Measuring Cables.

Cable characteristic impedance or Z0.

The characteristic impedance, Z0, of any cable is an AC parameter having a reasonably constant value above 1MHz, but at lower frequencies, Z0 increases rapidly, becoming near infinite near DC. At audible frequencies, characteristic impedance Z0 of any cable is many times higher than its high frequency value.

This increased characteristic impedance at low frequencies is especially significant for loudspeaker cables at audible frequencies, because Z0 of any practical speaker cable far exceeds that of the usual speaker impedance. You may wish to measure this for yourself, but lack any specific impedance measurement instrument.

For my paper, "Cables, Amplifiers and Speaker interactions" I already had available two accurate impedance measurement instruments. For high frequencies I used my HP4815A RF Vector Impedance Meter which is able to measure impedances from 2Ω to 100kΩ at frequencies from 500kHz to 108MHz.

For frequencies up to 100kHz I used my self build Impedance meter described in EW January 2001, pp 24-30, which measures from audio frequency to 1MHz and impedances larger than a few milliohms.

Prior to obtaining these instruments, for many years I used a surprisingly simple technique using only a 50Ω signal generator, a 50Ω BNC termination and a millivoltmeter or oscilloscope. However this simplicity does require that we use a pocket calculator, to calculate impedance.

Let us first explore how to measure impedances from a few milliohms to 500Ω.

For both low impedance and high impedance measurements, we first set up the test as shown in Figure 1, and adjust the signal generator output until the voltage at V_out reads 1 volt exactly.

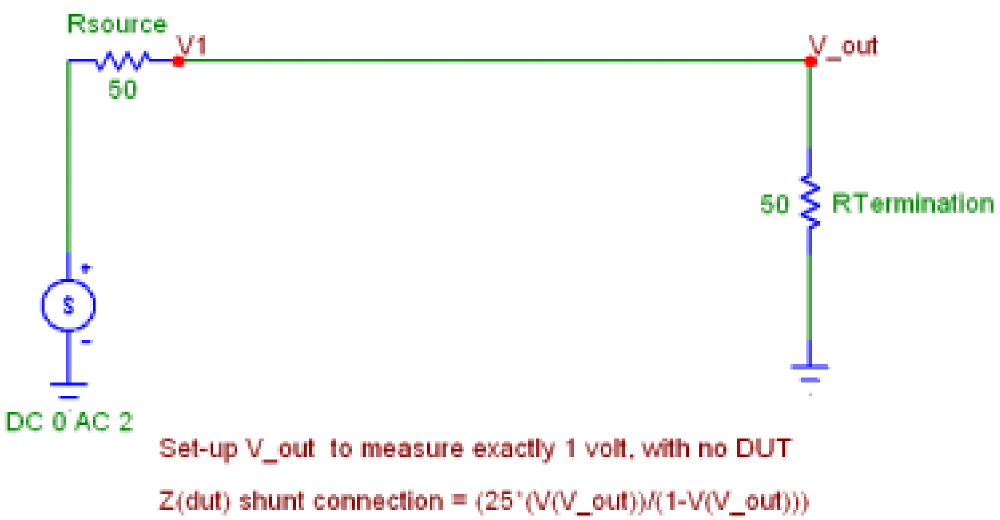

Figure 1.
We need to use a signal generator able to deliver at least 1v into a 50Ω load.

Simply adjust generator output to read 1v at the V-out test point.

When measuring low impedances, we use the "shunt" connection. The test piece (cable) is connected one wire to the lead connecting V1 to V_out to the signal generator, the other to the BNC termination ground connection. The "far end" cable wires must be connected together (shorted).

Do not adjust the signal generator setting from that set for Figure 1.

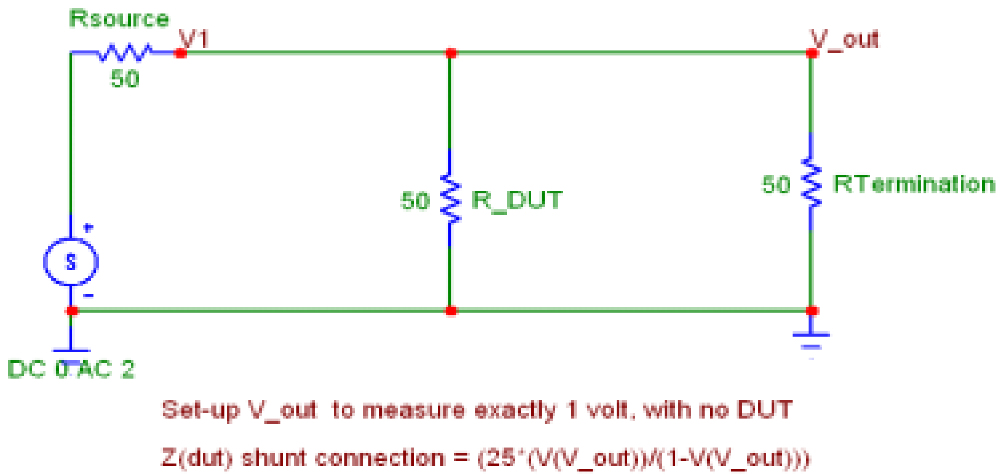

Figure 2.

The "shunt" measurement "DUT" connection allows measurement of impedances from some 500Ω to less than 0.1Ω.

Naturally the V-out voltage now reduces to measure 0.667v.

Dependant on the test piece impedance, the V_out voltage is now reduced. In this case with a 50Ω DUT we now measure V_out at 0.667v. Substituting 0.667 for V(V-out) in the equation:-

(25*(V(V_out))/(1-V(V_out))) we calculate the DUT impedance as 50Ω.

This method can also measure impedances greater than 50Ω but sensitivity reduces with increasing impedance, effectively establishing a measurement maximum at 500Ω. With a DUT of 50mΩ we find V-out reduces to just 2mV, requiring a sensitive millivoltmeter.

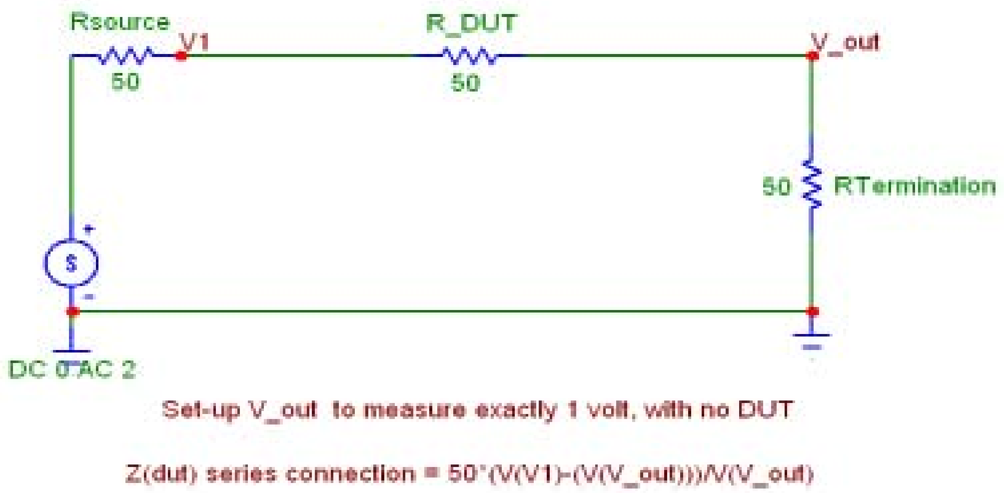

Figure 3.
We use this "Series" connection when measuring impedances greater than 50Ω, however when needed this test method can measure impedances down to 10Ω, but with reduced sensitivity.

Using the original 1v calibration but now inserting the DUT into the lead wire which connects V1 to V_out we can similarly measure impedances from some 10Ω to 500kΩ . At 500kΩ, V-out again reads 2mV, effectively placing an upper limit on the maximum measurable impedance.

Using a 50Ω test piece, now using the "series" connection mode we measure V_out as 0.667v. We measure V(V1) as 1.333v. Substituting for V(V1) and V(V-out) in the equation:-

(50*(V(V1)-(V(V_out)))/V(V_out)) we calculate the DUT impedance again as 50Ω.

These examples are quickly proven by running a SPice analysis.

This shunt connection is especially useful when measuring capacitor impedance by frequency and capacitor self resonant frequency, see Figure 4.

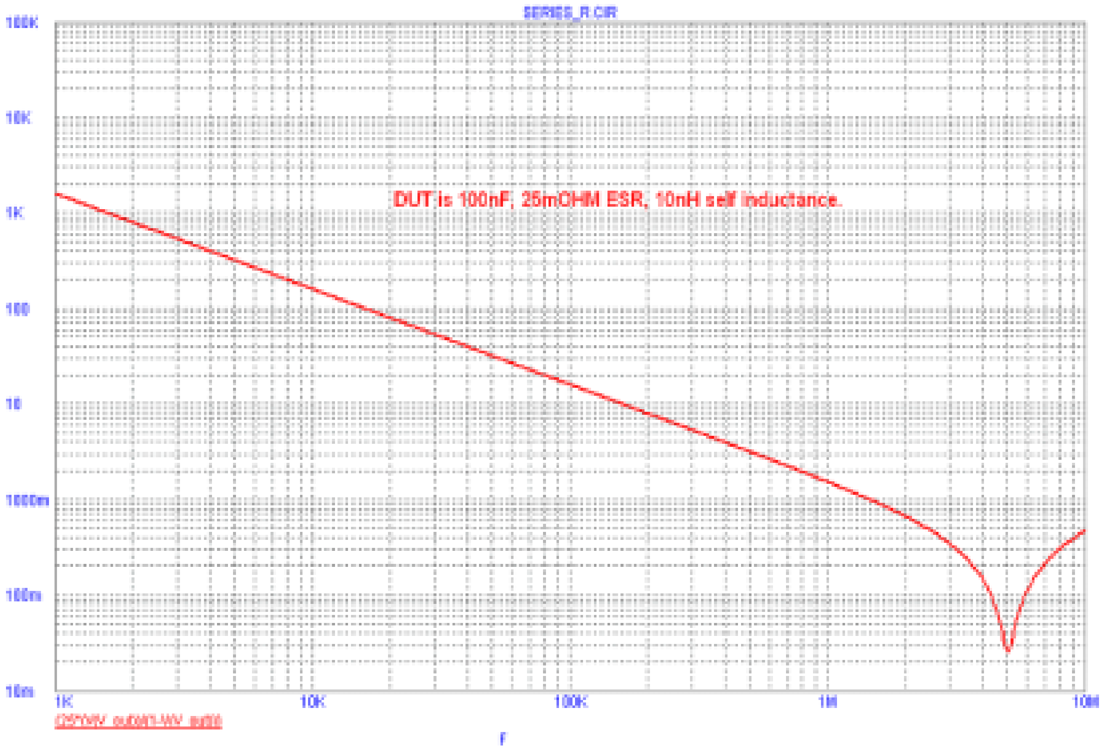

Figure 4. This Spice simulation shows the impedance plot using the “shunt” test method, measuring a 100nF exceptionally low inductance capacitor.

Such low self inductance is only found using chip ceramic capacitors.

Since impedance of almost all capacitors will be less than 10Ω at their self resonant frequency we cannot use the series method to investigate a capacitor’s self inductance. This mistake was made years ago in a widely published, learned paper, which then claimed that bead tantalum capacitors were non-inductive. Using the correct “shunt” method, even very small self inductance values, result in a capacitor impedance clearly increasing with frequency, above self resonance.

The millivoltmeter used of course must be accurate over the desired frequency range. Most low cost multimeters are only usable up to a few kHz, most are unusable at 10kHz or above.

Design of a suitable, very low cost millivoltmeter, usable to 5MHz, was described in EW April 2000, pp 281-285.

This millivoltmeter, also the Impedance meter published January 2001, are both fully detailed on my CapSounds CD rom.

For a fuller explanation about cable characteristic impedance, how it varies with frequency and how the wrong cable destroyed three of my amplifiers, see my paper “Cables, Amplifiers and Speaker interactions”.

When measuring cable short circuit impedance, or Zshort, connect together (short) both far end cable wires. Using the “shunt” connection mode, connect one “near end” cable wire to the wire connecting V1 to V_out, the second “near end” wire to ground.

When measuring cable open circuit impedance, or Zopen, ensure both “far end” cable wires are well separated (open), remove the wire connecting V1 to V_out. Connect one near end cable wire to V1, the other to V_out terminal.

Calculate both Zopen and Zshort values. Calculate Z0 as $\sqrt{Zshort \times Zopen}$ at that frequency.