Directional Couplers

In transmission lines, directional couplers allow the direct measurement of $V^+$ and $V^-$ in the time domain. (Altogether different components, also called directional couplers, are used in waveguide circuits.)

The idea in the above circuit is that current involves $V^+ - V^-$ and voltage involves $V^+ + V^-$. The voltages across $R_{\text{series}}$ will be proportional to line current and the voltages across $R_1$ are proportional to line voltage. By combining these two voltages (the voltages across $R_{\text{series}}$ and $R_1$), $V^+$ can be obtained through addition, and $V^-$ can be obtained by subtraction.

Once $V^+$ and $V^-$ are known, $\Gamma$ and VSWR can be readily determined.

Choose

$$\frac{R_{\text{series}}}{Z_c} = \frac{R_1}{R_1 + R_2}$$

$$Z_c = \sqrt{\frac{\text{series resistance}}{\text{parallel conductance}}} = \sqrt{2R_{\text{series}} (R_1 + R_2)}$$

Choose $R_{\text{series}}$ small for low attenuation, but it cannot be chosen too small since the voltage across $R_{\text{series}}$ must measured accurately for the technique to be of use.
Details of derivation
Applications
It is easy to get the idea that all EEs do is design circuits, program microprocessors, determine signal processing schemes, layout power systems, and so forth.

Nothing could be further from the truth.

Electrical engineering is a very broad discipline, and electromagnetics is one area where EEs are involved in an amazing variety of applications.

Microwave ovens
Water's polarity makes it an ideal material for heating via microwaves. Microwave ovens use 2.45 GHz. While microwaves are good at heating water, they're not so hot at heating ice—and not simply because of the heat of fusion (the energy required to change phase)—the loss tangent of ice is 3 or 4 orders of magnitude lower than that of water.

Radio-frequency
Widespread use in RADAR (RAdio Detection And Ranging).

Both microwave and RF are widely employed in semiconductor processing: plasma ashing of photoresist, plasma-enhanced deposition techniques like plasma-enhanced chemical vapor deposition (PECVD)
Tails of comets (in the Greek “hairy stars”)
The tails of comets are always pointed away from the sun, even when the comet is moving away from the sun.

What's going on? Radiation pressure. Photons have momentum (hf/c).

Well logging
Oil is most often found in a formation of porous rock. The oil occupies the empty spaces within the porous rock, just as a sponge holds water. Typically there are layers of brine above and below the oil. Brine (salt water) is a good conductor, and oil is a very poor one. One of the most powerful techniques in well logging is a measurement of resistivity with respect to depth.
Optical fibers
Communication with gobs of bandwidth, immune to electrical interference. Operating principle: total internal reflection.

Material characterization
Hall effect, photoluminescence (PL), electron paramagnetic resonance (EPR), scanning electron microscope (SEM), tunneling electron microscope (TEM), atomic force microscope (AFM), electron beam induced current (EBIC), optical admittance spectroscopy (OAS), synchrotron-based white-beam X-ray topography (SWBXT), ballistic electron emission spectroscopy (BEEM), ....

Material growth -- Many.

Nondestructive evaluation of pipe

Antennas and antenna arrays

Ion thruster (commonly used on satellites)
Rockets provide thrust by ejecting mass. By Newton’s 2nd-law,

\[ F = \frac{d}{dt}(mv) = v \frac{dm}{dt} \]

Chemical rockets can obtain \( v \approx 10^3 \) m/s.

Ion thrusters, via electrostatics, can readily obtain \( 10^5 \) m/s, or even higher. This allows less mass to be used which is important in space applications.
MEMS (microelectromechanical systems)

RF MEMS switches have enormous advantages in insertion loss, linearity, isolation, and power usage over solid state devices.

Electric actuators (opposite charge attacts)

Comb drives, with gears, can produce rotary motion, a microengine.
A microengine, together with hinged parts, can produce **out-of-plane** motion.

*Magnetic actuators (opposite poles attract)*

*Images from Sandia National Laboratories*

*Image from Georgia Tech Microfabrication Center*
Integrated passives

Integrated circuits have seen an enormous degree of miniaturization over the past decades. In contrast, discrete passive devices—primarily capacitors and resistors—have made only modest steps in miniaturization; the smallest surface mount technology (SMT) elements are approximately 0.5 x 0.25mm.

As a consequence, discrete passive devices occupy an increasing percentage of circuit board area and weight in modern electronic devices. For example, cell phones typically use 300-400 discrete passives. The trend is for an increasing number of passives to be used—e.g., resistors and capacitors for high-speed line terminations and capacitors for power bus decoupling. Taking the personal computer as an example to illustrate this trend, the 486 used 58 axial lead capacitors and 92 axial lead resistors whereas the Pentium III used 680 SMT capacitors, 200 capacitor arrays, 1000 SMT resistors, and 300 resistor arrays. Discrete passives are a serious impediment to miniaturization.

Consider the SMT capacitors used for power bus decoupling. A primary packaging issue in printed circuit boards is ensuring a constant voltage supply to integrated circuit chips. High-speed digital circuits present a significant challenge in this respect as they require widely different currents during each clock cycle. These rapidly changing currents in the time domain require a broad band of frequencies for their frequency domain representation. The goal when using decoupling capacitors is to permit all these frequency domain components to flow without causing the power bus voltage to vary much. A low resistance is required. At high frequencies, a low inductance is even more critical. If the capacitors present a low impedance at all frequencies of concern, then they will be effective as power bus decoupling capacitors.

Supplying the highest frequency currents in high-speed systems is the most difficult challenge. High-frequency decoupling capacitors are placed close as possible to integrated circuit (IC) chips in order to limit inductance and careful attention is paid to their mounting. Decoupling capacitors are designed for low equivalent series resistance (ESR) and low equivalent series inductance (ESL). Decoupling above 100MHz present challenges when standard SMT capacitors are used and decoupling above 500MHz typically requires special low-inductance capacitors. These capacitors are often four-lead capacitors to reduce magnetic coupling which can, in turn, result in a more stable voltage at the chip. Integrated capacitors are readily designed with a lower inductance than discrete capacitors because of the fundamental different current paths. In the leads of the SMT capacitor, the current are in the same direction whereas in the plates of an integrated capacitor, the leads are much shorter and the current on the plates are in opposite directions. This is the fundamental physical reason that integrated capacitors have a much greater potential for power bus decoupling at high frequencies.
The electromagnetic compatibility (EMC) performance benefits available through the use of IP for power-bus decoupling can readily be appreciated. Consider that the majority of passive devices in modern electronic systems are realized via SMT. Compare the performance of resistors, one realized through SMT, the other an IP. Outside signals can more readily couple, via Faraday’s law, to the circuit containing the SMT resistor than the circuit containing the IP resistor. There is simply less loop area to be linked by a magnetic field with the IP resistor. Similar arguments apply to coupling to the capacitor’s circuit. Moreover, if the capacitor were used as a decoupling capacitor, it is evident the SMT will introduce significantly more self inductance than the embedded capacitor. This will result in charge more readily available for power bus decoupling.

High-Speed Interconnects