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Barakat et al.

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(54) **SYSTEMS AND METHODS FOR SEISMIC DATA ACQUISITION EMPLOYING ASYNCHRONOUS, DECOUPLED DATA SAMPLING AND TRANSMISSION**

(75) Inventors: **Simon Barakat**, Chilly-Mazarin (FR); **Kambiz Iranpour**, Oslo (NO); **Daniel H. Golparian**, Oslo (NO)

(73) Assignee: **WesternGeco L.L.C.**, Houston, TX (US)

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G01V 1/22 (2006.01)

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(58) **Field of Classification Search** 367/59, 367/63, 76
See application file for complete search history.

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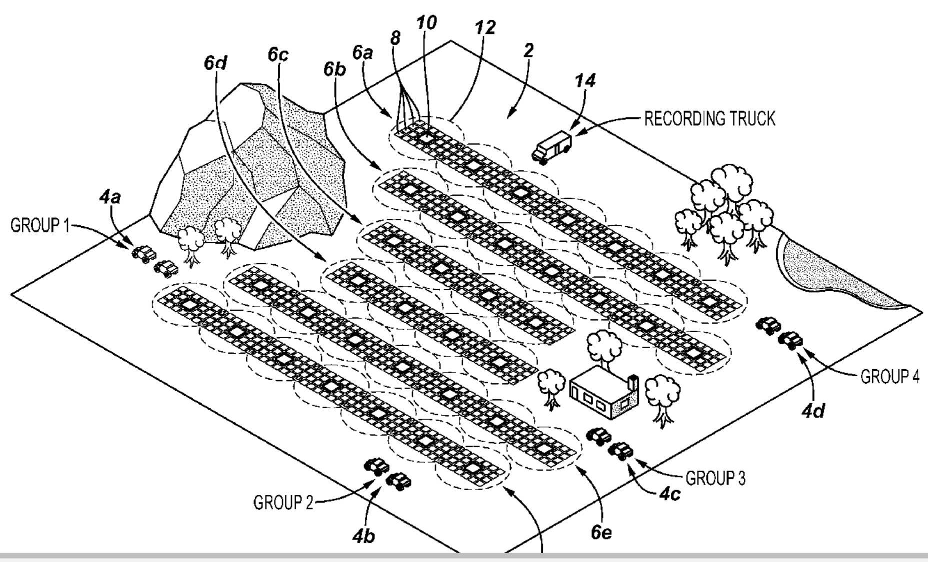
Primary Examiner—Ian J Lobo
(74) *Attorney, Agent, or Firm*—Ari Pramudji; Richard V. Wells; Kevin McEnaney

(57) **ABSTRACT**

Systems and methods for asynchronously acquiring seismic data are described, one system comprising one or more seismic sources, a plurality of sensor modules each comprising a seismic sensor, an A/D converter for generating digitized seismic data, a digital signal processor (DSP), and a sensor module clock; a seismic data recording station; and a seismic data transmission sub-system comprising a high precision clock, the sub-system allowing transmission of at least some of the digitized seismic data to the recording station, wherein each sensor module is configured to periodically receive from the sub-system an amount of the drift of its clock relative to the high precision clock.

11 Claims, 3 Drawing Sheets



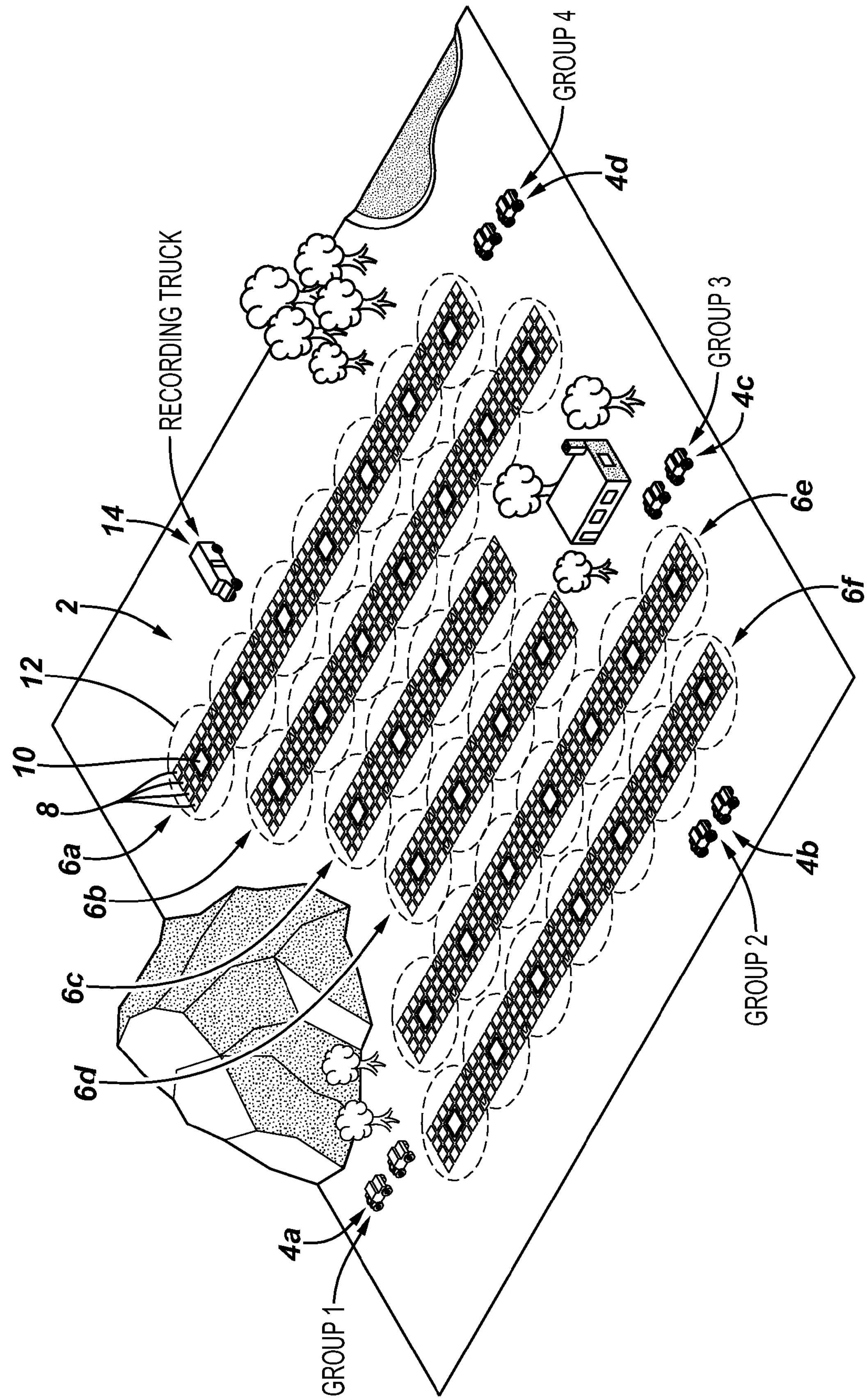
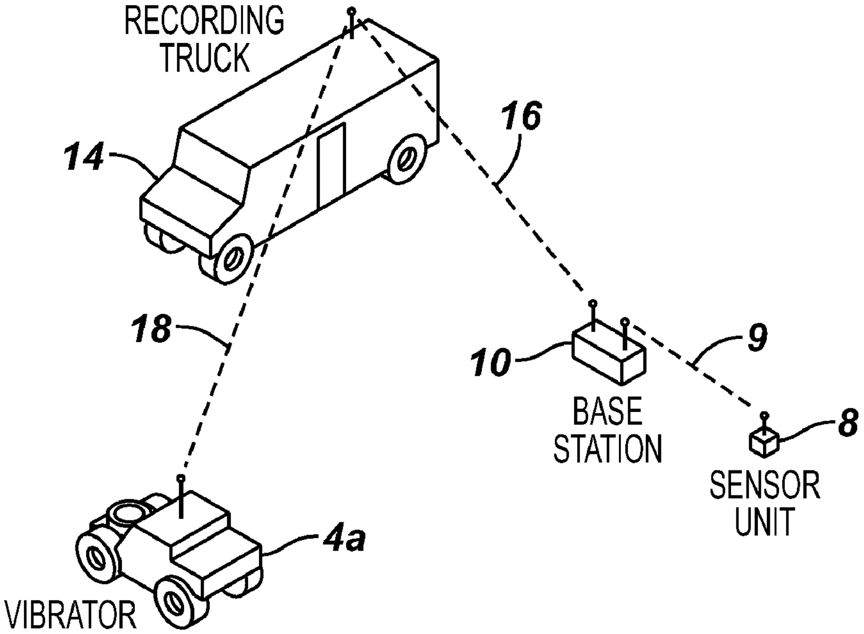

RECORDING TRUCK
14
2
12
10
8
6a
6b
6c
6d
6e
6f
4a
4b
4c
4d
GROUP 1
GROUP 2
GROUP 3
GROUP 4

FIG. 1

FIG. 2


RECORDING
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16
18
10
9
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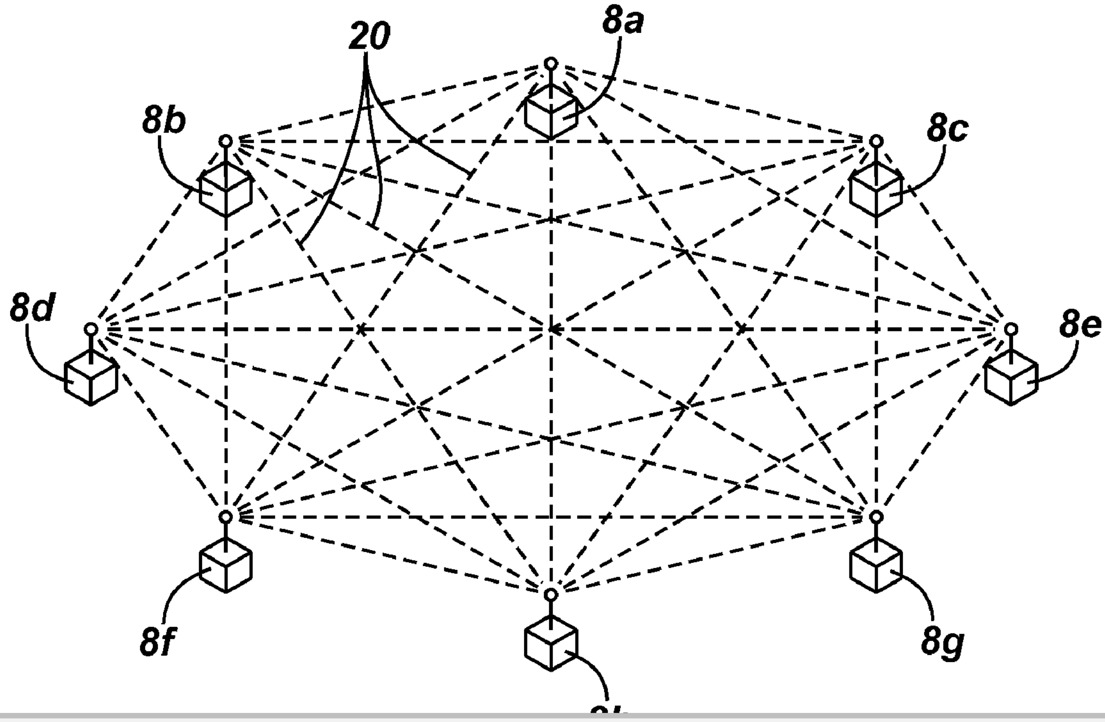
BASE
STATION
SENSOR
UNIT
4a
VIBRATOR

FIG. 3


20
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8c
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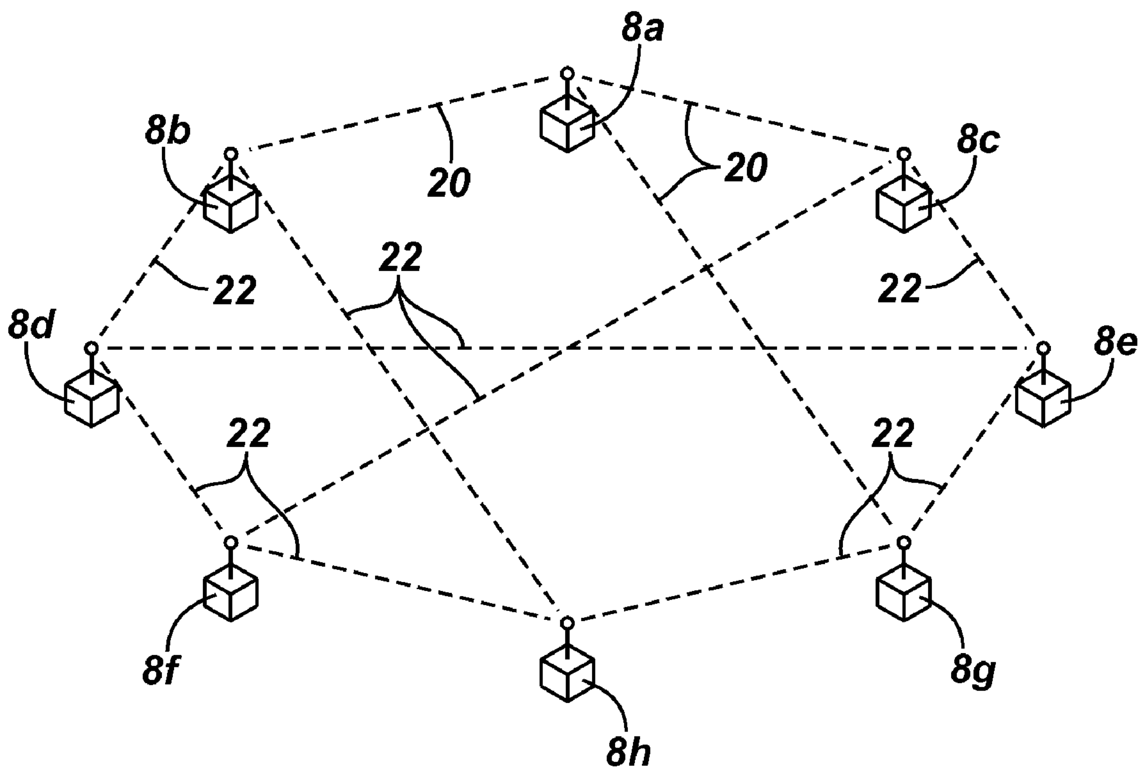
8f
8g

FIG. 4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8b
8c
8d
8e
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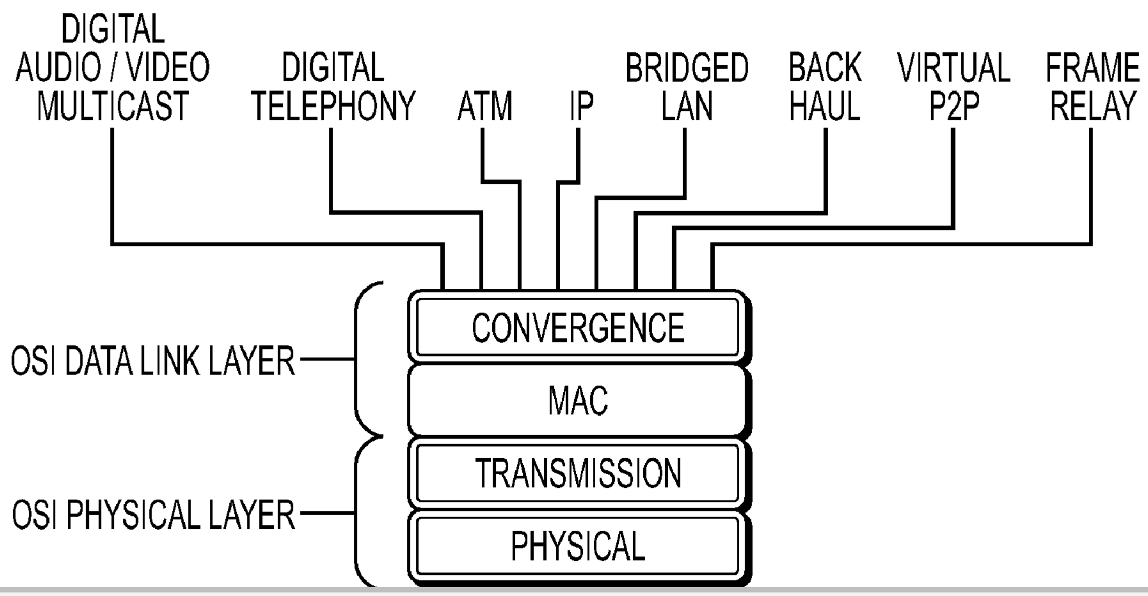
8g
8h
20
20
22
22
22
22
22
22

FIG. 5


DIGITAL AUDIO / VIDEO MULTICAST
DIGITAL TELEPHONY
ATM
IP
BRIDGED LAN
BACK HAUL
VIRTUAL P2P
FRAME RELAY
OSI DATA LINK LAYER
OSI PHYSICAL LAYER
CONVERGENCE
MAC
TRANSMISSION
PHYSICAL

SYSTEMS AND METHODS FOR SEISMIC DATA ACQUISITION EMPLOYING ASYNCHRONOUS, DECOUPLED DATA SAMPLING AND TRANSMISSION

BACKGROUND OF THE INVENTION

1. Field of Invention

The present invention relates to the field of seismic data acquisition systems and methods of using same. More specifically, the invention relates to systems and methods for seismic data acquisition in which the seismic sampling is decoupled from data transmission using asynchronous digital signal processors for data sampling, and interpolation for synchronizing the sampling.

2. Related Art

Land seismic acquisition aims to capture the acoustic and elastic energy that has propagated through the subsurface. This energy may be generated by one or more surface sources such as vibratory sources (vibrators). The vibrators produce a pressure signal that propagates through the earth into the various subsurface layers. Here elastic waves are formed through interaction with the geologic structure in the subsurface layers. Elastic waves are characterized by a change in local stress in the subsurface layers and a particle displacement, which is essentially in the same plane as the wavefront. Acoustic and elastic waves are also known as pressure and shear waves. Acoustic and elastic waves are collectively referred to as the seismic wavefield.

The structure in the subsurface may be characterized by physical parameters such as density, compressibility, and porosity. A change in the value of these parameters is referred to as an acoustic or elastic contrast and may be indicative of a change in subsurface layers, which may contain hydrocarbons. When an acoustic or elastic wave encounters an acoustic or elastic contrast, some part of the waves will be reflected back to the surface and another part of the wave will be transmitted into deeper parts of the subsurface. The elastic waves that reach the land surface may be measured by motion sensors (measuring displacement, velocity, or acceleration, such as geophones, accelerometers, and the like) located on the land. The measurement of elastic waves at the land surface may be used to create a detailed image of the subsurface including a quantitative evaluation of the physical properties such as density, compressibility, porosity, etc. This is achieved by appropriate processing of the seismic data.

Seismic sensor units typically also contain the electronics needed to digitize and record the seismic data. In one known embodiment, each sensor unit is connected to a land seismic cable, which is connected via cables to a recording instrument on a surface vehicle or other surface facility such as a platform. The land seismic cable provides electric power and the means for transferring the recorded and digitized seismic signals to the recording instrument. In other embodiments, there have been efforts to reduce the use of cables in performing land seismic, with movement toward wireless land seismic systems and methods.

Seismic sampling in a typical seismic sensor network (whether wired or wireless) may comprise up to tens of thousands or more seismic sensors measuring the seismic vibrations for oil and gas exploration. Each sensor with an analogue output has its output converted to a digital signal by an analog to digital converter (ADC) that is in turn connected to a digital signal processing (DSP) unit. Every sampling unit has its own clock frequency that drifts over time relative to the

centralized recording unit. The individual sampling ADC/DSP units are traditionally phase-synchronized to the data transmission line clock by an electronic phase-locked loop (PLL).

While these systems and methods have enjoyed some success, there remains room for improvement. It is of utmost important in seismic acquisition to phase synchronize the sampling of all the sampling units. However, presently known systems and methods are more expensive and less flexible due to the above-mentioned individual sampling ADC/DSP units being phase-synchronized to the data transmission line clock by an electronic phase-locked loop. There is a need in the seismic data acquisition arts for systems and methods wherein the transmission of data is decoupled from sampling of the data, and that eliminate the costly and inflexible electronic phase locking loop, while still ensuring that the output sampling frequency of each signal processing unit is phase synchronized with the data transmission line clock. The present invention is devoted to addressing one or more of these needs.

SUMMARY OF THE INVENTION

In accordance with the present invention, systems and methods for seismic data acquisition are described which reduce or overcome short-comings of previously known systems and methods wherein the transmission of data is coupled to sampling of the data. Systems and methods of seismic data acquisition in accordance with the invention eliminate the costly and inflexible electronic phase locking loop. In the inventive systems and methods, the drift of each clock associated with a seismic sensor is periodically measured and/or calculated relative to the data transmission line clock (which may be the master clock), and interpolation techniques are used to adjust for the sensor clock drift. In this way the output sampling frequency of each signal processing unit is phase synchronized with the data transmission line clock without the use of an electronic phase locked loop circuit. Systems and methods of the invention allow more efficient seismic data acquisition, for example 2-D, 3-D and 4-D land seismic data acquisition, such as during exploration for underground hydrocarbon-bearing reservoirs, or monitoring existing reservoirs. Electromagnetic signals may be used to transfer data to and/or from the sensor units, to transmit power, and/or to receive instructions to operate the sensor units.

A first aspect of the invention is seismic data acquisition system comprising:

one or more seismic sources (which may be land sources, such as vibrators, explosive charges, and the like, or marine sources, such as air-guns, vibrators, and the like);

a sensor system (which may be suitable for land seismic or marine seismic) for acquiring and/or monitoring analog seismic sensor data, the sensor system comprising a plurality of sensor modules each configured to asynchronously sample seismic data and comprising a seismic sensor, an A/D converter (ADC) for generating digitized seismic data, a digital signal processor (DSP), and a sensor module clock;

a seismic data recording station, and

a seismic data transmission sub-system comprising a high precision clock, the sub-system allowing the DSP to transmit at least some of the digitized seismic data to the recording station,

wherein each sensor module receives periodically from the

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