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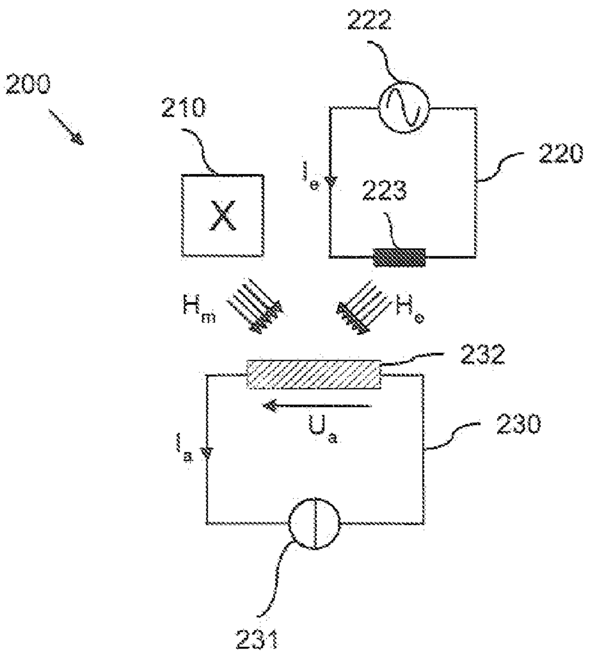

Fig. 2

(57) Abstract: The present invention proposes a sensor apparatus (200) for generating a measurement signal (U_a) based on an input signal (H_m). The input signal is preferably a magnetic field. The sensor apparatus includes a signal generation device (220) and a sensor device (230). The signal generation device (220) generates a periodic signal (H_e) of the same type as the input signal (H_m). The signal generation device further generates a mixed signal based on the input signal (H_m) and the periodic signal (H_e). The sensor device (230) finally generates the measurement signal (U_a) based on the mixed signal and a characteristic curve (110) of the sensor device (230). By mixing the input signal (H_m) with a periodic signal (H_e) of the same type, the sensitivity and robustness of the sensor apparatus (200) can be increased by synchronously reducing its complexity.

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MODULATION OF INPUT SIGNALS FOR A SENSOR APPARATUS

FIELD OF THE INVENTION

The present invention relates to a sensor apparatus for generating a sensor signal based on an input signal and to a method for measuring a physical characteristic of an input signal. In particular, the present invention relates to an anisotropic-magneto-resistive sensor and to a method for measuring a magnetic field with an anisotropic-magneto-resistive sensor.

BACKGROUND OF THE INVENTION

Measurement engineering is a field in electronic engineering that deals with processes for determining magnitudes of specified physical characteristics of an object. This may be for example the magnitude of a magnetic field of an electromagnet or the length of a geometric object. Such kind of processes are commonly called measurements and the technical apparatuses for performing a measurement are called sensor apparatuses.

The sensor apparatus measuring the magnitude of the interested physical characteristic outputs an electronic signal that is directly interpretable and allows a direct conclusion to the measured magnitude. For that reason, the measured magnitude and the magnitude of the electronic output signal should be mathematically proportional to each other. This is called linearity condition, which should be given over a wide range of magnitudes of the interested physical characteristic. In case of measuring a magnetic field, the sensor apparatus should double the magnitude of its output signal if the magnitude of the magnetic field to be measured doubles.

Besides the linearity condition, the requirements to sensor apparatuses are further defined by its application field. Since a sensor apparatus does not effect any mechanical effort, like the rotation in an engine or the heating in a melting furnace, its physical presence is usually unintended since the sensor apparatus consumes precious space. Thus, sensor apparatuses must be constructed as small as possible to not constrain the intended technical effect of a machine. Further, in the application field, a sensor apparatus is exposed a lot of outer physical influences that have an effect on the measurement, reduce the quality of the output signal and complicate its interpretation.

To provide an example for the above described sensor apparatuses, in the following, magnetic field sensors should be discussed in further detail. Magnetic field sensors take up an important place in the fields of measurement engineering, since they allow a contact-free measurement and are insensitive against acoustic noise and fouling. Magnetic field sensors may be divided into inductive sensors generating a voltage based on a magnetic field, field-plate sensors having a variable resistance based on a magnetic field and Wiegand-sensors changing its magnetic orientation based on magnetic fields. An example for inductive sensors may be a Hall sensor, which generates a voltage by deflecting the current in a current-carrying conductor based on a magnetic field.

The application of field-plate sensors is very widespread in the fields of measurement engineering. They are used as rotational speed and rotational angle sensors, as switches, as contact-free controlled resistors and for potential free measuring of direct currents.

Usually, field-plate sensors have a quadratic characteristic. That is, if the magnetic field, to which the field-plate sensor is exposed, will be doubled, the resistance of the field plate sensor will be reduced to a fourth. Usually, the bias point of field-plate sensors is situated in the peak of its characteristics. This reduces the sensitivity for small magnetic fields, since a field-plate sensor would not generate a detectable elongation around its peak. Various solutions have been proposed to the sensitivity of field-plate sensors.

In a first solution, the bias point will is artificially moved outside the peak by applying an offset. Although the sensitivity is increased, the offset must be cancelled out from the output signal. This offset cancellation requires complex and costly cancellation algorithms limiting the overall performance of the field-plate sensor. Further, due to lifetime and temperature drifts, the offset is not constant and has therefore a strong effect on the measurement quality of the sensor apparatus.

In a further solution, the characteristic of the field-plate sensor itself is changed by adding further mechanical features to the field-plate sensor. Such mechanical features may be e.g. so called Barber poles. Without going into further detail about the technical background of barber poles, these solutions increase the complexity of field plate sensors, such that such kinds of sensors are not only space intensive but also expensive in its production.

Summarized, sensor apparatuses must be sensitive, small sized and resistant against outer physical influences. As can be seen from the example of magnetic field-plate sensors, these conditions can not be achieved together. If by regulating one of these condition with technical means, another condition will be downgraded.

SUMMARY OF THE INVENTION

Thus, it is an object of the present invention to provide a sensor apparatus for generating a sensor signal and a method for measuring a physical characteristic of an input signal, reducing the size and increasing the sensitivity and the robustness of the sensor apparatus.

This object is solved by the independent claims. Further embodiments are subject of the dependent claims.

The basic idea of the invention is to benefit from carrier signals known from the fields of communication engineering. In detail, it is proposed to modulate the magnitude of the physical characteristic to be measured, hereinafter called input signal, onto a periodic signal operating as the carrier signal. In the fields of communication engineering, an information signal is modulated onto a carrier signal adapt the signal to be transmitted to the physical characteristics of the transmission channel. The invention is based on the thought to regard the sensor apparatus as a transmission channel. Thus, by modulating the input signal onto the periodic signal, the input signal can be adapted to the physical characteristics of the sensor apparatus.

Therefore, the present invention proposes a sensor apparatus for generating a sensor signal based on an input signal. The sensor apparatus includes a signal generation device and a sensor device. The signal generation device outputs a periodic signal, which is of the same type as the input signal. That is, if e.g. the input signal is a magnetic field, the periodic signal is also a magnetic field. Further, the signal generation device mixes the input signal and the periodic signal and generates a mixed signal. The sensor device now detects the mixed and generates a detection signal based on its internal characteristic. This detection signal can be directly interpreted with the same techniques as used in the fields of communication engineering, e.g. by demodulation. The signal generation device is a small technical element, increases the complexity of the sensor apparatus hardly noticeably and increases the sensor apparatus technically small. Further, the input signal can be adapted to the internal characteristic of the sensor apparatus and in detail to the internal characteristics of the sensor device. On the one hand, this allows to move the detection of the input signal to a part of the characteristic curve of the sensor apparatus, in which the characteristic curve is not only linear but also very steep. In other words, by modulating the input signal, the sensitivity of the sensor apparatus can be increased. On the other hand, it also allows to reduce noise, since the modulation transforms the input signal into a spectral part, in which influences by noise are minimal. Summarized, the present invention provides a small, sensitive and robust sensor apparatus.

The present invention may be especially suitably applied in the fields of magnetic field sensors. Therein, since field-plate sensors and especially anisotropic-magneto-resistive sensors have a quadratic characteristic curve, the present invention may especially effectively increase their sensitivity by synchronously decreasing their required space and increasing their robustness.

The best way to perform the mixing of the input signal and the periodic signal is to modulate the input signal onto the periodic signal by superposition. This enables an easy and convenient spectral treatment of the detection signal and thus facilitates the spectral interpretation of the detection signal. Further, a superposition of the input signal and the periodic signal can be realized without further technical means and is therefore simple.

The present invention can be implemented as system-on-chip and is therefore excellently appropriated to provide small sized sensor apparatuses for e.g. an implementation as rotational speed sensors in modern technical applications.

In a preferred embodiment, the signal generator may also generate a timely shifted periodic signal, wherein the input signal is also modulated onto the shifted periodic signal to generate a shifted mixed signal. Consequently the sensor device not only generates the detection signal but also a shifted detection signal. By generating two different periodic signals and consequently two different detection signals, there are two signals which may be verified with each other to recognize detection errors, or something else. This embodiment works best, if the time shift between the periodic signal and the shifted periodic signal is 180°. By that means, both generated periodic signals have the same shape but different signs. Thus, both signals can be verified in a especially convenient way.

There may be two different technical realizations for the sensor apparatus according to the preceding embodiment.

In a first realization, the sensor device my include two different sensor heads. The first sensor head is used for generating the detection signal based on the mixed signal and the second sensor head is used for generating the shifted detection signal. This allows to generate both detection signals with a minimum of loss of information.

The first realization works best, if the first sensor head and the second sensor head have the same physical characteristics and are arranged engaged to each other in a common layer. This would not only reduce the required space for that realization onto a minimum due to the arrangement in a common layer but also allows an effective error detection, since both sensor heads are comparably equal.

In a second realization, both detection signals may be generated by multiplexing. This means, that a switching device would alternatively allow the sensor device to generate the detection signal based on the mixed signal and to the generate the shifted detection signal based on the shifted mixed signal. The discontinuities in the resulting detection signals may be continued based on common mathematical methods. Since the second realization requires only one sensor head, the required space for the sensor apparatus can be further reduced.

In another embodiment of the invention, it can be omitted to shift the periodic signal for generating two different periodic signals. This can be achieved by sampling the detection signal. Therein, a first sampling unit samples the detection signal at first sampling points in time and a second sampling unit samples the detection signal at second sampling points in time. Therein, the first and second sampling points are different to each other. Since there is no need to generate two different periodic signals and also no need to generate two different mixing signals, the present embodiment can further reduce the required space for the present invention.

Best results have been reached, if the sampling points for the first sampling unit are derived from the maxima of the periodic signal and the sampling points for the second sampling unit are derived from the minima of the periodic signal. This guarantee, that both sampled detection signals are shifted by 180° in time to each other.

If the present invention is embodied by generating two different detection signals, a summing unit may sum the both signals. This method is especially effective, if the shift between both signals is 180°. This would erasure at least some spectral components in the detection signals, which occur due to the modulation of the input signal with the periodic signal. Thus, the summing unit may facilitate the following interpretation of the detection signals and decrease the complexity of the sensor apparatus. The above described erasure effect is especially effective by a time delay of 180°. However, the erasure effect can also be regarded at time delays higher or lower than 180°.

Additionally or alternatively, a demodulation unit may be used to remove at least some parts of the periodic signal. Such a demodulation unit may be simply realized by a multiplier multiplying the periodic signal itself onto the detection signal or the summed detection signals.

For further increasing the interpretability of the detection signal, a comparator unit may be applied to verify the detection signal or the summed detection signals against a threshold. Such a procedure is especially effective at sensor applications, in which the input signal has a periodic shape, and in which the frequency of the time shift and not the amplitude itself is of interest.

To remove noise components from the detection signal or the summed detection signals, the comparator device may be a Schmitt-Trigger.

The present invention also proposes a method for determining a magnitude of a physical characteristic of an input signal. Therein, a periodic signal is generated, which is of the same type as the input signal. Further, the periodic signal and the input signal are mixed, preferably by superposition. Finally, a detection signal is generated based on the input signal and a characteristic curve e.g. of a sensor device.

The method has the same advantages and technical effects as the above described sensor apparatus. Further, the above described additional apparatus features may all be introduced as method features in the forgoing method.

The invention will be described in greater detail hereinafter, by way of non-limiting examples with reference to the embodiments shown in the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a characteristic curve of a AMR-sensor;

Fig. 2 shows a sensor apparatus according to a first embodiment of the present invention;

Fig. 3 shows a diagram discussing the spectral components of a detection signal;

Fig. 4 shows a sensor apparatus according to a second embodiment of the present invention;

Fig. 5 shows sensor heads for the sensor apparatus according to the second embodiment;

Fig. 6 shows a sensor apparatus according to a third embodiment of the present invention;

Fig. 7 shows a sensor apparatus according to a fourth embodiment of the present invention;

Fig. 8 shows a diagram explaining the sampling principle of the sensor apparatus according to a fourth embodiment of the present invention; and

Fig. 9 shows a diagram explaining the generation of an interpretable sensor signal based on an input signal and a periodic signal.

DETAILED DESCRIPTION OF THE INVENTION

To discuss the sensor apparatus according to the present invention in further detail, an anisotropic magneto-resistive sensor (AMR-sensor) should be exemplary regarded. An AMR-sensor is a field plate sensor that changes its electric resistance R based on an applied magnetic field H. Thus, the input signal of an AMR-sensor is a magnetic field H and the output signal is a current or a voltage, which changes depending on the resistance R of the AMR-sensor.

Based on fig. 1, the characteristics of an AMR-sensor should be discussed in further detail.

As most of the electronic elements, an AMR sensor can be described by its characteristic curve 110 informing about the capability of an electronic element to change its output signal dependent on an applied input signal. The AMR-sensor has a negative parabola as characteristic curve 110. In other words, the AMR-sensor changes its resistance R based on an applied magnetic field H in a quadratic way.

The AMR-sensor has further a bias point 130 informing about the output signal of an electronic device, if no input signal is applied. Thus, the bias point 130 of the AMR-sensor indicates its resistance R if no magnetic field H is applied and is located in the maximum of the characteristic curve 110.

To exemplary discuss the operation of the AMR-sensor, an alternating magnetic field 120 should be applied. This alternating magnetic field 120 has the shape of a sinus curve shown in a time-magnetic field-diagram below the characteristic curve 110 of fig. 1. After applying the alternating magnetic field 120, the resistance R of the AMR-sensor will periodically move along the characteristic curve 110. In fig. 1, a certain elongation point 140 is shown, which indicates the resistance $R(t_0)$ under a magnetic field $H(t_0)$ which occurs to a specific point in time t_0. To keep fig. 1 clearly arranged, the magnetic field $H(t_0)$ of the elongation point 140 does not fit to any elongation of the sinus curve of the alternating magnetic field 120.

Based on the characteristic curve 120, some disadvantages of conventional AMR-sensors will become obvious complicating their technical implementation.

One of the most serious problems is the limited sensitivity of an AMR-sensor given by its parabolic characteristic curve 120 and its bias point 130 in the maximum of the parabolic characteristic curve 120. As can be seen in fig. 1, in case of applying only a very small magnetic field H, the resistance R of the AMR-sensor will keep nearly constant in the close environment of the bias point. Thus, a conventional AMR-sensor is not suitable for measuring small magnetic fields H.

Further, if the AMR-sensor is subjected to outer influences moving the bias point 130 outward from the maximum of the characteristic curve 110, the characteristic of the AMR-sensor will change depending on the direction of the movement. However, since this direction is usually undefined, it is undefined whether the AMR-sensor has a positive characteristic (wherein the resistance R of the AMR-sensor increases based on an increase in the applied magnetic field H) or a negative characteristic (wherein the resistance R of the AMR-sensor decreases based on an increase in the applied magnetic field H). This undefined condition complicates the analysis and interpretation of the measurement results of the AMR-sensor.

To counteract the unsuitable location of the bias point 130 it is already proposed to artificially move the bias point into another point of its characteristic curve 110. This can be achieved either by applying an offset or by amending its technical construction. However, both solutions suffer disadvantages leading to sources of defects and/or a more complex construction of the AMR-sensor.

The application of an offset usually not only involves temperature and lifetime drifts but also complicates the amplification of the output signal of the AMR-sensor for the post processing. Thus, an offset is usually cancelled out by complex and costly offset cancellation algorithms.

The amendment of the technical construction of the AMR-sensor, like using Barber poles, is also unsuitable, since additional technical features not only increase the size of the AMR-sensor but also increase the production costs.

By applying the idea of the present invention to an AMR-sensor, the sensitivity and robustness of an AMR-sensor can be increased by synchronously reducing its size and production costs.

Fig. 2 shows a measurement arrangement 200 for measuring a magnetic field H_m using an AMR-sensor 220, 230 according to the present invention.

The measurement arrangement 200 includes a magnetic source 210, a signal generation device being a magnetic field generator 220 and a sensor device being an AMR-sensor-head 230.

The magnetic source 210 excites a magnetic measurement field H_m to be measured by the AMR-sensor 220, 230. The magnetic field generator 220 excites a periodic signal of the same type as the signal to be measured. Thus, the excited periodic signal is a periodic magnetic field H_e. The magnetic measurement field H_m and the periodic magnetic field H_e are both directed against the AMR-sensor-head 230. This effects, that both magnetic fields H_m, H_e are summed together prior impinging on the sensor-head 230. In other words, by summing both magnetic fields H_m, H_e, the magnetic measurement field H_m will be modulated onto the periodic magnetic field H_e.

In a very basic embodiment, the magnetic field generator 220 may consist of a current source 222 and an excitation coil 223. To excite the periodic magnetic field H_e by the excitation coil 223, the current source 222 outputs a periodic excitation current I_e and supplies it to the excitation coil 223.

The AMR-sensor head 230 consists of an AMR-sensor element 232 and a constant current source 231. The constant current source 231 drives a constant current I_a through the AMR-sensor element 232. This effects a measurement voltage U_a at the AMR-sensor element 232, wherein the magnitude of the measurement voltage U_a depend on the resistance R of the AMR-sensor element 232. Since this resistance R is influenced by the sum of the magnetic measurement field H_m and the periodic magnetic field H_e, the resistance R and therefore the measurement voltage U_a directly includes an information about the magnitude of the sum of the magnetic measurement field H_m and the periodic magnetic field H_e. Further, since the shape of the periodic magnetic field H_e and the characteristic curve 110 of the AMR-sensor element 232 is known, the magnetic measurement field H_m can be directly calculated based on the resulting measurement voltage U_a.

To realize the invention, it is not forcibly necessary to measure the measurement voltage U_a, but to determine the resistance R of the AMR-sensor element 232. This can also be done by applying a constant voltage source into the AMR-sensor head 230 measuring the current through the AMR-sensor head 232. Also more complicated electronic circuits for measuring an electronic resistance may be applied. These are e.g. bridge circuits like a Wheatstone bridge.

Next, based on fig. 3, it should be shortly explained how to determine the magnetic measurement field H_m based on the measured resistance R. Assumed that both, the magnetic measurement field H_m and the periodic magnetic field H_e are periodic, the magnetic measurement field H_m may be described by:

$$H_m(t) = \hat{H}_m \sin(\omega_m t) \qquad (1)$$

and the periodic magnetic field H_e can be described by:

$$H_e(t) = \hat{H}_e \sin(\omega_e t) \qquad (2).$$

In (1) and (2), ω_m and ω_e specifies the circular frequency. The characteristic curve 110 of the AMR-sensor element 232 can be described by:

$$R(t) = R_0 + \Delta R\left(1 - \left(\frac{H_m(t) + H_e(t)}{H_0}\right)^2\right) \qquad (3).$$

R_0 is the resistance R of the AMR-sensor element 232 in the maximum of the characteristic curve 110. H_0 is the demagnetizing and anisotropic field. Both parameters are system specific.

Solving equation (3) in the time domain will lead to a harmonic function of the resistance R including five different spectral components:

$$R(t) = \quad R_0 + \Delta R\left(1 - \frac{\hat{H}_m^2}{H_0^2} - \frac{\hat{H}_e^2}{2H_0^2}\right) - \qquad (4.1)$$

$$\Delta R \frac{\hat{H}_m^2}{2H_0^2} \cos(2\omega_m t) - \qquad (4.2)$$

$$\Delta R \frac{\hat{H}_e^2}{2H_0^2} \cos(2\omega_e t) - \qquad (4.3)$$

$$\frac{\hat{H}_m^2 \cdot \hat{H}_e^2}{H_0^2} \cos(2(\omega_e - \omega_m)t) + \qquad (4.4)$$

$$\frac{\hat{H}_m^2 \cdot \hat{H}_e^2}{H_0^2} \cos(2(\omega_e + \omega_m)t) \qquad (4.5)$$

These five spectral components of the resistance R of the AMR-sensor element 232 are schematically shown in a spectral diagram in fig. 3. As can be seen from equation (4) and from fig. 3, the components (4.3)-(4.5) together represents an amplitude modulation. The components representing the amplitude modulation are surrounded by a box 300 in fig. 3. As well known for a skilled person, an amplitude modulation can be demodulated by simply multiplying the amplitude modulated signal with its carrier frequency. However, as can be seen from fig. 3, it is also possible to filter either component (4.1) or component (4.2) from the measured resistance R and to calculate the magnetic measurement field H_m. The constant component of the resistance R does not include any information about the circular frequency. It is left to the discretion of the skilled person how he would derive the magnetic measurement field H_m from the measured resistance R.

Next, three further embodiments for the AMR-sensor should be discussed. All of these embodiments propose an AMR-sensor according to the present invention, wherein some parts of the above discussed spectrum of the resistance R will be cancelled out due to the technical construction of the AMR-sensor. This would reduce the complexity when post-processing the measured resistance R.

Fig. 4 shows an AMR-sensor 400 according to a second embodiment of the present invention. The basic idea behind the second embodiment is to provide two different AMR-sensor heads. The first AMR-sensor head detects the magnetic measurement field H_m superposed with the periodic magnetic field H_e described above. The second AMR-sensor head detects the magnetic measurement field H_m superposed with a second periodic magnetic field, which has the same shape as the first periodic magnetic field H_e, but is shifted by 180° in time. For sake of a clear and precise description, the second periodic magnetic field should be named shifted magnetic field $H_{e,inv}$.

In the description of the next three embodiments, the presence of the magnetic measurement field H_m should be implicitly assumed. However, it would not be explicitly mentioned in the following description. Alternatively, it could also be assumed, that the magnetic measurement field H_m is zero and can therefore be omitted in the following description.

According to fig. 4, the AMR-sensor 400 according to the second embodiment includes a current source 440, a delay element 410, two different excitation coils 420, 450, two different AMR-sensor heads 430, 460, a summing unit 470, a multiplier 480 and a Schmitt-Trigger 490.

The current source 440 outputs an alternating excitation current i_e, which is directly provided to the second excitation coil 450. The excitation current i_e is further provided to the delay element 410 delaying the excitation current i_e by 180° in time. The delayed excitation current $i_{e,inv}$ is then provided to the first excitation coil 420. The first excitation coil 420 generates the shifted periodic magnetic field $H_{e,inv}$ based on the shifted excitation current $i_{e,inv}$. Synchronously, the second excitation coil 450 generates the periodic magnetic field H_e based on the excitation current i_e. Next, the first and second AMR-sensor heads 430, 460 respectively detect the shifted periodic magnetic field $H_{e,inv}$ and the periodic magnetic field H_e and respectively output a shifted detection voltage $U_{s,inv}$ and a detection voltage U_s. These detection voltages $U_{s,inv}$, $U_{s,inv}$ correspond to the measurement voltage U_a shown in fig. 2. Thus, the detection voltage U_s correspond to the measurement voltage U_a and the shifted detection voltage $U_{s,inv}$ correspond to a shifted measurement voltage $U_{a,inv}$. These detection voltages $U_{s,inv}$, U_s are summed the summing unit 470 to a summed voltage U_g, which is then demodulated in the multiplyer 480 by multiplying the summed voltage U_g with a voltage derived from the excitation current i_e. The demodulated voltage U_d is finally processed by the Schmitt-Trigger 490 to generate the output signal of the AMR-sensor 400.

If the shifted periodic magnetic field $H_{e,inv}$ is delayed by 180° in time, it can be described by:

$$H_e(t) = -\hat{H}_e \sin(\omega_e t) \qquad (5).$$

Assumed, that the characteristic curves 110 of the first AMR-sensor head 430 and the second AMR-sensor head 460 are equal, the shifted periodic magnetic field $H_{e,inv}$ generates a shifted resistance R_{inv} at the first AMR-sensor head 430, which can be calculated in the same way as shown in equations (1)-(4). For sake of conciseness, the shifted resistance R_{inv} should not be calculated in detail.

As already explained in fig. 2, it is proposed to apply a constant current source 231 to the first and second AMR-sensor head 430, 460 and to determine the resistances R, R_{inv} by measuring the dropped shifted measurement voltage $U_{a,inv}$ and respectively the dropped measurement voltage U_a. In fig. 4, these measurement voltages U_a, $U_{a,inv}$ are the detection voltages $U_{s,inv}$, $U_{s,inv}$. After summing these detection voltages together, the summed voltage U_g represents a summed resistance R_g of the first and second AMR-sensor head 430, 460. This summed resistance R_g can be described by the formula:

$$R_g(t) = R(t) + R_{inv}(t) = -4\Delta R \frac{\hat{H}_m \cdot \hat{H}_e}{H_0^2} \sin(\omega_m t) \sin(\omega_e t) \qquad (6).$$

As can be seen from formula (6) directly, the summed resistance R_g and consequently the summed voltage U_g represents an amplitude modulation out of a voltage corresponding to the magnetic measurement field H_m and a voltage corresponding to the periodic magnetic field H_e. That is, the summed voltage Ug can be demodulated my a multiplication with a voltage corresponding to the periodic magnetic field H_e or corresponding to the excitation current i_e.

Therefore, the summed voltage U_g is fed to the multiplier 480 multiplying it with a voltage derived from the excitation current i_e. The result is a demodulated voltage U_d including all information about the magnetic measurement field H_m and can therefore be used as output signal U_{out} of the AMR-sensor 400.

If the magnetic measurement field H_m is a periodic signal, it is suitable to further process the summed voltage U_g e.g. by a comparator. This would increase the readability of the output signal U_{out} of the AMR-sensor 400. Such a periodic magnetic measurement field H_m is given e.g. in rotational speed sensors in automotive applications. To further remove noise from the output signal U_{out} of the AMR-sensor 400, a Schmitt-Trigger 490 should be used as comparator. Since the construction and the operation of the Schmitt-Trigger 490 is well known for a skilled person, a detailed discussion can be omitted. As can be seen from the second embodiment, by cleverly mixing the magnetic measurement field H_m and the periodic magnetic field H_e, it is possible to receive an amplitude modulation. This increases the robustness and the sensitivity of the AMR-sensor 400 by synchronously keeping the complexity of the AMR-sensor 400 small.

The AMR-sensor heads 430, 460 according to the first embodiment are indicated in fig. 5. Therein, both AMR-sensor heads 430, 460 are arranged in a common layer. Further, both sensor heads 430, 460 are constructed as meanders and engaged into each other. Both sensor heads 430, 460 are also constructed by alternatively linking a metal element 530 and a Permalloy element 540. The material of the metal element 530 may aluminium (Al). The material of the Permalloy element 530 may be a nickel-iron-alloy (NiFe).

By such the construction of the AMR-sensor heads 430, 460 according to fig. 4, it is not only reached that the characteristic curve 110 of both AMR-sensor heads 430, 460 is nearly equal, it is also reached, that both sensor heads are exposed to nearly the same sum of the magnetic measurement field H_m and the periodic magnetic field H_e.

Fig. 6 shows an AMR-sensor 600 according to a third embodiment of the invention. This embodiment differs from the AMR-sensor 400 according to the second embodiment only in its construction of the AMR-sensor heads. Thus, an explanation of the other elements of the AMR-sensor 600 according to the third embodiment would not be repeated hereinafter.

The AMR-sensor 600 only includes the first AMR-sensor head 430 receiving the periodic magnetic field H_e and the shifted periodic magnetic field $H_{e,inv}$ from a multiplexer 610, multiplexing the shifted periodic magnetic field $H_{e,inv}$ excited from the first excitation coil 420 and the periodic magnetic field H_e excited from the second excitation coil 450.

The advantage of using only one AMR-sensor head 430 is not only that the characteristic curve 110 of the AMR-sensor head 430 is exactly equal for the periodic magnetic field H_e and the shifted periodic magnetic field $H_{e,inv}$ when generating the detection voltages U_s, $U_{s,inv}$, it is also possible to save the space required for the implementation of the second AMR-sensor head 460.

Further, it is also possible to combine the second and third embodiment of the AMR-sensor. This would increase the reliability of the AMR-sensor, because the AMR-sensor would still be operable even if one AMR-sensor head has a malfunction.

Figs. 7-9 show an AMR-sensor 700 according to a fourth embodiment of the present invention. Therein, only one excitation coil 420 excited by the current source 420 is used to generate a periodic magnetic field H_e for modulating the magnetic measurement field H_m. Further, one single AMR-sensor head 430 is exposed to the sum of the periodic magnetic field H_e and the magnetic measurement field H_m and generates a measurement voltage U_a. This measurement voltage U_a is sampled by two different sampling units 710, 720 at different sampling points in time 810, 820. The sampled voltage of the first sampling unit 710 represents the shifted detection voltage $U_{s,inv}$. The sampled voltage of the second sampling unit 720 represents the detection voltage U_s. Both detection voltages U_s, $U_{s,inv}$ are summed together by the summing unit 470 outputting a summed voltage U_g representing the demodulated voltage U_d from the second and third embodiment. Also this summed voltage U_g can optionally be further processed by the Schmitt-Trigger 490 to further increase the readability of the output signal U_{out} and to remove noise.

The sampling points 810 for the first sampling unit 710 are derived from the local minima 830 of the periodic magnetic field H_e. Accordingly, the sampling points 810 for the second sampling unit 720 are derived from the local maxima 840 of the periodic magnetic field H_e. Since the periodic magnetic field H_e is linearily excited based on the excitation current i_e, the local maxima 840 and minima 830 can also be taken from the excitation current i_e.

The result of the sampling operation in both sampling units 710, 720 are two timely shifted detection voltages U_s,$U_{s,inv}$. However, since the periodic magnetic field H_e is sampled respectively in its maxima 840 and minima 830, the frequency of the periodic magnetic field H_e is removed from the shifted detection voltages U_s,$U_{s,inv}$. In other words, the summing operation of the timely shifted detection voltages U_s,$U_{s,inv}$ in the summing unit 470 directly leads to a demodulated summed voltage. Thus, the summed voltage U_g outputted by the summing unit 470 directly corresponds to the demodulated voltage U_d of the second and third embodiment. As already discussed, this summed voltage may be optionally processed by the Schmitt-Trigger 490.

Fig. 9 shows diagrams explaining the generation of the output voltage U_{out} based on the magnetic measurement field H_m.

At first, the magnetic measurement field H_m is superposed with the periodic magnetic field H_e. Based on the characteristic curve 110 of the AMR-sensor head 430, the measurement voltage U_a is generated, which will be sampled twice. The first sampling operation leads to the detection voltage U_s and the second sampling operation leads to the shifted detection voltage $U_{s,inv}$. Both detection voltages U_s $U_{s,inv}$ are summed together resulting into the summed voltage U_g. This summed voltage U_g is finally post-processed by the Schmitt-Trigger 490 generating the output voltage U_{out}.

It should be mentioned, that the multiplexer 610 of the second embodiment is also able to realize the first and second sampling units 710, 720. Therein, the switch of the multiplexer 610 conducts the measurement voltage Ua in the minima 830 of the excitation current i_e to generate the shifted detection voltage $U_{s,inv}$ and in the maxima 840 of the excitation current i_e to generate the detection voltage U_s.

The present invention proposes to modulate a physical signal to be detected by a sensor apparatus onto a periodical physical signal of the same type as the physical signal to be detected. This increased the sensitivity and the robustness of the sensor apparatus and decreases its complexity.

CLAIMS:

1. Sensor apparatus for generating a measurement signal (U_a) based on an input signal (H_m) including:

a signal generation device (220) for generating a periodic signal (H_e) of the same type as the input signal (H_m) and for generating a mixed signal based on the input signal (H_m) and the periodic signal (H_e); and

a sensor device (230) for generating the measurement signal (U_a) based on the mixed signal and a characteristic curve (110) of the sensor device (230).

2. Sensor apparatus of claim 1, wherein the input signal (H_m) is a magnetic field and the sensor device (230) is a magnetic field sensor, preferably an anisotropic magneto-resistive sensor.

3. Sensor apparatus of claim 1 or 2, wherein the signal generator (220) is adapted to generate the mixed signal based on modulating the input signal (H_m) onto the periodic signal (H_e), wherein the modulation scheme is preferably a superposition.

4. Sensor apparatus according to one of the preceding claims, wherein the sensor apparatus (200) is implemented as system-on-chip.

5. Sensor apparatus according to one of the preceding claims, wherein

the signal generation device (220) is adapted

to generate a shifted periodic signal ($H_{e,inv}$), which is preferably shifted by 180° in respect to the periodic signal (H_e), and

to generate a shifted mixing signal based on the shifted periodic signal ($H_{e,inv}$) and the input signal (H_m), preferably by superposing both signals; and

the sensor device is adapted

to output the measurement signal (U_a) as a detection signal (U_s), and

to generate a shifted detection signal ($U_{s,inv}$) based on the shifted mixed signal and the characteristic curve (110) of the sensor device (220).

6. Sensor apparatus of claim 5, wherein the sensor device (220) includes

a first sensor head (430) for generating the detection signal (U_s) based on the mixed signal and a first characteristic curve; and a second sensor head (460) for generating the shifted detection signal ($U_{s,inv}$) based on the shifted mixed signal and a second characteristic curve,

wherein the first characteristic curve and the second characteristic curve are preferably equal.

7. Sensor apparatus of claim 6, wherein the first and second sensor head (430, 460) are arranged in a common layer and engaged into each other.

8. Sensor apparatus of claim 5, wherein the sensor device (220) is adapted to generate the detection signal (U_s) and the shifted detection signal ($U_{s,inv}$) by multiplexing the mixed signal and the shifted mixed signal.

9. Sensor apparatus according to one of the claims 1 to 4 including a sampling unit (710, 720)

for generating a detection signal (U_s) by sampling the measurement signal (U_a) at first sampling points (820), and

for generating a shifted detection signal ($U_{s,inv}$) by sampling the measurement signal (U_a) at second sampling points (810),

wherein the first sampling points (820) and the second sampling points (810) are preferably different in time.

10. Sensor apparatus of claim 9, wherein

the first sampling points (820) correspond to the maxima (840) of the periodic signal (H_e), and

the second sampling points (810) correspond to the minima (830) of the periodic signal (H_e).

11. Sensor apparatus according to one of the claims 5 to 10 including a summing unit (470) for generating a sum signal (U_g) by summing the detection signal (U_s) and the shifted detection signal (Us,inv).

12. Sensor apparatus according to claim 11 including a demodulation device (480) for generating a demodulated signal (U_d) by removing preferably the frequency component of the periodic signal (H_e) from the sum signal (U_g).

13. Sensor apparatus according to claim 11 or 12 including a comparator device (490) for generating an output signal (U_{out})

having a first signal level, if the demodulation signal (U_d) or the summing signal (U_g) exceeds a predetermined threshold, and

having a second signal level, if the demodulation signal (U_d) or the summing signal (U_g) falls below the predetermined threshold.

14. Sensor apparatus according to claim 13, wherein the comparator device (490) is a Schmitt-Trigger.

15. Measuring method for determining a magnitude of a physical characteristic of an input signal (H_m), preferably a magnetic field, including the steps:

generating a periodic signal (H_e) of the same physical type as the input signal (H_m) to be measured;

mixing the periodic signal (H_e) and the input signal (H_m), preferably by superposition; and

detecting the mixed periodic and input signal by a sensor device (230).

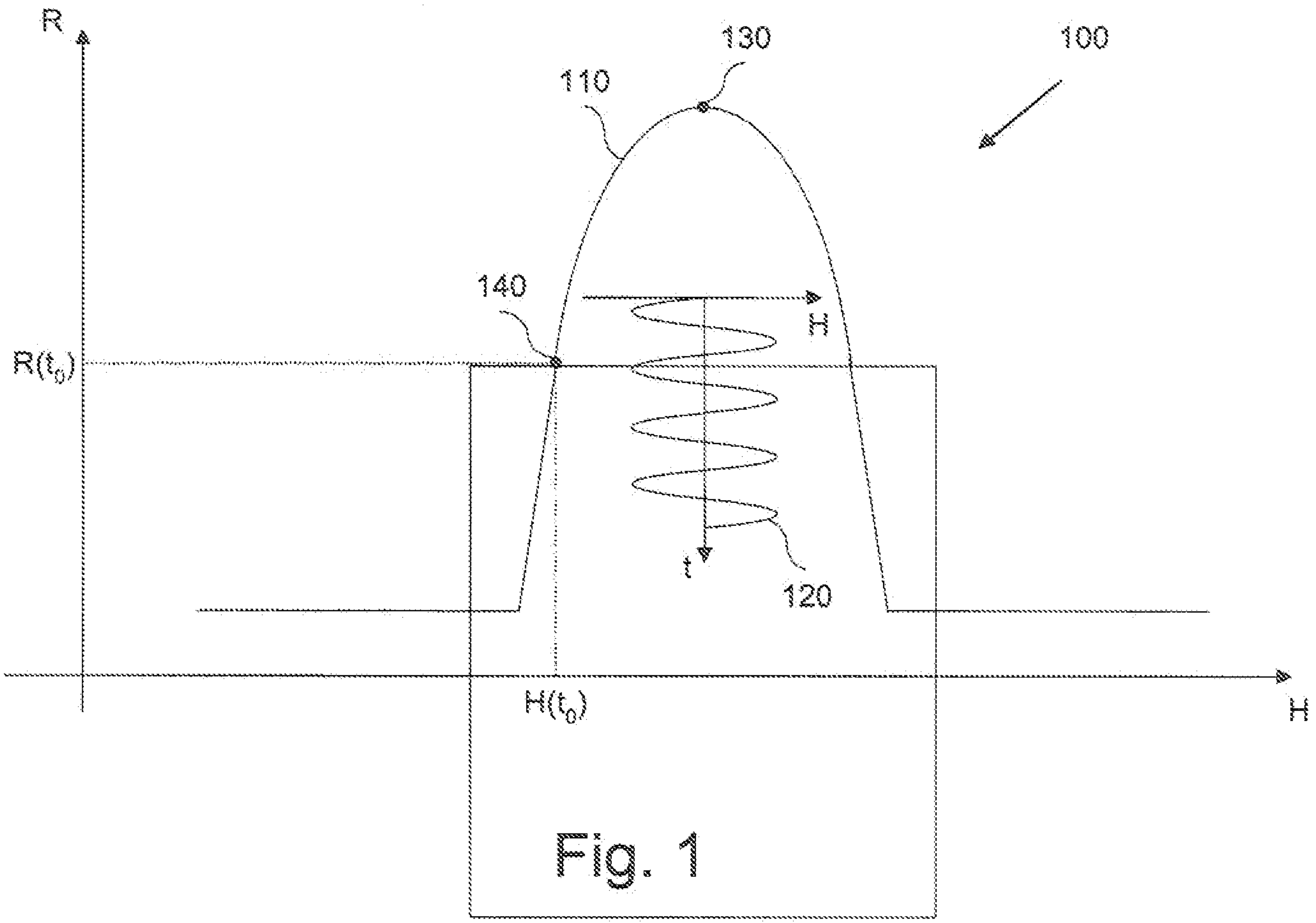
R
130
100
110
140
H
R(t0)
t
120
H(t0)
H

Fig. 1

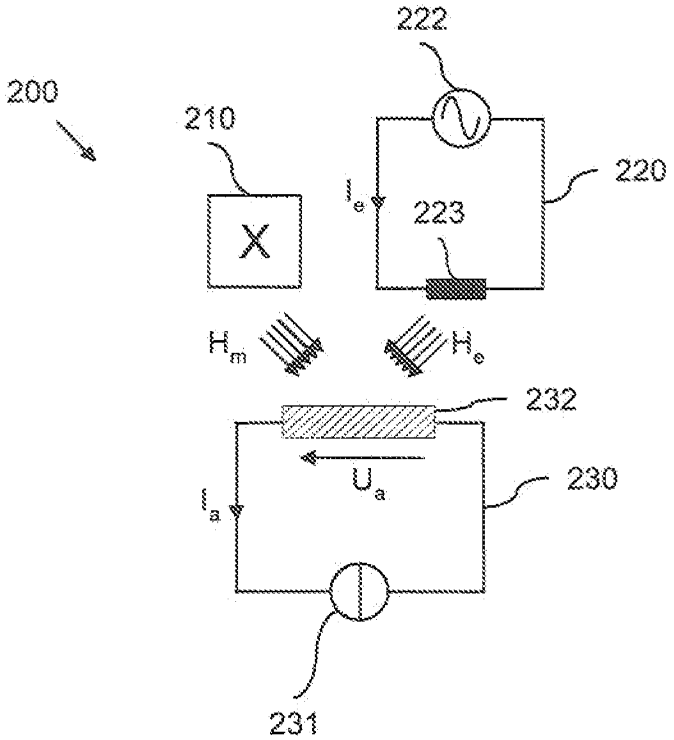
222
200
210
220
Ie
223
X
Hm
He
232
Ua
230
Ia
231

Fig. 2

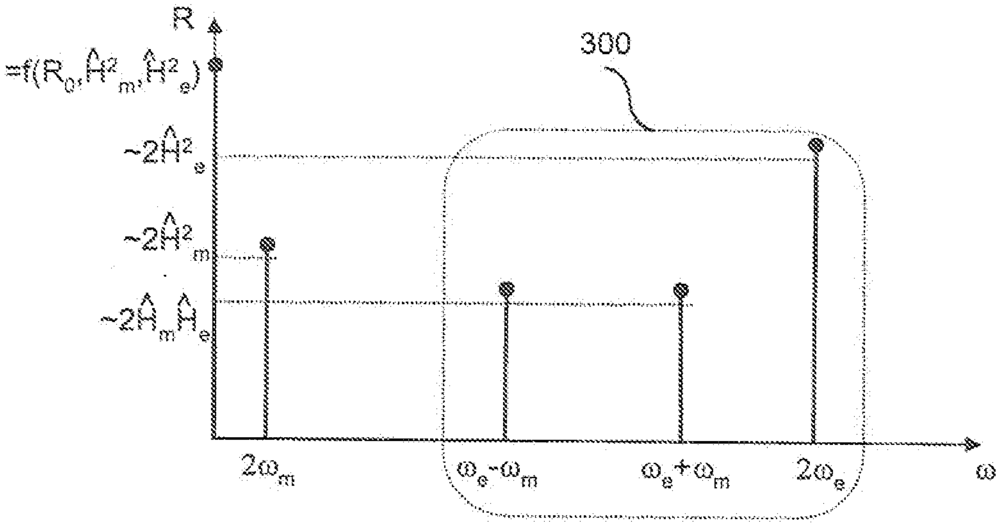
R
=f(R0,Ĥ²m,Ĥ²e)
~2Ĥ²e
~2Ĥ²m
~2ĤmĤe
300
2ωm
ωe-ωm
ωe+ωm
2ωe
ω

Fig. 3

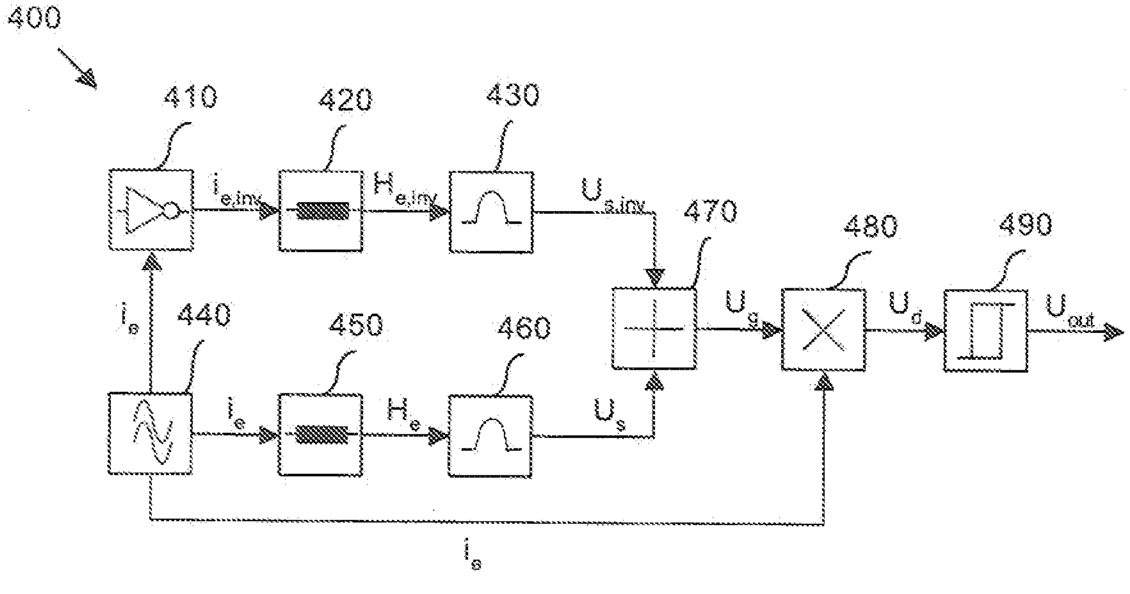
400
410
420
430
440
450
460
470
480
490
ie,inv
He,inv
Us,inv
ie
ie
He
Us
Ug
Ud
Uout
is

Fig. 4

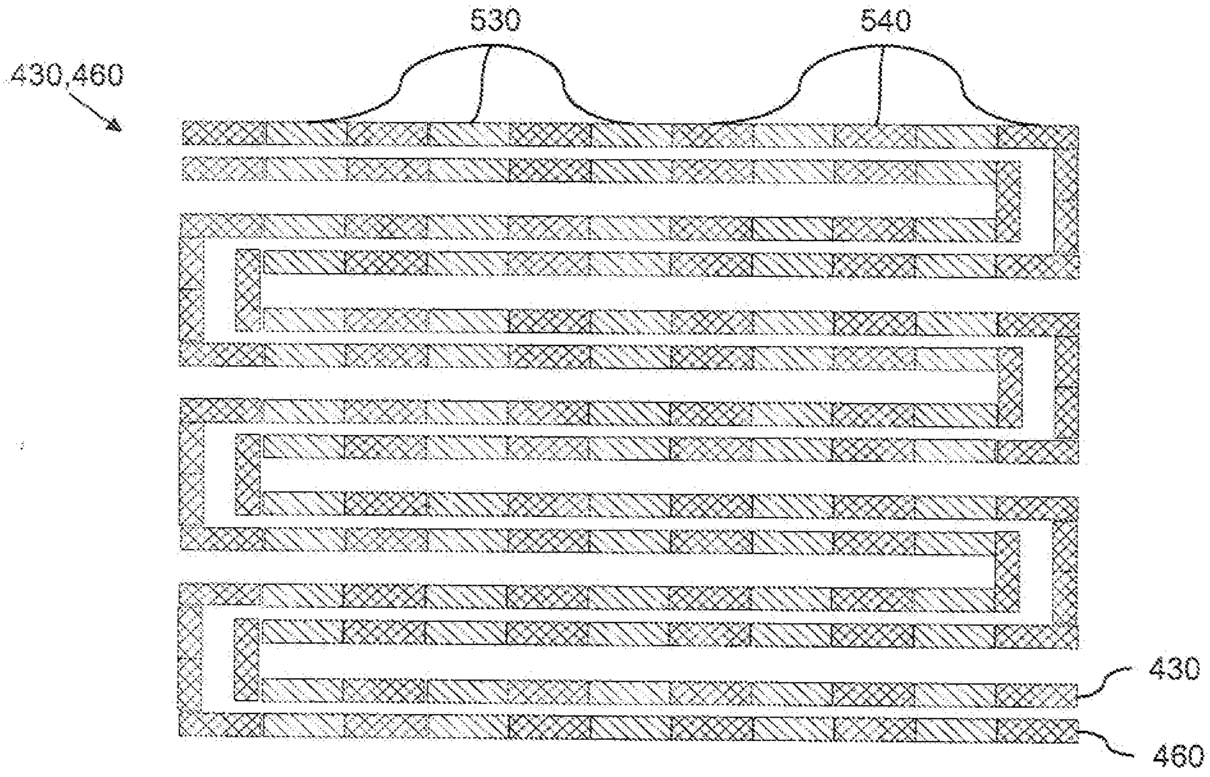
530
540
430,460
430
460

Fig. 5

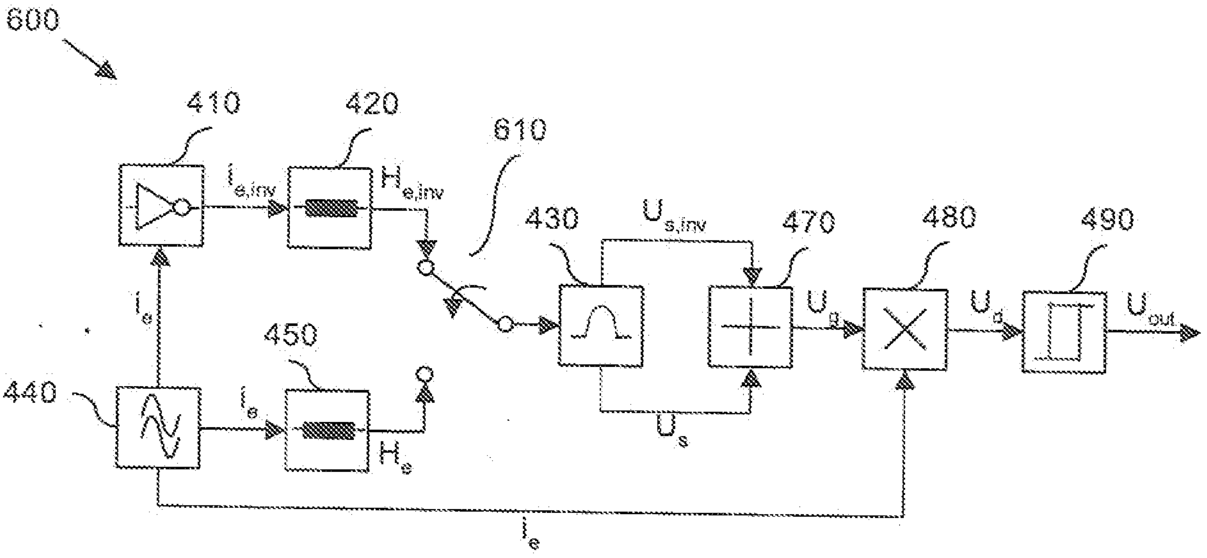
600
410
420
610
430
470
480
490
$i_{e,inv}$
$H_{e,inv}$
$U_{s,inv}$
i_e
440
450
i_e
H_e
U_s
U_g
U_d
U_{out}
i_e

Fig. 6

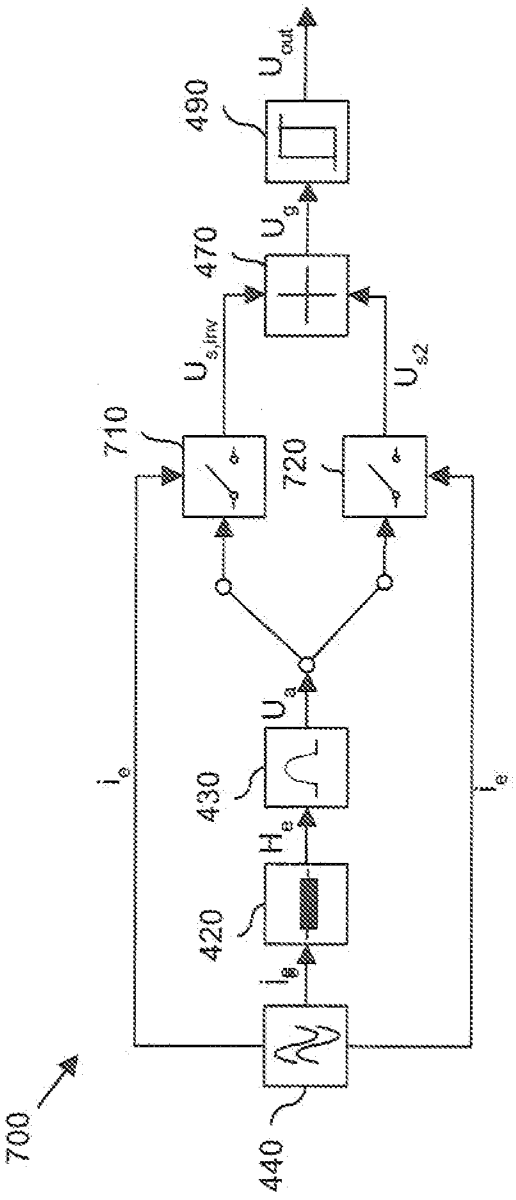

Fig. 7

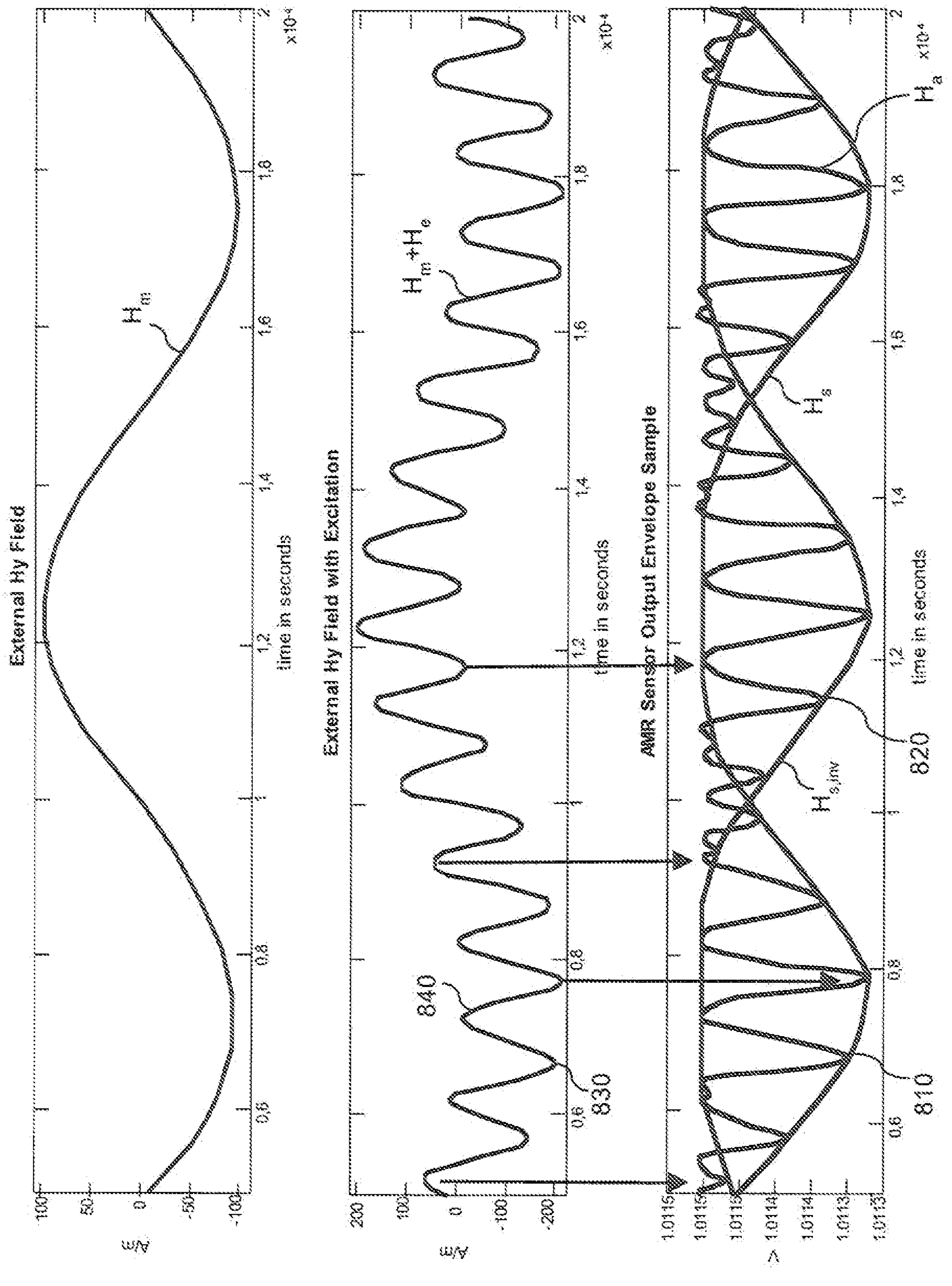
External Hy Field
A/m
100
50
0
-50
-100
H_m
0,6
0,8
1
1,2
1,4
1,6
1,8
2
x10⁻⁴
time in seconds
External Hy Field with Excitation
A/m
200
100
0
-100
-200
H_m+H_e
840
830
time in seconds
AMR Sensor Output Envelope Sample
V
1.0115
1.0115
1.0115
1.0114
1.0114
1.0113
1.0113
H_a
H_s
$H_{s,inv}$
820
810
time in seconds

Fig. 8

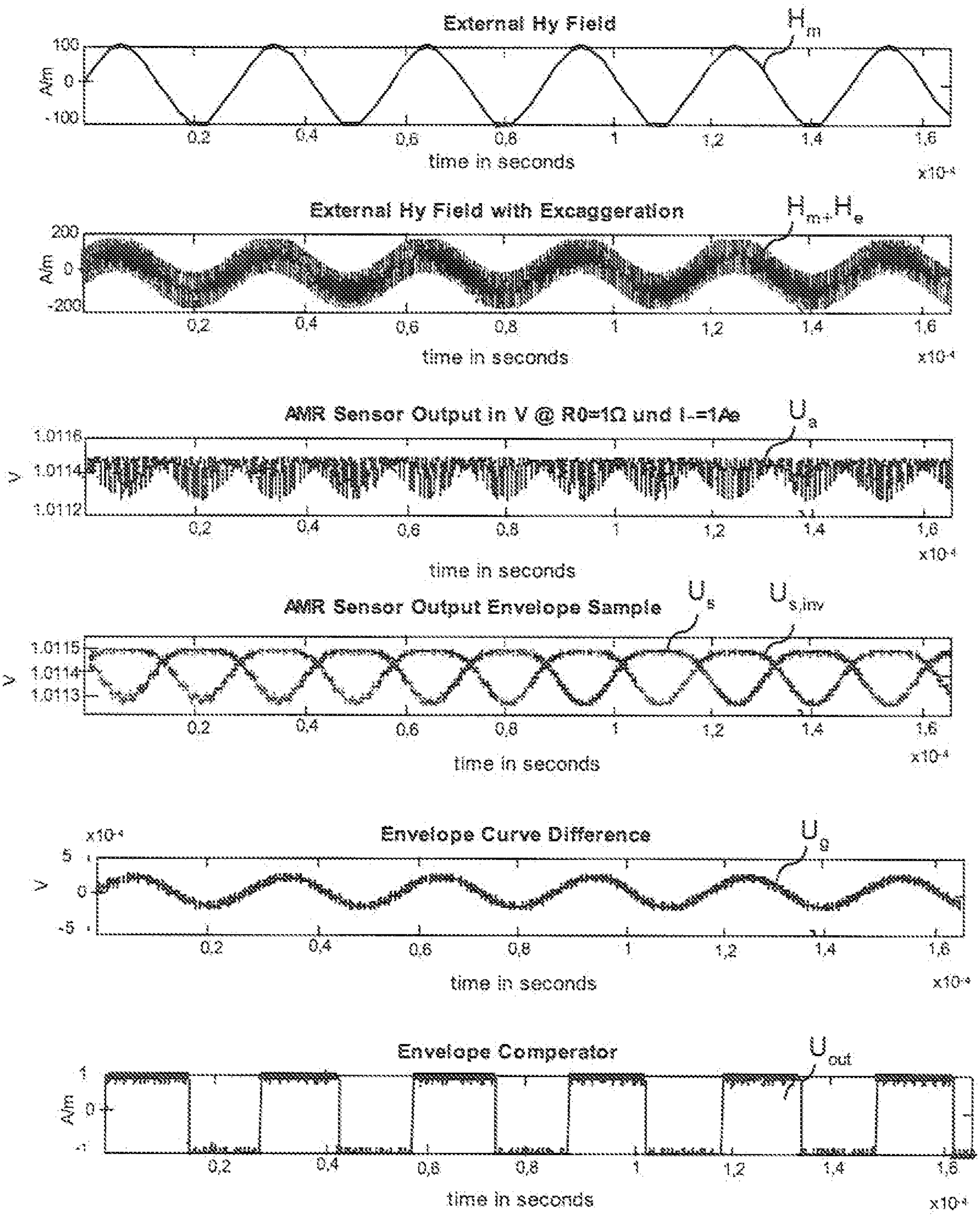
External Hy Field
H_m
100
0
-100
A/m
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6
time in seconds
x10-4
External Hy Field with Excaggeration
H_m+H_e
200
0
-200
A/m
time in seconds
x10-4
AMR Sensor Output in V @ R0=1Ω und I-=1Ae
U_a
1.0116
1.0114
1.0112
V
time in seconds
x10-4
AMR Sensor Output Envelope Sample
U_s
U_s,inv
1.0115
1.0114
1.0113
V
time in seconds
x10-4
Envelope Curve Difference
U_g
x10-4
5
0
-5
V
time in seconds
x10-4
Envelope Comperator
U_out
1
0
-1
A/m
time in seconds
x10-4

Fig. 9