CLAIMS

1. A measuring system for connection to a network analyzer, comprising:

a measuring instrument including:

a flexible elongate strap substrate having a length; and

a flexible antenna array extending substantially along the length of the strap substrate, in which the antenna array is either affixed to a surface of the strap substrate or embedded within the strap substrate, whereby compression or extension of the strap substrate causes compression or extension of the antenna array, and in which the antenna array comprises:

a plurality of interconnected patch antennas arranged in at least one row, in which the plurality of patch antennas are electrically connected to a feeding line extending alongside the at least one row, and in which the feeding line is configured to terminate in an impedance matched to the network analyzer such that the network analyzer can excite the antenna array with an input signal and measure electrical parameters relating to the antenna array's response to the input signal including a resonance frequency, and in which the antenna array is configured such that it has reference electrical parameters that correspond to a reference length of the antenna array and the measured electrical parameters vary relative to the reference electrical parameters as a function of a change in the physical length of the antenna array during use relative to the reference length.

2. A system according to Claim 1, further comprising:

a diagnostic computing system comprising:

a non-transitory computer readable storage medium,

a processor in electronic communication with the measuring instrument and the computer readable storage medium,

one or more software modules comprising executable instructions stored in the storage medium, in which the one or more software modules are executable by the processor and include:

an excitation module that configures the processor to, using the network analyzer connected to the antenna array, generate the input signal to excite the antenna array,

a parameter measurement module that configures the processor to, using the network analyzer, measure the electrical parameters including the resonance frequency relating to the antenna array's response to the input signal, and record the measured electrical parameters in the storage medium,

a parameter analysis module that configures the processor to calculate, based on the measured electrical parameters, a change in the electrical parameters including the resonance frequency relative to reference electrical parameters for the antenna array stored in the storage, in which the reference electrical parameters for the antenna correspond to a reference length of the antenna array and the strap substrate, and

a dimension analysis module that configures the processor to calculate a current length of the antenna array and the strap substrate based on the calculated change in electrical parameter and the reference length.

3. A system according to Claim 1, in which the antenna array is defined by one or more layers of conductive and one or more layers of dielectric materials deposited on the flexible strap substrate.

4. A system according to Claim 1, in which the measuring instrument comprising the flexible antenna array and strap substrate assembly is configured to be extended along and secured to an outer surface of a structure and is configured to conform to the outer surface of the structure such that expansion or contraction of the surface causes the length of the strap substrate and antenna array to expand or contract in a corresponding fashion.

5. A system according to Claim 1, in which the antenna array is designed such that it has a known reference resonance frequency, *f*, that corresponds to a known reference length, L, of the antenna array.

6. A system according to Claim 5, in which each patch is identically sized and has a resonant length, A, which is half a substrate wavelength ($\lambda s/2$) and in which the plurality of patch antennas are electrically connected to the feeding line by a respective matching section having a length C, which is a quarter of the substrate wavelength ($\lambda s/4$).

7. A system according to Claim 1, in which the plurality of patch antennas in a given row are evenly spaced apart along the length of the row.

8. A system according to Claim 1, in which the antenna array comprises a plurality of rows of patch antennas, in which the patch antennas defining a given row are interconnected by a common feeding line and in which the feeding lines of respective rows are interconnected.

9. A system according to Claim 2, further comprising:

a plurality of the measuring instruments, in which each measuring instrument is configured to be deployed on an exterior wall of a cylindrical storage container by extending the given measuring instrument circumferentially about the sidewall of the storage container at a respective height such that the length of the given measuring instrument corresponds to the circumference of the container at the respective height; and

in which the dimension analysis module further configures the processor to calculate the volume of the storage container based on the current length calculated for the antenna array of respective measuring instruments among the plurality of measuring instruments.

10. A system for measuring a volume of a storage container using a network analyzer, the system comprising:

a plurality of measuring instruments configured to be deployed on an exterior wall of a cylindrical storage, in which a given measuring instrument among the plurality of measuring instruments is extended circumferentially about the circumferential sidewall of the storage container at a respective height on the wall such that a length of the given measuring instrument corresponds to the circumference of the container at the respective height, and in which the given measuring instrument includes:

a flexible elongate strap substrate having the length; and

a flexible antenna array extending substantially along the length of the strap substrate, in which the antenna array is either affixed to a surface of the strap substrate or embedded within the strap substrate, whereby compression or extension of the strap substrate causes compression or extension of the antenna array, and in which the antenna array comprises:

a plurality of interconnected patch antennas arranged in at least one row, in which the plurality of patch antennas are electrically connected to a feeding line extending alongside the at least one row, and in which the feeding line is configured to terminate in an impedance matched to the network analyzer such that the network analyzer can excite the antenna array with an input signal and measure electrical parameters relating to the antenna array's response to the input signal including a resonance frequency, and in which the plurality of interconnected patch antennas comprising the antenna array are configured such that the antenna array has reference electrical parameters that correspond to a reference length of the antenna array and the measured electrical parameters vary relative to the reference electrical parameters as a function of a change in the physical length of the antenna array during use relative to the reference length; and

a diagnostic computing system comprising:

a non-transitory computer readable storage medium,

a processor in electronic communication with the given measuring instrument and the computer readable storage medium,

one or more software modules comprising executable instructions stored in the storage medium, in which the one or more software modules are executable by the processor and include:

an excitation module that configures the processor to, using the network analyzer connected to the antenna array, generate the input signal to excite the antenna array,

a parameter measurement module that configures the processor to, using the network analyzer, measure the electrical parameters relating to the antenna array's response to the input signal, and record the measured electrical parameters in the storage medium,

a parameter analysis module that configures the processor to calculate, based on the measured electrical parameters, a change in the electrical parameters relative to reference electrical parameters for the antenna array stored in the storage, in which the reference electrical parameters for the antenna array

correspond to a reference length of the antenna array and the strap substrate, and

a dimension analysis module that configures the processor to calculate a current length of the antenna array and the strap substrate based on the calculated change in electrical parameter and the reference length, and in which the dimension analysis module further configures the processor to calculate the volume of the storage container based on the calculated length of the antenna array of each of the plurality of measuring instruments.

11. A method of measuring an object using a measuring instrument, the method comprising:

providing a measuring instrument comprising:

a flexible elongate strap substrate having a length; and

a flexible antenna array extending substantially along the length of the strap substrate, in which the antenna array is affixed to a surface of the strap substrate or embedded within the strap substrate, whereby compression or extension of the strap substrate causes compression or extension of the antenna array, and in which the antenna array comprises:

a plurality of interconnected patch antennas arranged in at least one row, in which the plurality of patch antennas are electrically connected to a feeding line extending alongside the at least one row, and in which the feeding line is configured to be connected to a network analyzer,

in which the patch antennas are arranged to provide an antenna array having a reference resonance frequency that corresponds to a reference length of the antenna array and the strap substrate, and in which the antenna array is configured such that the resonance frequency of the antenna array varies relative to the reference frequency response as a function of changes in the length of the antenna array relative to the reference length; and

calibrating the length of the measuring instrument, the calibrating step including the steps of:

generating, with a network analyzer connected to the antenna array, an input signal that excites the antenna array,

measuring, with the network analyzer, a resonance frequency of the antenna array in response to the input signal,

calculating, with a diagnostic computing system, a change in the resonance frequency based on the measured resonance frequency relative to the reference resonance frequency, in which the reference resonance frequency and corresponding reference length of the antenna array and strap substrate are stored in a database that is accessible to the diagnostic computing system, and

determining, with the diagnostic computing system, a current length of the antenna array and the strap substrate based on the measured change in resonance frequency and the reference length of the antenna array and the strap substrate.

12. A method according to Claim 11, further comprising:

deploying the measuring instrument on an exterior wall of a cylindrical storage container, in which the measuring instrument is extended circumferentially about the circumferential wall of the storage container at a respective height such that the length of the measuring instrument corresponds to the circumference of the container at the respective height; and

calculating, with the diagnostic computing system, the volume of the storage container based on the calculated current length of the antenna array and strap substrate.

13. A method according to Claim 12, in which the calibrating step is performed one or more of prior to and during deployment of the measuring instrument on the cylindrical storage container and further comprising:

updating the reference resonance frequency and reference length stored in the database according to the measured resonance frequency and the current length calculated during an initial calibrating operation; and

periodically repeating the calibrating step and the step of calculating the volume of the storage container.

14. A system according to Claim 1, in which the antenna array is encapsulated within a protective material suitable for protection against harsh environments.

15. A system according to Claim 10, in which the antenna array is encapsulated within a protective material suitable for protection against harsh environments.

16. A system according to Claim 11, in which the antenna array is encapsulated within a protective material suitable for protection against harsh environments.