Four Channel Active Antenna Switch for UHF Band Satellite Reception

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***Abstract*—The aim of this work is to design and implement a complex electronic device, known as an antenna switch, that allows to receive a high-frequency satellite signals in the UHF band via one of five connected antennas at a given time. This device is capable of automatic antenna switching according to non-geostationary satellite position, from which signal is received, thus with suitable antenna selection, is alternative to motorized directional antennas. The device consists of outdoor and indoor unit and Human-Machine interface (HMI). The outdoor unit is driven by a microcontroller which collect diagnostic data about proper function and controls the RF switch. The outdoor unit amplifies the UHF signal too. indoor unit with power inserter, diplexer and USB to serial converter, allows diagnostic data and commands transfer between outdoor unit and users computer with Human-Machine interface.**

***Index Terms*—Antenna switch, RF switch, RF circuit, satellite, UHF, outdoor unit, indoor unit, signal reception**

I. Introduction

In recent decades, there has been and is still a rapid development of wireless communication. Its possibilities of use are enormous. A cascade of electronic devices that enable wireless communication is very long, but among its most basic building blocks, we can include an antenna, without which a signal would not be possible to transmit and to receive and antenna switch. Antenna switch enables flexibility of choice of connected antennas or even choice whether the antenna will be used for transmitting or receiving. This functionality is for example used in smartphones with Wi-Fi and Bluetooth connectivity for which is only one common antenna used, which greatly simplifies miniaturization of the device.

In case of this work, an antenna switch is designed, that it will enable signal receiving from small satellites that are on non-geostationary orbit. This means, that the satellite is moving relative to the reception point. In order to maintain good reception of the weak signal from small satellite, whose orbit is usually in 350 – 700 km altitude [1] and maximum transmission power is 30 dBm [2], directional antennas are necessary.

Motorization of the directional antenna enables to follow the movement of satellite so that main lobe of the directional antenna is heading to the signal source, thus the biggest gain is achieved. Another way of satellite position following is gradual switching of antennas. Antennas have to be carefully oriented, so that in certain time, signal is received by antenna, whose main lobe orientation corresponds to current satellite position so that the biggest gain is ensured. The main focus of this work is the design and implementation of such automatic antenna switch, which enables preamplification of the received signal and enables diagnostic data of the device collection.

II. Device requirements

The frequency of the received signal was chosen to be 435 MHz, as it corresponds to the amateur frequencies used to communicate with CubeSats [3]. Another requirement for the device is diagnostic data about working state collection, so that user can be warned if some error, such as RF amplifier failure or low power voltage, occurs. The next requirement is to design the device in such way, that by assembling some components, second variant of the device arises and by connection of these two variants, switching of both polarizations, horizontal and vertical, can be performed. This requirement should lead to lower expenses of manufacturing, because only one printed circuit board (PCB) is needed and the number of components is minimized.

III. Conceptual design

The device itself have to be divided to two parts: external unit and internal unit. The external unit will be placed near to the antennas and its purpose is as follows:

- Preamplification of the received signal
- Signal filtration
- Signal from antennas switching
- Signal diplexing
- Diagnostic data collection and transmission
- Ensuring a stable power supply
- Command reception

The internal units purpose is:

- Diagnostic data reception and command transmission
- Power insertion
- Signal diplexing

The simplified diagram of the resulting device is depicted in Fig. 1. As diagnostic data, current to RF amplifiers, which carries information about their proper function, phantom power voltage, vital for powering the whole outdoor unit, temperature and azimuth of the outdoor unit, should be measured.

For power savings, the power supply for each RF amplifier should be switchable, as their current draw is usually high.

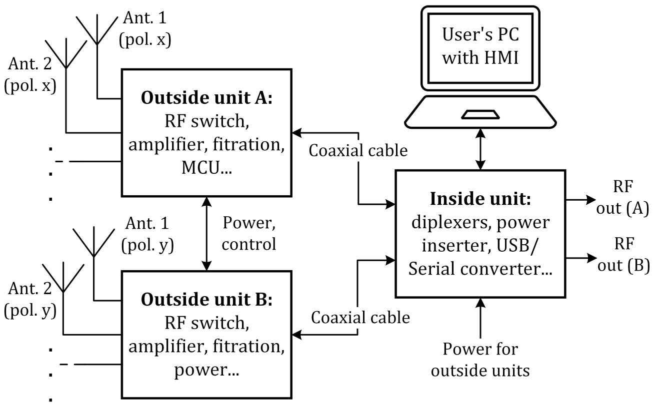

Fig. 1. Simplified diagram of designed device.

IV. Circuit design and component selection

A. RF switch

Because the heart of this device is the switching element itself, it is necessary to pay great attention on its selection. It can affect the device behavior and the quality of RF signal. There are three main options when selecting the RF switch: mechanical RF relay, MEMS RF switch and semiconductor RF switch. Each of them has its own advantages and disadvantages.

The integrated semiconductor RF switches are very easy to use and require small number of components to work. They offer small insertion losses, fast switching times and high range of switchable frequencies. The ease of use, good qualities of the integrated semiconductor RF switches and great selection, led to choosing of this type of RF switch to be used in designed device.

From the range of integrated RF switch on the market, AS195-306LF [4] from Skyworks was chosen. The main criteria for this selection were the capability of switching up to five channels (ST5P configuration), 5 V control voltage and possibility of manual soldering and that all while maintaining the lowest insertion loss. The main specifications of AS195-306LF as well as other possible integrated RF switches, which meet the requirements are in Table I.

TABLE I
RF switches which meet the requirements[a]

RF Switch	Max. Insertion loss [dB]	Max. Switched power [dBm]	Freq. Range [GHz]	SMD Package
AS195-306LF	**0.5**	**27.0**	**0.1 – 2.0**	**QFN-16**
ADRF5250	1.3	33.0	0.1 – 6.0	QFN-24
HMC252AQS24E	0.8	29.8	DC – 3.0	SOP-24
SKY13415-485LF	0.4	37.5	0.1 – 3.8	QFN-14
F2915	0.93	37.0	0.05 – 5.0	QFN-24

[a]Values taken from [4] [5] [6] [7] [8], at frequencies close to 435 MHz.

B. Other components

As the microcontroller for the outdoor unit, ATmega328PB [9] was selected because of the simplicity of use and vast user base which leads to big amount of available information. ATmega328PB has I2C and UART peripherals needed for communication between sensors and indoor unit as well as 10 bit A/D converter which is needed for diagnostic data collection.

MCP9808 [10] digital temperature sensor is used for measuring temperature of the surroundings of outdoor unit and outdoor unit itself. This sensor communicates with microcontroller via I2C. Module of digital compass [11] with HMC5883L integrated circuit is used for antenna orientation evaluating, and it communicates with microcontroller via I2C too. The main purpose of this sensor is the antenna's azimuth detection after it is installed so that the right order of switching is achieved. It is also used to detect displacement of the antenna.

The communication between outdoor unit and indoor unit needs to be at least half duplex and must be feasible on one line, thus can be diplexed with RF signal to one coaxial cable so that the installation of the outdoor unit is as convenient and easy as possible. LIN (Local Interconnect Network) bus is well suited for this. In this application only physical layer is used and classical serial protocol with 9600 baud speed is used. The transmitting and receiving on the physical layer are ensured by TJA1020 LIN transceiver integrated circuit [12].

Integrated circuit INA1802A was chosen for measurement of current to RF amplifiers. It is integrated differential amplifier and its amplification is 50 [13]. For phantom voltage stabilization was selected LM2940 low-dropout voltage regulator because it is capable to supply current up to 1 A. Its output voltage is 5 V and it can regulate input voltages in range from about 6 V to 28 V [14]. With that in mind the range of supply voltage was selected from 7 V to 12 V. The higher limit was set to maintain the power losses on the voltage regulator low so that it would not overheat.

C. Circuit design

The input part of the RF circuit and the RF amplifier with stabilisation circuit was taken from [4] and was adjusted for this circuit design (see Fig. 2). Antennas can be connected to the outdoor unit via SMA connectors. The input part which is resonant circuit used as input band pass filter, is used for filtering other close signals in this 435 – 438 MHz frequency band [15]. PGA103+ was chosen as the low noise RF amplifier (LNA). Its typical gain is 22.1 dB (@400 MHz) and typical noise figure is 0.5 dB (@400 MHz). Its supply voltage is 5 V and typical current consumption is 97 mA [4]. All the high frequency traces on final PCB needed to be done by microstrips, which ensures the impedance of 50 Ω.

Power switching for each LNA is provided by a SSM3J355R unipolar P-MOSFET transistor. The power is switched in high-side configuration, so the unexpected behaviour of ungrounded LNA is prevented. That is why the P type of MOSFET is used. It also means, that the powering of

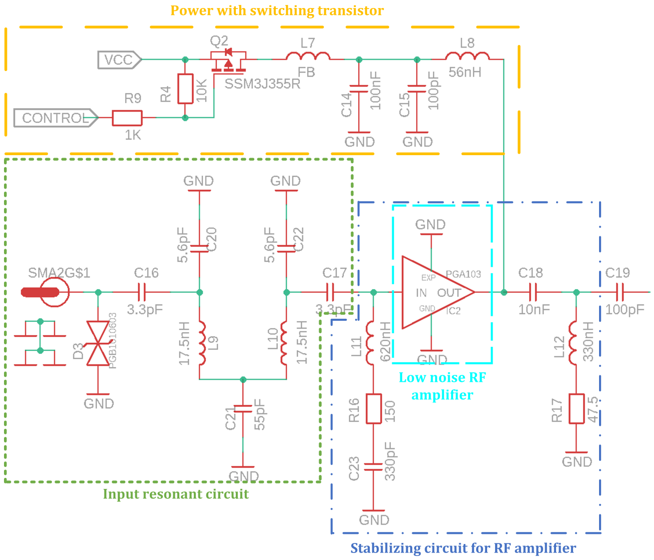

Fig. 2. Input part with resonant circuit and the low noise amplifier.

the LNA has to be driven from the microcontroller by negative logic. The voltage from the drain of the unipolar transistor is also used as driving voltage of the RF switch AS195-306LF, so the LNA and corresponding input of the RF switch are switched at the same time by one control signal from the microcontroller.

After the RF switch there is surface acoustic wave filter (SAW), which ensures filtering of only narrow band of frequencies. To ensure the lowest noise figure (NF) of antenna switch circuit, there is another LNA after SAW filter. By adding this second amplifier the noise figure at the output of internal unit drops from 1.72 dB to 1.04 dB.

To combine received RF signal and LIN communication, there is a diplexer at the output so that one coaxial cable can be used to route the signals to the indoor unit. There is also possibility to diplex GPS signal from active GPS antenna and to separate the phantom power.

To measure the current to LNAs, the INA180A2 is used as mentioned above. The amplified differential voltage is created on sensing resistors through which the current flows. There are used two 1 Ω resistors in parallel to ensure small voltage drop so that the power voltage at the LNAs is not highly affected by it, even when high current is drawn.

The phantom voltage is measured using a resistive divider, so the voltage is in safe range for microcontrollers A/D converter, which should use an internal 1.1 V voltage reference [9]. This ensures that the measured voltage is not dependent on the potentially volatile power voltage of the microcontroller so that the measurements are accurate.

D. Possible assembling variants

As was written above, the circuit was devised so that two variants (variant A and variant B) of assembly of designed PCB are possible. By connecting these two variants via pin header or ribbon cable, device which is capable of switching signals from five antennas in both polarization (horizontal and vertical polarization of one antenna simultaneously) arises.

While variant A includes microcontroller wiring and its purpose is the switching control and communication with internal unit, the B variant ensures regulating the incoming phantom powering and it adds feature of connecting active GPS antenna and diplex its signal into one coaxial cable together with RF signal from antennas. The variant A can be independent unit and for its working only external powering is needed. The resulting PCB design can be seen in Fig. 3.

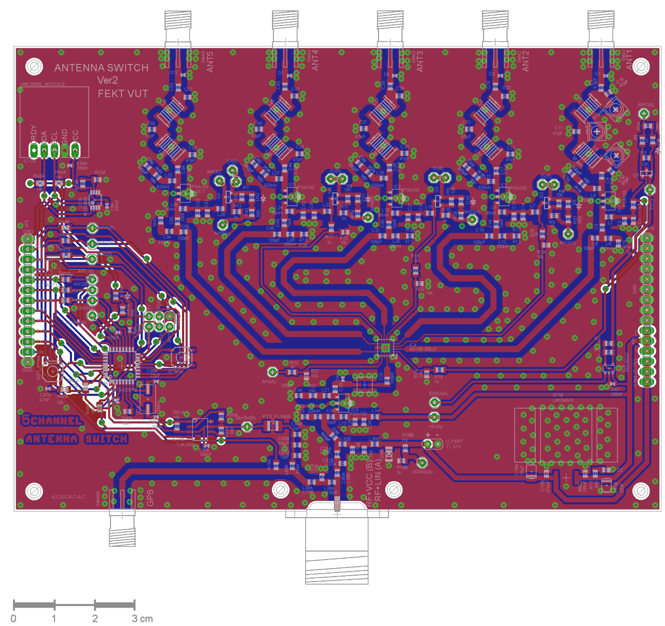

Fig. 3. Designed custom PCB for outdoor unit.

E. Indoor unit

The main purpose of the indoor unit is to split the diplexed signals from the outdoor unit. There are two RF inputs, for A and B variant of the outdoor unit. On one input there is diplexer which splits LIN communication and the RF signal coming from the outdoor unit assembled as variant A. On the second input there is diplexer splitting incoming RF signal and GPS signal from the variant B. There is also connected the phantom power inserter to this part of the indoor unit. Separated RF signals are fed to the SMA connectors so that software defined radio (SDR) receiver can be connected.

Command from the HMI running on the user's computer and diagnostic data from the outdoor unit are exchanged throughout USB/Serial converter, which is present on the indoor unit. Integrated circuit MCP2200 [16] was used for this and to connect to physical layer of LIN bus, TJA1020 is used in the same way as on the outdoor unit.

V. Human-Machine Interface: Control Application for User's Computer

To enable easy interfacing with basic settings of the antenna switch and viewing the diagnostic data, application for user's computer was written in Python programming language. The screenshot of antenna switch control application is depicted in Fig. 4.

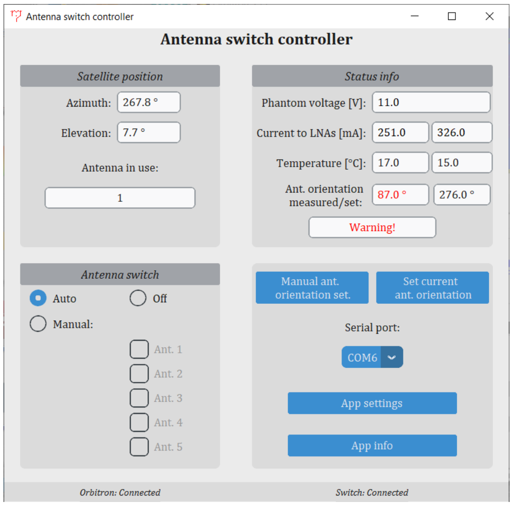

Fig. 4. Screenshot of created antenna switch control app.

The application communicates with the outdoor unit via the USB connected to indoor unit with USB/Serial converter and LIN transceiver. User can choose between manual antenna switching, when the user selects the switched-on antennas by clicking on buttons and auto switching, when the antennas are switched according to satellite position.

To ensure switching of the antennas according to selected satellite, data about its current position must be available. For this reason, Orbitron, satellite position prediction software [17], is used. By connecting to its DDE server, data about selected satellite are passed to the application and corresponding antennas are selected automatically.

The created application also displays received diagnostic data and notifies the user, when they are not in normal working range. Diagnostic data are also saved to file when an error occurs.

VI. Conclusion

This article presents the design and implementation of a device that enables the switching of high-frequency signals from satellites received by five antennas and provides their pre-amplification using LNAs and it provides filtration of the signal too. The device also allows for simple diagnostics by measuring the current drawn by the LNAs, the phantom power supply voltage, and the temperature of the device. Control and data transfer are ensured via the physical layer of the LIN communication bus.

Furthermore, the indoor unit, which consists of a diplexer with a USB/UART converter, was designed, which split the incoming high-frequency signal from the switch. It also serves to supply the phantom power to the switch and allows communication between the switch and the user's computer.

Suitable components (microcontroller ATmega328PB, temperature sensor MCP9808, differential amplifier INA180A2, LDO regulator LM2940...) were selected for the device with regard to the requirements. Great attention was paid to the selection of the switching element itself. After a thorough study of the high-frequency switch issue, the integrated circuit AS195-306LF from Skyworks was chosen.

The circuit diagrams of the outdoor unit and indoor unit were designed in Autodesk Eagle, where printed circuit boards (PCBs) were designed too. The outdoor unit consists of two combined circuits for switching vertical and horizontal polarization of the received signal. This combination allowed for the design of a single PCB for both variants. The variant can be selected when assembling components. By connecting these two variants together, a fully functional device arises. This, among other things, reduces production costs.

By the time of submission of this paper, indoor and outdoor unit PCBs has been manufactured and partly assembled. Now it is worked on the tuning of input resonant circuit for highest gain and the lowest noise figure and on firmware for the microcontroller of outdoor unit. Both of the activities are expected to be finished very soon.

For user control, a simple application for the computer was created. It enables automatic switching according to satellite position as well as manual selection of switched-on antennas and it displays the incoming diagnostic data from outdoor unit.

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