Science of 50 Ohms

The RF Experts

APPLICATION NOTE

Ohms Sweet Ohm

Introduction

Since 1942, Bird has been supplying quality Instruments for RF power measurement from 2 to 2300 MHz and from 25 milliwatts to 250 kilowatts in 50-ohm coaxial line systems. The standard coaxial line impedance for power transmission in the U.S. is almost exclusively 50 ohms, but why is this? This application note will look at the science of why 50 ohms is the integer-of-choice in the United States.

Wanted: The “Perfect” Impedance

In concentric transmission lines, the electromagnetic wave is propagated through a dielectric medium bounded by two coaxial cylinders. Since current penetration at microwave frequencies is small (skin depth at 1 GHz in a silver conductor is approximately 0.00008 inches), the only important dimensions are the diameter (d) of the center conductor and the bore (D) of the outer conductor.

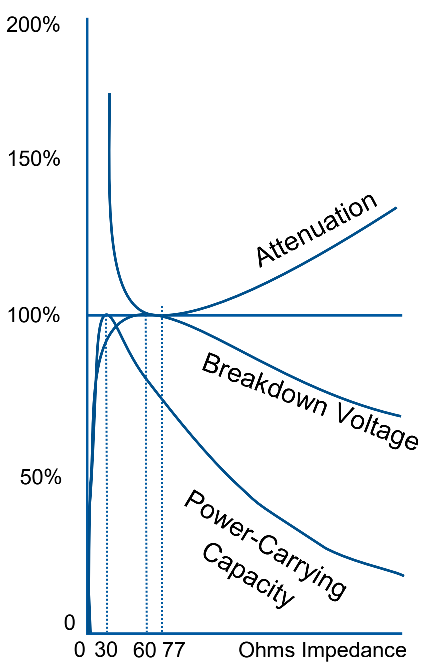

Figure. 1

For a coaxial line with small losses, such as used in the industry, the characteristic impedance is $Z_o = \sqrt{\frac{L}{C}} = \frac{138.16}{\sqrt{\varepsilon}} \log_{10} \frac{D}{d}$ or $\frac{60}{\sqrt{\varepsilon}} \ln(D/d)$ where L and C are the inductance and capacitance per unit length and ε is the dielectric constant of the medium between the concentric cylinders (ε equals 1 for air).

For example, here are a few representative outer-conductor bore values for an airline with a one-inch diameter center conductor:

30 ohms	1.65”
50 ohms	2.3”
75 ohms	3.5”
100 ohms	5.3”
150 ohms	12.2”

There is no diameter ratio that is ideal for all important transmission parameters. In a coaxial line with power propagating in normal TEM mode, the highest voltage gradient occurs at the surface of the center conductor. Using a maximum Breakdown Gradient E_m (e.g. 74 peak volts per mil for air), the highest permissible potential difference between conductors is then $V_{rms} = \frac{E_m}{\sqrt{2}} \frac{D}{2} \frac{\ln(D/d)}{(D/d)}$

This leads to the curve of Breakdown Voltage in Fig. 1. The curve peaks at a diameter ratio of 2.718 which corresponds to a 60-ohm impedance.[1]

Power, of course, is V_{rms}^2/Z_o. The curve of Power Carrying Capacity in Fig. 1 is a plot of

$$P = \frac{V_{rms}^2}{Z_o} = \frac{E_m^2}{2} \frac{D^2}{4} \left[\frac{\ln(D/d)}{(D/d)}\right]^2 \frac{1}{60 \ln(D/d)} = \frac{E_m^2 D^2 \ln(D/d)}{480 (D/d)^2}$$

If, for example, V_{max} of a 60-ohm line is assumed to be $100V_{rms}$, the maximum power associated with this V_{max} would be 167 watts. A 30-ohm line

[1] Differentiating $\frac{dV}{d(D/d)}$ and equating it to zero to obtain V_{max} yields $\ln(D/d) = 1$, i.e. $D/d = 2.718\ (60\ ohms)$. Similarly, $\frac{dP}{d(D/d)}$ equated to zero for P_{max} results in $\ln(D/d) = 1/2$ and $D/d = 1.65\ (30\ ohms)$.

with the same outer conductor diameter can only sustain a V_{max} of $82.5V_{rms}$ before breakdown. The power associated with this V_{max}, however, is $82.5^2/30$ or 226 watts, i.e. the 30-ohm airline has a higher Power Carrying Capacity, but a lower Breakdown Voltage than the 60-ohm line.

Power capacity based on voltage considerations ignores the current density, which goes up as impedance goes down. Attenuation due to the conductor losses alone is almost 50% higher at 30 ohms than at the minimum-attenuation line-impedance of 77 ohms (Diameter ratio of 3.6). Since such a line is limited to only about half the power capacity of a 30-ohm line, 77 ohms is usually selected for low-power long-distance transmission (e.g. CATV, TV antenna lead-in, etc.). According to Consultant C.L. Rouault, an RMA committee in the 40's recommended an impedance standard of 50 ohms to the U.S. Navy as a compromise between transmission parameters, as well as commercially available copper water-tubing sizes. It is interesting to think where the communication industry might be today without input from the plumbers!

Adding Attenuators

While minimum attenuation is desirable in signal transmission, equipment with a known amount of attenuation is a valuable tool in the laboratory.

Coaxial attenuators are used for a variety of applications such as isolation, comparison standards, power reduction at the source or at the receiving end, and for signal observation. Components under test, such as filters and antennas, typically exhibit impedances other than 50 ohms. In these cases, fixed attenuator pads are used to reduce interaction between components in order to make measurements meaningful.

For example, a matched 10 dB pad reduces a 2:1 voltage standing wave ratio to 1.07, a 3:1 VSWR to 1.11, and so on. Figure 2. demonstrates the correlation between the three parameters of dB attenuation and VSWR before and after attenuation. Since this is accomplished at the expense of power level, Figure 2. shows the best compromise between correlating the three

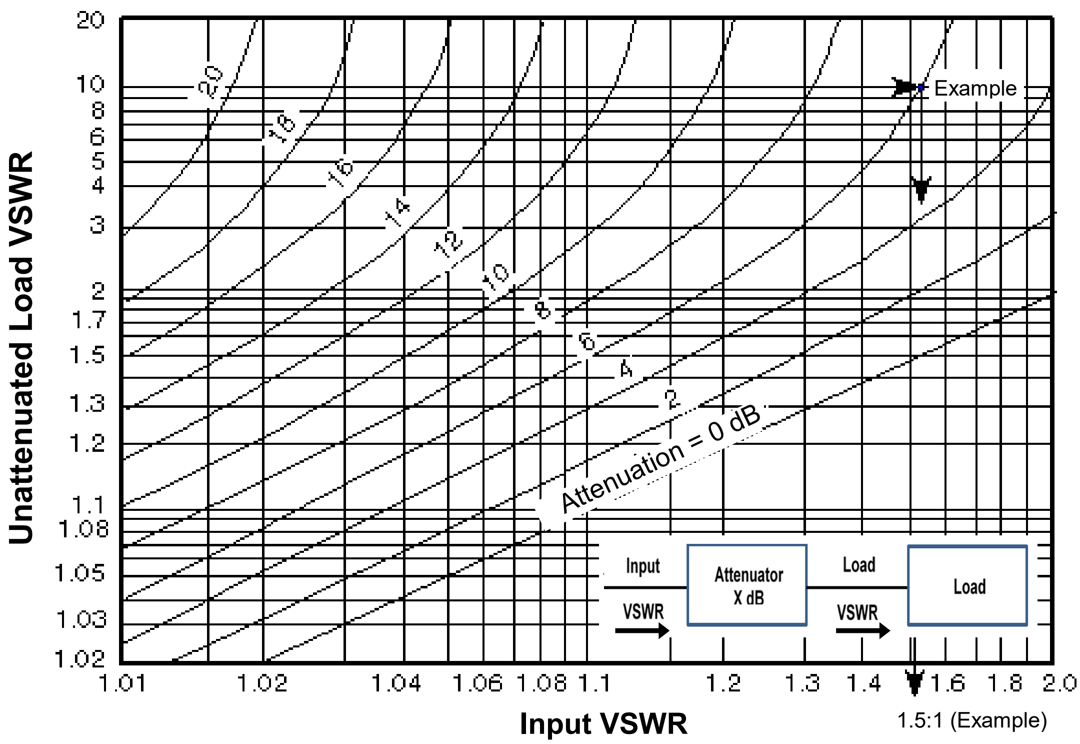

Figure 2. Reduction of VSWR by Attenuation

parameters of dB attenuation and VSWR before and after attenuation.

Points on the graph have been calculated from the following relationships:

$$VSWR = \frac{1+\sqrt{\frac{P_r}{P_i}}}{1-\sqrt{\frac{P_r}{P_i}}} \qquad \frac{\overrightarrow{P_i} = Power\ Incident}{\overleftarrow{P_r} = Power\ Reflected} \boxed{Load}$$

$$\frac{\overrightarrow{P_i}}{\frac{1}{R^2} \times \overleftarrow{P_r}} \boxed{Attenuator\ Pad - R} \frac{\frac{1}{R} \times \overrightarrow{P_i}}{\frac{1}{R} \times \overleftarrow{P_r}} \boxed{Load}$$

When a pad is added, the power level into the attenuator (P_i) remains unchanged and is then reduced by the attenuator's ratio (10:1 for 10 dB, 100:1 for 20 dB) to $\frac{1}{R} \times P_i$. This reflected level passes through the attenuator and is reduced again by the attenuation ratio $\left(\frac{1}{R} \times \frac{1}{R} \times P_r\right)$. The new VSWR is then $\frac{1+\sqrt{\frac{P_r}{P_i}\frac{1}{R^2}}}{1-\sqrt{\frac{P_r}{P_i}\frac{1}{R^2}}}$

The values for each point have been calculated to five significant places and plotted in Figure 2.

Attenuators are also used for signal observation, such as scope display or counters. They reduce the line signal level to an amount the test equipment can utilize without distortion. Attenuators for these applications and for power measurement with low level wattmeters must be designed to withstand the higher power dissipated within their elements.

Bird manufactures a broad spectrum of attenuators from 2W to 4000W. Our resistive product portfolio includes air-cooled, water-cooled, oil-dielectric, convection cooled, and conduction cooled RF attenuators with a wide range of connectors and attenuation values. For more information on these products and more, visit BirdRF.com/Products.