Do You Know Where Your Radios Are? Phase-Comparison Direction Finding

Remember jumping on a trampoline as a child and "stealing the bounce" of a friend? A perfectly timed jump would create the destructive interference necessary to bring the unfortunate jumper to their knees. Sometimes, you would try "giving a bounce," using constructive interference to send your friend much higher than they could have made it on their own.

This behavior was observed in waves long before your experiments on the modern trampoline and has found its way into many applications. In 1905, Karl Ferdinand Braun showed this property could actually be used to enhance a radio transmission in a given direction by using two or more antennas. Since then, applications such as beamforming; multiple input, multiple output (MIMO) communications; and direction finding (DF) have all benefited from this effect.

Figure 1 illustrates two transmitters and two possible scenarios of a signal source creating constructive and destructive interference at the receiver with the phase shown in the simplified polar plots. In beamforming applications, a delay in the transmission (phase change) from one of the sources will steer the direction of highest RF intensity, controlling the direction of transmission.

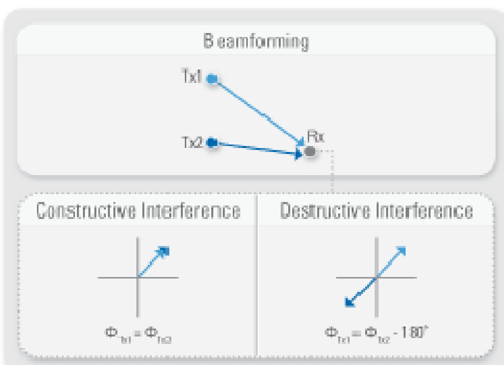

Figure 1

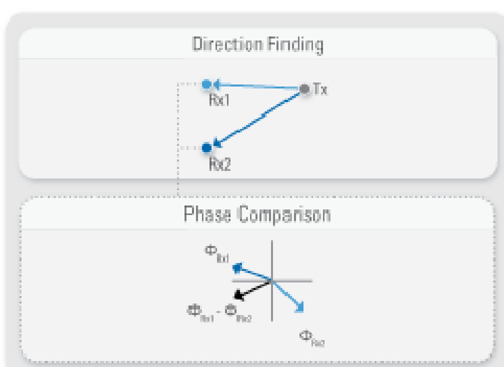

Figure 2

In Figure 2, receivers are used to measure the difference in phase of a signal received by two different paths. Using this phase comparison, you can detect the direction from which the transmission originated, also known as the direction of arrival.

Technically, this should also apply to the trampoline example. If two jumpers acted as stationary observers to a third jumper, it would be theoretically possible for them to detect the location of the third jumper solely based on the arrival time of the wave crest created from each bounce. Even though this may not be practical on a trampoline, detecting the direction of an RF transmission in this way is possible using the right tools and techniques.

Constructing a Direction Finder

To construct a basic phase-comparison direction finder, you need multiple antennas, the ability to measure the phase difference between the received signals, and then some math. You can satisfy the first requirement by adding additional analyzers to the system, but accurately measuring the difference in phase between two signals is more challenging. To compare the phase difference between two measurements, you must precisely know the phase differences between each oscillator used along the downconversion path from RF, as well as the time difference between multiple records from the analog-to-digital converters (ADCs).

Figure 3 shows a solution using two NI PXIe-5663E vector signal analyzers (VSAs) sharing a common local oscillator (LO) for downconversion from RF and a 10 MHz reference clock.

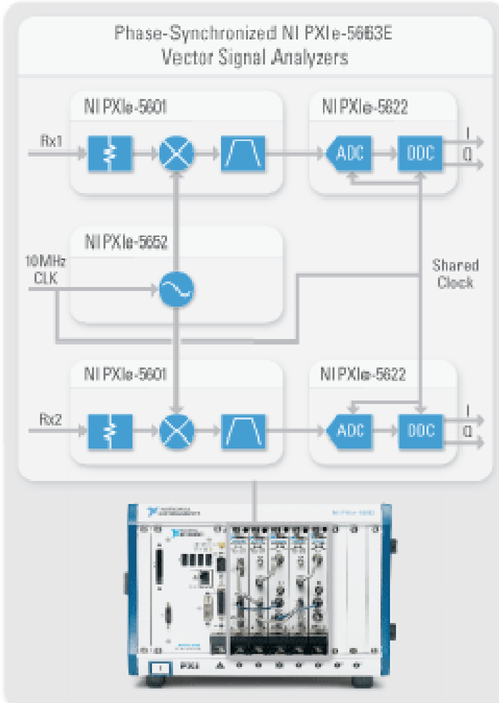

Figure 4

The software-defined PXI platform makes this approach possible, and each NI PXIe-5663E consists of three modular instruments: the NI PXIe-5652, NI PXIe-5601, and NI PXIe-5622. Cascading a common LO between VSAs eliminates the difference in phase noise introduced when each analyzer uses its own LO and the resultant phase measurement error. By sharing a common 10 MHz reference between VSAs, you can synchronize the acquisition triggers of the ADCs and the numerically controlled oscillators used for digital downconversion to baseband. By synchronizing each stage of conversion from RF to baseband, you can accurately compare phase measurements between multiple signals.

With two phase-coherent analyzers, you have the ability to accurately measure any phase difference between the two RF channels and apply it to direction-finding applications. For example, a two-way family radio from Motorola – the T5000 Talkabout – is used as a transmitter at 462.56 MHz along with a pair of general-purpose ultra high frequency (UHF) telescoping antennas connected to two NI PXIe-5663E VSAs. By positioning the antennas 32.3 cm (one half-wavelength) apart, you can expect the phase difference to be 180 degrees when the antennas share a line of sight to the receivers and the phase difference to be zero degrees when the transmitter is equidistant from both antennas.

By setting the radio to channel one, you can tune the VSAs to the carrier frequency of 462.56 MHz and begin to continuously acquire I and Q samples to extract the phase. Verify the zero and 180 degree cases by observing the difference between the phase measurements of the VSAs. Lastly, solve for the intermediate cases.

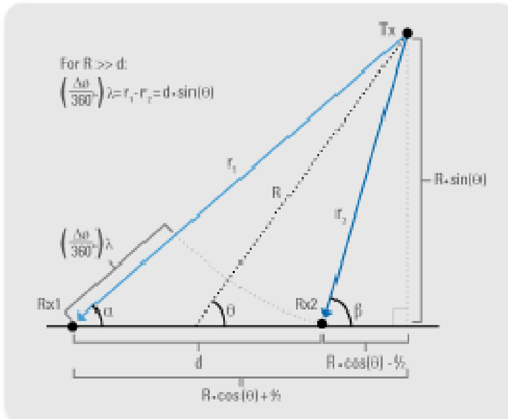

Figure 4

As illustrated in Figure 4, the goal of a direction finder is to solve for θ. Even though this system can be solved for all values of *R* and θ for a given transmission, the math is greatly simplified if we assume that *R* is much larger than *d*, which is a valid approximation for most signals of interest. This assumption then reduces the system to the following equation:

$$\left(\frac{\Delta\phi}{360°}\right)\lambda = r_1 - r_2 = d \cdot \sin(\theta)$$

Knowing the frequency of interest, the distance between the antennas, and the difference in the measured phase, you can solve for the corresponding values for θ. For example, measuring a phase difference between two analyzers of 58 degrees would translate to a θ of 71.2 degrees where as a phase difference of -121 degrees would yield a θ of 132.2 degrees.

Benefits of Phase-Synchronized Instruments

Direction finding is only one of many applications that benefit from phase-coherent analysis and generation. MIMO-based protocols such as 802.11n, WiMAX, and Long Term Evolution (LTE) can significantly increase data rates using these techniques to accurately distinguish between multiple broadcast signals that differ by a spatial signature created by the path traveled from the transmitter to the receiver. With the flexibility of the modular PXI platform, you can prototype and test these types of unique systems and deliver them to market faster than ever before.

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