Wide Band Spectrum Monitoring System from 30MHz to 1800MHz with limited Size, Weight and Power Consumption by MRC-100 Satellite

Yasir Ahmed Idris Humad and Levente Dudás

Abstract—**Today, the usage of radio frequencies is steadily increasing based on the continuous development of modern telecommunication technologies, and this, in turn, increases the electromagnetic pollution not only on Earth but also in space. In low Earth orbit, electromagnetic pollution creates some kind of difficulty in controlling nano-satellites. So it is necessary to measure the electromagnetic pollution in the Low Earth Orbit. The basic aim of this paper is to present the capability of designing and developing a PocketQube-class satellite 3-PQ 5 x 5 x 15 cm as a potential continuation of SMOG-1, the fourth satellite of Hungary. The planned scientific payload of MRC- 100 is a wideband spectrum monitoring system for radio frequency smog in the frequency range of 30-2600 MHz on Low Earth Orbit (600 Km). In this paper, we have executed qualifying measurements on the whole system in the frequency range of 30-1800 MHz (first phase), and we calibrated its broadband antenna with a measurement system. We present the capabilities of the wideband spectrum monitoring system to measure radio frequency signals, with the limited size, weight, and power consumption of the designed system. The working spectrum measurement system was tested on the top of the roof of building V1 at BME University and An-echoic chamber, we were able to show that there is significant radio frequency smog caused by the upper HF band, FM band, VHF band, UHF band, LTE band, GSM band, 4G band, and UMTS band. This is relevant to the main mission target of MRC-100.**

Index Terms—**Educational Student Satellite, PocketQube, Radio frequency Smog, Spectrum Monitoring System.**

I. Introduction

STUDENT satellite development, which is now common in a variety of applications, is categorized as nano-satellites. Due to their small sizes, minimal costs, and shorter manufacturing times, student satellites have shown to be a great alternative for large satellites in a variety of applications including space exploration. Nano-satellites, as opposed to traditional space missions, rely on commercial off-the-shelf (COTS) components which reduce prices and speed development. Typically, the term ”nano-satellite” refers to satellites sized between 1 and 10 kg. The modern proposed class is the Pocket Qube Satellite, which restricts developers to a volume of approximately 5 x 5 x 5 cm for a single unit and a mass range of 0.1 to 1 kilogram. Many Pocket Qube Satellite experiments can be found in the Microwave Remote Sensing Laboratory at the Department of Broadband Infocommunications and Electromagnetic Theory at BME University. [12]. [8]

MRC-100 is a 3-PQ (PocketQube) class student satellite $(5 \times 5 \times 15) cm$ with a total mass of 750 grams. SMOG-1 is 1-PQ $(5 \times 5 \times 5) cm$ with 175 g total mass. SMOG-P was the first and smallest operational satellite in the world during its lifetime. MRC-100 is considered a possible continuation of SMOG-P, ATL-1, and SMOG-1, which were created by the students of BME university and are classified as second, third, and fourth-class Hungarian PocketetQube satellites that are integrated into the BME educational system [1]. [6]. [10]. [9]. First, the hardware used for the measurements is presented. MRC-100 main subsystems are: COM, EPS, OBC, and **SP**. The 3D model of MRC-100 student satellite can be seen in Fig. 1.

The proposed trajectory for the MRC-100 is a polar, circular, and sun-synchronous Low Earth Orbit with a distance of 600 km apogee and perigee. The planned launch will be in December 2022.

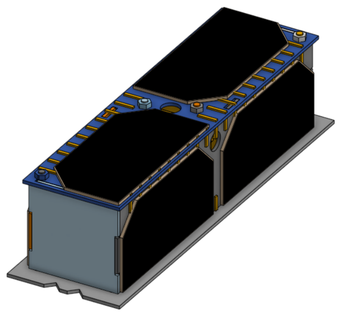

Fig. 1.: Three dimensional view of MRC-100.

Yasir Ahmed Idris Humad is a Ph.D student at the dept. of Broadband Infocommunications and Electromagnetic Theory, faculty of Electrical Engineering and Informatics, Budapest University of Technology and Economics (BME), Budapest, Hungary. (e-mail: yasirahmedidris.humad@edu.bme.hu)

As a supervisor, Levente Dudás Ph.D. is a communicational and system engineer for the MRC-100 student satellite project at the dept. of Broadband Infocommunications and Electromagnetic Theory, faculty of Electrical Engineering and Informatics, Budapest University of Technology and Economics (BME). (e-mail: dudas.levente@vik.bme.hu)

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The distance between Sun and Earth is about 150 million km. Around the Earth, the averaged power density equals to $1360\frac{W}{m^2}$ [2]. [11]. MRC-100 will be covered by solar panels made by AzurSpace [3]: 8 pieces of three-layers 80 mm $\times$ 40 mm cells.

Because of the atmosphere, the solar power density on Earth's surface is $1000\frac{W}{m^2}$ (due to the ozone layer). A 15 cm satellite has a 1.088 W incoming power. The three-layer solar cells of the MRC-100 have a 28 percent efficiency and a $40mm \times 80mm$ dimension, resulting in a DC (Direct Current) power of 0.8 W. MRC- 100's LEO lasts 100 minutes, with 60 minutes in the light and 40 minutes in the dark. As a result, due to the MRC-100's essentially random movement, while orbiting around 800 mW, the average DC input is 0.68 W, with a 1.7 W peak (on LEO DC input will be 36% more). On-board systems on the MRC-100 will have single-point- failure tolerant and cold-redundant.

The peak power of 1.7 W is estimated using the three-layer solar cell dimension $(80 \times 40)mm$ and the solar cell cut-off edge$(13.5 \times 13.5)mm$ for 1U cube $(100 \times 100)mm$ as seen in Eq.(1) - (5).

$$\frac{(80 \times 40 - 13.5 \times 13.5) \cdot 2}{100 \times 100} = 60\% \tag{1}$$

The solar power density on Earth's surface is 1000 $\frac{W}{m^2}$, for 10 cm^2 cube it equals to 10 $\frac{W}{cm^2}$

$$\text{The total D.C power } = 10\ W \times 60\% = 6 \text{ W} \tag{2}$$

$$\text{The peak D.C input } = 6\ W \times 28.5\% = 1.71 \text{ W} \tag{3}$$

$$\text{Average D.C power } = 1.71\ W \cdot \frac{4\ sides\ of\ cube}{6\ sides\ of\ cube} = 1.14\ W \tag{4}$$

$$\text{Average D.C input } = 1.14\ W \times 60\% = 0.684\ \frac{W}{90\,\text{min}} \tag{5}$$

The 3-PQ electrical power system is referred to as the EPS. The 3-PQ surfaces is covered by 8 pieces of solar panels, which serve as a source of energy. The electrical power system's main responsibilities are to independently control the operating point of the solar panels in order to achieve maximum input DC power, charge the Lithium-ion accumulator in order to work on the dark side of the Earth, and provide a stable +3.3 V power supply voltage to all subsystems.

The on-board computer is referred to as the OBC. The OBC is in control of the operation of the on-board subsystems, such as SP (spectrum monitoring system) and COM (communication system). The OBC is responsible for data collecting and handling on-board (these will be the Communication radiated telemetry data).

The COM (communication system) is responsible for establishing a two-way data link between MRC-100 and the ground stations. Because of the size of the onboard antenna, which should be opened from the cube, this radio transmission is on the 70 cm UHF (radio amateur band).

The SP (spectrum monitoring system) is the MRC-100 main payload. The mission of this monitoring system is to monitor the (upper HF band, FM band, VHF band, UHF band, 5G band, GSM band, and UMTS band) radiated from the Earth in (LEO) orbit. As a result, this power is considered as a lost power.

II. MRC-100 PAYLOADS

There are several payloads on-board the satellite: **spectrum analyzer (30 - 2600 MHz)**, active magnetic attitude control, horizon + Sun camera, GPS + LoRa downlink (satellite identification), 1 Mbit/s S-band down-link, total ionizing dose measurement system, automatic identification system receiver for vessel traffic services, UHF-band LoRa-GPS Tracking, memory based single event detector, special thermal insulator test. The 3D model of MRC-100 student satellite subsystems can be seen in Fig. 2.

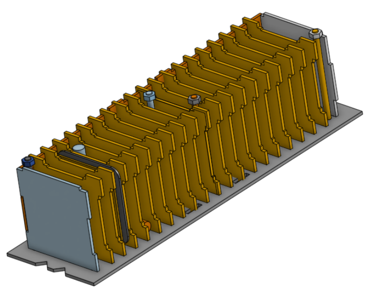


Fig. 2.: Three dimensional view of MRC-100 Subsystems.

III. THE MAIN PAYLOAD OF MRC-100 SATELLITE

The main payload of MRC-100 will be a wide band spectrum monitoring system (SP). the spectrum monitoring is a single-chip radio transceiver (in receiver mode) from Silicon Laboratories SI 4464. This receiver is working from 119 to 960 MHz with 1 to 850 KHz bandwidth. [4]. The monitored frequency band is 30 - 1800 MHz. The block scheme of the single-chip transceiver (SI4464) is in Fig. 3.

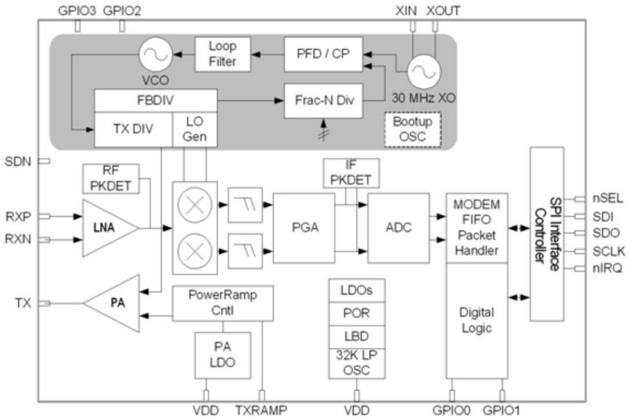


Fig. 3.: Single-chip radio transceiver as a spectrum monitor. [4].

The receiver part of this transceiver is a conventional super-hetrodyne receiver with digital IF (Intermediate Frequency) unit. The SI4464 chip contains a wide-range fractional-PLL (Phase Locked Loop) as a local oscillator, a wide-band LNA (Low Noise Amplifier) and mixer, PGA (Programmable Gain Amplifier) as IF amplifier with low pass filter, I-Q ADCs(Analogue to Digital Converters) and digital OOK-FSK MODEM (MOdulator and DEModulator). [4]. [5]. In the case of the spectrum monitor, the mission is to tune the carrier frequency of the receiver from 119 to 960 MHz and read the RSSI (Received Signal Strength Indicator) register of the receiver chip. Fig. 4. Shows the Locked frequencies and the frequencies gab of the local oscillator with fractional-PLL (Phase Locked Loop).

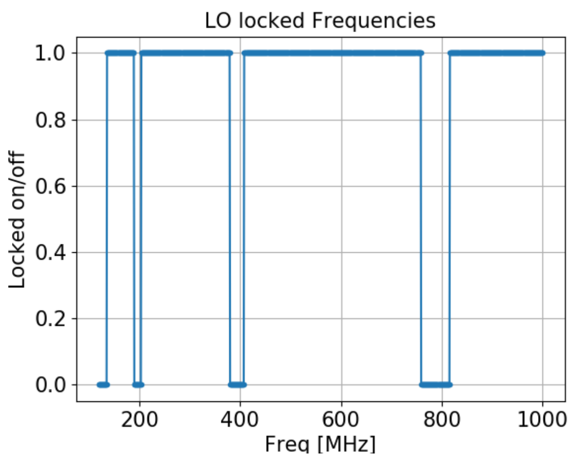


Fig. 4.: SI1060 as Local Oscillator.

IV. Wideband Spectrum Analyzer

The main payload of MRC-100 will be a wide band spectrum analyzer $40mm \times 40mm$ dimension, on the upper HF band, FM band, VHF band, UHF band, 5G band, GSM band and UMTS band (30 to 1800) MHz frequency range.

The spectrum monitoring system of MRC-100 is based on a RF microcontroller from Silabs SI1060. It contains a C8051F930 micro-controller in a single Quad Flat No-Lead (QFN) package and a SI4464 digital radio module. Fig. 5. shows the block diagram of the MRC-100's spectrum monitoring system.

The receiver side of the above mentioned transceiver (SI4464) can operate in RF scanning mode. At a given frequency and bandwidth, the SI4464 chip measures the RSSI (Received Signal Strength Indicator) level with enough dynamic range and 1 dB accuracy. According to the working frequency range of the receiver part (119-960)MHz, this wideband (30-1800)MHz must be divided into sub-bands.

In the RF Scanning mode, the communication antenna is first connected to the RF BPF (Band Pass Filter), then the RF signal passed through the RF switch, next to a LNA and the active mixer, after that it will pass through the IF/ BPF (Band Pass Filter) and a LNA and finally to the receiver input.

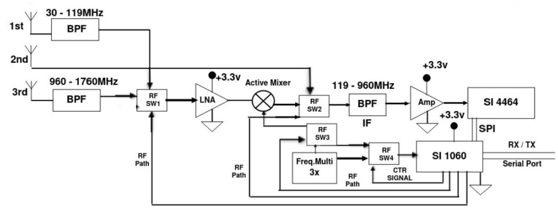


Fig. 5.: Block Diagram of Wideband Spectrum Monitoring System.

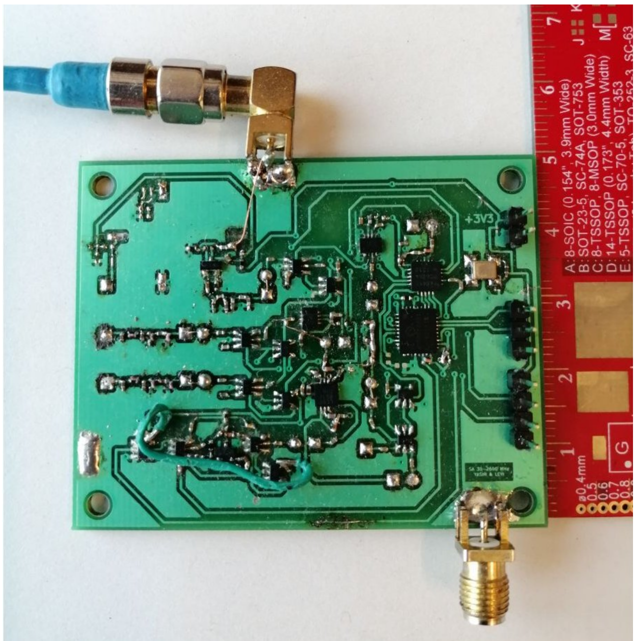
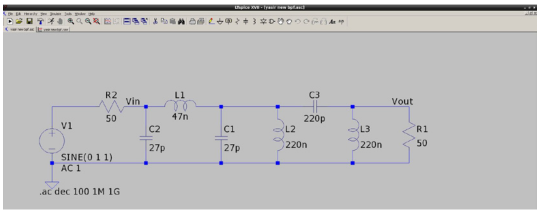


Fig. 6: The experimental model of a Wide Band spectrum monitoring system.

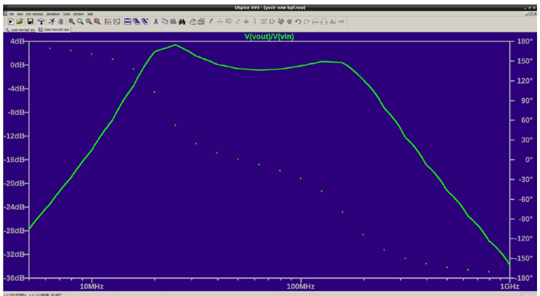
Several electronic components are present: the SMA connector, TCXOs (temperature compensated crystal oscillators) as a reference oscillator, and (SI4464) as a radio transceiver chip is on the right up. the RF switches, an active mixer, and a LNA (Gain Block Ampilifier) in the middle. The monopole antenna connection for the three sub-bands in the left and the frequency multiplier in the left down. as shown in Fig. 6.

A. First Band 30-119 MHz

In the case of the first band, the task is to adjust the receiver carrier frequency from 119 to 960 MHz and read the values of the RSSI register of the receiver chip (Received Signal Strength Indicator), but the first band frequencies are lower than the range of the receiver chip. So by tuning the local oscillator at 820MHz to up-convert the received signal to the receiver chip frequency range. the monopole antenna is connected directly to the RF BPF (Band Pass Filter) controlled by the first RF Switch stage in order to filter the first band signals. as shown in Fig. 7.



(a) First Band Filter Circuit

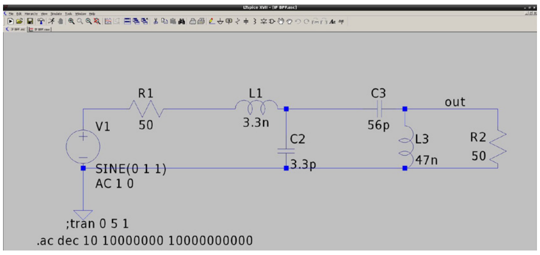


(b) First Band Filter

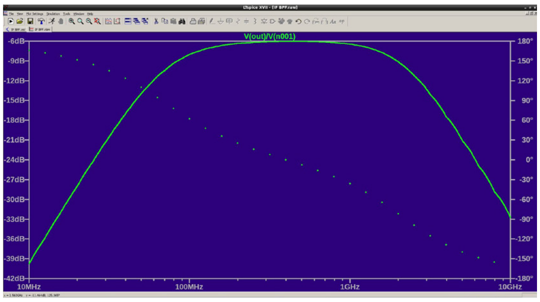
Fig. 7.: 2 Figures of First Band Pass Filter.

B. Second Band 119-960 MHz

The task in the second band is to adjust the receiver carrier frequency from 119 to 960 MHz and read the values of the RSSI register of the receiver chip (Received Signal Strength Indicator), in the case of the second band the monopole antenna is connected directly to the IF BPF (Band Pass Filter) controlled by the second RF Switch stage in order to filtered the second band signals, because the second band's frequencies are within the receiver chip's range. as shown in Fig. 8.



(a) Second Band Filter Circuit

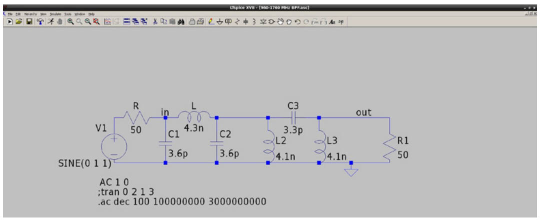


(b) Second Band Filter

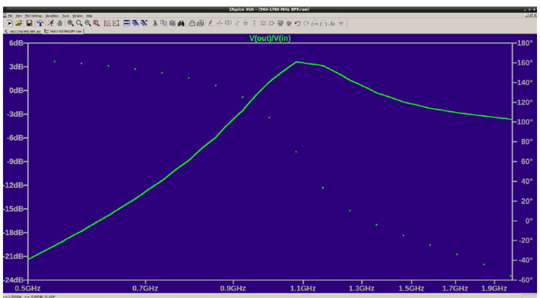
Fig. 8.: 2 Figures of Second Band Pass Filter.

C. Third Band 960-1800 MHz

In the case of the third band, the task is to adjust the receiver carrier frequency from 119 to 960 MHz and read the values of the RSSI register of the receiver chip (Received Signal Strength Indicator), but the third band frequencies are higher than the receiver chip's range . So by tuning the local oscillator at 841MHz to down-convert the received signals to the receiver chip frequency range. the monopole antenna is connected directly to the RF BPF (Band Pass Filter) controlled by the third RF Switch stage in order to filtered the third band signals. as shown in Fig. 9.



(a) Third Band Filter Circuit



(b) Third Band Filter

Fig. 9.: 2 Figures of Third Band Pass Filter.

The wideband spectrum monitor's antenna is a 470 mm monopole used in a wide frequency range without any matching circuit. The real part of the input impedance is between 1Ω and $1k\Omega$, depending on the actual frequency. The only way to calibrate the measurement system is: in our an-echoic chamber, in front of a log-periodic wide-band antenna, fed with known transmit power at fixed distance, the RSSI values had been recorded versus the frequency in 1 MHz step. As a result, the spectrum receiver has a calibration vector. This calibration vector is stored in the GND signal processing software. MRC-100 will downlink the original time-stamped RSSI values versus frequency, the correction based on the calibration vector will be done at the ground station (post processing).

As shown in Fig. 10.and Fig. 12.The radiation pattern of the on-board antenna with 45 degree and Fig. 11. Antenna on-board cube-skeleton.

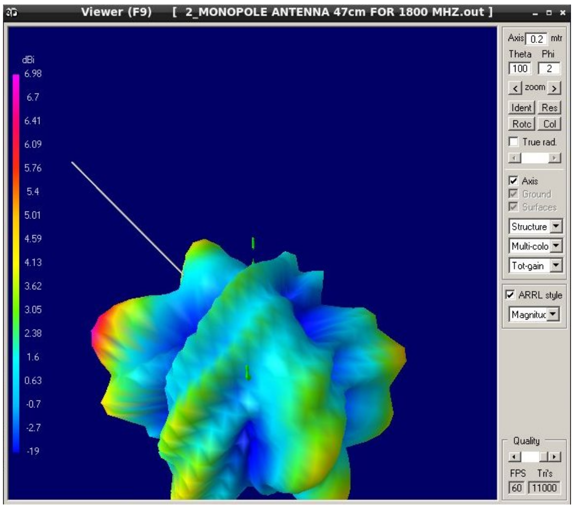


Fig. 10.: Three dimensional radiation pattern of the antenna with 45 degree.

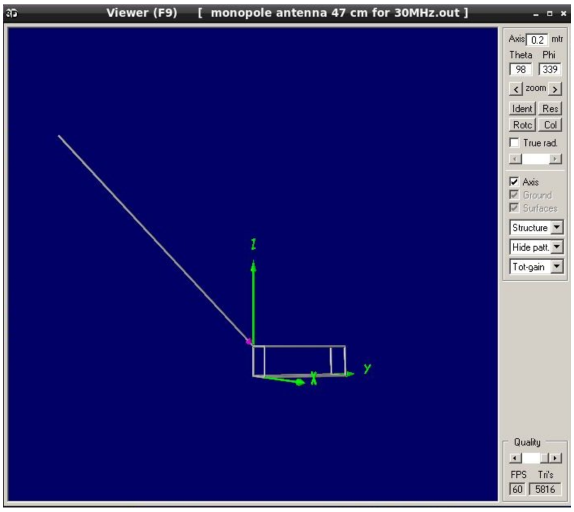
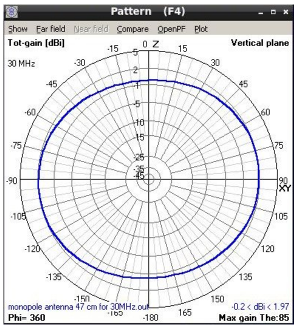
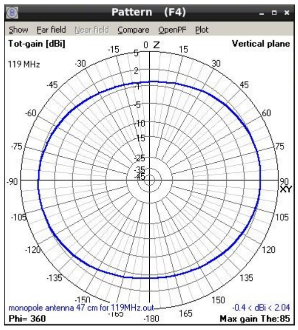


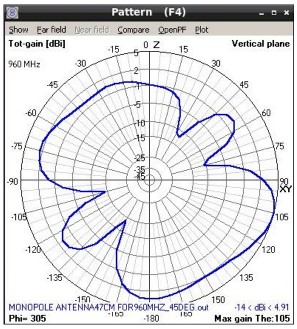
Fig. 11.: Antenna on-board cube-skeleton.



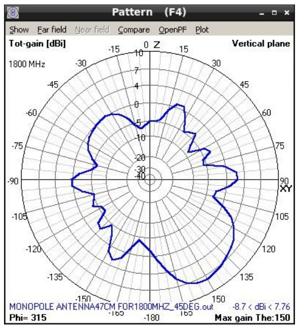
(a) 30 MHz Antenna Radiation Pattern



(b) 119 MHz Antenna Radiation Pattern



(c) 960 MHz Antenna Radiation Pattern



(d) 1800 MHz Antenna Radiation Pattern

Fig. 12.: 4 Figures of Antenna Radiation Patterns with 45 degree.

V. SPECTRUM MEASUREMENT RESULTS

A wide band spectrum monitoring system of MRC-100 satellite tested on the top of the roof of building V1 in BME to measure the upper HF band, FM band, VHF band, UHF band, LTE band, GSM band, 4G band and UMTS band signal levels. The experimental model of the measurement system is mentioned in Fig. 6.

The maximum distance between the satellite and the ground station (communication in zero degree elevation angle - horizon) as in Fig. 13. is based on the equation(6) at 600 km apogee/perigee of the orbit.

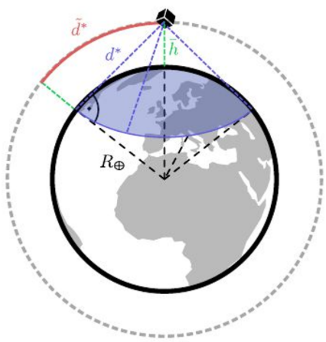


Fig. 13.: Diagram of MRC-100 Horizon. [7]

$$d = \sqrt{(R+h)^2 - R^2} \tag{6}$$

Where h = 600 km, R = 6,371 km and d = 2830 km (where d is the maximal distance between the satellite and the ground station).

The speed of a satellite in a circular orbit, it is calculated by equation (7).

$$v = \sqrt{\frac{g \cdot R}{1 + H/R}} = 7.55\ \frac{km}{s} \tag{7}$$

g is the gravitational acceleration on the surface of the Earth.

The used bandwidth of the monitoring receiver is 800 kHz (the receiver chip maximal bandwidth is 850 kHz), controlled by the configuration software. So it is necessary to calculate the measurement minimum time for each band as shown in TableI, the minimal time depends on the Resolution Bandwidth (RBW) and the step frequency.

TABLE I
MINIMAL TIME [S] TO COMPLETE RF SCANNING.

	RBW [kHz]	GMSK [kbit/s]	1st Band [s]	2nd Band [s]	3rd Band [s]
0	1.5	1	1582	1495	14933
1	3	2	396	3737	3733
2	6	4	99	934	933
3	12	8	24	233	233
4	24	16	6	58	58
5	48	32	1.5	14	14
6	96	64	0.3	3.6	3.6
7	192	128	0.096	0.9	0.9
8	384	256	0.024	0.22	0.22
9	768	512	0.006	0.057	0.057

$$Minimal\ Time = \frac{f_{\max} - f_{\min}}{f_{step}} \cdot \frac{1}{RBW} \cdot 10 \tag{8}$$

$$DataRate_{GMSK} = 2^{RBW} \tag{9}$$

$$RBW = 1.5 \cdot DataRate \tag{10}$$

$$Step\ Frequency = \frac{RBW}{4} \tag{11}$$

TABLE I
MINIMAL TIME TO COMPLETE BAND SCANNING.

Band	RBW KHz	GMSK(DR) kb/s	Step Frequency KHz	Minimal Time second
FM	192	128	48	0.022
DVB-T	192	128	48	0.009
LTE	192	128	48	0.011
4G	192	128	48	0.022
GSM	192	128	48	0.048
UMTS	192	128	48	0.005

The total measurement points of the wideband spectrum (30 - 1800)MHz, when the Resolution Bandwidth (RBW) is 192 kHz and the f_{step} is 48 kHz can be calculated by equation 12.

$$Total\ Points = \frac{f_{\max} - f_{\min}}{f_{step}} = 36875\ points \tag{12}$$

The maximum flash memory of the OBC (On-Board Computer) of MRC-100 is 8 MB, this means 36875 measurement points will be saved on 36 KB (Because every 1 RSSI value equals to 1 Byte memory size).

The minimum time of measuring the RSSI values of the wideband spectrum (30 - 1800)MHz, when the Resolution Bandwidth (RBW) is 192 kHz and the Step Frequency is 48 kHz can be estimated by equation 13.

$$Minimal\ Time = TotalPoints \cdot \frac{1}{RBW} \cdot 10 = 1.92\ s \tag{13}$$

According to the estimated time in Eq. 13, we can analyze the wideband spectrum every 23 seconds.

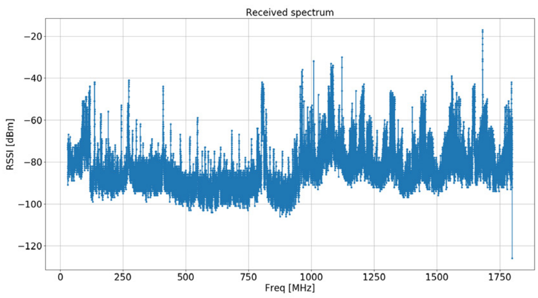


Fig. 14.: The hole Band Received Signals.

The transceiver chip measures the spectrum of the first band 30MHz to 119MHz, as shown in Fig.15 . There is a huge amount of RF power radiated from several FM local transmitters (88 - 108)MHz.

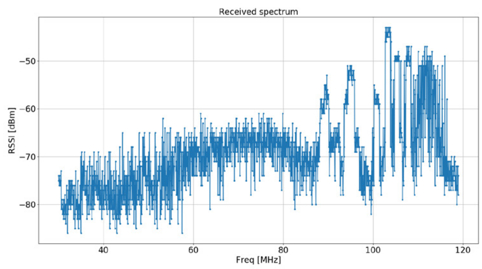
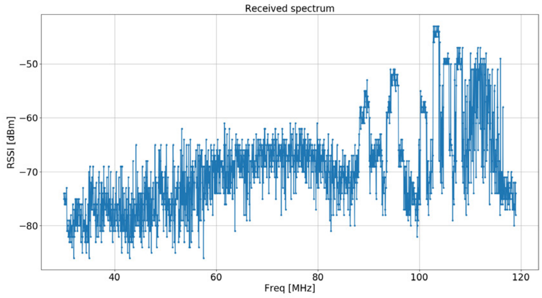
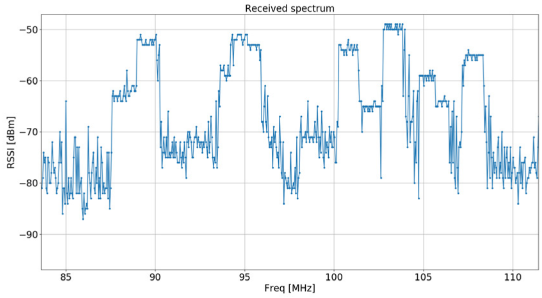


Fig. 15.: The First Band Received Signals.



(a) First Band



(b) FM Received Spectrum

Fig. 16.: 2 Figures of FM Received Spectrum

As shown in Fig.17 . the transceiver chip measures the spectrum of the second band (119 - 960)MHz, There is a huge a mount of RF power radiated from several transmitters.On 406, 500, 610, 640, 750, and 770 MHz the local TV transmitter's signals are very visible.. On 800 MHz the LTE is also highly visible and on (950 - 960)MHz the GSM band is highly visible. The digital terrestrial TV channel (DVB-T) has an 8 MHz bandwidth, hence the usable bandwidth is 800 kHz. Because the (DVB-T) bandwidth is 10 times highest than the bandwidth of the receiver chip, the only way is to modify the level of the measured data by increasing the RSSI values by 10 decibels.

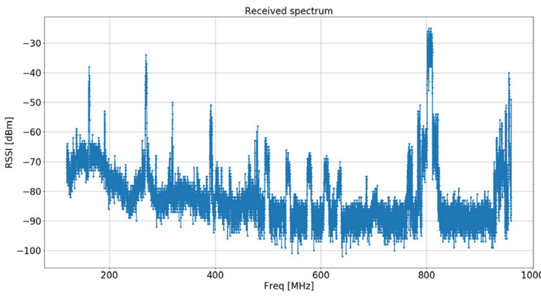
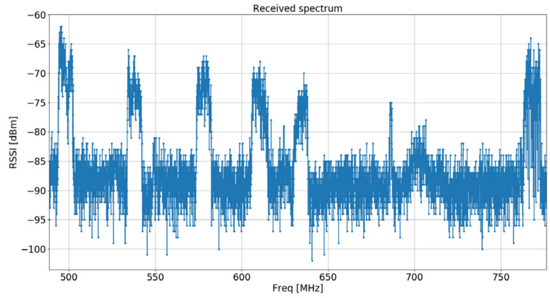
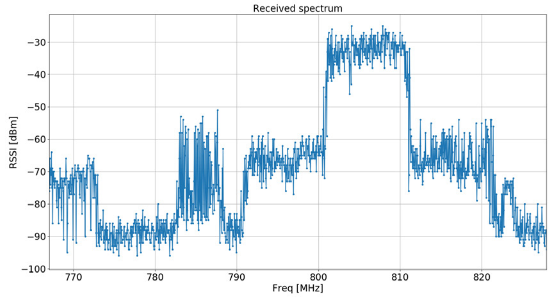


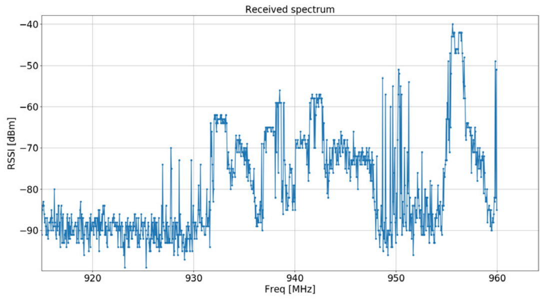
Fig. 17.: The second Band Received Signals.



(a) DVB-T Received Spectrum



(b) LTE Received Spectrum



(c) GSM Received Spectrum

Fig. 18.: 3 Figures of The Second Band Received Spectrum

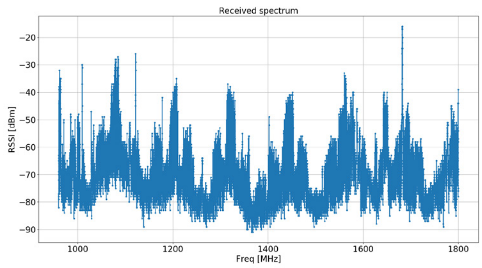


Fig. 19.: The Third Band Received Signals.

As shown in Fig.19 . the transceiver chip measures the spectrum of the third band 960MHz to 1800MHz, There is a huge amount of RF power radiated from several UMTS local transmitters between(1.77 - 1.8)GHz. The effect of the second harmonics of the local oscillator of the third band is highly visible at 1682MHz as shown in Fig. 21.

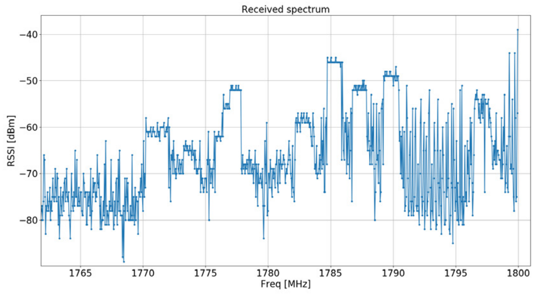


Fig. 20.: UMTS Received Spectrum.

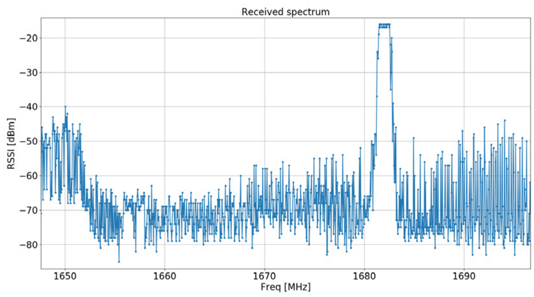


Fig. 21.: The Second Harmonic of the Local Oscillator.

As determined by the measurements, the SI4464 chip can sense RF signal level in -110...-10 dBm range linear in dB scale: the RSSI level can be calculated by the RSSI register value: $RSSI_{dBm} = \frac{RSSI_{reg}}{2} - 130$ modified the calibration vector.

VI. Conclusion

MRC-100 is in the designing and developing phase and will be launched in December 2022. The wideband spectrum monitoring system now is working and is able to measure RSSI (Received Signal Strength Indicator) values on three different RF bands according to the presented measurement results, it can be used as a conventional scalar spectrum analyzer with less than 120 mA current consumption from +3.3 V nominal regulated bus voltage and $40mm \times 40mm$ PCB (Printed Circuit Board) size. The system has enough sensitivity and enough dynamic range to be a payload on the MRC-100 3-PQ (PocketQube) satellite to measure RF (Radio Frequency) smog of the upper HF band, FM band, VHF band, UHF band, LTE band, GSM band, 4G band, and UMTS band over the globe in (LEO) orbit.

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Yasir Ahmed Idris Humad received his Bachelor's Degree in Electronic Engineering (Telecommunication) from AL-Neelain University, Faculty Of Engineering in 2012. He continued his graduate studies at AL-Neelain University Faculty of Engineering and he received his MSc in Electronic Engineering (Data and Communication Networks) in 2015. He enrolled as a researcher assistant at the Institute of Space Research and Aerospace (ISRA) Sudan in 2014. While working in ISRA, his research effort has been in the area of CubeSat Systems Design. In 2020, he granted a scholarship to complete his Ph.D. in electrical engineering at BME, Hungary. His current research areas include CubeSat and PocketQube type satellite development; analog RF hardware, antenna design; automated and remote-controlled satellite control station development; Software Defined Radio-based signal processing for satellites.https://gnd.bme.hu/smog

Levente Dudás At the Budapest University of Technology and Economics, he got his MSc in electrical engineering in 2007 and his Ph.D in 2018 in Radar and Satellite Applications of Radio and Antenna Systems (BME). He is currently a senior lecturer at BME's Department of Broadband Infocommunications and Electromagnetic Theory, an electrical engineer in the Microwave Remote Sensing Laboratory, and the president of the BME Radio Club. Microwave Remote Sensing (RADAR) lab. is working on: active and passive radars; CubeSat and PocketQube satellite development; analog RF hardware and antenna design; automated and remote-controlled satellite control station development; Software Defined Radio based signal processing for satellite and radar applications are just a few of his research interests. http://radarlab.hvt.bme.hu/, https://gnd.bme.hu/