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DATA TRANSFER PROCEDURES FOR A 24-BIT ADC AND AN APPLICATION FOR MAGNETIC ANOMALY MEASUREMENTS

ABSTRACT

In an experimental study, manual collection of data taken by some sensors is tedious and it requires man power in most of the cases. This causes loss of time and work. If the amount of data is significantly high, then it is better to transfer them to a computer automatically. The data collected from the sensors are analog in nature. Therefore, before the transmission, they have to be digitized by analog-to-digital converter. In this case, the resolution of the digitized value is important. In this work, the process of using the AD7714 for 24-bit conversion and the use of parallel port for transfer of digital data obtained are explained in detail. As an application, the data obtained by UGN3503 Radiometric Linear Hall Sensor is digitized by 8-bit, 12-bit and 24-bit ADCs and the results are compared. The effect of resolution on the digital data is observed.
Keywords: Sensor, Resolution, Parallel Port, Analog Digital Converter

24 BİT ADC İÇİN VERİ GÖNDERME PROSEDÜRLERİ VE MANYETİK ANOMALİ ÖLÇÜMLERİ İÇİN BİR UYGULAMA

ÖZET

Bir deneysel çalışmada sensör ya da sensörlerden gelen verilerin çok sayıda olması durumunda verilerin elle alınması uzun zaman ve işgücü kaybına sebep olmaktadır. Bu durumda verilerin deney sırasında otomatik olarak bilgisayara aktarılması önem kazanmaktadır. Bunun için analog verinin öncelikle yüksek çözünlükle dijital veriye dönüştürülmesi gerekmektedir. Bu durumda dijital verinin çözünürlüğü önem kazanmaktadır. Bu çalışmada, AD7714 entegresiyle 24 bit çözünürlükte dijital veri oluşturma prosedürleri ve oluşturulan dijital verinin paralel port üzerinden bilgisayar ortamına aktarımı hususunda ayrıntılı olarak bilgi verilecektir. Bir uygulama olarak UGN3503 lineer Hall etkili sensör ile alınan veriler 8-bit, 12-bit ve 24-bit ADC'lerle dijital verilere dönüştürülmüş ve sonuçlar karşılaştırılmıştır. Dijital veri çözünürlüğünün etkisi gösterilmiştir.
Anahtar Kelimeler: Sensör, Çözünürlük, Paralel Port, Analog Digital Dönüştürücü

1. INTRODUCTION (GİRİŞ)

Electronically processed quantities such as temperature, velocity, weight, voice, image, ect. obtained by the related sensors (e.g., thermo-couples, opto-couplers, strain gauges, microphones, cameras, ect.) are in the form of analog electrical signals. These signals are converted to digital form by use of analog-to-digital converters. There are several types of ADCs such as successive approximation type, pipeline type and delta-sigma type [1 and 3]. A sigma-delta type ADC has higher resolution than the others [4 and 6].

The Delta-Sigma converters are preferred because of the facts that they have high resolution, high speed and low power requirement. Furthermore, they are produced as a digital circuit. This gives them some capabilities such that their performances are not affected by temperature and time, their outputs are always linear, they don't need an external sample-and-hold circuit, their filter requirements are low and their base noise is independent [7 and 10].

If a wide-band sensor data has to be collected, then the use of a delta-sigma ADC is a good choice since it prevents the negative effect of undesired high frequency components on digitization and reduces the conversion error [11 and 13]. Because of the need to convert a wide-band data, a delta-sigma converter performing a conversion at a rate of 50kS/s and a resolution of 24-bit is used and the digital data obtained are transferred in real-time to a computer through a parallel port. The process of conversion and transfer to the computer through parallel port are described in detail in this work. In addition, a comparison analysis to see the effect of resolution is made by using 8-bit,12-bit and 24-bit ADCs.

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

In the experimental studies with analog data transfer, using high resolution (24 bit) ADC like AD7714 provides almost exactly the analog data to convert to the digital data. However, data reading process is not easy to similar ADCs. Therefore, this study is important to demonstrate A/D conversion process of AD7714, to transfer digital data to the computer via the parallel port and to show the importance of the transferring data in high resolution.

3. A/D CONVERSION PROCESS (A/D DÖNÜŞTÜRME İŞLEMİ)

In order to read an analog sensor voltage at a resolution of 24-bit by a delta-sigma ADC (AD7714) as used in this work, first of all, the registers given below have to be set. There are eight registers as in the following:

- Communications Register
- Mode Register
- Filter High Register
- Filter Low Register
- Test Register
- Zero-Scale Calibration Register
- Full-Scale Calibration Register
- Data Register

Now, setting of each register will be explained.

3.1. Communications Register (İletişim Kaydı)

To set the Communications register, an 8-bit data is sent to the DIN pin of the integrated circuit. The most significant bit is chosen as logical zero for write operations. The other three significant bits is used to select the register. Third significant bit is for Read/Write operation. It is 0 for write and 1 for read operation. The last three bit locations are used to determine from which channel the analog data is read. Table 1 shows clearly the bits of the communications register. The register selection of the ADC by the three RS bits is shown in Table 2.

Table 1. Communications register
(Tablo 1. İletişim kaydı)

Bit	7	6	5	4	3	2	1	0
	$0/\overline{DRDY}$	RS2	RS1	RS0	$R/\overline{W}$	CH2	CH1	CH0

Table 2. Register selection of ADC
(Tablo 2. ADC'nin kayıt seçimi)

RS2, RS1, RS0			Register	Size
0	0	0	Communications Register	8 Bits
0	0	1	Mode Register	8 Bits
0	1	0	Filter High Register	8 Bits
0	1	1	Filter Low Register	8 Bits
1	0	0	Test Register	8 Bits
1	0	1	Data Register	24 Bits
1	1	0	Zero-Scale Calibration Register	24 Bits
1	1	1	Full-Scale Calibration Register	24 Bits

Table 3. Channel selection of ADC
(Tablo 3. ADC'nin kanal seçimi)

CH2, CH1, CH0			Operations
0	1	0	AIN3, resistance, measuring current I_M
0	1	1	AIN4, resistance, measuring voltage U_x
1	0	0	AIN1/AN2, DC voltage/current
1	1	0	AIN5, AC voltage/current

When the 8-bit digital data is entered through the DIN pin of the ADC to set the communications register, the related register becomes ready for setting. As seen in Table II, the required number of bits is entered through DIN pin to complete the setting of that register. Each time a register setting is required to be updated, the communications register must be reset again.

3.2. Mode Register (Mod Kaydı)

Mode register (RS2-RS0=0,0,1); Power On/Reset Status: 00 Hex. The Mode Register is an eight bit register from which data can either be read or to which data can be written. Table 4 outlines the bit designations for the Mode Register.

Table 4. Mode Register
(Tablo 4. Mod Kaydı)

Bit	7	6	5	4	3	2	1	0
	MD2	MD1	MD0	G2	G1	G0	BO	FSYNC

When setting the Mode register for operation, BO (Burnout Current) and FSYNC (Filter Synchronization) bits are made 0. Thus, the calibration mode and gain selection have been defined. There are 8 different calibration modes and 8 different gain settings for the Mode register. These are shown in Table 5 and Table 6.

Table 5. Calibration modes
(Tablo 5. Kalibrasyon modu)

MD2, MD1, MD0			Calibration Modes
0	0	0	Normal Mode(default)
0	0	1	Self-Calibration
0	1	0	Zero-Scale System Calibration
0	1	1	Full-Scale System Calibration
1	0	0	System Offset Calibration
1	0	1	Background Calibration
1	1	0	Zero-Scale Self-Calibration
1	1	1	Full-Scale Self-Calibration

Table 6. Gain setting
(Tablo 6. Kazanç ayarı)

G2, G1, G0			Gain Setting
0	0	0	1
0	0	1	2
0	1	0	4
0	1	1	8
1	0	0	16
1	0	1	32
1	1	0	64
1	1	1	128

Channel selection in the Communications register and the gain setting in the Mode register are determined based on the analog data to be measured. The analog data can be AC or DC current or voltage. Table 7 shows the selections.

Table 7. Applicable channels of the ADC
(Tablo 7. ADC'nin uygulanabilir kanalları)

Measurement Mode	ADC Inputs	ADC Input Voltage	CH	Gain
DC voltage/current	AIN1	2.5 V±1.25V	100	1
	AN2	2.5 V±1.25V		
AC voltage/current	AIN5	0…….2.5 V	110	1, 2[1]
	AN6	COM(0V)		

[1]Use gain=1 for crest factor $\leq$4; use gain= 2 for crest factor up to 8 and half the RMS range

3.3. Filter High Register (Yüksek Filtre Kaydı)

The Filter High Register is selected by RS2-RS0=0, 1, 0 of the Communications Register. The content of the Filter High Register for A Versions is shown in Table 8.

Table 8. Filter high register
(Tablo 8. Yüksek filtre kaydı)

Bit	7	6	5	4	3	2	1	0
	$\overline{B}$/U	WL	BST	ZERO	FS11	FS10	FS9	FS8

The MSB of the Filter High Register, that is $\overline{B}$/U, determines whether the operation is bipolar or unipolar. For standard DC measurements, this bit must be Logic-0 (bipolar). If the measurement is a standard AC or or if someone wants to measure a resistance, this bit must be 1. 6^{th} bit of the Filter High Register (WL) determines whether the A/D conversion is 16-bit or 24-bit. A 0 in this bit selects 16-bit word length when reading from the data register (i.e., *DRDY* returns high after 16 serial clock cycles in the read operation). This is the default (Power-On or RESET) status of this bit. A 1 in this bit selects 24-bit word length.

BST (5^{th} bit), Zero (4^{th} bit) bits always are set to 0.

Filter Selection is done with 12 bits of data.. The on-chip digital filter provides a $Sinc^3$ (or $(Sinx/x)^3$) filter response. The 12 bits of data programmed into these bits determine the filter cut-off frequency, the position of the first notch of the filter and the data rate for the part. In association with the gain selection, it also determines the output noise (and hence the effective resolution) of the device. In reset condition of the ADC, the value of the Filter High Register is 01 Hex.

3.4. Filter Low Register (Alçak Filtre Kaydı)

The Filter High Register is selected by RS2-RS0=0, 1, 1 of the Communications Register. The content of the Filter High Register for all versions is shown in Table 9.

Table 9. Filter low register
(Tablo 9. Alçak filtre kaydı)

Bit	7	6	5	4	3	2	1	0
	FS7	FS6	FS5	FS4	FS3	FS2	FS1	FS0

Filter selection is done by the Filter Low Register. The 8 bits of the 12 bits of data necessary for the filter selection of the ADC is done by the Filter Low Register. The value of the Filter Low Register at reset condition of the ADC is 40 Hex (binary 0100 0000). Filter selection determines the time between two 24-bit digital data produced at the DOUT pin of the ADC. In addition, this time interval is dependent on the frequency of the crystal oscillator connected to the CLKIN pin of the IC and the gain selection.

3.5. Test Register (Test Kaydı)

The Test Register is selected by RS2-RS0=1, 0, 0 of the Communications Register. The value of the Test Register at the reset condition is 00Hex. It is advised not to set this value afterwards.

3.6. Zero-Scale/Full-Scale Calibration Registers (Sıfır skala/Tam skala Kalibrasyon Kaydı)

The AD7714 contains three zero-scale calibration registers, labeled Zero-Scale Calibration Register 0 to Zero Scale Calibration Register 2. The Zero-Scale/Full-Scale Calibration Registers are selected by RS2-RS0=1, 1, 0 and RS2-RS0=1, 1, 1 of the Communications Register. The three registers are totally independent of each other such that in fully differential mode there is a zero-scale register for each of the input channels. Each of these registers is a 24-bit read/write register and, when writing to the registers, 24 bits must be written; otherwise no data will be transferred to the register. The register is used in conjunction with the associated full-scale calibration register to form a register pair. These register pairs are associated with input channel pairs as outlined in Table 3.

When the IC is reset, the Zero-scale calibration register becomes 1F4000 Hex, the Full-scale register becomes 5761AB Hex. During writing the registers, it should be noted that they are 24 bits. Otherwise, the data cannot be transferred to the registers. Normally, the reset values of these registers are not changed.

3.7. Data Register (Veri Kaydı)

The Data Register is selected by RS2-RS0 = 1, 0, 1 and by setting 3rd bit to 1 of the Communications Register. When the DRDY pin of the IC becomes 0, the 24-bit data is ready at the DOUT output and whenever it is wanted, the data can be read by starting the reading loop and transferred to the computer.

4. READING AND WRITING CYCLES (OKUMA VE YAZMA DÖNGÜSÜ)

The serial interface of AD7714 can be controlled by the pins $\overline{CS}$, SCLK, DIN, DOUT and $\overline{DRDY}$. The DIN pin is used for transferring the data to the registers of the ADC. The DOUT pin is used as the output for 24-bit data stored in the Data Register. SCLK is used as a serial clock needed for data transfer from DIN and DOUT pins of the IC. $\overline{DRDY}$ gives an information whether the Data Register already contains the 24-bit data or not. If there is no data, this pin is logic-1, otherwise it is logic-0. $\overline{CS}$ pin is the chip select pin of the IC and allows the analog data to enter.

In order to program the registers of the IC, the 8- or 24-bit data has to be entered from the DIN pin and written into the register. The write cycle is shown in Fig.1.

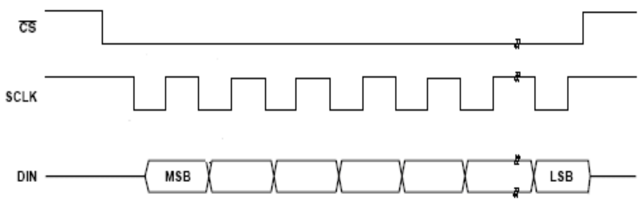


Figure 1. Write cycle timing diagram (POL=1)
(Şekil 1. Yazma döngü diyagramı)

The 24-bit data which is ready in the Data Register can be taken from the DOUT pin. The read cycle for reading serial data from the DOUT is as shown in Fig.2.

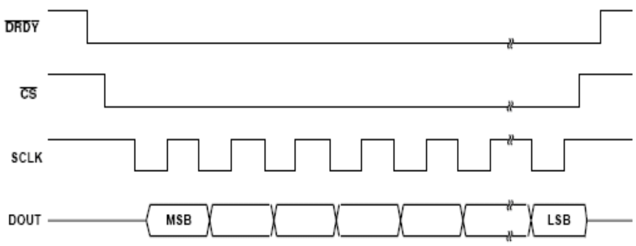


Figure 2. Read cycle timing diagram (POL=1)
(Şekil 2. Okuma döngü diyagramı)

4. DATA TRANSFER WITH PARALLEL PORT (PARALEL PORT İLE VERİ TRANSFERİ)

As it is known that there are three different interfaces for data transfer for a computer such as USB ports, Serial ports and Parallel ports. In this work, the registers of the AD7714 are programmed through a parallel port of the computer (Fig.3).

For controlling the serial interface pins of the IC, it is advised that an optical isolator has to be used between the pins of the IC and the parallel port of the computer. The reason for it is that any short-circuit could cause damage to both the IC and the computer. As seen from Fig.3, data entrance is done by the first four pins of the data port, while the data output is achieved by the 12th and 13th pins of the status port. After programming registers, when the value of the $\overline{DRDY}$ pin falls down from logic-1 to logic-0, the data at DOUT pin is transferred to the computer through the 13th pin of the status port.

In this work, the flow chart that is shown in Fig.4 explains the conversion process of an analog data to a digital data by the AD7714. It clearly gives how the appropriate registers are programmed and controlled.

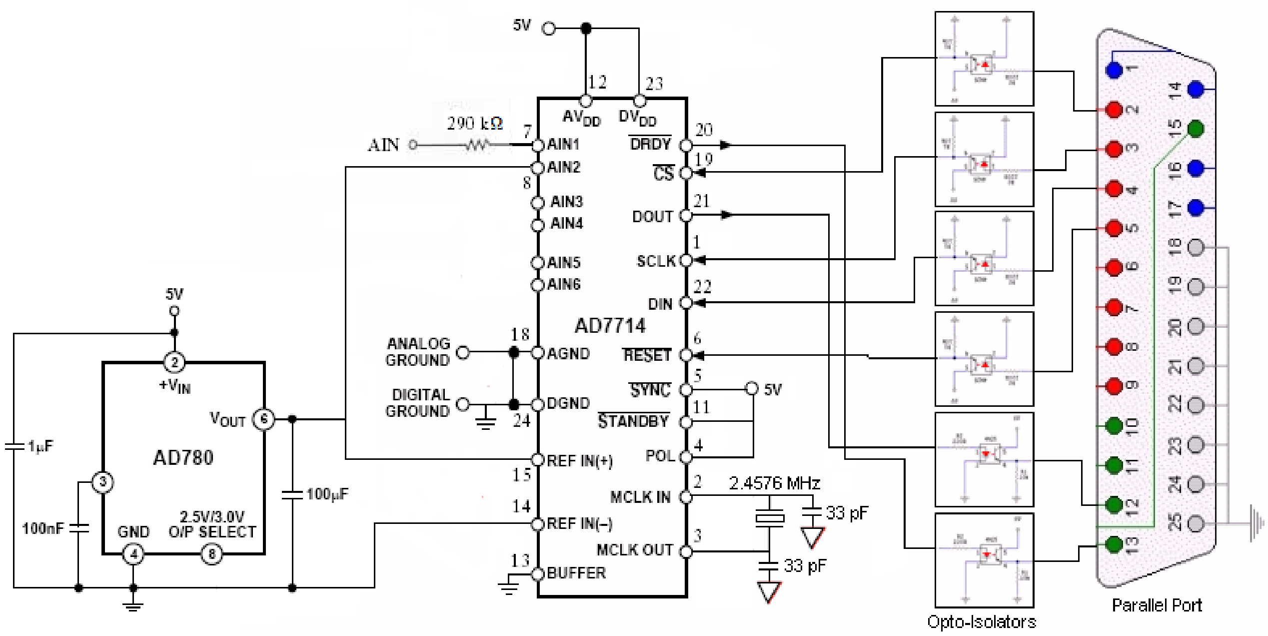


Figure 3. Data transfer from parallel port
(Şekil 3. Paralel porttan veri transferi)

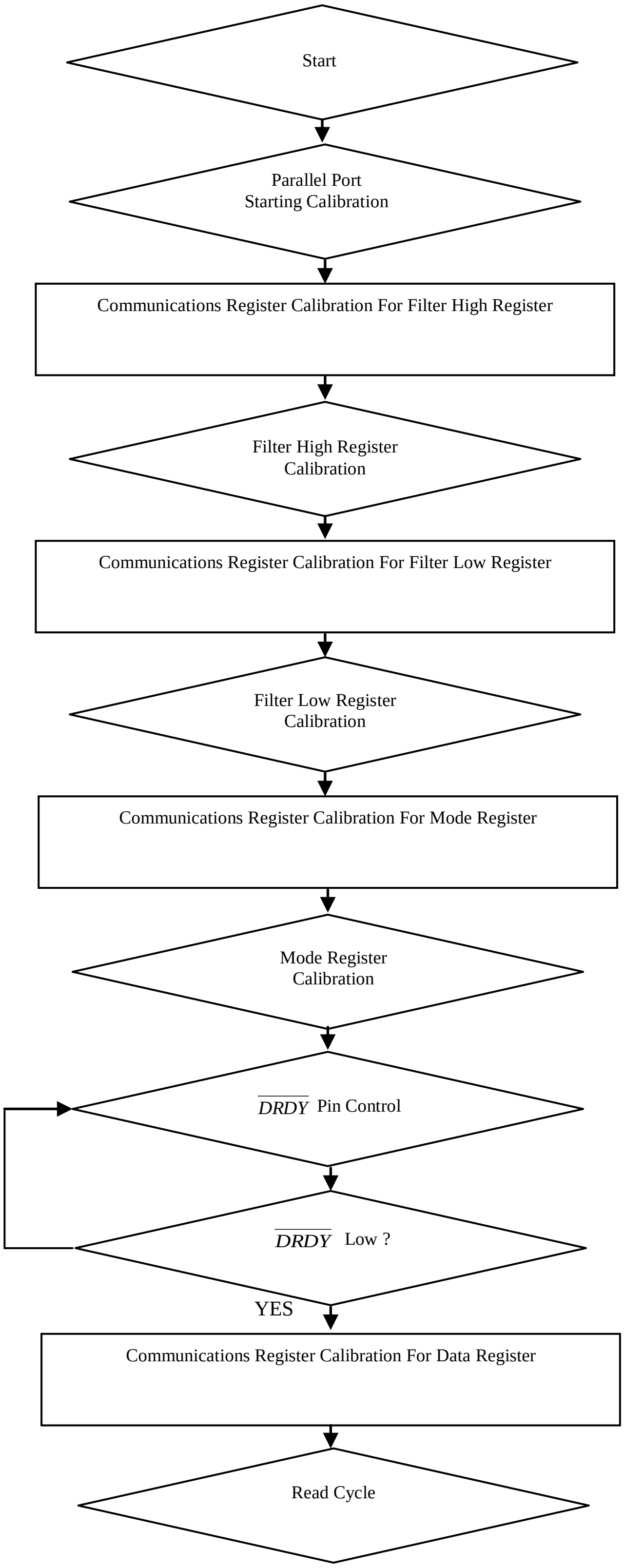


Figure 4. Flowchart for setting up and reading from the AD7714
(Şekil 4. AD7714'ten okuma ve ayar için akış diyagramı)

Figure 5. Programming interface for setting up and reading from the AD7714
(Şekil 5.AD7714'ten okuma ve ayar için arabirim programı)

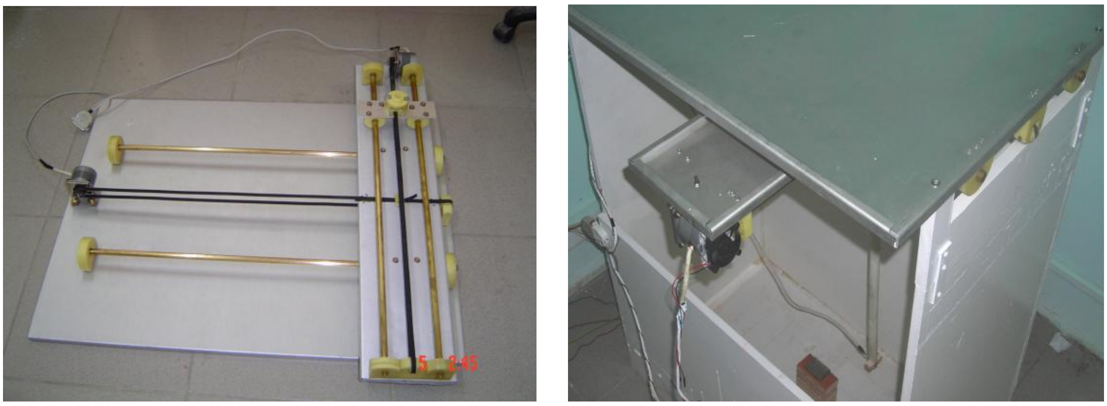
As seen in Fig.5, first of all parallel port calibration is done before the registers are programmed. Hence, the data and status ports are reset. When the program is run, only the Calibration button is active. This facilitates the usage of the program by any user who is unfamiliar to the Program. In the next steps of the program, the command buttons from top to down become active one by one. After pressing each of the buttons, a message appears on the screen. Table 10 depicts the operations after pressing the command buttons.

Table 10. Operations after each command button
(Tablo 10. Herbir komut butonundan sonra yapılanlar)

Button	IC pin controlled	Data sent (Hex)	Data sent (Binary)
AD7714 Reset Calibration	Reset pin	3 B	00000011 00001011
Filter high Register Calibration	DIN pin	24 4F	00100100 01001111
Filter low Register Calibration	DIN pin	34 A0	00110111 10100000
Mode Register Calibration	DIN pin	14 20	00010100 00100000
Poll DRDY Pin Control	DRDY pin	-	-
Data Register Calibration	DIN pin	5C	01011100
Read from Data Register	DOUT pin	-	-

5. AN EXPERIMENTAL STUDY ON THE DATA TRANSFER OF THE RESOLUTION (VERİ TRANSFER ÇÖZÜNÜRLÜĞÜ ÜZERİNE BİR DENEYSEL ÇALIŞMA)

To determine the resolution on the data transfer, first of all a scanner that can scan in two dimensions is developed. A UGN3503 Ratio-metric Linear Hall Sensor is mounted on the moving arm of the scanner. A 20×20 cm^2 scanning area is selected. A permanent magnet with dimensions of 5.5×4 cm^2 is located at the center of the scanning area. The distance between the sensor and the magnet is adjusted as 8 cm. Fig.6 illustrates the scanner. The Finite Element Method (FEM) is used to draw the magnetic flux behavior of the permanent magnet (Fig.7).



(a) (b)

Figure 6. (a) The scanner system, (b) Measurement system
(Şekil 6. (a)Tarayıcı sistem, (b)Ölçüm sistemi)

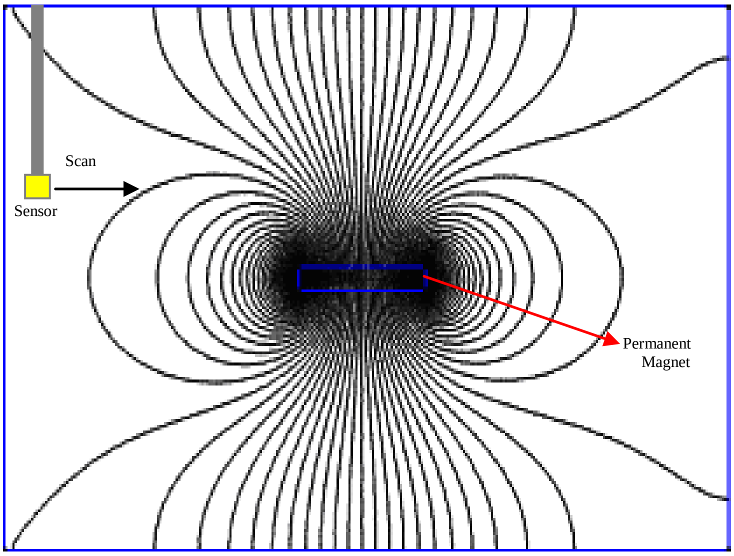
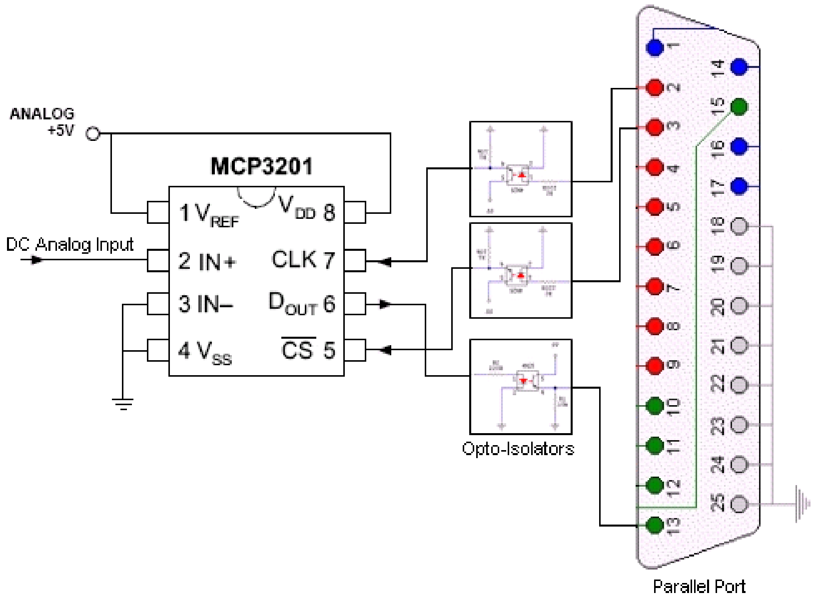
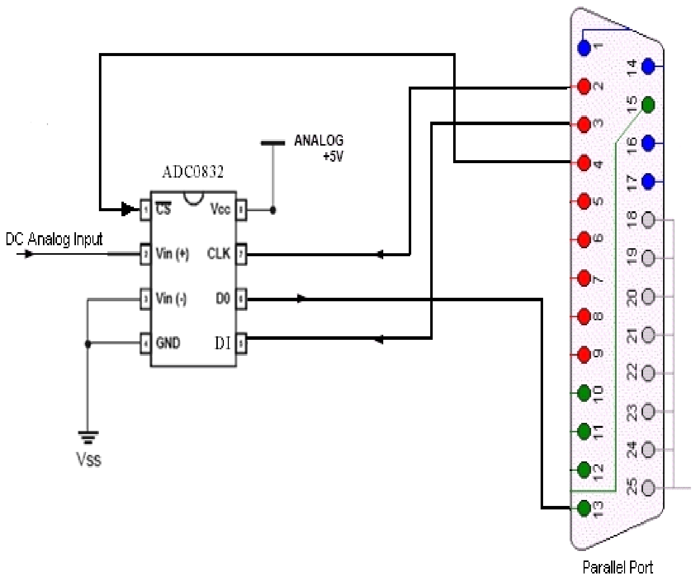


Figure 7. Magnetic flux variation at the sensor scanning axis
(Şekil 7.Sensörün tarama ekseninde manyetik akı değişimi)

As seen from Fig.7 that since the magnetic field strength of the magnet is not the same at every location inside the scanning area, the Hall sensor produces various voltages while scanning the area. In the experiments, three different resolutions are used to convert the analog data into digital data. The ADCs used in the work are the ADC0832 for 8-bit resolution, MCP3201 for 12-bit resolution and AD7714 for 24-bit resolution. The control circuits for the ADC0832 and MCP3201 IC’s are given in 8.



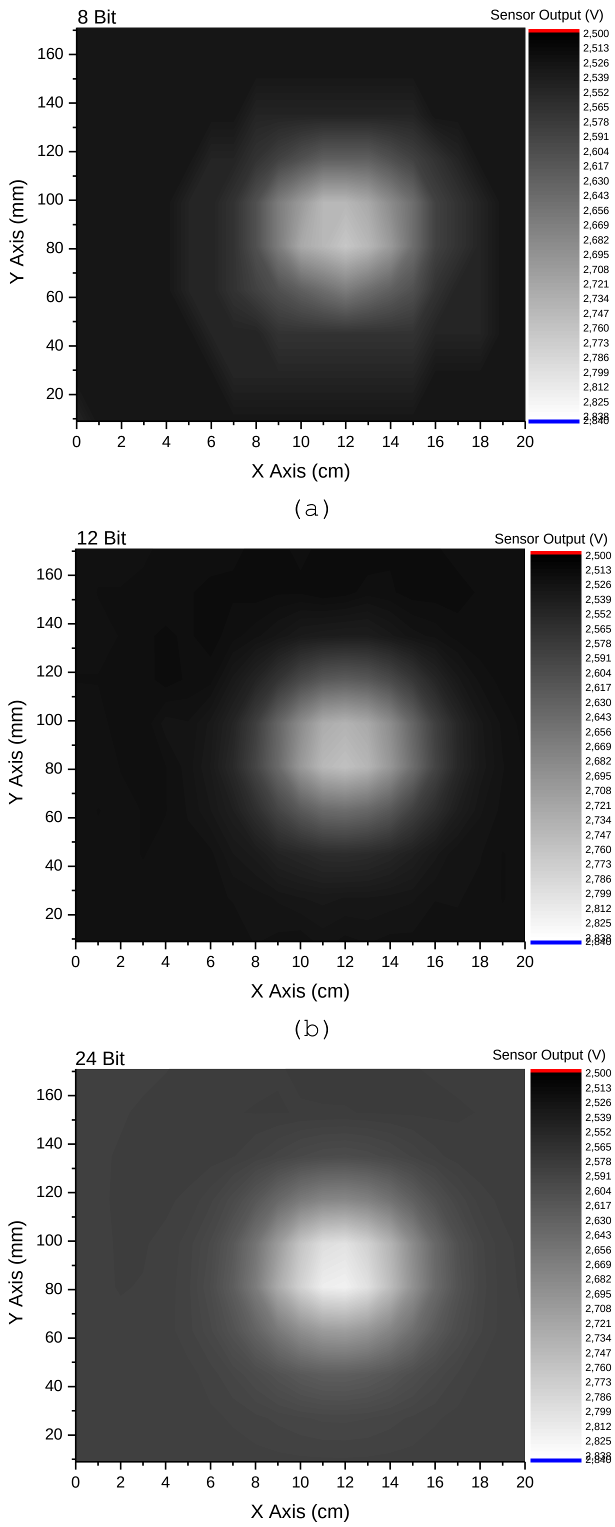
(a)



(b)

Figure 8. The control circuits for the ADC0832 and MCP3201
(Şekil 8. ADC0832 ve MCP3201 için kontrol devreleri)

The scanning is a computer controlled operation. During the scanning operation, the sensor output is electronically connected to the DC analog input at the control circuit. Thus, at each step of 1 cm, sensor output voltage is transferred to the computer as 8-bit, 12-bit and 24-bit resolutions. The data collected are plotted at the same scale as graphics and they are compared to each other (Fig.9).



(c)

Figure 9. The sensor voltages versus scanning area for different resolutions
(Şekil 9. Farklı çözünürlükte tarama alanına göre sensör voltajları)

It can be noticed that although the measured areas are the same for each of the resolutions of the sensors, they appear as if different. The reason for it is that as the resolution increases, the sensor can sense small variations in the magnetic field. This is obvious in the graphics depicted in Fig.9. With an ADC having 8-bit resolution can give the voltage levels about 19.5 mV, and an ADC having 12-bit resolution can give the voltage levels about 12 mV. But an ADC having 24-bit resolution can give the voltage levels about 30 nV. This level of measurement is very useful in works such as mine detections and MFL (Magnetic Flux Leakage) [14 and 20]. Fig.10 illustrates the effects of three different resolutions when the height of the sensor is y=45 mm and it is moved along the x-axis. As seen, as the resolution increases, the variation approaches the actual shape.

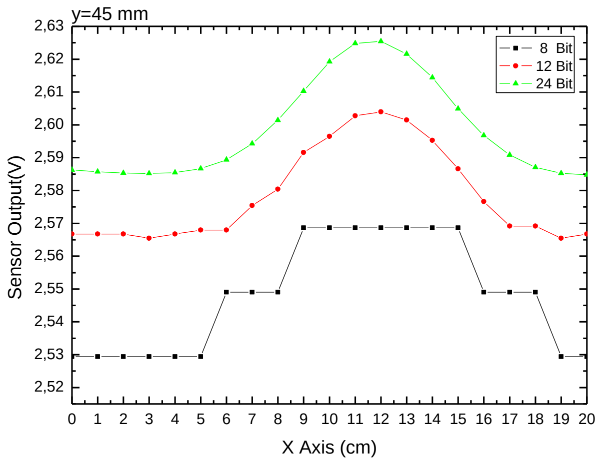


Figure 10. The sensor output voltage variations for different resolutions along the x-axis.
(Şekil 10. X ekseni boyunca farklı çözünürlükler için sensör çıkış voltajı değişimi)

6. CONCLUSION AND RECOMMENDATIONS (SONUÇ VE ÖNERİLER)

In this work, the procedures necessary for the conversion of an analog data to a 24-bit digital data by means of an AD7714 delta-sigma analog-to-digital converter are realized and explained in detail. The conversion process is controlled by the parallel port of a computer. The effect of resolution on the data acquisition is determined. The higher the resolution, the closer the digitized data to the original information can be obtained. Therefore, in applications where accuracy is important, it is better to use high resolution ADCs. This is very important some industrial applications such as robotic arms and CNC systems. When transferring an AC signal to the computer, the frequency of it has to be noticed. The sampling period of the IC may not be sufficient to sample it. Also the optical isolator should not be forgotten between the parallel port of the computer and the ADC. When the level of the sensor output voltage is in mV, it is better to amplify it before conversion.

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