Common-impedance plumbing

Bob Witte - October 25, 2019

Have you ever taken a shower only to find the water pressure suddenly decrease when someone else in the house used water? In my recent case, the water temperature shifted a bit but stayed comfortable, probably due to the hot/cold flow balancing in the faucet. (There are several different mechanisms that may be built into a modern shower faucet to maintain constant temperature with varying pressure.)

This reminded me of the water flow analogy that is commonly used in introductory electronics classes. Sometimes referred to as the electronic–hydraulic analogy, it is a method to explain electrical current flow and Ohm’s Law (V=I/R).

In this analogy, water pressure is analogous to electrical pressure or voltage. Water flow corresponds to electrical current, the flow of electrical charge. Electrical resistance is analogous to a constriction in the path of the water flow, such as the inverse size of a water pipe (Figure 1). The smaller the pipe, the greater the resistance to water flow. It’s the same with the diameter of a wire.

As the water pressure dropped in the shower (and quickly recovered), I began sketching out the analogous electrical circuit in my head. Figure 2 shows the water source feeding the toilet and shower. The water source in my house is a well pump connected to a pressure tank, with pipes connected individually to the toilet and shower. The return path at the bottom of the drawing is a bit suspect because the toilet and shower both drain into a septic system and are not a closed loop. The septic system does drain into the ground (dirt-type ground, not electrical ground) so I suppose the water might eventually make it back to the source (the well) but that’s a stretch. I will invoke the disclaimer that all analogies are imperfect, but some are useful. If you live in a place with a sewer
system, then the water could eventually make it back to your house after purification.

The shower is modeled as a variable load (turn the handle on the faucet) while the toilet has an on/off switch (valve). In the circuit shown, changing the condition of the toilet switch would not affect the flow of water through the shower. Therefore, the circuit in Fig. 2 doesn’t explain the drop-in water flow at the shower.

**Figure 3** shows a more realistic configuration that has the toilet and shower sharing the same pipe coming from the water tank. Now we can see that switching the toilet on can have an effect on the water flow through the shower. The presence of the common pipe resistance means that the pressure at the shower will drop as water flows to the toilet. The magnitude of this effect depends on the size of the common pipe and the relative loads of the toilet and shower. We hope that the plumber has anticipated this issue and provided a large enough pipe to carry the flow without too much variation.
Figure 3

Modified electrical circuit analogy shows how two loads share a common source.

Common-impedance coupling

While I've used the water analogy to introduce this problem, it's also well known in electrical and electronic circuits. In electrical house wiring, we often see lights dim slightly as large electrical loads are turned on (e.g., an air conditioning unit or laser printer). In electronic systems, this phenomenon is commonly referred to as *common-impedance coupling*.

*Figure 4* shows a basic electronic circuit that has common impedances in both the power supply and the common paths. The common path is often referred to as "ground," which is one of those handy simplifications that can easily lead to a false sense of security and poor circuit performance. The presence of R2 is a reminder that our common or ground system has a non-zero impedance that can affect circuit performance. Fig. 4 includes an analog device and a digital device, each driving independent loads. Of course, this is a simplified model, and a real circuit may be much more complex.
Electrical circuit with common-impedance coupling.

The combined power supply current, $I_1$, includes the supply current for both the analog and digital devices. Therefore, the presence of the common impedance $R_1$ means that the supply current to either device can affect the supply voltage delivered to the other device. Whether this matters or not will depend on the device’s power-supply rejection. Some circuits are very tolerant of power-supply variations but others can be very sensitive.

Similarly, the common impedance, $R_2$ has current $I_2$ flowing through it, which includes the return currents of the devices plus the currents flowing through each load ($R_3$, $R_4$). All four of these currents can return through $R_2$ and cause a voltage drop across it. If we consider the negative terminal of the power supply to be our zero-volt reference, then the devices and loads will see an $I_2 \times R_2$ voltage imposed on the common connection. The supply current from either device can cause a voltage shift for the other device. In addition, signaling currents from the output of either device can induce a change in voltage. A common scenario is a large, fast-switching digital signal introducing noise onto a low-level analog signal.

**For more study**

I’ve introduced the basic idea of common-impedance coupling, which can be applied in many different electronic applications. This concept is important to mixed-signal system design, integrated circuit design, power integrity work, high-speed digital design and electromagnetic compatibility (EMC) work. To go deeper, take a look at the references and related articles below.

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**References**


Related articles:

- The ground illusion: Don't let it come back to get you
- The Ground Myth
- Can we find common ground about "common" and "ground"?
- Grounding in mixed-signal systems demystified, Part 1
- Grounding in mixed-signal systems demystified, Part 2
- Grounding and shielding: No size fits all
- Quick & dirty cable length & impedance measurement
- Simple trick to measure plane impedance with a VNA
- Friday Quiz: Measuring Characteristic Impedance