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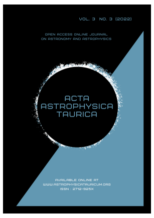

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Control system of the solar spectrophotometer of the Solar Tower Telescope-2 at the Crimean Astrophysical Observatory

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ABSTRACT

The paper describes the control system of the spectrophotometer scanner at STT-2. The device is intended for observations of the Sun in the near infrared region (in the vicinity of the He I 10830 Å spectral line). We provide a description of the mechanical assemblies, electronic units, and software of the system. All the units were manufactured at the Laboratory of Solar Physics of CrAO.

Key words: control system, modernization, solar scanner

1 Introduction

In recent years, the observations of the Sun have mainly been focused on high-spatial-resolution observations and on the studies of upper layers of the solar atmosphere – the chromosphere and the corona. All the explosive events are predominantly started in these layers where the reconnection of magnetic loops presumably takes place. For the chromospheric studies, certain chromospheric spectral lines are used. These lines are not numerous in the visible and near infrared ranges. Many instruments use a well-studied He I 10830 Å triplet line. The spectral line is exclusively sensitive to the magnetic field and is often used to probe the magnetic field in the chromospheric structures such as prominences, active region magnetic field loops, and faculae. In the weak magnetic field of coronal holes, the depth of the spectral line diminishes as compared to the quiet-Sun regions. This property of the He I 10830 Å triplet allows one to observe the coronal holes from the Earth: other coronal lines are usually formed in ultraviolet and do not penetrate through the Earth's atmosphere.

In the second half of the 1980s, a solar spectrophotometer was installed at the Solar Tower Telescope-2 (STT-2) of the Crimean Astrophysical Observatory (Bukach et al., 1990). The instrument made it possible to observe the Sun in He I 10830 Å spectral line and was intended for the studies of chromospheric structures and coronal holes. The data acquired by STT-2 during more than two solar cycles allow one to analyze the evolution of coronal holes, their latitudinal distribution, the processes of coronal hole formation and their relation to other solar structures. The scientific program is worth continuing in order to extend the data on the current solar cycle. At the same time, the units of the instrument are getting old and worn out due to mechanical deterioration and obsolescence.

In the late 1990s, the STT-2 spectrophotometer was upgraded (Stepanyan et al., 2000). The device was based on a long-focus slit spectrograph. A photoelectron multiplier sensitive to visible and infrared ranges was used as a detector. The upgrade was related to the way the Sun image shifted through the spectrograph slit. In the original version, the shift of the image was performed by large flat coelostat mirrors. As a result, a mechanical wear of the telescope gear wheels and backlash appeared rapidly. These issues were addressed by introducing a new scanner system: the image of the Sun was shifted by tilting the light and small primary mirror. Two three-phase stepper motors were used to drive the tilting mechanism of the mirror.

The stepper motors had excessive electric power consumption for the application and low efficiency. As a result, the motors emitted a lot of heat and produced convective flows. The motors were placed below the primary mirror, and the convective flows could degrade the quality of solar images. We decided to replace the motors with less powerful ones. We chose commercial two-phase 42HM40-0404 motors with a standard NEMA-17 flange. The power consumption of the new motors is an order of magnitude less than that of previous motors, although the torque moment was kept the same. In addition, the new motors do not heat up due to high efficiency. As a consequence, we had to develop new electronic units to drive the motors and to create a new control software.

2 Electronic units of the device

One of the main units of the spectrophotometer is the system for scanning the Sun image by the spectrograph slit. This unit

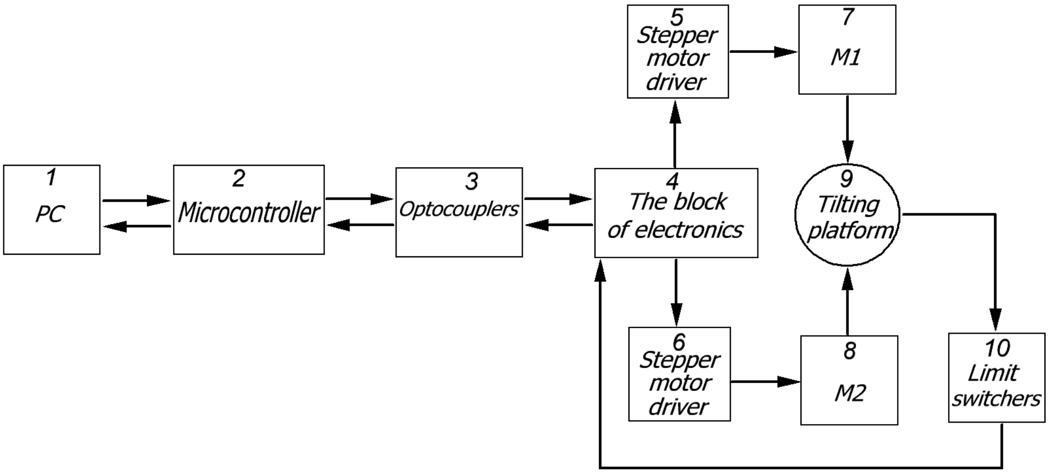

Fig. 1. A block diagram of the scanner control unit.

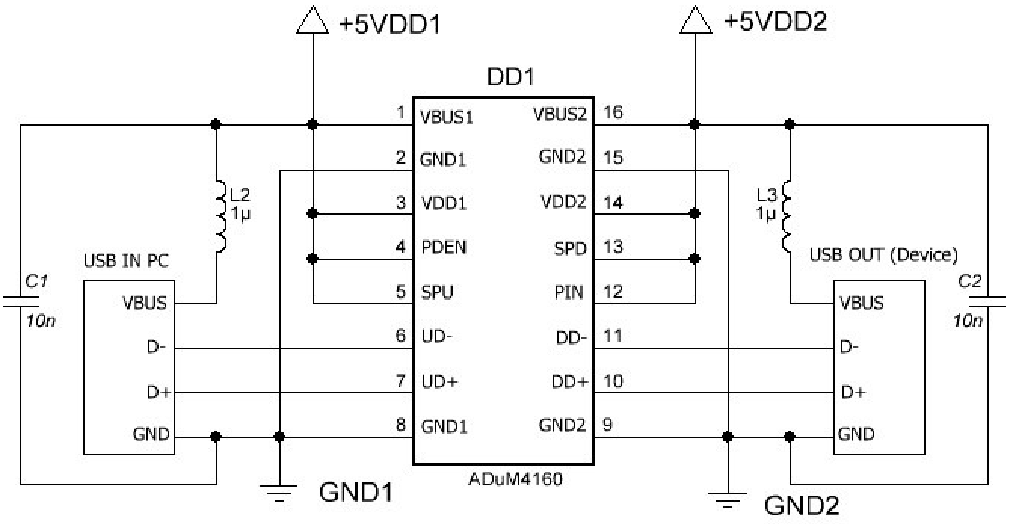

Fig. 2. A schematic diagram of the digital isolator of the universal serial bus.

will hereafter be referred to as a scanner. A block diagram of the scanner control unit is shown in Fig. 1. Below we examine the interaction between the blocks (the numbers of the blocks in Fig. 1 are listed in parentheses).

A personal computer (PC, block 1) controls the scanner unit through a universal serial bus (USB). The bus is galvanically isolated using the ADUM4160 USB digital isolator (the schematic diagram is shown in Fig. 2). The control unit of the scanner (block 2) was built on the 32-bit STM32F103RBT microcontroller by ST Microelectronics. The CPU frequency of the microcontroller is 72 MHz. It has a number of peripheral devices on board, including a 16-channel 12-bit analog-to-digital converter and a USB interface. The microcontroller provides control impulses according to the PC commands and interrogates limit switches. The microcontroller also interfaces a block (not shown) that measures the signal level of the photoelectron multiplier. The control unit also moves a carriage with the photoelectron multiplier inside the spectrograph. In such a way the change of the wavelength of the spectrophotometer takes place.

The stepper motor drivers are located at a large distance from the control unit. This is the reason why we added an optogalvanic isolation between the control unit and the stepper motor drivers (block 3, Fig. 3). The decision allowed us to decrease the interference between the modules and to protect the electronics. Connector XS1 in Fig. 3 is connected to the control unit. “Step α”, “step δ”, and the direction of the stepper motor rotation logical levels are passed through the connector XS1 to logical inverters DD6 (block 3) that control the optocouplers DD7-DD9. The signals are further passed to block 4 through the connector XS2. The limit switches control the optocouplers DD1-DD4 through the connector XS2 and logical inverters DD5. The optocouplers drive corresponding inputs of the microcontroller through the connector XS1.

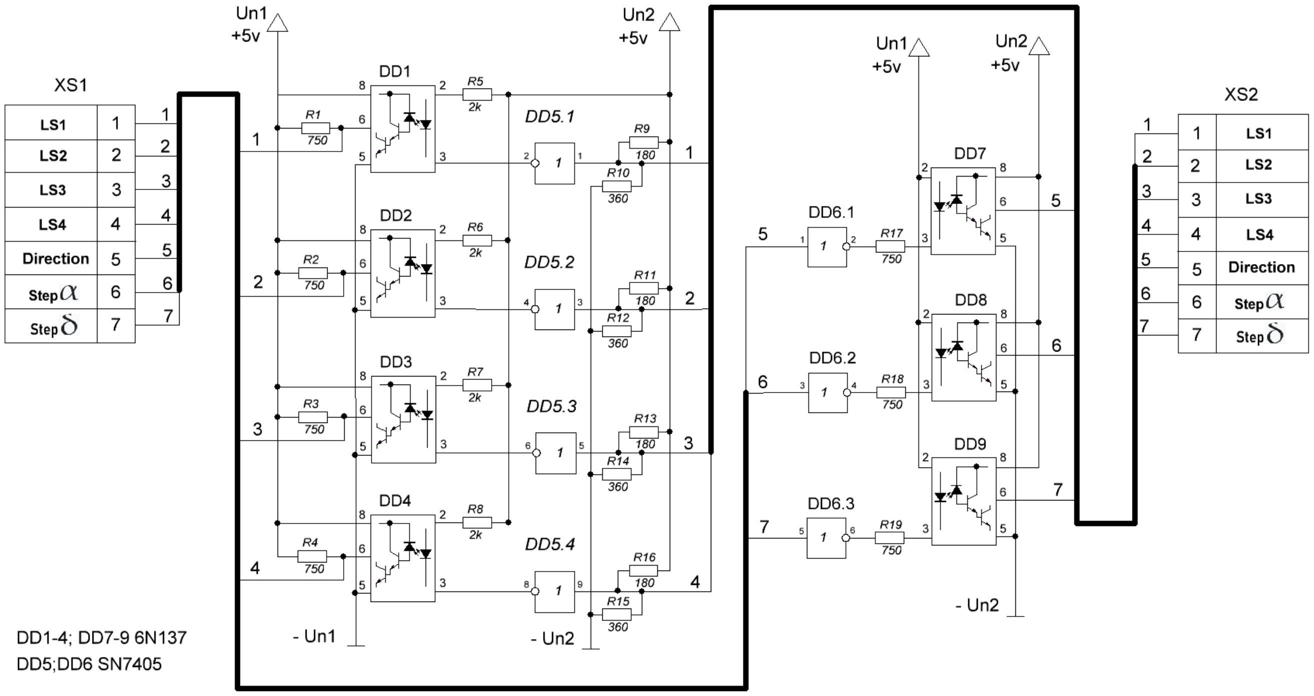

Fig. 3. A schematic diagram of the block of optoisolators.

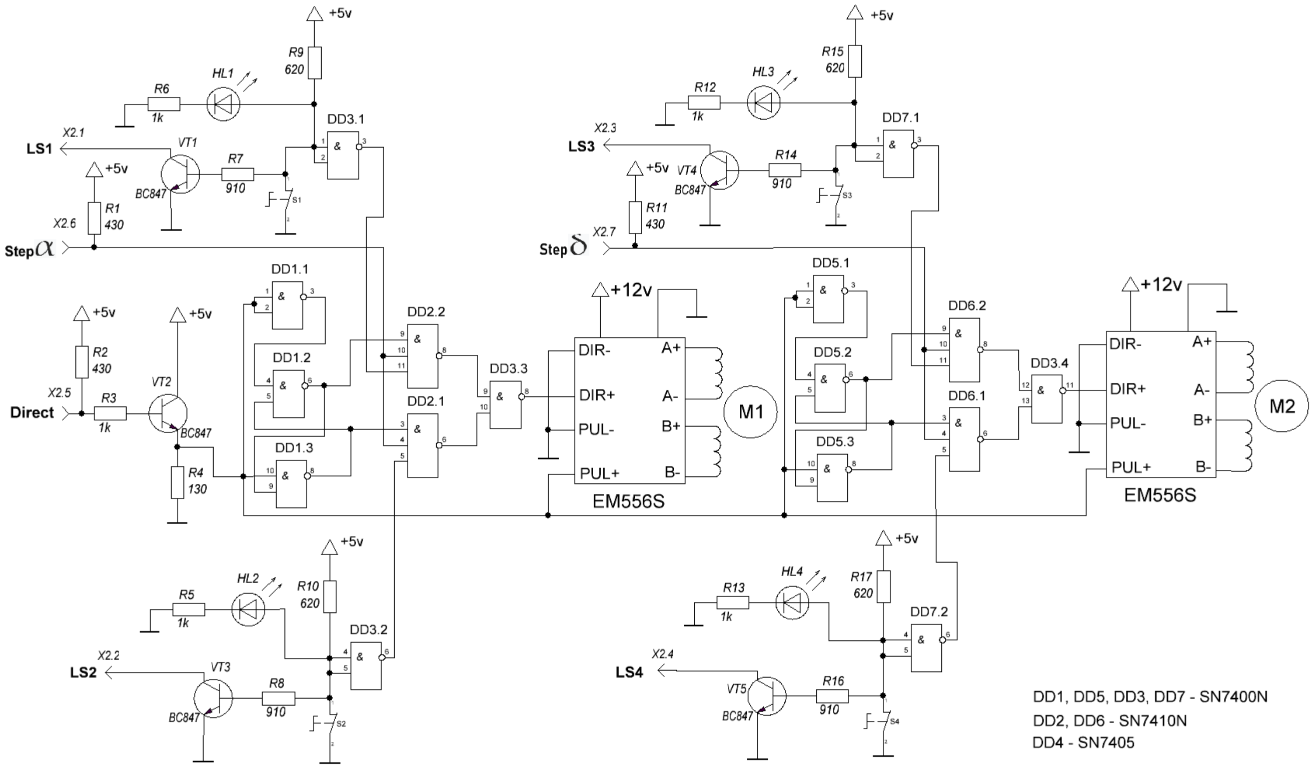

Fig. 4. A schematic diagram of the block of electronics.

Block 4 referred to as the “block of electronics” is installed between the control unit and the stepper motor drivers. The main function of this block is to exclude fault operations of the drivers if some firmware malfunction occurs. The schematic diagram of this block is shown in Fig. 4. Block 4 distributes the control signal to stepper motor drivers of right ascension α and declination δ and prevents a signal pass if the corresponding limit switch was activated (block 10). The activation of limit switches is controlled by the PC through blocks 3 and 2. The block of electronics is a two-channel flip-flop with the common line of rotation direction. The block also has limit switches state detectors. Let us examine one of these detectors – channel α. A signal from the connector XS2.5 (direction of the rotation) comes through the transistor VT2 to the input PUL+ of the motor driver EM556S and to the inverter DD1.1 and the flip-flop DD1.2-DD1.3. The output of the flip-flop is connected to the inputs of logical AND-NOT elements DD2.1 and DD2.2. The “step α” line as well as limit switches state signal come to another input of logical AND-NOT. The direction signal passes through DD3.3 to the DIR+ input of the driver EM556S that drives motor M1.

The next block are stepper motor drivers (block 5 and 6). We have used commercial EM556S drivers by Leadshine. The drivers have optoisolated control inputs STEP/DIR/ENABLE and the microstep resolution between 1:1 and 1:256. Drivers decrease the electrical current through the motors by 90% after 0.4 s idle time. This property minimizes the heat dissipation of the motors. The drivers are based on signal processors providing the most effective control of the current flowing through the winding of the motors. In comparison to cheaper drivers, EM556S exhibited a very stable functioning and more smooth rotation of the motors. The motors are denoted as M1 and M2 in Fig. 1.

The technical specifications of the motors 42HM40-0404 (block 7 and 8) are as follows: the step angle is 0.9°, and the torque moment is 0.34 N·m. The change of the tilt of the primary mirror is $0.49''$ per one step of the motor as compared to $0.82''$ per step with the previous stepper motor. Hence, we succeeded in increasing the spatial resolution and smoothness during scanning.

3 Mechanical units of the device

We developed and produced new mechanical units in order to install the 42HM40-0404 stepper motor into the mechanical parts of the scanner.

4 The software

A new software under Windows 10 was developed to control the spectrophotometer. Since the hardware is connected via a standard USB interface, we can use any PC to control the device.

In addition to the control of the scanner, the software interrogates the current-to-voltage converter fed by the photoelectron multiplier. The software also controls the position of the detector carriage. This function allows us to draw the spectral profiles and to set the detector into a certain part of the spectrum.

An entrance slit isolates a single pixel at the solar surface. In order to get a map of the solar disk, we have to scan the entire image of the Sun taking into account current coordinates of the slit. The scanner has no absolute referencing of the solar disk. As a reference point we use the central position of a tilting platform with the primary mirror. The controller counts the number of steps required to tilt the platform from one extreme position to another (as determined by limit switches activation). Then the stepper motor makes half of these steps in the opposite direction. The procedure is repeated for every axis. In that way the platform is set into some middle position that is further assumed as a reference. The observer’s task at this step is to set the image of the Sun at the center of the spectrograph slit by coelostat tilting.

At the next step the scanning of the solar image is performed. The size of the acquired map is determined by the observer. The scanning is performed by a serpentine-like trajectory: the scanner shifts the solar image in right ascension α from limb to limb, i.e. in a direction perpendicular to the slit. Then, the image is shifted in the declination δ by a single step and moves again in right ascension from limb to limb, although in the opposite direction. Such a trajectory does not allow us to waste time during observations. On the other hand, a backlash exists inevitably during movements in opposite directions. As a result, adjacent columns in the acquired solar maps become shifted with respect to each other. Fortunately, this effect can be removed easily during data processing: adjacent columns in the maps are shifted to fit a circumference in the best way. In the final maps, heliographic coordinates are calculated using the information on limb positions and the inclination angle between the solar axis, the Earth’s axis, and the tilt of the coelostat mirrors. The whole procedure will be described in detail in our forthcoming paper.

In order to decrease the time needed to acquire the solar disk map, the scanner trajectory fits a circle rather than a square. The time consumption was decreased by about 40%. After the scanning completes, the tilting platform returns to the reference position.

The measurement of the photoelectron multiplier output occurs synchronously to the shift of the solar image. The time constant of the current-to-voltage converter was set to 1 ms, which is approximately three times less than the interval between stepper motor steps. Since Windows 10 is not a real time system, all the time delays are determined by the microcontroller. The microcontroller calculates the number of steps and tracks the current scanner position as well. The software in real time images the current maps of the Sun. This feature makes it possible to evaluate the quality of the map and to restart the observations if needed. Note that this option was absent in the previous version of the scanner.

The software makes solar maps with a size from 211×211 to 701×701 pixels. The time needed to acquire the full-disk map is 15 minutes for the smallest map and 40 minutes for the largest map. The map is stored as a FITS file. The date and time of observations, the size of the map, as well as some other information are stored in the header of the file.

5 Conclusions

The modernization of the spectrophotometer allowed us to improve the quality of the full-disk solar images in

He I 10830 Å and to decrease the time needed for observations. These data can be used to pose new tasks on the studies of the solar chromosphere. The replacement of the stepper motors in the scanner decreased the heating in the vicinity of the primary mirror. The minimal tilt step of the primary mirror was also decreased by a factor of 1.5 allowing us to increase the spatial resolution of the acquired solar maps.

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