TECH TIME

Helpful tips for the Avionics Technician

BY AL INGLE

Last month the electrical pickoffs from a gyro were reviewed and how, through transformer action, an amplitude/phase varying signal can effectively represent the attitude of an aircraft. One unintended consequence of this transformer action is a phase shift between the excitation or reference signal and the resultant output. The phase shift is important and must be dealt with due to the potential errors it can create when attitude signals are being processed by the computer. A little background theory is in order.

In a purely resistive circuit, the current and voltage are in phase with one another. In other words, as the voltage increases, the current increases and as the voltage decreases, the current decreases as:

$$I = E / R$$

Where I = current in Amps, E = Voltage in Volts and R = resistance in Ohms. This is classic ohm's law.

However, where the circuit has an inductive or capacitive component, the voltage and current no longer follow one another in a linear fashion. Those with previous electronics training may remember the mnemonic: ELI the ICE man. This is an easy way to remember that in an inductive circuit (L) the voltage leads the current, whereas in a capacitive circuit (C) the current leads the voltage. In a purely inductive circuit, the current lags the voltage by 90° and in a capacitive circuit the current leads the voltage by 90°. See Figures 1, 2, 3 below:

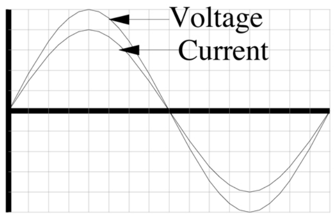


Figure 1
Purely Resistive Circuit:
Current and Voltage are
In Phase

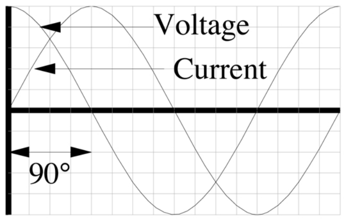


Figure 2
Purely Inductive Circuit:
Current Lags Applied
Voltage by 90°

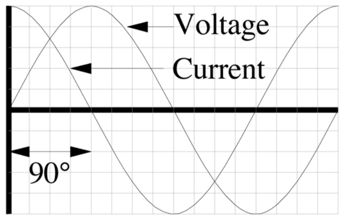


Figure 3
Purely Capacitive Circuit:
Current Leads Applied
Voltage by 90°

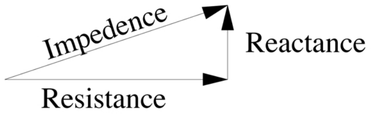
Impedance, Z, is the total opposition to current flow offered by a circuit with both resistance and reactance (AC resistance). It is measured in ohms and may be calculated, like its DC counterpart, by using Ohm's law:

$$Z = E / I$$

Where Z = total DC resistance and AC reactance in Ohms, I = current in Amps, E = Voltage in Volts

The impedance of a series resistive-inductive circuit is equal to the square root of the sum of the squares of resistance (R) and reactance (X_L). Impedance also may be thought of as a vector sum of the resistance and reactance vectors at right angles to one another. See below:

$$Z = \sqrt{R^2 + X_L^2}$$ **or**



Which bring us to phase shift. If a circuit is purely resistive, the phase shift (□) between the source voltage and circuit current is zero. If the circuit is purely inductive, voltage leads current by 90º ; the phase shift is therefore +90º. If the resistance and inductive reactance are equal, the phase shift is 45º. The phase shift in an inductive and resistive circuit is the degrees of lead between the source voltage (V_S) and the current (I). Mathematically this is expressed as:

$$\bullet = \arctan X_L / R$$

As the current is the same in both the inductor and the resistor in a series circuit, the voltage drops across the inductor and resistor are directly proportional to reactance and resistance. The phase shift can be calculated by measuring the voltage drop across the inductor (V_L) and resistor (V_R):

$$\bullet = \arctan V_L / V_R$$

Putting this theory to practice, the inductive reactance of the transformer in an autopilot gyro causes the voltage on the secondary to lead the current in phase. To compensate for this, capacitors are typically added to the secondary windings to retard the voltage with respect to current so that the reference or excitation signals are again in phase with the signals being processed by the autopilot. This is important for the following reason:

To demodulate the attitude signal, the phase of the incoming signal from the gyro is compared with the excitation or reference. If it is in phase the aircraft may by banking right or climbing or yawing in one direction, and if the signal is out of phase, the opposite conditions are occurring. This is cut and dry. But throw in a phase error and now the computer cannot accurately determine the *amplitude* of the signal because it is being reduced by the amount of phase error that exists. See Figures 4 through 7 below:

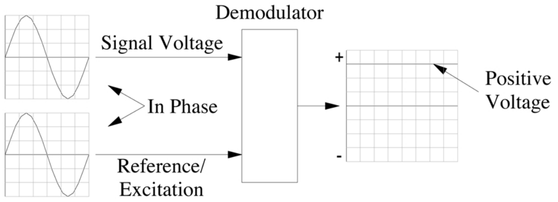


Figure 4

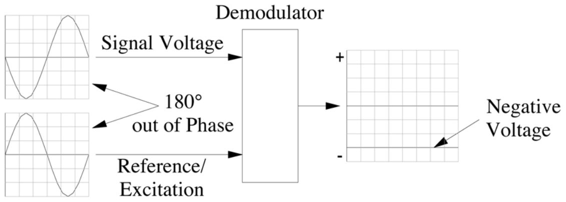


Figure 5

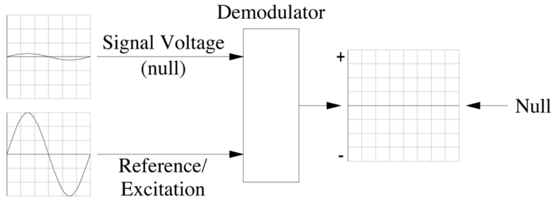


Figure 6

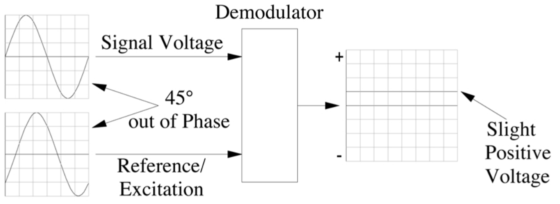


Figure 7

Understand that the attitude signals from a gyro, when measured with a voltmeter or scope, only show the amplitude – not the phase error that exists. This is why many General Aviation autopilots must be flown and adjusted when a gyro has been replaced. This compensates for gyro alignment and phase errors. In the case of the Bendix/King KFC 200, the KI 256 attitude indicator is tested and adjusted not solely for its signal output, but for the resultant DC voltage using the same demodulator circuitry found in the KC 295 autopilot computer. This insures that the phase shift has proper compensation. What would be the symptoms of an autopilot that had a gyro that produced the requisite mV / º , but had excessive phase error in Roll? In Pitch? In Yaw?

Next Month: More Autopilots, and the answers to the above questions.