③ Electronics for Interferometers Using Single-Frequency Lasers

To compute a simple displacement from a homodyne interferometer, a quadrature decoder is needed to both count fringes and generate direction - essentially similar to the function of a the quad-A-B output of a linear or rotary encoder. And for basic measurements, it doesn't need to be much more complex than this, at least in principle.

Quadrature Decoders for Homodyine Interferometers

Many approaches can be used to generate displacement signals in homodyne interferometers. A search on the Internet will return dozens of complex convoluted schemes that may be appropriate for research projects, but not those that are used most often in commercial systems - which are usually quite simple. The goal of a quadrature decoder in a homodyne interferometer is accept the combined REF and MEAS otherogonally linearly polarized components from the interferometer optics and to generate a pair of electrical signals shifted by 90 degrees with respect to each-other to be used to compute the position and direction of motion of the "Tool". Interferometer Using Single Frequency HeNe Laser shows the overall organization with one specific type of quad sin/cos decoder. The same type of quadrature signals are used in common optical rotary or linear encoders but here they depend on the interference of light. For metrology applications, one of the optical components is generally fixed and called "REF" (reference) while the other is the return from the Tool and called "MEAS" (measurement). As noted above, REF and MEAS are linearly polarized and orthogonal, aligned vertically and horizontally, though which is which depends on the specific implementation. The only effect of swapping them (with everything else fixed) is to flip the sign of the motion direction. And for differential measurements, REF will also be changing. The same decoders may also be used in other applications like Ring Laser Gyros (RLGs) where both the CCW (counterclockwise) and CW (clockwise) beams are orthogonally polarized. Then REF and MEAS are replaced with CCW and CW. However, for most RLGs, both beams have the same polarization. So one will need to have its polarization rotated by 90 degrees using a Half WavePlate (HWP) at 45 degrees before merging in the NPBS.

Basic Homodyne Laser Interferometer Quadrature Decoders shows several possible schemes. These all depend on using a Quarter WavePlate (QWP) to shift the phase of the horizontal and vertical polarized components so that the resulting signals differ by 90 degrees in phase. Several of these schemes have been found in commercial homodyne optical receivers as noted. All should produce similar results except possibly for the sign of the phase shift between A and B (+90 or -90 degrees). Types 1 and 2 are essentially equivalent so there's no reason not to use Type 1 as it's simpler.

Type 3 has the benefit that the QWP and LP at 45 degrees are exactly what are present in LCD screen contrast enhancing circular polarizing sheets. These are really inexpensive and simplify assembly by not requiring a separate and possibly delicate and/or expensive QWP. Enough CP material to construct several dozen of these decoders is under $3 on eBay. ;-) The alignment even works out so that they can be cut up into tiny rectangles all aligned with the edges. While arbitrary adjustment of the phase is a bit more limited with the Type 3 decoder, there will probably be enough range to get to 90 degrees by fine tuning the angle of the CP with the piece of QWP facing the beam before glueing. If not, a piece of almost any clear household plastic - or even the protective film that comes with the CP sheets - can be used in front of the B photodiode to adjust it. In fact, both PDs can have LPs (only) at 45 degrees glued to their faces and a plastic sheet oriented in front of one to provide a precise 90 degree phase shift and perfact quadrature behavior.

In short, it's almost trivial to do this, but then there would be no way to get those convoluted schemes published. ;-)

Whenever the orthogonal REF and MEAS aligned with the X and Y axes are passed through a QWP at 45 degrees, the result is counter-rotating field vectors so that the relative phase can be tuned by adjusting the angle of the LP and thus the precise phase shift between Channels A and B can be fine tuned. This would be of importance if taking advantage of all the state changes to multiply the basic number of counts by a factor of 4, and then to analyze the actual waveforms for interpolation to achieve even higher resolution.

In the diagram, the Intensity channel generally present in these systems is NOT shown since it would be identical for all of them with just a non-polarizing beam-splitter providing a fraction of the total power to a photodiode. The Intensity signal is needed to keep track of the actual signal level to be used in interpolation calculations and to compensate for the normal decline in laser power with use and effects of alignment and/or contamination of the interferometer optics. Also, the precise sign of the angles of the QWPs in the diagram may not agree with the actual implementation since it's not straightforward to determine these from simple tests. And there could also be (offsetting) differences among specific models of systems from the same manufacturer. In other words, your mileage may vary and adjustments may be required to get these to work as desired in an experimental implementation. ;-)

In attempting to visualize what's going on, think of REF as a fixed sinusoid with MEAS being similar but shifting with respect to REF as the Tool moves. Then pick the case where they are both in phase and thus identical coming from the interferometer optics figure out what the QWP(s) and LP(s) to do them. Fancy calculations are not needed for an understanding of what's going on. Or if it's easier to visualize of a pair of sinusoidal combs, that works as well. :-)

There are two types of approaches shown in the diagram:

- Types 1 and 2: If the QWP is oriented at 45 degrees, the horizontally and vertically polarized input components are converted to left and right circularly polarized components. This results in a net field vector which rotates in a direction and at a rate determined by the difference frequency (rate of change of phase) between the two components. If the frequencies are identical, the vector sits at a fixed orientation determined by their phase difference. The orientations of the two LPs must differ by 45 degrees so that the phase difference of the photodiode signals differ by 90 degrees. In general, the phase shift between identical counter-rotating left and right circularly polarized beams passing through LPs will be twice the difference in the orientation of the LPs.

- Type 3: An LP is placed at +45 or -45 degrees in front of the Channel-A PD. The result is a interference signal at a 0 degree phase shift. A QWP followed by an LP rotated by 45 degrees from its optical axis is placed in front of the Channel-B PD for the signal with a 90 degree phase shift. The diagram shows an orientation of 0 degrees for the QWP, but remarkably, it can actually be at any angle as long as the 45 degree relationship with its LP is unchanged. (Why?) The phase difference between Channels A and B cannot be tuned totally arbitrarily with this scheme, but usually adjusting angles or tilts will have enough range to result in near perfect performance even with the CP sheet implementation.

  More dramatic effects can be achieved by adding a second QWP in front of the QWP for the B channel - or even a piece of clear packaging plastic or the protective film from the CP sheet as these are highly birefringent - and adjusting for optimal phase. But how stable such stunts would be is not known. The plastic solutions have very high order retardation and may be very sensitive to temperature.

  Type 3 is definitely the simplest solution if using CP sheet - a pair of these stuck to the PDs aligned with their edges (one flipped) is all that's needed for government work. ;-) It works really well and is nearly foolproof.

One assumption with all of these is that the NPBS does not alter the relative phase of the the optical components (either linear or circular) due to the behavior of its dielectric coating. Being able to compensate for this could be a benefit of Type 2, which places dual QWPs after the NPBS to add additional degrees of freedom in adjustment. So there will be cost trade-offs when selecting among these implementations.

Types 1 and 2 are functionally equivalent. Compared to the third scheme, they can have up to twice the signal amplitude for the same laser power, as well as more flexibility in setting the precise phase shift by simply adjusting the relative orientation of the linear polarizers. So this could be why all the commercial implementations I've analyzed are designed like this.

But Type 3 has the advantage of being easier to understand without visualizing rotating E/M field vectors. ;-) So it was used for my RLG out of expediency since a nearly complete beam sampler assembly was available to repurpose with an NPBS, LPs, and PDs, and a sliver of a QWP just had to be slipped inside of it. ;-) See the section: Sam's Home-Built Ring Laser Gyro 1.

Where there is plenty of laser power and a QWP providing a precise 90 degree phase shift (or where this accuracy doesn't matter), there's no particular advantage to one scheme over the other. And there may be other variations that produce similar signals. However, a Web search for "homodyne decoder" or the like had generally proven pretty useless as what mostly turned up were much more complex obscure convoluted schemes, probably from post-graduate theses or esoteric research projects, that may or may not even be useful for their intended purpose, let alone for basic interferometry. Now that this document other others of mine describing quadrature decoders are on the Web, these searches have a better chance of being useful. ;-)

Two Simple Quad-Sin-Cos Decoders and Scope Display of Reflector Movement shows implementations of the Type 1 and Type 3 versions using a variable attenuator as the NPBS. The reflector is mounted on a mini-woofer driven with a sine-wave from a function generator. The opposite phase shift determined by the direction of movement is clearly visible on my "Continuum Laser Zapped Scope" but a close examination shows that it is slightly more than 90 degrees for the Type 3 decoder. The phase shift can be fine-tuned for the Type 1/2 detectors by rotating either LP while monitoring the detected signals using the scope's X-Y mode. The resulting Lissajous display should be an ellipse with its principal axes aligned with X and Y or a perfect circle if the X and Y sensitivities are adjusted so the sizes are equal. A phase shift of other than 90 degrees will produce an ellipse with its principal axes at an angle. Direction will be indicated by clockwise or counter-clockwise motion of the spot on the scope. Lissajous Display of Quadrature Decoder Signals for Oscillatory Motion - 90 Degrees shows the display when the relative phase is near optimal and Lissajous Display of Quadrature Decoder Signals for Oscillatory Motion - Less than 90 Degrees shows when it's misadjusted.

The simplest way to put these together with bits of the CP sheet uses the adhesive already present on the QWP-side that is to be stuck to something like the PD. For the LP-side where there is no adhesive, 5 minute Epoxy or UV-cure index matching optical cement can be used. The UV-cure stuff ends up being less messy but more expensive. I use Norland 65 UV-cure cement from Thorlabs and a $1 1W 365 nm LED to cure it. No need for the $2,583 UV cure gizmo they sell (or much higher cost for the same thing that dentists buy). ;-) Similar UV-cure cement is also available for replacing smart phone screens and is less expensive.

And one laser manufacturer's Power Point tutorial on homodyne interferometers calls the QWP a "Special Optic". This I assume is to protect their valuable intellectual property from grand theft, as though basic optical components are somehow company proprietary, and they assume their intended audience is too stupid to figure this out. :) Every first-year physics student should know in their sleep that the "Special Optic" is a QWP. ;-)

Micro Measurement Display 2 (μMD2)

μMD2 is an inexpensive system for precision readout of displacement (change in position), angle, straightness, and more in metrology applications. It is designed and optimized for HeNe laser (homodyne) interferometry as well as devices like linear and rotary encoders with Quad-A/B or up/down pulsed signals, but also supports heterodyne applications. It is based on a Teensy 4.0 microcontroller along with a hand-full of other components mounted on the custom SG-μMD2 PCB. Virtually everything is built-in as shown in Typical Homodyne Interferometer Setup using μMD2.

A version that can be replicated based on this approach is now available. The total parts cost for the display electronics excluding the PC should be well under $50. The Teensy firmware and Windows Graphical User Interface (GUI) software are available free for non-commercial or research applications. Laser and interferometer not included. :-) (The GUI is the same one used for μMD1, a similar system for heterodyne interferometers using two frequency lasers.)

See:

- Installation and Operation Manual for Micro Measurement Display 2 (μMD2). Specifications and anything else that may affect the state of the Universe are subject to change without notice. :-)
- μMD1 GUI. This is the actual μMD1 applications software and requires a PC running Windows XP (or later) and MS Net Framework 4.0 (or later). Using the "Test Mode" option, it's possible to simulate the behavior of the most common interferometers without anything attached to the PC. This is the actual application software, lacking only the Teensy 4.0 and its firmware. Save to a file on your PC and run it. Note: This version may not be the latest and is set up for hereodyne interferometers but it will provide the general idea.

And sorry, the "1" and "2" are logically swapped because the system for two frequency lasers was developed first, live with it. ;-)