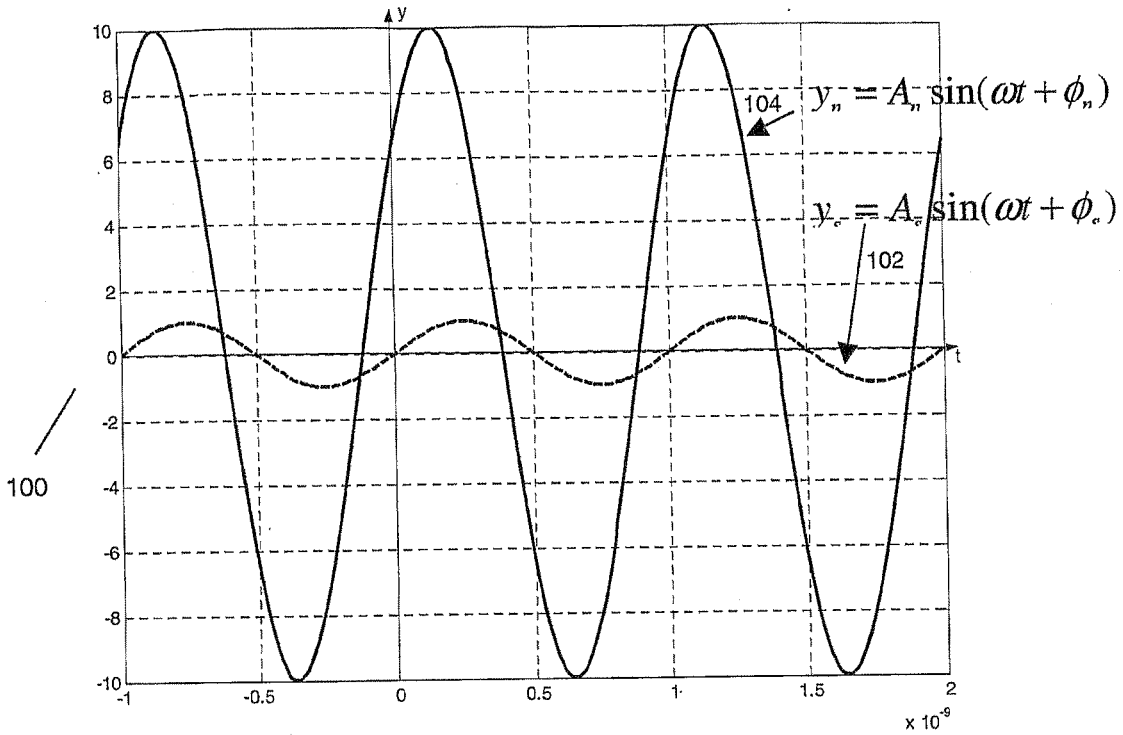

y
10
8
6
4
2
0
-2
-4
-6
-8
-10
-1
-0.5
0
0.5
1
1.5
2
x 10^-9
t
104
$y_n = A_n \sin(\omega t + \phi_n)$
$y_e = A_e \sin(\omega t + \phi_e)$
102
100

**FIGURE 1**

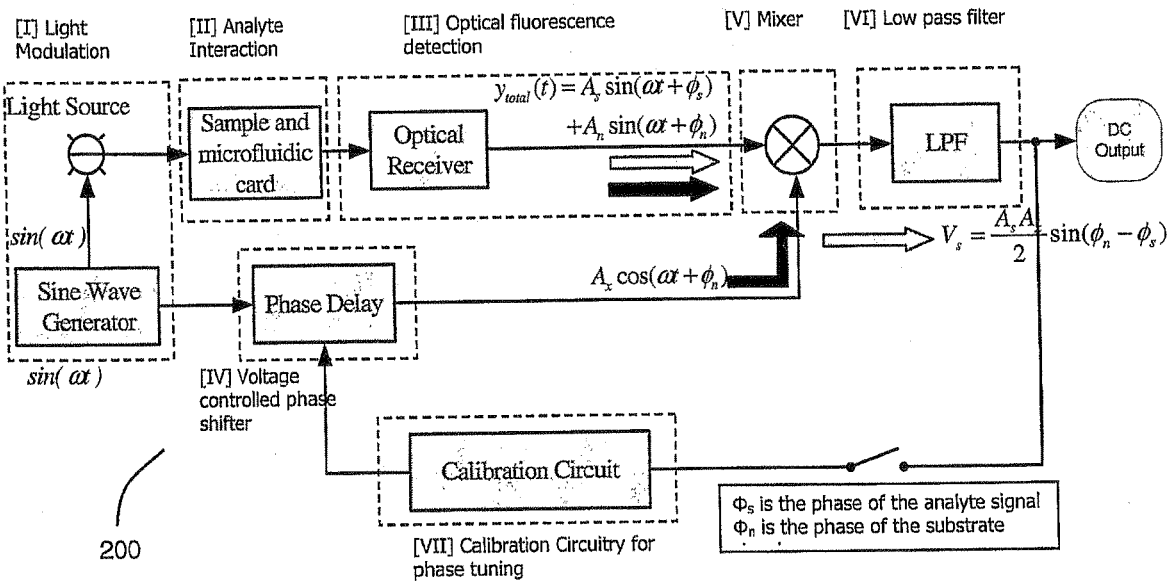

[I] Light Modulation
[II] Analyte Interaction
[III] Optical fluorescence detection
[V] Mixer
[VI] Low pass filter
Light Source
Sample and microfluidic card
Optical Receiver
$y_{total}(t) = A_s \sin(\omega t + \phi_s)$
$+A_n \sin(\omega t + \phi_n)$
LPF
DC Output
$\sin(\omega t)$
Sine Wave Generator
Phase Delay
$A_x \cos(\omega t + \phi_n)$
$V_s = \frac{A_s A_x}{2} \sin(\phi_n - \phi_s)$
$\sin(\omega t)$
[IV] Voltage controlled phase shifter
Calibration Circuit
$\Phi_s$ is the phase of the analyte signal
$\Phi_n$ is the phase of the substrate
200
[VII] Calibration Circuitry for phase tuning

**FIGURE 2**

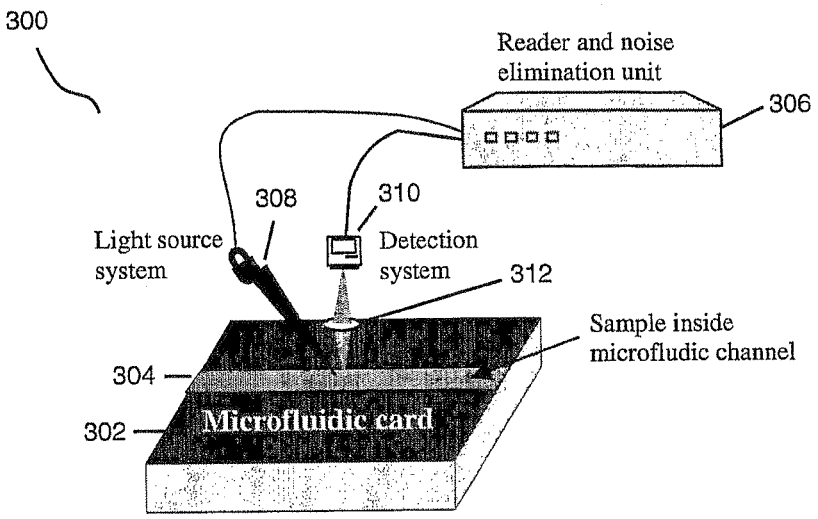

300
Reader and noise elimination unit
306
308
310
Light source system
Detection system
312
Sample inside microfludic channel
304
Microfluidic card
302

**FIGURE 3**

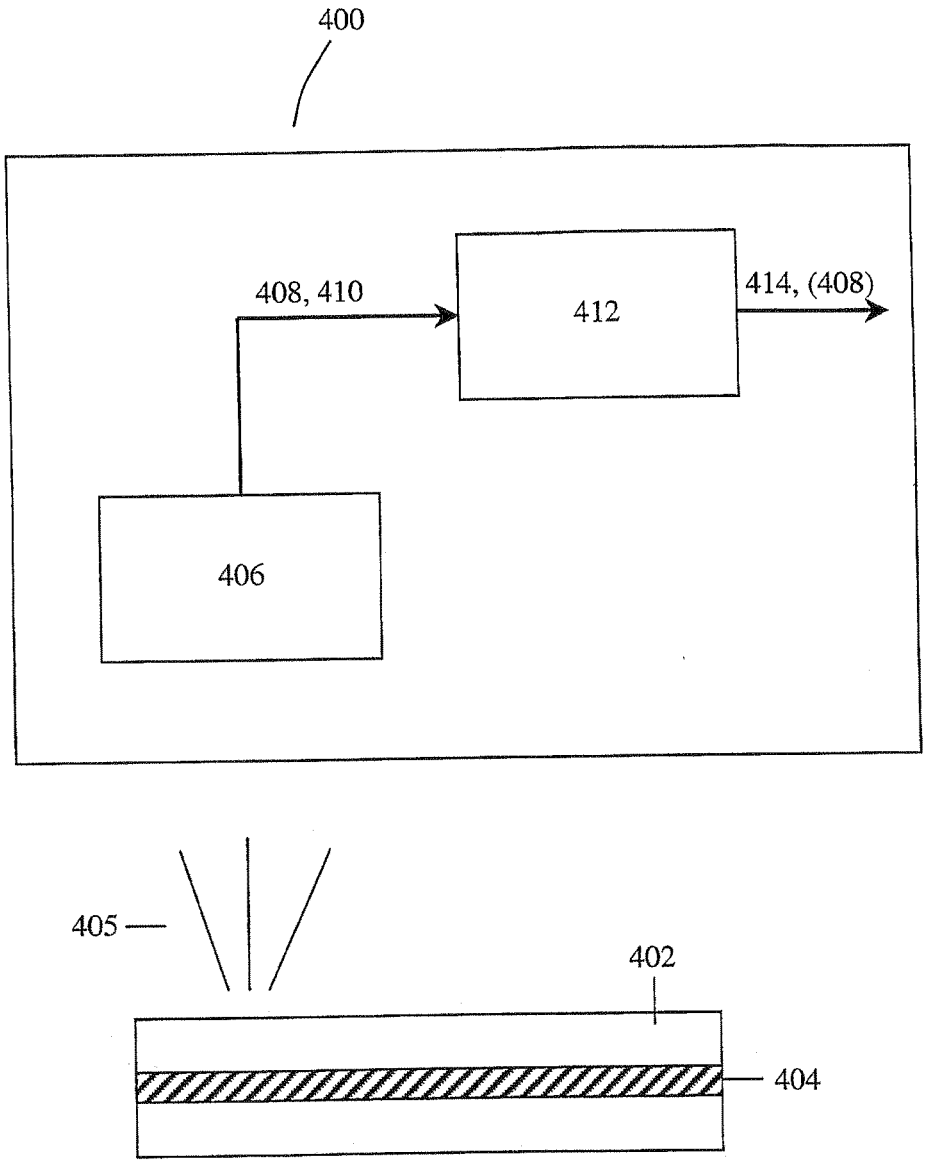



FIGURE 4

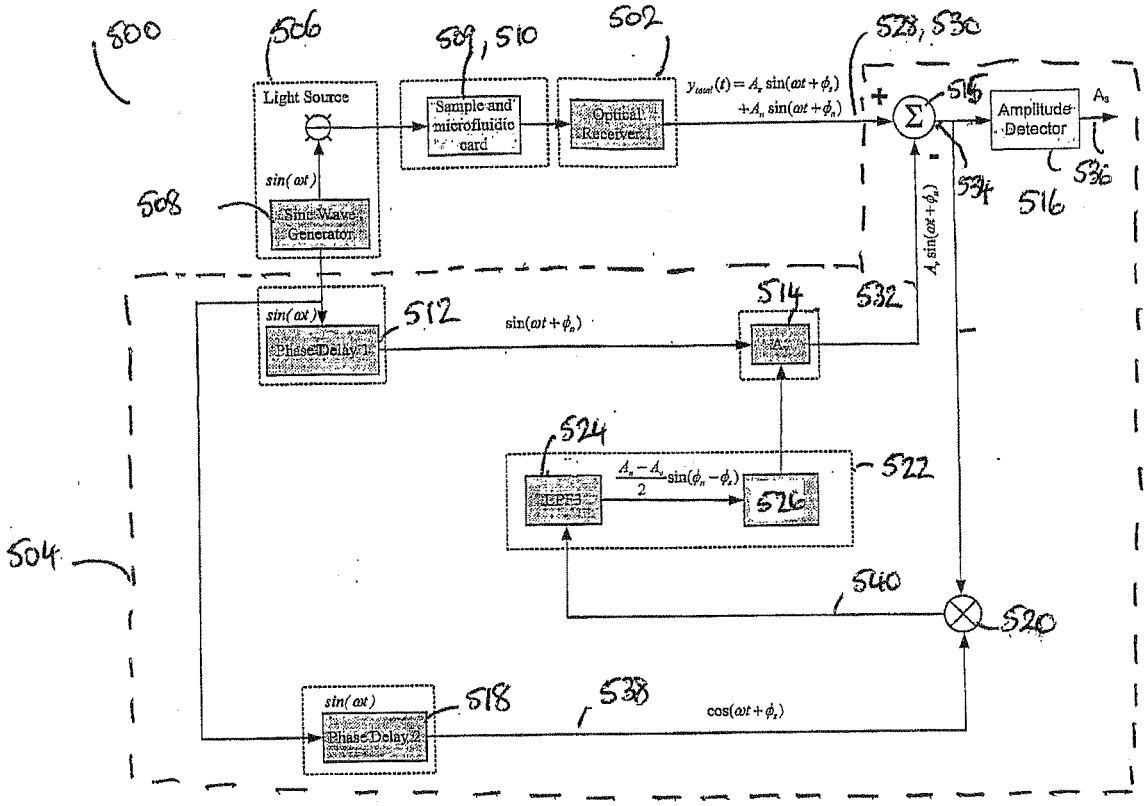

500
506
509, 510
502
528, 530
Light Source
Sample and microfluidic card
Optical Receiver 1
$y_{total}(t) = A_s \sin(\omega t + \phi_s) + A_n \sin(\omega t + \phi_n)$
+
Σ
-
516
Amplitude Detector
$A_s$
534
536
516
sin(ωt)
508
Sine Wave Generator
$A_s \sin(\omega t + \phi_s)$
532
sin(ωt)
512
Phase Delay 1
$\sin(\omega t + \phi_n)$
514
524
$\frac{A_s - A_n}{2}\sin(\phi_n - \phi_s)$
522
LPF1
526
504
540
520
sin(ωt)
518
538
Phase Delay 2
$\cos(\omega t + \phi_s)$

**FIGURE 5**

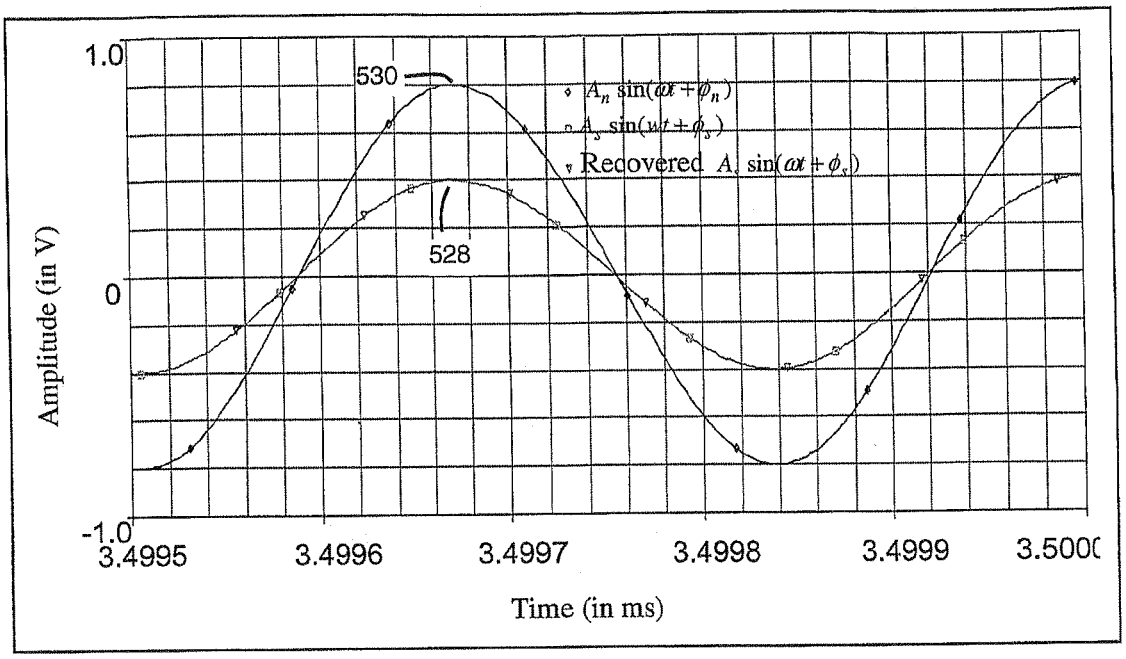

1.0
0
-1.0
530
528
$A_n \sin(\omega t + \phi_n)$
$A_s \sin(\omega t + \phi_s)$
Recovered $A_s \sin(\omega t + \phi_s)$
Amplitude (in V)
3.4995
3.4996
3.4997
3.4998
3.4999
3.500(
Time (in ms)

**FIGURE 6**

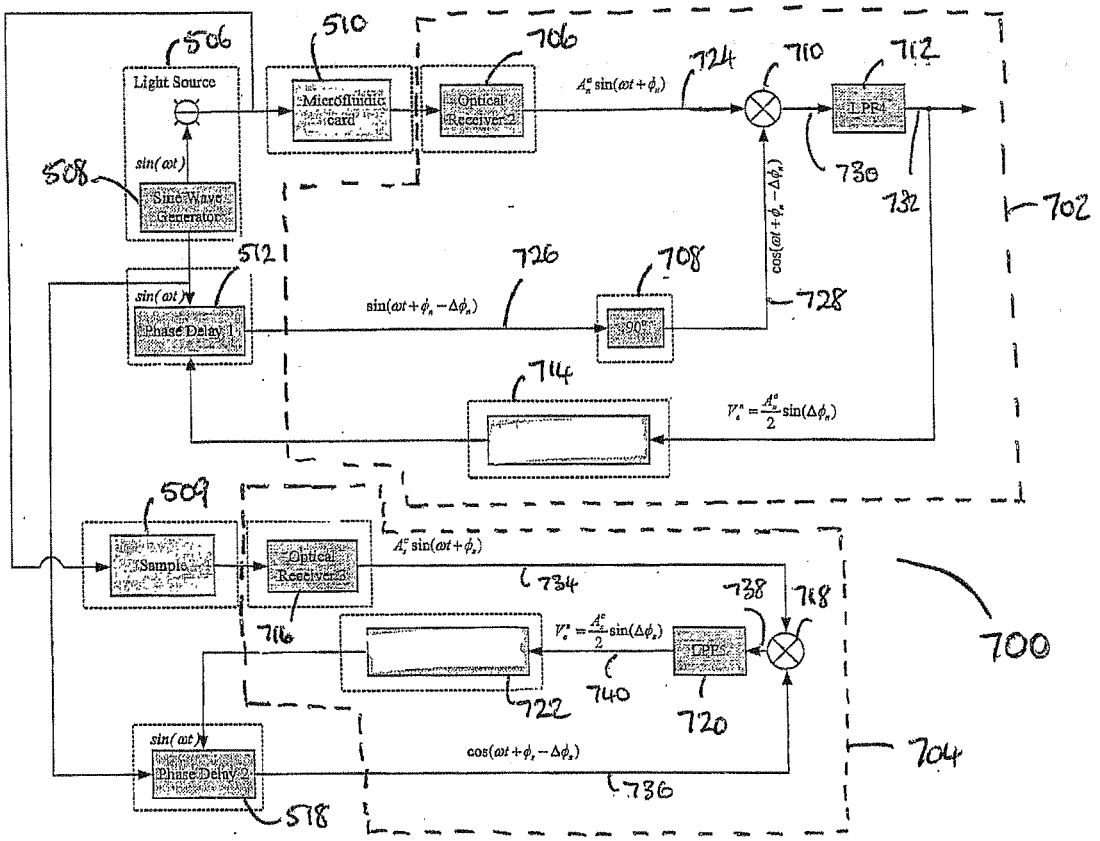

506
510
706
724
710
712
Light Source
Microfluidic card
Optical Receiver 2
LPF1
730
732
702
508
Sine Wave Generator
512
726
708
728
Phase Delay 1
90°
714
509
Sample
Optical Receiver 1
734
738
718
716
DPF1
700
722
740
720
704
Phase Delay 2
736
518

FIGURE 7

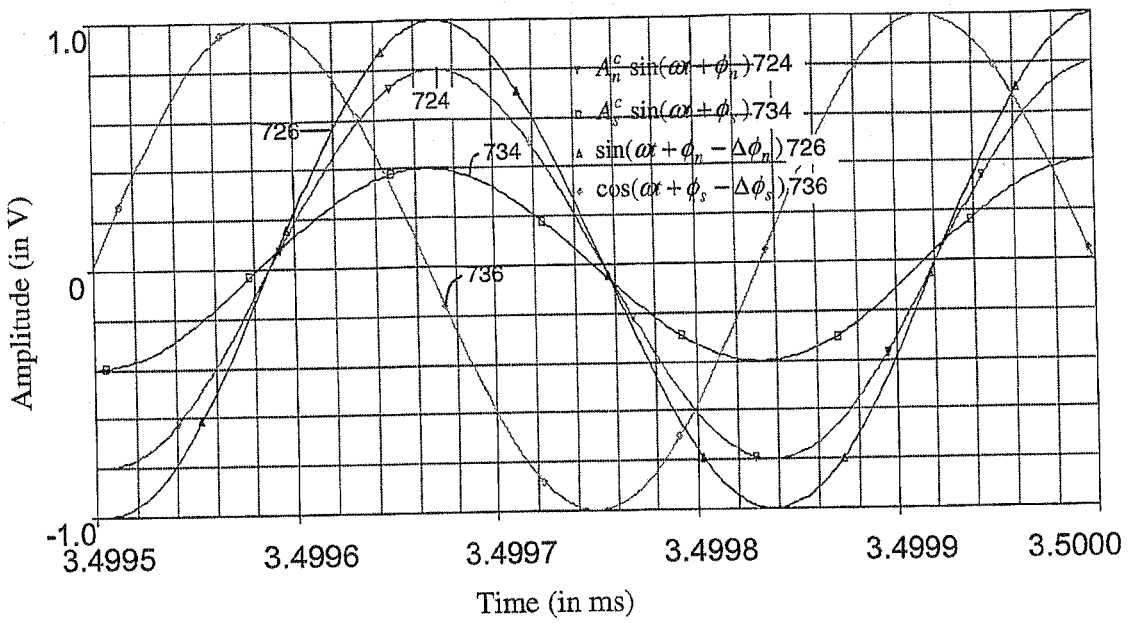

1.0
0
-1.0
Amplitude (in V)
3.4995
3.4996
3.4997
3.4998
3.4999
3.5000
Time (in ms)
$A_n^c \sin(\omega t + \phi_n)$ 724
$A_s^c \sin(\omega t + \phi_s)$ 734
$\sin(\omega t + \phi_n - \Delta\phi_n)$ 726
$\cos(\omega t + \phi_s - \Delta\phi_s)$ 736
724
726
734
736

**FIGURE 8**

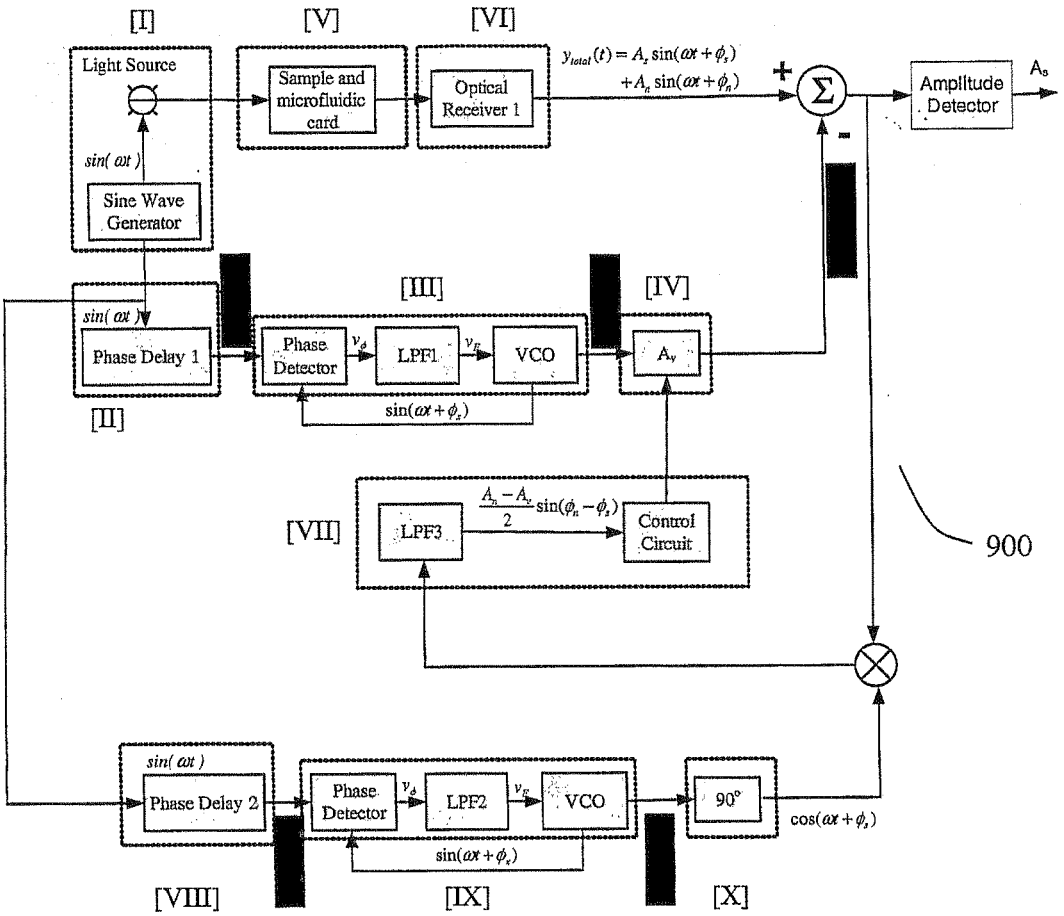

[I]
[V]
[VI]
Light Source
Sample and microfluidic card
Optical Receiver 1
$y_{total}(t) = A_s \sin(\omega t + \phi_s) + A_n \sin(\omega t + \phi_n)$
+
Σ
-
Amplitude Detector
$A_o$
sin( ωt )
Sine Wave Generator
[III]
[IV]
sin( ωt )
Phase Delay 1
Phase Detector
$v_d$
LPF1
$v_c$
VCO
$A_v$
$\sin(\omega t + \phi_s)$
[II]
[VII]
$\frac{A_n - A_s}{2}\sin(\phi_n - \phi_s)$
LPF3
Control Circuit
900
sin( ωt )
Phase Delay 2
Phase Detector
$v_d$
LPF2
$v_c$
VCO
90°
$\cos(\omega t + \phi_s)$
$\sin(\omega t + \phi_s)$
[VIII]
[IX]
[X]

**FIGURE 9**

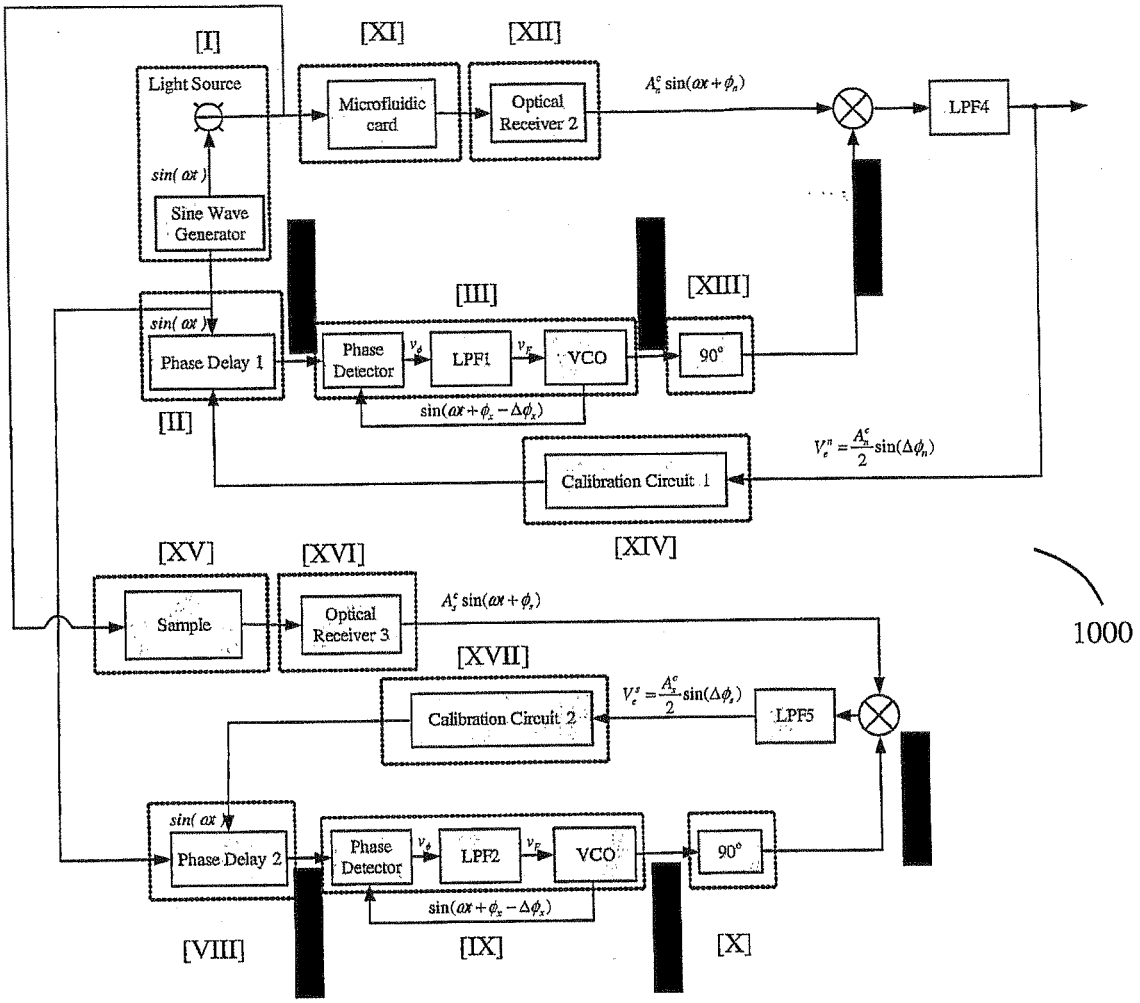

[I]
Light Source
sin( ωt )
Sine Wave Generator
[XI]
Microfluidic card
[XII]
Optical Receiver 2
$A_n^c \sin(\omega t + \phi_n)$
LPF4
[III]
[XIII]
sin( ωt )
Phase Delay 1
Phase Detector
$v_\phi$
LPF1
$v_F$
VCO
90°
$\sin(\omega t + \phi_x - \Delta\phi_x)$
[II]
$V_e^n = \frac{A_n^c}{2}\sin(\Delta\phi_n)$
Calibration Circuit 1
[XIV]
[XV]
[XVI]
Sample
Optical Receiver 3
$A_x^c \sin(\omega t + \phi_x)$
[XVII]
Calibration Circuit 2
$V_e^x = \frac{A_x^c}{2}\sin(\Delta\phi_x)$
LPF5
1000
sin( ωt )
Phase Delay 2
Phase Detector
$v_\phi$
LPF2
$v_F$
VCO
90°
$\sin(\omega t + \phi_x - \Delta\phi_x)$
[VIII]
[IX]
[X]

**FIGURE 10**

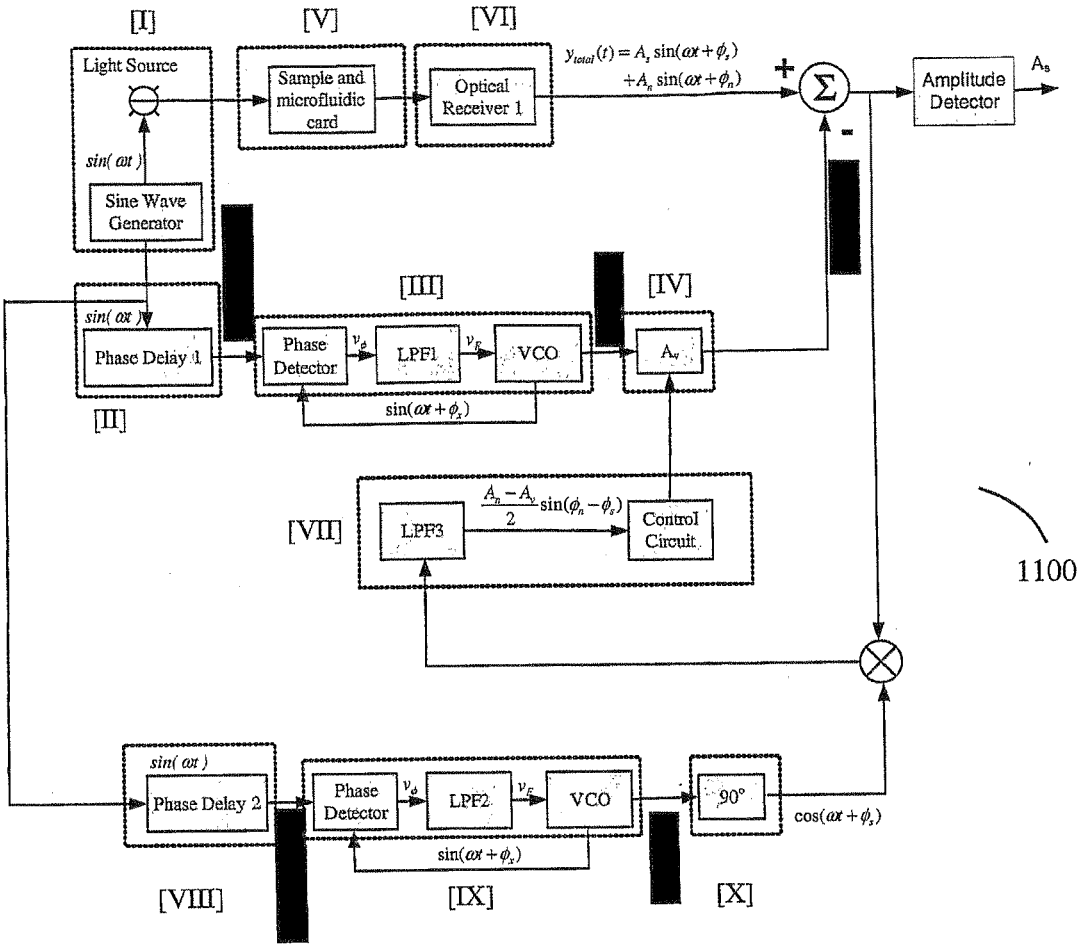

[I]
[V]
[VI]
Light Source
Sample and microfluidic card
Optical Receiver 1
$y_{total}(t) = A_s \sin(\omega t + \phi_s) + A_n \sin(\omega t + \phi_n)$
+
Σ
-
Amplitude Detector
$A_s$
sin( ωt )
Sine Wave Generator
[III]
[IV]
sin( ωt )
Phase Delay 1
Phase Detector
$v_\phi$
LPF1
$v_E$
VCO
$A_v$
$\sin(\omega t + \phi_s)$
[II]
[VII]
LPF3
$\frac{A_n - A_s}{2}\sin(\phi_n - \phi_s)$
Control Circuit
1100
sin( ωt )
Phase Delay 2
Phase Detector
$v_\phi$
LPF2
$v_E$
VCO
90°
$\cos(\omega t + \phi_s)$
$\sin(\omega t + \phi_s)$
[VIII]
[IX]
[X]

**FIGURE 11**

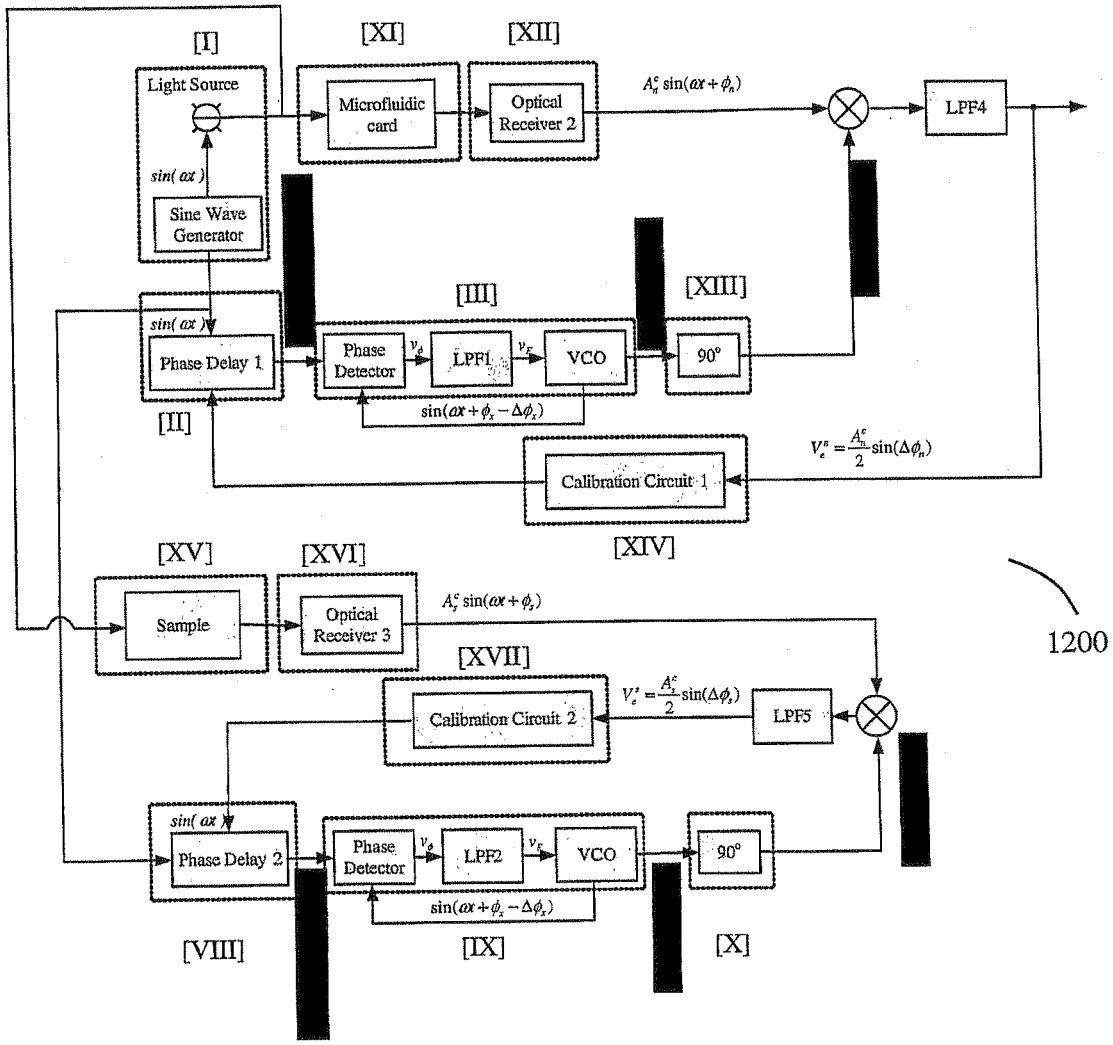

[I]
Light Source
sin( ωt )
Sine Wave Generator
[XI]
Microfluidic card
[XII]
Optical Receiver 2
$A_n^c \sin(\omega t + \phi_n)$
LPF4
[III]
[XIII]
sin( ωt )
Phase Delay 1
Phase Detector
$v_\phi$
LPF1
$v_c$
VCO
90°
$\sin(\omega t + \phi_x - \Delta\phi_x)$
[II]
$V_e^n = \frac{A_n^c}{2}\sin(\Delta\phi_n)$
Calibration Circuit 1
[XIV]
[XV]
[XVI]
Sample
Optical Receiver 3
$A_s^c \sin(\omega t + \phi_s)$
[XVII]
Calibration Circuit 2
$V_e^s = \frac{A_s^c}{2}\sin(\Delta\phi_s)$
LPF5
1200
sin( ωt )
Phase Delay 2
Phase Detector
$v_\phi$
LPF2
$v_c$
VCO
90°
$\sin(\omega t + \phi_x - \Delta\phi_x)$
[VIII]
[IX]
[X]

**FIGURE 12**

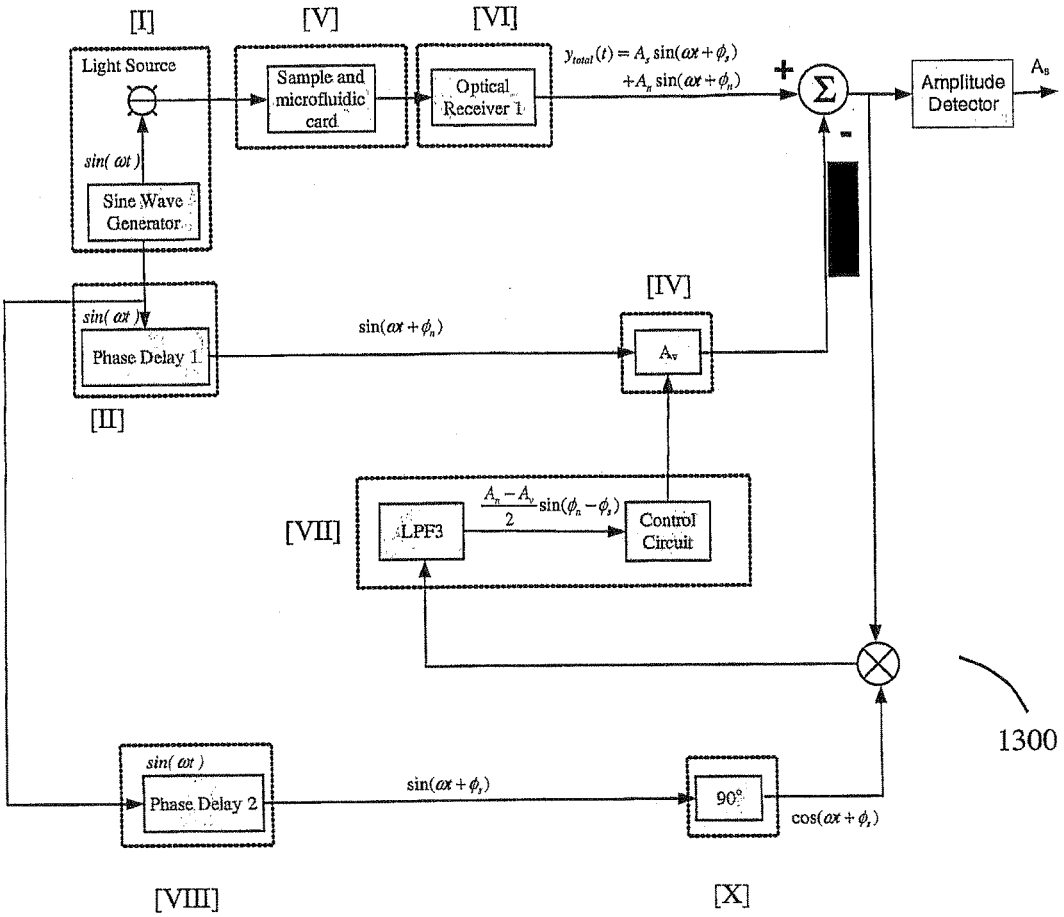

[I]
[V]
[VI]
Light Source
Sample and microfluidic card
Optical Receiver 1
$y_{total}(t) = A_s \sin(\omega t + \phi_s) + A_n \sin(\omega t + \phi_n)$
Amplitude Detector
$A_s$
$\sin(\omega t)$
Sine Wave Generator
[IV]
$\sin(\omega t + \phi_n)$
Phase Delay 1
$A_v$
[II]
[VII]
LPF3
$\frac{A_n - A_v}{2}\sin(\phi_n - \phi_s)$
Control Circuit
1300
$\sin(\omega t + \phi_s)$
Phase Delay 2
90°
$\cos(\omega t + \phi_s)$
[VIII]
[X]

**FIGURE 13**

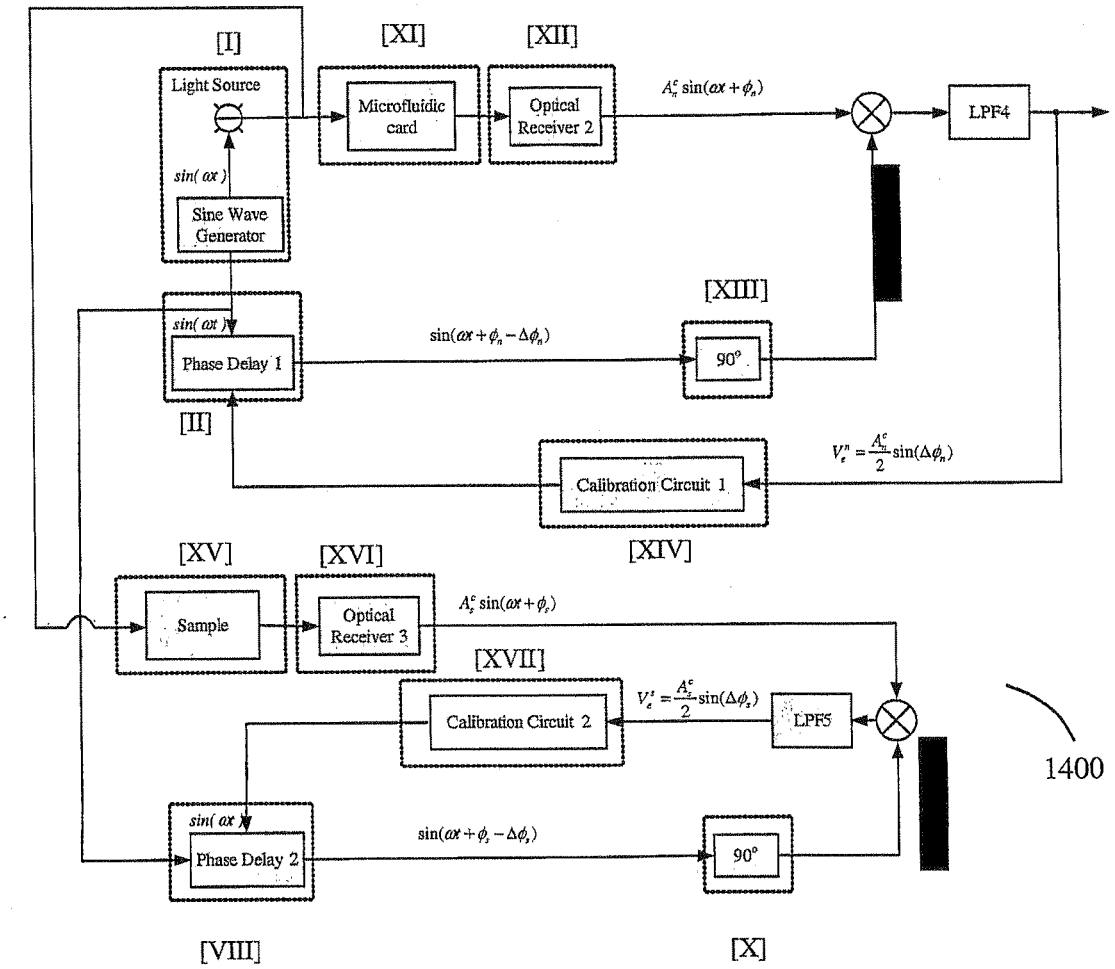

[I]
Light Source
sin( ωt )
Sine Wave Generator
[XI]
Microfluidic card
[XII]
Optical Receiver 2
$A_n^c \sin(\omega t + \phi_n)$
LPF4
[XIII]
sin( ωt )
Phase Delay 1
$\sin(\omega t + \phi_n - \Delta\phi_n)$
90°
[II]
$V_c'' = \frac{A_n^c}{2}\sin(\Delta\phi_n)$
Calibration Circuit 1
[XIV]
[XV]
Sample
[XVI]
Optical Receiver 3
$A_s^c \sin(\omega t + \phi_s)$
[XVII]
Calibration Circuit 2
$V_c' = \frac{A_s^c}{2}\sin(\Delta\phi_s)$
LPF5
1400
sin( ωt )
Phase Delay 2
$\sin(\omega t + \phi_s - \Delta\phi_s)$
90°
[VIII]
[X]

**FIGURE 14**

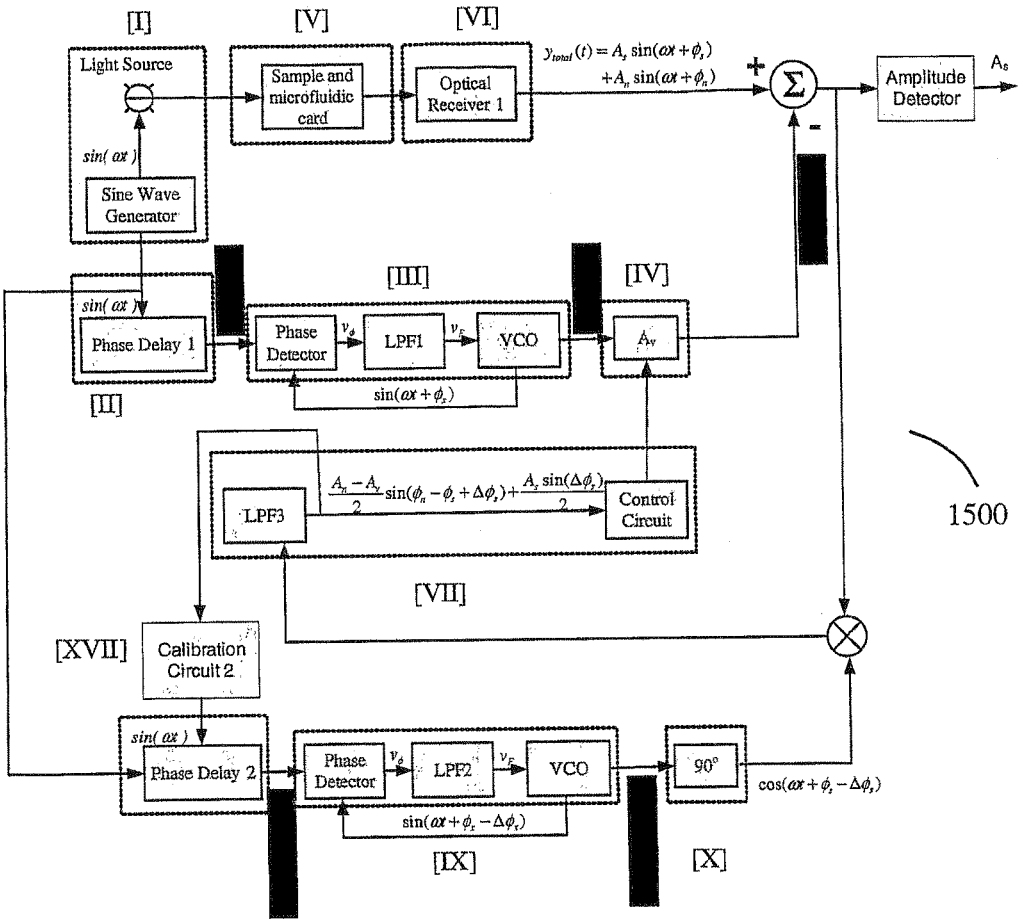

[I]
[V]
[VI]
Light Source
Sample and microfluidic card
Optical Receiver 1
$y_{total}(t) = A_s \sin(\omega t + \phi_s) + A_n \sin(\omega t + \phi_n)$
Amplitude Detector
$A_s$
$\sin(\omega t)$
Sine Wave Generator
[III]
[IV]
Phase Delay 1
Phase Detector
$v_\phi$
LPF1
$v_F$
VCO
$A_V$
$\sin(\omega t + \phi_s)$
[II]
LPF3
$\frac{A_n - A_s}{2}\sin(\phi_n - \phi_s + \Delta\phi_s) + \frac{A_s \sin(\Delta\phi_s)}{2}$
Control Circuit
1500
[VII]
[XVII]
Calibration Circuit 2
Phase Delay 2
Phase Detector
LPF2
VCO
90°
$\cos(\omega t + \phi_s - \Delta\phi_s)$
$\sin(\omega t + \phi_s - \Delta\phi_s)$
[IX]
[X]

**FIGURE 15**

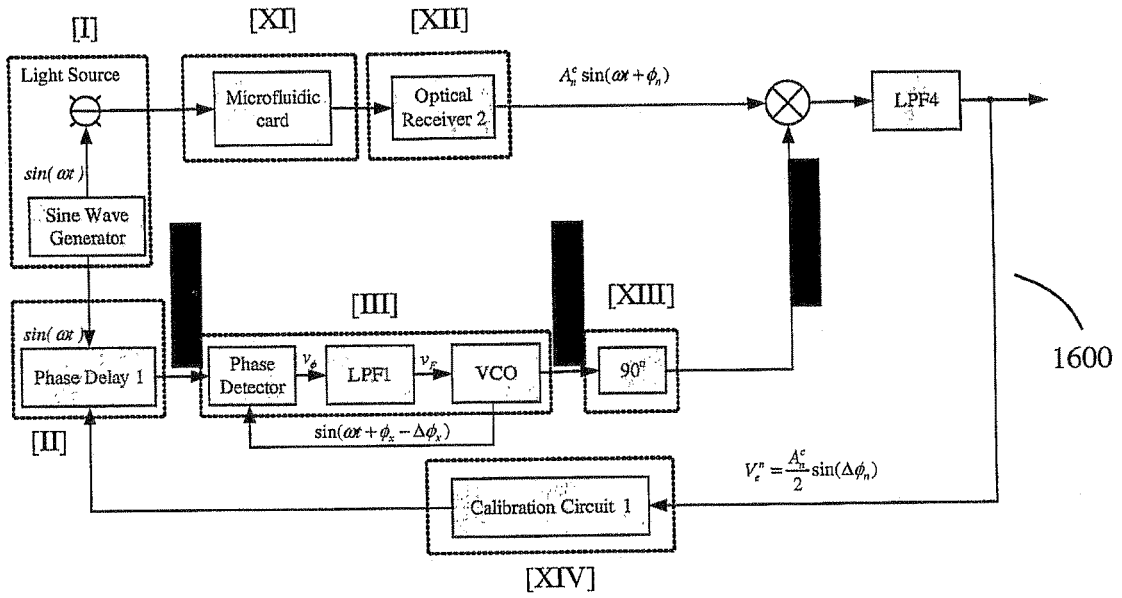

[I]
[XI]
[XII]
Light Source
Microfluidic card
Optical Receiver 2
$A_n^c \sin(\omega t + \phi_n)$
LPF4
$\sin(\omega t)$
Sine Wave Generator
[III]
[XIII]
$\sin(\omega t)$
Phase Delay 1
Phase Detector
$v_\phi$
LPF1
$v_E$
VCO
90°
1600
[II]
$\sin(\omega t + \phi_x - \Delta\phi_x)$
$V_e^n = \frac{A_n^c}{2}\sin(\Delta\phi_n)$
Calibration Circuit 1
[XIV]

**FIGURE 16**

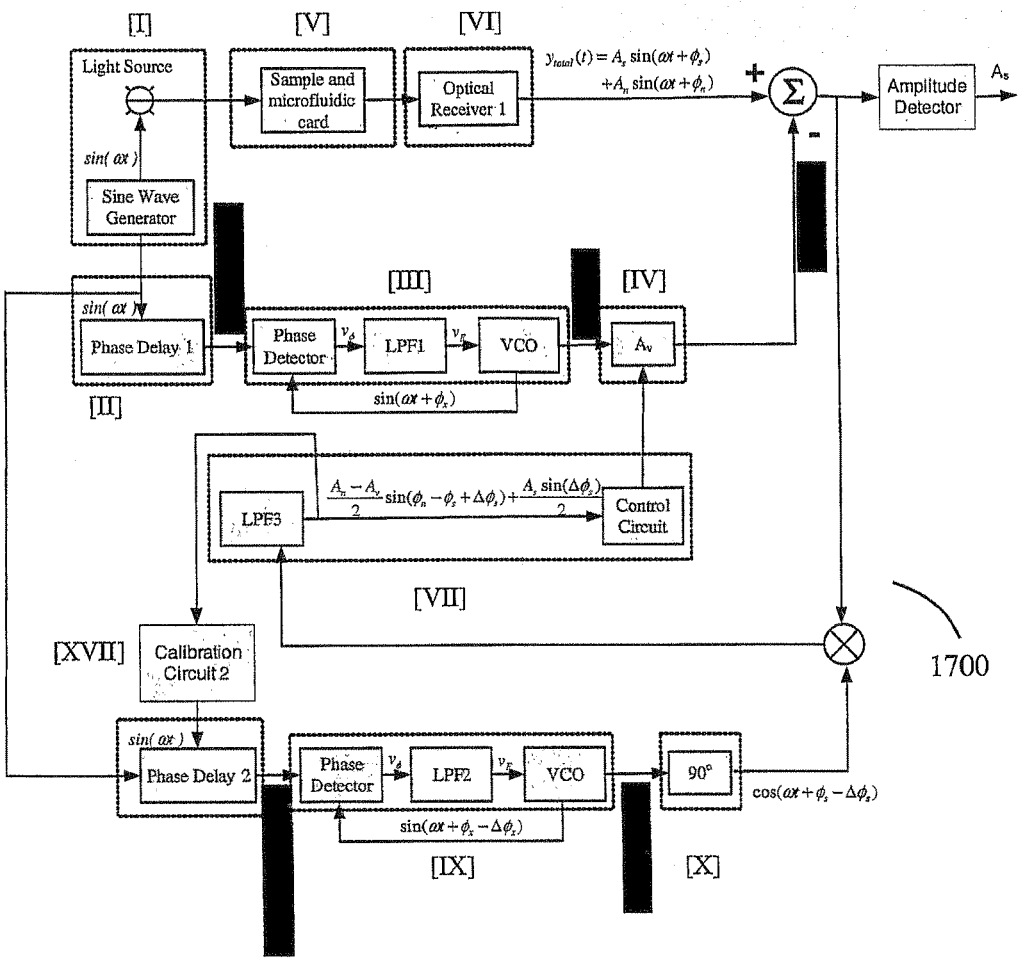

[I]
[V]
[VI]
Light Source
Sample and microfluidic card
Optical Receiver 1
$y_{total}(t) = A_s \sin(\omega t + \phi_s) + A_n \sin(\omega t + \phi_n)$
+
Σ
-
Amplitude Detector
$A_s$
sin( ωt )
Sine Wave Generator
[III]
[IV]
sin( ωt )
Phase Delay 1
Phase Detector
$v_d$
LPF1
$v_F$
VCO
$A_v$
[II]
$\sin(\omega t + \phi_s)$
LPF3
$\frac{A_n - A_v}{2}\sin(\phi_n - \phi_s + \Delta\phi_s) + \frac{A_s \sin(\Delta\phi_s)}{2}$
Control Circuit
[VII]
1700
[XVII]
Calibration Circuit 2
sin( ωt )
Phase Delay 2
Phase Detector
$v_d$
LPF2
$v_F$
VCO
90°
$\cos(\omega t + \phi_s - \Delta\phi_s)$
$\sin(\omega t + \phi_s - \Delta\phi_s)$
[IX]
[X]

**FIGURE 17**

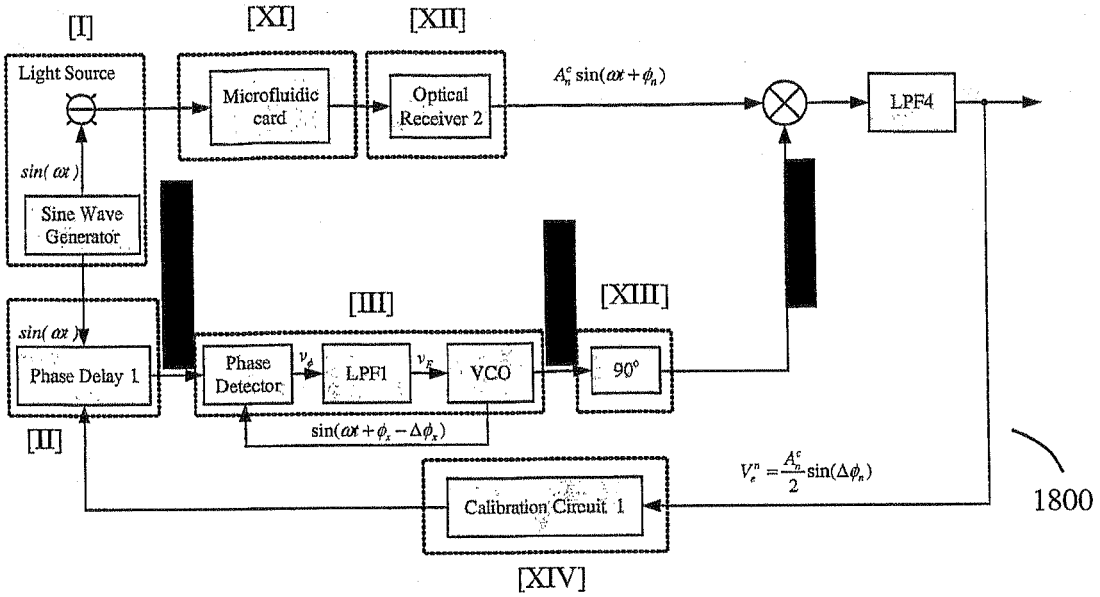

[I]
[XI]
[XII]
Light Source
Microfluidic card
Optical Receiver 2
$A_n^c \sin(\omega t + \phi_n)$
LPF4
$sin(\omega t)$
Sine Wave Generator
[III]
[XIII]
$sin(\omega t)$
Phase Delay 1
Phase Detector
$v_\phi$
LPF1
$v_F$
VCO
90°
[II]
$\sin(\omega t + \phi_x - \Delta\phi_x)$
$V_e^n = \frac{A_n^c}{2}\sin(\Delta\phi_n)$
Calibration Circuit 1
1800
[XIV]

**FIGURE 18**

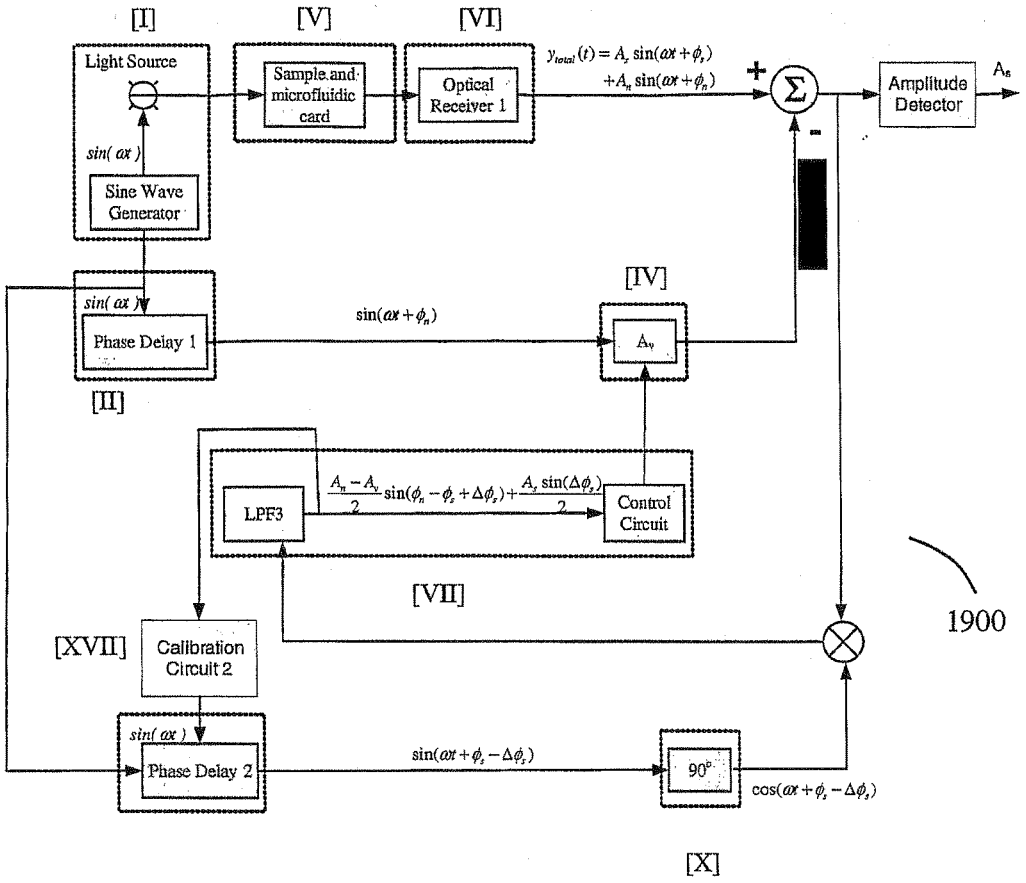

[I]
[V]
[VI]
Light Source
Sample and microfluidic card
Optical Receiver 1
$y_{total}(t) = A_s \sin(\omega t + \phi_s) + A_n \sin(\omega t + \phi_n)$
+
Σ
-
Amplitude Detector
$A_R$
sin( ωt )
Sine Wave Generator
sin( ωt )
Phase Delay 1
[II]
$\sin(\omega t + \phi_n)$
[IV]
$A_N$
LPF3
$\frac{A_n - A_N}{2}\sin(\phi_n - \phi_s + \Delta\phi_s) + \frac{A_s \sin(\Delta\phi_s)}{2}$
Control Circuit
[VII]
1900
[XVII]
Calibration Circuit 2
sin( ωt )
Phase Delay 2
$\sin(\omega t + \phi_s - \Delta\phi_s)$
90°
$\cos(\omega t + \phi_s - \Delta\phi_s)$
[X]

**FIGURE 19**

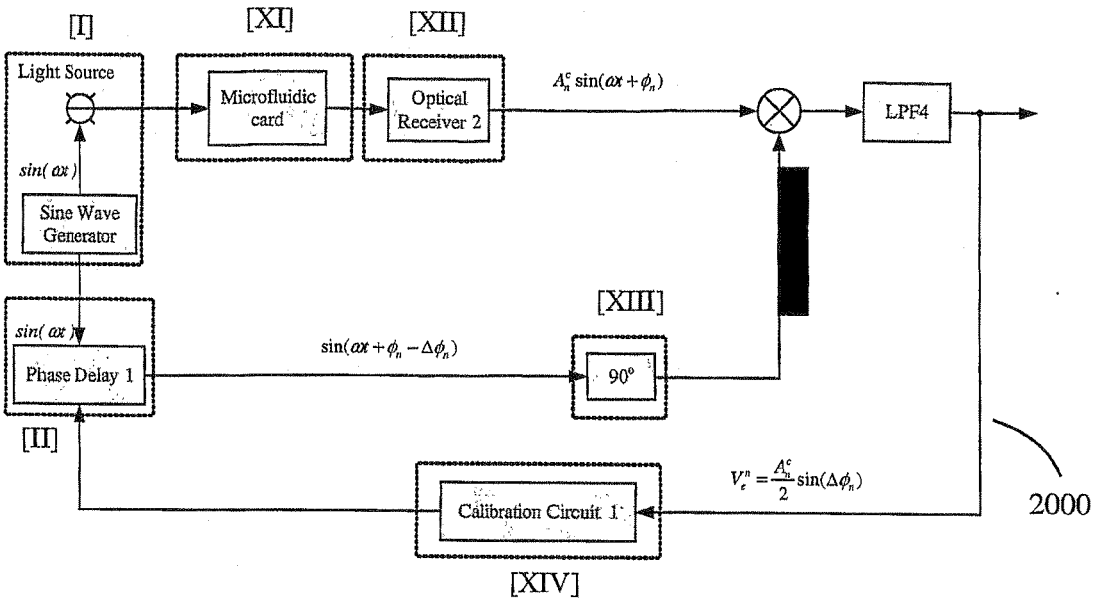

[I]
[XI]
[XII]
Light Source
Microfluidic card
Optical Receiver 2
$A_n^c \sin(\omega t + \phi_n)$
LPF4
$\sin(\omega t)$
Sine Wave Generator
[XIII]
$\sin(\omega t)$
Phase Delay 1
$\sin(\omega t + \phi_n - \Delta\phi_n)$
90°
[II]
$V_e^n = \frac{A_n^c}{2}\sin(\Delta\phi_n)$
Calibration Circuit 1
2000
[XIV]

**FIGURE 20**

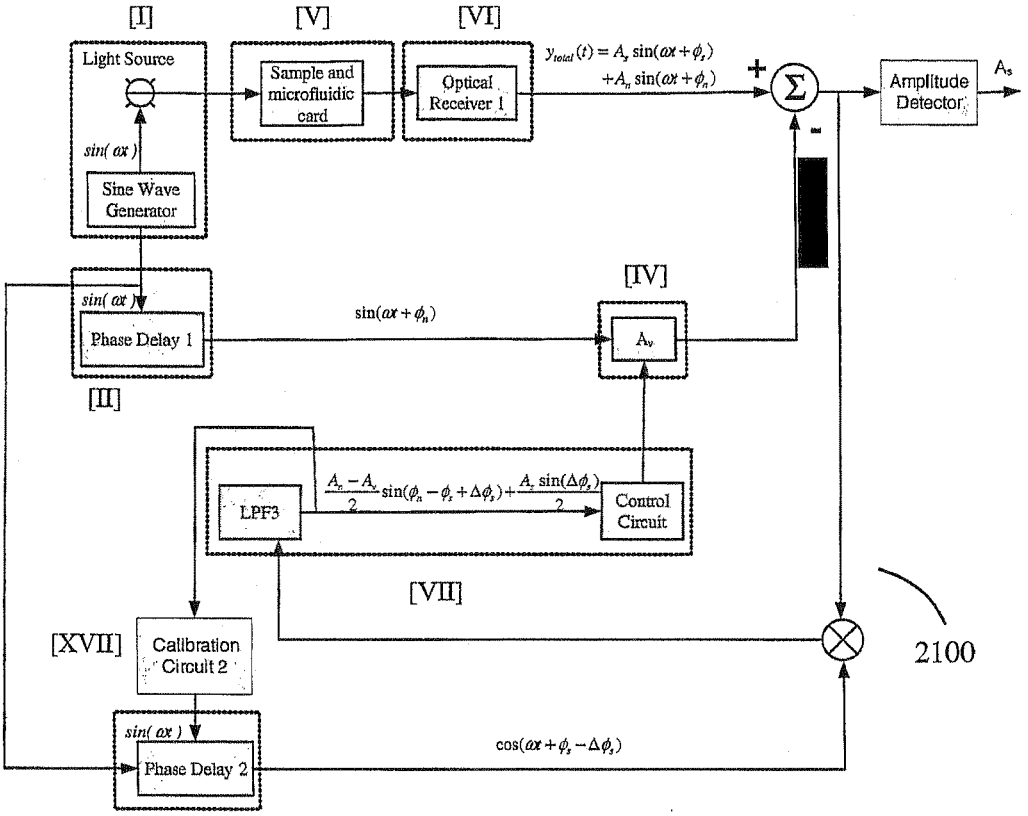

[I]
[V]
[VI]
Light Source
Sample and microfluidic card
Optical Receiver 1
$y_{total}(t) = A_y \sin(\omega x + \phi_s) + A_n \sin(\omega x + \phi_n)$
+
Σ
-
Amplitude Detector
$A_s$
$sin(\omega x)$
Sine Wave Generator
$sin(\omega x)$
Phase Delay 1
$\sin(\omega x + \phi_n)$
[IV]
$A_v$
[II]
LPF3
$\frac{A_n - A_v}{2} \sin(\phi_n - \phi_s + \Delta\phi_s) + \frac{A_s \sin(\Delta\phi_s)}{2}$
Control Circuit
[VII]
[XVII]
Calibration Circuit 2
2100
$sin(\omega x)$
Phase Delay 2
$\cos(\omega x + \phi_s - \Delta\phi_s)$

**FIGURE 21**