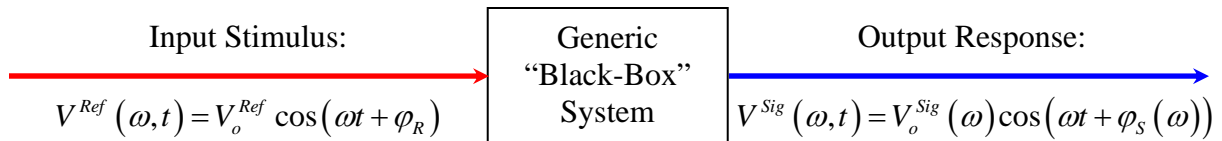


## Measurement of Complex Sound Fields – Part 2:

### The Use of Lock-In Amplifiers for Phase-Sensitive Measurements of Complex Harmonic Sound Fields

What do Lock-In Amplifiers (*LIA*'s) do, and how do they work?

Consider a “generic” experimental situation where a harmonic (*i.e.* periodic/pure-tone/single-frequency) signal of {angular} frequency  $\omega = 2\pi f$  is used as a “stimulus” to excite a system (*i.e.* input a known signal into an unknown “black-box”). We are interested in measuring the linear, but possibly complex response of the “black-box” system to the input stimulus signal – *i.e.* its “output” signal strength (amplitude) and phase of the output signal relative to the input “stimulus” signal (*aka* the input reference signal). This “generic” situation is shown in the figure below:



A dual-channel LIA is a narrow-bandwidth electronic device that measures/determines the in-phase and 90°-out-of-phase/quadrature amplitude components of the response signal output from a generic “black-box” system relative to a harmonic/pure-tone/single-frequency reference signal input to that system. The generic “black-box” system’s output response signal is:

$$V^{Sig}(\omega, t) \equiv V_o^{Sig}(\omega) \cos(\omega t + \varphi_S(\omega)) \text{ of \{angular\} frequency } \omega = 2\pi f .$$

Note that in general, both the system’s output signal amplitude  $V_o^{Sig}(\omega)$  and phase  $\varphi_S(\omega)$  are frequency-dependent quantities. Whether they in fact are (or are not) depends on the detailed physics associated with how the system’s output signal is actually produced, *i.e.* what the output response signal  $V^{Sig}(\omega, t)$  physically represents.

Note that the in-phase and 90°-out-of-phase/quadrature components of the harmonic output response signal amplitude  $V^{Sig}(\omega, t)$  are defined relative to a reference/input sine-wave of the same frequency  $f$ :

$$V^{Ref}(\omega, t) \equiv V_o^{Ref} \cos(\omega t + \varphi_R) \text{ of \{angular\} frequency } \omega = 2\pi f$$

Note further that {here} the reference/input signal’s amplitude  $V_o^{Ref}$  and {absolute} phase  $\varphi_R$  are both constants, *i.e.* time-independent.