PRODYN APPLICATION NOTE 606
Prepared By: W. Reed Edgel, PhD, PE

FREE FIELD SENSORS AND BALUNS

Free field sensors are dual sensors. They have two elements that are sensitive to the same field but measure in opposite directions. They have their own ground reference, which is located between the two elements. They are really composed of two ground plane sensors mounted so that their ground planes are common. Figure 1 shows two ground plane D-dot sensors mounted back to back to form a free field D-dot sensor, and figure 2 shows two ground plane B-dot sensors mounted back to back to form a free field B-dot sensor. The essential difference between the electric (D-dot) and Magnetic (B-dot) sensors is that electric sensors have capacitive sensing elements and magnetic sensors have inductive sensing elements or loops.

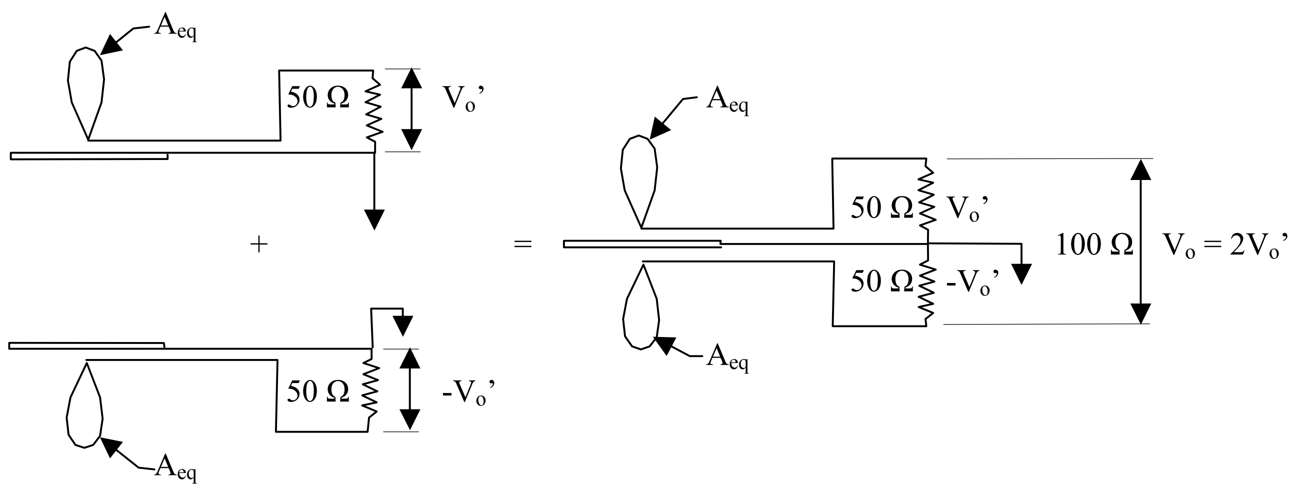

Figure 1. Free field Electric (D-dot) Sensor

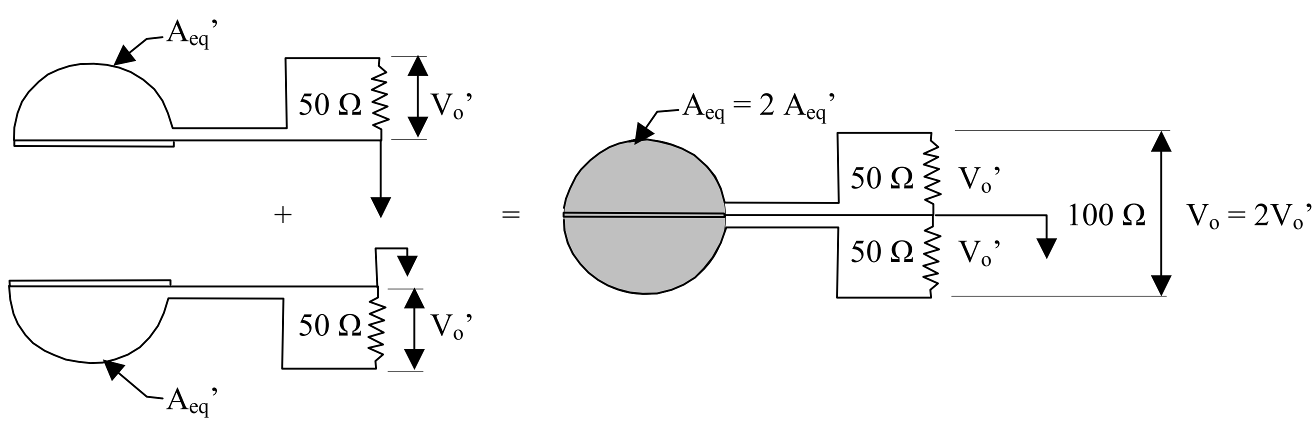

Figure 2. Free field Magnetic (B-dot) sensor

In the case of D-dot sensors, several ground plane models can be combined back to back to form free field sensors:

- Two AD-10 ground plane sensors combined back to back form an AD-20 free field sensor.
- Two AD-180 ground plane sensors combined back to back form an AD-80 free field sensor.
- Two AD-110 ground plane sensors combined back to back form an AD-70 free field sensor.
- Two AD-30 ground plane sensors combined back to back form an AD-40 free field sensor.
- Two AD-60 ground plane sensors combined back to back form an AD-100 free field sensor.

To obey a time honored but confusing convention, the equivalent areas for free field D-dot sensors listed in the PRODYN catalog are the equivalent areas of a single element, but the output impedance, R, is 100 Ω for the free field sensor as opposed to 50 Ω for the corresponding ground plane sensor. The output of a free field sensor is

$$V_o = V'_o - (-V'_o) = 2V'_o = R\, A_{eq}\, d/dt(\mathbf{D})$$

where V'_o is the voltage generated by one element driving half the total load or 50 Ω and R is the total load, 100 Ω.

The output is balanced with respect to ground, ie half appears as V'o and half appears as -V'o with respect to ground. For a sensor with two coaxial output connectors, one unbalanced (single ended) output will be +V'o with respect to ground and the other will be –V'o with respect to ground. The output between the two center conductors will be Vo = 2V'o.

In the case of B-dot sensors, the output impedance does not appear in the transfer function of the sensor, so the equivalent area is taken as the combined area of the two elements. Two cataloged ground plane B-dot sensors mounted back to back would still provide a balanced output equal to twice the single-ended output of one ground plane B-dot sensor, but PRODYN offers no free field B-dot sensors that are composed of cataloged ground plane sensors mounted back to back.

The free-field sensor has a useful self-diagnostic property. It should give the same signal regardless of which element is exposed to a given field. In other words, it should give the same signal when the axis of sensitivity is turned 180 degrees. If it does not, there is probably something wrong with the sensor.

If the measured field is not symmetric with respect to the ground plane, the two elements will give different signals. This can be a powerful diagnostic tool.

The dual outputs of free-field sensors may be recorded separately using independent recording channels, or combined into one output using a converter that has come to be called a "balun". The term (which stands for BALanced to UNbalanced) means that the ideally identical (balanced) signals from the two halves of the sensor, which together form a differential signal, each component being referenced to a common ground, are combined to form a single ended (unbalanced) signal.

The balanced signal may be transmitted over a twinaxial cable which has 100 Ω impedance between the two center conductors and 50 Ω impedance between each center conductor and ground. This practice is less common today, having been largely replaced by the practice of locating a balun close to the free-field sensor.

A typical PRODYN balun is idealized in figure 3. It consists of reactive filters on the two balanced input signals and a Wheatstone bridge circuit that applies the two signals across opposite corners of the bridge. Conventional Wheatstone bridge analysis readily shows that two equal magnitude but opposite polarity bridge inputs give an output that is one-half the magnitude of the positive input.

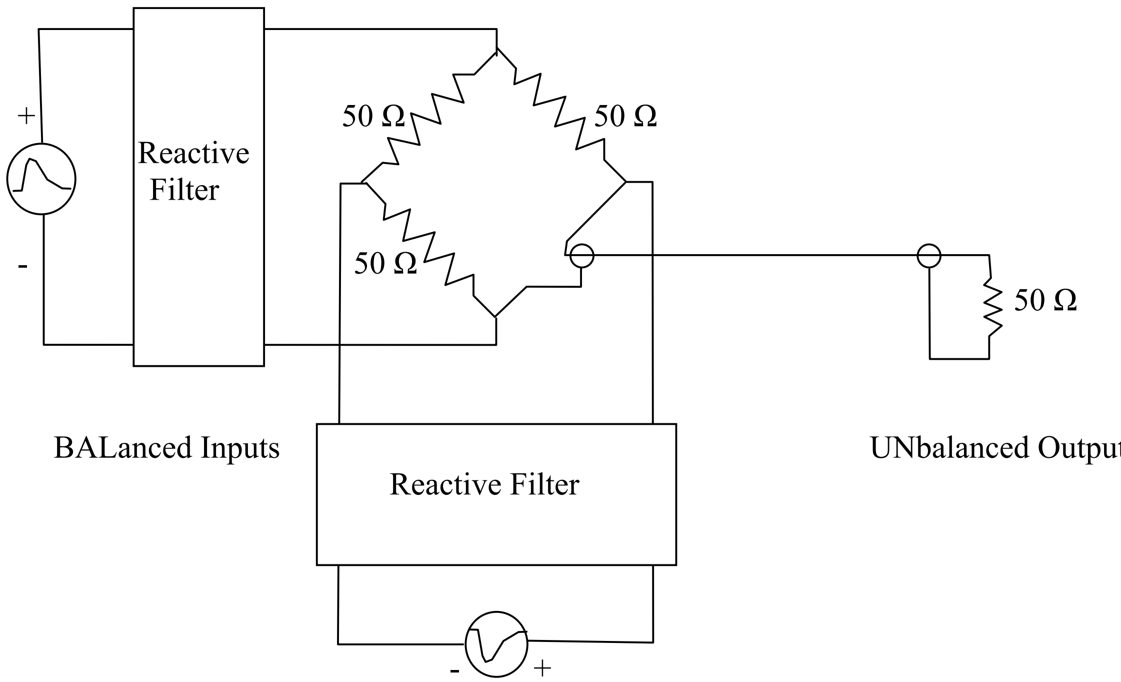

Figure 3. BALanced to UNbalanced Converter (BALUN).

The advantage offered by the balun is that it combines two signals into one and averages them if they are not truly equal and opposite. The combination of two signals into one inherently carries with it the disadvantage that some information pertinent to each channel is lost. Another disadvantage is that the reactive filters and the bridge introduce distortions of the signal. Another is that the filters reduce the signal by as much as 2 dB and the Whatstone bridge inherently reduces the signal by 6 dB.

The reactive filters are broadband filters that reduce frequency dependent distortions induced by the components of the balun. They sacrifice signal for “flatness”, but being imperfect passive devices, can only achieve perfect flatness with infinite attenuation. Thus the trade-off between frequency response and accuracy inherent to broadband filters applies to baluns. PRODYN offers several baluns with various bandwidths and loss characteristics.