(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
30 May 2025 (30.05.2025)

WIPO | PCT

(10) International Publication Number
WO 2025/110883 A1

(51) International Patent Classification:
G01F 1/58 (2006.01) *E21B 43/00* (2006.01)
G01F 1/66 (2022.01) *G01N 22/00* (2006.01)
G01F 1/708 (2022.01) *G01N 33/22* (2006.01)
G01F 1/712 (2006.01) *G01N 33/24* (2006.01)
G01F 1/74 (2006.01) *G01N 33/28* (2006.01)

(21) International Application Number:
PCT/NO2024/050251

(22) International Filing Date:
18 November 2024 (18.11.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
20231283 24 November 2023 (24.11.2023) NO

(71) Applicant: **WIONETIC AS** [NO/NO]; Asnesåsen 17, 3222 Sandefjord (NO).

(72) Inventor: **GODAGER, Øivind**; Asnesåsen 17, 3222 Sandefjord (NO).

(74) Agent: **LIGL IP CONSULT AS**; Apotekergata 10, 0180 Oslo (NO).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE,

(54) Title: FLOW METER AND METHOD FOR REAL-TIME MONITORING OF A PROPERTY OF A MULTIPHASE FLUID FLOW

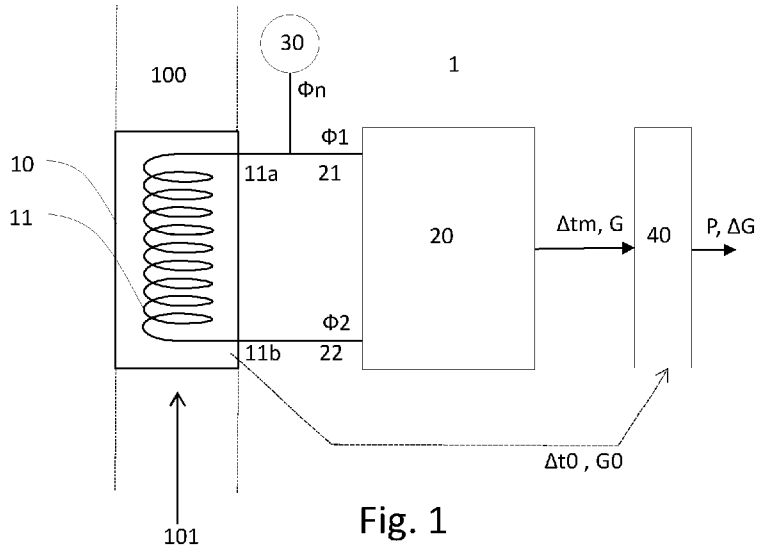


Fig. 1

(57) Abstract: Flowmeter and method for real-time monitoring of a property P of a multiphase fluid flow comprising; - a transmission line 11 configured to be arranged in a multi-phase fluid flow, wherein the transmission line comprises a first electric conductor with transmission line first and second ends 11a, 11b, - a radio frequency RF signal source 30 with a source signal Φn connected to the transmission line first end 11a, - a digital interval timer 20 configured to accumulate a time difference Δt between the first and second signals Φ1, Φ2 into an accumulated time difference Δtbeat, and determine a measured time difference Δtm representative of the time difference Δt based on the accumulated time difference Δtbeat.

[Continued on next page]

WO 2025/110883 A1

SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

FLOW METER AND METHOD FOR REAL-TIME MONITORING OF A PROPERTY OF A MULTIPHASE FLUID FLOW

TECHNICAL FIELD

[0001] The invention relates to instrumentation and measurement techniques to measure ratios of constituents in a multiphase flow, such as water content in a fluid stream related to e.g., petroleum production, wastewater treatment, etc.

BACKGROUND

[0002] The subject of multiphase flow measurement encompasses a number of technologies and applications, and the ability to predict or determine the properties of the fluid flow is important for the result of the processes where the multiphase flow is involved.

[0003] One such process may be oil and gas production, where the output from an oil and gas reservoir in many cases consists of a mixture of oil, water and gas. In order to successfully manage reservoirs and to optimize production and allocation of equipment, it is important to monitor oil, gas and water rates from individual wells.

[0004] Conventionally, test separators are used for this purpose. However, such separators require interruption of the production for a significant amount of time and cannot be used in real time. Due to fluctuations in the wells behavior, the results obtained during the measurement may not be correct in the periods between the measurements.

[0005] In addition, since test separators are costly, a common test separator is often connected to multiple wells by pipes and valves that in itself increases complexity and costs of the plant.

[0006] Therefore, production could be optimized if fluid flow could be monitored in-line in real time separately for each well.

[0007] The same considerations apply for other industries involving multiphase flow, such as e.g., for vegetable oils and fats, or wastewater treatment or recycling. Real time monitoring of the flow components and flow composition could improve production and reduce waste.

[0008] Norwegian patent 345738 Bl discloses an electromagnetic flowmeter and a method for measuring a property of a fluid composition, comprising a first electric conductor with first and second ends, configured to be arranged inside a fluid conduit carrying a fluid composition comprising hydrocarbons connected to an RF electric signal source.

[0009] US2008/0319685A1 discloses systems for measuring multiphase flows in a pipeline using a combination of venturi, microwave and radiation techniques, where the pipeline is configured to transport hydrocarbons.

[0010] CN112452565A discloses a cyclone for multiphase flow measurement, wherein the cyclone separates gas and liquid phases in three-phase flow and has a standard flow pattern.

[0011] CN103697950B is using a switchable venturi tube component, a single-energy gamma sensor, an online gas-liquid separation device and a double-energy gamma sensor for measuring flow of oil, gas and water.

[0012] WO2020204724 A1 and WO2023048578 A1 disclose in-line flowmeters 100 configured to be arranged in-line with a conduit supporting a multi-phase fluid flow comprising first and second matter groups, wherein a transmission line is connected to an RF source and a dual RF receiver connected to a signal processor in order to determine a property of the fluid composition of the multi-phase fluid flow.

[0013] US20200217708A1 discloses an ultrasonic flowmeter arrangement based on sequential measurements from two independent transducers placed in the flow path.

[0014] Flowmeters with phase comparison using analog components to convert the phase difference into voltage, is known from prior art. However, they may suffer from process, voltage and temperature variations, resulting in voltage drift, quantization error, increasing measurement nonlinearity and measurement error.

[0015] While the flowmeters above can give detailed information about multiphase flows, they require complex and costly instrumentation, which may limit their applicability, especially when it comes to permanent or long term installations in challenging environments.

SHORT SUMMARY

[0016] A goal with the present invention is to overcome the problems of prior art, and to disclose an in-line flow meter that may be used to monitor properties of a multi-phase fluid flow, such as e.g., water content, and that is less costly and simpler than prior art flowmeters.

[0017] The invention solving the above-mentioned problems is an in-line flowmeter and a method for real-time monitoring of a volumetric ratio of fluid according to the independent claims.

[0018] The flowmeter according to the invention is simple to manufacture and use in real life situations, such as in process plants where real time monitoring of a few essential parameters is important for the downstream processes.

[0019] In a specific application, the flowmeter may be installed in a well of a petroleum production system close to where the fluids are flowing into the production system and to monitor zones individually. If changes in the flow composition are detected, such as increased water level, measures can be taken immediately to keep production clean, and to save costs related to downstream treatment of increased water levels.

[0020] Continuous monitoring of individual zones and can also be used to continuously update the reservoir model in use.

[0021] As such the flowmeter may allow improved optimization of multi-zone intelligent wells.

[0022] The flowmeter may in some applications be deployed in harsh environments, such as in-line with a production tubing of a wellbore, allowing water ratio to be determined in real-time before the gas leaves the fluid due to reduced pressure.

[0023] The flowmeter requires few components and may be integrated on a single chip, such as an FPGA or ASIC chip.

[0024] Since the measurements can be carried out in real-time, processes, such as wellbores, may be optimized based on the output of the flowmeter while they are in operation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] Fig. 1 illustrates schematically an in-line flowmeter 1 according to an embodiment of the invention.

[0026] Fig. 2 illustrates schematically an in-line flowmeter 1 according to an embodiment of the invention, with additional details with regards Fig. 1.

[0027] Fig. 3 illustrates in a block diagram an embodiment of the invention where the interval timer 20 comprises a pair of chained hold sub-sub circuits 23a, 23b, 24a, 24b in the form of D Flip Flops, as well as a Phase Locked Loop PLL 26, responsible for setting the timebase signal $\emptyset_{TB}$ used by the hold sub-sub circuits 23a, 23b, 24a, 24b based on the signal source 30 as a reference.

[0028] Fig. 4 illustrates graphically an example of the relationship between the time difference Δt between the first and second signals Φ1, Φ2, the timebase signal ΦTB for triggering a sample, the first and second time accumulated outputs Φbeat1, Φbeat2 for the first and second signals Φ1, Φ2, respectively, and the accumulated time difference Δtbeat.

[0029] Fig. 5 illustrates graphically an example of the relationship between the velocity factor and the relative permittivity of a fluid for a given frequency.

[0030] Fig. 6 illustrates graphically a relationship between phase change and relative permittivity of the fluid for a transmission line of 1.5 m at a frequency of 22.125 MHz.

[0031] Fig. 7 is a schematic drawing showing the in-line flowmeter 1 arranged in line with a fluid conduit 100, where the fluid conduit section 10 is arranged in-line with the fluid conduit. A downhole unit 2 may be arranged close to the fluid conduit section 10. The local unit may comprise the digital interval timer 20 and the signal source 30 and communicate, as indicated by the arrow, with a remote unit that may be responsible for visualizing and/or further processing of the data.

[0032] Fig. 8 illustrates in a schematic drawing an embodiment where the in-line flowmeter 201 is part of a multi-zone intelligent well 200 frequently also termed an intelligent well completion. For the purpose of simplicity, typical components of a completion, such as packers, casings, gauges etc. have been left out from the drawing.

EMBODIMENTS OF THE INVENTION

[0033] In the following description, various examples and embodiments of the invention are set forth in order to provide the skilled person with a more thorough understanding of the invention. The specific details described in the context of the various embodiments and with reference to the attached drawings are not intended to be construed as limitations. Rather, the scope of the invention is defined in the appended claims.

[0034] The embodiments described below are numbered. In addition, dependent embodiments defined in relation to the numbered embodiments are described. Unless otherwise specified, any embodiment that can be combined with one or more numbered embodiments may also be combined directly with any of the dependent embodiments of the numbered embodiments referred to.

[0035] In a first independent embodiment ED01 the flowmeter 1 comprises;
- a transmission line 11 comprising a first electric conductor wherein the transmission line 11 has transmission line first and second ends 11a, 11b,
- a radio frequency RF signal source 30 with a source signal Φn connected to the

transmission line first end 11a,
- a digital interval timer 20 comprising interval timer first and second inputs 21, 22 connected to the transmission line first and second ends 11a, 11b, respectively, wherein the digital interval timer 20 is configured to accumulate a time difference Δt between the first and second signals Φ1, Φ2 on the interval timer first and second inputs 21, 22 into an accumulated time difference Δtbeat, and determine a measured time difference Δtm representative of the time difference Δt based on the accumulated time difference Δtbeat.

[0036] In an embodiment ED02 according to ED01, the flowmeter comprises a timebase circuit 25, wherein the source signal Φn is input to the timebase circuit 26, and wherein the timebase circuit 26 is configured to derive a timebase signal ΦTB from the source signal Φn, where a frequency of the timebase signal ΦTB is different from a frequency of the source signal Φn.

[0037] In an embodiment ED03 according to ED02, the frequency of the timebase signal ΦTB is a function of the frequency of the source signal Φn and a delay factor N given by

[0038] $\emptyset_{TB} = \left[\frac{N}{N+1}\right] \emptyset_n$.

[0039] In an embodiment ED04 according to any of ED01 to ED03, the digital interval timer comprises a hold circuit 25 configured to accumulate the time difference Δt between the first and second signals Φ1, Φ2 into the accumulated time difference Δtbeat.

[0040] In an embodiment ED05 according to ED04, the hold circuit 25 is clocked by the timebase signal ΦTB.

[0041] In an embodiment ED06 according to ED05, the hold circuit comprises first and second sub hold circuits 23, 24, with respective first and second signal inputs, first and second signal outputs and first and second clock inputs, wherein the first signal Φ1 is connected to the first signal input, the second signal Φ2 is connected to the second signal input, and wherein the the timebase signal ΦTB is connected to the first and second clock inputs.

[0042] In an embodiment ED07 according to ED06, the first signal output only changes digital value when the first signal has a different digital value than its previous value for a previous timebase clock pulse when the first sub hold circuit is triggered by a timebase clock pulse.

[0043] Likewise, the second signal output only changes digital value when the second signal has a different digital value than its previous value for a previous timebase clock pulse when the second sub hold circuit is triggered by a timebase clock pulse.

[0044] In an embodiment ED08 according to any of ED03 to ED07, the digital interval timer 20 is configured to determine a measured time difference Δtm as a function of the accumulated time difference Δtbeat and the delay factor N.

[0045] The digital interval timer may comprise a phase shift detection circuit 28 configured to determine the measured time difference Δtm as a function of the accumulated time difference Δtbeat and the delay factor N.

[0046] In an embodiment ED09, according to any of the embodiments ED01 to ED08, the accumulated time difference Δtbeat is determined by a difference between first and second time accumulate output Φbeat1, Φbeat2 for the first and second signals Φ1, Φ2, respectively.

[0047] The delay factor N should always be the same in the hold circuit 25 and the phase detection circuit 28, since the hold circuit multiplies the incoming phase difference with N to delay the difference and the detection circuit 28 divides the difference by N in order to end up with a correct value for the measured phase difference.

[0048] In an embodiment ED10 according to ED09, the measured time difference is

[0049] $\Delta tm(t) = \Delta t_{beat}(t) \cdot \frac{\emptyset_{beat}}{\emptyset_n} = \left(\Delta t_{beat}(t)\right) \cdot \left[1 - \left(\frac{N}{N+1}\right)\right]$

[0050] The higher N is, the smaller is the difference between the signals $\emptyset_{TB}$ and $\emptyset_n$. This frequency difference is represented by $\emptyset_{beat}t$. $\emptyset_{beat1}t$ and $\emptyset_{beat2}t$ representing the first and second time accumulated output of the respective first and second signals $\emptyset_1 t$ and $\emptyset_2 t$ are identical and is therefore denoted $\emptyset_{beat}t$ in parts of the description.

[0051] In an embodiment ED11 according to any of ED06 to ED10, each of the first and second sub hold circuits 23, 24 comprises chained delay circuits 23a, 23b, 24a, 24b, where an output of on one delay circuit is connected to the input of the next delay circuit, wherein the delay factor N increases with the number of delay circuits in the chain.

[0052] In an embodiment ED12 according to any of ED01 to ED11 the digital interval timer is a time interval counter.

[0053] In an embodiment ED13 according to any of ED11 or ED12, any of the delay circuits 23a, 23b, 24a, 24b, are D Flip-Flops with at least a data input D, an output Q and a clock input.

[0054] In an embodiment ED14 according to any of ED01 to ED13 the digital interval timer 20 is a progressive phase shift PPS detection circuit.

[0055] In an embodiment ED15 according to any of ED01 to ED14, the flowmeter 1 comprises;
- a property calculation circuit 40 configured to determine a property P of the fluid composition, based on the measured time difference Δtm.

[0056] In an embodiment ED16 according to ED15 the transmission line has a predetermined signature electric length G0 and the property calculation circuit 40 is configured to determine the property P based on the measured time difference Δtm and the signature electric length G0.

[0057] In an embodiment ED17 according to any of ED01 to ED16 the property P is water ratio.

[0058] In an embodiment ED18 according to any of ED01 to ED17 the signal source 30 has a single fixed frequency.

[0059] In an embodiment ED19 according to ED18 the signal source 30 is a crystal resonator.

[0060] In an embodiment ED20 according to any of ED01 to ED19 the flowmeter 1 comprises one or more deglitching circuits 27a, 27b. The deglitching circuits may be configured to deglitch e.g., source signal Φn and/or the first and second time accumulate output Φbeat1 and Φbeat2.

[0061] In an embodiment ED21 according to any of ED01 to ED20, the flowmeter comprises a second signal source 31, wherein the flowmeter is configured to temperature compensate the measured time difference Δtm or phase change based on the frequency of the second signal source.

[0062] Compensation may be needed where the temperature differs from the temperature that was used to characterize the phase change dependency of the permittivity, e.g., 20 degrees Celsius.

[0063] The signal from the second signal source may be coupled to the phase shift detection circuit 28 that takes the frequency of the second signal source into account when calculating the measured time difference Δtm.

[0064] In an embodiment ED22 according to ED21, any of the first and second signal sources are quartz crystal resonators.

[0065] In an embodiment ED23 according to ED22, the crystallographic orientation of the first signal source is selected from a temperature stable cut comprising an SC-Cut.

[0066] In an embodiment ED24 according to any of ED20 to ED23, the crystallographic orientation of the second signal source is selected from the group of cuts comprising AC-Cut, BC-Cut or Y-Cut.

[0067] Due to its crystallographic orientations, the second signal source will have an output frequency that is a function of temperature and after calibration the frequency may be seen as a representation of the responsiveness of the permittivity to temperature.

[0068] Due to its electric and mechanical characteristics, the flowmeter of the invention may be used to achieve practical results in new applications. One such application is to control flow in an aggregated fluid flow of a process plant, where the aggregated fluid flow is aggregated from smaller tributary flows, and wherein the quality of the aggregated fluid flow depends on the quality of each of the tributary flows.

[0069] In an embodiment ED25 according to any of ED13 to ED24 the flowmeter comprises;
- a fluid conduit section 11 configured to be arranged in-line with a fluid conduit 100, wherein the first electric conductor is arranged inside or outside the fluid conduit section 11 to determine the parameter P of a fluid flow internal or external to the fluid conduit section 10, respectively.

[0070] In an embodiment ED26 according to ED25, wherein the first electric conductor is arranged in an annulus of a multi-zone intelligent well 200.

[0071] In an independent embodiment ED27, the invention is a process plant comprising;
- an aggregate conduit,
- two one or more tributary conduits and
- two one or more controllable valves, each arranged between one or more of said respective tributary conduits and the aggregate conduit, wherein the controllable valves are configured to control fluid flows from the one or more tributary conduits into the aggregate conduit,
- one or more flowmeters 1 of any of ED13 to ED26 configured to measure the parameter P in each of said two one or more tributary fluid conduits, wherein the one or more flowmeters 1 are connected to the respective one or more controllable valves, via a control system, wherein the control system is configured for reducing throughput in a controllable valve if the property P of the corresponding tributary fluid flow is above or below a pre-defined value.

[0072] A specific application is optimization of multi-zone intelligent wells for petroleum production. The tributary conduits may here be lateral bores and the aggregate conduit may be the production tubing. The inside of and outside of the production tubing are therefore different zones in this context.

[0073] In an embodiment ED28 according to ED27, the aggregate conduit and the two one or more tributary conduits are members of a multi-zone intelligent well and the property P is water ratio, wherein the control system is configured for;
- reducing throughput of at least one of said intelligent control valves if the water ratio of a corresponding zone is above a pre-defined value.

[0074] The invention is also a method for real-time monitoring of a property P of a multiphase fluid flow.

[0075] In an independent embodiment EM01 the method comprises;
arranging a fluid conduit section 10 comprising a transmission line 11 with transmission line first and second ends 11a, 11b in -line with a fluid conduit 100 supporting a multiphase fluid flow,
- connecting a radio frequency RF signal source 30 with a source signal Φn to the transmission line first end 11a,
- connecting interval timer first and second inputs 21, 22 of an interval timer 20 to the transmission line first and second ends 11a, 11b, respectively,
- accumulating a time difference between the first and second signals Φ1, Φ2 on the interval timer first and second inputs 21, 22 into an accumulated time difference Δtbeat,
- determine a measured time difference Δtm between first and second signals Φ1, Φ2 on the interval timer first and second inputs 21, 22 based on the accumulated time difference Δtbeat.

[0076] In an embodiment EM02, according to EM01, the method comprises;
– deploying the fluid conduit section 10 with the transmission line 11 in vacuum,
- measuring an electric length of the transmission line 11, wherein the electric length in vacuum is the signature electric length G0.

[0077] In an embodiment EM03 according to EM01 or EM02, the frequency of the timebase signal ΦTB is a function of the frequency of the source signal Φn and a delay factor N given by

[0078] $\emptyset_{TB} = \left[\frac{N}{N+1}\right] \emptyset_n$.

[0079] In an embodiment EM04 according to any of EM01 to EM03, the method comprises;
- determining a property P of the fluid composition, based on the measured time difference Δtm.

[0080] In an embodiment EM05 according to EM06 the method comprises;
- determining the measured time difference Δtm based on the accumulated time difference Δtbeat and the delay factor N.

[0081] In an independent embodiment EM06 the invention is a method for real-time monitoring of a property P of a multiphase fluid flow, comprising;
- arranging a flowmeter 1 of any of ED01 to ED24 in-line with a fluid conduit 100.

[0082] In an embodiment EM07 according to any of EM01 to EM07, the method comprises;
- deriving a timebase signal ΦTB from the source signal Φn, wherein a frequency of the timebase signal ΦTB is different from a frequency of the source signal Φn.

[0083] In an embodiment EM08 according to EM05, the method comprises;
- determining the property P based on the measured time difference Δtm and the predetermined electric length G0.

[0084] In an embodiment EM06 according to EM05 the method comprises;
- determining the measured time difference Δtm based on the accumulated time difference Δtbeat and the delay factor N.

[0085] In an independent embodiment ES01 the invention is a method for real-time monitoring of a property P of a multiphase fluid flow, comprising;
- arranging a flowmeter 1 of any of ED01 to ED23 in-line with a fluid conduit 100.

[0086] In an independent embodiment ET01 the invention is a method for optimization of an aggregated fluid flow aggregated from one or more tributary fluid flows, wherein the flows from each of the tributary fluid flows flowing into the aggregate fluid flow is controlled by respective controllable valves, wherein the method comprises;
- arranging one or more flowmeters 1 of any of ED01 to ED24 in each of said respective one or more tributary fluid flows,
- connecting the one or more flowmeters 1 to respective controllable valves,
- reducing throughput of at least one of said controllable valves if the property P of a corresponding tributary fluid flow is above or below a pre-defined value.

[0087] In an embodiment ET02 of ET01 the aggregated fluid flow and the two or more tributary fluid flows are members of a multi-zone intelligent well and the property P is water ratio, wherein the method comprises;
- reducing throughput of at least one of said intelligent control valves if the water ratio of a corresponding zone is above a pre-defined value.

[0088] In this manner production from the different tributaries, e.g., laterals in this case can be optimized.

[0089] The controllable valves may be connected to the flowmeters via one or more control systems and be operated electrically or hydraulically.

[0090] The controllable valves may be interval control valves ICV used in intelligent wells.

[0091] In the following sections more details related to the characteristics of the transmission line as a function of the composition of the fluid flowing through the fluid conduit section will be given.

[0092] Velocity factor and electric length are two terms that are related to the characteristics of a transmission line.

[0093] The velocity factor is the ratio of the speed of a wavefront in a medium, to the speed of light in a vacuum.

[0094] In Fig. 5, an example of the relationship between the velocity factor and the relative permittivity of a fluid is illustrated for a specific frequency. These characteristics are often referred to in the terms of phase shift or "electrical length" at a given frequency. The "electrical length" is used to define phase shift introduced by transmission of a signal over a conductor or transmission line.

[0095] Due to the velocity factor of a particular transmission line, for instance, the transit time of an RF signal in a certain length of cable is equal to the transit time over a longer distance when traveling at the speed of light. So, for example, a pulse sent down a 2 meter long coaxial cable whose velocity factor is 67% would arrive at the end of the cable at the same time that the pulse arrives at the end of a bare wire of length 3 meters over which it propagates at the speed of light, and one might refer the 2 meter section of coax having an electrical length of 3 meters. If the coax is loaded additionally the velocity factor would change correspondingly. So, for a 50 % factor the electrical length of the line would equal 4 meters. Thus, we see that the propagation of the RF-Wave is delayed in the transmission line and highly depending on the line electrical characteristics. These characteristics is often referred to in design as terms of phase shift or electrical length at a

given frequency. Some transmission lines consist only of bare conductors, in which case their signals propagate at the speed of light, c. More often the signal travels at a reduced velocity κc, where κ kappa is the velocity factor, a number less than 1, representing a ratio of the speed of light.

[0096] Thus, in a transmission line, a signal travels at a rate controlled by the effective capacitance and inductance.

[0097] In the multiphase flow meter of the invention, the transmission line and the fluid conduit section are exposed to a dielectric fluid filling the space in between the wire and ground plane. The relative permittivity or dielectric constant of the fluid therefore affects the distributed capacitance along the transmission line. In turn, this reduces the velocity factor below unity. The velocity factor will also be reduced due to relative permeability μ_r of the materials surrounding the transmission line and the ground plane which increase the disturbed inductance.

[0098] Taking permittivity and permeability properties of the fluid conduit section into account as fluid flows through the Multiphase flow meter, the space between the transmission line and the internal wall of the fluid conduit section is filled with a dielectric fluid of relative permittivity ϵ_r. The velocity of the electromagnetic RF-wave is then reduced by the velocity factor κ stipulated below:

$$\kappa = \frac{v_p}{c} = \frac{1}{\sqrt{\epsilon_r \mu_r}} \approx \frac{1}{\sqrt{\epsilon_r}}.$$

[0099] Thus, this reduced velocity factor would apply to propagation of the RF-signal along the transmission line which is immersed in a large space filled with that fluid dielectric. Part of the electromagnetic RF-wave surrounding each of the conductors ¨feels¨ the effect of the dielectric fluid, and parts are in free property space of multiphase flow meter. Then it is possible to define an effective relative permittivity ϵ_{eff} which then predicts the velocity factor according to:

$$\kappa = \frac{1}{\sqrt{\epsilon_{eff}}}$$

[0100] ϵ_{eff} is computed as a weighted average of the relative permittivity of free space and that of the dielectric properties of the fluids as given in e.g. Table 1 below:

$$\epsilon_{eff} = 1 - F + F\epsilon_r$$

[0101] where the Cell factor, F, expresses the effective proportion of space so affected by the dielectric fluid.

[0102] In the case of a cell where the majority of the volume in between the electric wire and the ground plane is filled with a dielectric fluid, the Cell factor is unity, since the electromagnetic RF-wave is confined to that region. In some applications, typically as in smaller dimensions flow meters, the Cell factor can be much smaller due to dimensional proportions between the meters housing and the transmission lines. Regardless, any dimensional proportions mentioned, radio frequencies will have its velocity factor as well as its characteristic impedance specific for the application intended. In the case of an ideal flow meter, where the Cell factor F=1, the velocity factor is solely determined by the dielectric fluid properties according to e.g. Table 1 below.

[0103] For example, a typical velocity factor for a flow meter is 0.577, corresponding to a dielectric constant of 3.0 typical for oil. Suppose we send a 22.125 MHz signal down a short section of a transmission line, and delay it by 36°. In free space, this frequency corresponds to a wavelength of λ_0=13.56m, so a delay of λ/10 would require an electrical length of 1.36m. Applying the velocity factor of 0.577, this results in a physical length of cable 0.78 m long.

[0104] Vice-versa, for a dielectric fluid corresponding to 80 seawater the velocity factor is 0.112. Again, using the 22.125 MHz signal the resulting physical length of the transmission line would be reduced to 0.15 m to measure the same 36 degrees phase change.

[0105] Nevertheless, as the transmission line length of the WCM is given by the ratio of phase change needed to accurately measure the properties of the fluid is given by the lower dielectric values to be measured using a 22.125 MHz RF-Wave, the transmission line length would in typical application be 1.5 meter long.

[0106] As an example, the phase change measured to establish the fluid dielectric properties could typically be as illustrated in Fig. 6, illustrating the relationship between phase change and relative permittivity of the fluid for a transmission line of 1.5 m at a frequency of 22.125 MHz. If we consider the endpoints of the graph, a phase difference of 69 degrees corresponds to a relative fluid permittivity of 3.0, while a phase difference of 360 degrees corresponds to a relative permittivity of 80.0.

[0107] TABLE 1, below, shows the characteristic dielectric and conductive properties of fluids produced from a well.

[0108] Petroleum Stream	[0109] Dielectric Constant	[0110] Conductivity S/m
[0111] Water	[0112] 80	[0113] 3
[0114] Oil	[0116] 3	[0118] 0.01

[0115] Gas	[0117] 1	[0119]

TABLE 1. Typical electric properties of fluids produced from an oil well.

[0120] The fluid conduit section 10 of the flowmeter 1 is an electric conductor and has an electric length G that is the physical length of the conduit divided by the wavelength λ. The electric length can therefore be seen as the length of the conduit measured in wavelengths. The wavelength and the corresponding electric length depend on the permittivity of the material inside the conduit for a given frequency due to the change in phase velocity caused by different fluids as explained previously.

[0121] Based on the considerations above, we see that the difference in relative permittivity and/or dielectric constant of the fluid passing through the fluid conduit section will result in different electric-lengths.

[0122] A signature electric length G0 of the fluid conduit may be determined initially to ease determination of fluid properties when the flowmeter is installed. The signature electric length may e.g., be measured when the intended reference signal and frequency is applied to the internal transmission line of the empty fluid conduit in vacuum.

[0123] The electric length for the fluid conduit section filled with fluids is an electric length G that varies with the permittivity of the fluid. Permittivity is an electrical property that will be different for each of the components in the fluid mixture, and the permittivity of the mixture is therefore a measure of the fractions of the different components.

[0124] The electric length difference ΔG can be calculated from the difference between the signature electric length G0 and the measured electric length G. The electric length difference ΔG corresponds directly to a difference in phase shift or a time difference Δt.

[0125] Due to the small variations, phase shift or time delay cannot easily be directly measured by comparing the input first signal Φ1, and output second signal Φ2 of the transmission line 11. According to the invention, a digital interval timer circuit 20 is used to increase measurement resolution and accuracy. The digital interval timer circuit is designed to digitally compare the two signals in order to determine the phase deviation and thus the time difference Δt between them. The electric length G0 of the fluid conduit can then be found from the time difference.

[0126] The invention can also be seen as a simplified liquid phase meter where electric properties of the fluid is established by measuring the change of "electrical length" of an exposed reference sensor conduit directly. This can be accomplished e.g. by time accumulation as explained in the following.

[0127] The electric length difference ΔG can be found by comparing the phase difference between input and output signals of the sensor reference conduit. As the signals compared have the same frequency and the conduit have a fixed mechanical length i.e. the signature length G0 as measured in vacuum exposed to a fluid or fluid composition, the property of the fluid composition exposed will change the electric length G of the conduit. Thus, the effective change in electrical length of the conduit can the directly measured by calculating the time difference between the signals. The time difference Δt between first and second signals ∅1 and ∅2 is shown in Figure 3. The rising edges of the two signals are detected by phase detection circuits and compared with a timebase signal ΦTB. When the any of the first or second signals ∅1 and ∅2 are not aligned with the timebase signal, the incoming signal is delayed by a delay time τ until edge alignment of the two signals are detected. The edge alignment is then detected after m time delays τ, and the total delay time is given by:

$$\Delta tTD = m \cdot \tau$$

[0128] Circuits to measure and calculate the time difference between the signals can be constructed by analog elements according to prior art. However, in some applications, such as e.g., oilwell, the environment is severe and its conditions do not favor the use of analog elements as they suffer to large area and poor environment stability. Hence, a crystal resonator Timebase Oscillator with output frequency $\emptyset_n$ and digital circuits may be used to measure the progressive phase shift over the sensor reference conduit. F

[0129] Moreover, a digitally controlled delay line consisting of finite elements of step time delay elements equal to τ has been proposed. Further, a stable wide-temperature crystal reference oscillator may be selected as the timebase to get an acceptable measurement precision. Typically, this is achieved by constructing a reference oscillator or time-source based on a SC-cut crystal resonator. Using this reference timebase will ensure the step delays τ maintain relative constant in time over the temperature range.

[0130] This concept is reconfigurable as it is built around a fully digital time machine to measure the propagation of the signal over the conduit which allows us to select a suitable time reference source, e.g., a crystal frequency, that will fit a given length of wire and vise versa.

[0131] A specific embodiment ED0 of the invention will now be explained with reference to Fig. 3 and Fig. 4. In this embodiment, the digital interval timer circuit is a digital progressive phase shift PPS detector. The PPS detector is capable of femtosecond time resolution using a relatively low frequency counter or timebase frequency.

[0132] The PPS detector circuit is designed to digitally compare the first and second signals $\emptyset_1(t)$ and $\emptyset_2(t)$ in order to determine the frequency and phase deviation between them. In this case the source signal $\emptyset_n$ of the signal source 30 is fed to the transmission line first end 11a as well as to the input for the internal Phase Locked Loop PLL responsible for setting the timebase signal $\emptyset_{TB}(t)$ used by the first and second hold sub-sub circuits 23a, 23b in the form of D Flip-Flops 23a, 23b, 24a, 24b.

[0133] The frequency of the timebase signal $\emptyset_{TB}(t)$ is set by the following equation:

$$\emptyset_{TB} = \left[\frac{N}{N+1}\right] \emptyset_n$$

[0134] N is selected and determines the precision of the PPS estimation of Δt and is an integer number. In the current embodiment N=4. As the N and $\emptyset_n$ values increase, the maximum resolution increases. The equation below gives the maximum resolution or the smallest detectable phase shift for the selection or combination of N and $\emptyset_n$.

$$\Delta t_{MIN} = \frac{1}{[N \cdot \emptyset_n]}$$

[0135] Figure 4 shows a timing diagram of the D-type Flip-Flop´s outputs Φbeat1 and Φbeat2, for N=4. It is easy to verify that the higher N is, the smaller is the difference between the signals $\emptyset_{TB}$ and $\emptyset_n$, this frequency difference is represented by $\emptyset_{beat}t$. $\emptyset_{beat1}t$.and $\emptyset_{beat2}t$ in Fig. 4 representing the first and second time accumulated output of the respective first and second signals $\emptyset_1 t$ and $\emptyset_2 t$ are identical and is therefore denoted $\emptyset_{beat}t$ in the following.

[0136] In turn the time difference $\Delta t(t)$, between $\emptyset_1(t)$ and $\emptyset_2(t)$ is given by:

$$\Delta t(t) = \Delta t_{beat}(t) \cdot \frac{\emptyset_{beat}}{\emptyset_n} = \left(\Delta t_{beat}(t)\right) \cdot \left[1 - \left(\frac{N}{N+1}\right)\right]$$

[0137] Where $\Delta t_{beat}(t)$ is the time difference between the positive transition of both $\emptyset_{beat1}(t)$ and $\emptyset_{beat2}(t)$, as shown in Figure 4.

[0138] The output of the Flip-Flop´s normally show glitches as the time resolution increases. This occurs as the PPS starts to sample the jitter from the timing signals. These glitches need to be filtered and removed and this is achieved by adding the first and second digital deglitch circuits 27a, 27b as shown in Fig. 3. Thus, the function of the deglitching algorithm is to remove the glitches preventing erroneous measurements.

[0139] Typically, one of the following deglitching techniques may be used:

- First Edge – selects the first positive edge as a good edge for the Progressive Phase Shift Detector

- Mean Edge – selects the as the best edge the mean edge between all the glitches

- Zero Count – counts the number of 1´s and 0´s and selects as the best edge the time position where the number of 0´s is the same as the number of 1´s.

[0140] The PPS detector circuit includes a section for deglitching of the signals as the system will encounter glitches from the signal source 30, as well as the signal propagating along the reference sensor.

[0141] The deglitching needs normally be very simple, due to the fact that they are going to be implemented in high-temperature rated hardware where resources are limited.

[0142] For a given multiphase fluid, such as a multiphase fluid comprising oil water and gas, the relationship between fractions of the components and permittivity have been pre-determined and are available in the literature. Given the permittivity, other properties of the components, such as the water fraction can therefore be found from permittivity from already established data.

[0143] For the purpose of the invention, however, a further characterization is needed in order to determine the relationship between the change in electric length and permittivity, and/or more directly the properties, such as the water fraction. This can be done by e.g., characterization of the electric length of some known fluids and applying curve approximation.

[0144] Fig. 8 shows an embodiment wherein the flowmeter is part of an intelligent well 200. The wellbore 210 has a main bore 211 and a lateral bore 212. In the main bore the fluid flow 101 flows directly into the production tubing 215, while the fluid flow 101 from the lateral bore flows into the annulus around the production tubing and enters the production tubing through the interval control valve IVC 220. The ICV enables zonal control and is usually operated from the surface through control and signal lines 225. The flowmeter is also connected to the surface via the control and signal line and the control system operating the ICV. The ICV may therefore be controlled by a parameter P detected by the flowmeter, such as water level in order to optimize production. More ICVS and flowmeters can be added, e.g., where there are more lateral bores. For readability the transmission line of the flowmeter is shown without physical protection in the drawing.

[0145] In the exemplary embodiments, various features and details are shown in combination. The fact that several features are described with respect to a particular

example should not be construed as implying that those features by necessity have to be included together in all embodiments of the invention. Conversely, features that are described with reference to different embodiments should not be construed as mutually exclusive. As those with skill in the art will readily understand, embodiments that incorporate any subset of features described herein and that are not expressly interdependent have been contemplated by the inventor and are part of the intended disclosure. However, explicit description of all such embodiments would not contribute to the understanding of the principles of the invention, and consequently some permutations of features have been omitted for the sake of simplicity or brevity.

CLAIMS

1. A flowmeter 1 comprising;
- a transmission line 11 configured to be arranged in a multi-phase fluid flow, wherein the transmission line comprises a first electric conductor with transmission line first and second ends 11a, 11b,
- a radio frequency RF signal source 30 with a source signal Φn connected to the transmission line first end 11a,
- a digital interval timer 20 comprising interval timer first and second inputs 21, 22 connected to the transmission line first and second ends 11a, 11b, respectively, wherein the digital interval timer 20 is configured to accumulate a time difference Δt between the first and second signals Φ1, Φ2 into an accumulated time difference Δtbeat, and determine a measured time difference Δtm representative of the time difference Δt based on the accumulated time difference Δtbeat.

2. The flowmeter of claim 1, comprising a timebase circuit 26, wherein the source signal Φn is input to the timebase circuit 26, and wherein the timebase circuit 26 is configured to derive a timebase signal ΦTB from the source signal Φn, where a frequency of the timebase signal ΦTB is different from a frequency of the source signal Φn.

3. The flowmeter of claim 2, wherein the frequency of the timebase signal ΦTB is a function of the frequency of the source signal Φn and a delay factor N, given by

$$\emptyset_{TB} = \left[\frac{N}{N+1}\right] \emptyset_n \ .$$

4. The flowmeter of any of claims 1 to 3, wherein the digital interval timer comprises a hold circuit 25 configured to accumulate the time difference Δt between the first and second signals Φ1, Φ2 into the accumulated time difference Δtbeat.

5. The flowmeter of claim 4, wherein the hold circuit 25 is clocked by the timebase signal ΦTB.

6. The flowmeter of claim 5, the hold circuit comprises first and second sub hold circuits 23, 24, with respective first and second signal inputs, first and second signal outputs and first and second clock inputs, wherein the first signal Φ1 is connected to the first signal input, the second signal Φ2 is connected to the second signal input, and wherein the timebase signal ΦTB is connected to the first and second clock inputs.

7. The flowmeter of any of claims 3 to 6, wherein the digital interval timer 20 is configured to determine a measured time difference Δtm as a function of the accumulated time difference Δtbeat and the delay factor N.

8. The flowmeter of any of any of the claims above, wherein the accumulated time difference Δtbeat is determined by a difference between the first and second time accumulate output Φbeat1, Φbeat2 for the first and second signals Φ1, Φ2, respectively and the measured time difference Δtm is given by

$$\Delta tm = (\Delta t_{beat}) \cdot \left[1 - \left(\frac{N}{N+1}\right)\right]$$

9. The flowmeter of any of claims 6 to 8 above, wherein each of the first and second sub hold circuits 23, 24 comprises chained delay circuits 23a, 23b, 24a, 24b, where an output of on one delay circuit is connected to the input of the next delay circuit, wherein the delay factor N increases with the number of delay circuits in the chain.

10. The flowmeter of any of the claims above, wherein the digital interval timer is a time interval counter.

11. The flowmeter of any of claims 1 to 10, wherein the digital interval timer 20 is a progressive phase shift PPS detection circuit.

12. The flowmeter of any of the claims above, comprising;
- a property calculation circuit 40 configured to determine a property P of the fluid composition, based on the measured time difference Δtm.

13. The flowmeter of claim 12, wherein the transmission line has a predetermined signature electric length G0 and the property calculation circuit 40 is configured to determine the property P based on the measured time difference Δtm and the signature electric length G0.

14. The flowmeter of any of the claims above, wherein the property P is water ratio.

15. The flowmeter of any of the claims above, wherein the signal source 30 is a crystal resonator.

16. The flowmeter of any of the claims above, comprising a second signal source 31, wherein the flowmeter is configured to temperature compensate the measured time difference Δtm based on the second signal sources.

17. The flowmeter of claim 15 or 16, wherein the crystallographic orientation of the first signal source is selected from a temperature stable cut comprising an SC-Cut.

18. The flowmeter of any of claims 16 to 17 wherein the crystallographic orientation of the second signal source is selected from the group of cuts comprising AC-Cut, BC-Cut or Y-Cut.

19. The flowmeter of any of claims 1 to 18, comprising;
- a fluid conduit section 11 configured to be arranged in-line with a fluid conduit 100, wherein the first electric conductor is arranged inside or outside the fluid conduit section 11 to determine the parameter P of a fluid flow internal or external to the fluid conduit section 10, respectively.

20. The flowmeter of claim 19, wherein the first electric conductor is arranged in an annulus of a multi-zone intelligent well.

21. A process plant comprising
- an aggregate conduit,
- one or more tributary conduits and
- one or more controllable valves, arranged between one or more of said respective tributary conduits and the aggregate conduit, wherein the controllable valves are configured to control fluid flows from the one or more tributary conduits into the aggregate conduit,
- one or more flowmeters 1 of any of claims 13 to 24 configured to measure the parameter P in each of said one or more tributary fluid conduits, wherein the one or more flowmeters 1 are connected to the one or more controllable valves via a control system, wherein the control system is configured for reducing throughput in a controllable valve if the property P of the corresponding tributary fluid flow is above or below a pre-defined value.

22. The process plant of claim 21 wherein the aggregate conduit and the one or more tributary conduits are members of a multi-zone intelligent well and the property P is water ratio, wherein the control system is configured for;
- reducing throughput of at least one of said intelligent control valves if the water ratio of a corresponding zone is above a pre-defined value.

23. A method for real-time monitoring of a property P of a multiphase fluid flow, comprising;
- arranging a transmission line 11 with transmission line first and second ends 11a, 11b in a multiphase fluid flow,
- connecting a radio frequency RF signal source 30 with a source signal Φn to the transmission line first end 11a,
- connecting interval timer first and second inputs 21, 22 of an interval timer 20 to the transmission line first and second ends 11a, 11b, respectively,

- accumulating a time difference Δt between the first and second signals Φ1, Φ2 into an accumulated time difference Δtbeat,
- determine a measured time difference Δtm between first and second signals Φ1, Φ2 oo the interval timer first and second inputs 21, 22 based on the accumulated time difference Δtbeat.

24. The method of claim 23 comprising;
– deploying the fluid conduit section 10 with the transmission line 11 in vacuum,
- measuring an electric length of the transmission line 11, wherein the electric length in vacuum is the signature electric length G0.

25. The method of claim 24, comprising;
deriving a timebase signal ΦTB from the source signal Φn, wherein a frequency of the timebase signal ΦTB is different from a frequency of the source signal Φn.

26. The method of any of claims 23 to 25, comprising;
- determining a property P of the fluid composition, based on the measured time difference Δtm.

27. The method of any of claims 23 to 26 comprising;
– deploying the transmission line 11 in vacuum,
- measuring an electric length of the transmission line 11, wherein the electric length in vacuum is the signature electric length G0.

28. The method of any of claims 23 to 27 comprising;
- determining the property P based on the measured time difference Δtm and the predetermined electric length G0.

29. The method of any of claims 25 to 28 comprising;
- determining the measured time difference Δtm based on the accumulated time difference Δtbeat and the delay factor N.

30. A method for real-time monitoring of a property P of a multiphase fluid flow, comprising;
- arranging the transmission line 11 inside a fluid conduit 10 for measuring the multiphase flow inside the conduit or arranging the transmission line 11 outside the fluid conduit for measuring the multiphase flow outside the fluid conduit.

31. A method for real-time monitoring of a property P of a multiphase fluid flow, comprising;
- arranging a flowmeter 1 of any of claims 1 to 22 in-line with a fluid conduit 100.

32. A method for optimization of an aggregated fluid flow aggregated from one or more tributary fluid flows, wherein the flow of each of the one or more tributary fluid flows into the aggregate fluid flow is controlled by respective controllable valves, wherein the method comprises;
- arranging one or more flowmeters 1 of any of claims 13 to 22 in each of said one or more tributary fluid flows, respectively,
- connecting the one or more flowmeters 1 to respective controllable valves,
- reducing throughput of said respective controllable valve if the property P of a corresponding tributary fluid flow is above or below a pre-defined value.

33. The method of claim 32, wherein the aggregated fluid flow and the one or more tributary fluid flows are members of a multi-zone intelligent well and the property P is water ratio, wherein the method comprises;
- reducing throughput of at least one of said intelligent control valves if the water ratio of a corresponding tributary or zone is above a pre-defined value.

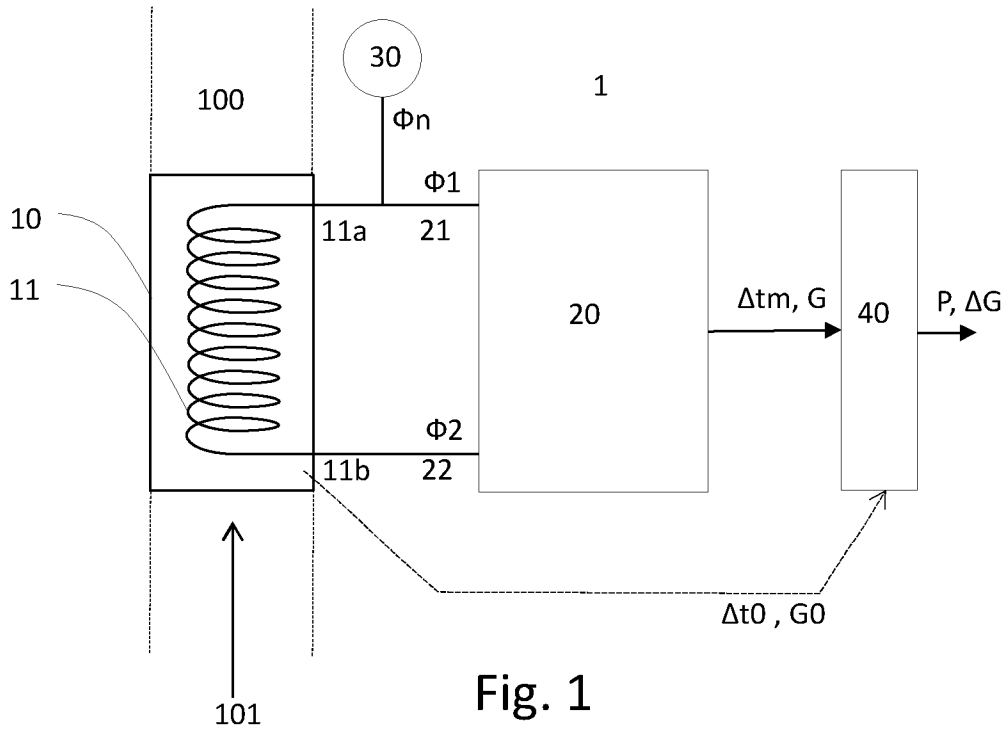

30
100
1
Φn
Φ1
10
11
11a
21
20
Δtm, G
40
P, ΔG
Φ2
11b
22
Δt0 , G0
101

Fig. 1

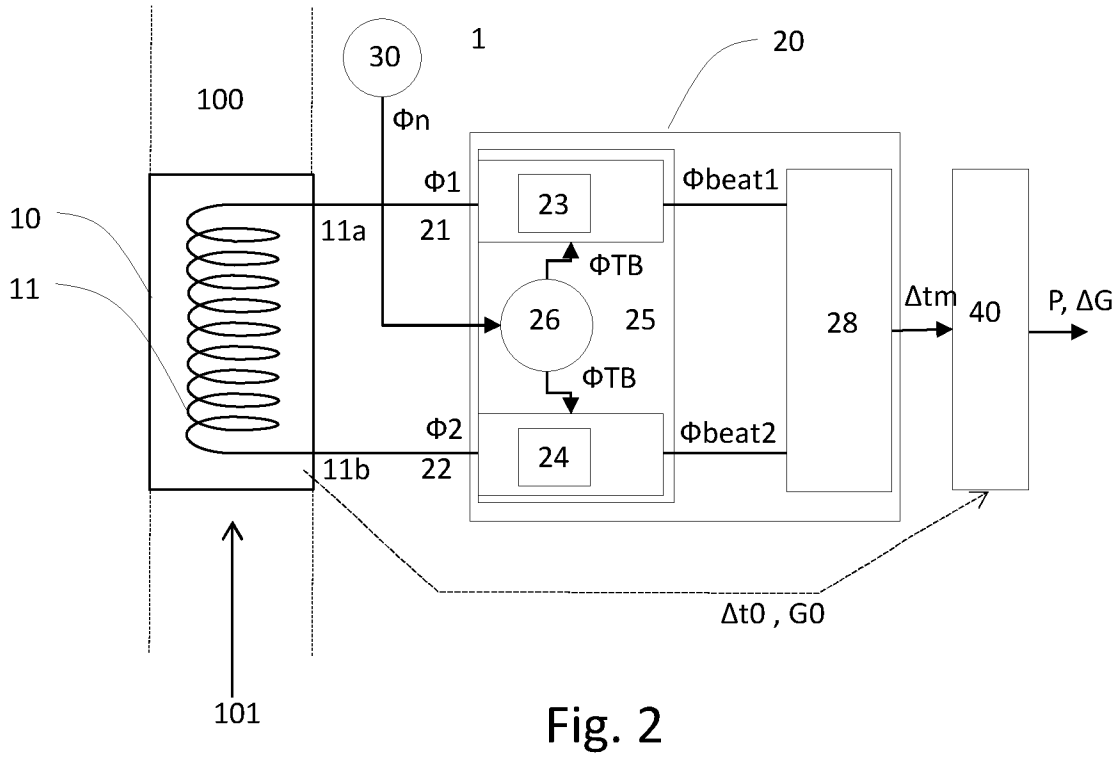

30
1
20
100
Φn
Φ1
Φbeat1
10
11
11a
21
23
ΦTB
26
25
28
Δtm
40
P, ΔG
ΦTB
Φ2
Φbeat2
24
11b
22
Δt0 , G0
101

Fig. 2

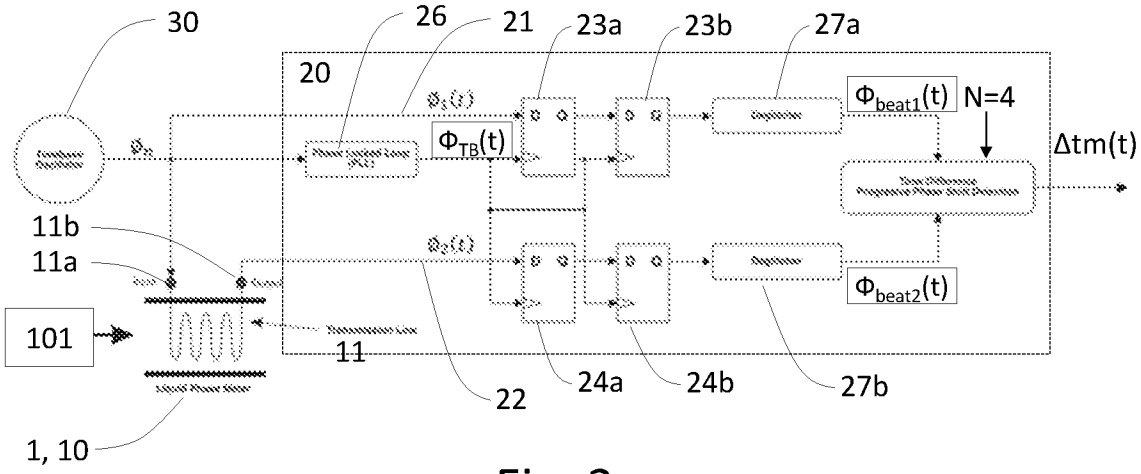

30
26
21
23a
23b
27a
20
$\Phi_{beat1}(t)$
N=4
$\Phi_{TB}(t)$
Δtm(t)
11b
11a
$\Phi_{beat2}(t)$
101
11
22
24a
24b
27b
1, 10

Fig. 3

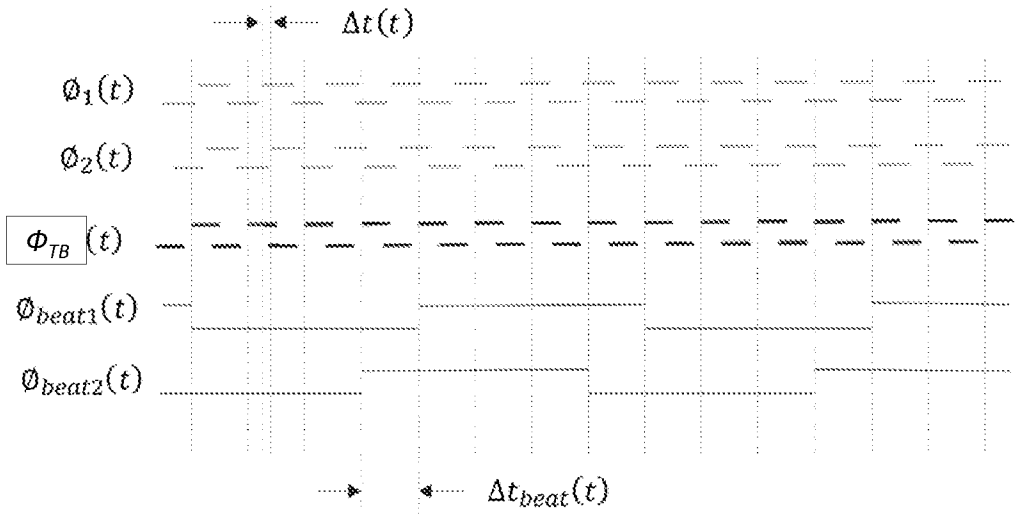

$\Delta t(t)$
$\emptyset_1(t)$
$\emptyset_2(t)$
$\Phi_{TB}(t)$
$\emptyset_{beat1}(t)$
$\emptyset_{beat2}(t)$
$\Delta t_{beat}(t)$

Fig. 4

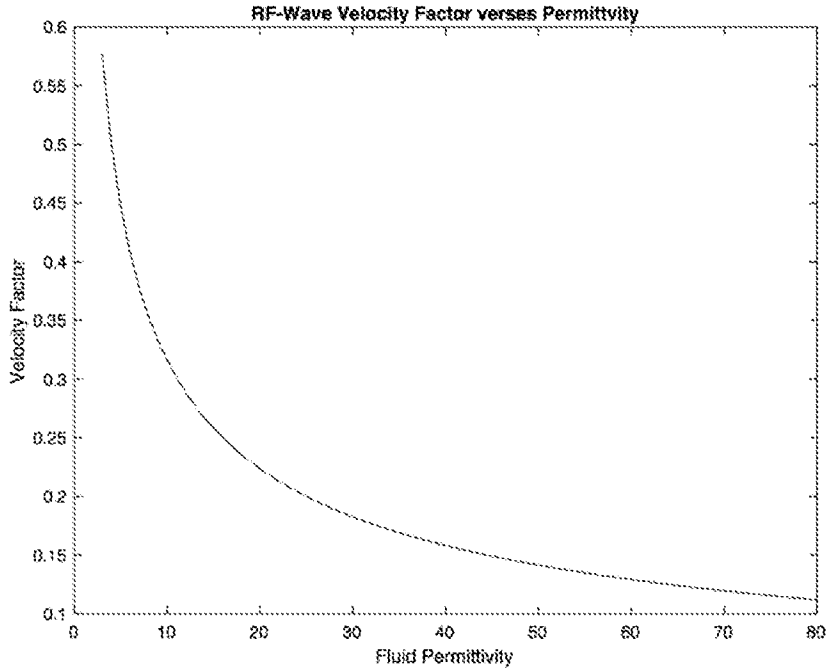

RF-Wave Velocity Factor verses Permittivity
Velocity Factor
Fluid Permittivity
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0
10
20
30
40
50
60
70
80

Fig. 5

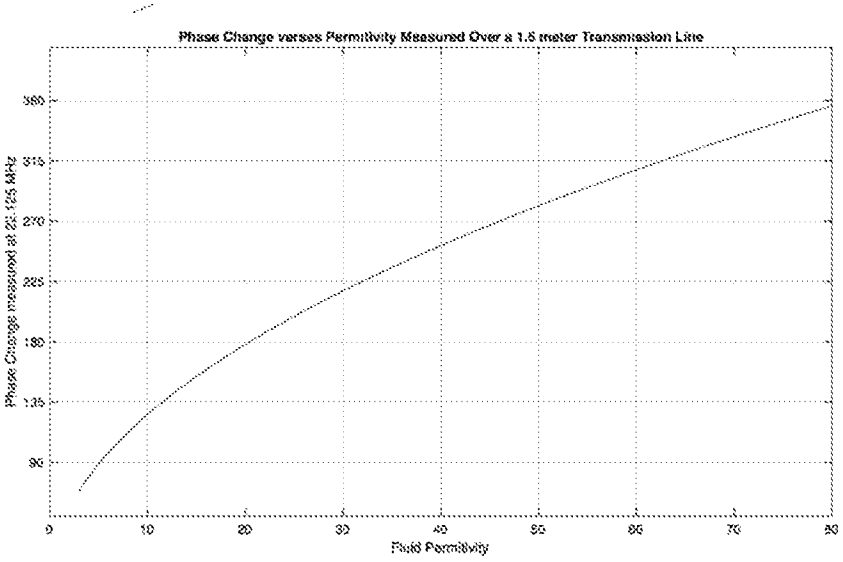

Phase Change verses Permittivity Measured Over a 1.5 meter Transmission Line
Fluid Permittivity
0
10
20
30
40
50
60
70
80

Fig. 6

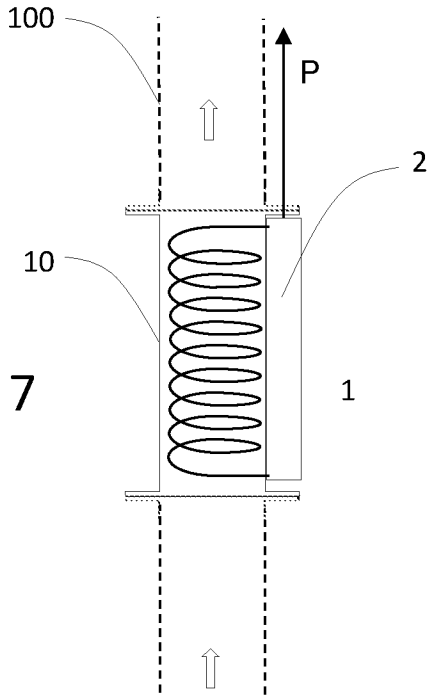


Fig. 7

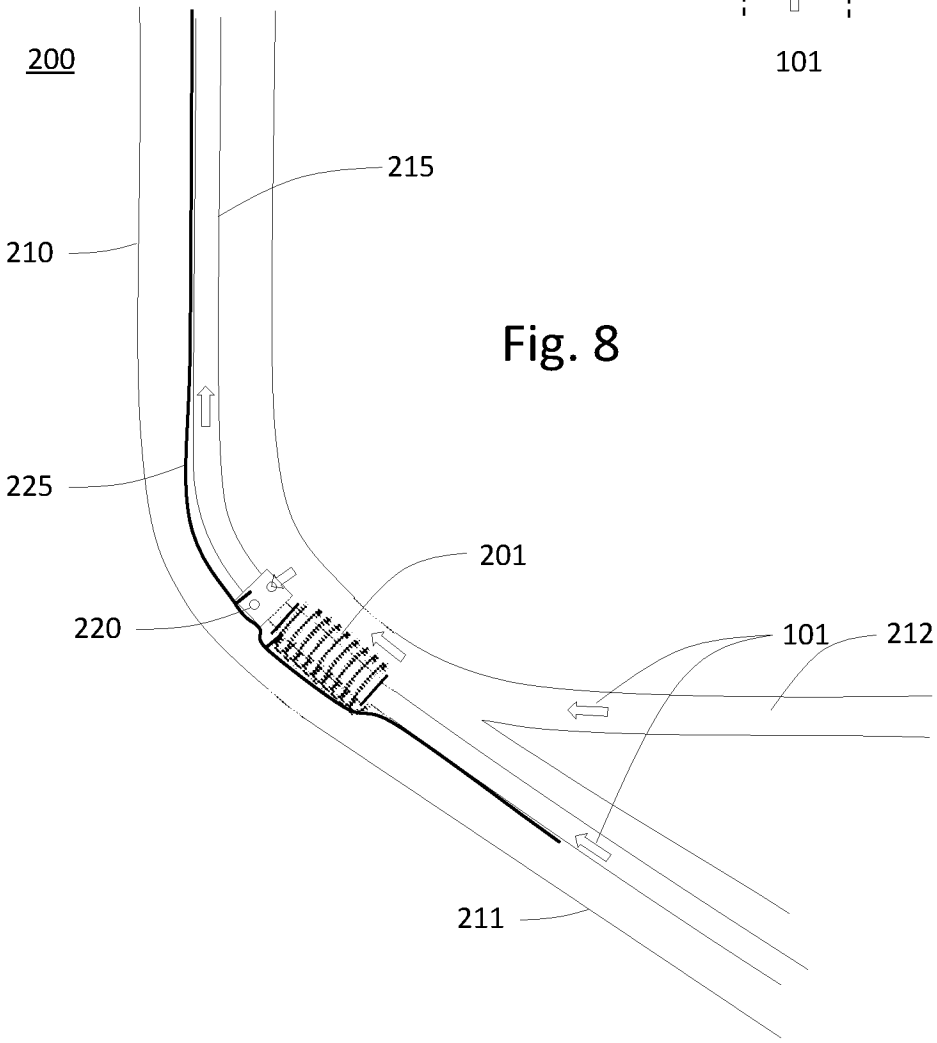


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/NO2024/050251

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01F1/58 G01F1/66 G01F1/708 G01F1/712 G01F1/74
E21B43/00 G01N22/00 G01N33/22 G01N33/24 G01N33/28
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01F E21B G01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2020/204724 A1 (WIONETIC AS [NO]) 8 October 2020 (2020-10-08) cited in the application	30
A	paragraphs [0121], [0122], [0145]; claims 1-17; figures 1-13	1-29, 31-33

X	WO 2023/048578 A1 (WIONETIC AS [NO]) 30 March 2023 (2023-03-30) cited in the application	30
A	claims 1-12; figures 1-8	1-29, 31-33

X	CN 104 141 491 B (UNIV YANGTZE) 5 April 2017 (2017-04-05)	30
A	claim 1; figures 1-6	1-29, 31-33

	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 February 2025	06/03/2025

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Rambaud, Dilek

4

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/NO2024/050251

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 707 307 B1 (MCFARLANE RONALD A [CA] ET AL) 16 March 2004 (2004-03-16) claims 1-14; figures 1-32	1-33

4

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/NO2024/050251

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2020204724 A1	08-10-2020	EP 3833937 A1	16-06-2021
		US 2020309580 A1	01-10-2020
		WO 2020204724 A1	08-10-2020
WO 2023048578 A1	30-03-2023	EP 4405643 A1	31-07-2024
		NO 20211133 A1	16-01-2023
		US 2024401994 A1	05-12-2024
		WO 2023048578 A1	30-03-2023
CN 104141491 B	05-04-2017	NONE	
US 6707307 B1	16-03-2004	CA 2310417 A1	30-11-2001
		US 6707307 B1	16-03-2004
		WO 0192861 A2	06-12-2001