US009400179B2

(12) **United States Patent**
Fesshaie et al.

(10) **Patent No.: US 9,400,179 B2**
(45) **Date of Patent: Jul. 26, 2016**

(54) **PROPAGATION VELOCITY COMPENSATED POSITION MEASUREMENT SENSOR**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 134 days.

(21) Appl. No.: **14/250,087**

(22) Filed: **Apr. 10, 2014**

(65) **Prior Publication Data**

US 2014/0306721 A1 Oct. 16, 2014

Related U.S. Application Data

(60) Provisional application No. 61/810,802, filed on Apr. 11, 2013.

(51) **Int. Cl.**

G01R 27/28	(2006.01)
G01B 21/16	(2006.01)
G01D 5/48	(2006.01)

(52) **U.S. Cl.**
CPC . ***G01B 21/16*** (2013.01); ***G01D 5/48*** (2013.01)

(58) **Field of Classification Search**
CPC G01R 27/02; G01R 27/26; G01R 1/30; G01B 21/16
See application file for complete search history.

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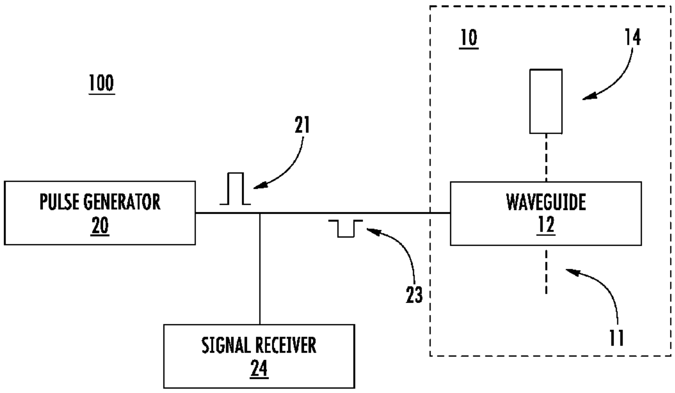
Assistant Examiner — Dominic Hawkins

(57) **ABSTRACT**

A position sensing system including a waveguide, a magnet movable relative to the waveguide, and a compensator configured to compensate for a change in propagation velocity of the waveguide in determining a position of the magnet relative to the waveguide. The compensator coupled to the waveguide and configured to receive a pulse, an end of line pulse corresponding to the pulse transmitted through the waveguide, and a reflected pulse corresponding to a reflection of the pulse at a point in the waveguide. The compensator configured to determine the point based at least in part on the pulse, the end of line pulse, and/or the reflected pulse.

17 Claims, 8 Drawing Sheets



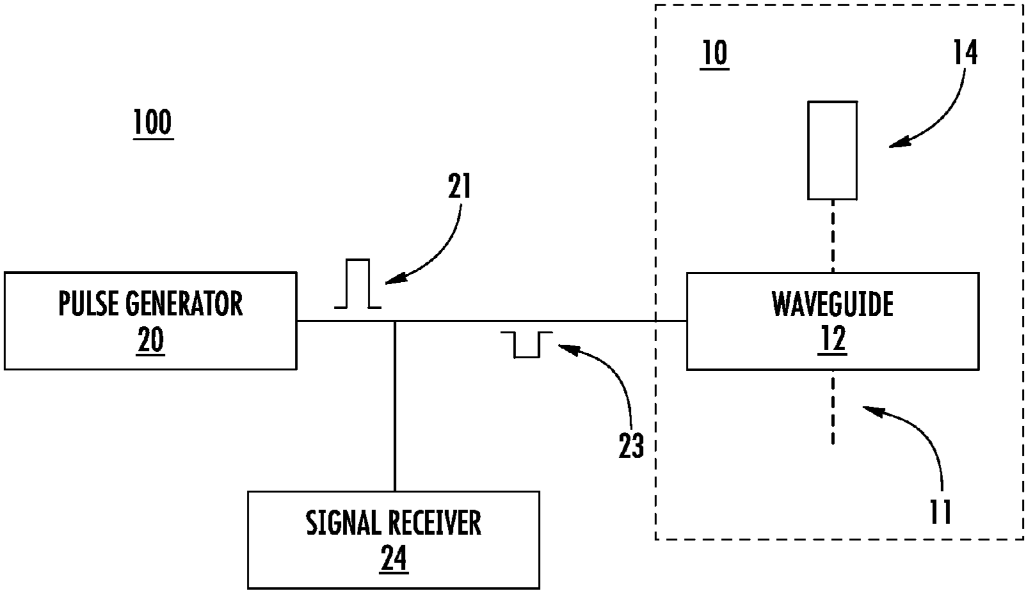

100
10
14
21
PULSE GENERATOR
20
WAVEGUIDE
12
23
11
SIGNAL RECEIVER
24

FIG. 1A

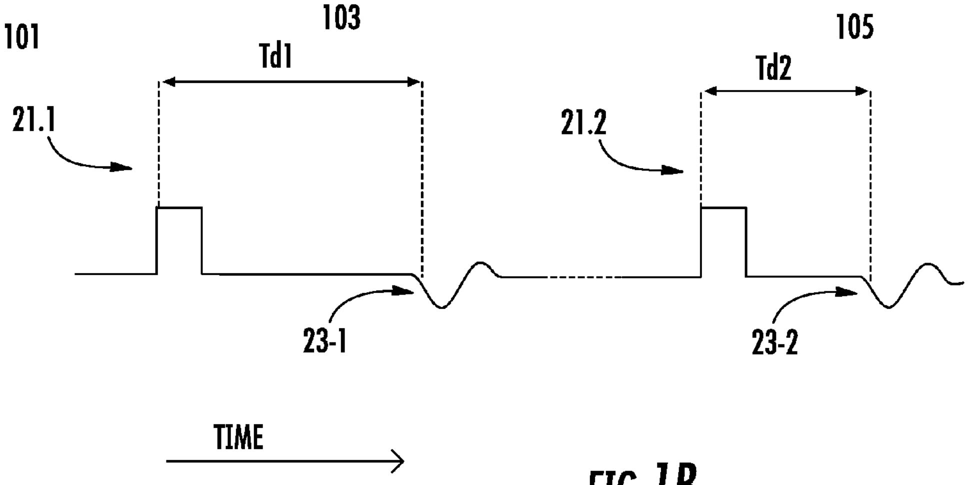

101
103
Td1
105
Td2
21.1
21.2
23-1
23-2
TIME

FIG. 1B

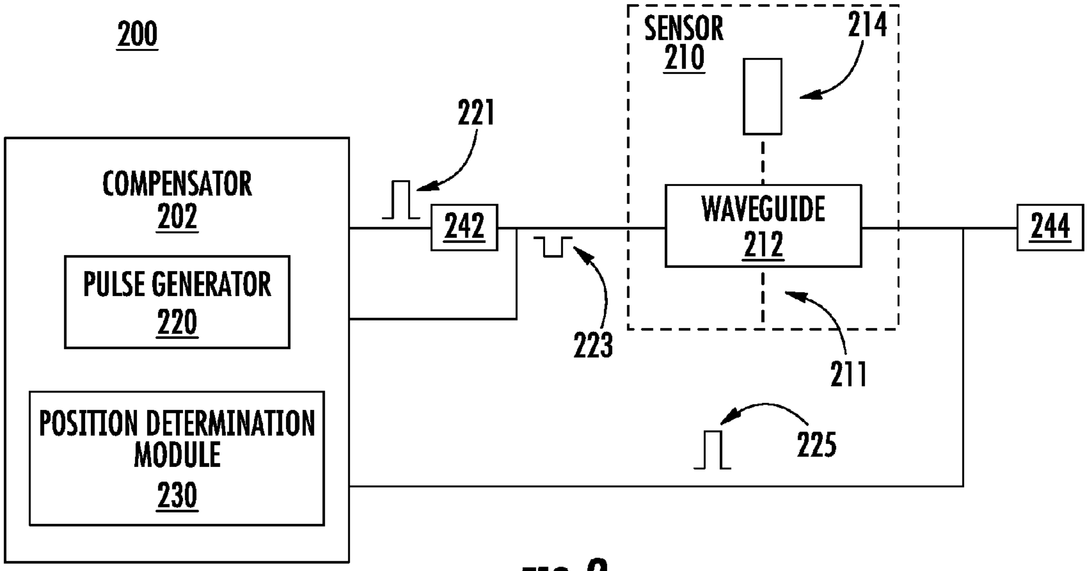

200
SENSOR
210
214
221
COMPENSATOR
202
242
WAVEGUIDE
212
244
PULSE GENERATOR
220
223
211
POSITION DETERMINATION MODULE
230
225

FIG. 2

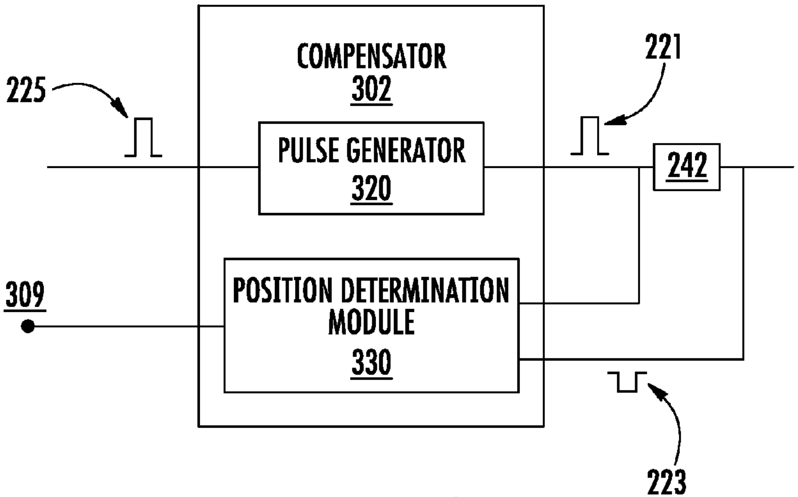

COMPENSATOR
302
221
225
PULSE GENERATOR
320
242
309
POSITION DETERMINATION MODULE
330
223

FIG. 3

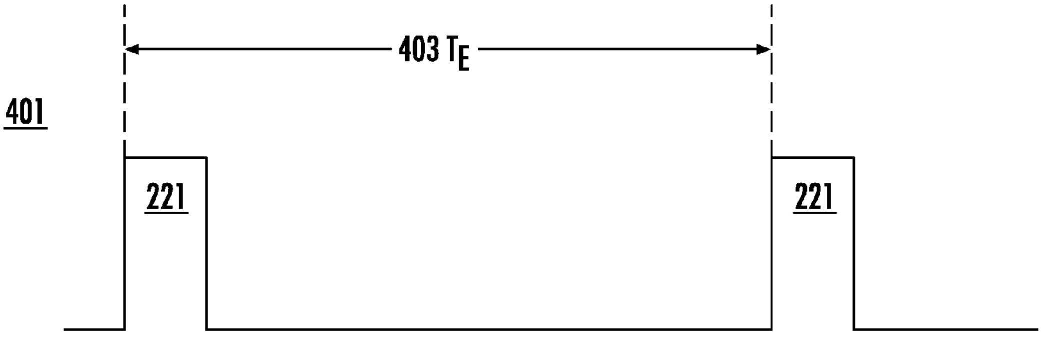


FIG. 4

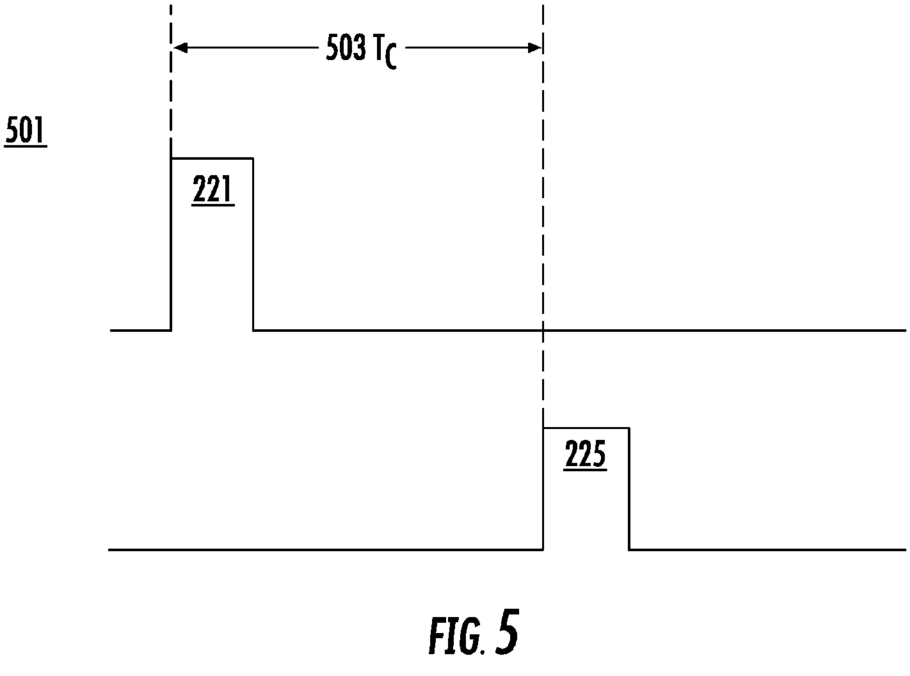


FIG. 5

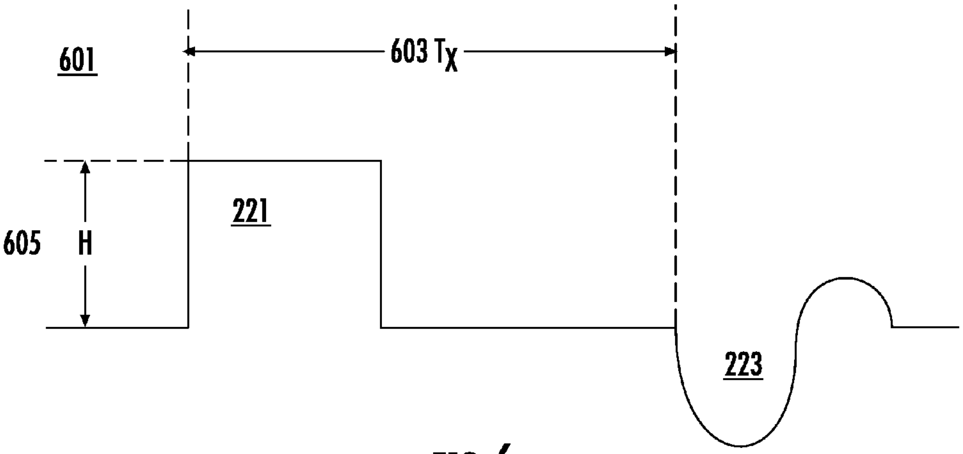

601
603 T_X
221
605
H
223

FIG. 6

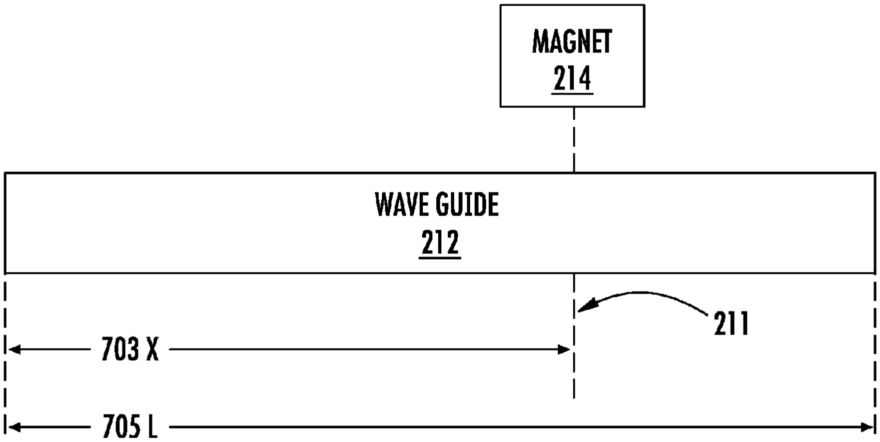

MAGNET
214
WAVE GUIDE
212
211
703 X
705 L

FIG. 7

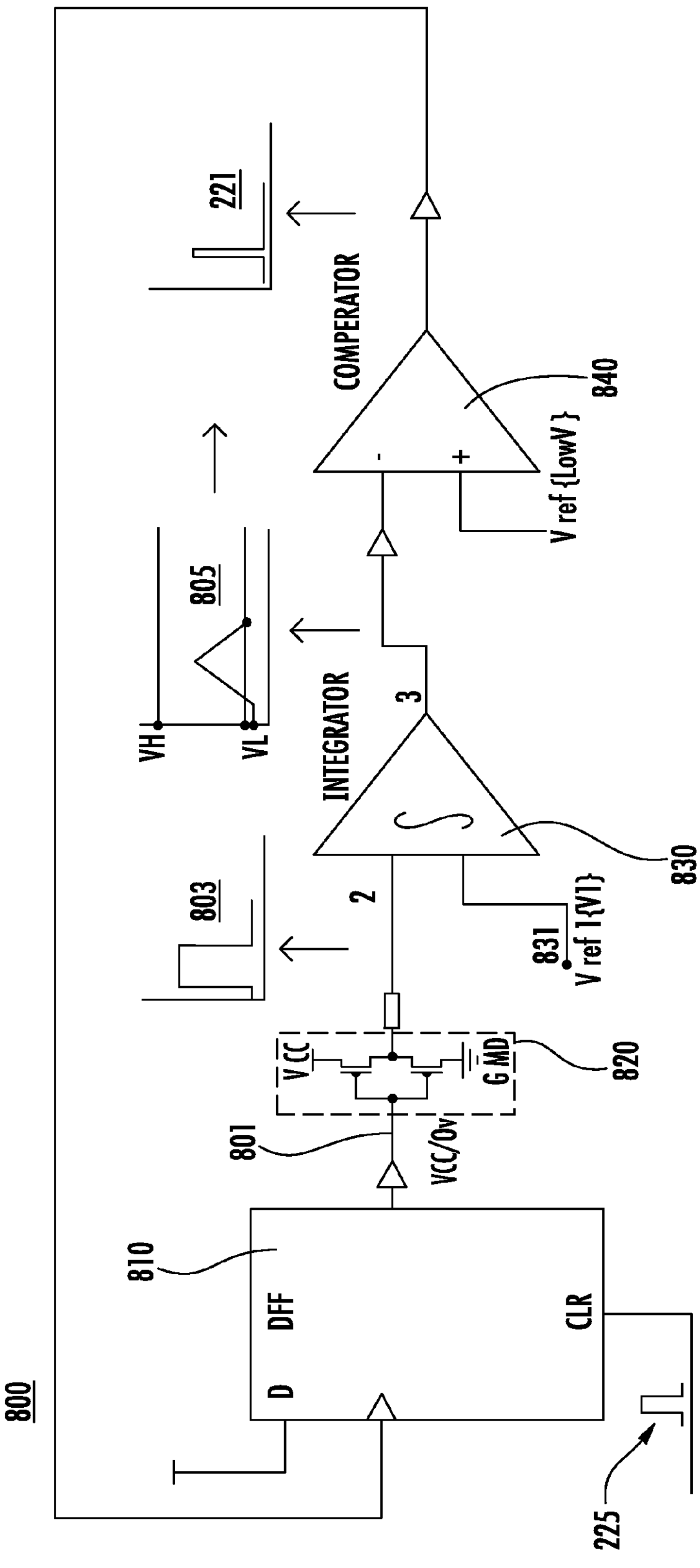

800
D
DFF
CLR
810
225
VCC/0v
801
V CC
G MD
820
2
803
V ref 1{V1}
831
INTEGRATOR
830
3
VH
VL
805
COMPERATOR
-
+
840
V ref {LowV}
221

FIG. 8

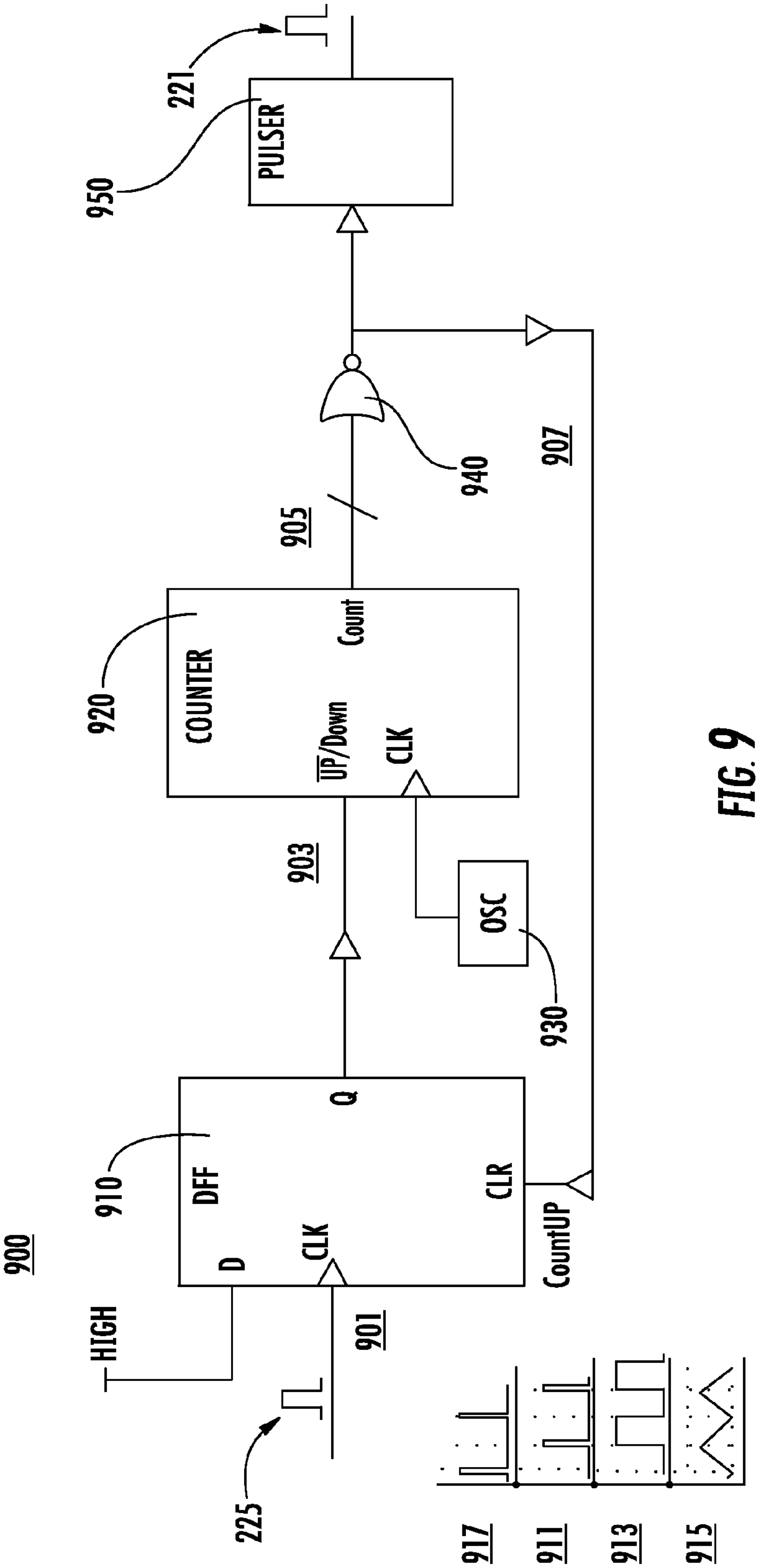

221
PULSER
950
940
907
905
920
COUNTER
Count
$\overline{\text{UP}}$/Down
CLK
903
OSC
930
910
DFF
Q
CLR
CountUP
900
D
CLK
HIGH
901
225
917
911
913
915

FIG. 9

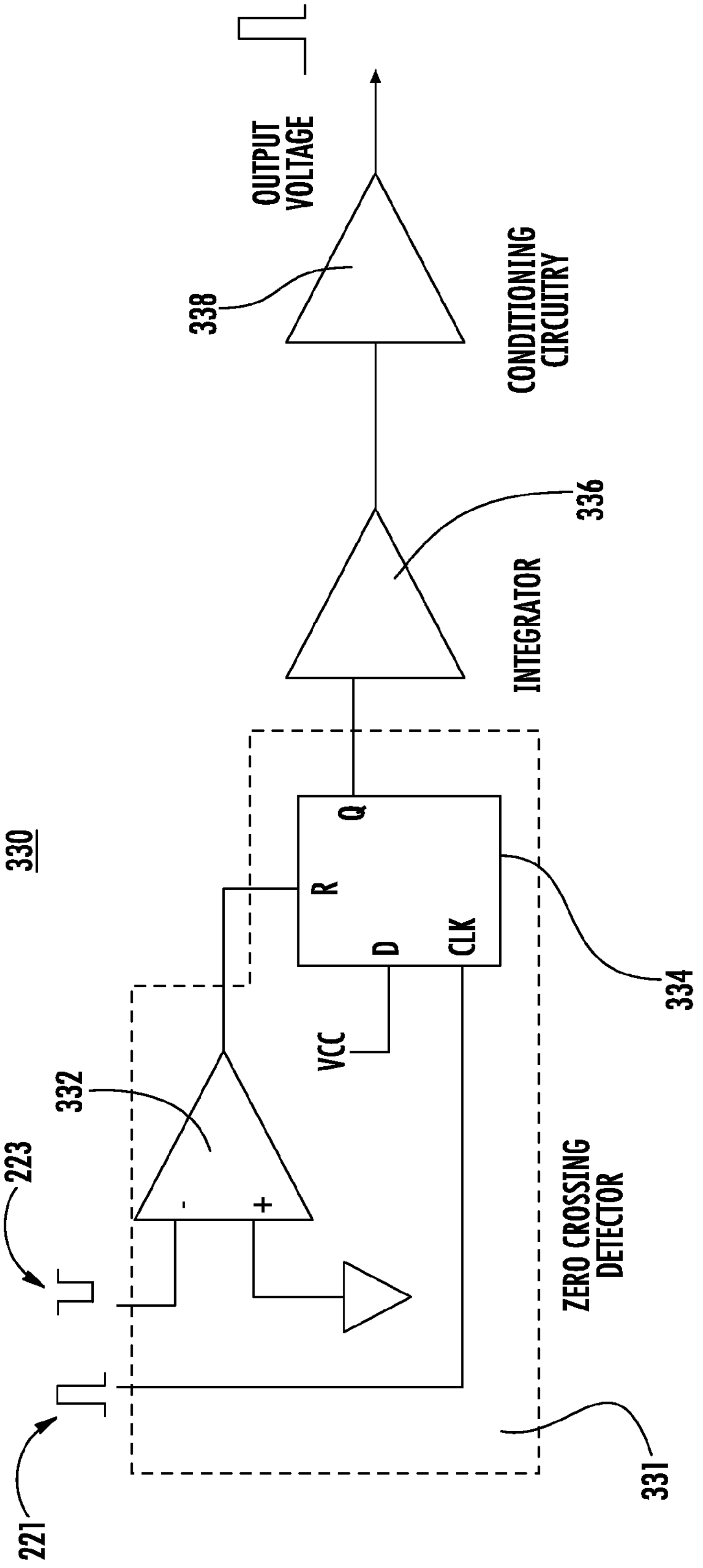

330
OUTPUT VOLTAGE
338
CONDITIONING CIRCUITRY
336
INTEGRATOR
Q
R
D
CLK
334
VCC
332
223
-
+
ZERO CROSSING DETECTOR
221
331

FIG. 10

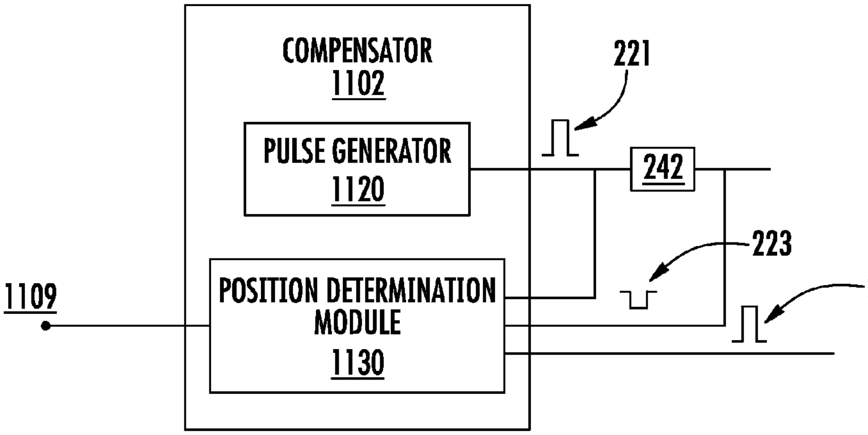

COMPENSATOR
1102
PULSE GENERATOR
1120
POSITION DETERMINATION MODULE
1130
1109
221
242
223
225

FIG. 11

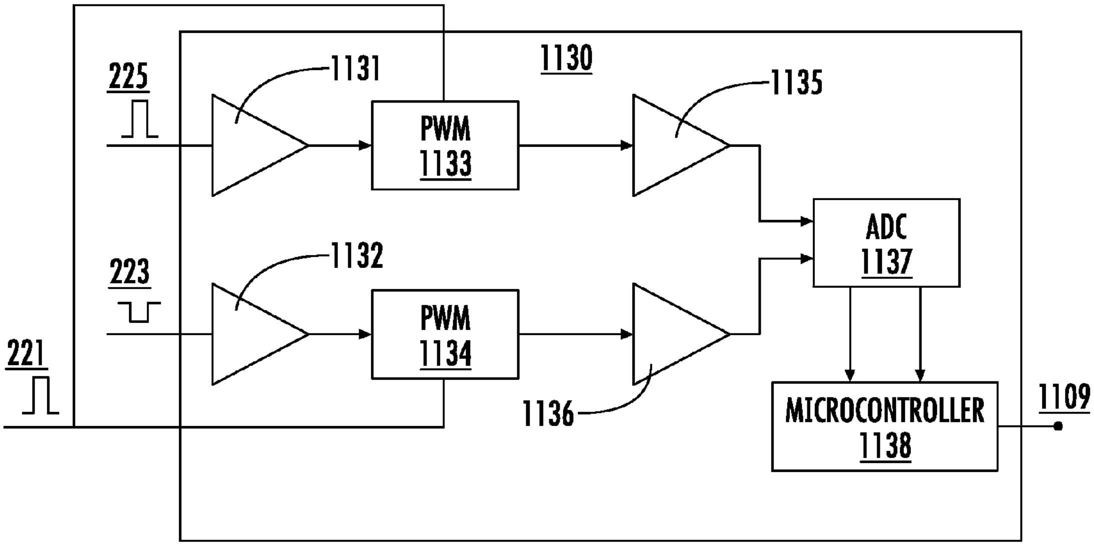

1130
225
223
221
1131
1132
PWM
1133
PWM
1134
1135
1136
ADC
1137
MICROCONTROLLER
1138
1109

FIG. 12

PROPAGATION VELOCITY COMPENSATED POSITION MEASUREMENT SENSOR

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/810,802 filed Apr. 11, 2013, entitled "Temperature Compensated Position Measurement Apparatus and Method," which application is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

Embodiments of the present disclosure relate generally to waveguide based position sensors and more particularly to compensating for changes in the propagation velocity of waveguide position sensors.

GENERAL BACKGROUND

A conventional position measurement system **100** is shown in FIG. **1**A. The system **100** includes a sensor **10**, a pulse generator **20**, and a signal receiver **24**. The sensor **10** includes a waveguide **12** and a magnet **14**. Such a position measurement system is described in greater detail in European Patent Application No. 12006827.5, filed Oct. 1, 2012, which application is incorporated herein by reference in its entirety. In general, the magnet **14** is attached to a moveable object. During operation, the pulse generator **20** generates a pulse **21** that is communicated to the waveguide **12**. The magnet **14** creates an impedance discontinuity **11** in a region of the waveguide **12** proximate to the magnet **14**. A reflection of the pulse **21** is reflected from the point of impedance discontinuity **11**, resulting in reflected pulse **23**. The signal receiver **24** receives the pulse **21** and the reflected pulse **23**. The position of the magnet **14** relative to the waveguide **12** can be determined based on the timing of the pulse **21** with respect to the reflected pulse **23**. More specifically, the difference between the time the pulse **21** is received and the time the reflected pulse **23** is received can be used to determine the position of the magnet **14**.

The waveguide **12**, however, is often temperature dependent. Said differently, the timing between receipt of the pulse **21** and receipt of the reflected pulse **23** may be dependent on temperature in addition to the position of the magnet **14**. More specifically, temperature may affect the permittivity, capacitance, permeability, and/or inductance of the waveguide **12**. Accordingly, the velocity of waves transmitted through the waveguide **12** may change; thereby changing the speed in which the pulse **21** and the reflected pulse **23** travel through the waveguide **12**. Correspondingly, the time of receipt of the reflected pulse **23** may differ even when the point of discontinuity **11** is the same. For example, FIG. **1**B shows a timing diagram **101**. The timing diagram **101** shows a first pulse **21-1** and a second pulse **21-2**. First and second reflected pulses **23-1** and **23-2** corresponding to the first and second pulses **21-1** and **21-2** respectively are also shown. The first and second reflected pulses **23-1** and **23-2** are reflected from the point of discontinuity **11** shown in FIG. **1**A. In particular, the position of the magnet **14** is the same for both reflected pulses **23-1**, **23-2**. However, due to changes in temperature, the time **103** (T_{d1}) between the first pulse **21-1** and the first reflected pulse **23-1** is different than the time **105** (T_{d2}) between the second pulse **21-2** and the second reflected pulse **23-2**.

Conventionally, position sensors attempt to compensate for temperature by using look-up tables, or the like. However, this requires additional circuitry to measure the ambient temperature, additional memory to store the lookup table, and additional processing capability to determine the actual position based on the look-up table. Furthermore, any inaccuracy or difference between the temperature data in the lookup table and the actual temperature dependence of the waveguide **12** will result in position measurement errors.

Furthermore, the propagation velocity of waves in a waveguide may be affected by other factors in addition to temperature. For example, the propagation velocity may change over the lifetime of the waveguide. The propagation velocity may be affected by external magnetic fields. Additionally, the propagation velocity may be affected by manufacturing tolerances.

It is with respect to the above that the present disclosure is provided.

SUMMARY OF THE INVENTION

Various embodiments of the present disclosure provide a position sensing system. The position sensing system may include a waveguide configured to receive a pulse at a first end and transmit the pulse through the waveguide resulting in an end of line pulse exiting the waveguide at a second end, a magnet moveable relative to the waveguide configured to cause a reflected pulse to be reflected back to the first end of the waveguide from a point of impedance discontinuity in the waveguide proximate the magnet, and a compensator electrically coupled to the waveguide and configured to receive the pulse, the end of line pulse, and the reflected pulse and determine the point of impedance discontinuity based at least in part on the pulse, the end of line pulse and the reflected pulse.

Some examples of the present disclosure provide a position sensor comprising a pulse generator electrically coupled to a waveguide and configured to generate a pulse and communicate the pulse to a first end of the waveguide, and a position determination module electrically coupled to the waveguide, the position determination module configured to receive the pulse, an end of line pulse exiting a second end of the waveguide, and a reflected pulse reflected from a point of discontinuity in the waveguide, the position determination module further configured to determine the distance from the first end of the waveguide to the point of impedance discontinuity based on a time between receiving the pulse and the reflected pulse and a time between receiving the pulse and the end of line pulse, wherein the end of line pulse corresponds to the pulse transmitted from the first end to the second end of the waveguide.

Some examples of the present disclosure provide a method of determining a position of a magnet relative to a waveguide. The example method may include providing a waveguide, providing a magnet movable relative to the waveguide, the magnet configured to generate a point of impedance discontinuity in the waveguide proximate to the magnet, communicating a pulse to a first end of the waveguide, receiving an end of line pulse from a second end of the waveguide, the end of line pulse corresponding to the pulse transmitted from the first end of the waveguide to the second end of the waveguide, receiving a reflected pulse from the first end of the waveguide, the reflected pulse corresponding to a reflection of the pulse reflected from the point of impedance discontinuity, and determining the position of the magnet relative to the waveguide based at least in part on the end of line pulse and the reflected pulse.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A shows a block diagram of a positioning sensing system;

FIG. **1**B shows a timing diagram associated with the position sensing system of FIG. **1**A;

FIG. **2** is a block diagram illustrating a position sensing system;

FIG. **3** is a block diagram illustrating a portion of the position sensing system of FIG. **2** in greater detail;

FIGS. **4-6** illustrate timing diagrams and example waveforms for signals associated with the position sensing system of FIG. **2**;

FIG. **7** is a block diagram illustrating a portion of the position sensing system of FIG. **2** in greater detail;

FIGS. **8-10** are block diagrams illustrating portions of the position sensing system of FIG. **3** in greater detail;

FIG. **11** is a block diagram illustrating a portion of the position sensing system of FIG. **2** in greater detail; and

FIG. **12** is a block diagram illustrating a portion of the position sensing system of FIG. **11** in greater detail, all arranged according to at least some embodiments of the present disclosure.

DESCRIPTION OF EMBODIMENTS

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention, however, may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, like numbers refer to like elements throughout.

The present disclosure describes multiple example embodiments of propagation velocity compensated position sensors. In general, these examples are pulsed waveguide (PWG) based position sensors that incorporate a waveguide and a magnet. The present disclosure provides compensation by measuring both a reflected pulse and an end of line pulse (refer to FIGS. **2**, **3**, and **11**.) It is noted, that the example sensors detailed herein may be implemented in a variety of different systems, such as, for example, fluid level systems, gearboxes, welding machines, robotic systems, or the like. Examples, however, are not to be limited in this context.

Additionally, the present disclosure may be implemented to compensate for variations in propagation velocity due to temperature, external magnetic fields, manufacturing tolerances, changes in the characteristic response of the waveguide due to the age of the waveguide, or the like. It is noted that examples herein reference compensating for the effects of temperature on the propagation velocity. This is done for convenience and clarity of presentation. However, this is not intended to be limiting.

FIG. **2** illustrates a block diagram of a position sensing system **200**, arranged in accordance with at least some embodiments of the present disclosure. The system **200** includes a position sensor **210** (sometimes referred to herein as the "sensor") comprising a waveguide **212** and a magnet **214**. In general, the waveguide **212** may be any type of waveguide (e.g., a microstrip waveguide, a stripline waveguide, a rectangular waveguide, or the like). Additionally, the magnet **214** may be any of a variety of types of magnets (e.g., a permanent magnet, an electromagnet, or the like). The magnet **214** is movable relative to the waveguide **212**. In general, the magnet **214** creates a point of impedance discontinuity **211** in the waveguide **212**. The impedance discontinuity **211** is created at the location of the magnet **214** relative to the waveguide **212**. As will be described in greater detail below, the location of the waveguide **212** relative to the magnet **214** can be determined based on an initial pulse (e.g., **221**), a reflected pulse (e.g., **223**), and an end of line pulse (e.g., **225**). In particular, this position may be determined irrespective of the propagation velocity of waves within the waveguide **212**. For example, this position may be determined irrespective of the temperature of the waveguide **212**.

In practice, either the magnet **214** or the waveguide **212** may be attached to a moveable object whose position is to be determined. For example, in some embodiments, the magnet **214** can be affixed to a movable object (e.g., a sewing head, a laser, a welding tip, a liquid float, or the like). The waveguide **212** can be affixed to a cooperating structure that may be placed along the path of the moveable object. As another example, in some embodiments, the waveguide **212** can be affixed to a movable object while the magnet **214** is affixed to a cooperating structure. Accordingly, during operation, as the moveable object moves, its position relative to the cooperating structure can be determined based on determining the location of the waveguide **212** relative to the magnet **214**.

In order to determine the location of the waveguide **212** relative to the magnet **214**, the system **200** includes a compensator **202**. The compensator **202** includes a pulse generator **220** and a position determination module **230**. The pulse generator **220** and the position determination module **230** are operatively connected to the waveguide **212** (e.g., via electrical connection, or the like). The pulse generator **220** is configured to generate signal pulses (e.g., pulse **221**). The pulse **221** is communicated to the waveguide **212** and reflected at the point of impedance discontinuity **211**, resulting in reflected pulse **223**. Additionally, the pulse **221** is transmitted through the waveguide and exits the waveguide **212** as an end of line pulse **225**. The compensator **202** is configured to determine the position of the waveguide **212** relative to the magnet **214** based on the pulse **221**, the reflected pulse **223**, and the end of line pulse **225**. In some examples, the compensator **202** may be configured to determine the position of the waveguide **212** relative to the magnet **214** based at least in part by controlling the timing of the pulse **221**; more specifically, by controlling the period for a series of pulses **221** (refer to FIGS. **3**, and **8-10**). With some examples, the compensator **202** may be configured to determine the position of the waveguide **212** relative to the magnet **214** based at least in part by comparing the time between the pulse **221** and the end of line pulse **225** to the reflected pulse **223** (refer to FIGS. **11-12**). These will be explained in greater detail below. It is worthy to note, the example embodiments are described with reference to the system **200** of FIG. **2**, but may be implemented with other waveguide based position sensors to compensate for variations of the propagation velocity of waves in the waveguide.

Propagation Velocity Compensating Position Sensor with Controlled Timing

As noted, in some examples, the system **200** may be configured to determine the position of the waveguide **212** relative to the magnet **214** in part by controlling the timing of the pulse **221**. For example, the period between pulses **221** may be controlled to compensate for temperature dependence of the time between the pulse **221** being communicated to the waveguide **212** and the reflected pulse **223** exiting the waveguide **212**. FIG. **3** illustrates a block diagram of an example implementation of a compensator **302**. In some examples, the compensator **302** may be implemented as the compensator **202** in the system **200** of FIG. **2**. The compensator **302** includes a pulse generator **320** and a position determination module **330**. As depicted, the pulse generator **320** is operably connected to the waveguide **212** to both communicate the pulse **221** to the waveguide and receive the end of line pulse **225** from the waveguide **212**. Additionally, the position determination module **330** is operably connected to both the pulse generator **320** and the waveguide **212** to receive the pulse **221** and the reflected pulse **223**.

The pulse generator **320** is configured to generate a series of pulses **221** where the period (e.g., the time between pulses **221**) corresponds to the time between the pulse **221** and the end of line pulse **225**. For example, FIG. **4** illustrates a timing diagram **401**, which shows pulses **221** having a period **403** (T_E). As stated, the period (e.g., T_E) between pulses **221** is set by the pulse generator **320** to equal N times the time it takes the pulse **221** to travel down the waveguide **212**.

In general, the period T_E may be set to equal N (where N greater than or equal to 2) times the time between the pulse **221** and the end of line pulse **225**. For example, FIG. **5** illustrates a timing diagram **501**, which shows the pulse **221**, and a corresponding end of line pulse **225**. As depicted, a time **503** (T_C) separates the pulse **221** and the end of line pulse **225**. The time T_C corresponds to the time it takes for the pulse **221** to be transmitted through the waveguide **212**. The pulse generator **320** is configured to generate pulses having a period equal to N times the time between the pulse **221** and the end of line pulse **225** (e.g., T_C). As will be appreciated, this period may change during operation and can be dynamically updated by the pulse generator **320**. Accordingly, as the temperature changes and/or the velocity of waves propagating through the waveguide **212** changes (e.g., due to temperature, or the like) the time T_C, and correspondingly the period T_E will change. Example pulse generators configured to generate a series of pulses **221** with the period T_E based on the time T_C are described in greater detail below (refer to FIGS. **8**-**9**).

It is noted, that although the period T_E can be determined with N>=2, the examples provided herein use N=2 for purposes of illustration and clarity. Using N=2, the period T_E can be represented by the following equation:

$$T_E=2L/Vg(\text{temp}) \tag{1}$$

where Vg(temp) is the actual group velocity of the translating wave resulting from all perturbing causes, and L is the length of the waveguide.

Using Equation (1), the output from the position determination module **330** (refer to FIG. **10**) can be expressed as a voltage using the following equations:

$$V=H*T(x)/TE \tag{2}$$

$$Tx=2*X/Vg(\text{temp}) \tag{3}$$

where Tx is the time difference between the pulse **221** and the reflected pulse **223**, H is the magnitude of the pulse **221**, and X is the position of the magnet **214** along the length of waveguide **212**. For example, FIG. **6** illustrates a timing diagram **601** showing a pulse **221** and a corresponding reflected pulse **223**. The time **603** (Tx) between the pulse **221** and the reflected pulse **223** as well as the magnitude **605** (H) of the pulse **221** are shown.

Furthermore, FIG. **7** illustrates a block diagram showing the position **703** (*x*) of the magnet **214** relative to the length **705** (L) of the waveguide **212**. Using Equations (1-3), the group velocity Vg(temp) can be canceled out, and the output from the position determination module **330** can be represented as a voltage using the following equations:

$$V=H*X/L \tag{4}$$

$$X=V*L/H \tag{5}$$

As can be seen from Equation (4), the position X of the magnet **214** is now expressed independently of group velocity Vg(temp). It is noted, since X, the position of the magnet for any given time=t and pulse **221** magnitude H is constant; the measurement of the distance X of the magnet **214** relative to the length L of the waveguide **212** is temperature independent.

Additionally, the calculation below shows that the ratio of the time Tx to the period T_E is equal to the ratio of the distance X to the distance L. More particularly,

$$Tx=2*X/Vg(\text{temp}) \tag{6}$$

Therefore,

$$Vg(\text{temp})=2*X/Tx \tag{7}$$

Using Equation (1),

$$Vg(\text{temp})=2*L/TE \tag{8}$$

Consequently from equations (7) and (8),

$$2*X/T_R=2*L/T_E \tag{9}$$

Which can be simplified into:

$$Tx/T_E=X/L \tag{10}$$

Equation 10 illustrates that by controlling the period T_E to be a multiple (e.g., in this case 2) of the time T_C, the ratio of the time delay T_X of the reflected signal, (due to the magnet position at position X), and the delay T_E, (two times the time for excitation signal to travel the length of the waveguide **12**), is equal to the ratio of the distance of the magnet position X relative to the total length of the sensor L. This relationship is independent of the group velocity Vg(temp), consequently of all causes impacting group velocity, including temperature changes, nominal design fluctuations, quality and other variations.

FIGS. **8**-**9** illustrate example signal pulse generator **320**. In general, FIG. **8** illustrates an analog circuit that may be used to implement the signal pulse generator **320** while FIG. **9** illustrates a digital circuit that may be used to implement the pulse generator **320**.

Turning more specifically to FIG. **8**, a block diagram of a variable pulse width pulse generator circuit **800** is shown. Circuit **800** comprises a D-type flip-flop or counter **810**, a buffer **820**, an integrator **830**, and a comparator **840**, operably connected as shown. The flip-flop **810** is configured to receive as input the end of line pulse **225**. The end of line pulse **225** is operably connected to the clear (CLR) input of the flip-flop **810**. The flip-flop **810** is set high by feeding back the pulse **221**. When the output of the flip-flop **810** is logically high, the output of the integrator **830** begins to ramp up. The output of flip-flop **810** is a voltage at circuit location **801**, which is communicated to a buffer **820** (e.g., a push-pull buffer, or the like).

The output of the buffer **820** is provided to the integrator **830**. The input waveform **803** to the integrator **830** is shown. The output waveform **805** of the integrator **830** is also shown. The output of the integrator **830** is communicated to comparator **840**. The output of comparator **840** is set high when the integrator output falls below a reference voltage (Vref) present on the positive terminal **831** of the integrator **830**. As the integrator **830** output begins to rise above the reference voltage (Vref), the output of the comparator **840** falls low.

This short pulse at the output of the comparator **840** is the pulse **221**, the pulse width of which can be modified as required. By feeding back the pulse **221** and the end of line pulse **225**, the frequency of the repetition of the pulse **221** (e.g., the period T_E) becomes dependent on the group velocity Vg(temp) at which the end of line pulse is transmitted through the waveguide **212**.

Turning more specifically to FIG. **9**, a block diagram of a variable pulse width pulse generator circuit **900** is shown. Circuit **900** comprises a D-type flip-flop **910**, a counter **920**, a clock **930**, an AND Gate **940**, and a conditioning circuit **950**, operably connected as shown. The flip-flop **910** communicates to the counter **920**, which is controlled by the clock **930**. The output of the counter **920** is connected to the AND Gate **940**. The output of the AND Gate **940** is fed to the clear (CLR) input of the flip-flop **910** and the conditioning circuit **950**. The output of the conditioning circuit **950** is the pulse **221**. The end of line pulse **225** is input to the clock (CLK) input of the flip-flop **910**. The operation of the circuit **900** is substantially the same as the circuit **800** described above. Notably, waveforms **911**, **913**, **915**, and **917** are shown corresponding to the waveforms present at points **901**, **903**, **905**, and **907**, respectively.

FIG. **10** illustrates a block diagram of the position determination module **330**. As depicted, the position determination module **330** is implemented using a zero crossing detector **331** comprising a comparator **332** and a D-type flip-flop **334**. The flip-flop **334** is set by the pulse **221** and reset by the reflected pulse **223**. Said differently, the output of the flip-flop **334** is high from the time it is set by the pulse **221** to the time it is reset by the reflected pulse **223**. The position determination module **330** also includes an integrator **336** and a conditioning circuit **338**.

Propagation Velocity Compensating Position Sensor without Controlled Timing

FIG. **11** illustrates a block diagram of an example implementation of a compensator **1102**. In some examples, the compensator **1102** may be implemented as the compensator **202** in the system **200** of FIG. **2**. The compensator **1102** includes a pulse generator **1120** and a position determination module **1130**. The pulse generator **1120** may be any of a variety of pulse generators (e.g., VCO, or the like) configured to generate the pulse **221**. It is important to note, that the pulse generator **1120** can be a standard pulse generator and need not be configured to generate a series of pulses having a period based on the end of line pulse as described above in conjunction with FIG. **3**. The position determination module **1130** is configured to receive the pulse **221**, the end of line pulse **225**, and the reflected pulse **223** and determine the position x (refer to FIG. **7**) of the magnet **214** relative to the waveguide **212**. The position of the magnet **214** relative to the length L of the waveguide **212** can be output as a voltage on output **1109**.

In general, the position determination module **1130** may be configured to determine the position X based on T_C and T_X for an arbitrary T_E (refer to FIGS. **4**-**6**). More specifically, the time between the pulse **221** and the end of line pulse **225** can be expressed as a function of the length L (refer to FIG. **7**) of the waveguide **212** and the group velocity Vg(temp) as follows:

$$T_C=L/Vg(\text{temp}) \quad (11)$$

Equations 7 and 11 can be expressed as the following:

$$L/T_C=2*X/T_X \quad (12)$$

Which can be simplified into:

$$P=TX/2*TC \quad (13)$$

where P=X/L (or the position of the magnet **214** relative to the waveguide **212**).

FIG. **12** illustrates a block diagram of example implementation of the position determination module **1130**. As depicted, the position determination module **1130** includes amplifiers **1131** and **1132**, pulse width modulators **1133** and **1134**, integrators **1135** and **1136** an analog to digital converter **1137**, and a microcontroller **1138**, operably connected as shown. During operation, the end of line pulse **225** and the reflected pulse **223** are input to the amplifiers **1131**, **1132**. The pulse width modulators **1133**, **1134** receive the amplified end of line pulse **225** and the amplified reflected pulse **223**, and generate output pulses having a duty cycle corresponding to the times T_C and T_X. The outputs from the pulse width modulators **1133** and **1134** are input to integrators **1135** and **1136**, respectively. Additionally, the outputs from the integrators **1135** and **1136** are input to the analog to digital converter **1137** (ADC). The output from the ADC **1137** is input to the microcontroller **1138**. Accordingly, the microcontroller **1138** receives a digital signal from the ADC **1137** representative of the time between the pulse **221** and the end of line pulse **225** as well as the pulse **221** and the reflected pulse **223**.

The microcontroller **1138** is configured to determine the position (e.g., X) of the magnet **214** relative to the length L of the waveguide **212** based on these received quantities. In some examples, the microcontroller **1138** is configured to determine the position based on Equation 13 described above.

In some examples, the position determination module **1130** may include switching circuitry to switch the inputs to the integrators **1135** and **1136**. Said differently, the position determination module **1130** may be configured to repeatedly switch (e.g., based on a fixed period, or the like) the inputs to the integrators **1135** and **1136** to compensate for temperature dependent variations in the integrators output. Similarly, the inputs to the pulse width modulators **1133** and **1134** may be repeatedly switched. The microcontroller may be configured to compensate for the repeated switching. Said differently, the microcontroller **1138** may include logic and/or circuitry to determine the position of the magnet **214** relative to the waveguide **212** as described above while taking into account the periodic switching of signal within the position determination module **1130**.

While the present invention has been disclosed with reference to certain embodiments, numerous modifications, alterations and changes to the described embodiments are possible without departing from the sphere and scope of the present invention, as defined in the appended claims. Accordingly, it is intended that the present invention not be limited to the described embodiments, but that it has the full scope defined by the language of the following claims, and equivalents thereof.

What is claimed is:

1. A position sensing system comprising:

a waveguide configured to receive a pulse at a first end and transmit the pulse through the waveguide resulting in an end of line pulse exiting the waveguide at a second end;

a magnet moveable relative to the waveguide, the magnet configured to cause a reflected pulse to be reflected back to the first end of the waveguide from a point of impedance discontinuity in the waveguide proximate the magnet; and

a compensator electrically coupled to the waveguide and configured to receive the pulse, the end of line pulse, and the reflected pulse and determine the point of impedance discontinuity based at least in part on the pulse, the end of line pulse and the reflected pulse, wherein the compensator comprises:

a pulse generator configured to generate the pulse; and

a position determination module configured to receive the pulse, the reflected pulse, and the end of line pulse and determine the point of impedance discontinuity based on a time between receiving the pulse and the reflected pulse and on a time between receiving the pulse and the end of line pulse.

2. The position sensing system of claim **1**, the position determination module further configured to determine the point of impedance discontinuity as a ratio of the time between receiving the pulse and the reflected pulse and two (2) times the time between receiving the pulse and the end of line pulse.

3. The position sensing system of claim **2**, wherein the ratio corresponds to the distance between the first end of the waveguide and the point of impedance discontinuity and the distance between the first and second end of the waveguide.

4. The position sensing system of claim **1**, wherein the magnet comprises either a permanent magnet or an electromagnet.

5. The position sensing system of claim **1**, wherein the waveguide is one of a microstrip waveguide, a stripline waveguide, or a rectangular waveguide.

6. The position sensing system of claim **1**, the pulse generator configured to:

generate the pulse;

receive the end of line pulse; and

generate one or more additional pulses with a period based at least in part on a time between generating the first pulse and receiving the end of line pulse.

7. A position sensor comprising:

a pulse generator electrically coupled to a waveguide and configure to generate a pulse and communicate the pulse to a first end of the waveguide; and

a position determination module electrically coupled to the waveguide, the position determination module configured to receive the pulse, an end of line pulse exiting a second end of the waveguide, and a reflected pulse reflected from a point of discontinuity in the waveguide, the position determination module further configured to determine the distance from the first end of the waveguide to the point of impedance discontinuity based on a time between receiving the pulse and the reflected pulse and a time between receiving the pulse and the end of line pulse,

wherein the end of line pulse corresponds to the pulse transmitted from the first end to the second end of the waveguide.

8. The position sensor of claim **7**, the position determination module configured to determine the distance from the first end of the waveguide to the point of impedance discontinuity based on a ratio of the time between receiving the pulse and the reflected pulse and two (2) times the time between receiving the pulse and the end of line pulse.

9. The position sensor of claim **8**, wherein the ratio corresponds to the distance between the first end of the waveguide and the point of impedance discontinuity and distance between the first and second end of the waveguide.

10. The position sensing system of claim **7**, wherein the point of impedance discontinuity is caused by a magnet proximate to the waveguide.

11. The position sensing system of claim **7**, the position determination module comprising:

a first pulse width modulator operably coupled to the signal generator and the second end of the waveguide, the first pulse width modulator configured to receive the pulse and the end of line pulse and generate a first voltage signal corresponding to the time between receiving the pulse and the end of line pulse;

a second pulse width modulator operably coupled to the first and the second end of the waveguide, the second pulse width modulator configured to receive the reflected pulse and the end of line pulse and generate a second signal voltage corresponding to the time between receiving the reflected pulse and the end of line pulse;

a first and a second integrator electrically coupled to the first and the second pulse width modulators, the first and the second integrators configured to generate third and fourth voltage signals corresponding to the first and the second voltage signals;

an analog to digital converter electrically coupled to the first and the second integrators and configured to generate a first digital signal and a second digital signal corresponding to the third and the fourth voltage signals; and

a microprocessor electrically coupled to the analog to digital converter and configured to receive the first and the second digital signals and determine the distance between the first end of the waveguide and the point of impedance discontinuity based on the first and the second digital signals.

12. The position sensor of claim **11**, wherein the microprocessor is configured to determine the distance based at least in part by dividing the first digital signal by two (2) times the second digital signal.

13. A method of determining a position of a magnet relative to a waveguide, the method comprising:

providing a waveguide;

providing a magnet movable relative to the waveguide, the magnet configured to generate a point of impedance discontinuity in the waveguide proximate to the magnet;

communicating a pulse to a first end of the waveguide;

receiving an end of line pulse from a second end of the waveguide, the end of line pulse corresponding to the pulse transmitted from the first end of the waveguide to the second end of the waveguide;

receiving a reflected pulse from the first end of the waveguide, the reflected pulse corresponding to a reflection of the pulse reflected from the point of impedance discontinuity; and

determining the position of the magnet relative to the waveguide based at least in part on the end of line pulse and the reflected pulse, wherein determining the position of the magnet relative to the waveguide comprises:

determining a time between communicating the pulse to the first end of the waveguide and receiving the end of line pulse from the second end of the waveguide; and

determining a time between communicating the pulse to the first end of the waveguide and receiving the reflected pulse from the first end of the waveguide.

14. The method of claim **13**, wherein the waveguide attached to either a movable object or a cooperating structure and the magnet is attached to the other of the movable object or the cooperating structure, the method further comprising determining the position of the moveable object relative to the cooperating structure based on the determined position of the magnet relative to the waveguide.

15. The method of claim **13**, determining the position of the magnet relative to the waveguide comprising determining the position of the magnet based at least in part on a ratio of the time between communicating the pulse to the first end of the waveguide and receiving the reflected pulse from the first end of the waveguide and two (2) times the time between communicating the pulse to the first end of the waveguide and receiving the end of line pulse from the second end of the waveguide.

16. The method of claim **15**, wherein the ratio corresponds to the distance between the first end of the waveguide and the point of impedance discontinuity and the distance between the first and second end of the waveguide.

17. The method of claim **13**, further comprising:

generating one or more additional pulses based at least in part on a time between communicating the pulse to the first end of the waveguide and receiving the end of line pulse from the second end of the waveguide; and

communicating the one or more additional pulses to the first end of the waveguide.

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