Measuring EMAT Impedances Using a Ritec RAM System

The recent increase in use of electromagnetic acoustic transducers (EMATs) has been made possible by better EMAT design, high power transmitters, and improved impedance matching between drivers and transducers. Some information on matching can be found in the application note *L-Matching the Output of a Ritec Gated Amplifier to an Arbitrary Load.* The proper design of impedance matching networks require knowledge of the impedance of both the driver or receiver and the EMAT. The output impedance of the transmitter is usually known from its specifications, but the EMAT impedance must be measured. In cases where a high quality impedance measuring instrument is unavailable, a simple circuit will enable the reactance (Xe) and resistance (Re) of an EMAT to be determined using a RITEC RAM system.

The measurement circuit is shown in Fig. 1.

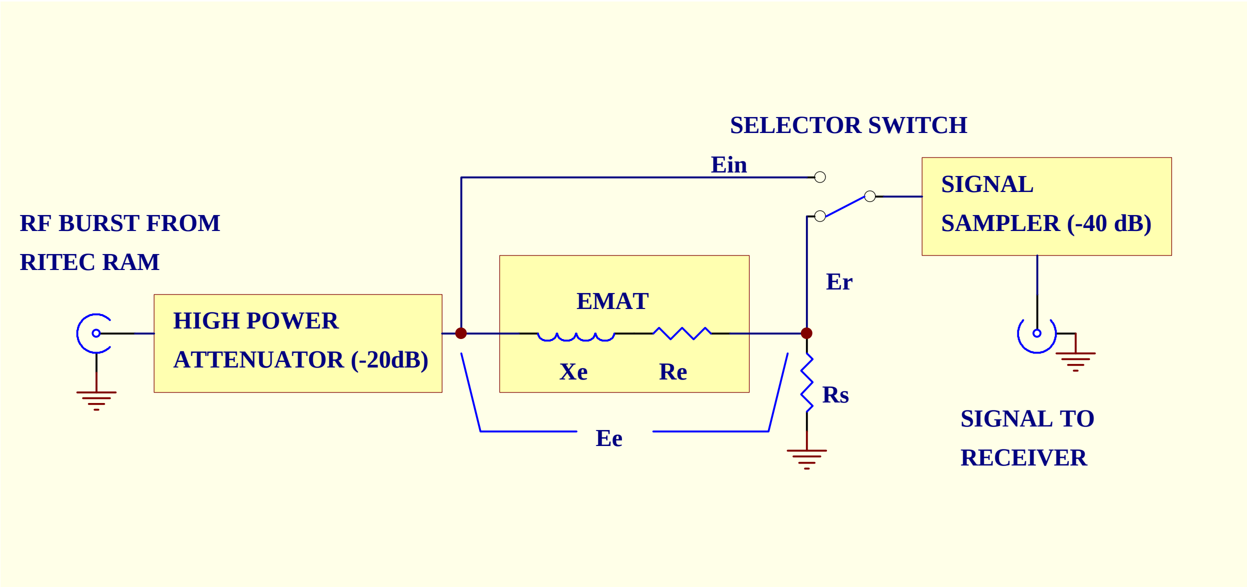

Fig. 1
Circuit for determining EMAT impedance

A high power attenuator (Ritec model RA-30 or other) reduces the RF burst amplitude which is applied to the EMAT-resistor network by at least 20 dB and the Signal Sampler reduces the voltage by an additional 40 dB. This attenuation is needed to avoid over driving the receiver input or the integrator output. The Signal Sampler must also present a impedance high with respect to the EMAT-resistor network to avoid loading and affecting the measurement. The circuit is shown in Fig. 2.

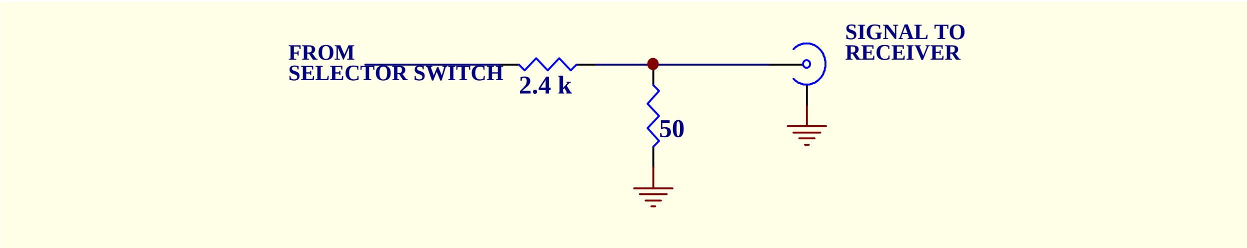

Fig. 2
Signal Sampler (-40dB)

The theory of the measurement scheme is most easily understood by using phasor diagrams. When a pure reactance X is placed in series with a resistance R, the voltages across each element are at a 90° phase angle with respect to each other and add as vectors as is shown in Fig. 3.

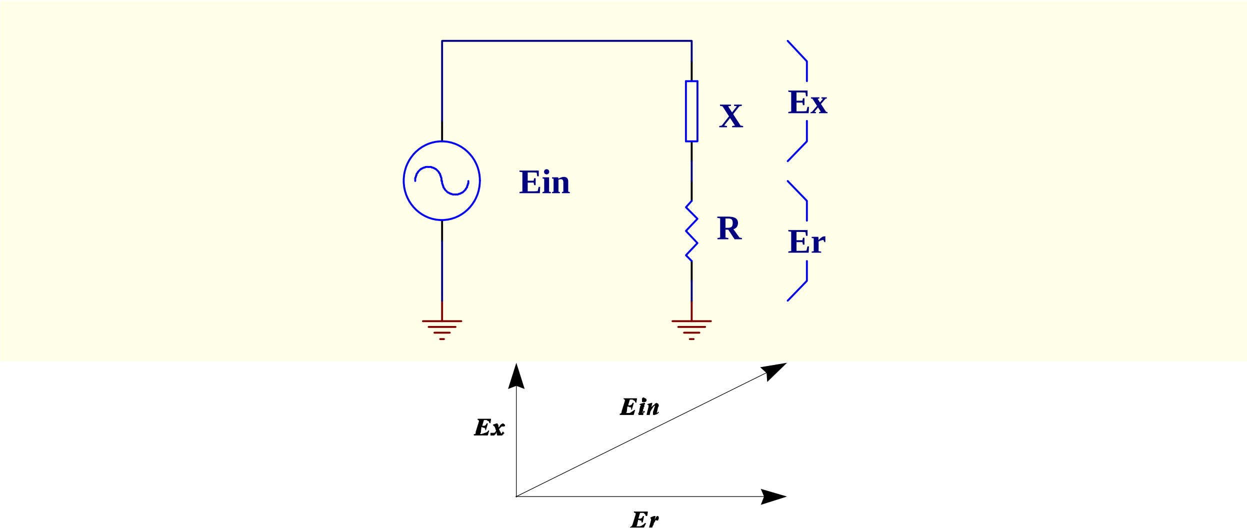

Fig. 3
Voltage Phasor Relationships

Note that in the above representation the phase of **Er** was assumed to be zero. Because the Voltage is always in phase with the current in a resistance and Ohms law applies in phasor form (Equation 1), the impedance vector diagram (Fig. 4) is similar to Fig. 3.

$$E = IZ \qquad \textbf{(1)}$$

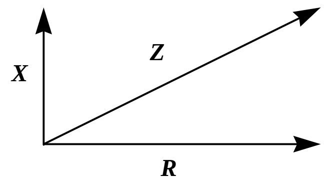

Fig. 4
Impedance Phasor Relationships

Note that the current has the same phase and magnitude everywhere in the circuit.

When the EMAT impedance **Ze** is added to the sense resistor **Rs**, the phasor diagram is given by Fig. 5.

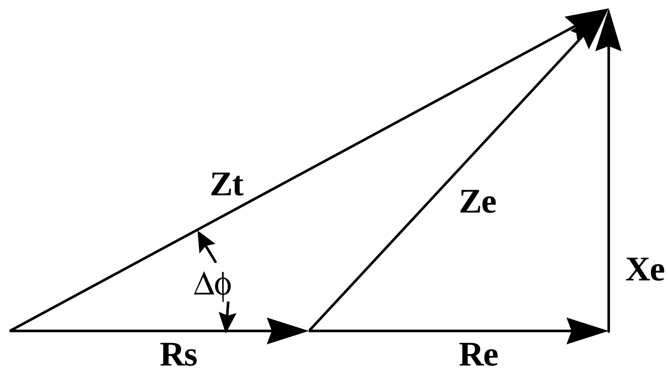

Fig. 5
Impedance Phasor for EMAT/Sense Resistor Network

The Voltage phasor is shown in Fig. 6. Note that in the Voltage diagram the phase of the current is assumed to be zero. If it is not , the Voltage diagram will rotate about the origin. However, the phase relationships between the elements will remain the same.

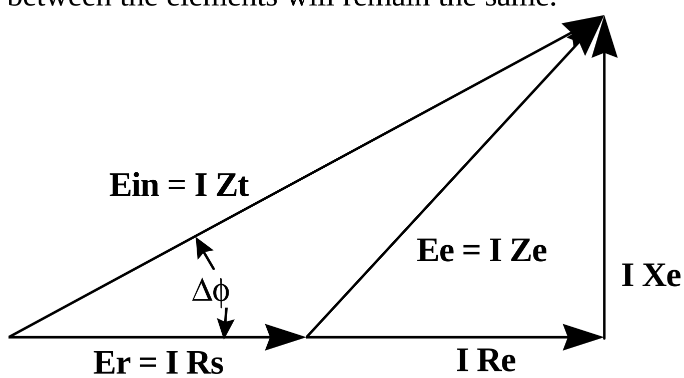

Fig. 6
Voltage Phasor for EMAT/Sense Resistor Network

Using the Ritec RAM, measurements of **| Ein |**, **Φin**, **| Er |**, and **Φr** may be easily obtained. The following relations for the EMAT reactance **Xe** and resistance **Re** are obtained from the phasor diagram.

$$Xe = \frac{|Ein|}{|Er|} Rs \sin \Delta\Phi \qquad \textbf{(2)}$$

$$Re = \frac{|Ein|}{|Er|} Rs \cos \Delta\Phi - Rs \qquad \textbf{(3)}$$

To accomplish an impedance measurement:

1) Connect as shown in Fig. 1.

2) Turn on the RAM and select the frequency which should be the same as the operating frequency of the EMAT.

3) Set the RF burst width. It is a good idea to use more than 10 cycles.

4) Observe the *RF Burst Monitor* on an oscilloscope and adjust the amplitude for ~ 100 Volts peak-to-peak.

5) Set the integrate delay to zero and the width to slightly more than the burst width.

6) Set the receiver gain to 22 dB.

7) Set the selector switch to examine **Ein** and observe the receiver monitor output on an oscilloscope. If it is greater than 100mV peak-to-peak, reduce the power output of the gated amplifier.

8) In *Setup 2* of the RAM software there is a button to *Examine Levels*. *Examine Levels* and adjust the integrate rate as high as possible without over driving the integrator. No level should exceed 4.5 Volts.

9) Set averaging to >10.

10) *Examine Levels* and record **| Ein |** and **Φin**.

11) Set the selector switch to examine **Er** and without changing gain or integrate rate examine levels and record **| Er |** and **Φr**.

10) Calculate **ΔΦ**, **Xe**, and **Re** using equations 2 and 3.

> Note: The RAM software calculates the phase angle from $\mathbf{\Phi_{REFERENCE} - \Phi_{SIGNAL}}$. In order to obtain the sign usually used in phasor diagrams, the sign of the angle obtained in Setup 2 should be changed. Thus **ΔΦ = -(Φt - Φr)**. If **ΔΦ** approaches 0 or π/2, **Rs** should be changed to a value closer to **| Ze |** and the procedure repeated. This will minimize measurement errors.

These values may then be used to determine the matching network parameters.

Example

A magnetostrictive surface wave EMAT designed to operate at 500 kHz was measured with a RAM-10000 and chosen as a typical example. The results are as follows:

F = 500 kHz Pulse Width = 10 cycles

Trial 1

Rs = 16.6 Ohms
| Er | = 3.396 **Φr = 2.894 radians**
| Ein | = 4.386 **Φin = 2.371 radians**
$\Delta\Phi = -(2.371 - 2.894) = 0.523$ **radians**
Xe = 10.7 Ohms
Re = 1.97 Ohms

Trial 2

Rs = 8.19 Ohms
| Er | = 1.897 **Φr = 2.906 radians**
| Ein | = 3.439 **Φin = 2.101 radians**
$\Delta\Phi = -(2.101 - 2.906) = 0.805$ **radians**
Xe = 10.7 Ohms
Re = 2.1 Ohms

Trial 3

Rs = 3.89 Ohms
| Er | = 0.969 **Φr = 2.901 radians**
| Ein | = 3.064 **Φin = 1.858 radians**
$\Delta\Phi = -(1.858 - 2.901) = 1.043$ **radians**
Xe = 10.63 Ohms
Re = 2.3 Ohms

The results show a very small change in the reactance value as the sense resistor is changed but a significant change in the calculated value of the EMAT resistance. Theoretically, a $\Delta\Phi$ value of $\pi/4$ (0.785 radians) should give the most reliable result. Therefore, the data with Rs equal to 8.19 Ohms should be chosen and the inductance of the EMAT calculates as 3.4 μH with a series resistance component of 2.1 Ohms.