

# Advanced Timing Circuit for Magnetization of AMR Magnetometer

David Vala

VSB-TU Ostrava, 17. listopadu 15, Ostrava-Poruba, Czech Republic.  
[david.vala@vsb.cz](mailto:david.vala@vsb.cz)

**Abstract**—This contribution describes the invention of Magnetometer with protection against detection by electronic countermeasure (ECM) registered by Czech patent office as patent no. 305322.[1] Magnetic sensors are often part of dual use or security instruments and equipment. For this purpose, it is very interesting to build a sensor, which is hidden against electronic countermeasure. In this case, the level and behavior of electromagnetic noise produced by a sensor has become very important. Further, there has been a significant growth of the electromagnetic compatibility of electronic devices. As the consequence of this growth, there is a continuous process of making strict standards focused on the electromagnetic radiation of electronic devices. Sensors technology begins to be a part of these issues due to the increasing usage of sensors bandwidth and the approach to frequency of radio communication band. Nowadays, microcontrollers and similar digital circuits are integrated into sensors devices and it brings new sources of electromagnetic radiation in modern smart sensors.

**Index Terms**—Anisotropic Magnetoresistors; AMR; Magnetic Sensor; EMC, Weak Magnetic Field; Electronic Countermeasure; ECM.

## I. INTRODUCTION

Magnetometers using AMR (Anisotropic Magneto-Resistor) sensors are currently used in a wide variety of applications, particularly in the measurement of physical quantities intensity of the magnetic field, or in cases where another physical value is transferred to it. Most of these sensors are mainly used in industrial automation, automotive and consumer electronics and for a variety of purposes, ranging from sensors of weak magnetic fields that are intended for navigation through displacement sensors and angle sensors to current sensor with a large dynamic range. In all these areas, these sensors are applied because of its low cost, high degree of integration options and high-resolution measurement of magnetic field. The description of AMR technology may be found in several books, like the Magnetic sensors and magnetometers [2] or patents like US4847584A [3], US5247278 [4], US5521501 [5] or US5952825 [6] and in this paper, the description of this contribution will be focusing on the invention point of view only.

The materials used to make magneto-resistive sensor layer is based on its physical reasons to dispense with repeated magnetization sensor, especially when measuring weak magnetic fields, or in the case of large dynamic range of the sensor [7].

AMR sensor magnetization and its management are primarily designed for the function of the sensor element of

the sensor, disregarding its possible negative impacts on electromagnetic radiation sensor.

As the constantly increasing operating frequency of the sensor, there is a significant shift of the frequency of magnetization (orientation) pulses, thereby shortening their duration. This leads to a higher intensity current in the demagnetizing coils of the sensor, which are repeated at a higher frequency and consequently leading to higher radiation sensor, particularly at higher frequencies.

In some applications, it may be a magnetizing impulse or a source thereof, a source of undesirable interference, for example, from the perspective of self interference "passive" sensor. The actual sensor is due to the method of measuring the intensity of the magnetic field in its own phase measurements, which causes a complete "passive", in which the DC power supply does not emit any electromagnetic alternating fields. This situation is different from the sensor type "Fluxgate", where there is a periodic magnetization of the core sensor, which is based on the principle function of this type of sensor. When using the feedback, measurement of the magnetic field is generated in the sensor magnetic field, but it does not change if the external magnetic field is at its steady state. In this case, the coil that generates the compensation field supplied the "DC" current. However, in cases where it is necessary to perform periodic magnetization magneto-resistor, whilst its physical properties cannot be avoided, the positive and negative pulses need to be brought to the magnetization ("flip"), coils, hence resulting in the violation of the "passivity" sensor. This may adversely affect, or prevent the use of these sensors in some applications, where it is necessary to reduce their emission to a minimum.

The usual effective method in sensor technology is the electromagnetic shielding of the sensor. In addition to reducing the level of electromagnetic radiation from the sensor itself, it has a positive influence on the shielding of the sensor compared to the external undesired electromagnetic fields. This method, however, cannot be used with magnetic field sensors because their electromagnetic shielding (and due to shielding or alteration of the measured magnetic field) is in direct contradiction with the principles and requirements for the sensor.

The main trend in sensor technology is to maintain stable working conditions, including the work frequency. Although it has an advantage, it does not always mean a precondition for the correct function of the sensor. It is true that the simplicity of involvement and efforts to suppress interference sensor is one of the most direct ways to achieve good properties of the sensor. From this perspective, very often it involves the use of the fundamental harmonic signals, usually sinusoidal, of constant frequency, phase and

amplitude. Another very common sign used by the alarm sensors is a square wave signal with a constant period, phase, and amplitude and duty cycle. The disadvantage of such a signal is theoretically infinite number of harmonic frequencies, which produces such a signal.

## II. ANISOTROPIC MAGNETO-RESISTIVE SENSOR

Anisotropic Magneto-Resistive (AMR) sensors are fabricated with permalloy (NiFe) thin films that create changes in resistivity with respect to external magnetic fields [2]. These film materials are similar to magnetic recording tapes in that strong magnetic fields can disrupt the magnetic domains of the film particles from a smooth factory orientation to arbitrary directions. The accuracy and resolution of these sensors will suffer until the film magnetic domains are "reset" to recreate a uniform direction. In the application notes, AN-213 is a detailed description of the set and reset functions for AMR sensors including the reasons to perform this function, characteristics of set/reset components, and example of circuits showing the present state of the art in set/reset pulse generation.

AMR sensors are designed in Wheatstone bridge configurations, with four magneto-resistive elements that remain identical electrically when no external magnetic fields are applied. With linear-mode AMR sensors, the externally applied magnetic fields are to be limited in strength so as it does not disrupt the factory set magnetic domains of the permalloy thin-film elements. Figure 1 shows three examples of magnetic orientation of the film domain structure.

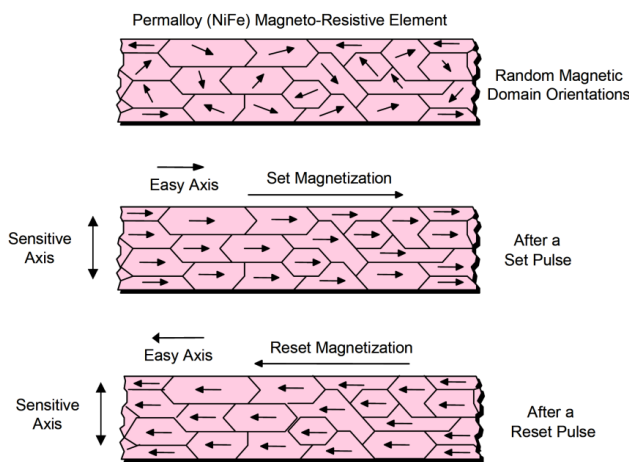


Figure 1: Domain orientation in permalloy magneto-resistive element [8]

The alignment of the magnetic domains is along the "easy" axis of the material. The "sensitive" axis is perpendicular to the direction of the easy axis and serves as the driving function of the magneto-resistive characteristic curve, shown in AN-213 [8]. When an external magnetic field has a vector component in the sensitive axis, the field rotates the magnetic moment creating a change in resistance. If the external magnetic fields are in the operational field range, the magnetic moments will return to their set or reset orientations after the field is removed. To put some numbers on the magnetic fields involved, typically a "set" or "reset" field requires about 4 mT or more to be applied to completely orient the magnetic domains.

## III. MAGNETIZATION PROCESS

The above description explained that providing pulses of electrical current creates the needed magnetic fields to realign the magnetic domains of the sensor resistive elements. Further, the rationale for performing these set and reset pulses has been justified. The following paragraphs shall show when and how to apply these pulsed currents, and circuits to implement them. The tempco math shows the importance of choosing appropriate strap voltages to create the correct strap currents. Further, both the resistances and the currents are variables to be dealt with. The direction of the strap currents also determines what is considered as a "set" or a "reset" pulse. Set pulses are defined as pulsed currents that enter the positive pin of the set/reset strap. Like-wise negative pulsed currents are considered as the reset pulses. Figure 2. shows a simplistic schematic of a set/reset circuit.

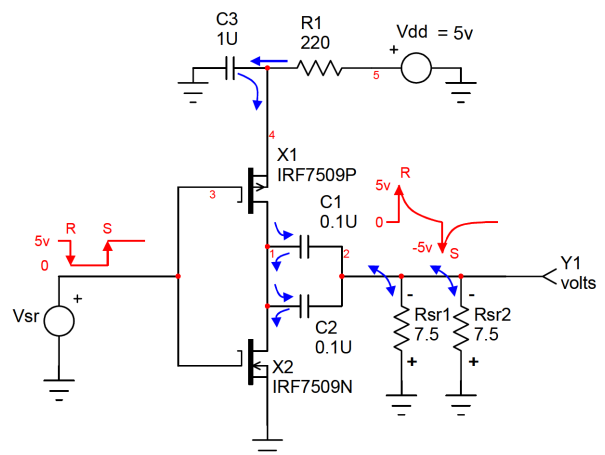


Figure 2: Simplified schematic of set/reset pulse [8]

These set and reset pulses are shown on Figure 2 as dampened exponential pulse waveforms because the most popular method of generating these relatively high current, short duration pulses is via a capacitive "charge and dump" type of circuit. Most electronics, especially in consumer battery powered devices, do not have the capability to supply these high current pulses from their existing power supply sources. Thus "Vsr" is actually a charged up capacitor that is suddenly switched across the set/reset strap. The value of this capacitor is usually a couple hundred nano-Farads to a few micro-Farads depending on the strap resistance to be driven. The decay of the exponential waveform will mostly be governed by a time constant ( $\tau$  or  $\text{Tau}$ ) that is, the capacitance in farads multiplied by the resistance, and it is measured in seconds.

## IV. ELECTRONIC COUNTERMEASURE

An electronic countermeasure (ECM) is an electrical or electronic device designed to trick or deceive radar, sonar or other detection systems, like infrared (IR) or lasers. It may be used both offensively and defensively to deny targeting information to an enemy. The system may make many separate targets appear to the enemy, or make the real target appear to disappear or move about randomly. It is used effectively to protect aircraft from guided missiles. Most air forces use ECM to protect their aircraft from being attacked. It has also been deployed by military ships and recently on

some advanced tanks to fool laser/IR guided missiles or changing magnetic signature of vehicle to fool anti-tank mines. It is frequently coupled with stealth advances so that the ECM systems have an easier job. Offensive ECM often takes the form of jamming. Defensive ECM includes using blip enhancement and jamming of missile terminal homers. This area is very wide and for more information, look for examples such as the International electronic countermeasures [9], Surveillance countermeasures [10], Electronic countermeasures [11] or scientific papers [12],[13],[14].

V. DESCRIPTION OF INVENTION

The above disadvantages of AMR magnetometer and derived sensors are suppressed in a manner, which is characterized in that the excitation of demagnetization AMR magnetoresistor is used to spread spectrum signals, especially Direct Spread spectrum signals.

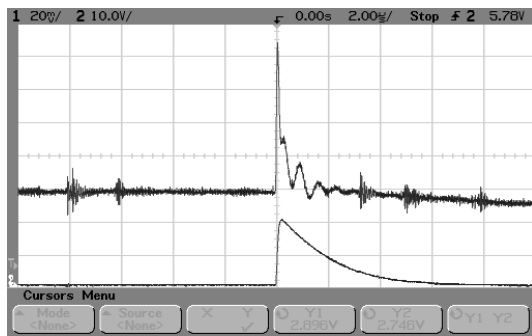


Figure 3: Crosstalk from conductors for generating of magnetization, the top signal - output module, the lower the voltage to the magnetisation coil

If the sensor is excited by a signal different from a constant, it is in most cases necessary that it was a harmonic signal with a constant period and phase. It is obvious that the creation of the excitation signal requires necessary attention of the limitations resulting from the physical nature of the sensor or of its structure and the materials selected. Additionally, it is necessary to adapt the evaluation part of the proposed sensor excitation signal. However, it should be done after an appropriate modifications connection and consideration of the properties of the sensor used for the excitation pseudo random signal (binary signal having characteristics similar to the noise. However, it is generated according to a fixed algorithm and composed of a repetitive sequence of zeros and ones. With a frequency spread spectrum, the amount of energy supplied to the magnetization of the sensor in the desired direction ( i.e. the size of the created magnetic field around the sensor element) must be preserved. Using this technique and ensuring that its progress unaltered from the perspective of one for each of the magnetization, the repetition of that event can be spread in time. This current pulse is necessary to ensure that the sensor occurs repeatedly at a time rather than occurring in a short time evident periodicity of the excitation signal. The optimal use of methods of direct spread spectrum i.e. switching time of current pulses to the magnetization (flipping) coil is used as the method of controlling the magnetization.

The main benefits of the new method of generating magnetization without a doubt is that it reduces the radiation sensor and the risk of undesirable tracing. A side benefit of

this method is related to the improvement of electromagnetic compatibility. If it is in the monitored area sensor that works with a normal demagnetization, it can be in its periodic pulses using known methods to detect or locate. If the sensor is used for excitation demagnetization spread spectrum, its detection is very difficult as it will appear only as a higher level of noise in a given frequency band, especially in the case where the driven-sequence, such as the case with classic techniques DSSS. If the same "secret" excitation sequence of sufficient length occurred, it is highly unlikely that the sensor has detected an unauthorized person. Among other benefits for AMR magnetometer controlled from the control unit are that the application of this technology has only modifications in the firmware magnetometer and it is not necessary to make extensive changes in electronics magnetometer.

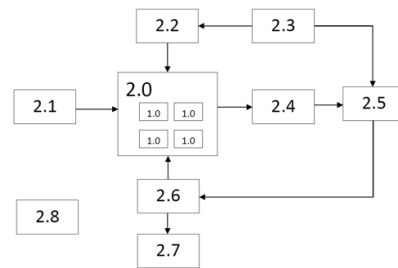


Figure 4: Schematic diagram of invention

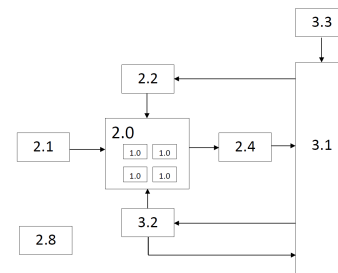


Figure 5: Schematic diagram of invention (with microcontroller)

Magnetometer, which allows the use of the above method is characterized by using a specific circuit for the formation of the aforementioned spread spectrum signal. Clock signals required to control the magnetization is formed by an electronic circuit generator or appropriate software in the control unit magnetometer. Individual variants of an electronic circuit for generating a clock signal magnetization AMR sensor varies according to the type of succession. If one is to use the DSSS technique, it is the most appropriate combination of implementation of combinational and sequential logic, which is implemented using a digital circuit or its equivalent (eg gate array). With sufficient computing power control unit one can implement DSSS technique and use the software of the control unit. The proposed device may also allow the user to change the control sequence, both in the version with control unit and the variant with an electronic circuit for generating a sequence, thus allowing it to specify a sequence regardless of the manufacturer magnetometer. Among other benefits for AMR magnetometer is that it is controlled by the control unit in which the application of this technology has only modifications in the firmware magnetometer and it is not necessary to make extensive changes in electronics magnetometer.



VI. MEASUREMENT AND REDUCTION OF SET RESET PULSE RADIATION

Each current pulse can produce wide spectrum of electromagnetic radiation. This radiation can disturb another devices or measurement itself, especially in multisensors application. For this reason, the author aimed to reduce this source of radiation because shielding of sensor is in direct conflict with the function of the sensor. A fusion of techniques from telecommunication technologies with sensor techniques reduced the radiation of AMR magnetic sensor at least of 3 dB in the worst case, but generally the radiation reduction is significantly higher.



Figure 6: Measured result DSSS OFF

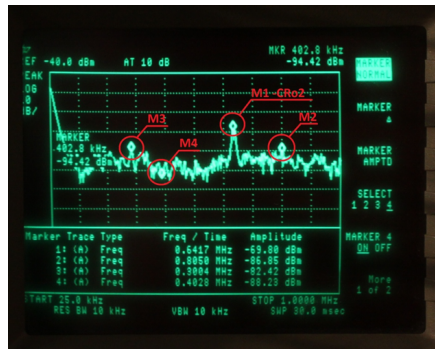


Figure 7: Measured result DSSS ON

Table 1  
Measured Peak for DSSS On and DSSS Off

Marker	DSSS off [dBm]	DSSS on [dBm]	Difference [dBm]
M2	-75.32	-86.86	11.54
M3	-75.96	-82.42	6.46
M4	-80.28	-88.23	7.95

VII. CONCLUSION

In this paper, we described the approach to significantly reduce electromagnetic radiation of AMR magnetoresistor that can be applicable in several areas, including the wide variety of weak magnetic field sensors for industrial [15,16,17], security application as well as for cooperating with global position system[18,19] in different area of usage and finally dual use products. Additionally, this technique is possible to be used when classic designed magnetometer has difficulty to pass EMC test during certification. This technique has also been described in detail in the application of the invention on Czech Industrial property office under the number E193142 from 30<sup>th</sup> of January 2014, which is now recognised publicly as Czech patent [1]. The future

work is now aimed on improving the spreading sequencer to obtain maximum efficiency of hiding and reducing radiated field.

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