mode:

In local sense mode the power supply regulates the output voltage at it's output terninals. The voltage drop between the power supply and the DUT is given by Equation 1.

$$Vd = R*I + L*dI/dt \qquad (1)$$

Vd is the voltage drop in the path, R the total path resistance, I the current, L the total cable inductance, and t is time.

The voltage "V load", illustrated in figure 2, will occur at the load when the power supply is controlling the voltage at its output terminals, not at the load. *This mode of operation is called the local sense mode, as shown in figure 1a.*

At the power source end of the cable, a small transient voltage occurs for each transition of the load. This transient voltage duration and amplitude are commonly provided transient response specifications of the power supply. *The transient response is a measure of how well the power source is able to hold its output constant in response to load changes.*

Most good system power sources have a transient response time of 50 to 100 microseconds. This time reflects how long it takes for the power supply to catch up with the change in load. The transient response amplitude at the output terminals is largely determined by the quality of the power supply's output capacitor and is directly proportional to the magnitude of the load change. For a load change of 1 to 3 amps the resulting transient will typically be 20 to 300 mV at the power supply's output terminals.

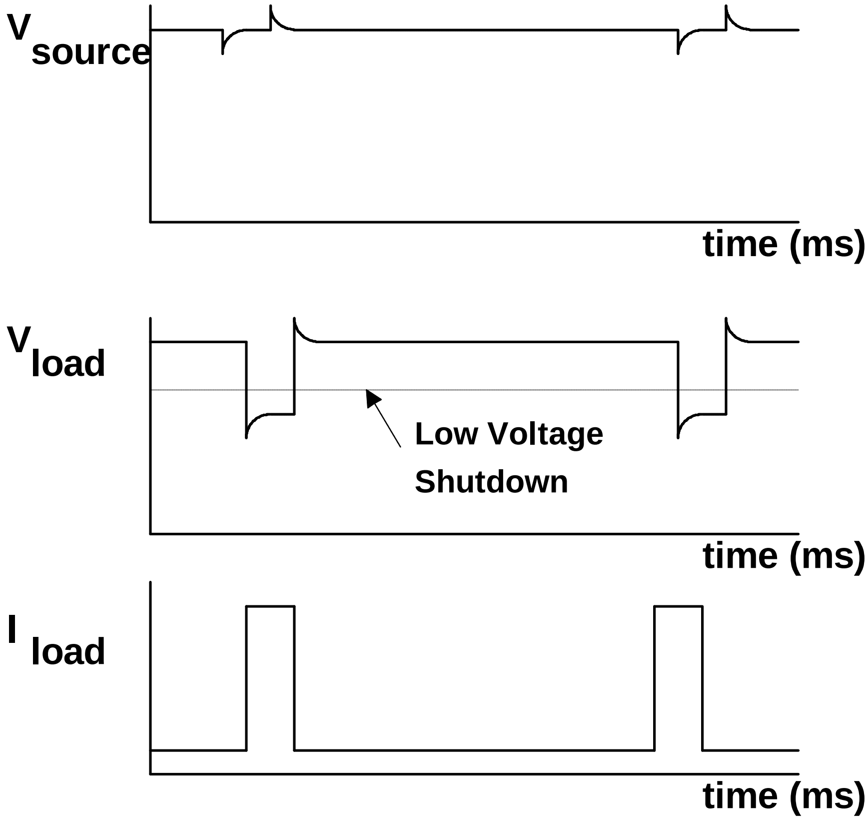


Figure 2: Voltage Drop at DUT due to Pulse Current. Local Sense Mode

Local sense modeling is analogous to the DUT being powered directly by it's battery. The battery can be modeled as an ideal voltage source with a small amount of series resistance. With a peak current draw of 1.25 amps from a digital wireless product, the corresponding voltage drop at the load is typically tens of millivolts.

In most digital wireless, product testing, the cable connecting the power supply to the phone can be several meters long. There may be additional resistance in the path due to relays, connectors and contacts. The following parameters are representative of a typical application:

- Cable type: twisted pair, 0.5 mm sq., 2 meters long (3 linear meters)
- Cable Resistance: 0..25 ohms total for both leads
- Cable Inductance: 2 micro henries
- Relay Resistance: 0.05 to 3.75 ohms total
- DUT load current: Pulsed, 0.25A low, 1.25 A high, 15 usec rise/fall time, 577 usec duration

There are two cases worth examining. The first is for zero line impedance and the second is for a high value of path impedance. Both of these cases can actually be observed in figure 2. For zero line impedance, the load voltage is equal to the source voltage. For a path impedance of 2 ohms and 2 microhenries, the load voltage drop is 2.13 volts. This is illustrated by the graph of "V_load". This transient voltage drop is sufficient to trigger the low voltage detect circuitry in a battery-powered product.

It is critical for the test system engineer to determine the path impedance between the power supply and DUT in the test system, and maximum acceptable transient voltage drop at the DUT. Generally, if the path impedance is below 0.1 to 0.2 ohms, there should not be an issue using a standard power supply. If it is more than a few tenths of an ohm, extra steps need to be taken to assure acceptable performance of the test system.

Power Supply Performance In Remote Sense Mode:

When the path impedance between power supply and DUT is significant, the voltage drop can be several volts. To compensate for this, the power supply is used in the remote sense mode. As shown in figure 1b, the sense leads of the power supply are now connected to the DUT for the purpose of accurately controlling the voltage at the DUT.

In figure 3, it can be seen that, in remote sense mode, the power supply is a feedback control system, designed to control a voltage at the DUT. The figure represents the DUT voltage control system in block diagram form. "Vprog" represents the desired voltage at the DUT. The summing amplifier compares the desired output voltage with the voltage at the DUT as measured by the sense amplifier. Any difference is amplified and applied as a correction signal to the power control circuit block. This block adjusts the power supply output until the measured output voltage equals the desired output, compensating for any external voltage drop as well. As can be observed in figure 3, the load and lead impedance become part of the voltage control system.

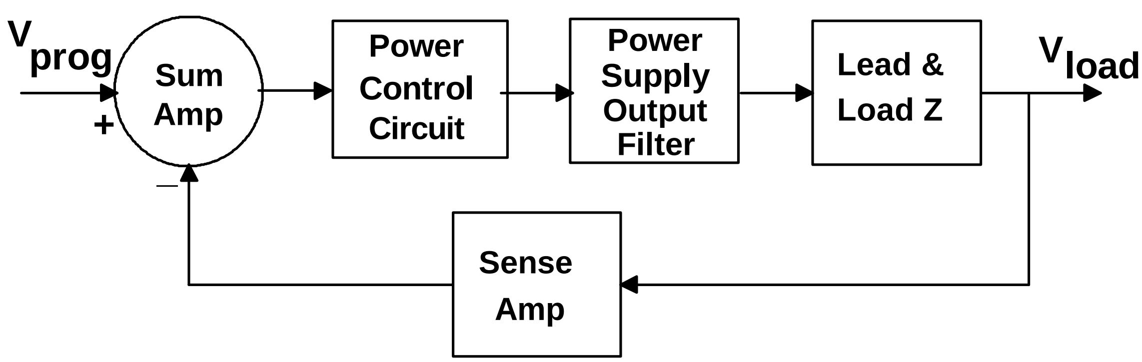


Figure 3: Power Supply Feedback Loop with Remote Sensing

There is no problem controlling the DC voltage at the DUT since the control system maintains the average or DC voltage at the DUT constant. However, the accuracy to which the *instantaneous* voltage can be controlled for pulse loads depends on several factors, namely:

1. The resistance and inductance of the cable connecting the power supply and DUT.
2. The input impedance of the DUT.
3. The amplitude, rise and fall times of the current pulse.
4. The bandwidth of the power supply control loop.
5. The voltage slew rate capability of the power supply.
6. The power supply's dynamic response characteristics.

The final result is that while the average voltage may be ideal, the instantaneous value may be far less than ideal. Most power supplies do not have sufficient control loop bandwidth in remote sense mode to correct for substantial path impedance voltage drops when testing remotely fixtured digital cellular phones. This bandwidth has been intentionally limited because of the need to stabilize the power supply for a wide variety of loads and path impedances. Limiting the bandwidth inhibits the power supply's ability to react to high frequency signals, but improves the stability of the power supply control system when remote sensing. This causes the power supply to be less than ideal for digital phone testing under this given situation.

Even if a DC power supply has sufficient bandwidth, it still typically does not have the voltage slew rate capability to raise the output voltage quickly enough to compensate for the path impedance voltage drop. The slew rate limitation is due to the large output capacitor (used in most power supplies to give low ripple and low output impedance) and the limited current available to charge this capacitor.

The net result of optimizing the power supply design to be "load independent" and work for a variety of applications is that they do not have the necessary characteristics to work well in digital phone testing application when there is significant cable resistance. Typical performance in remote sense mode is illustrated in figure 4. For fast rise time current pulses, the transient voltage amplitude may not be much better than using local sensing and the settling time may be much longer now that the path and load impedance are now part of the feedback loop.

With these parameters used in the earlier example, a resulting peak voltage drop amplitude of 1.8V was observed when using a good general purpose power supply having a specified transient response of 50 usec. This is only a small improvement over the 2.13 V drop with local sensing. In this example, the general purpose power supply does not have the bandwidth or slew rate to effectively reduce the transient voltage amplitude.

The test engineer needs to be aware that the characteristics that make a power supply have ideal performance at its output, i.e. ability to hold the voltage constant and provide good transient response at the output terminals, may not be adequate when the test fixture is remotely located. Interaction of the wiring impedance, the load demands, and the power supply's remote sense bandwidth and output voltage slew rate need to be examimed in aggregate to assure performance requirements are met.

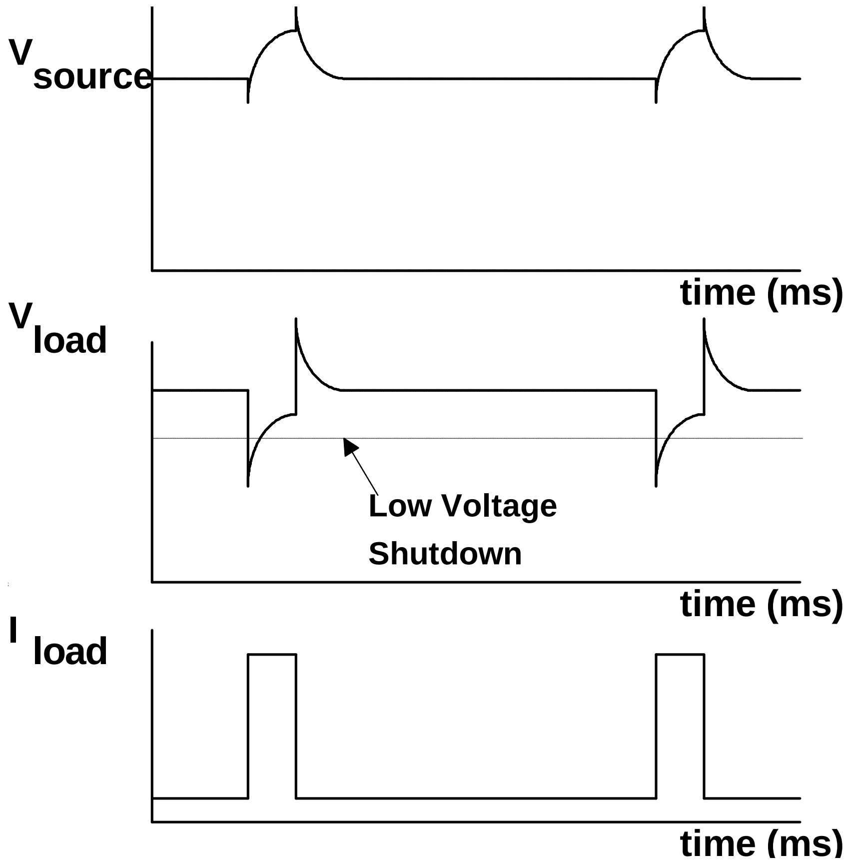


Figure 4: Voltage Drop at DUT due to Pulse Currents. Remote Sense Mode

Alternate solutions for reducing the transient voltage at a remote DUT

Best Practice; Minimize Path Impedance:

The most preferable solution is to minimize the impedance between the power supply and the DUT. It was possible to accomplish this in a variety of ways as illustrated for the previous example with the following list:

1. Use larger wire. Switch from 0.5 mm sq. to 6 mm sq. where possible.
2. Reduce distance between the power source and remote DUT by 40% to 1.2 meters.
3. Eliminate relays or use low contact resistance relays.
4. Always use twisted wire pair to minimize inductance.

Twisting the pair of leads is one technique already suggested. It has the additional benefit of reducing noise pick up. Connect the remote sense wires to the DUT with twisted pair as well. The resulting transient voltage drop at the DUT was reduced below the desired goal of 300 mV for the standard purpose power supply by making these changes.

This solution meets the requirement, but may not always be practical from an application point of view. It may be necessary to have additional resistance in the path due to connectors, contacts, and smaller relays for switching the power supply output. This can also dictate having to use a small wire size to fit onto the relay card and connector terminations.

Filter at the DUT:
A second solution is to place a large electrolytic capacitor across the terminals of the DUT right at the test fixture. With the test conditions and power supply configuration set up per the first remote sensing example, adding a 3,000 uf electrolytic capacitor limited the transient amplitude to 100 mV.

The voltage transient at the phone is well within the minimum requirement due to the low impedance of the capacitor. However, there are drawbacks associated with this solution:

1. Electrolytic capacitors of this magnitude are large and may not be convenient to mount at the test fixture.
2. A 3,000 uf capacitor will take around 20 milliseconds to charge and discharge. As the power supply will likely be programmed to many different voltages during testing, this settling time can add significant overall time to the testing.
3. In cellular phone testing it is desirable to measure the phone standby and off state currents. The leakage current of a large electrolytic is significant compared to the phone off state or standby current. Furthermore, the leakage current of electrolytic capacitor is a function of time, voltage and temperature.
4. If it is desirable to measure the magnitude of the pulse current of the phone under test; a large capacitor at the DUT terminals will corrupt this measurement, because the pulse current will be supplied by the capacitor and not the power supply.

While this solution is possible, it may not be practical if any of the above factors are an important consideration in the application.

Use a power source with wide bandwidth and high voltage slew rate:
A third possible solution is to increase the bandwidth of the power supply control loop to at least 50 and to increase the voltage slew rate of the power supply to greater than 250 mV/microsecond. This required voltage slew rate is given by equation 2 below for a worst- case path resistance of 4 ohms and the current pulse characteristics as previously defined

$$Vs = R * dI/dt + L * d^2I/dt^2 \qquad (2)$$

Figure 5 illustrates the results of having a power source with these dynamic response characteristics. It now responds to the speed of the load change and compensates for the path impedance voltage drop. The net result is that the transient voltage at the DUT is greatly reduced to well within acceptable limits. *Thus, it is the dynamic response characteristics of the power source that ultimately determine what the remotely sensed transient response characteristics are for this situation.*

Increasing the bandwidth of the power source has the drawback of not being able to maintain stability for as wide a variety of loads. The path impedance and the DUT impedance now significantly influence the power supply control loop. The power source is no longer "load independent". It is now more optimized for a particular application, limited by a range of load characteristics that it is designed to accommodate. This usually is not an issue for cellular phone testing as they typically have a capacitive input impedance by nature.

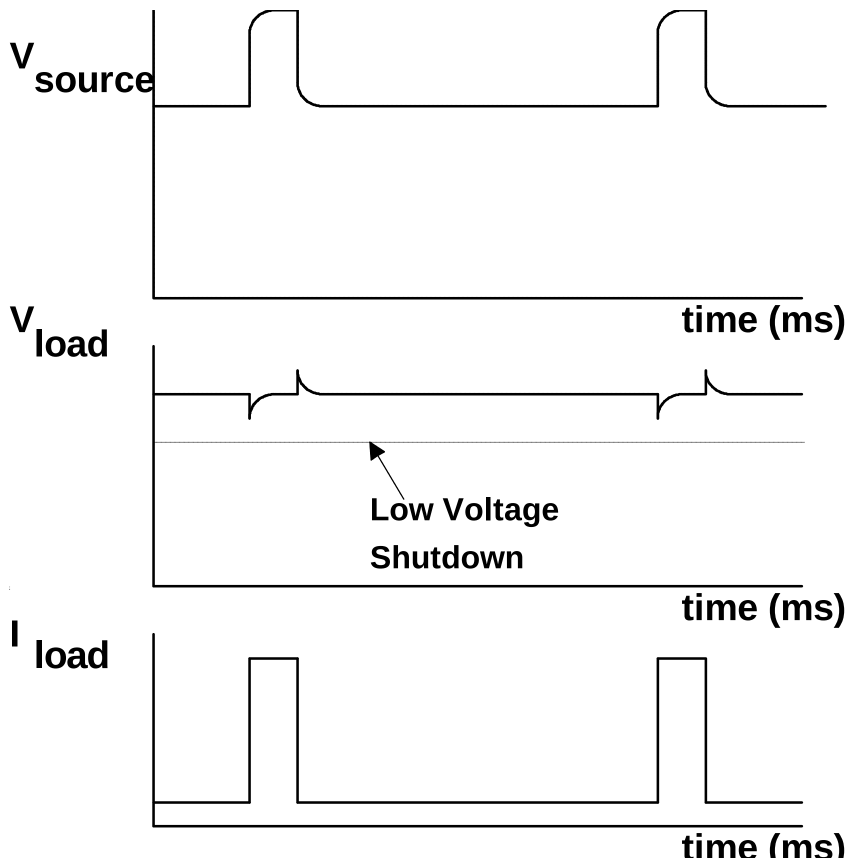


Figure 5: Voltage Drop at DUT with optimized source. Remote Sense Mode

<u>Special Considerations for Higher Wiring Inductance and Current:</u>

In all of the various examples so far, the wiring inductive voltage drop has been considered to be small compared to the wiring resistive voltage drop. When the wiring is not twisted or the length is in excess of two meters, the inductance becomes significant. The problem is compounded further with the trend towards lower voltage and higher current. The latest generation of cellular phones operate at 3 to 4 volts and thus draw much higher current. As the current rise time remains the same the current slew rate significantly increases.

Up to now it was assumed that the load was purely a negative current source (sink) with a linear rise time of 15 usec. For digital wireless products, the input circuit can be more accurately modeled as a current source in parallel with a capacitor and a small series resistor. Typical values range from 5 to over 40 microfarads in series with 0.1 to 0.4 ohms. The rising portion of the current, illustrated in figure 6, is be modeled as an exponential in equation (3):

$$I(t) = I_o(1 - \in^{-t/\tau}) \qquad (3)$$

The power supply bandwidth and slew rate requirements can be determined by considering the limiting case of zero load capacitance and examining the voltage drop in the cable given by equation (1) when the current drawn by the DUT has the characteristics illustrated in figure 6.

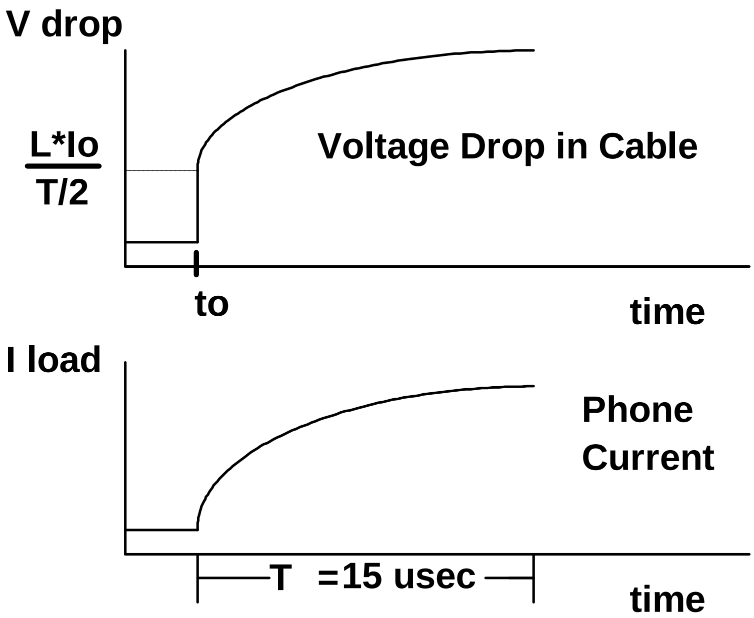


Figure 6: Voltage Drop in wiring with large inductive term

When the capacitance of the DUT is zero, the voltage drop in the cable is found by substituting equation (3) to equation (1). The resulting voltage drop is now given by equation (4):

$$V_d = R * I_o(1 - \in^{-t/\tau}) + L * (I_o/\tau) * \in^{-t/\tau} \qquad (4)$$

In equation (4), R is the cable resistance, L the inductance, I_o , the final value of the current, τ is 1/2 the current rise time, and V_d is the cable voltage drop.

In figure 6 it can be seen that the initial voltage drop in the cable, (L*Io)/(T/2), occurs in zero time even though the current has a finite rise time. This is due to the cable inductance. With lower voltage wireless products drawing higher current, this effect is very significant; e.g., for a 15 microsecond rise time, 4 microhenries of cable inductance and current pulse amplitude of 3 amps, the inductive effect alone gives a 1.5 volt drop in the cable. To compensate for the zero rise time inductive voltage drop in the cable, the power supply would have to have infinite bandwidth and slew rate, which is not possible to achieve. In practice, cellular phones do have input capacitance, typically 5 microfarads or greater. This capacitance gives a greater-than-zero rise time of about 10 microseconds to the inductive voltage drop.

Another consideration is the voltage drop amplitude. Where 300 millivolts was a desired goal for current 6 volt products, in practice, 150 millivolts is a desireable goal for the 3 to 4 volt operating voltage of the latest generation products.

These factors dictate additional measures. The bandwidth of the optimized supply should further increase to be better than 100 KHz. Alternatively, the test sytem engineer can add around a 20 microfarad, low leakage film capacitor at the fixture to negate the effect of wiring inductance. *Unlike a large electrolytic capacitor, the small film capacitor does not impede measurement of microamp and pulse currents.*

A Practical Approach Using the Agilent 66321B Mobile Communicatons DC Source

Faster control loop compensation of the 66321B Mobile Communications DC Source was implemented to give wider remote sense bandwidth and higher output voltage slew rate to optimize it for powering remotely fixtured digital wireless products. The 66321B also offers the right range of voltage, peak and steady state power, and provides microamp and pulsed current measurement capabilities, making it tailored specially for digital wireless product testing.

Figure 7 shows the power supply output current and voltage at the DUT in response the pulse current draw. With 2.5 ohms of path resistance and 2 microhenries of inductance, the transient voltage drop at the DUT is less than 30 mV. This is a 60-fold improvement over the standard power supply control loop compensation using either local or remote sensing.

The 66321B has four programmable compensation settings to optimize transient response for a wide range of cellular phones and system wiring configurations.

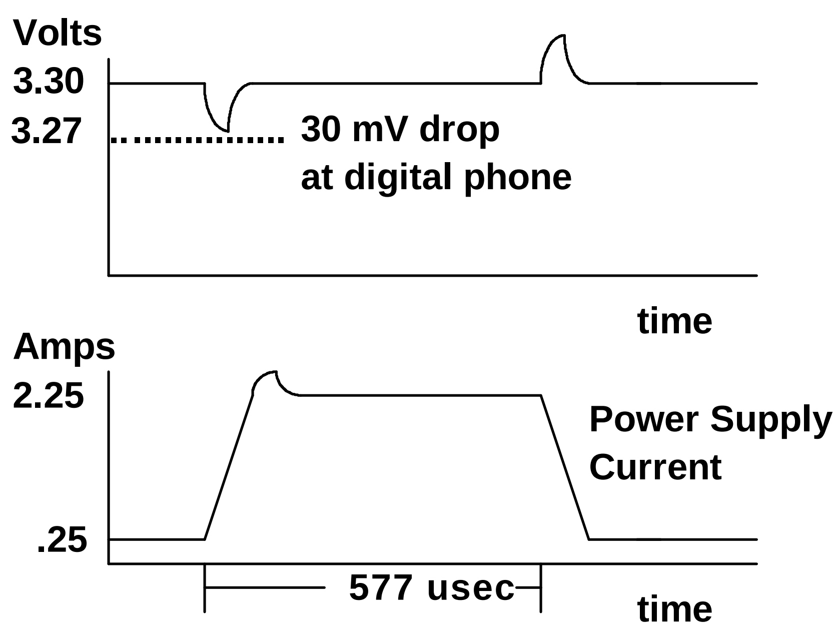


Figure 7. Transient voltage at power supply due to pulse current from digital phone

Summary

Several solutions have been proposed to address the problem of power source voltage transients resulting from testing remotely fixtured digital wireless products which draw currents in pulses. These solutions are summarized in the following table:

Solution Description	Requirement	Benefit	Liability
Best Practice: Minimize path impedance	• Use heavy twisted wire pair. • Minimize distance. • Eliminate relays and connectors	• Uses standard power supply.	• Not always practical to achieve very low resistance needed.
Add filter at load	• Mount 3,000 uf capacitor at fixture	• Very effective at lowering voltage transients. • Uses standard power supply.	• Cannot measure pulse or uA currents. • Large capacitor difficult to mount.
Power source optimized for application	• Power source requires high bandwidth and voltage slew rate.	• Compensates for large values of path impedance • Can add relays or components in path	• Power source optimimized for a limited range of load impedance.

To mimimize voltage transients, it is always a best practice to minimize the path impedance between the power source and the DUT. However, practical requirements of the overall test system configuration have to be considered. This requires that the test engineer needs to understand the more subtile interactions of the power source in the test system and how various characteristics of the power source impact these voltage transients. Circumstances may dictate the need of a power source with enhanced performance characteristics to meet overall test system performance requirements.

By being aware and understanding the source and nature of these transient voltages and alternate solutions available, the test engineer can effectively plan ahead in the design of the test system and circumvent this from being a problem at the outset.