Paper No. ________

UNITED STATES PATENT AND TRADEMARK OFFICE

____

BEFORE THE PATENT TRIAL AND APPEAL BOARD

____

MICRO MOTION, INC.
Petitioner
v.

INVENSYS SYSTEMS, INC.
Patent Owner

Patent No. 6,754,594
Issue Date: June 22, 2004
Title: DIGITAL FLOWMETER

____

Inter Partes Review No. Unassigned

DECLARATION OF DR. MICHAEL D. SIDMAN

1. I, Dr. Michael D. Sidman, resident at 6120 Wilson Road Colorado Springs, CO, hereby declare as follows:

2. I have been retained by Foley & Lardner LLP to provide my opinion concerning the validity of U.S. Pat. No. 6,754,594. I am being compensated for my time at the rate of $450/hour in preparing this declaration.

I. QUALIFICATIONS

3. I completed my undergraduate studies at Northeastern University, where I received a Bachelor's and a Master's degree in Electrical Engineering concurrently in 1975.

4. I received my Ph.D. from Stanford University in 1986. My work at Stanford as a Digital Equipment Corporation Fellow and University Resident included developing a high-performance digital control system for a lightly-damped mechanism in the Stanford Aero/Astro Robotics Laboratory.

5. My dissertation was entitled: *Adaptive Control of a Flexible Structure*. This research culminated in an adaptive control system that actively damps the vibrations of a lightly-damped mechanism, like a large space structure or disk drive actuator, whose resonant frequencies may be unpredictable or variable. The system performed on-line system identification of the frequencies of the mechanism's mechanical resonances.

6. I have worked for over 35 years in the field of motor, motion and servo control systems, and specifically in the field of digital control and signal processing systems. I have researched the control and mechanical dynamics of high performance, precision digital servo systems such as found in a range of computer peripheral devices.

7. Since 1992, I have been working as an independent engineering consultant. I am currently President of Sidman Engineering, Inc. I provide engineering design services to manufacturers worldwide, which span a range of industries. This work has included the following: (1) optimizing and simulating mechatronic systems (2) developing comprehensive custom design and dynamic system simulation tools including computer models of motor, motion and servo control systems; (3) teaching on-site technical short courses to design engineers and scientists; and (4) consulting on high-performance digital servo systems design and problem resolution.

8. The field of "mechatronics" encompasses mechanics, electronics and control systems technologies.

9. A "servo" or "servomechanical" system is a control system that controls position, velocity or acceleration, often utilizing motion sensor feedback .

10. Through Sidman Engineering, I provide interdisciplinary analysis and resolution of complex design issues. This may include providing clients with

customized, comprehensive computer based design tools and simulation models of a variety of dynamic systems, including electromechanical products and systems. These comprehensive models integrate actuator dynamics and electrodynamics, mechanical resonances, electronic circuitry, sensors, signal processing and filtering. In this role I have developed comprehensive servo system simulation models and design tools. The design tools I provide generally are used by product or system design engineers to understand system behavior and to optimize system parameters. As discussed below, I also provide on-site high level technical training courses for design engineers and scientists at companies. My business address is at 6120 Wilson Road, Colorado Springs, Colorado, 80919.

11. My commercial clients span the following industries and applications:

- Industrial and commercial: chemical process control, steel manufacturing, hydraulic control, commercial aviation, medical equipment, textile manufacturing, food processing, bicycle motor control, fuel cells.
- Computer peripherals and related test equipment: hard disk drives, optical disc drives, tape drives, printers, digital pens, robotics.
- Automotive: tire manufacturing & test, engine and vehicle dynamometers, electromechanical EGR valves, electric power assisted steering.

- Chip design: motor, motion and digital servo control IC's, DSPs and microcontrollers.
- Defense: aerospace, naval, optical reconnaissance, security scanning.
- Instrumentation: software, flow meters, optical position sensing, coordinate measurement machines.
- Telecommunications: digital signal processing, speech analysis, optical switching.

This list is simply representative of my technical consulting activities to companies over a period of more than two decades.

12. Before I became an independent engineering consultant, I spent 17 years at Digital Equipment Corporation (DEC) in roles spanning product development, advanced development and research. I headed DEC's Advanced Servo Development Group and Servo-Mechanical Advanced Development Group, both of which I founded. These groups developed and demonstrated technology involving, for example, position and velocity sensing, MEMS accelerometers, active vibration control, optimal seek control, piezoelectric head positioning actuators and DSP-based digital servo systems for hard disk drives. In a prior product design development role, I was the Project Engineer for DEC's RK07 disk drive product.

13. I served as DEC's representative to the Berkeley Sensor and Actuator Center (BSAC), which conducts industry-relevant interdisciplinary research on micro- and nano-scale sensors and moving mechanical elements and actuators constructed using integrated-circuit technology. I also served as DEC's representative for servo and mechanical technology to the National Storage Industry Consortium (NSIC).

14. I also sponsored applied research and/or researchers at Stanford University, U.C. Berkeley and the University of Colorado at Colorado Springs.

15. I have taught numerous courses and seminars relating to the field of mechatronics to product and system design engineers and a graduate level course in Optimal Control at the University of Colorado in Colorado Springs.

16. Through Sidman Engineering, I have provided my on-site, customized Digital Servo System Short Courses and MATLAB/SIMULINK/Toolbox Laboratory Training Courses to product development and research engineers and scientists worldwide in a wide range of industries and government entities since 1993. These courses may optionally include portions devoted to control systems and/or signal processing analysis and simulation. I developed these courses to enable attendees, who usually represent a range of technical disciplines, to model and simulate dynamic systems and the operation of products they are developing.

17. I became a Third Party Provider for The MathWorks, Inc. in 1993 and authored an invited feature article, entitled “Control Design Made Faster and More Effective,” for MATLAB News and Notes, Summer/Fall 1994.

18. I am a member of professional organizations dedicated to control systems and mechatronic technology. I am a Senior Member of the Institute of Electrical and Electronics Engineers (IEEE) where I am a member of the Control Systems Society.

19. I am also a member of the American Society of Mechanical Engineers (ASME), where I was Chairman of the Pikes Peak Section and member of the Dynamic Systems and Control Division (DSCD).

20. I am the named inventor of eighteen U.S. patents relating to technologies including: analog and digital electronics, digital signal processing, high performance digital servo systems, adaptive runout control, active damping of mechanical vibrations, adaptive control system gain regulation, etc.

21. I have published numerous articles relating to control systems, and specifically, articles relating to the motion sensing and control of precision actuators.

II. INTRODUCTION TO CORIOLIS FLOWMETERS

A. Uses of Coriolis Flowmeters

22. Gaspard-Gustave de Coriolis was a French mathematician, mechanical engineer and scientist who lived from 1792 to 1843. Coriolis studied forces as observed from a rotating frame of reference.

23. A Coriolis flowmeter is a measurement device used to measure mass flow rate and/or density of a material flowing through an oscillating conduit (i.e., tube) in the flowmeter. (See, e.g., U.S. Pat. No. 4,872,351, Ex. 1020, 1:49-2:4.)

24. Coriolis flowmeters include one or two conduits through which material flows. One conduit is described for simplicity, but the discussions herein are generally applicable to a system with two conduits. (See, e.g., U.S. Pat. No. 4,823,614, Ex. 1021, 1:44-47, 2:51-55.)

25. Coriolis flowmeters measure mass flow rate by sensing the effect of Coriolis forces on the material flowing through the vibrating conduit.

26. The material flowing in the tube may be a single type of material (single phase) or multiple types of material mixed together (multi-phase). Examples of materials include a wide variety from gas to liquid to near-solid. (E.g., U.S. Pat. No. 4,679,947, Ex. 1007, 1:41-43 ("two-phase flow"); U.S. Pat. No. 4,823,614, Ex. 1021, 3:14-17 ("highly viscous fluids and thick slurries, for example, asphalt, latex paint and peanut butter"); U.S. Pat. No. 4,872,351, Ex. 1020, 1:29-44 (sweetening agent, oil); U.S. Pat. No. 5,068,116, Ex. 1028, 1:18-20 (water, syrup for beverage mixing); U.S. Pat. No. 5,143,257, Ex. 1022, 1:7

(“medication and/or nutrients”); U.S. Pat. No. 5,148,945, Ex. 1023, 1:12-14 (“ultra-high purity chemicals . . . such as in the manufacture of semiconductor wafers”).) Examples of multi-phase materials include a gas/liquid mixture, a liquid/solid mixture, and a gas/liquid/solid mixture. (E.g., U.S. Pat. No. 5,224,372, Ex. 1024, 1:34-38 (“multiphase fluid emanating from oil and gas wells wherein essentially, mixtures of water, hydrocarbon liquids, such as crude oil; and gas are continually produced in varying proportions of the total fluid flowstream”); U.S. Pat. No. 5,317,928, Ex. 1025, 1:17-20; 1:25-30 (“Typically a two-component fluid mixture consists of either a solid component fully or partially dissolved within a liquid carrier fluid, or a liquid component mixed with a liquid carrier fluid” such as “sugar in water” in the “beverage industry,” “concentration of TiO2” in the “pulp and paper industry”).)

27. As described below, Coriolis flowmeters rely on the principle that the mass flow rate of material passing through a sinusoidally oscillating conduit can be determined by sensing conduit twist induced by the Coriolis force. And, the natural frequency of conduit oscillation provides the basis for measurement of the density of the material inside the conduit. The Coriolis flowmeter’s electronics are responsible for initiating, sustaining and, in general, controlling the sinusoidal oscillation of the conduit(s). For example, through the use of the conduit motion sensors and an electromagnetic conduit driver or actuator, Coriolis flowmeter

electronics provides the mechanical energy to vibrate the conduit and to regulate the amplitude of conduit oscillation. Coriolis flowmeters rely on the persistence of sustained sinusoidal oscillation of the conduits.

28. The flowmeter induces a Coriolis force on flowing material in the conduit by oscillating the conduit, and determines a property of the material based on information about the effect of the Coriolis force. (See, e.g., U.S. Pat. No. 4,733,569, Ex. 1026, 1:27-36; U.S. Pat. No. 4,823,614, Ex. 1021, 1:47-61.).) For example, by measuring a phase difference in the sinusoidal oscillation of the conduit between two points on the tube, it is possible to determine the mass flow rate of the fluid flowing through the tube. Coriolis flowmeters were first commercialized by petitioner Micro Motion in the late 1970s and early 1980s. *See* U.S. Pat. No. 5,373,745, Ex. 1003, 1:24-25 ("[Coriolis flowmeters were] first made commercially successful by Micro Motion, Inc. of Boulder, Colorado.")

B. Components of Coriolis Flowmeters

29. Coriolis flowmeters include the following basic components: a vibratable conduit (which can have various shapes and sizes) through which fluid flows; an electromechanical drive mechanism (including one or more electromagnetic drivers or actuators) for vibrating the conduit; one or more sensors that transduce the vibration of the tube; and electronics for controlling the drive mechanism and for analyzing signals from the sensors.

30. Coriolis (and other) flowmeters were originally implemented with analog electronic components. *E.g.*, U.S. Pat. No. 2,865,201, Ex. 1004. To do the necessary signal processing and control, such an analog flowmeter uses analog components to process signals from the sensors and to control the drive mechanism. As digital electronic components became more readily available, flowmeters also incorporated digital components. (*See, e.g.*, U.S. Pat. No. Re. 31,450, Ex. 1005, which discloses a predominantly analog system incorporating some digital components.) Digital components include digital logic and programmable digital devices (e.g., microprocessors). (*E.g.*, U.S. Pat. No. 4,934,196 ("Romano"), Ex. 1006, Fig. 3; U.S. Patent No. 5,009,109 ("Kalotay"), Ex. 1008, Fig. 4; U.S. Pat. No. 5,050,439 ("Thompson"), Ex. 1027, 16:11-15.) A digital flowmeter may include analog and digital components. For example, a digital flowmeter may process signals from the sensors using digital components but control the drive signal using analog components. A digital flowmeter may alternatively control the drive signal using digital components.

31. The flowmeter must process the sensor signals to extract information of interest from other information in the signals. Thus, all flowmeters, whether analog or digital, perform signal processing on the sensor signals. For example, in a Coriolis flowmeter, fluid flowing through an oscillating flowtube may cause a phase shift in the flowtube oscillation due to the Coriolis effect, and the flowmeter

processes the sensor signals to extract the information related to the Coriolis effect from other information in the signals to determine mass flow rate or density. If the signal processing is performed in digital components, then the signal processing is digital signal processing.

C. Operating Principles

32. The Coriolis effect caused by oscillating a conduit in which fluid is flowing results in a twist in the conduit, with a resulting phase shift in the oscillation between two points physically spaced apart on the conduit. The phase shift is proportional to the mass flow rate of the material.

33. A tutorial showing the principles underlying the operation of Coriolis flowmeters may be found at www3.emersonprocess.com/micromotion/tutor/28_flowoprinccurvtubevib.html.

34. The Coriolis effect as related to a Coriolis flowmeter was described in a 1990 article by the petitioner, where the term "flow tube" is synonymous with the term "conduit":

> The Micro Motion flowmeter measures fluid mass in motion. A flowmeter is comprised of a sensor and a signal processing transmitter. Each sensor consists of one or two flow tubes enclosed in a sensor housing. The principle of operation is the same for all Micro Motion sensors.
>
> The sensor operates by application of Newton's Second Law of Motion: Force = mass x acceleration (F = ma). The flowmeter uses

this law to determine the precise amount of mass flowing through the sensor tubes.

Inside the sensor housing, the flow tube is vibrated at its natural frequency (Figure 1) by an electromagnetic drive coil located at the center of the bend in the tube. The vibration is similar to that of a tuning fork, covering less than a tenth of an inch and completing a full cycle about 80 times each second.

As the fluid flows into the sensor tube, it is forced to take on the vertical momentum of the vibrating tube. When the tube is moving upward during half of its vibration cycle (Figure 2), the fluid flowing into the sensor resists being forced upward by pushing down on the tube. Having the tube's upward momentum as it travels around the tube bend, the fluid flowing out of the sensor resists having its vertical motion decreased by pushing up on the tube (Figure 2). This causes the flow tube to twist (Figure 3). When the tube is moving downward during the second half of its vibration cycle, it twists in the opposite direction. This tube twisting characteristic is called the Coriolis effect.

Due to Newton's Second Law of Motion, the amount of sensor tube twist is directly proportional to the mass flow rate of the fluid flowing through the tube. Electromagnetic velocity detectors located on each side of the flow tube measure the velocity of the vibrating tube. The two velocity signals are sent to the transmitter where they are processed and converted to an output signal proportional to the mass flow rate. Sensor tube twist is proportional to mass flow and is determined by measuring the time difference exhibited by the velocity detector signals. During zero flow conditions, no tube twist occurs and both sides of the tube cross the midpoint simultaneously. With flow, a

> twist occurs along with a resultant time difference between midpoint crossing. This time difference appears as a phase shift between the two velocity signals and indicates mass flow.

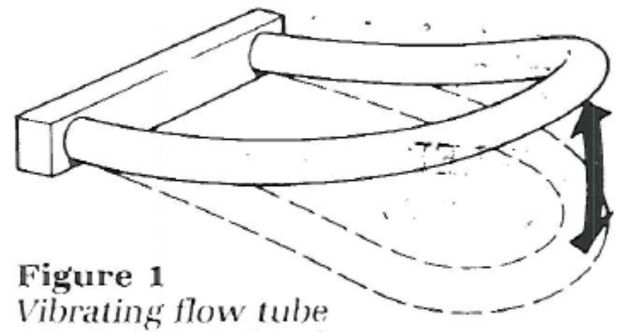


Figure 1
Vibrating flow tube (single flow tube shown)

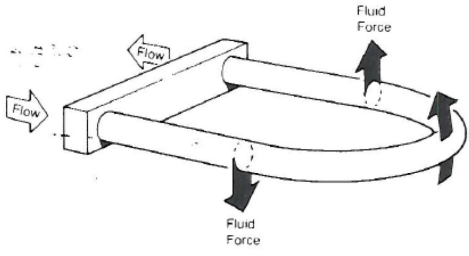


Figure 2
Fluid forces reacting to vibration of flow tube

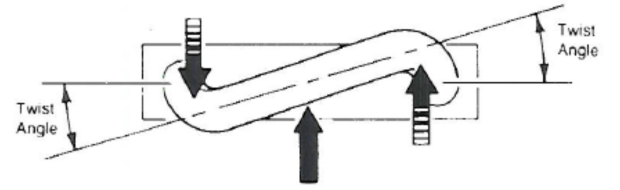


Figure 3
End view of flow tube showing twist

("How the Micro Motion Mass Flow and Density Sensor Works", Micro Motion, Inc., 1990, Ex. 1009, p. 1.)

35. Note that in the Micro Motion article, only one conduit (flow tube) is shown. In a one-conduit system, velocity measurements would be made with respect to the housing. In a two-conduit system, velocity measurements are made

as relative velocity between the conduits. In either case, the concepts described below apply.

36. As seen from the Micro Motion article, measurement of mass flow rate is based on oscillation of the conduit. Similarly, measurement of density is based on frequency of oscillation. Thus, if measurement is being performed, necessarily there will be oscillation.

37. Measuring the phase shift described in the Micro Motion article is no different than measuring phase shift of input signals in any other system, and thus may be addressed by conventional signal processing techniques. Additionally, maintaining oscillation at a desired amplitude and/or frequency is addressed by conventional control theory techniques.

D. Control Systems for Coriolis Flowmeters

38. The control system of the Coriolis flowmeter provides a drive signal to an electromagnetic mechanism (driver) external to the conduit to initiate oscillation of the conduit. The conduit at some point generally settles into sinusoidal oscillation at the resonant frequency (or a harmonic) of the conduit. The resonant frequency of the conduit depends in part on properties of the material in the conduit, and may change if the properties of the material change. (*See*, *e.g.*, U.S. Pat. No. 4,823,614, Ex. 1021, 2:9-50 3:14-17.) For example, as the density of the material changes (e.g., during aeration, or during transitions from empty to full

and full to empty), the resonant frequency of the flowtube will also change, and the amount of energy required to keep the flowtube oscillating will generally change. Additionally, because the flowtube is a fixed volume, changes in density will result in changes in mass of the material in the flowtube, and corresponding changes in mass flow rate. The faster the density changes (e.g., in a rapid empty-to-full transition), the more quickly the mass within the flowtube will change.

39. As disclosed, for example, in the many prior art patents listed above, a flowmeter incudes a control system that performs at least the following functions.

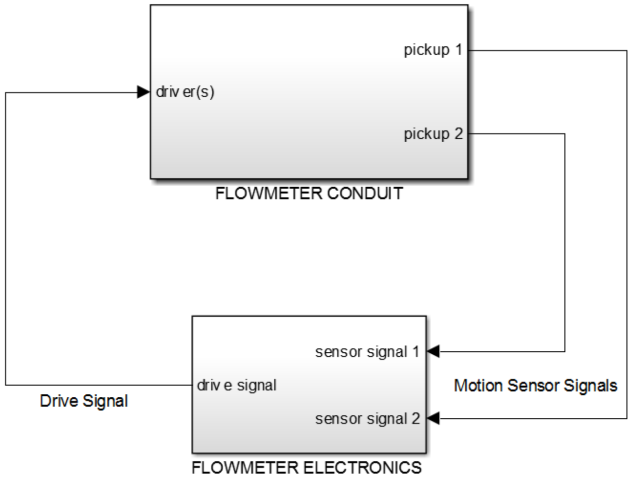
40. The control system provides signals to the driver to add energy to the oscillation of the conduit as necessary to maintain oscillation of the conduit at a desired frequency (typically at or near the resonant frequency of the conduit).

41. The control system receives signals from one or more motion sensor pick-ups mounted externally on the conduit to sense conduit oscillation. These transducers are located apart from each other on the vibrating conduit in order to provide information about conduit torsion induced by the Coriolis forces during flow conditions.

42. The control system processes the signals received from the pick-ups, drives the conduits in synchronism with the resonant frequency of oscillation, and determines a property of the material (e.g., mass flow rate and/or density) from the pick-up signals. Information extracted from the pick-up signals (including the

property of the material) may be stored, displayed, and/or exported to another system by the flowmeter.

43. A block diagram illustration of the relationship between the electronics and conduit of the flowmeter is shown in the figure below by way of an example which uses two pick-ups. The flowmeter electronics includes a drive control system.



44. The control system of a Coriolis flowmeter therefore performs control functions – processes system input signals and controls system output signals – as described in well-known control theory dating back far before the 1990s (i.e., long before the filing of the application leading to the patent that is the subject of this Inter Partes Review.) Further, the processing of signals was described by well-known signal processing techniques also dating back far before the 1990s. Some elements of control theory and signal processing techniques will be discussed below.

III. CONTROL SYSTEMS BACKGROUND

A. Open Loop Control

45. A control system may be used to control the motion of a device or mechanism. Open loop control refers to a control action without feedback.

46. In a Coriolis flowmeter, open loop control may be used to initially impart energy into a conduit to initiate oscillation of the conduit. For example, a drive signal having the appropriate spectral content could be used to initially excite resonant vibration of the conduit.

47. Because an open loop control system cannot observe actual conduit motion or the effect of a control action, it cannot, for example, act to regulate or maintain oscillation amplitude of a conduit. Without feedback, there is no basis for the control system to modify the drive signal or adjust the control action. Thus, oscillation may decrease, to a stall condition, or oscillation may increase, resulting in amplifier saturation or even causing damage to the conduit.

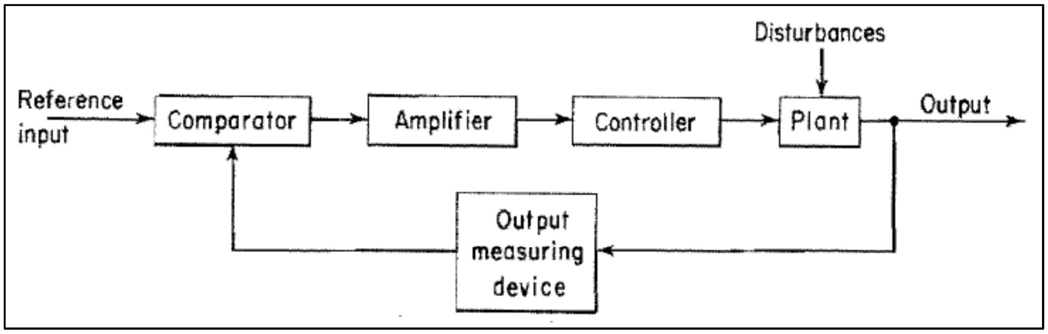
B. Closed Loop Control

48. Closed loop control refers to the use of feedback as the basis for control action. For example, a feedback sensor or transducer such as a velocity sensor allows a feedback control system to monitor the effects of its control actions and to adjust the control action.

49. A servo system is a motion control system. Most servo system are closed-loop systems which track or follow a desired setpoint or trajectory

command, sometimes referred to as a reference command level or signal. The term 'servo' comes from the Latin word *servus* – meaning servant or slave. A closed loop motion control system may regulate position, velocity or acceleration.

50. The following illustrates a simple example of a closed-loop control system. Closed-loop control relies on feedback (e.g., a feedback loop) to control a "plant" or mechanism in such a way as to make the plant's output closely track a reference input signal. The "plant" in the figure below is the mechanism whose output is to be controlled. In the case of the Coriolis flowmeter, the plant would include the conduit driver and the dynamics of the conduit. The pick-ups in a Coriolis flowmeter correspond to the output measuring device in the figure below.



51. In this closed-loop control system, the plant's output is fed back for comparison with the reference input, and the difference, or error, is then used as the basis for a control or drive signal applied to the plant. The difference (error) is sensed by the comparator and amplified before being processed by a controller such as a PI controller, described below. Typically, a power amplifier (not shown) boosts the drive signal produced by the controller. The blocks illustrated in the

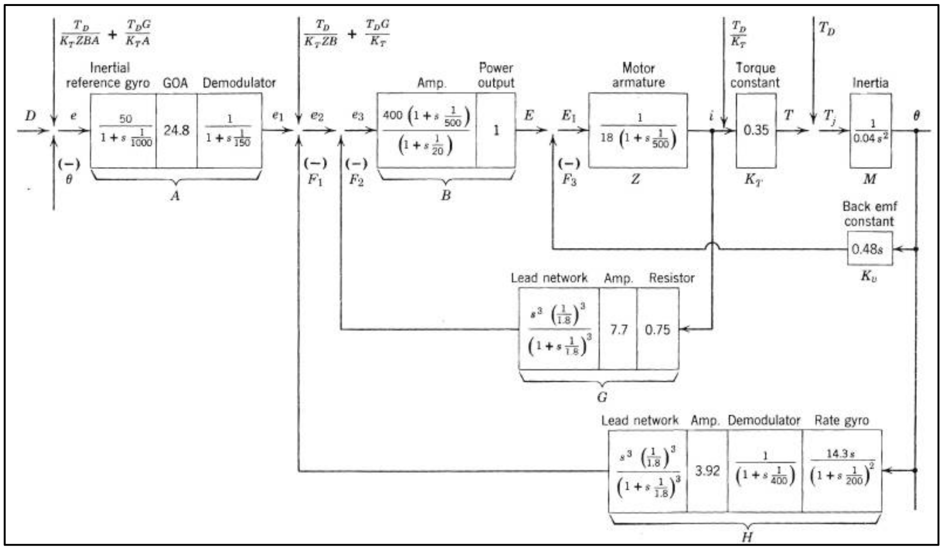
above figure form a control loop that provides a feedback control path which enables self-correction. The control system produces a dynamically controlled drive signal by way of a controller or control law that acts to minimize error. In some control systems, the reference input may be zero. Generally, "a feedback system has the ability to **correct for load disturbances and inaccuracies in the controller**." (*Introduction to Continuous and Digital Control Systems*, Saucedo & Schering, Macmillan, 1968, Ex. 1029, p. 3 (emphasis added).)

i. Negative Feedback

52. If the phasing of the feedback acts in such a way as to reduce error, instead of to accentuate it, then the closed loop control system would be said to be operating in a stable manner and operating with negative feedback. Stability of closed loop systems is a key consideration in control systems design. Oscillatory behavior is an indication that the control system is unstable.

ii. Multi-Loop Feedback

53. It is common to add an outer control loop to stabilize or enhance the dynamic performance of an inner control loop (or vice versa). The following is an example of multi-loop control in a servo system.



(*Electromechanical Control Systems and Devices*, Canfield, Robert E. Kreiger Publishing Company, Original Edition 1965, Reprint 1977, Ex. 1030, p. 42.)

54. As described below, an outer control loop can be used to regulate the amplitude of oscillation of an inner control loop. Prior art patents describing flowmeters discuss implementing control loops having inner and outer control loops. (*See*, *e.g.*, U.S. Pat. No. 4,524,610, Ex. 1031, Fig. 6; U.S. Pat. No. 4,655,089 Ex. 1047, Fig. 9.)

iii. Positive Feedback

55. If the feedback signal is in phase with the error signal, the closed loop control loop is said to be operating with positive or regenerative feedback, i.e., there is positive loop gain around the feedback loop. “Two alternating quantities are said to be "in phase" when their maximum values occur at the same instant of

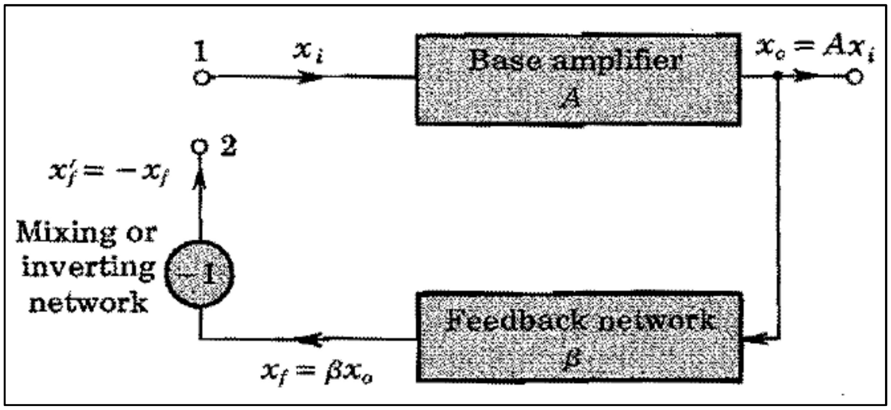
time." (*Dictionary of Mechanical Engineering*, Fourth Edition, Nayler, Butterworth-Heinemann, 1996, Ex. 1013, p. 277.) When positive feedback occurs, disturbances or oscillations may naturally increase even without, for example, a reference input. An example of a closed loop system having positive feedback is the squealing sound produced by speaker to microphone feedback in a public address system.

IV. SINUSOIDAL OSCILLATORS

56. While most feedback control systems are designed to avoid positive feedback, electronic sinusoidal oscillators have long been designed to employ positive feedback to sustain oscillation. Coriolis flowmeters are, in fact, sinusoidal oscillators, in which the dynamic elements include the resonant mechanical dynamics of the conduit.

57. With respect to a sinusoidal oscillation, such as that which is (desirably) established in a Coriolis flowmeter conduit, a regenerative positive feedback control loop was used in prior art flow meters to maintain the amplitude of sinusoidal oscillation of the conduits at a desired value. (*See*, *e.g.*, U.S. Pat. No. 4,524,610, Ex. 1031, 7:45-50 ("a positive feedback circuit is interconnected between the detector coil 2a and the torsional driver coil la, and the power supplied to the driver coil la in order to maintain a predetermined amplitude of torsional oscillation of the tube 50 is measured"); U.S. Pat. No. 4,934,196, Ex. 1006, Fig. 4.)

58. Analog circuit engineers used positive (i.e., regenerative) feedback in sine wave oscillator designs at least back to the early 1970s to maintain oscillation amplitude, as described in the following excerpt.

> [The following figure] shows an amplifier, a feedback network, and an input mixing circuit not yet connected to form a closed loop.
>
> 
>
>
> The amplifier provides an output signal x_0 as a consequence of the signal x_i applied directly to the amplifier input terminal. The output of the feedback network is $xf = \beta x_0 = A\beta x_i$, and the output of the mixing circuit (which is now simply an inverter) is
>
> $$x'_f = -x_f = -A\beta x_i$$
>
> From [the figure] the loop gain is
>
> $$\text{Loop gain} = x'_f / x_i = -x'_f / x_i = -\beta A$$

(*Integrated Electronics: Analog and Digital Circuits and Systems*, Jacob Millman and Christos Halkias, McGraw-Hill, 1972, Ex. 1032, p. 483.)

59. In the figure above, if points 1 and 2 were connected and the relationship $x'_f = x_i$ were true (i.e., the waveforms x'_f and x_i were identical in

amplitude, phase and frequency for a sinusoid), then loop gain $-\beta A$ would be equal to one (unity). Unity gain is called the Barkhausen Criterion, which expresses a necessary, but not sufficient, condition for sine wave oscillation in a positive feedback control loop. The Barkhausen Criterion is described in the following excerpt:

> The frequency at which a sinusoidal oscillator will operate is the frequency for which the total shift introduced, as a signal proceeds from the input terminals, through the amplifier and feedback network, and back again to the input, is precisely zero (or, of course, an integral multiple of 2π.) Stated more simply, the frequency of a sinusoidal oscillator is determined by the condition that the loop-gain phase shift is zero.
>
> Oscillations will not be sustained if, at the oscillator frequency, the magnitude of the product of the transfer gain of the amplifier and the magnitude of the feedback factor of the feedback network (the magnitude of the loop gain) are less than unity.

(*Integrated Electronics: Analog and Digital Circuits and Systems*, Jacob Millman and Christos Halkias, McGraw-Hill, 1972, Ex. 1032, p. 484 (emphasis omitted).)

60. The signal x'_f can be provided by another source instead of as feedback from the output, as long as the Barkhausen Criterion is maintained. Thus, for example, when the oscillation is relatively stable, knowledge of the oscillation (such as frequency and phase for a sinusoid) may be used to synthesize a waveform to be applied as x'_f without directly feeding back the signal x_o." since the

amplifier has no means of distinguishing the source of the input signal" (*id.*) Moreover, the concepts described with respect to the figure above may be implemented in software such that a synthesized drive signal may be provided directly to the electromechanical device driving the oscillation (i.e., the driver.)

A. Problems Faced by Sinusoidal Oscillators

61. The *Integrated Electronics* 1972 textbook cited above identifies a number of issues found in sinusoidal oscillators using positive feedback, which are also key issues found in the control of an oscillating conduit in a Coriolis flowmeter.

62. An example of the problems described is a problem of oscillation initiation using regenerative feedback: the oscillator is not guaranteed to start, may not lock onto the desired frequency of oscillation, or may oscillate at more than just the desired frequency of oscillation. A number of techniques have been proposed over the years to "kick start" Coriolis Flowmeter vibration with various open or closed loop techniques.

63. Another example of problems described is that unity gain is an unrealizable theoretical ideal:

> If /*ßA*/ is less than unity, the removal of the external generator will result in a cessation of oscillations. But now suppose that /*ßA*/ is greater than unity. Then, for example, a 1-V signal appearing initially at the input terminals will, after a trip around the loop and back to the

> input terminals, appear there with an amplitude larger than 1 V. This larger voltage will then reappear as a still larger voltage, and so on. . . . such an increase in the amplitude can continue only as long as it is not limited by the onset of nonlinearity of operation in the active devices associated with the amplifier. . . The condition /*ßA*/= 1 [is] a single and precise value. Now suppose that initially it were even possible to satisfy this condition. Then, because circuit components and, more importantly, transistors change characteristics (drift) with age, temperature, voltage, etc., it is clear that if the entire oscillator is left to itself, in a very short time /*ßA*/ will become either less or larger than unity. In the former case the oscillation simply stops, and in the latter case we are back to the point of requiring nonlinearity to limit the amplitude. An oscillator in which the loop gain is exactly unity is an abstraction completely unrealizable in practice.

(*Integrated Electronics: Analog and Digital Circuits and Systems*, Jacob Millman and Christos Halkias, McGraw-Hill, 1972, Ex. 1032, p. 485.)

64. For a Coriolis flowmeter, the difficulty of maintaining persistent sinusoidal oscillation is exacerbated by changes in plant mechanical dynamics as well as system disturbances. By way of example, the density of a homogenous material in the conduit may change; or the density may change due to inconsistencies in the material flowing through the conduit (e.g., aeration, bubbles, slug flow, particulates, change of the mix in a multi-phase flow, volume changes in near-solid flow such as ground meat and peanut butter). (*See, e.g.*, U.S. Pat. No.

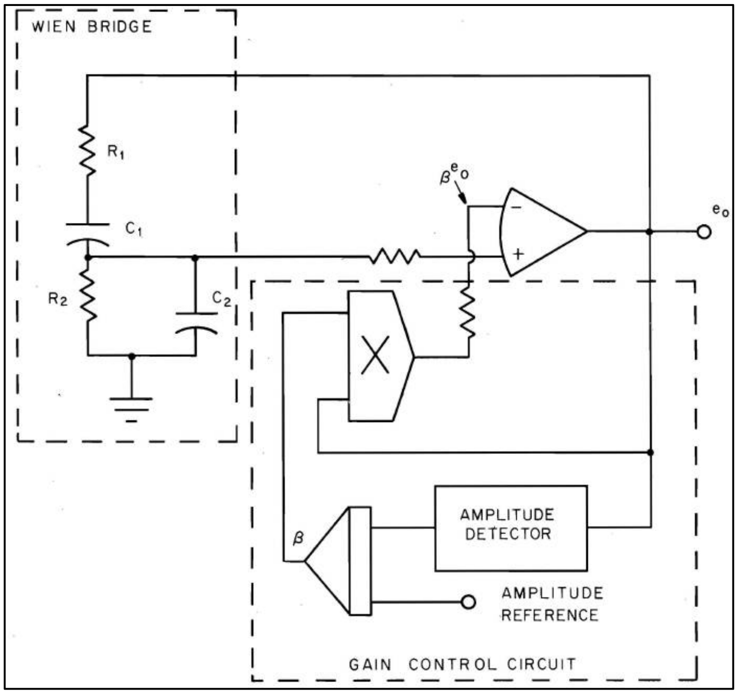
4,823,614, Ex. 1021, 2:25-50.) A change in density of the material results in a change in the resonant frequency of the conduit.

65. One solution for stabilizing the amplitude of a positive (regenerative) feedback sine wave oscillator is the addition of an outer control loop to multiplicatively control the inner loop gain. An example of this is an outer loop which utilizes an integral controller to modulate the loop gain of a Wien-bridge sine wave oscillator circuit to stabilize sine wave amplitude.

B. Stabilization of Sinusoidal Oscillators

66. The Wien-bridge oscillator circuit (described in a 1972 textbook as excerpted below) detects the amplitude of sine wave oscillation, compares the amplitude to a reference level, integrates the difference (i.e., the error) and adjusts the loop gain of the regenerative oscillating inner loop to regulate the amplitude of oscillation. The outer loop in this case is an integral controller which modulates the gain of the inner loop through the use of a multiplier.

> A Wien bridge may be combined with an operational amplifier to form an excellent sine wave generator. Some sort of automatic gain control is generally used to stabilize the magnitude of the output sinusoid. A general schematic of a Wien-bridge oscillator is shown [below]



> … [T]he general Wien-bridge oscillator diagram [is shown in the figure.] … The amplifier … acts as an error integrator and will stabilize only when the absolute value of the input equals the reference amplitude.

(*Operational Amplifiers Design and Applications*, Graeme, Tobey and Huelsman, McGraw-Hill, 1971, Ex. 1033, pp. 381-382, 383.)

67. When the gain of the inner loop decreases to below unity at the frequency of oscillation, the outer loop increases the gain of the inner loop. Conversely, when the gain of the inner loop increases to above unity at the frequency of oscillation, the outer loop decreases the gain of the inner loop. The decrease in gain may be a reduction in the positive value of gain of the inner loop, leading to a decay of oscillation amplitude, or the gain may become negative (i.e.,

the inner loop producing negative feedback) leading to a more rapid, forced reduction in oscillation through negative reinforcement of the oscillation.

68. The amplitude stabilization technique used in Wein-bridge sine wave oscillators is just one of the known techniques in the art for stabilizing an inner control loop.

V. PID AND PI CONTROLLERS

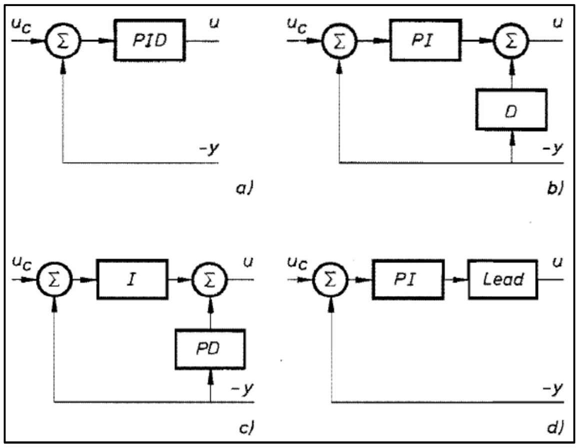
69. Proportional-plus-Integral (PI) controllers have long been used in closed loop control systems to process control system error and transform it into a control signal that over time acts to reduce steady state error to zero.

70. Proportional-plus-integral-plus-derivative (PID) control adds a 'derivative' term to the PI controller. Integral controllers are PI controllers without the proportional gain term. Setting the gain of one or more of the P, I, or D terms to zero results in a sub-category of PID control: PI, PD, proportional, or integral.

> The manner in which the automatic controller produces the control signal is called the control action. . . Industrial automatic controllers may be classified according to their control action as
>
> - two-position or on-off controllers
> - proportional controllers
> - integral controllers
> - proportional-plus-integral controllers
> - proportional-plus-derivative controllers
> - proportional-plus-derivative-plus-integral controllers

(*Modern Control Engineering*, Chapter 5 Basic Control Actions and Industrial Automatic Controls, Ogata, Prentice-Hall, 1970, Ex. 1034, pp. 151-152 (emphasis omitted).)

71. A PID controller may be implemented in many different forms, as shown in the following examples.

> [The following figure] shows different PID-structures, **which can be used both in continuous and discrete time**.
>
> 
>

(*Computer Controlled Systems, Theory and Design*, Astrom and Wittenmark, Prentice-Hall, 1984, Ex. 1036, pp. 181-182 (emphasis added).)

72. As seen from the excerpts above, PID control, and the sub-category of PI control, has been known for a long time in both digital (discrete) and analog (continuous) systems. A PI controller is described below:

> . . . The control action of a proportional-plus-integral controller is defined by the following equation:
>
> $$m(t) = K_p e(t) + \frac{K_p}{T_i} \int_0^t e(t)\, dt$$

> . . . where K_p represents the proportional sensitivity or gain, and T_i represents the integral time. Both K_p and T_i are adjustable. The integral time adjusts the integral control action, while a change in the value of K_p affects both the proportional and integral parts of the control action.

(*Modern Control Engineering*, Chapter 5 Basic Control Actions and Industrial Automatic Controls, Ogata, Prentice-Hall, 1970, Ex. 1034, p. 156.)

VI. DIGITAL CONTROL SYSTEMS

A. Analog Versus Digital Control Systems

73. The drive control system of a Coriolis flowmeter is an electronic control system. As noted above, prior to the availability of digital components, electronic control systems were implemented using analog components. As digital components (e.g., latches and counters) became available, electronic systems generally began incorporating digital components. As digital processors (a form of digital component) became available and commercially viable, digital processors were also incorporated into electronic systems to, for example, reduce cost, weight, or size; or to improve speed, accuracy, or functionality. "Because digital computers provide many advantages in size and flexibility, computer control has become increasingly popular in recent years." (*Automatic Control Systems*, Third Edition, Benjamin C. Kuo, Prentice-Hall, 1975, Ex. 1035, p. 14) "Digital computers are increasingly being used to implement control systems. It is therefore important to understand computer-controlled systems well. One can view computer-controlled

systems as approximations of analog-control systems, …" (*Computer Controlled Systems Theory and Design*, Astrom and Wittenmark, Prentice-Hall 1984, Ex. 1036, p. 1.)

> The control of physical systems with a digital computer is becoming more and more common. Aircraft autopilots, mass-transit vehicles, oil refineries, paper-making machines, and countless electromechanical servomechanisms are among the many existing examples. Furthermore, **many new digital control applications are being stimulated by microprocessor technology** including control of various aspects of automobiles and household appliances.

(*Digital Control of Dynamic Systems*, 2d. Ed., Franklin, Powell & Workman, Addison-Wesley Publishing Company, 1990, Ex. 1037, p. 1 (emphasis added).)

74. A large percentage of systems incorporating digital components, including systems incorporating digital processors, are not completely digital – there are analog components in the control system as well. Additionally, many digital components include analog portions. For example, a digital processor may include built-in analog-to-digital or digital-to-analog converters. Digital control theory describes control implemented at least in part by a computer (including a processor, which is a microcomputer).

B. Digital Control History

75. The field of digital control theory has been known to industry at least since the 1950s, as described in the following textbook excerpts.

> The demand for servomechanisms in military applications during World War II provided much incentive and many resources for the growth of control technology. Early efforts were devoted to the development of analog controllers, which are electronic devices or circuits. [M]ost analog controllers were limited to on/off and proportional-integral-derivative (PID) actions. …
>
> [I]t was soon apparent that analog control techniques had serious limitations. … The digital computer …was employed as a controller in complex control systems in the 1950s and 1960s.

(*Control Sensors and Actuators*, De Silva, Prentice-Hall, 1989, Ex. 1038, p. 1.)

> The idea of using digital computers as components in control systems emerged around 1950. … Applications in missile and aircraft control were investigated first. … The idea of using digital computers for process control emerged in the midfifties.
>
> To discuss the dramatic developments, it is useful to introduce four periods.
>
> Pioneering period ≈ 1955
> Direct-digital-control period ≈ 1962
> Minicomputer period ≈ 1967
> Microcomputer period ≈ 1972
>
> . . . The dates given refer to the first appearance of new ideas.

(*Computer Controlled Systems Theory and Design*, Astrom and Wittenmark, Prentice-Hall 1984, Ex. 1036, pp. 3-4.)

> Since there are even more drastic developments in microelectronics to come with the very large scale integration (VLSI) technology in the eighties, it is a safe guess that there will be a large increase in

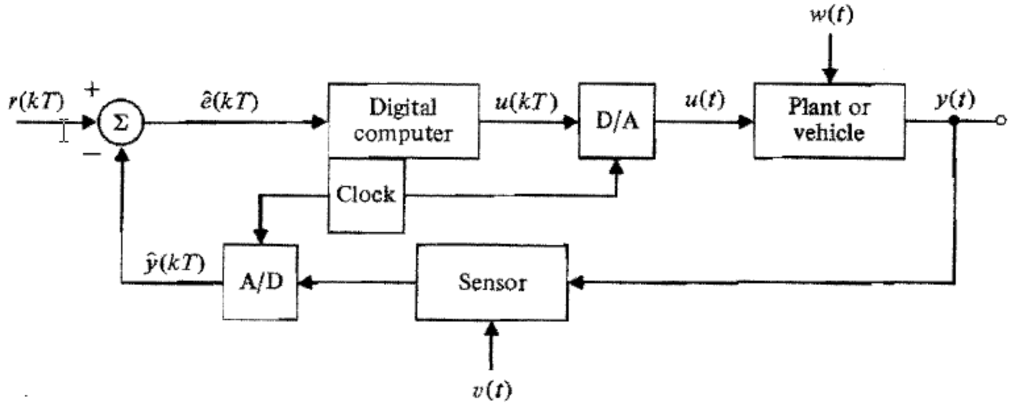
> computer-control applications then. **Microcomputers have already made an impact on control equipment: Microcomputers are replacing analog hardware** even as single-loop controllers; small DDC systems have been made using microcomputers; operator communication has been vastly improved in these systems with the introduction of color video-graphics displays; hierarchical control systems with a large number of microprocessors have been constructed; and special-purpose regulators based on microcomputers have been designed.

(*Computer Controlled Systems, Theory and Design*, Astrom and Wittenmark, Prentice-Hall, 1984, Ex. 1036, p. 6 (emphasis added).)

C. Digital Control Systems

76. Digital control can be conceptually based on analog control, as can be seen in the following excerpt:

> A typical topology of the elementary type of [digital control] system … is sketched schematically in [the figure below.] . . . The process to be controlled is called the plant and may be any of the physical processes mentioned above whose satisfactory response requires control action.



Notation:
r = reference or command inputs
u = control or actuator input signal
y = controlled or output signal
$\hat{y}$ = instrument or sensor output, usually an approximation to or estimate of y. (For any variable, say θ, the notation $\hat{\theta}$ is now commonly taken from statistics to mean an estimate of θ.)
$\hat{e}$ = $r - \hat{y}$ = indicated error
e = $r - y$ = system error
w = disturbance input to the plant
v = disturbance or noise in the sensor
A/D = analog-to-digital converter
D/A = digital-to-analog converter

(*Digital Control of Dynamic Systems*, Franklin et al., Addison-Wesley Publishing Company, 1990, Ex. 1037, pp. 1-2.)

77. Digital control requires that analog input and output signals be converted to digital signals, with discrete amplitudes at discrete times. This will be described in the digital signal processing section below. Conversion of the analog signals to digital signals is performed by an analog-to-digital converter (“A/D converter”, or “ADC”). Conversion of the digital signals to analog signals is performed by a digital-to-analog converter (“D/A converter”, or “DAC”). The figure above illustrates an A/D converter and a D/A converter. “… the A/D converter … provides a quantized signal. By this we mean that the output of the

A/D converter must be stored in digital logic composed of a finite number of digits." (*Digital Control of Dynamic Systems*, Franklin et al., Addison-Wesley Publishing Company, 1990, Ex. 1037, pp. 3.)

78. In the same fashion as for analog control, digital inner control loops may be stabilized using an outer (analog or digital) control loop or loops, such as a digital PI control loop.

D. Digital PI control

79. While continuous time (analog) controllers may be described in terms of differential equations, digital controllers may be described using discrete-time difference equations. The following excerpt from a 1990 textbook compares the relationship between continuous and digital control equations.

> Just as in continuous systems, there are three basic types of control: Proportional, Integral, and Derivative, hence the name, PID. … The term PID is widely used because there are commercially available modules that have knobs for the user to turn that set the values of each of the three control types. …
>
> **Proportional Control**
>
> A discrete implementation of proportional control is identical to continuous; that is, where the continuous is
>
> $$u(t) = K_p e(t)$$
>
> . . . the discrete is
>
> $$u(k) = K_p e(k)$$
>
> . . . where *e(t)* is the error signal. . . .

> > **Integral Control**
> >
> > For continuous systems, we integrate the error to arrive at the control,
> >
> > $$u(t) = \frac{K_p}{T_I}\int_{t_0}^{t} e(t)dt$$
> >
> > . . . The discrete equivalent is to sum all previous errors, yielding
> >
> > $$u(k) = u(k-1) + \frac{K_p T}{T_I} e(k)$$
> >
> > … Just as for continuous systems, the primary reason for integral control is to reduce or eliminate steady-state errors…
>
> Combining all the above yields the PID controller. . . This form of control law is able satisfactorily to meet the specifications for a large portion of control problems and is therefore packaged commercially and sold for general use.

(*Digital Control of Dynamic Systems*, 2d. Ed., Franklin et al., Addison-Wesley Publishing Company, 1990, Ex. 1037, pp. 222-224.) Note that with a zero value for the "D" or derivative term, a PID controller is a PI controller.

80. Redesign from an analog PID controller to a digital PID controller (and thus the sub-category of analog PI controller to digital PI controller, respectively) was described in one 1984 textbook as not requiring any special control system knowledge. The discrete-time PID-controllers have the advantage that they look and behave as continuous-time PID-controllers when the sampling

interval is short. Thus there is no educational problem if a controller is redesigned into digital form, so the same heuristic rules for tuning a PID-controller can be used. (*Computer Controlled Systems, Theory and Design*, Astrom and Wittenmark, Prentice-Hall, 1984, Ex. 1036, p. 186.) In conventional process-control with **PI-regulators**, the regulator has one state only-namely, the integrator. (*Computer Controlled Systems, Theory and Design*, Astrom and Wittenmark, Prentice-Hall, 1984, Ex. 1036, p. 375 (emphasis added).)

81. As mentioned above, digital control systems generally process digital input signals and generate digital output signals.

VII. SIGNAL PROCESSING

82. Signal processing may be performed by analog or digital components. The term "signal processing" describes the processing of signals, and includes operating on the signals (e.g., filtering, multiplication, combination, modulation, phase shifting, etc.) and extracting information from the signals. It may also describe the generation, synthesis, or encoding of signals.

A. Digital Signal Processing

83. The term "digital signal processing" describes the processing of digital signals using digital techniques, as discussed below. Digital signal processing lends itself to digital systems such as microprocessors which process sequences of numbers. A "digital signal processor" is a type of microprocessor

optimized to perform particular signal processing techniques. Digital signal processing per se does not even require the use of a programmable digital computer. Digital signal processing is discussed below.

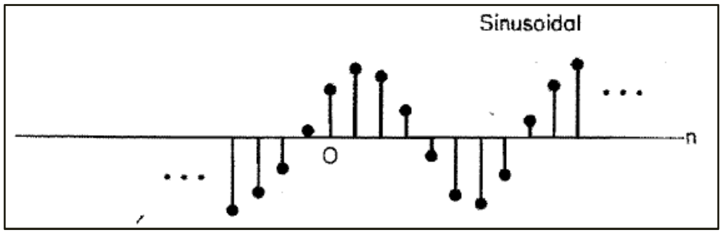
84. The inventor(s) of the patent that is the subject of the present Inter Partes Review did not redefine the term "digital signal processing." The field of digital signal processing has been well known to industry at least since the mid-1970s, as seen from a 1975 digital signal processing textbook by Oppenheim and Schafer.

> A signal . . . conveys information, generally about the state or behavior of a physical system. . . Discrete-time signals are defined at discrete times . . . Digital signals are those for which both time and amplitude are discrete. . .
>
> In almost every area of science and technology, signals must be processed to **facilitate the extraction of information**. Thus, the development of signal processing techniques and systems is of great importance. These techniques usually take the form of a transformation of a signal into another signal that is in some sense more desirable than the original. For example, we may wish to design transformations for **separating two or more signals that have been combined in some way**; we may wish to **enhance some component or parameter of a signal**; or we may wish to **estimate one or more parameters of a signal**.
>
> . . . digital signal processing systems have many attractive features. They can be realized with great flexibility using general-purpose

> digital computers, or they can be realized with digital hardware. They can, if necessary, be used to simulate analog systems or, more importantly, to realize signal transformations impossible to realize with analog hardware. Thus, digital representations of signals are often desirable when sophisticated, signal processing is required. . .

(*Digital Signal Processing*, Alan V. Oppenheim, Ronald W. Schafer, Prentice-Hall, January 1975, Ex. 1039, pp. 6-7, emphasis in original omitted, emphasis added.)

85. The following figure from this textbook illustrates how a sinusoidal signal in the time domain may be represented by signal values at discrete time intervals (n).



(*Digital Signal Processing*, Alan V. Oppenheim, Ronald W. Schafer, Prentice-Hall, January 1975, Ex. 1039, p. 9.)

86. A 1979 book describes that digital signal processing techniques, including Discrete Fourier Transforms, were known at least in the mid-1960s.

> During the past fifteen years, digital signal processing has been an extremely active and dynamic field. Advances in integrated circuit technology and in processor architecture have greatly enlarged the

> scope of the technical areas to which digital signal processing techniques can be applied." "The programs [in this book] have been carefully selected to cover a broad spectrum of digital signal processing applications and design techniques. … The first chapter focuses on the Discrete Fourier Transform (DFT) and presents a variety of Fast Fourier Transform (FFT) and related algorithms.
>
> The book is the culmination of a project undertaken in early 1976 by the Digital Signal Processing Committee of the IEEE Acoustics, Speech, and Signal Processing Society.

(*Programs for Digital Signal Processing*, IEEE Acoustics, Speech, and Signal Processing Society, John Wiley and Sons, 1979, Ex. 1040, p. ix.)

B. Fourier Analysis of Signals

i. The Fourier Transform

87. The use of Fourier transforms and Fourier based techniques to extract spectral information from analog (i.e., continuous) signals has been well known for well over a century. Joseph Fourier, for whom the Fourier transform was named, lived in 1768-1830.

88. The Fourier Transform F(s) of a signal f(x) is given by

$$F(s) = \int_{-\infty}^{\infty} f(x) e^{-i2\pi xs} dx$$

(*The Fourier Transform and its Applications*, Bracewell, McGraw-Hill, Second Edition, 1978, Ex. 1041, p. 7.) By changing variable names and utilizing the mathematical identity $e^{-i2\pi ft} = \cos(2\pi ft) - i \sin(2\pi ft)$, it can be seen that the Fourier

Transform X(f) of a continuous signal x(t) in essence consists of *multiplying the time signal x(t) by a sine wave or cosine wave and then integrating*.

$$X(f) = \int_{-\infty}^{\infty} x(t)\cos(2\pi ft)dt - i\int_{-\infty}^{\infty} x(t)\sin(2\pi ft)dt$$

ii. The Discrete Fourier Transform

89. The Fourier Transform makes use of integrals, which are not directly implementable by a digital computer. However, Bracewell's 1978 book also includes a definition of the Discrete Fourier Transform (DFT), which is a digital signal processing technique. The use of discrete-time Fourier digital signal processing techniques have been used in microprocessor-based products for many decades. The following excerpt is from a 1978 textbook.

> By definition, $f(\tau)$ possesses a discrete Fourier transform $F(\nu)$ given by
>
> $$F(v) = \mathrm{N}^{-1}\sum_{v=0}^{N-1} f(\tau)\, e^{-i2\pi\left(\frac{v}{N}\right)\tau}$$
>
> The quantity ν/N is analogous to frequency measured in cycles per sampling interval.

(*The Fourier Transform and its Applications*, Bracewell, McGraw-Hill, Second Edition, 1978, Ex. 1041, p. 358.)

90. By changing variable names and utilizing the mathematical identity $e^{-i2\pi(\nu/N)\tau} = \cos(2\pi(\nu/N)\tau) - i\sin(2\pi(\nu/N)\tau)$, it can be seen that the Discrete Fourier

Transform X(k) of a digital signal x(k) is in essence determined *by multiplying the signal sequence x(k) by a sine wave or cosine wave sequence and then summing*:

$$X(k) = \mathrm{N}^{-1}\sum_{n=0}^{N-1}\left(\mathrm{x(k)cos}\frac{2\pi kn}{N}\right) - i\mathrm{N}^{-1}\sum_{n=0}^{N-1}\left(\mathrm{x(k)sin}\frac{2\pi kn}{N}\right)$$

Summation (Σ) is the discrete-time equivalent of continuous-time integration (∫).

91. The undersigned similarly employed multiplying a sensor signal sequence x(k) by a sine wave sequence and then summing to extract specific frequency components of head positioning runout error in a disk drive servo system, as seen in the patent to the author issued in 1985. (See U.S. Pat. No. 4,536,809 to Sidman, titled "Adaptive Misposition Correcting Method and Apparatus for Magnetic Disk Servo System," issued August 20, 1985, Ex. 1042, col. 10 lines 4-52.)

92. As discussed above, in a Coriolis flowmeter, the difference between the phase of two pick-up signals is proportional to the mass flow rate of the material. Thus, demodulation may be used as a signal processing technique to identify a phase difference between the pick-up signals.

C. Signal Demodulation

93. Demodulation is a general term for the process of extracting signal information from a modulated sinusoidal carrier wave. An example of demodulation is the recovery of an audio signal from an AM radio signal.

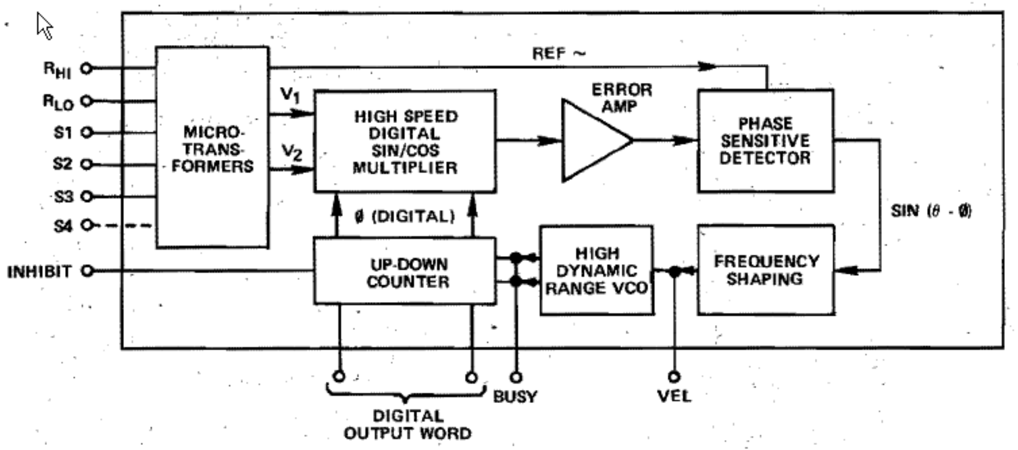
94. In Coriolis flowmeters, demodulation occurs in the detection of quadrature signal components of sinusoidal signals produced by the motion sensors mounted to a vibrating conduit. Known techniques for demodulating sinusoidal quadrature signals include the use of a resolver or a synchro. Synchronous demodulators used in measurement systems, such as resolvers, may utilize a drive or excitation signal as a time reference with which to synchronize the signal processing of a sensor signal. Demodulators have been implemented using analog or digital techniques. An example of a resolver follows, from a 1989 textbook.

> The resolver. This mutual-induction transducer is widely used for measuring angular displacements. . . If the angular position of the rotor with respect to one pair of stator windings is denoted by θ, the induced voltage in this pair of windings is given by
>
> $v_{o1} = a\, v_{ref} \cos \theta$ . . .
>
> The induced voltage in the other pair of windings is given by
>
> $v_{o2} = a\, v_{ref} \sin \theta$ . . .
>
> The two output signals v_{o1} and v_{o2} of the resolver are termed quadrature signals. … these quadrature signals could be demodulated to obtain the speed of rotation directly.

(*Control Sensors and Actuators*, De Silva, Prentice-Hall, 1989, Ex. 1038, pp. 104-105.)

95. The same 1989 textbook describes a digital version of the resolver. "Digital resolvers . . . The direction of rotation is determined by the phase difference in the two modulating output signals. … Very fine resolutions are obtainable from a digital resolver." (*Control Sensors and Actuators*, De Silva, Prentice-Hall, 1989, Ex. 1038, p. 244.)

96. A description of synchronous demodulation of sinusoidal synchro/resolver sensor signals is illustrated in the 1984 specification of the SDC1700/1702/1704 SERIES Synchro/Resolver-to-Digital Converter from Analog Devices. The synchro/resolver to digital converter demodulation process involves multiplying the sinusoidal sensor signals from the synchro/resolver respectively with a digital sine wave and cosine wave.



Functional Diagram of the SDC1700/2/4 Converters

> A phase sensitive detector, integrator and Voltage Controlled Oscillator (VCO) form a closed loop system which seeks to null Sin (θ-φ). When this is accomplished, the word state of the up-down counter (φ), equals within the rated accuracy of the converter, the

> synchro shaft angle θ.

(Analog Devices Data-Acquisition Databook, 1984, Ex. 1043, p. 13-49 – 13-52.)

97. Almost a decade before the above data book was published, a 1976 article described demodulating synchro signals “with respect to the synchro’s ac reference signal,” as well as microprocessor-based inverse trigonometric techniques.

> After conversion, the binary X and Y signals are stored in RAM. The microprocessor then executes the conversion equation, $\theta = \tan^{-1} Y/X$ and the result is placed on the output-data lines and stored in RAM … A look-up table for converting the tangent function to angular data is burned into the microprocessor's nonvolatile ROM.

(*Convert all your synchro channels to digital with a single µP-based system*, Arthur Berg, Micro Networks, ELECTRONIC DESIGN 25, December 6, 1976, Ex. 1044, pp. 78-79.)

98. Therefore, the extraction of phase information from two out-of-phase signals by way of synchronous demodulation was well known long before the 1990s (i.e., long before the filing of the application leading the patent that is the subject of this Inter Partes Review.)

D. Problems Encountered by Digital Systems Employed in Coriolis Flowmeters

i. The Need for Conversion Between Analog and Digital

99. Analog pick-ups are used to transduce the oscillatory motion of a Coriolis flowmeter conduit. Because the transduced electrical signals are generally analog, and because digital signal processing requires digital signals, the sensor signals must first be converted into digital signals. This generally requires the use of an analog-to-digital (A/D) converter, which samples its analog input and quantizes the sampled value into a number that can be subsequently processed. Additionally, in Coriolis flowmeters in which a digital component generates the conduit drive signal or a component of the conduit drive signal, one or more digital processor outputs may need to be converted to analog signals. This requires a digital-to-analog (D/A) converter. Thus, A/D and D/A conversions are a necessary part of a digital flowmeter. A/D converters and/or D/A converters may be collocated with the digital processor on the same semiconductor chip.

ii. Time Delay

100. The use of electronic components introduces time delay into a signal path. Invensys has asserted claims in the Invensys Litigation related to compensating for time delay. However, compensation for time delay was well known in the prior art.

a) Sources of Time Delay in Digital Systems

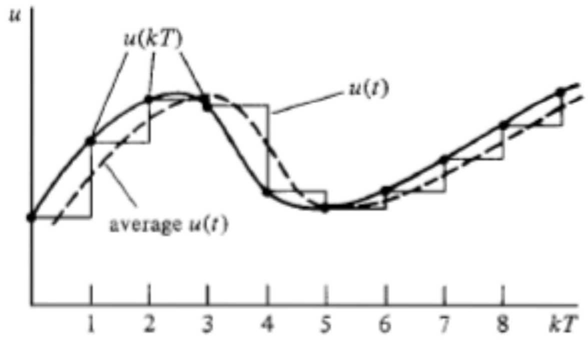
101. Time delays in digital signal processing and control systems are unavoidable. In closed-loop control systems, phase shift due to time delays within

the control loop may be deleterious to control system tracking and dynamic performance, and may even lead to instability of the control system. Time delays stem from a number of sources, some of which are described in detail below.

102. A basic digital control system operates in general by (1) sampling the amplitude of an input analog signal (e.g., a sensor voltage), (2) converting this sampled valued to a digital number using an A/D converter, (3) transmitting that number to the digital signal processor or computer, (4) performing a numeric calculation based on that number inside a digital computer or processor to compute an updated digital value of a control signal, (5) transmitting this control signal value to a D/A converter, (6) and using the D/A converter to convert this control signal value to an analog (e.g. voltage) signal, which may then be used to drive a mechanism. (See, by way of illustration, the figure generally describing a control system in section C above.) This entire process (1-6) is repeated over and over on a periodic basis at the sample rate of the digital control system.

103. An inherent key source of time delay in such a digital system is caused by the fact that the analog output signal from the D/A converter is held at a constant value until the next digital control signal value is computed by and received from the processor. The value of the analog output signal from the D/A converter becomes increasingly stale as time progresses after the last update. This effect is called a (zero-order) hold (time) delay. The following figure is descriptive

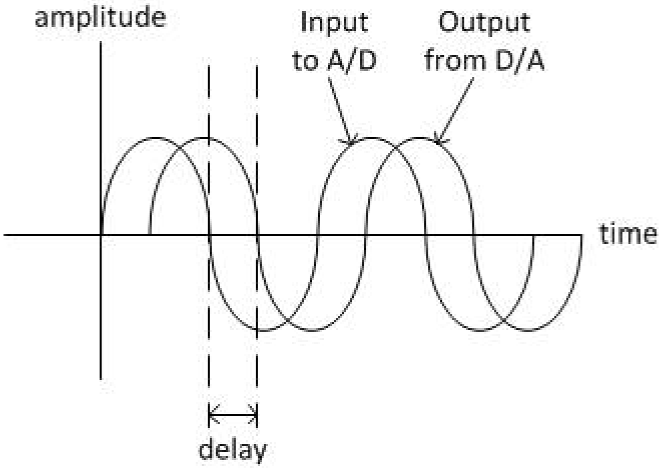
of the effect of hold delay. Illustrated is an analog input signal sampled by the A/D converter (the darker solid line), and the corresponding output of the D/A converter (the stepped lighter solid line) as the D/A converter receives periodic updates of the sampled input signal from the digital processor. In this idealized example, no digital signal processing computation occurs – the input signal value presented by the A/D converter to the processor is immediately sent as an output value to the D/A converter. An "average" (i.e., smoothed) version of the D/A output signal is shown in dashed lines.



(Digital Control of Dynamic Systems, Franklin, Powell & Workman, Addison-Wesley Publishing Company, Second Edition, 1990, Ex. 1037, Fig. 1.3.)

104. Comparing the smoothed output signal to the analog input signal illustrates the time delay caused by the hold delay. The amount of hold delay is related to the time period between samples and is thus inversely related to the sample rate of the system.

105. The following figure illustrates the hold delay and resulting phase shift when processing sinusoidal signals. In the figure, a sinusoidal analog A/D converter input signal is illustrated as well as the smoothed version of the D/A output signal. The output signal is a phase-shifted or time delayed version of the sinusoidal input signal.



106. This example illustrates the inherent delay and associated phase lag present when using digital signal processing to process analog signals.

107. In addition to the hold delay described, a D/A conversion time delay contributes to the overall time delay. After the updated digital output signal is presented to the D/A converter, there is a conversion delay during which time the D/A analog output changes and settles to a new level.

108. A/D converters also introduce conversion time delay. There generally is a time delay after the A/D conversion is initiated before a corresponding new digital value is available to the digital signal processor. The A/D conversion delay

may include a sample/hold delay. The sample/hold function may be performed by a separate component.

109. An analog multiplexer may be employed in the analog signal path ahead of the A/D converter to enable sampling and A/D conversion of two or more analog signals using a single A/D converter. When sampling of different analog input signals is performed on an interleaved basis, there will be a different time delay associated with each input.

110. In addition to components used in D/A and A/D conversion, other analog and digital electronic components not described herein may also add time delays into the signal path or the control loop.

111. Further, the time it takes the computer takes to perform a digital signal processing calculation during each sample period introduces a fixed or variable computational delay, which is another key contributor to overall time delay in a digital signal processing system.

112. Thus, hold delay, sampling delay, A/D conversion delay, computational delay, and D/A conversion delay, among other component delays, can have a significant impact in a basic digital signal processing or control system. In the case of sinusoidal signals, these delays each contribute a phase shift whose cumulative effect must be accounted for.

b) Prior Art Coriolis Teachings Regarding Time Delay

113. The Coriolis flowmeter system includes an electronic control system, with inherent delays as described above. These delays must be accounted for to properly synchronize driving forces or torques applied to the flowtube with the phase of existing flowtube oscillation.

114. To synchronize the application of control effort applied to the flowtube with the existing flowtube oscillation, the drive signal must be adjusted to compensate for the delays incurred by the electronic components (including the aforementioned delays associated with processing components and circuitry). For a sine wave drive signal (and other periodic signals), this delay may be referred to as a phase shift. Such compensation for "component delays" was well known long prior to the filing of the applications leading to the patents asserted in the Invensys Litigation.

115. For example, U.S. Pat. No. 4,799,385 ("Hulsing", Ex. 1050), issued January 24, 1989, describes a Coriolis rate sensor, in which the phase shift between a drive signal and a sensed signal is determined.

> A Coriolis rate sensor comprising first and second accelerometers mounted with their force sensing axes parallel to a common sensing axis. The accelerometers are vibrated along arcs in response to a periodic drive signal at a first frequency . . . The accelerometer output signals are demodulated to . . . detect the phase shift between the drive signal and the periodic compounds of

> the output signals.

(Hulsing, Ex. 1050, Abstract.) Hulsing describes that two accelerometer signals are processed together, "in the digital domain by a programmed data processor" (*id*., 6:42-44) "to produce a signal proportional to angular rate . . ." (*id*., 4:68-5:5.) Hulsing describes that in an actual (i.e., non-ideal) system, phase shift is introduced by the accelerometers:

> . . . in an actual system, there will be a phase shift between the periodic components of the output signal and the drive signal on line 20. Thus ideally, the demodulation of the output signal should be performed by a signal synchronous with cosωt that has been time delayed or <u>phase shifted by an amount corresponding to the phase shift ϕ_ω introduced by the accelerometer assembly at frequency ω</u>.

(Hulsing, Ex. 1050, 5:12-21 (emphasis added).) Fig. 3 of Hulsing illustrates timing/control circuit 102, which operates to compensate the drive signal for the delay incurred by operation of the accelerometers. (See also, Hulsing, Ex. 1050, Abstract.)

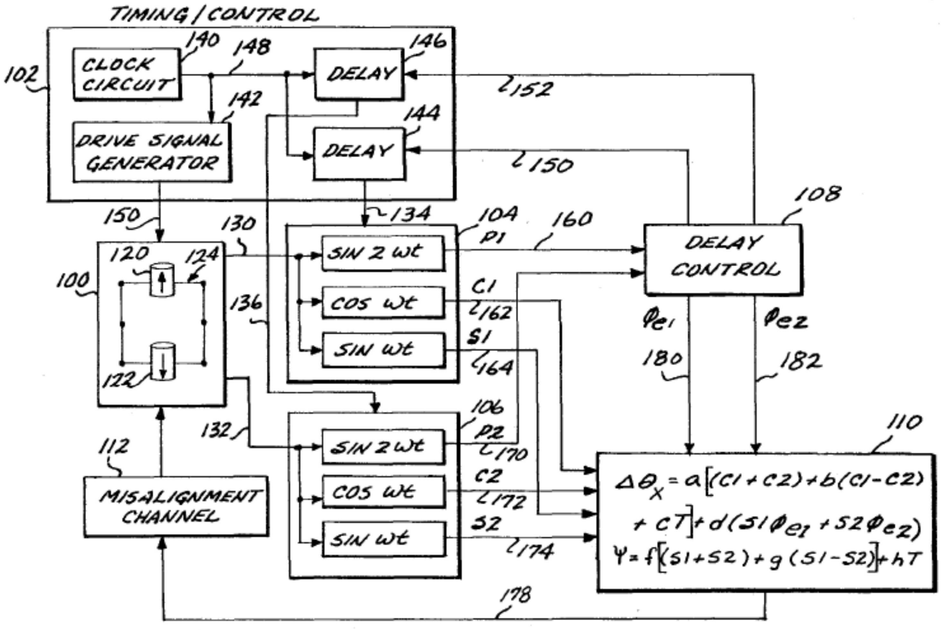


Fig. 3.

116. Similarly, U.S. Pat. No. 5,231,884 ("Zolock", Ex. 1052), issued August 3, 1993 to Micro Motion, discloses a Coriolis flowmeter that senses angular rate of motion, and describes: "Each input channel in a Coriolis meter imparts some internal phase delay to its input signal." (Zolock, Ex. 1052, 2:53-54.) Zolock uses digital signal processing (*id.*, 19:20-46) to correct for the phase delay incurred by the input channels (*id.*, 5:42-45 ("Once the current internal phase delay value is known for each pair, that value is then used to correct flow based Δt values subsequently produced by that pair during its next measurement mode."))

117. Zolock describes that it was known in the prior art to synchronize the drive signal with flowtube oscillation. "Flow tube drive circuit 27, depicted in FIG. 2, provides an appropriate repetitive alternating or pulsed drive signal, via lead

185, to drive mechanism 180. This circuit synchronizes the drive signal to the left velocity signal." (Id., 11:35-39.) Thus, Zolock describes compensating for component delays, and further describes synchronizing the drive signal with the flowtube oscillation.

118. Zolock refers the reader to three other Micro Motion patents for details of the drive circuit, including U.S. Pat. No. 5,009,109 to Kalotay and U.S. Pat. No. 4,934,196 to Romano. The Kalotay and Romano patents both describe that the processor generates a drive signal. Therefore, it would have been obvious to use the compensation for component delay determined by the processor in Zolock to compensate a drive signal generated by a processor as in Kalotay and Romano to synchronize the drive signal with the oscillation as described by Zolock, in the same manner taught by Hulsing.

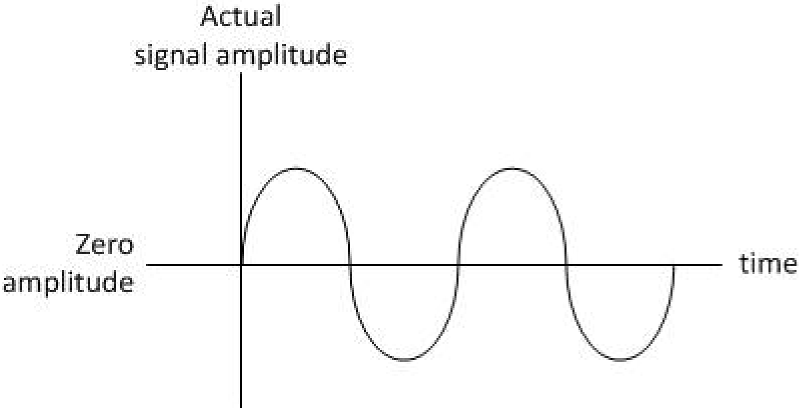
119. As can be seen by the above discussion, time delay is an inherent part of any digital control or signal processing system, and the time delay must be compensated for.

iii. Offset

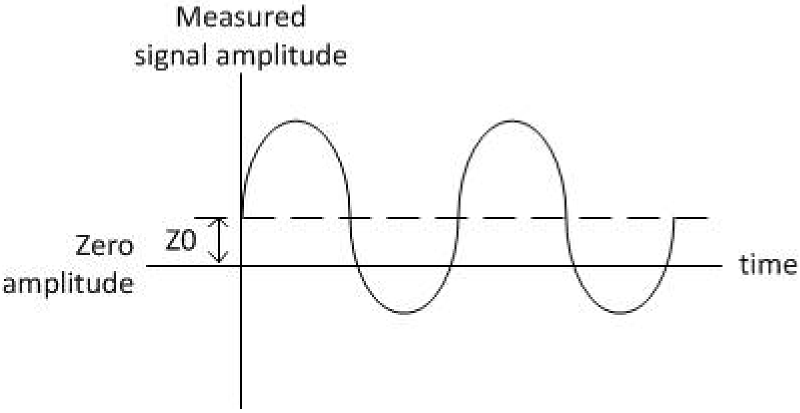
120. The use of electronic components introduces errors into a signal path, such as the inherent errors due to offset. Invensys has asserted claims in the Invensys Litigation related to compensating for offset. However, compensation for offset was well known in the prior art.

a) A Description of Offset

121. A signal having no offset has an average value of zero. This applies both to analog and to digital signals and to signals which are not pure sinusoids. The following figure is illustrative for a sinusoidal signal.



122. A signal may have a positive or negative offset. The signal illustrated below has a positive offset of Z0.



123. Offset is referred to in many ways, including using the terms DC offset, DC bias, and zero offset.

b) Sources of Offset in a Coriolis Flowmeter

124. Pick-ups (typically in the form of velocity or position sensors) are used in Coriolis flowmeters to detect the oscillatory motion of a vibrating conduit. Such sensors are analog in nature. As discussed above, one or more A/D converters are utilized to convert analog sensor signals into digital values required by a digital signal processor or digital control system in a Coriolis flowmeter.

125. Ideally, there should be no offset in the analog signals presented to the A/D converter or in the digitized sensor signals. However, small offsets do develop generally in analog electronics having active components, such as, for example, operational amplifiers. The presence of such offsets may be of concern when trying to extract precision amplitude, frequency and phase information from the sensor signals. Moreover, as discussed below, the combination of offsets and time delays may interact to limit the accurate extraction of this information.

126. The sources of sensor signal offset are well understood by circuit design engineers and are not peculiar to Coriolis flowmeters. For example, offsets are generated by sensor preamplifiers, buffers and other amplifiers in sensor signal paths. Operational amplifiers used in analog stages are well known sources of offset. Offsets are present in A/D converters and may develop in ground and voltage references in the analog electronics of a flowmeter. These and other sources of offset are potentially additive.

127. Offsets are generally unpredictable and variable. For example, offset may vary from one sensor channel or signal path to another, from one amplifier stage to another, from one amplifier on a semiconductor chip to another amplifier on the same chip, and from one chip to the next, etc. Amplifier offset generally varies with changes in temperature.

128. As described above, a signal having no offset has an average value of zero. Thus, offset may be described as the measured average value for a signal in which the true average value is zero. A known method of compensating for offset was to average the measured value over a large number of cycles. This is the approached advocated in U. S. Pat. No. 6,311,136 (the "'136 patent") and its continuations (the '136 patent and its continuations are referred to as "the '136 patent family", which includes six of the seven asserted patents in the Invensys Litigation).

c) "Zero Offset" and "DC Offset" as Disclosed in the Invensys Patents is "Offset" as Described Above

129. In the '136 patent asserted by Invensys, "zero offset" is mentioned but not defined. However, the "Zero Offset Compensation" section of the '136 patent describes:

> zero offset may be introduced into a sensor voltage signal by drift in the pre-amplification circuitry and by the analog-to-digital converter. Slight differences in the pre-amplification gains for positive and negative voltages due to the use of

> differential circuitry may worsen the zero offset effect. The errors vary between transmitters, and with transmitter temperature and component wear.

(’136 patent, Ex. 1051, 29:11-17.) Additionally, the “Compensation Technique” section of Invensys patent 6,311,136 discloses averaging the signal over, e.g., 10,000 oscillation cycles to determine zero offset. (’136 patent, Ex. 1051, 29:65-30:5.) Thus, “zero offset” as used in the ’136 patent is “offset” as described above. Further, the Invensys ’136 patent uses the terms “zero offset” and “DC offset” interchangeably with no distinction between the terms.

130. For example, in the “Zero Offset Compensation” section, the Invensys ’136 patent discloses that low-cost A/D converters “may be employed for economic reasons. FIGS. 19A-19D show how offset and positive and negative gains vary with chip operating temperature for one such converter (the AD1879 converter).” (’136 patent, Ex. 1051, 29:18-23.) The title of the plot in Fig. 19D is “SV1: Zero Offset”, and the vertical axis is labeled “AD1879 Zero Offset”. (’136 patent, Ex. 1051.) Therefore, the DC offset described in the text as related to the AD1879 A/D converter is interchangeably described in Fig. 19 as zero offset.

131. The same interchanging of the terms “DC offset” and “zero offset” may be found throughout the “Zero Offset Compensation” section of the Invensys ’136 patent. (See, e.g., ’136 patent, Ex. 1051, 29:43-48.) Therefore, the

synonymous terms “zero offset” and “DC offset” used in the ’136 patent describe the concept of “offset” in general.

d) Prior Art Coriolis Flowmeters Which Address Offset

132. Several prior art patents to the Invensys ’136 patent addressed the issue of offset, as it an inherent part of any Coriolis flowmeter electronics.

133. U.S. Pat. No. 4,655,089 (“Kappelt”)(Ex. 1047), issued April 7, 1987, describes a mass flow meter, and illustrates in Fig. 9 two auto zero circuits 142 and 112 in the measurement and drive circuits, respectively. With respect to auto zero 112 in the drive circuit, Kappelt describes that “any accumulated DC offset produced or received by preamplifier 102 will be eliminated, and the signal produced by preamplifier 102 will be an AC signal with virtually no DC component” (Kappelt, Ex. 1047, 9:56-59); “auto zero 142 . . . operate[s] in the same manner as . . . auto zero 112” (Kappelt, Ex. 1047, 9:60-62), and “latch 132, digital counter 120, ROM 122 and auto zero 142 can be replaced by any suitably programmed general purpose microprocessor” (Kappelt, Ex. 1047, 24:11-13).

134. U.S. Patent No. 5,009,109 (“Kalotay”), issued April 23, 1991, describes a Coriolis flowmeter, and discloses compensation for DC offsets by providing an “equation, which advantageously eliminates the effects of any DC offsets in the sampled signal.” (Kalotay, Ex. 1008, 15:20-25.)

135. U.S. Pat. No. 5,767,665 ("Morita")(Ex. 1053), filed September 12, 1995, describes a Coriolis mass flowmeter and provides motivation for compensating for offset in that "when measuring a phase difference with high accuracy, variations of the frequency, amplitude, and DC level of a measured signal make errors"(Morita, Ex. 1053, 4:43-45). Morita describes a technique such that "phase difference measurement error due to variations in frequency, amplitude, and DC level has been compensated for." (Morita, Ex. 1053, 15:9-11. See also Fig. 14B; 14:28-33.) U.S. Patent No. 5,804,741 ("Freeman")(Ex. 1054), filed November 8, 1998, describes a Coriolis flowmeter, and that a DC bias signal is introduced by the analog-to-digital converter (Freeman, Ex. 1054, 10:17-20). Freeman also discloses eliminating the DC bias through a combination of signal processing and filtering. "(Freeman, Ex. 1054, 12:14-20.)

136. As can be seen from the above, the issues related to offset, the need to compensate for offset, and techniques for compensating for offset were well known in the prior art related to Coriolis flowmeters long before the application leading to the Invensys patents asserted in the Invensys Litigation were filed. It would have been obvious when faced with issues related to offset in a Coriolis flowmeter as described in the Invensys '136 patent to look to these prior art examples for known solutions of compensating for offset, with a reasonable

expectation of success that the known solutions would be successful in another Coriolis flowmeter.

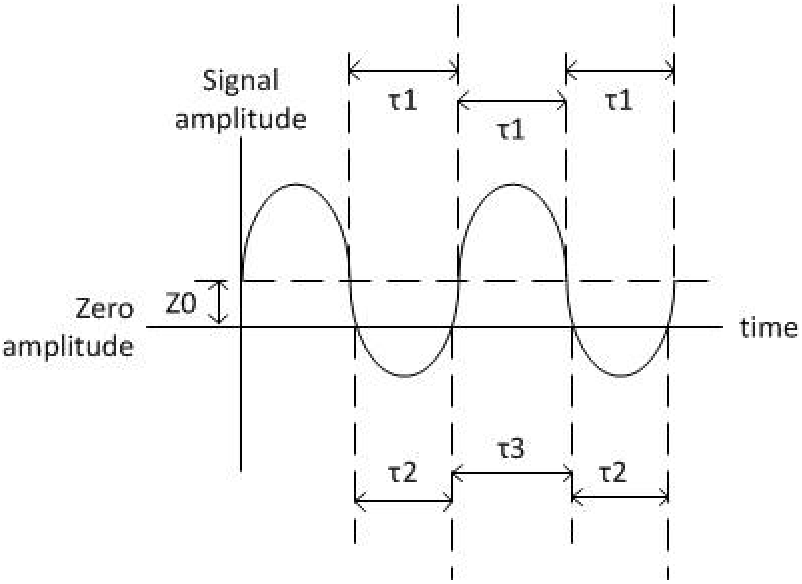
iv. Problems Caused by Time Delay and Offset

a) Zero Crossing Asymmetry

137. Offset of a sinusoid waveform causes time asymmetry of its zero crossings. This is of particular concern in Coriolis signal processing schemes which make use of zero crossings of sensor signals to ascertain phase, frequency or amplitude. The measurement problem that signal offset creates is exacerbated in methods which estimate these parameters every half cycle of oscillation because the time duration of alternating half cycles will alternate in duration.

138. Offset should be minimized in systems in which it can affect the accuracy of phase, frequency, or amplitude estimates. By way of explanation, consider the following sine wave as measured, with offset (the sine wave shown represents the amplitude envelope of a sequence of discrete values). If offset were equal to zero ($Z0=0$), then the sine wave would cross the zero amplitude line (i.e., zero crossing) each time the sine wave changes phase (at $\omega=0, \pi, 2\pi$, etc.). The duration τ of each half-cycle would be equal, as shown by the equal half-cycles with duration $\tau 1$ in the figure. However, if offset is not zero ($Z0>0$ or $Z0<0$), then the sine wave does not cross the zero amplitude line at a change of phase, and thus

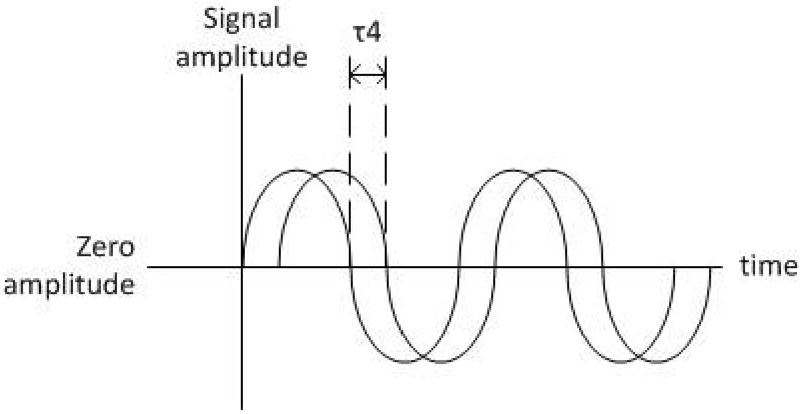
the duration of the half-cycles would be different, as indicated by the difference between τ2 and τ3 in the figure.



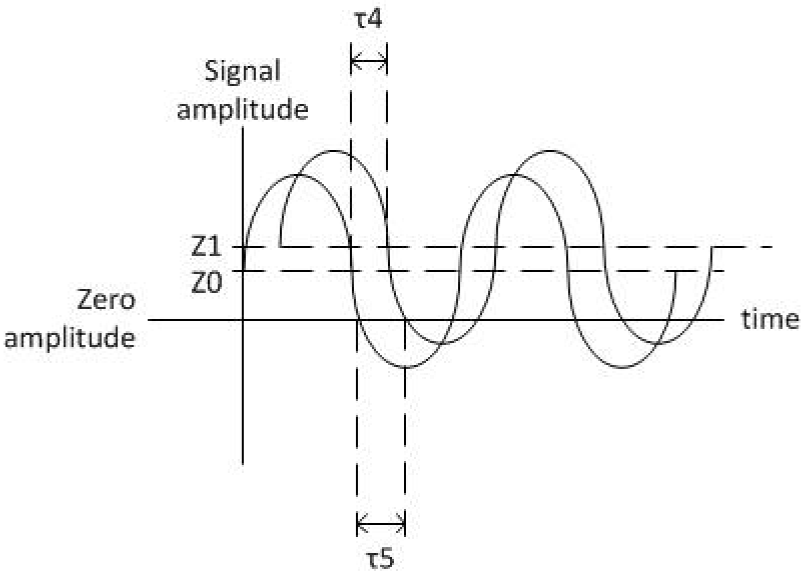
139. In other words, with no offset present, the period of a sine wave is twice the duration of each measured half-cycle. However, in the presence of offset, the measured period of each half cycle (based on zero crossings) will alternate in duration. If the estimated frequency of the sine wave is based on the measured duration of each half-cycle, then frequency estimates will correspondingly alternate in magnitude at every half cycle.

140. Frequency estimates based on sensor signal data are used as a basis to drive or sustain flowtube oscillation in a Coriolis flowmeter. However, an offset which results in an incorrect frequency estimate may result in a drive signal frequency which is not proximal to the conduit's resonant frequency. Oscillation amplitude can be affected, possibly resulting in a stall condition.

141. Another calculation that may be affected by offset is the phase difference measurement used in calculating mass flow rate. If phase difference is calculated using zero crossings, then ideally the measured phase difference is equal to the difference in time between when the two sensor signals cross the zero amplitude line, as shown by the phase difference τ4 in the following figure (each sine wave represents the amplitude envelope of a sequence of discrete values).



142. However, as described above, the measured zero crossing is not the true zero crossing in the presence of offset. Moreover, the offset of each signal will generally not be equal. The figure below illustrates the measured phase difference τ5 as compared to the actual phase difference τ4 in the presence of offsets Z0 and Z1 (each sine wave represents the amplitude envelope of a sequence of discrete values).



143. Thus, if amplitude measurement is critical to calculation, such as in a flowmeter using zero crossings to determine resonant frequency, phase, and/or other features of a signal, then offset must be compensated for.

144. The problem of phase shift resulting from DC offset I have described above is an issue that the Invensys '136 patent recognized. "If phase is calculated using the time difference between zero crossing points on the two sensor voltages, DC offset may lead to phase errors." ('136 patent, Ex. 1051, 29:28-30).

E. Digital Signal Processing Overlap Techniques

i. A Description of Overlap

145. Digital signals may be represented as arrays of data stored in the form of sequences of numbers in a digital processor. It is possible to digitally process digital signal data in small batches or data sets instead of simply processing a long sequence one data sample or number at a time. There is a long history of breaking

digital signal data streams into fixed length blocks for digital signal processing. Similarly, there is a long history of disassembling data streams into overlapping blocks of data. It has been found advantageous to batch process overlapping sets of data for variety of reasons and for a wide variety of applications.

ii. Invensys' Disclosure of Overlap

146. Invensys mentions in the '136 patent family using data sets which include data for overlapping cycles of flowtube oscillation, but does not provide detail of how the overlap is actually incorporated into the processing of the sensor signals, and does not provide the impetus for using overlap. Illustratively, Invensys patent U.S. 7,571,062 ("the '062 patent") of the '136 patent family includes the following claims:

> 12. The digital flowmeter of claim 1, wherein the sensor signal is generally periodic and the control and measurement system is configured to process the sensor signal in sets, wherein each set includes data for a complete cycle of the periodic sensor signal.
>
> 13. The digital flowmeter of claim 12, wherein consecutive sets include data for **overlapping cycles** of the periodic sensor signal.

147. Several prior art references similarly describe data sets in which each set "includes data for a complete cycle" of a periodic signal, and "consecutive sets include data for overlapping cycles" of the signal. The use of such techniques was known in digital signal processing and not originated by Invensys.

iii. Prior Art References Disclose Digital Signal Processing Using Overlapping Data Sets

148. The sensor input signals representing oscillation of a flowtube in a Coriolis flowmeter are continuous signals with constantly-changing frequency, phase, and amplitude. Persons skilled in the art of Coriolis flow meter design recognized the desirability of accurately and quickly measuring such changes. For example, U.S. Pat. No. 3,251,226 issued May 17, 1966 to Cushing described a Coriolis flowmeter (1:28-29) in which an "object of the invention is to provide apparatus for measuring mass flow which has rapid response time." (Cushing, Ex. 1055, 3:40-42.) U.S. Patent No. 5,373,745 to Cage included an extensive discussion of the desirability of minimizing the signal to noise ratio in Coriolis flow meter sensor signals to be processed by a digital signal processor. (Cage, Ex. 1003, 21:62-22:43) U.S. Pat. No. 5,469,748 to Kalotay describes that accuracy is limited by signal-to-noise ratio. (Kalotay '748, Ex. 1056, 2:36-40) ("The magnitude of the minimum time delay that can be measured between the two Coriolis flowmeter output signals at a given drive frequency is limited by various factors including the signal to noise ratio.")

149. Goals such as improving response speed and signal-to-noise ratio were common to signal processing in general, and not merely to flowmeters. Signal processing techniques were generally agnostic to the source of the signal.

Therefore, the techniques developed for processing periodic signals in one field were carried over into other fields.

150. For example, A/D converters and other components in the electronics of a Coriolis flowmeter inherently introduce error into the sampled data representation of the flowtube oscillation, therefore undesirably affecting the signal-to-noise ratio. U.S. Pat. No. 5,570,093 ("Aker", Ex. 1057) discloses an overlap technique to improve signal-to-noise ratio of microwave (i.e., "periodic") signals.

> The Fast Fourier Transform (hereafter FFT) is performed on the 2048 samples by doing seven consecutive 40 FFT's, each being performed on 512 samples with a 50% overlap

(Aker, Ex. 1057, 22:38-40.)

151. U.S. Pat. No. 5,479,933 ("Atarius") (Ex. 1058), describes an overlap technique for processing electrocardiograph (ECG) signals (which are also periodic) to expose low amplitude structures in the signals.

> The signals are supplied to the averager 24 in the form of an ensemble of time-synchronized signals from a plurality of cardiac cycles. One sub-average value is formed by the signals from <u>successive, overlapping intervals</u> or time windows. . .

(Atarius, Ex. 1058, 3:24-28 (emphasis added).)

152. U.S. Pat. No. 5,365,592 ("Horner") (Ex. 1059) describes an overlap technique to increase the rate of identification of a cepstrum in an audio signal, which is also a periodic signal. (A cepstrum is the result of taking the Inverse Fourier transform of the logarithm of the estimated spectrum of a signal.)

> The data is read out of RAMS 70 and 72 in blocks of N points . . . The memory pointer is then shifted by N/2 and another N point block is processed. This <u>N/2 overlapping</u> allows more voicing decisions per second to be made while maintaining length N.

(Horner, Ex. 1059, 3:51-60 (emphasis added).)

153. Moreover, overlap techniques, such as the modified discrete cosine transform (MDCT), were well known by the mid-1990s. For example, U.S. Pat. No. 5,646,960 ("Sonohara") (Ex. 1060) describes an MDCT "signal transforming device for executing fast calculation of linear transformation on digital signals" (Sonohara, Ex. 1060, 1:12-14) for application to PCM audio signals (another form of periodic signal), where

> . . . chronological sample data, such as PCM audio data, are grouped into blocks each made up of a predetermined number of, herein N samples. The blocks are set so that an <u>overlap with neighboring blocks amounts to 50%</u> . . .

(Sonohara, Ex. 1060, 15:14-19 (emphasis added).)

154. An MDCT overlap technique applicable to periodic audio signals was also described in section 2.3.3 of a 1995 article (*A Tutorial on MPEG/Audio Compression*, Davis Pan, Motorola Inc., IEEE Multimedia Journal, Summer 1995, Ex. 1061), describing that "[t]here is a 50% overlap between successive transform windows" of the MDCT overlap technique. A "modified DCT (MDCT) with 50% overlap" was also mentioned in a November 1997 article (*Local Cosine Bases in Two Dimensions*, Jelena Kovacevic, IEEE Trans. on Image Proc., Vol. 6, No. 11, November 1997, Ex. 1048, footnote 1.)

155. Another well-known overlap technique is the Welch method, described in a 1967 article by Peter Welch. Fig. 1 of Welch, reproduced below, illustrates the overlapping segments (data sets) in an N-length record.

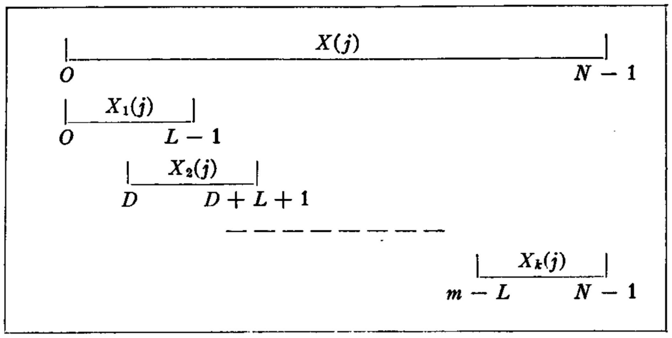


Fig. 1. Illustration of record segmentation.

156. (*The Use of Fast Fourier Transform for the Estimation of Power Spectra: A Method Based on Time Averaging Over Short, Modified Periodograms*, Peter Welch, IEEE Tras. Audio and Electroacoust., Vol. AU-15, pp. 70-73, June

1987, Ex. 1049, Abstract.) The Welch method was taught in undergraduate digital signal processing textbooks prior to 1997. For example, the Proakis textbook published in 1992 includes the Welch method (pp. 877-878) in a book "suitable for either a one-semester or a two-semester undergraduate-level course in discrete systems and digital signal processing". (*Digital Signal Processing*, Proakis and Manolakis, Macmillian Publishing Company, Second Edition, 1992, Ex. 1046, preface, p. v.)

157. Thus, the prior art abounds with examples of overlap techniques.

VIII. DIGITAL SIGNAL PROCESSING IN PATENTS ASSIGNED TO PETITIONER MICRO MOTION

158. The inventor(s) of the patent that is the subject of the present Inter Partes Review did not originate the use of digital signal processing for a Coriolis flowmeter. Several patents originally assigned to petitioner Micro Motion described the use of digital processors for signal processing. For example, the non-limiting list of Micro Motion patents disclosing digital signal processing includes:

- U.S. Pat. No. 4,817,448 issued Apr. 4, 1989, Fig. 2 (showing use of a microprocessor for signal processing) (Ex. 1045.)
- U.S. Pat. No. 4,872,351 issued Oct. 10, 1989 at 5:10-15 describing use of a microprocessor for signal processing (Ex. 1020.)
- U.S. Pat. No. 4,934,196 issued Jun. 19, 1990 at 21:19-28 describing use of a digital signal processor (optimized for digital signal processing) for "digital signal processing of both

velocity sensor waveforms" (Ex. 1006.)

- U.S. Pat. No. 4,996,871 issued Mar. 5, 1991 at 21:10-27 describing use of a digital signal processor optimized for digital signal processing (Ex. 1018.)
- U.S. Pat. No. 5,379,649 issued Jan. 10, 1995 at 8:11-24 describing use of microprocessor for signal processing. (Ex. 1015.)
- U.S. Pat. No. 5,555,190 issued Sep. 10, 1996 at 4:53-56 "applying digital filtering and digital signal processing (DSP) methods and apparatus to improve the accuracy of mass flow measurements in a Coriolis mass flow meter." (Ex. 1016.)
- U.S. Pat. No. 5,734,112 issued Mar. 31, 1998 at 2:20-22: "Digital signal processing (DSP) techniques improve the accuracy of processing the signals from the Coriolis flowmeter sensors." (Ex. 1017.)

IX. GROUNDS FOR UNPATENTABILITY

159. U.S. Patent No. 6,754,594 ("the '594 patent") is directed to a Coriolis type flowmeter ("Coriolis flowmeter"), which may be a mass flow rate meter or a densitometer. (Ex. 1001, 1:20-22; 6:27-29.)

160. I understand that anticipation of a claim requires that every element of a claim is disclosed expressly or inherently in a single prior art reference, arranged as in the claim.

161. I understand that obviousness must be analyzed from the perspective of a person of ordinary skill in the relevant art, at the time the invention was made.

In analyzing obviousness, I understand that it is important to understand the scope of the claims, the level of skill in the relevant art, the scope and content of the prior art, the differences between the prior art and the claims, and any secondary considerations. I understand that such secondary evidence can include evidence of commercial success caused by an invention, evidence of a long-felt need that was solved by an invention, evidence that others copied an invention, or evidence that an invention achieved a surprising result. I understand that such evidence must have a nexus, or causal relationship, to the elements of a claim, in order to be relevant to the obviousness or non-obviousness of the claim. I am unaware of any such secondary considerations that would suggest that the ’594 patent is valid.

162. I also understand that the earliest patent application filing leading to the ’594 patent was made on November 26, 1997. I have therefore analyzed obviousness as of that day or somewhat before (approximately 1996 – November 26, 1997), understanding that as time passes, the knowledge of a person of ordinary skill in the art will increase. I understand that under certain circumstances the owner of the ’594 patent might try to prove an earlier date of invention. If this occurs, I reserve the right to revise my opinion.

163. I believe that I would qualify as a person of at least ordinary skill in the art in 1996-1997.

164. Regarding the scope of the claims, I understand that claims in an i*nter partes* review proceeding are given their broadest reasonable construction that is consistent with the patent specification. I have reviewed the Petition for *inter partes* review, and agree with the facts stated in the Petition.

165. I understand that claim charts from another proceeding may be submitted as exhibits to a Petition for *inter partes* review and that certain of the claim charts from the *Invensys Systems, Inc. v. Emerson Electric Co. et al.*, CA. No. 6:12-cv-00799-LED (E.D. TX) proceeding are exhibits to the Petition.

166. In forming my opinion, I have relied on the ’594 patent claims and disclosure, including the incorporated provisional application and the prosecution history of the ’594 patent, the exhibits to the Petition for *inter partes* review of the ’594 patent, and my own experience and expertise in the knowledge of the person of ordinary skill in the relevant art in the 1996-1997 timeframe.

167. The ’594 patent includes several independent claims. Independent claims 1, 3, 8 and 13 identically or nearly identically[1] recite the language set forth below in paragraphs [a]-[h] which I will refer to collectively as “the Common Features”.

A digital flowmeter comprising:

---

[1] Independent Claim 3 recites nearly identical language to paragraphs [a]-[h] with the addition of a second sensor.

> [a] a vibratable conduit;
>
> [b] a driver connected to the conduit and operable to impart motion to the conduit;
>
> [c] a sensor connected to the conduit and operable to sense the motion of the conduit;
>
> [d] a control and measurement system connected to the driver and the sensor, the control and measurement system comprising circuitry to:
>
> [e] receive a sensor signal from the sensor,
>
> [f] generate a drive signal based on the sensor signal using digital signal processing,
>
> [g] supply the drive signal to the driver, and
>
> [h] generate a measurement of a property of material flowing through the conduit based on the sensor signal ...

A. Ground 1

168. I have reviewed U.S. Patent No. 6,073,495 ("Stadler"). It is my opinion that claims 3, 4, 6, and 13-14 of the '594 patent are anticipated by Stadler. Stadler claims an earliest priority date of April 22, 1997. I understand that the '594 patent claims an earliest priority date of November 26, 1997. Thus, it is my understanding that Stadler is prior art to the '594 patent under 35 U.S.C. § 102(e).

169. I understand that Stadler was submitted with a large number of references in an Information Disclosure Statement by Applicant during prosecution

of the application leading to the ’594 patent and thus is listed on the ’594 patent. It is my understanding that Stadler was not mentioned during prosecution of the application.

170. Stadler discloses the Common Features as recited in independent claims 3 and 13, including the basic Coriolis meter operation admitted as prior art in the Background section of the ’594 patent as well as generating the drive signal using a microprocessor (i.e., “using digital signal processing”). Stadler discloses “a Coriolis-type mass flow rate meter” including a “digital processor.” (Stadler, Ex. 1010, Abstract and Fig. 2.) Stadler also discloses a “vibratable conduit,” a “driver” and sensors: “[T]he latter comprises a measuring tube (4), a subcircuit measuring circuit and a subcircuit exciting circuit … [t]wo vibration sensors (17,18) and a vibration exciting [sic] (16) are arranged on the measuring tube.” (Stadler, Ex. 1010, Abstract.)

171. Stadler also discloses “a control and measurement system connected to the driver and the sensors.” For example, Fig. 2 of Stadler illustrates a system that processes analog sensor signals X17 and X18 received from vibration sensors 17 and 18 respectively ” (Stadler, Ex. 1010, 8:32-33), and provides an “output signal X16 … fed to a vibration exciter” (*id.* at 10:29-31) via circuitry including analog-to-digital converters aw1, aw2, and aw3 and a digital processor dp (*id.* at 9:38-42), a digital frequency controller fr, digital amplitude controller ar1, digital

generator dg, digital-to-analog converter dw2, and analog output stage ls (*id*. at 10:7-32) (i.e., "circuitry to generate a drive signal based on the sensor signals"). Stadler also discloses that the frequency and amplitude information output by the processor shown in Fig. 2 is based on the sensor signals: "Fig. 2 shows, in the manner of a block diagram, a measuring and operating circuit for mass flow meters … signals generated in the measuring subcircuit are required by the exciting subcircuit." (Stadler, Ex. 1010, 8:58-64.) Stadler further discloses that "output signal X16 of this stage is fed to a vibration exciter, for example the vibration exciter 16 of FIG. 1" (i.e., "circuitry to supply the drive signal to the driver"). (*Id.* 10:31-32.) Stadler further discloses that "[a]n analog signal x17 and x18 is produced by the vibration sensor 17 and 18, respectively" (i.e., "circuitry to receive signals from the sensors"). (*Id.* 8:31-32.)

172. Stadler further discloses generating "a measurement of a property of material flowing through the conduit based on the first and second sensor signals." For example, Fig. 2 of Stadler illustrates that the digital processor dp outputs digital density signal d and digital mass flow rate signal m. Stadler discloses that "FIG. 3 shows, in the manner of a block diagram, a preferred embodiment of the digital processor dp of FIG. 2." (Stadler, Ex. 1010, 10:33-34.) Fig. 3 of Stadler illustrates that the density d and mass m measurements are based on input signals X17 and X18 (i.e., based on the sensor signals).

173. Stadler also discloses using digital signal processing to generate the drive signal. For example, Fig. 2 of Stadler illustrates that output signal X16 is generated from frequency and amplitude information contained in signals output by the digital processor dp. Stadler discloses a digital generator dg, a digital frequency controller fr and a digital amplitude controller ar1 that receive inputs from digital processor dp in order to generate output signal X16, which then drives the vibration exciter ("driver"). (Stadler, Ex. 1010, 9:38-10:32.) Thus, it is my opinion that Stadler discloses the Common Features as recited in independent claims 3 and 13, including use of a digital processor dp to generate output signal X16 (i.e., "using digital signal processing").

174. **Claim 3:** In addition to the Common Features, independent claim 3 further recites "wherein the control and measurement system combines the sensor signals to produce a combined signal and to generate the drive signal based on the combined signal." This additional feature is also disclosed by Stadler. For example, Figs. 2 and 3 of Stadler illustrate that input signals X17 and X18 are combined at the first summing stage ss1 and used to generate the output signal X16 via a digital generator dg. Stadler discloses that "amplifiers v1, v2 are followed by a first summing stage ss1 for the output signal of the first amplifier and that of the second amplifier" and that "[t]he output signal of the first summing stage ss1 is fed

to an input of an integrating stage ig … ." (i.e., "combines the sensor signals to produce a combined signal"). (Stadler, Ex. 1010, 9:8-12.)

175. Stadler also discloses that "a first analog to digital converter aw1 follows the integrating stage … ." (*Id.* 9:21-22.) Stadler further discloses that "digital processor dp has three inputs, one of which follows the first, one follows the second, and one follows the third analog-to-digital converters aw1, aw2, aw3 … ." (*Id.* 9:38-40.) Fig. 3 of Stadler illustrates that the combined signal from aw1 is routed to the digital generator dg via the bandpass filter bp1 and first 90° phase shifting and normalizing stage ps1 of digital processor dp, and further via a digital frequency controller fr and a digital amplitude controller ar1. The first output of the digital generator dg produces a "digital signal driving the second digital to analog converter dw2" (*id*. at 16:24-25); digital to analog converter dw2, in turn "drives an analog output stage ls," the output of which drives the "vibration exciter" (i.e., "generate the drive signal based on the combined signal"). (*Id*. at 10:27-32 and Fig. 1.) Fig. 3 thus illustrates that output signal X16 is based on the combined signal from sensors 17 and 18. As such, it is my opinion that Stadler discloses combining, filtering, and digitizing sensor signals X17 and X18 for use in generating a drive signal. Therefore, because Stadler discloses the Common Features and the "wherein" clause as recited in independent claim 3, in my

opinion, Stadler anticipates claim 3. The disclosure of Stadler with respect to claim 3 is summarized in the claim chart below.

176. **<u>Claim 13</u>:** In addition to the Common Features, independent claim 13 further recites "wherein the control and measurement system digitally generates a gain for use in generating the drive signal based on one or more properties of the sensor signal." Stadler also discloses this additional feature. Specifically, Figs. 2 and 3 of Stadler illustrate a "digital amplitude controller ar1" (i.e., "digitally generates") whose output (i.e., a "gain") is a digital amplitude-setting signal that is provided as "the amplitude control input of the digital generator dg" (i.e., for "generating the drive signal"). (Stadler, Ex. 1010, 10:14-23.) Fig. 10 illustrates a preferred design of amplitude controller ar1 in which the output from bp1 (i.e., "based on one or more properties of the sensor signal") and an amplitude setting signal am are inputs to a subtractor sb2 that provides an error signal to a PID controller pi2, the output of which is connected to the amplitude control input of the digital generator dg. (*Id.,* 16:9-18.) Stadler further discloses how the output of digital amplitude controller ar1 is a gain used to modulate the amplitude of output signal X16. Fig. 11 is a preferred design of a digital generator dg whose first output a1 becomes drive output signal X16 as shown in Fig. 3. Stadler discloses that the amplitude control input of digital generator dg is connected to the output of the first amplitude controller ar1, and "is connected to a first input of seventh

multiplier mp7, whose output is the first output of the digital generator dg; the digital signal driving the second digital to analog converter dw2 occurs here." (*Id.* 16:18-25.)

177. Digital to analog converter dw2, in turn drives an "analog output stage ls," the output signal of which drives the "vibration exciter" (i.e., "driver"). (Stadler, Ex. 1010, 10:27-32 and Fig. 1.) The effective gain of multiplier mp7 determines the amplitude of the output signal X16. The output of digital amplitude controller ar1 is therefore an amplitude-setting gain based on the combined signal from aw1 (i.e., "based on one or more properties of the sensor signal"). Thus, Stadler discloses digitally generating a gain for use in generating the output signal X16 based on one or more properties of the sensor signals X17 and X18. Therefore, because Stadler discloses the Common Features and the "wherein" clause as recited in independent claim 13, in my opinion, Stadler anticipates claim 13. The chart below demonstrates how, in my opinion, the elements of claims 3 and 13 are mapped to the teachings of Stadler.

Claims 3 and 13 of 6,754,594	**Stadler 6,073,495**
[Common Features] A digital flowmeter comprising: a vibratable conduit;	Stadler discloses "a Coriolis-type mass flow rate meter" including a "digital processor." (Stadler, Ex. 1010, Abstract and Fig. 2.) Stadler discloses "a measuring tube (4), a subcircuit measuring circuit and a subcircuit exciting circuit. Two vibration sensors (17, 18) and a vibration exciting (16) are arranged on the measuring tube." (*Id.* Abstract.)

a driver connected to the conduit and operable to impart motion to the conduit;	Stadler discloses "a measuring tube (4), a subcircuit measuring circuit and a subcircuit exciting circuit. Two vibration sensors (17, 18) and a vibration exciting (16) are arranged on the measuring tube." (*Id.* Abstract.)
a sensor connected to the conduit and operable to sense the motion of the conduit;	Stadler discloses "a measuring tube (4), a subcircuit measuring circuit and a subcircuit exciting circuit. Two vibration sensors (17, 18) and a vibration exciting (16) are arranged on the measuring tube." (*Id.* Abstract.)
a control and measurement system connected between the driver and the sensor, the control and measurement system comprising circuitry to:	Stadler discloses in Fig. 2 a system that inputs and processes sensor signals X17 and X18, and provides an output signal X16. Stadler '495 further discloses that "output signal X16 of this stage is fed to a vibration exciter, for example the vibration exciter 16 of FIG. 1." (*Id.* 10:31-32.) Stadler discloses "[a]n analog signal x17 and x18 is produced by the vibration sensor 17 and 18, respectively." (*Id.* 8:31-32.)
receive a sensor signal from the sensor,	Stadler discloses that "analog signal x17 and x18 is produced by the vibration sensor 17 and 18, respectively." (*Id.* 8:31-32.)
generate a drive signal based on the sensor signal using digital signal processing, supply the drive signal to the driver, and	Stadler discloses in Fig. 2 that output signal X16 is generated from frequency and amplitude information output by the digital processor 'dp.' Stadler further discloses that the frequency and amplitude information output by the processor is based on the input signals: "FIG. 2 shows, in the manner of a block diagram, a measuring and operating circuit for mass flow meters . . . signals generated in the measuring subcircuit are required by the exciting subcircuit." (*Id.* 8:58-64.)
generate a measurement of a property of material flowing through the conduit based on the signal from the	Stadler discloses in Fig. 2 that the digital processor 'dp' output density 'd' and mass 'm' (i.e., "a property of material flowing through the conduit"). Stadler discloses that "FIG. 3 shows, in the manner of a block diagram, a preferred embodiment of the digital

sensor;	processor dp of FIG. 2.” (*Id.* 10:33-34.) Stadler discloses in Fig. 3 that the density ‘d’ and mass ‘m’ measurements are based on input signals X17 and X18.
[Claim 3, wherein clause.] wherein the control and measurement system combines the sensor signals to produce a combined signal and to generate the drive signal based on the combined signal.	Stadler discloses in Figs. 2 and 3 that input signals X17 and X18 are combined at the ‘ss1’ block and used to generate the output signal X16 via a digital generator ‘dg’. Stadler discloses that “the amplifiers v1, v2 are followed by a first summing stage ss1 for the output signal of the first amplifier and that of the second amplifier. The output signal of the first summing stage ss1 is fed to an input of an integrating stage ig …” (*Id.* 9:8-12.) Stadler discloses “a first analog to digital converter aw1 follows the integrating stage…” (*Id.* 9:21-22.) Stadler discloses “[a] digital processor dp has three inputs, one of which follows the first, one follows the second, and one follows the third analog-to-digital converters aw1, aw2, aw3, and which delivers a digital mass flow rate signal m at a first input and/or a digital density signal d at a second input.” (*Id.* 9:38-42.) Stadler discloses that the first output of the digital generator ‘dg’ produces a “digital signal driving the second digital to analog converter ‘dw2’” (*Id.* 16:24-25.) Stadler discloses that digital to analog converter ‘dw2,’ in turn “drives an analog output stage ‘ls,’” the output of which drives the “vibration exciter.” (*Id.* 10:27-32; Fig. 1.)
[Claim 13, wherein clause.] wherein the control and measurement system digitally generates a gain for use in generating the drive signal based on one or more properties	Stadler further discloses in Figs. 2 and 3 that a gain ‘ar1’ is applied to the digital generator to generate the drive signal. Stadler discloses “digital generator dg, which has a frequency control input and an amplitude control input.” (*Id.* 9:63-65.) Stadler further discloses in Fig. 3 that a bandpass filter ‘bp1’ follows analog-to-digital converter ‘aw1’ and

of the sensor signal.	therefore filters a digital representation of the summed signal from summer ‘ss1.’ Stadler further discloses in Fig. 3 that the output of bandpass filter ‘bp1’ is provided to amplitude controller ‘ar1.’ Stadler discloses “[a] first digital amplitude controller ar1 has a first and a second input and an output. The first input is connected to the output of the first bandpass filter bp1.” (*Id.* 10:14-16.)

178. Claim 4 depends from independent claim 3 and further recites “wherein the control and measurement system generates the drive signal by applying a gain to the combined signal.” Figs. 2 and 3 of Stadler illustrate that the output of “ar1” (i.e., “gain”) is applied to the digital generator “dg” to generate the drive signal, output signal, X16. As discussed above, the amplitude controller ar1 applies a gain to the combined signal. (Stadler, Ex. 1010, 8:16:8-25.) Figs. 2 and 3 of Stadler illustrate that the output of ar1 (i.e., “gain”) is applied to the digital generator dg to generate the drive signal (output signal X16), which drives Stadler’s “vibration excited.” Therefore, it is my opinion that Stadler anticipates claim 4.

179. Claim 6 depends from independent claim 3 and further recites “wherein the control and measurement system combines the sensor signals by summing the sensor signals.” As set forth above, Figs. 2 and 3 of Stadler illustrate that input signals X17 and X18 are combined at the summing stage ss1 block and

used to generate the output signal X16 via a digital generator dg. Stadler discloses that "amplifiers v1, v2 are followed by a first summing stage ss1 for the output signal of the first amplifier and that of the second amplifier" (i.e., "summing the sensor signals"). (Stadler, Ex. 1010, 9:8-10.) Therefore, in my opinion, Stadler anticipates claim 6.

180. Claim 14 depends from independent claim 13 and further recites "wherein the control and measurement system digitally generates the gain based on an amplitude of the sensor signal." As set forth above, Fig. 3 of Stadler illustrates that an input of digital amplitude controller ar is connected to the output of bp1, which includes the combined sensor signal from aw1, which is based on the sum of (and therefore the amplitudes of) sensor signals X17 and X18. Therefore, it is my opinion that Stadler anticipates claim 14.

181. A detailed claim chart of how, in my opinion, Stadler discloses the features of claims 3, 4, 6 and 13-14 can be found in the Invalidity Charts from the Invensys proceeding submitted with the Petition as Exhibit 1011.

182. The chart from the Invensys proceeding, attached to the Petition as Ex. 1011, summarizes how, in my opinion, Stadler anticipates each feature of claim 3 of the '594 patent. (Ex. 1011, pp. 1-2.)

183. The chart from the Invensys proceeding, attached to the Petition as Ex. 1011, summarizes how, in my opinion, Stadler anticipates each feature of claim 4 of the ’594 patent. (Ex. 1011, p. 2.)

184. The chart from the Invensys proceeding, attached to the Petition as Ex. 1011, summarizes how, in my opinion, Stadler anticipates each feature of claim 6 of the ’594 patent. (Ex. 1011, p. 4.)

185. The chart from the Invensys proceeding, attached to the Petition as Ex. 1011, summarizes how, in my opinion, Stadler anticipates each feature of claim 13 of the ’594 patent. (Ex. 1011, pp. 9-11.)

186. The chart from the Invensys proceeding, attached to the Petition as Ex. 1011, summarizes how, in my opinion, Stadler anticipates each feature of claim 14 of the ’594 patent. (Ex. 1011, p. 11.)

187. Therefore, it is my opinion that claims 3, 4, 6 and 13-14 of the ’594 are anticipated by Stadler.

B. Ground 2

188. I have reviewed U.S. Patent No. 5,804,741 (“Freeman”). In my opinion, claims 8-10 of the ’594 patent are anticipated by Freeman.

189. The Freeman patent was filed November 8, 1996. The ’594 patent claims an earliest priority date of November 26, 1997. Thus, it is my understanding that Freeman is prior art to the ’594 patent under 35 U.S.C. § 102(e).

190. I understand that Freeman was submitted with a large number of references in an Information Disclosure Statement by Applicant during prosecution of the application leading to the ’594 patent and thus is listed on the ’594 patent. It is my understanding that Freeman was not mentioned during prosecution of the application.

191. Freeman discloses the Common Features as recited in independent claim 8, including the basic Coriolis meter operation admitted as prior art in the Background section of the ’594 patent. Freeman also discloses generating the drive signal using a “DSP microprocessor chip” and digital signal processing.

> Digital signal processing is used to implement filtering and signal manipulation so as to respectively determine phase and frequency estimates for both of the two digitized signals. … Digitally obtained phase and frequency estimate data are used to determine an optimized drive signal for continuing tube vibration.

(Freeman, Ex. 1054, Abstract and Fig. 2.) “[T]he subject signal processing apparatus and methodology may be utilized in conjunction with … a vibrating tube design.” (Freeman, Ex. 1054, 6:12-17.) Freeman also discloses “a driver connected to the conduit and operable to impart motion to the conduit”: “[D]river means generally 28 may be provided for oscillating the first and second conduits relative to each other about their respective oscillation axes.” (Freeman, Ex. 1054, 6:63-

65.) Freeman further discloses sensors “connected to the conduit and operable to sense the motion of the conduit”:

> [R]espective first and second sensor means generally 30 and 32 may be associated with the conduits for generating analog sinusoidal outputs from the two indicated respective predetermined locations … the relative motion of the two conduits at such two predetermined locations may be determined through the output signals from the respective sensors.”

(Freeman, Ex. 1054, 7:10-16.)

192. Freeman also discloses “a control and measurement system connected to the driver and the sensors.” For example, Fig. 2 of Freeman illustrates a DSP microprocessor chip 62 and associated circuitry of processing means 40 connected to a driver 28 and sensors 30 and 32. Fig. 2 of Freeman also illustrates sample and hold devices 46 and 48 and analog-to-digital converters 54 and 56 for processing sensor signals on lines 42 and 44 (i.e., “circuitry to receive a sensor signal from the sensor”) as well as a digital-to-analog converter 66 and amplifier 70 to output final driver signal 72 (i.e., “circuitry to supply a drive signal to the driver”). Freeman discloses processing means 40 (e.g., DSP microprocessor chip 62 and associated circuitry shown in Fig. 2) for processing the digitized sensor outputs into a drive signal (i.e., “circuitry to generate a drive signal based on the sensor signal”):

> FIG. 2 represents means of the present invention generally 40 for processing such digitized outputs so as to estimate a fundamental

> frequency thereof, to estimate phases and a phase shift between such digitized outputs, and to establish from such estimates an optimized driver signal input for the driver means 28.

(Freeman, Ex. 1054, 7:45-51.) Freeman further discloses generating "a measurement of a property of material flowing through the conduit based on the first and second sensor signals": "Phase estimate information for the two respective sensor signals is used to determine phase shift data, used in turn to determine a fluid flow rate through the flow meter." (*Id.*)

193. Freeman also discloses using digital signal processing to generate the drive signal: "Digitally obtained phase and frequency estimate data are used to determine an optimized drive signal for continuing tube vibration." (Freeman, Ex. 1054, Abstract.) Thus, in my opinion Freeman discloses the Common Features as recited in independent claim 8, including use of a DSP microprocessor chip 62 to generate a drive signal 72 (i.e., "using digital signal processing").

194. Independent claim 8 concludes with "wherein the control and measurement system initiates motion of the conduit by using a first mode of signal generation to generate the drive signal, and sustains motion of the conduit using a second mode of signal generation to generate the drive signal." Freeman discloses different modes of drive signal generation for initiating and sustaining motion of the conduit. For example, with regard to sustaining motion, Freeman discloses:

> With operation and practice of the present invention, such drive signal 72 is an optimized waveform generated at the sensed resonant frequency and with the proper phase relationship to the magnet transducer signal on the previous filter cycle. For example, a trapezoidal waveform with such characteristics may be output through the digital-to-analog converter 66 to amplifier means 70, and thereafter output to driver means 28. In such fashion, the present invention accomplishes the broader purpose of optimized maintenance of tube vibration by generating an optimized tube vibration drive signal.

(Freeman, Ex. 1054, 15:22-32.) The sensed resonant frequency is tracked with a phase locked loop: "[T]he illustrated means for processing includes phase locked loop tracking of the digitized outputs 58 and 60." (*Id.* 11:8-9.) That is, Freeman discloses using a "sensed resonant frequency" for optimized "maintenance" of tube vibration (*i.e.*, "sustains motion of the conduit using a second mode of signal generation to generate the drive signal").

195. With regard to initiating motion of the conduit, however, Freeman discloses:

> In practice with various actual flow meters 10, the extreme range of tube resonant frequencies generally falls in a range between 30 and 120 Hz. Also, any given tube typically drifts less than 10 Hz during use. With the above advantageous arrangement, the relatively instantaneous capture range of the phase locked loop is roughly plus or minus 45% of the current heterodyne

> frequency. Accordingly, it is sufficient in accordance with practice of the present invention to initialize the tracker rather coarsely to a tube-size dependent default frequency. From there, it will reliably track all frequency excursions during use, and testing has shown such tracking abilities in fact to be extremely robust.

(Freeman, Ex. 1054, 15:7-18.) Initiating tracking allows the "phase locked loop to lock onto the fundamental input frequency." (*Id.* 14:66-67.) Freeman discloses using a "default frequency" to "coarsely" "initialize" the phase locked loop to enable it to lock onto the tube's resonant frequency, based on the size of the tube (i.e., "initiates motion of the conduit by using a first mode of signal generation to generate the drive signal"), after which phase locked loop tracking of the tube resonant frequency drift during use (i.e., "a second mode of signal generation") will "reliably" occur for purposes of "optimized maintenance of tube vibration." Therefore, because Freeman discloses the Common Features and the "wherein" clause as recited in independent claim 8, it is my opinion that Freeman anticipates claim 8.

196. The chart below demonstrates how, in my opinion, the elements of claim 8 are mapped to the teachings of Freeman.

Claim 8 of 6,754,594	**Freeman 5,804,741**
A digital flowmeter comprising:	Freeman discloses "a Coriolis-type fluid flow rate measuring system" using "digital signal processing."

a vibratable conduit;	(Freeman, Ex. 1054, Abstract and Fig. 2.) "[T]he subject signal processing apparatus and methodology may be utilized in conjunction with … a vibrating tube design." (Freeman, Ex. 1054, 6:12-17.)
a driver connected to the conduit and operable to impart motion to the conduit;	"[D]river means generally 28 may be provided for oscillating the first and second conduits relative to each other about their respective oscillation axes." (*Id.* 6:63-65.)
a sensor connected to the conduit and operable to sense the motion of the conduit;	[R]espective first and second sensor means generally 30 and 32 may be associated with the conduits for generating analog sinusoidal outputs from the two indicated respective predetermined locations … the relative motion of the two conduits at such two predetermined locations may be determined through the output signals from the respective sensors." (*Id.* 7:10-16.)
a control and measurement system connected to the driver and the sensor, the control and measurement system comprising circuitry to:	Fig. 2 of Freeman illustrates a DSP microprocessor chip 62 connected to a driver 28 and sensors 30 and 32.
receive sensor signal from the sensor,	Fig. 2 of Freeman illustrates sampling devices 46 and 48 and analog-to-digital converters 54 and 56 for processing sensor signals 42 and 44.
generate a drive signal based on the sensor signal using digital signal processing, supply the drive signal to the driver, and	FIG. 2 represents means of the present invention generally 40 for processing such digitized outputs so as to estimate a fundamental frequency thereof, to estimate phases and a phase shift between such digitized outputs, and to establish from such estimates an optimized driver signal input for the driver means 28. (*Id.* 7:45-51.) Fig. 2 of Freeman illustrates a digital-to-analog converter 66 and amp means 70 to output driver signal 72.
generate a measurement of a	"Phase estimate information for the two respective sensor signals is used to determine phase shift data, used in turn

property of material flowing through the conduit based on the sensor signal;	to determine a fluid flow rate through the flow meter." (*Id.* Abstract.)
wherein the control and measurement system initiates motion of the conduit by using a first mode of signal generation to generate the drive signal, and sustains motion of the conduit using a second mode of signal generation to generated the drive signal.	With regard to sustaining motion, Freeman discloses: "With operation and practice of the present invention, such drive signal 72 is an optimized waveform generated at the sensed resonant frequency and with the proper phase relationship to the magnet transducer signal on the previous filter cycle. For example, a trapezoidal waveform with such characteristics may be output through the digital-to-analog converter 66 to amplifier means 70, and thereafter output to driver means 28. In such fashion, the present invention accomplishes the broader purpose of optimized maintenance of tube vibration by generating an optimized tube vibration drive signal." (*Id.*, 15:22-32.) With regard to initiating motion of the conduit, Freeman discloses: "In practice with various actual flow meters 10, the extreme range of tube resonant frequencies generally falls in a range between 30 and 120 Hz. Also, any given tube typically drifts less than 10 Hz during use. With the above advantageous arrangement, the relatively instantaneous capture range of the phase locked loop is roughly plus or minus 45% of the current heterodyne frequency. Accordingly, it is sufficient in accordance with practice of the present invention to initialize the tracker rather coarsely to a tube-size dependent default frequency. From there, it will reliably track all frequency excursions during use, and testing has shown such tracking abilities in fact to be extremely robust." (*Id.* 15:7-18.) "[T]he illustrated means for processing includes phase locked loop tracking of the digitized outputs 58 and 60." (*Id.* 11:8-9.)

197. Claim 9 depends from independent claim 8. Claim 9 further recites "wherein the first mode of signal generation comprises synthesis of a periodic

signal having a desired property and the second mode of signal generation comprises using a feedback loop including the sensor signal."

198. Freeman discloses synthesis of periodic drive signals having a desired property:

> With operation and practice of the present invention, such drive signal 72 is an optimized waveform generated at the sensed resonant frequency and with the proper phase relationship to the magnet transducer signal on the previous filter cycle. For example, a trapezoidal waveform with such characteristics may be output through the digital-to-analog converter 66 to amplifier means 70, and thereafter output to driver means 28. In such fashion, the present invention accomplishes the broader purpose of optimized maintenance of tube vibration by generating an optimized tube vibration drive signal.

(Freeman, Ex. 1054, 15:22-32.)

199. Freeman also discloses:

> It is to be understood that practice of the subject invention provides output data 64 representative of an optimized driver signal for driver means 28. Such digital data 64 is converted by digital-to-analog converter means 66 into an analog sinusoidal signal on line 68, the frequency and phase of which had been determined by operation of processing means 40.

(Freeman, Ex. 1054, 8:12-18.) That is, Freeman discloses generating digital optimized sinusoidal or trapezoidal drive signal waveforms (*i.e.*, "a periodic signal") having a desired frequency and phase (*i.e.*, "having a desired property").

200. Freeman also discloses using a feedback loop including the sensor signal:

> The overview of present FIG. 5 further represents that the illustrated means for processing includes phase locked loop tracking of the digitized outputs 58 and 60, for the elimination of interference and noise distortions in establishing ultimately the driver signal input for driver means 28. As discussed in greater detail below, such phase locked loop tracking preferably includes heterodyne mixing of the respective digitized outputs with an adjusted phase locked loop tracker frequency, and filtering and processing respective outputs of the heterodyne mixing so as to determine the frequency and phase estimates 92 and 94 respectively.

(Freeman, Ex. 1054, 11:7-17.) Freeman further discloses that "the phase locked loop feedback methodology tracks both the fundamental signal as well as its relative interference in order to maintain the above-discussed favorable conditions over time with a time-varying input signal." (Freeman, Ex. 1054, 15:48-52.) That is, Freeman discloses phase locked loop feedback tracking (*i.e.*, "a feedback loop") based on digitized outputs 56 and 60 (*i.e.*, "including the sensor signal"). "[I]n accordance with the subject invention, frequency tracking is preferably performed by phase locked loop signal processing." (*Id.* 14:9-21)

201. Thus, in Freeman, while the phased locked loop tracker is initializing, a drive signal with a default frequency is synthesized to initiate coarse tracking (*i.e.*, "the first mode of signal generation comprises synthesis of a periodic signal having a desired property" as recited in claim 9), and, thereafter, the phase locked loop tracks the resonant frequency for optimally maintaining tube vibration while reliably tracking drift in tube resonant frequency (*i.e.*, "the second mode of signal generation comprises using a feedback loop including the sensor signal" as recited in claim 9). As such, it is my opinion that Freeman anticipates claim 9.

202. Claim 10 depends from independent claim 8 and further recites "wherein the desired property comprises a desired initial frequency of conduit vibration." As set forth above, Freeman discloses that "it is sufficient in accordance with practice of the present invention to initialize the tracker rather coarsely to a tube-size dependent default frequency." (Freeman, Ex. 1054, 15:13-16.) That is, it is my opinion that Freeman discloses generating a drive signal having a default frequency to initialize the tracker (*i.e.*, "a desired initial frequency"). Therefore, in my opinion, Freeman anticipates claim 10.

203. Therefore, it is my opinion that claims 8-10 of the '594 are anticipated by Freeman.

C. Ground 3

204. I have reviewed U.S. Patent U.S. Patent No. 4,934,196 (“Romano”). It is my opinion that claims 1, 8, 13, and 14 are obvious in view of Romano. The Romano patent issued June 19, 1990. The ’594 patent claims an earliest priority date of November 26, 1997. Thus, it is my understanding that Romano is prior art to the ’594 patent under 35 U.S.C. § 102(b).

205. I understand that Romano was submitted with a large number of references in an Information Disclosure Statement by Applicant during prosecution of the application leading to the ’594 patent and thus is listed on the ’594 patent. It is my understanding that Romano was not mentioned during prosecution of the application.

206. Romano discloses the Common Features as recited in independent claims 1, 8 and 13, including those described in the Background section of the ’594 patent as well as using digital signal processing to generate the drive signal. Romano discloses that “a flow tube, that is used in a Coriolis meter is first driven in a sinusoidal vibratory pattern and at a resonant frequency thereof while the fluid flows therethrough.” (Romano, Ex. 1006, 6:12-15.) Fig. 1 of Romano illustrates meter electronics 20 (*i.e.*, “a control and measurement system”) connected to a Coriolis meter assembly 10 including a drive mechanism 180 (also referred to as drive coil 180) (*i.e.*, “driver”) and velocity sensing coils 160 (also referred to as velocity sensors 160) (*i.e.*, “sensor”). Drive mechanism 180 “supplies the

sinusoidal oscillatory driving forces” to the flowtubes. (Romano, Ex. 1006, 15:5-11.) Romano discloses measuring flow rate based on the velocity sensor waveforms: “. . . the meter relies on measuring mass flow rate by determining the phase difference that occurs between real and imaginary components of the discrete fourier transform (DFT) of both the left and right velocity sensor waveforms evaluated at the fundamental frequency at which the flow tubes vibrate.” (Romano, Ex. 1006, Abstract.) Thus, it is my opinion that Romano discloses “measurement of a property of material flowing through the conduit based on the signal from the sensor.”

207. Romano also discloses using digital signal processing to generate the drive signal. For example, Figs. 2 and 3 of Romano illustrate that meter electronics 20 include a time interval measurement circuit 30 with a digital signal processor 330 that computes the Discrete Fourier Transform (“DFT”) of the velocity sensor waveforms. (Romano, Ex. 1006, 21:18-19; 22:59-23:3.) Romano further discloses using the DFT to locate the resonant frequency of flow tube vibration based on the velocity sensor waveforms, generate a sinusoidal waveform at the frequency, and output the waveform for control of drive coil 180 (*i.e.*, “generate a drive signal based on the sensor signal using digital signal processing, supply the drive signal to the driver”). (*Id.* 24:32-60; Fig. 3.) For example, Romano discloses that microprocessor 330 uses a DFT to “locate the frequency at which the flow tubes

resonantly vibrate [and] generate a quantized sinusoidal waveform at exactly this frequency." (*Id.* 24:36-45.)

208. Thus, in my opinion, Romano discloses the Common Features as recited in independent claims 1, 8 and 13, including generating the drive signal using a DFT (*i.e.*, "using digital signal processing") in digital signal processor 330.

209. **Claim 1:** In addition to the Common Features, independent claim 1 further recites the additional feature of "circuitry associated with the driver for measuring current supplied to the driver." The wherein clause recites the function of a transconductance power amplifier. The use of transconductance power amplifiers were known to those skilled in the art of designing motor drivers, servo systems and similar systems. It is my opinion that it would have been obvious and well within the skill of those in the art to implement a transconductance power amplifier to monitor and measure the current supplied to the driver.

210. It is my understanding an obviousness analysis for a motivation to combine under KSR Rationale (G) requires some teaching, suggestion, or motivation in the prior art that would have led one of ordinary skill to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention. (*See* MPEP § 2143(G).)

211. It is my understanding an obviousness analysis for a motivation to combine under KSR Rationale (B) applies a "simple substitution of one known element for another to obtain predictable results." (*See* MPEP § 2143(B).)

212. Therefore, as Romano discloses the Common Features and the additional feature as recited in independent claim 1 of the '594 patent, in my opinion, Romano renders independent claim 1 obvious.

213. **Claim 8:** Independent claim 8 concludes with "wherein the control and measurement system initiates motion of the conduit by using a first mode of signal generation to generate the drive signal, and sustains motion of the conduit using a second mode of signal generation to generate the drive signal." Romano also discloses these additional features. With regard to a drive circuit 40, Romano discloses that:

> Whenever the flow tubes are to be initially placed into vibratory motion, the flow tubes would generally require approximately 10 seconds for the amplitude of the vibratory motion to reach and stabilize at a desired peak value. To shorten this time period, the output of integrator 425 is applied to one input of comparator 430. A pre-defined threshold voltage is applied to the other input of the comparator. Whenever the output of the integrator exceeds the threshold voltage, the output of the comparator assumes a high level which, in turn, is applied, over lead 433, to the variable gain input of power amplifier 450. This increases the gain of the power amplifier by

> approximately tenfold. As such, the flow tubes are driven with a much higher amplitude drive signal than under steady state operation."

(Romano, Ex. 1006, 26:17-32.) Romano further discloses a digital time interval measurement circuit 30 including a microprocessor 330 that uses a DFT to locate the frequency at which the flow tubes resonantly vibrate and "generate a quantized sinusoidal waveform at exactly this frequency." (*See* Romano, Ex. 1006, 24:36-45.) Romano further discloses that the waveform is "amplified by amplifier 394 to an appropriate drive level and thereafter routed, via lead 396, to drive coil 180." (Romano, Ex. 1006, Fig. 3, 24:58-59.)

214. It is my understanding an obviousness analysis for a motivation to combine under KSR Rationale (G) requires some teaching, suggestion, or motivation in the prior art that would have led one of ordinary skill to modify the prior art reference or to combine prior art reference teachings to arrive at the claimed invention. (See MPEP § 2143(G).)

215. Romano discloses initially increasing the gain of the power amplifier to a much higher level than under steady state operation (*i.e.*, "the control and measurement system initiates motion of the conduit by using a first mode of signal generation to generate the drive signal"), and then correspondingly reducing the gain under steady state operation (*i.e.*, "sustains motion of the conduit using a second mode of signal generation to generate the drive signal"). As set forth above, Romano also discloses that a quantized sinusoidal waveform may be generated,

amplified, and sent to a drive coil. Romano describes the quantized sinusoidal waveform drive signal in the context of a digitally based drive circuit receiving quantized sinusoidal waveform signal information generated by digital signal processor (also called microprocessor) 330 (*see* Fig. 3) in lieu of analog drive circuit 40 illustrated in Figure 4. However, in my opinion, one of ordinary skill in the art seeking to implement the digital drive circuit of time interval measurement circuit 30 would have been motivated to integrate the high amplitude drive signal technique provided by drive circuit 40 with the digital drive circuit in time interval measurement circuit 30 in order to obtain the benefit of shortening the time period for the amplitude of the vibratory motion to reach and stabilize at a desired peak value. In my opinion, one of ordinary skill in the art would have a reasonable expectation of success based on Romano's suggestion that other aspects of meter electronics 20 may be incorporated with the digital drive circuit in time interval measurement circuit 30 (*see*, *e.g.*, Romano, Ex. 1006, 24:60-64) and further based on Romano's teaching of amplifying the waveform to an appropriate drive level (*e.g.*, a higher gain for initiating vibration and a lower gain for steady state vibration) (*see*, *e.g.*, Romano, Ex. 1006, 24:58-59). Therefore, as Romano discloses the Common Features and the "wherein" clause as recited in independent claim 8 of the '594 patent, it is my opinion, Romano renders independent claim 8 obvious.

216. **Claim 13:** Independent claim 13 concludes with "wherein the control and measurement system digitally generates a gain for use in generating the drive signal based on one or more properties of the sensor signal." Romano also discloses this additional feature. Specifically, Romano discloses a digital time interval measurement circuit 30 including a microprocessor 330 that uses a DFT to locate the frequency at which the flow tubes resonantly vibrate and "generate a quantized sinusoidal waveform at exactly this frequency." (Romano, Ex. 1006, 24:36-45.) Romano also discloses that microprocessor 330 utilizes "a sine look up table" (*id.* at 24:42-55) to produce this waveform from which an equivalent analog voltage would be produced and "amplified by amplifier 394 to an appropriate drive level and thereafter routed, via lead 396, to drive coil 180." (*Id.* 24:58-59.) In my opinion, one skilled in the art of would understand that in order to set an appropriate sinusoidal drive waveform amplitude, Romano would necessarily have to compute and then apply an appropriate gain in order to scale the amplitude of the stored sine waveform as required.

217. Further, Romano describes "this digitally based drive circuit" could "be used in lieu of drive circuit 40 illustrated in Figure 4 but in conjunction with the host microprocessor system." (Romano, Ex. 1006, 24:60-63.) As discussed above, with regard to a drive circuit 40, Romano discloses that:

> Whenever the flow tubes are to be initially placed into vibratory motion, the flow tubes would generally require approximately 10 seconds for the amplitude of the vibratory motion to reach and stabilize at a desired peak value. To shorten this time period, the output of integrator 425 is applied to one input of comparator 430. A pre-defined threshold voltage is applied to the other input of the comparator. Whenever the output of the integrator exceeds the threshold voltage, the output of the comparator assumes a high level which, in turn, is applied, over lead 433, to the variable gain input of power amplifier 450. This increases the gain of the power amplifier by approximately tenfold. As such, the flow tubes are driven with a much higher amplitude drive signal than under steady state operation.

(Romano, Ex. 1006, 26:17-32; 24:64-25:1.) In performing the function of drive circuit 40 digitally, it would be necessary to use digital gain values to set drive signal amplitude. Thus, "the control and measurement system would digitally generate a gain for use in generating the drive signal."

218. Finally, Romano discloses a digital time interval measurement circuit 30 (*i.e.*, "digitally") that uses magnitude and frequency data from a sensor signal (*i.e.*, "based on one or more properties of the sensor signal") to generate a quantized sinusoidal drive signal to which a gain is applied (*i.e.*, "generates a gain for use in generating the drive signal"). Romano does not appear to explicitly describe digital generation of the gain. However, it is my opinion that under KSR Rational (G), one of ordinary skill in the art seeking to implement the digital drive

circuit of time interval measurement circuit 30 would have been motivated to digitally generate the gain using microprocessor 330 based on Romano's teaching above. Therefore, as Romano discloses the Common Features and the "wherein" clause as recited in independent claim 13 of the '594 patent, it is my opinion that Romano renders independent claim 13 obvious.

219. Claim 14 depends from independent claim 13 and further recites "wherein the control and measurement system digitally generates the gain based on an amplitude of the sensor signal." As just established, Romano discloses a control and measurement system that digitally generates a gain. In my opinion, it would have been obvious to one of ordinary skill in the art to generate that gain based on the amplitude of the sensor signal. Indeed, in the prior art analog system shown in Figure 4 of the '594 patent, the gain produced by amplifier 405 is based on (i.e., a multiple of) the signal produced by the sensor 48a. This signal is applied to the operational amplifier 425 to create the drive signal V_{DRV}. Likewise, the system of Stadler, discussed above, shows in Figure 3 that the input of digital amplitude controller ar1 is based on the amplitudes of sensor signals X17 and X18. In short, it was common in Coriolis flowmeters to base generate the gain based on the sensor signals. In simple terms, the amplitude of oscillation of the tubes is measured by the magnitude of the sensor signal. When that signal got weak (i.e., the magnitude of oscillation was low), the drive signal was amplified based on that sensor signal

to increase the amplitude of oscillation. It is my opinion that it would have been obvious, therefore, to generate the drive gain in Romano in the same way that ththis was done in analog and other prior art systems – based on the sensor signal.

220. The disclosure of Romano with respect to claims 1 and 8 is summarized in the Invalidity Charts from the *Invensys v. Micro Motion* litigation, which are submitted with the as Ex. 1062.

221. The chart from the Invensys proceeding, attached to the Petition as Ex. 1062, summarizes how, in my opinion, Romano discloses all the features of claim 1 of the ’594 patent. (Ex. 1062, pp. 1-3.)

222. The chart from the Invensys proceeding, attached to the Petition as Ex. 1062, summarizes how, in my opinion, Romano discloses all the features of claim 8 of the ’594 patent. (Ex. 1062, pp. 6-9.)

223. Therefore, it is my opinion that claims 1, 8, 13, and 14 are obvious in view of Romano.

D. Ground 4

224. I have reviewed U.S. Pat. No. 5,373,745 (“Cage”), U.S. Pat. No. 5,540,106 (“Lew”) and U.S. Pat. No. 5,050,439 (“Thompson”), as well as Romano, as discussed above. It is my opinion that claims 1, 3-4, 6, and 13-14 of the ‘594 patent are obvious based on Cage alone or in combination with Romano, Lew or Thompson.

225. Cage issued on December 20, 1994; Lew issued on July 30, 1996; and Thompson issued on September 24, 1991. The ’594 patent claims an earliest priority date of November 26, 1997. Thus, it is my understanding that Cage, Lew and Thompson are prior art to the ’594 patent under 35 U.S.C. § 102(b).

226. Cage discloses each of the Common Features recited in independent claims 1, 3 and 13, including the basic Coriolis meter operation admitted as prior art in the Background section of the ’594 patent, with the exception that Cage does not disclose generating a drive signal using a microprocessor (i.e., “using digital signal processing”). However, it is my opinion that it would have been obvious to one skilled in the art to use the digital computational power of a processor to digitally process sensor signals in order to generate drive signals. In addition, that element is expressly disclosed in Lew.

227. Cage discloses “a flow meter apparatus for measuring the mass flow rate of a fluid using the Coriolis principle” and that a “flow conduit is employed which is vibrated in a radial-mode of vibration.” (Cage, Ex. 1003, Abstract.) Cage also discloses a “driver connected to the conduit and operable to impart motion to the conduit”: “Fixedly attached to support bracket 110 are drive coils 118 and 121 which are arranged in association with drive magnets 117 and 120 respectively to collectively form motion drivers 119 and 122 respectively.” (Cage, Ex. 1003, 20:16-19.) “Drive coils 118 and 121 are electrically excited in series fashion, as

shown in FIG. 26, by signals 137 and 138, at a prescribed frequency and phase, from circuit component 144, to produce oppositely directed forces on drive magnets 117 and 120 respectively, thus causing the primary two lobe elliptical mode of vibration." (Cage, Ex. 1003, 21:13-17.) Cage further discloses "a sensor connected to the conduit and operable to sense the motion of the conduit":

> Fixedly attached to support bracket 110 and arranged in association with pickoff magnets 111 and 114 are pickoff coils 112 and 115 respectively which collectively form motion detectors 113 and 116 respectively. Fixedly attached to support bracket 110 and arranged in association with pickoff magnets 123 and 126 are pickoff coils 124 and 127 respectively which collectively form motion detectors 125 and 128 respectively.

(Cage, Ex. 1003, 20:20-27.) Fig. 26 of Cage illustrates circuit components (*e.g.*, primary drive circuit component 144, secondary drive circuit component 145, etc.), which are connected to drive coils 118 and 121 and sensor coils 112, 115, 124, and 127 (*i.e.*, "a control and measurement system connected to the driver and sensor"). Cage also discloses that the circuit components "generate a drive signal based on the sensor signal" and "supply the drive signal to the driver":

> A similar method is employed to combine signals 132 and 133, from pickoff coils 124 and 127 respectively, using circuit component 142, to make signal 135 which represents the sum of signals 132 and 133. … Signal 135 is … additionally conveyed to circuit component 144 to complete the drive servo loop … Circuit component 144 uses

> amplitude and phase information from signal 135 and produces signals 137 and 138 at appropriate amplitudes and phases to maintain the primary radial mode vibration at a prescribed level.

(Cage, Ex. 1003, 22:53-68.) Fig. 26 of Cage illustrates that processor 140 receives sensor signals and outputs various parameters such as mass flow rate, pressure, density, temperature, and viscosity (*i.e.*, the circuit components "generate a measurement of a property of material flowing through the conduit based on the sensor signal").

228. Cage plainly discloses the use of digital signal processing. Cage discusses "digital techniques involving Fast Fourier Transforms" in component 30 of Fig. 16, which "accepts input from motion sensor signal 16." (Cage, Ex. 1054, 13:43-44.) Similarly, Figure 26 illustrates processor circuit component 140 which accepts sensor sum and sensor difference signals. "Circuit component 140, uses signals 134, 135, 136, 165 and 166, and determines the mass flow rate, pressure, 60 density, temperature, viscosity, and other user defined parameters of fluid 129." (*Id.* at 23:59-62.) "Differential signal 136 is then conveyed to circuit component 140 for further processing and additionally to circuit component 145 to complete the secondary drive servo loop. Circuit component 145 uses amplitude and phase 55 information from signal 136 and produces signal 139 at the appropriate amplitude and phase to maintain the secondary vibration mode at a prescribed level." (*Id.* at 21:51-62.) Cage does not explicitly disclose whether his circuit

component 144 also uses that “digital” signal processing approach to process that same amplitude and phase information of the sensor signal to generate the drive signal. However, as I explained above, in my opinion, the use of digital signal processing would have been obvious to one of ordinary skill in the art at the time, and particularly in light of Cage’s disclosure of the use of digital signal processing to determine mass flow and other measurements from the same sensor data. Again, it is my opinion that it would have been obvious to one skilled in the art based on Cage alone to use the digital computational power of a processor (like 140) to digitally process sensor signals in order to generate drive signals (like 137 and 138).

229. As explained above, digital signal processing was widely used, particularly in oscillating, closed loop systems, to more precisely control and monitor the behavior of the system. Numerous prior art references, including Romano, Stadler, and Freeman which I have discussed, made use of digital signal processing in the context of Coriolis flowmeters for precisely these reasons. It is my opinon that it would have been obvious to employ these DSP techniques in the flowmeter of Cage. Moreover, digital signal processing was a well-developed field by the filing date of the ’594 patent. In my opinion, one of skill in the art would have reasonably expected success in implementing the well-known DSP techniques in a flowmeter, such as the flowmeter of Cage.

230. In addition, Lew discloses digital signal processing in the context of "determining mass flow rate[s] of media moving through at least one conduit under flexural vibration." (Lew, Ex. 1012, Abstract.) Lew discloses that:

> [D]ata processor 11 may also provide the information on the natural frequency of the relative flexural vibration of the pair of conduits 1 and 2 and the phase relationship relative to the electromagnetic vibratory force imposed by the electromagnetic vibrator 3, whereby the electromagnetic vibrator power supply 13 energizes the electromagnetic vibrator 3 in such a way that the relative flexural vibration between the pair of conduits 1 and 2 occurs at the natural frequency thereof.

(Lew, Ex. 1012, 4:30-38.) "The data processor 11 shown in FIG. 1, that receives the two electrical signals … representing the flexural vibrations … of the conduit, executes the algorithms or calculations defined by one of the equations … , and determines the mass flow rate." (*Id.* at 11:47-55.) Since an analog component cannot execute algorithms, in my opinion, it would be understood by one skilled in the art that Lew's data processor circuit 11 performs digital signal processing on the motion sensor signals it receives.

231. Accordingly, even if the circuit component 144 of Cage is interpreted to be an analog component, in my opinion, one of ordinary skill in the art would have understood Cage's data processor and the electromagnetic vibrator power supply of Lew could perform the disclosed functions of drive circuit 40 (*i.e.*,

"generate a drive signal based on the sensor signal using digital signal processing"). The results of such a substitution would have been predictable given that data processor 11, together with electromagnetic vibrator power supply 13, and circuit component 144 are both disclosed as performing the function of generating a drive signal based on the sensor signal(s) in Lew and Cage respectively.

232. It is my understanding that an obviousness analysis for a motivation to combine under KSR Rationale (B) applies a "simple substitution of one known element for another to obtain predictable results"). (*See* MPEP § 2143(B).)

233. Thus, it is my opinion that the combination of Cage and Lew discloses the Common Features as recited in independent claims 1, 3 and 13, including generating the drive signal using digital signal processing.

234. As discussed above, Romano also discloses using digital signal processing to generate the drive signal. For example, Figs. 2 and 3 of Romano illustrate that meter electronics 20 include a time interval measurement circuit 30 with a digital signal processor 330 that computes the Discrete Fourier Transform ("DFT") of the velocity sensor waveforms. (Romano, Ex. 1006, 21:18-19; 22:59-23:3.) Romano further discloses using the DFT to locate the resonant frequency of flow tube vibration based on the velocity sensor waveforms, generate a sinusoidal waveform at the frequency, and output the waveform for control of drive coil 180

(*i.e.*, "generate a drive signal based on the sensor signal using digital signal processing, supply the drive signal to the driver"). (*Id*. 24:32-60; Fig. 3.) For example, Romano discloses that microprocessor 330 uses a DFT to "locate the frequency at which the flow tubes resonantly vibrate [and] generate a quantized sinusoidal waveform at exactly this frequency." (*Id.* 24:36-45.)

235. Accordingly, it is my opinion that even if the circuit component 144 of Cage is interpreted to be an analog component, in my opinion, one of ordinary skill in the art would have understood Cage's data processor could be combined with the digital signal processing disclosed in Romano to perform the disclosed functions of drive circuit 40 (*i.e.*, "generate a drive signal based on the sensor signal using digital signal processing"). The results of such a substitution would have been predictable given that circuit component 144 of Cage and the microprocessor 330 of Romano are both disclosed as performing the function of generating a drive signal based on the sensor signal(s) in Cage and Romano, respectively. (*See* MPEP § 2143(B).)

236. Thus, in my opinion, the combination of Cage and Romano discloses the Common Features as recited in independent claims 1, 3, and 13, including generating the drive signal using digital signal processing.

237. **Claim 1:** In addition to the Common Features, independent claim 1 further recites the additional feature of "circuitry associated with the driver for

measuring current supplied to the driver.” As explained above, this is what is known as a “transconductance” power amplifier. Such amplifiers have been used for decades to drive actuators and motors in a wide range of applications, including aerospace, automotive and computer disk drives. Since motor force or torque is generally directly proportional to motor winding current, a transconductance amplifier is useful in closed loop or servo applications to ensure a torque command produces a corresponding torque in the actuator relatively independent of available power supply voltage. By monitoring motor current and, in effect, “servoing” it to a requested current, the motor resistance does not enter into closed loop system dynamics unless current generated by the transconductance amplifier is ultimately limited by power supply voltage.

238. This additional feature is disclosed by Cage:

> [B]y including appropriate circuitry within component 144, drive power signal 166 is produced which represents the power necessary to maintain the primary vibration level, and thus represents energy losses in the vibrating system. One method of determining this power using component 144, is to measure the primary drive current supplied to coils 118 and 121. This current interacting with the magnetic fields of drive magnets 117 and 120 is therefore proportional to the primary drive force on flow conduit 101.

(Cage, Ex. 1003, 26:43-54.) Therefore, as the combination of Cage and Lew discloses the Common Features and the additional feature as recited in independent claim 1 of the ’594 patent, the combination of Cage and Lew renders claim 1 obvious. The claim chart below summarizes how, in my opinion, Cage and Lew disclose all the features of claim 1.

239. **Claim 3:** Independent claim 3 concludes with “wherein the control and measurement system combines the sensor signals to produce a combined signal and to generate the drive signal based on the combined signal.” Cage also discloses this additional feature:

> A similar method is employed to combine signals 132 and 133, from pickoff coils 124 and 127 respectively, using circuit component 142, to make signal 135 which represents the sum of signals 132 and 133. … Signal 135 is … additionally conveyed to circuit component 144 to complete the drive servo loop … Circuit component 144 uses amplitude and phase information from signal 135 and produces signals 137 and 138 at appropriate amplitudes and phases to maintain the primary radial mode vibration at a prescribed level.

(Cage, Ex. 1003, 22:53-68.) That is, Cage discloses combining signals 132 and 133 into signal 135 (i.e., “produce a combined signal”) and producing “drive signals 137” and “drive signal” 138 (*see id.* 21:13-15 and 24:27-29) from signal 135 to maintain vibration (i.e., “generate the drive signal based on the combined signal”). Therefore, as the combination of Cage and Lew discloses the Common Features and the “wherein” clause as recited in independent claim 3 of the ’594 patent, the combination of Cage and Lew renders claim 3 obvious. The claim chart below summarizes how, in my opinion, Cage and Lew disclose all the features of claim 3.

240. **Claim 13:** Independent claim 13 concludes with "wherein the control and measurement system digitally generates a gain for use in generating the drive signal based on one or more properties of the sensor signal."

241. As discussed above, Romano discloses this additional feature. Specifically, Romano discloses a digital time interval measurement circuit 30 including a microprocessor 330 that uses a DFT to locate the frequency at which the flow tubes resonantly vibrate and "generate a quantized sinusoidal waveform at exactly this frequency." (Romano, Ex. 1006, 24:36-45.) Romano also discloses that microprocessor 330 utilizes "a sine look up table" (*id.* at 24:42-55) to produce this waveform from which an equivalent analog voltage would be produced and "amplified by amplifier 394 to an appropriate drive level and thereafter routed, via lead 396, to drive coil 180." (*Id.* 24:58-59.) It is my opinion that one skilled in the art of would understand that in order to set an appropriate sinusoidal drive waveform amplitude, Romano would necessarily have to compute and then apply an appropriate gain in order to scale the amplitude of the stored sine waveform as required.

242. In my opinion, it would have been obvious to one of ordinary skill in the art to combine the digital gain generation system of Romano with the system of

Cage. As explained above, Cage and Romano both disclose data processors. It would have been obvious to one of ordinary skill in the art to perform the digital drive generation method disclosed in Romano on the data processor disclosed in Cage or to use the microprocessor in Romano in the device of Cage.

243. In addition, Thompson in Figure 15 illustrates amplitude servo 110 whose input is based on the output of position sensor 80 and whose output (i.e., integrator output) is a gain command that sets the gain of voltage controlled gain control 112. The resulting DRV signal is used to control the force drivers 70. (Thompson, Ex. 1027 at Fig. 15 and 11:52-65.) As explained above, in my opinion, it would have been obvious to one of ordinary skill in the art to digitally implement the drive gain technique of Thompson for use with Cage and Lew. It is my opinion that it would have been a matter of routine skill in the art to have implemented the features of Thompson in the data processor of Cage or Lew. Moreover, it is my opinion that it would have been desirable to do so, in order to make use of the data processor that already existed in the Cage and Lew devices.

244. Therefore, it is my opinion that because the combination of Cage and Lew and/or Romano discloses the Common Features and because the "wherein" clause as recited in independent claim 13 of the '594 patent would have been obvious based on Romano and Thompson, the combination of Cage, Lew and/or Romano and Thompson renders claim 13 obvious.

245. The claim chart below demonstrates how, in my opinion, the Cage, Lew and Romano disclose each feature of claims 1, 3, and 13.

Claims 1, 3 and 13 of 6,754,594	**Cage 5,373,745 in combination with Lew 5,540,106 (disclosure of Romano is described in Ground 3 above)**
[Common Features] A digital flowmeter comprising: a vibratable conduit;	Cage discloses a "flow meter apparatus for measuring the mass flow rate of a fluid using the Coriolis principle." (Cage, Ex. 1003, Abstract.) Figure 26 of Cage illustrates a processor 140 (i.e., "digital flowmeter"), and further describes "digital techniques involving Fast Fourier Transforms (FFT)." (*Id*. 13:48-49.) Cage discloses that a "flow conduit is employed which is vibrated in a radial-mode of vibration." (*Id*. Abstract.)
a driver connected to the conduit and operable to impart motion to the conduit;	Cage discloses: "Fixedly attached to support bracket 110 are drive coils 118 and 121 which are arranged in association with drive magnets 117 and 120 respectively to collectively form motion drivers 119 and 122 respectively." (*Id*. 20:16-19.) "Drive coils 118 and 121 are electrically excited in series fashion, as shown in FIG. 26, by signals 137 and 138, at a prescribed frequency and phase, from circuit component 144, to produce oppositely directed forces on drive magnets 117 and 120 respectively, thus causing the primary two lobe elliptical mode of vibration." (*Id*., 21:13-18.)
a sensor connected to the conduit and operable to sense the motion of the conduit;	Cage discloses: "Fixedly attached to support bracket 110 and arranged in association with pickoff magnets 111 and 114 are pickoff coils 112 and 115 respectively which collectively form motion detectors 113 and 116 respectively." (*Id*. 20:20-23.) Cage further discloses: "Fixedly attached to support bracket 110 and arranged in association with pickoff magnets 123 and 126 are pickoff coils 124 and 127 respectively which collectively form motion detectors 125

	and 128 respectively.” (*Id*., 20:24-27.)
a control and measurement system connected between the driver and the sensor, the control and measurement system comprising circuitry to:	Figure 26 of Cage illustrates “a block diagram of one possible configuration of circuit components used to measure the mass flow rate of fluid and other parameters.” (*Id*. 6:42-44.) Figure 26 further illustrates that the circuit components are connected to drive coils 118 and 121 and sensor coils 112, 115, 124, and 127 .
receive a sensor signal from the sensor,	Figure 26 of Cage illustrates that the circuit components receive sensor signals 130, 131, 132, and 133.
generate a drive signal based on the sensor signal using digital signal processing, supply the drive signal to the driver, and	Cage discloses to “combine signals 132 and 133, from pickoff coils 124 and 127 respectively, using circuit component 142, to make signal 135 which represents the sum of signals 132 and 133. . . Signal 135 is then conveyed . . . to circuit component 144 to complete the drive servo loop . . . Circuit component 144 uses amplitude and phase information from signal 135 and produces signals 137 and 138 at appropriate amplitudes and phases to maintain the primary radial mode vibration at a prescribed level.” (*Id*., 22:54-68.) Lew discloses “determining mass flow rate of media moving through at least one conduit under a flexural vibration.” (Lew, Ex. 1012, Abstract.) Lew discloses digital signal processing, and that “data processor 11 may also provide the information on the natural frequency of the relative flexural vibration of the pair of conduits 1 and 2 and the phase relationship relative to the electromagnetic vibratory force imposed by the electromagnetic vibrator 3, whereby the electromagnetic vibrator power supply 13 energizes the electromagnetic vibrator 3 in such a way that the relative flexural vibration between the pair of conduits 1 and 2 occurs at the natural frequency thereof.” (Lew, Ex. 1012, 4:30-38.)
generate a measurement of a property of material flowing through the	Cage discloses that Figure 26 illustrates “a block diagram of one possible configuration of circuit components used to measure the mass flow rate of fluid and other parameters.” (Cage, Ex. 1003, 6:42-44.)

conduit based on the signal from the sensor;	Figure 26 of Cage illustrates that processor 140 receives sensor signals and outputs various parameters such as mass flow rate, pressure, density, temperature, and viscosity (i.e., "property of material.") Cage further discloses: "In the art of Coriolis mass flow rate meters it is well known that a vibrating flow conduit carrying mass flow causes Coriolis forces which deflect the flow conduit away from its normal vibration path proportionally related to mass flow rate. These deflections or their effects can then be measured as an accurate indication of mass flow rate." (*Id*., 1:17-23.)
[Claim 1, additional feature] circuitry associated with the driver for measuring current supplied to the driver;	Cage discloses in reference to Figure 26 that "by including appropriate circuitry within component 144, drive power signal 166 is produced which represents the power necessary to maintain the primary vibration level, and thus represents energy losses in the vibrating system. One method of determining this power using component 144, is to measure the primary drive current supplied to coils 118 and 121. This current interacting with the magnetic fields of drive magnets 117 and 120 is therefore proportional to the primary drive force on flow conduit 101." (*Id*. 26:43-54.)
[Claim 3, wherein clause.] wherein the control and measurement system combines the sensor signals to produce a combined signal and to generate the drive signal based on the combined signal.	Cage discloses to "combine signals 132 and 133, from pickoff coils 124 and 127 respectively, using circuit component 142, to make signal 135 which represents the sum of signals 132 and 133. . . Signal 135 is then conveyed . . . to circuit component 144 to complete the drive servo loop . . . Circuit component 144 uses amplitude and phase information from signal 135 and produces signals 137 and 138 at appropriate amplitudes and phases to maintain the primary radial mode vibration at a prescribed level." (Cage, Ex. 1003, 22:54-68.)
[Claim 13, wherein clause.] wherein the control and measurement system digitally	Thompson in Figure 15 illustrates amplitude servo 110 whose input is based on the output of position sensor 80 and whose output (i.e., integrator output) is a gain command that sets the gain of voltage controlled gain control 112. The resulting DRV signal is used to control

generates a gain for use in generating the drive signal based on one or more properties of the sensor signal.	the force drivers 70. (Thompson, Ex. 1027 at Fig. 15 and 11:52-65.) Romano discloses a digital time interval measurement circuit 30 including a microprocessor 330 that uses a DFT to locate the frequency at which the flow tubes resonantly vibrate and "generate a quantized sinusoidal waveform at exactly this frequency." (Romano, Ex. 1006, 24:36-45.) Romano also discloses that microprocessor 330 utilizes "a sine look up table" (*id.* at 24:42-55) to produce this waveform from which an equivalent analog voltage would be produced and "amplified by amplifier 394 to an appropriate drive level and thereafter routed, via lead 396, to drive coil 180." (*Id.* 24:58-59.)

246. Claim 4 depends from independent claim 3 and further recites "wherein the control and measurement system generates the drive signal by applying a gain to the combined signal." Cage discloses:

> A similar method is employed to combine signals 132 and 133, from pickoff coils 124 and 127 respectively, using circuit component 142, to make signal 135 which represents the sum of signals 132 and 133. … Signal 135 is … additionally conveyed to circuit component 144 to complete the drive servo loop … Circuit component 144 uses amplitude and phase information from signal 135 and produces signals 137 and 138 at appropriate amplitudes and phases to maintain the primary radial mode vibration at a prescribed level.

(Cage, Ex. 1003, 22:53-68.) That is, Cage discloses producing "drive signal 137" and "drive signal" 138 (*see id.* at 24:27-29) from signal 135 (*i.e.*, "the combined signal") at appropriate amplitudes to maintain vibration (*i.e.*, applying a gain to the combined signal"). Therefore, the combination of Cage and Lew discloses each feature of claim 4.

247. Claim 6 depends from independent claim 3 and further recites "wherein the control and measurement system combines the sensor signals by summing the sensor signals." Cage discloses that a "method is employed to combine signals 132 and 133, from pickoff coils 124 and 127 respectively, using circuit component 142, to make signal 135 which represents the sum of signals 132 and 133." (Cage, Ex. 1003, 22:53-56.) That is, Cage discloses generating signal 135 as the sum of signals 132 and 133 (*i.e.*, "combines the sensor signals by summing the sensor signals"). Therefore, the combination of Cage and Lew discloses each feature of claim 6.

248. Claim 14 depends from independent claim 13 and further recites "wherein the control and measurement system digitally generates the gain based on an amplitude of the sensor signal." Cage discloses:

> A similar method is employed to combine signals 132 and 133, from pickoff coils 124 and 127 respectively, using circuit component 142, to make signal 135 which represents the sum of signals 132 and 133. … Signal 135 is … additionally conveyed to circuit component 144 to complete the drive servo loop … Circuit component 144 uses

> amplitude and phase information from signal 135 and produces signals 137 and 138 at appropriate amplitudes and phases to maintain the primary radial mode vibration at a prescribed level.

(Cage, Ex. 1003, 22:53-68.) That is, Cage discloses producing signals 137 and 138 at appropriate amplitudes to maintain vibration using amplitude information from signal 135 (*i.e.*, “generates the gain based on an amplitude of the sensor signal”). Moreover, as discussed above, Thompson in Figure 15 illustrates amplitude servo 110 whose input is based on the output of position sensor 80 and whose output (i.e., integrator output) is a gain command that sets the gain of voltage controlled gain control 112. The resulting DRV signal is used to control the force drivers 70. (Thompson, Ex. 1027 at Fig. 15 and 11:52-65.) It is my opinion that it would have been obvious at the time of the invention to digitally implement the drive control method of Thompson in the data processor of Cage or Lew. Therefore, in my opinion, the combination of Cage, Lew and Thompson discloses each feature of claim 14.

249. A detailed claim chart of how, in my opinion, the combination of Cage and Lew discloses features of claims 1, 3-4, 6 and 13-14 can be found in the Invalidity Charts from the Invensys Litigation submitted herewith as Exhibit 1019.

250. The chart from the Invensys proceeding, attached to the Petition as Ex. 1019, summarizes how, in my opinion, Cage, in combination with Lew, discloses all the features of claim 1 of the ’594 patent. (Ex. 1019, pp. 1-4.)

251. The chart from the Invensys proceeding, attached to the Petition as Ex. 1019, summarizes how, in my opinion, Cage, in combination with Lew, discloses all the features of claim 3 of the ’594 patent. (Ex. 1019, pp. 3-7.)

252. The chart from the Invensys proceeding, attached to the Petition as Ex. 1019, summarizes how, in my opinion, Cage, in combination with Lew, discloses all the features of claim 4 of the ’594 patent. (Ex. 1019, pp. 7-8.)

253. The chart from the Invensys proceeding, attached to the Petition as Ex. 1019, summarizes how, in my opinion, Cage, in combination with Lew, discloses all the features of claim 6 of the ’594 patent. (Ex. 1019, p. 8.)

254. The chart from the Invensys proceeding, attached to the Petition as Ex. 1019, summarizes how, in my opinion, Cage, in combination with Lew, discloses all the features of claim 13 of the ’594 patent. (Ex. 1019, pp. 8-11.)

255. The chart from the Invensys proceeding, attached to the Petition as Ex. 1019, summarizes how, in my opinion, Cage, in combination with Lew, discloses all the features of claim 14 of the ’594 patent. (Ex. 1019, p. 11-12.)

256. Therefore, it is my opinion that claims 1, 3-4, 6 and 13-14 of the ’594 patent are obvious based on Cage alone or in combination with Romano, Lew or Thompson.

E. Ground 5

257. I have reviewed U.S. Patent No. 4,679,947 (“Miller”). It is my opinion that claim 8 is anticipated in view of Miller. Miller issued July 14, 1987. The ’594 patent claims an earliest priority date of November 26, 1997. Thus, it is my understanding that Miller is prior art to the ’594 patent under 35 U.S.C. § 102(b).

258. Miller discloses the Common Features as recited in independent claim 8, including the basic Coriolis flowmeter operation admitted in the Background section of the ’594 patent as well as implementing the drive function digitally (*i.e.*, “using digital signal processing”). With respect to basic Coriolis flowmeter operation, Miller discloses a densitometer having “a vibrator for causing the tubes to vibrate, and a transducer for detecting the frequency and amplitude of vibrations.” (Miller, Ex. 1007, Abstract.) Miller illustrates in Fig. 4 strain gauges 90 and 92, a magnetic coil 80, coil driver electronics 106, and tubes 62 and 72. Miller discloses that “the coil driver electronics 106 powers and drives the magnetic coil 80 with an oscillating current,” and that “[t]he result is that the magnetic coil 80 imparts energy to cause a vibrating motion in the metallic

densitometer tubes 62, 72." (Miller, Ex. 1007, 11:36-40.) Miller further discloses that "the magnitude and frequency of the vibration of tube 62 is detected by the strain guages {sic} 90, 92." (*Id.* 11:40-42.)

259. Miller also discloses the use of a computer (*i.e.*, "digital signal processing"). In particular, Miller illustrates in Fig. 4 a digital computer 100 (Miller, Ex. 1007, 12:47) coupled to the coil driver electronics 106, and also to strain gauges 90 and 92 via A/D input module 102. Miller further discloses calculations handled by "microcomputers." (Miller, Ex. 1007, 6:11-14.) Miller also discloses use of the computer to generate a drive signal based on the sensor signal. For example, Miller discloses that "the strain guage {sic} output is directed to a computer 100." (Miller, Ex. 1007, 11:42-43.) Miller further discloses that "the computer 100 is connected to the coil driver electronics 106 in such a manner that the computer can control the frequency of the field generated by the magnetic coil 80." (Miller, Ex. 1007, 12:22-25.) Miller further discloses that the coil 80 is driven with a frequency based on the resonant frequency determined from the strain gauge measurements (*See*, *e.g.*, Miller, Ex. 1007, 3:32-36; 8:22-31; 11:35-43; 12:29-39; 13:19-32; 17:48-53.) Miller further discloses that the computer "is used to monitor the vibrations … and to calculate steam quality … [t]he bulk density of the steam is determined as a function of the fundamental frequency of the densitometer with

the steam flowing therethrough, and the steam quality is determined as a function of the bulk density." (Miller, Ex. 1007, Abstract.)

260. Therefore, it is my opinion that Miller discloses the Common Features as recited in claim 8, including that functions of the control and measurement circuitry (which includes the drive function) could be implemented digitally, including using digital signal processing.

261. Claim 8 concludes with "wherein the control and measurement system initiates motion of the conduit by using a first mode of signal generation to generate the drive signal, and sustains motion of the conduit using a second mode of signal drive generation to generate the drive signal." Miller discloses different drive signal generation modes for startup and sustained motion. For example, Miller discloses that "[d]uring start-up, the computer is programmed to cause the magnetic coil 80 to vibrate the tubes 62, 72, throughout the band of frequencies between 2,700 Hz and 4,500 Hz." (Miller, Ex. 1007, 12:26-29.) Miller further discloses that "it has been found preferable to program the computer to narrow the frequency band through which the magnetic coil 80 sweeps when the fundamental or harmonic frequency of the system is determined." (Miller, Ex. 1007, 13:7-11.) Therefore, in my opinion, Miller discloses each feature of the "wherein" clause of claim 8 of the '594 patent.

262. Therefore, as Miller discloses the Common Features and the "wherein" clause as recited in independent claim 8 of the '594 patent, it is my opinion that Miller anticipates independent claim 8. The disclosure of Miller with respect to independent claim 8 is summarized, in my opinion, in the Invalidity Charts from the *Invensys v. Micro Motion* litigation, which are submitted with the Petition as Ex. 1014. (Ex. 1014, pp. 2-4.)

CONCLUSION

263. I am therefore of the opinion that claims 1, 3-4, 6, 8-11 and 13-14 of the '594 patent are invalid for the reasons given above.

264. I hereby declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct, and that all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true. I understand that willful false statements and the like are punishable by fine or imprisonment, or both (18 U.S.C. § 1001).

Executed on January 30, 2014

Michael D. Sid

Dr. Michael D. Sidman