and the second value

$$I \propto \cos\left(\frac{4\pi\Delta L}{\lambda}\right).$$

Then, as before, one can use the unwrapping arctan function (that obtains an angle in any of all four quadrants) to obtain the displacement as

$$\Delta L = \frac{\lambda}{4\pi}\arctan(Q/I').$$

This modification makes use of frequency components of $I_{PD}$ separate from the original modulation frequency $\omega_m$ applied to the VCSEL diode bias current $I_{BIAS}$. This may reduce the need for filtering and/or isolation of $I_{PD}$ at the original modulation frequency $\omega_m$.

**[0150]** In a still further modification, one can use the form of the Baseband Signal (DC signal component) in the expansion above to obtain an alternative I-component derived by filtering and demodulation at the DC component:

$$I' \propto \cos\left(\frac{4\pi\Delta L}{\lambda}\right).$$

This alternative I-component can then be used with the Q-component above to obtain

$$\Delta L = \frac{\lambda}{4\pi}\arctan(Q/I').$$

**[0151]** The low pass filtering and demodulations just discussed can be further explained in relation to FIGS. **9**A-C and FIG. **10**. FIG. **9**A is a flow chart of a method **900** for detecting skin deformation and/or skin vibration surface, using distance or displacement measurements.

**[0152]** At block **902**, the modulation waveform for the bias current to the VCSEL diode is generated. The generation may involve separately generating a direct current (DC) input signal and a sine wave current input signal with desired modulation frequency $\omega_m$ (in radians), and then summing the two signals to produce $I_{BIAS}$. The two input signals can be generated either by current sources, or from voltage sources that produce $I_{BIAS}$. The generation of the two input signals may initially begin using one or more digital generators, such as digital-to-analog (DAC) converters.

**[0153]** At block **904**, the generated modulation waveform may be filtered to reduce signal frequency components not at the desired modulation frequency $\omega_m$. Such filtering may be a digital filtering applied to a digital sine wave source, or an analog filtering of an analog sine wave current input signal. Filtering may also be applied to the DC signal source before being summed with the sine wave current input signal.

**[0154]** The generated modulation waveform is applied to $I_{BIAS}$, modifying the VCSEL diode's emitted laser light accordingly. Self-mixing interference then may occur due to reflections from the location on the user's head.

**[0155]** At block **906**, a photodetector receives the VCSEL diode's laser light, and a corresponding signal produced. The signal may be a photodetector current, a voltage of the photodetector, or another interferometric property. Further, as explained above, the photodetector may be integrated with the VCSEL diode itself.

**[0156]** Because the bias current of the VCSEL diode was modulated at desired modulation frequency $\omega_m$, it may well be that the received photodetector signal also has a frequency component at $\omega_m$. At block **908**, a scaled version of the modulated form of $I_{BIAS}$ and received photodetector signal may be differenced in a differential filtering to reduce cross-talk or other interferences. The result may be a differenced signal that correlates with the self-mixing interference in the VCSEL diode's laser light.

**[0157]** At block **910**, an I and a Q component of the filtered form of the photodetector signal are then extracted. These extractions may be performed by separate mixing (multiplying) of the filtered form of the photodetector signal with separately generated sinusoidal signals at respective frequencies $\omega_m$ and $2\omega_m$, as discussed above. Alternatively, the modifications discussed above based on using either Q' or I' may be used. The mixed signals are then separately low pass filtered.

**[0158]** At block **912**, the phase of the I and Q components may be calculated using unwrapping arctan function, as described above. An alternative method of obtaining the phase may also be used. At block **914**, the displacement is determined based on the phase, as described above.

**[0159]** FIGS. **9**B-C show two time correlated graphs: **920**, **930**. Graph **920** shows a plot **922** of a bias current $I_{BIAS}$ of a VCSEL diode modulated by a sine wave at a single frequency. The amplitude of the sinusoidal modulation is only for illustration, and need not correspond to amplitudes used in all embodiments. The bias current $I_{BIAS}$ has its sinusoidal variation about a fixed direct current value, **924**.

**[0160]** As a result of the sinusoidal modulation, the output current of a photodetector receiving the VCSEL's self-mixing laser light undergoes a time variation, shown in the plot **932** in the graph **930**. The time axes of graphs **926** and **936** are correlated. The plot **932** illustrates that the output current of the photodetector varies around a fixed direct current value **934**.

**[0161]** The sinusoidally modulated bias current $I_{BIAS}$ and corresponding photodetector current may arise within the circuit shown in FIG. **10**, as now described. Other circuits may be used to implement the time domain I/Q methods as described, and may produce bias currents and respective photodetector currents having respective plots similar to **922** and **932**.

**[0162]** FIG. **10** shows an exemplary circuit block diagram that may be used to implement the third family embodiments. Other circuits may also be used, as would be clear to one skilled in the art. The circuit block diagram of FIG. **10** shows the relationships and connections of certain components and sections; other circuits that implement these embodiments may use more or fewer components. As explained in more detail below, FIG. **10** shows components which generate and apply a sinusoidally modulated bias current to a VCSEL. The sinusoidal bias current can generate in a photodetector **1016** an output current depending on the frequency of the sinusoidal bias and the displacement to the target. In the circuit of FIG. **10**, the photodetector's **1016** output current is digitally sampled and then multiplied with