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# High Frequency Radio Surveillance System

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*Abstract*— **The radio system for high frequency spectrum monitoring and signal processing used in direction finding is presented in this paper. This main function is realized using 6-channel HF radio signal receiver. The high degree of flexibility is achieved by the application of antenna multicoupler unit which allows that signals from several antennas may be processed in the system. The system signal processing especially in the demodulator is based on the most modern components of software defined radio. The system is completely developed in the Institute IRITEL applying commercial components wherever such an approach may fulfill the expected performances. The realized development is highly multidisciplinary and specific, especially HF radio signal receiver and the structure of its modules (local oscillator, RF/IF receiver subsystem, demodulator and control block) which is presented in the paper in more details. User handling is simple over intuitive user interface and system functional parameters may be easily changed. Special attention in the paper is devoted to this interface and software control procedures. The designed electrical characteristics are verified by comprehensive set of measurements according to military specifications both for HF radio signal receiver and antenna multicoupler unit and these characteristics are illustrated by several examples. The system is approved for the application in real conditions.**

***Keywords-antenna multicoupler unit; 6-channel HF radio signal receiver; demodulator; RTL-SDR –Software Defined Radio, SCPI protocol***

## I. INTRODUCTION

The radio surveillance systems have very long tradition in the Institute IRITEL. IRITEL solutions in this area cover wide frequency band including HF, VHF and UHF bands separately or all together [1] – [11]. The basic equipment of these direction finding solutions are the radio signal receivers [4], [7] – [9]. The integral receiver module is also demodulator in addition with the signal processing unit [12]. IRITEL applies also antenna multicoupler units to allow more antennas to be used in order to increase system flexibility [1], [5], [6], [10]. The separate problem in the implemented solutions is the common control of the system consisting of the receivers and antenna multicoupler units [2], [3]. The receivers in [2], [3] are not developed in IRITEL. It should be emphasized that the complete high frequency radio surveillance system has been developed and tested in IRITEL.

Today there are a number of companies which supply antenna multicoupler units and RF receivers suitable for direction finding [13] – [18]. But the world market available receivers and antenna multicouplers have extremely high prices and they do not satisfy all system requirements. For example, antenna multicouplers may not fulfill specific request to allow switching of twelve receiving antennas to three receivers for direction finding. In addition three receivers for RF spectrum monitoring are used in our system providing in the same time calibration signal input and output connection port [6].

*This paper is a revised and expanded version of the paper presented at the XX International Symposium INFOTEH-JAHORINA 2021[11]*

The short prereview of the developed system is presented in the section II. The two main hardware constitutive parts: multicoupler unit and RF signal receiver are described in the sections III and IV, respectively. The measured electrical characteristics are shown by several examples in the section V. The elements dealing with software: system control from the remote PC and user interface to achieve this control are presented in the section VI. Conclusions are in the section VII.

## II. SYSTEM STRUCTURE

Fig. 1 presents IRITEL HF direction finding system. The system consists of three units: 1) PS250 – power supply unit for the receiver and antenna multicoupler; 2) ARK 30 – antenna multicoupler unit and 3) wideband 6-channel HF radio receiver. All these three units are placed in one shelf and all HF receiver modules are realized as replaceable parts.

## III. ARK 30

ARK 30 is the antenna multicoupler unit in the HF radio surveillance system. Its dimensions are 48x13x52cm and the weight is 17kg. The main functions are: 1) signals reception from antenna arrays intended for direction finding function realization and their distribution/switching to HF receivers; 2) signals reception from antennas used for HF spectrum (1.5-30MHz) monitoring and their distribution/switching to the receiving surveillance subsystem; 3) calibration signal forwarding to direction finding system.

Detailed block-scheme of ARK 30 is presented in the Fig. 2. There are total 13 inputs to the system: 9 antenna inputs (antenna inputs IN 1-9) which should be used for signal processing in direction finding processor, 3 antenna inputs (HF connections IN 10-12) for HF connections which are forwarded to the receiving surveillance subsystem and 1 input (KLS in) for calibration signal. The antenna multicoupler switches these 13 signals towards total 8 outputs: 4 outputs (3 active and 1 reserve) to receivers devoted to signal preparation for processing in separate direction finder processor (RGOUT4-7), 3 outputs to receivers intended for spectrum surveillance (MOUT1-3) and 1 calibration output (KLSOUT).

Each of 13 input signals are first processed in low noise amplifier (LNA) modules. The name of these modules is defined according to amplifier sub-module which exists in each of these modules. Besides amplifier sub-module, each LNA module contains power splitter and first 12 modules contain band-pass filter for HF band 1.5-30MHz. Power splitters for antenna signals fed to direction finding processor and for calibration signal are 1:4 because there are total 4 outputs in this group (RGOUT4-7), while power splitters for signals directed to spectrum surveillance system are 1:3 as there are 3 outputs in the group (MOUT1-3).


Figure 1. System for monitoring high frequency spectrum and signal preparation for processing in direction finding processor

There are two switching matrices in ARK 30. The first one is 10:4 and it directs 4 of total 10 signals (9 antenna input signals and 1 KLS IN signal) to outputs RGOUT4-7. This matrix is realized by 10 multiplexers MUX 1-10. The second matrix is 3:3 and it directs 3 HF connections input signals to outputs MOUT1-3 using 3 multiplexers MUX 1-3.

Antenna supply module provides necessary DC voltage 24V to first 9 antennas if it is necessary. The next two modules are power supply module which is the source of DC voltages necessary for the system operation and module for indication of all DC voltages state and all 9 antennas power supply.

All modules elaborated in this description are controlled and supervised by the separate control module in the device. This module accepts and executes commands received via the Ethernet interface from the superior computer system. It sets the programmable parameters of ARK 30 in accordance to these commands, returns the required statuses and executes automatic algorithms of the device. The hardware platform of the module is the processor board TS-7250-32-32F which is realized as single board computer on the base of Cirrus EP9302 ARM9 CPU processor. Switching matrices (multiplexers), antennas supply and calibration signal forwarding are under the supervision of control module. The total cross-points number in the switching matrices is 50 (as presented in the Fig. 2) and the number of command signals for antennas power supply is 9. In order to reduce the total number of necessary command signals from the control module, the command signals in both cases are sent over processor serial port and then converted by serial/parallel converter at the place of implementation.

The interior of the system ARK 30 is presented in the Fig. 3. The position of each block from the block-scheme in the Fig. 2 may be seen in the Fig. 3. The high frequency modules in the system are placed in metal boxes.

## IV. RF SIGNAL RECEIVER

Radio receiver is 6-channel HF signal receiver and demodulator unit. The receiver dimensions are 48x31x50cm and the weight is 36kg. Its main functions are: 1) RF spectrum surveillance; 2) as a part of the system for direction finding according to the principals explained in [19].

The block scheme of 6-channel receiver and demodulator unit is presented in the Fig. 4. The function of receivers is separated in three groups of two modules, as may be seen in this figure. Three antenna signals from ARK 30 are connected to RF/IF receivers 1, 3 and 5 respectively and the output from receivers 1, 3 and 5 or 2, 4 and 6 is transmitted to direction finding processor whether wide-band or narrow-band user signal is processed. The receivers are placed in the first 6 positions of the HF radio receiver rack, as may be seen in the Fig. 1.

Signal reception in all six receivers is allowed by the two sinusoidal signals generated in the block Local oscillators. These local oscillators are placed in the upper, horizontal part of HF radio receiver rack (Fig. 1).

The function of local oscillators and receivers is defined according to the commands from Control block which is in the connection with the computer PC2 according to Fig. 4. Control block is situated in the position 8 in the rack, according to the Fig. 1.

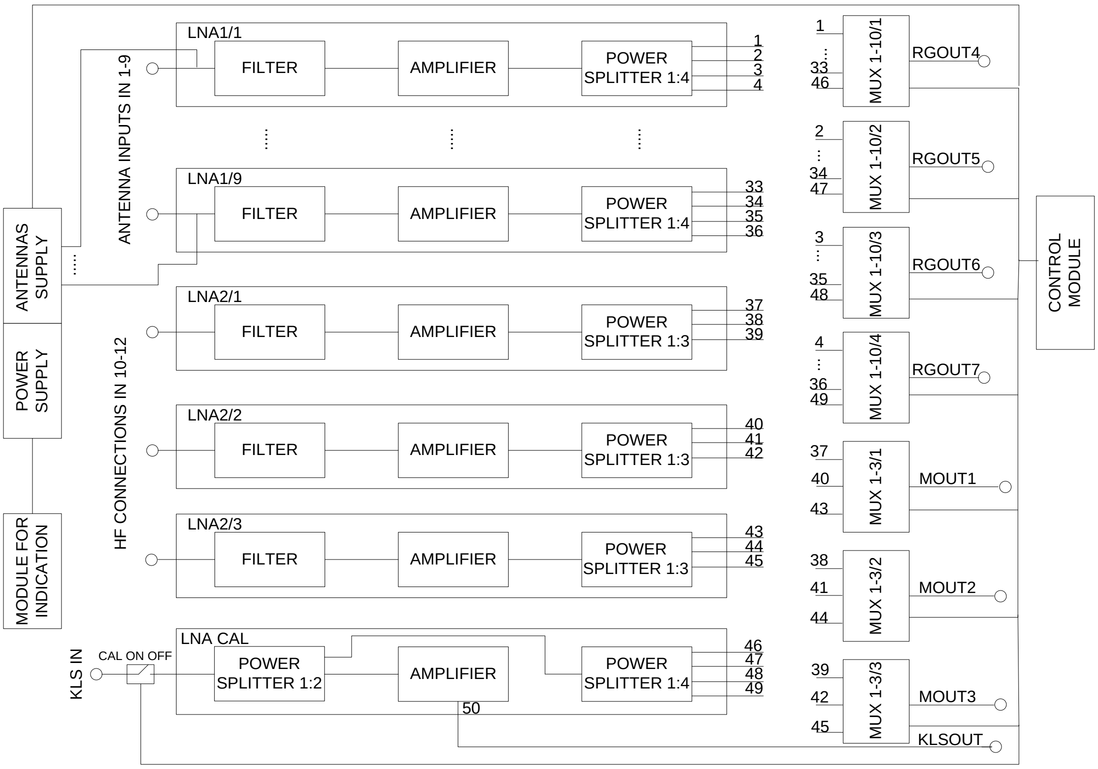


Figure 2. Detailed block-scheme of ARK 30

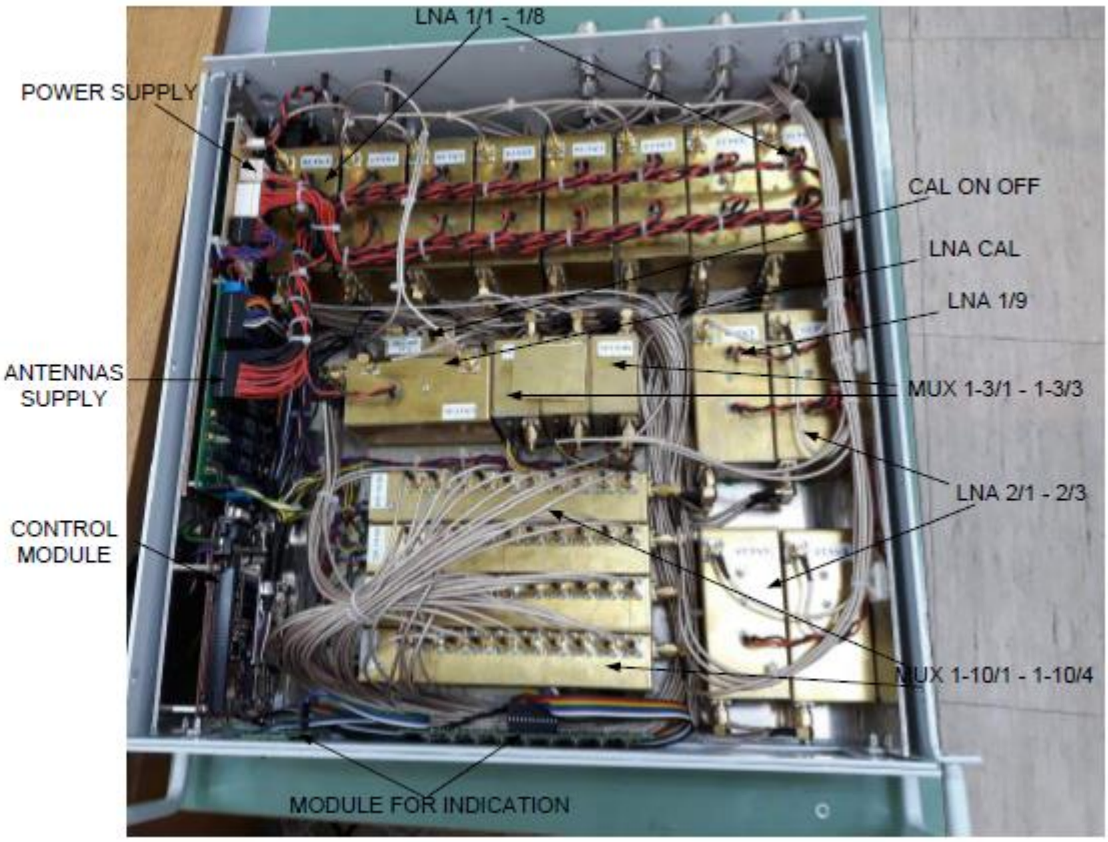


Figure 3. The interior of the system ARK 30

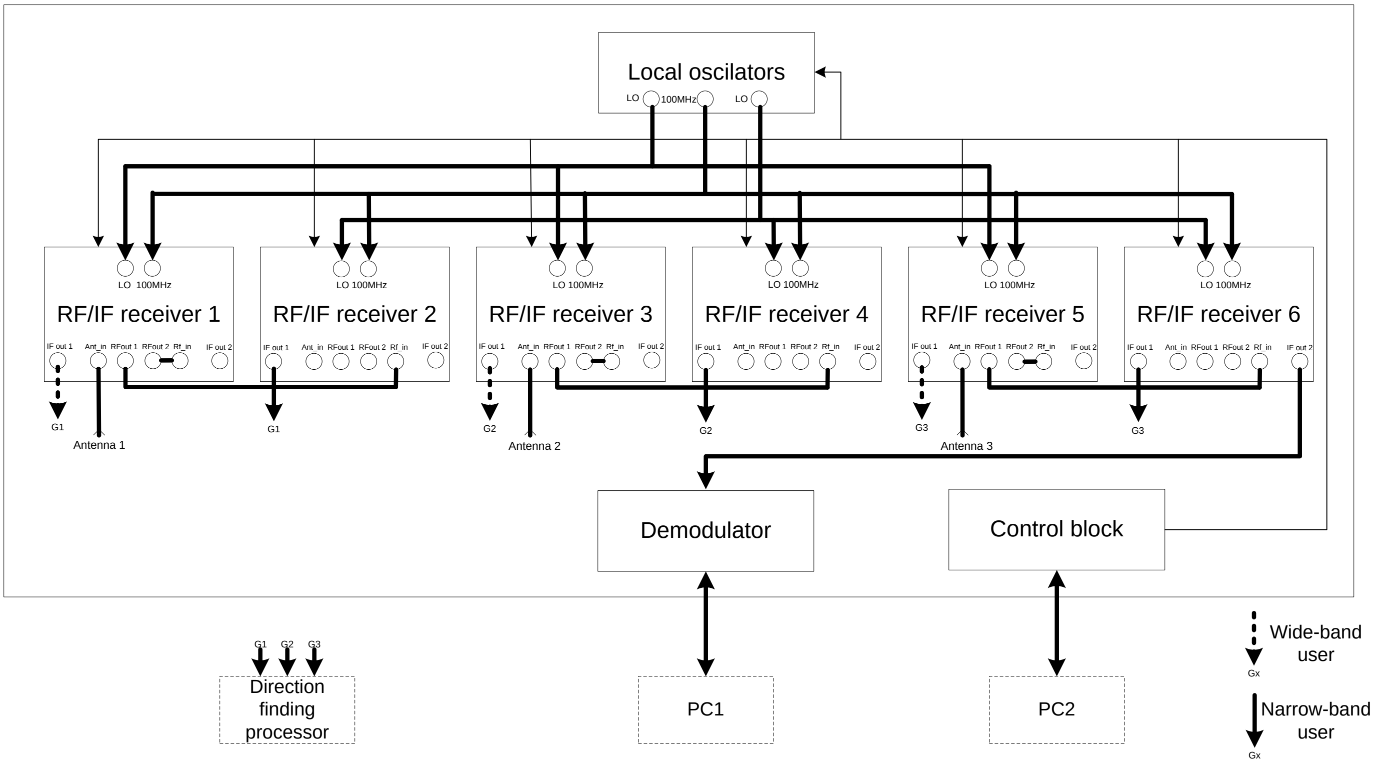


Figure 4. Block scheme of HF radio receiver subsystem

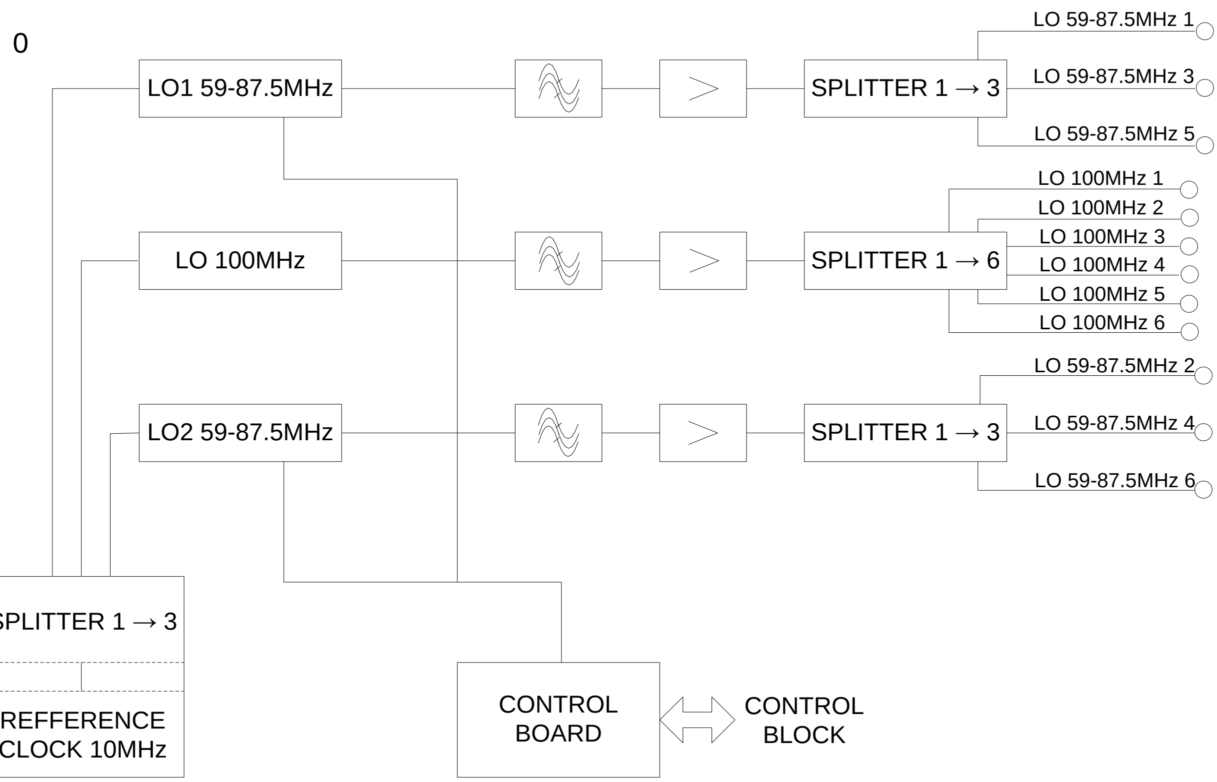


Figure 5. Block scheme of local oscillators module

The most important part for the implementation of the first system function of RF spectrum surveillance is demodulator module. This module is under the control of the separate computer PC1, as presented in the Fig. 4. Demodulator is placed in the position 7 of HF radio receiver rack (Fig. 1).

*A. Local oscillattor*

The first goal when processing antenna signals in the presented system is to transfer the received signal to the unique predefined frequency band around 42.5MHz. Starting from the input signal from the HF range 1.5-30MHz, the first step is to obtain signal at the fixed band around 57.5MHz regardless of the input signal frequency. In the second step, this signal is shifted to the fixed band around 42.5MHz.

The block scheme of the local oscillator module is presented in the Fig. 5. The structure of this module follows the principles of signal processing in 6 receiver modules.

All sinusoidal signals in the system are generated starting from the very stable, temperature compensated oscillator at 10MHz. This signal is split to three identical signals to allow operation of three oscillators. The first two oscillators (LO1 and LO2) are variable ones and their frequencies may be software defined in the range 59-87.5MHz. The third oscillator (LO) has fixed frequency 100MHz. All three generated sinusoidal signals are further filtered in the band-pass filter (BPF) to eliminate signal harmonics and amplified in an amplifier (AMP). The last step is to split generated oscillator signals for the function of 6 receivers. Signals of variable frequency from LO1 and LO2 are split into 3 signals: signal from LO1 is intended for the receivers in the odd positions in the rack, while signal from LO2 is intended for the receivers in the even positions in the rack. On the contrary, unique signal of stable frequency 100MHz from LO is split to 6 signals, each for one of 6 receivers.

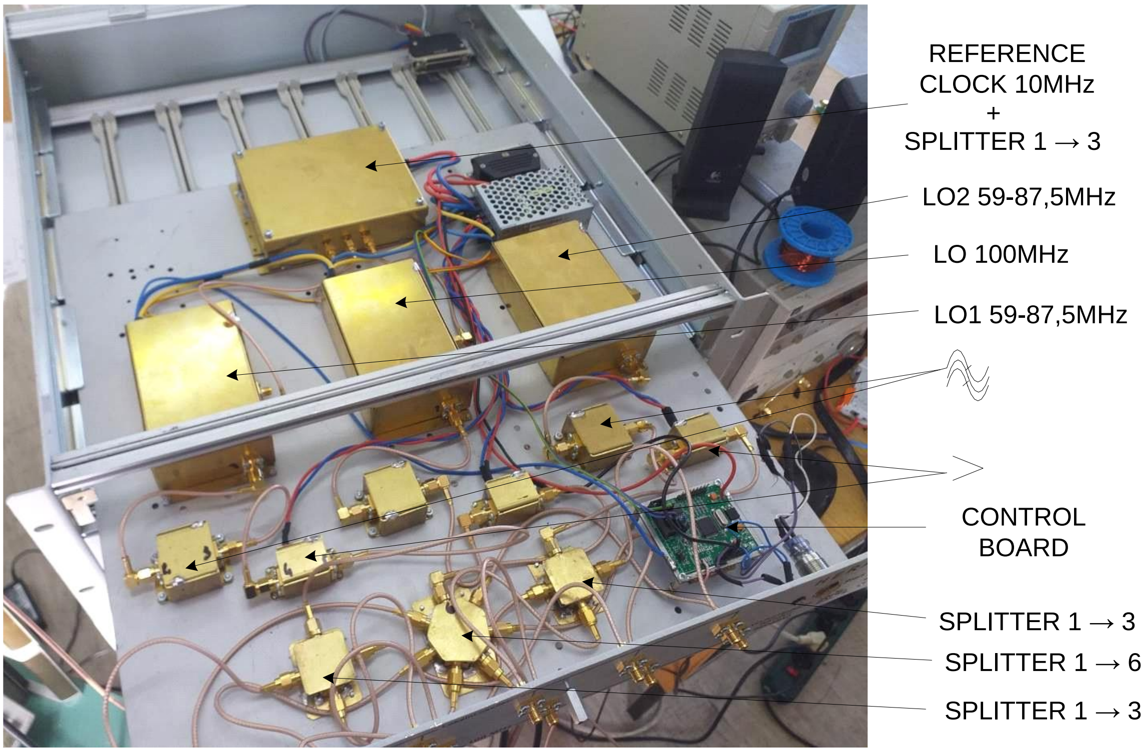


Figure 6. The interior of the local oscilator module

Just as an example for all modules included in the HF/IF receiver, the interior of the local oscillator module is presented in the Fig. 6. The position of all blocks from the Fig. 5 is presented in this Fig. 6. The complete hardware except the control board is placed in a number of separate metal boxes. This is the principle in both ARK 30 and HF/IF receiver implementation to achieve satisfactory system function when considering electromagnetic disturbances.

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The algorithm of frequencies changes in LO1 and LO2 is selected in the separate control block (Fig. 4). According to the selected algorithm, particular frequencies of LO1 and LO2 are defined in the module Control board in the Fig. 5.

### *B. RF/IF receiver subsystem*

Fig. 7 presents the block scheme of RF/IF receiver subsystem consisting of 6 receivers each shown in this figure. Antenna signal from ARK 30 enters the receiver at the ANTENA IN input. Two successive receivers at odd and even position operate together and their mutual connection is presented in the Fig. 4.

The first block in the RF/IF receiver is an input filter (preselector). It is possible to select one of 6 narrower filters, each covering 5MHz of total approximately 30MHz of input frequency band or the seventh filter which covers the whole frequency band 1.5-30MHz. The selection of one filter from this filter bank is realized by 7 command lines from the block control logic (Fig. 7).

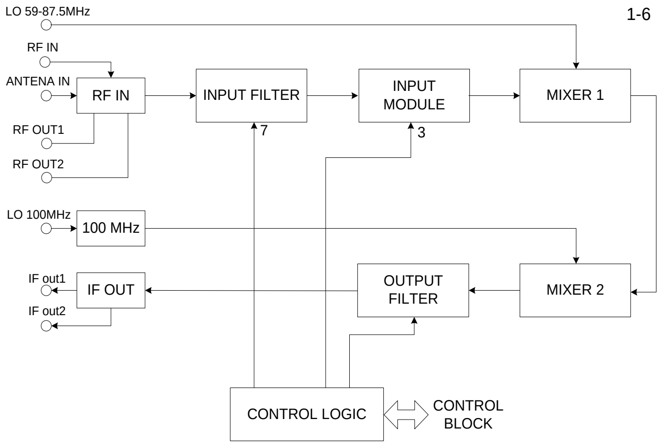



Figure 7. Block scheme of RF/IF receiver subsystem per channel

The second block in the receiver is an input module. In this module it is possible to activate one amplifier stage of 20dB, two attenuator stages of 10dB each, or to deactivate these stages. These are 7 selections for fixed amplification intended for manual gain control (MGC). The eighth possibility is to select variable amplification, realized by automatic gain control (AGC). There are 3 command lines from control logic to select one of total 8 described possibilities (Fig. 7).

Input signals to mixer 1 are the signal from antenna and the variable frequency signal from the local oscillator module. This signal frequency is in the range 59-87.5MHz. We are interested in the signal around 57.5MHz at the mixer 1 output. The oscillator signal frequency at the mixer 2 input is fixed at 100MHz from local oscillator. The result is that signal frequency is then shifted to the intermediate frequency 42.5MHz at the output of mixer 2. In principle, output signal frequencies from mixer 2 may be in a wider range, but we select only the band of 5MHz width around 42.5MHz using the output filter (Fig. 7).

### *C. Demodulator*

Signal demodulation may be performed for any of 6 RF/IF receivers. The block scheme of this module is presented in the Fig. 8.

The signal at the intermediate frequency 42.5MHz is demodulated using software defined radio (SDR) processing by application of RTL-SDR commercial-of-the-shelf (COTS) component also implemented in other IRITEL solutions [20]. Demodulation may be applied to AM, FM, LSB, USB, ISB and CW modulated signals. The signal from RTL-SDR is further processed in the processor to produce audio output from the whole module. The function of the processor in this module is under the control of PC1, as already presented in the Fig. 4. In this way the realization of demodulator is simplified to the great extent in the hardware sense comparing to the earlier demodulator solution [12].

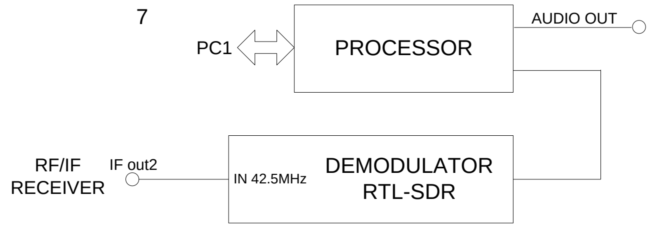



Figure 8. Block scheme of demodulator

### *D. Control block*

Hardware realization of control block in 6-channel RF signal receiver corresponds to the same module in ARK 30 and its block scheme is presented in the Fig. 9. This block performs following functions using the separate interfaces:

*1)* receives commands referred to the receiver operation parameters and sends system statuses to the superior processor PC2 using Ethernet interface;

*2)* selects corresponding parameters of RF/IF receiver function: filter in preselector, AGC or MGC and desired level in amplifier input module and output filter at intermediate frequency. These functions are programmed over digital input-output lines;

*3)* controls the operation of local oscillators using SPI interface over COM0 processor port. Frequency definition in the device is using fixed frequency mode and the operation frequency may be changed in the steps of 1Hz.

The device parts under the supervision of control block which are here elaborated in the points 2) and 3) are designated as SYSTEM in the Fig. 9.

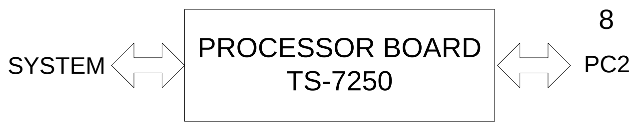



Figure 9. Control block scheme

## V. MEASURED ELECTRICAL CHARACTERISTICS

The complete set of transmission characteristics is measured on the realized ARK 30 and RF receiving subsystem. The predefined recommendations according to the end user requests are fulfilled for both devices. The obtained characteristics are illustrated by several examples for both systems. In the case of ARK 30 the presented characteristics are gain and frequency characteristic (Fig. 10) and the return loss (or voltage standing wave ratio – VSWR) at the system input in the Fig. 11 and output at the Fig. 12.

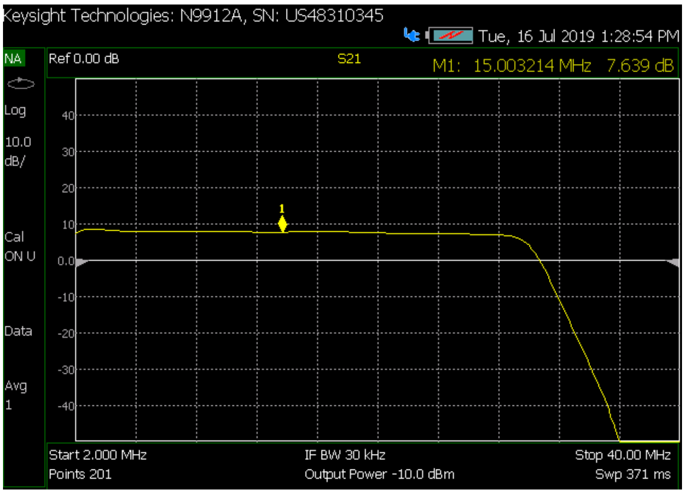



Figure 10. Gain and frequency characteristic between the input and output of ARK 30

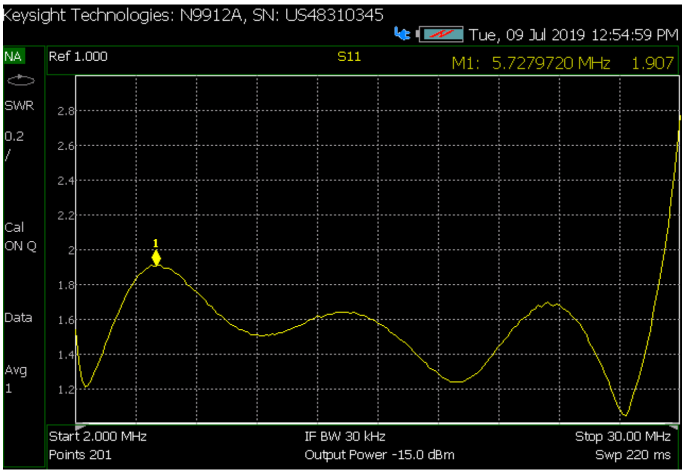



Figure 11. Voltage standing wave ratio (VSWR) characteristic at the input of ARK 30

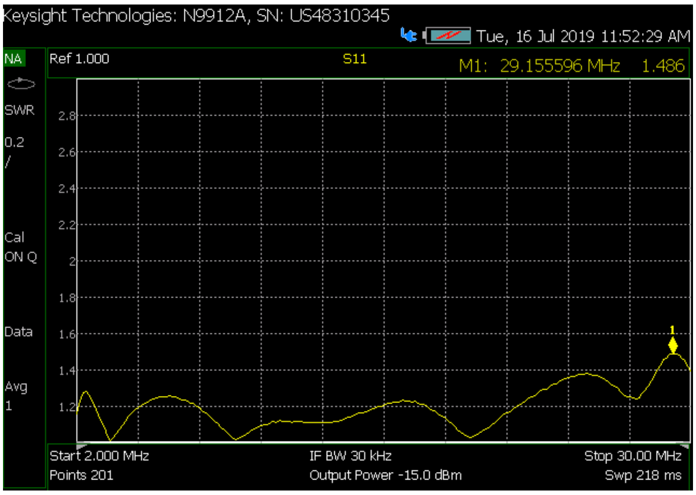



Figure 12. Voltage standing wave ratio (VSWR) characteristic at the output of ARK 30

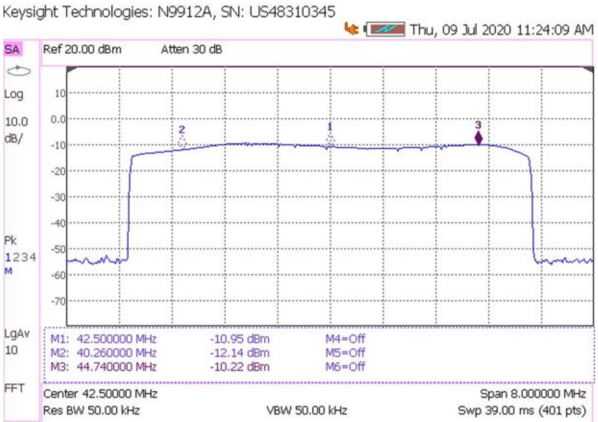



Figure 13. Frequency bandwidth on the intermediate frequency at the RF/IF receiver output

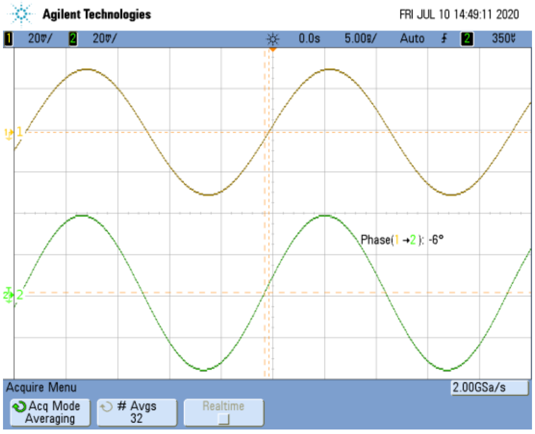



Figure 14. Coherence between signals at the outputs of two RF/IF receiver subsystems in the RF receiver system

The characteristics for RF signal receiver are presented in the Figs. 13 - 15. The frequency bandwidth on the intermediate frequency at one RF/IF receiver output is presented in the Fig. 13, while the coherence (phase difference) between outputs from two RF/IF receiving subsystems is presented in the Fig. 14. These are two typical characteristics for only one of six RF/IF receiver subsystems in the system. Such characteristics are investigated for all six subsystems.

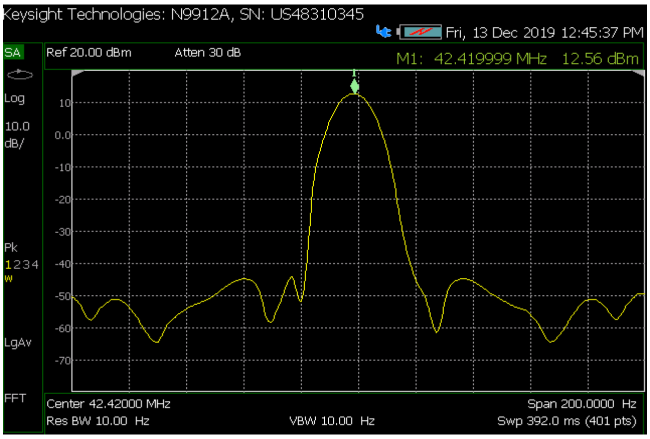
Fig. 15 presents the graph intended to calculate linearity for the third intermodulation product. Attenuation at the intermediate frequency is presented in the Fig. 15a) while the attenuation of the third intermodulation product is presented in the Fig. 15b). Starting from these two determined values, the linearity is calculated according to the formula [21]:

$$IP3 = P_{in} + \frac{a}{2} = P_{in} + \frac{P_{in} - P_{IP3}}{2} = 34.83dBm \qquad (1)$$

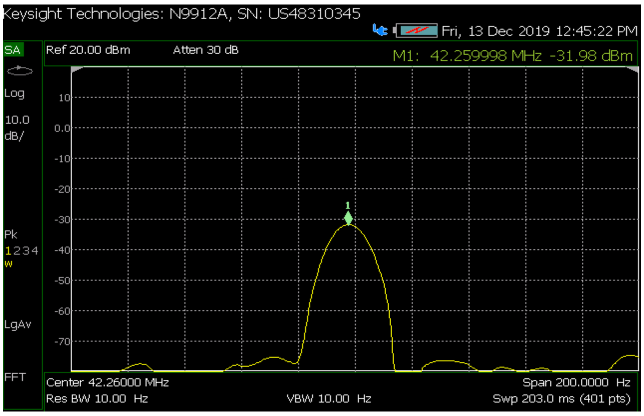
where $P_{in}$ is the signal level at the intermediate frequency (Fig. 15a)) and $P_{IP3}$ is the signal level at the third intermodulation product (Fig. 15b)).

The presented characteristics prove that the desired limits in all cases are completely satisfied. Signal pass-band is 1.5-30MHz and attenuation is at least 60dB in the stop-band (Fig.

10) for ARK 30. Also for ARK 30, VSWR is less than 2 both at system input and output (Figs 11 and 12). When considering RF signal receiver, the output filter around intermediate frequency satisfies the request that intermediate frequency is 42.5MHz with filter bandwidth at least ±2.24MHz (Fig. 13). Phase difference between receiver outputs is low i.e. coherence degree is high (Fig. 14) and linearity (*IP3*) is more than 20dBm (Fig. 15 and equation (1)).




a)




b)

Figure 15. Measured characteristics to determine linearity (crosssection for intermodulation products) of RF/IF receiver subsystem: a) attenuation at the intermediate frequency; b) attenuation at the third intermodulation product

## VI. User Interface and Software Control

ARK 30 and HF receiving subsystem with demodulator are under the control of different processors. That's why different user interfaces are defined for control of these two systems. User interface for the control of ARK 30 is presented in the Fig. 16.

First, it is possible to select the ordinary number of the antenna from the range 10-12 which have to be connected to the outputs MOUT1-3 and directed towards the spectrum surveillance system (Fig. 2). Then, the antennas from the range 1-9 are selected to be connected to the outputs RGOUT4-7 towards HF system. In the column „Napajanje LNA“ it is possible to select whether DC voltage is provided to antennas 1-9. Selection of the option „Kalibracija“ allows calibration signal to be directed to the output KLSOUT.

User interface for the control of HF receiving subsystem is presented in the Fig. 17. In the first field „RECEIVER“ it is possible to select whether data in the following fields are defined for odd or even group of RF/IF receivers. The function of the fields „PRESELECTOR“, „RF GAIN“ and „Local Oscillator“ are intuitively clear.

Multiprocessor software control in the system is based on the implementation of ARM9 processor EP9302 board in the central place both in ARK 30 and the RF signal receiver. Besides, each one of 6 RF/IF modules and the local oscillator module in the receiver have its own ARM7 processor LPC2148 which communicate with the ARM9 processor using parallel interface over back-plane (RF/IF modules) or using SPI interface (local oscillator). Software for all these processors is IRITEL original development realized in C/C++ programming language under Linux operating system. Control processor in demodulator is COTS module LattePanda also programmed by IRITEL software, while demodulation is performed in RTL-SDR. Demodulation in RTL-SDR realizes commercial readily available software.

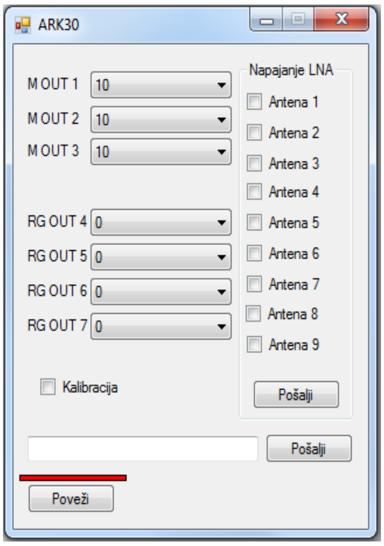



Figure 16. User interface for ARK 30

Software commands between the PC2 and Control block in HF radio receiver subsystem (Fig. 4) are defined by Standard Commands for Programmable Instruments (SCPI) protocol. There is one unique command which contains necessary data to specify the operational characteristics of all parts in local oscillator, RF/IF receiver subsystem and demodulator. This unique command consists of total 20 subcommands. Just as an example, the subcommand which is used to select input filter has the syntax:

SENSe:FREQuency:CENTer <*psel*>

where the value of parameter *psel* is between 1 and 7 depending on the desired input filter frequency range. The type of the modulated signal which has to be demodulated in demodulator is selected by the subcommand:

SOURce:DM:FORMat <*dmd*>

where the value of parameter *dmd* is in the range 1-6 depending on the modulation type: AM, FM, LSB, USB, ISB or CW.

SCPI protocol implementation simplifies creation of application programs for remote control of programmable instruments [22]. It also allows that different end users may program the desired system functionality in the same way. In the case of our system we achieved by SCPI implementation in Control block that end users may easily develop even their own functionality, not only to implement the predefined one.

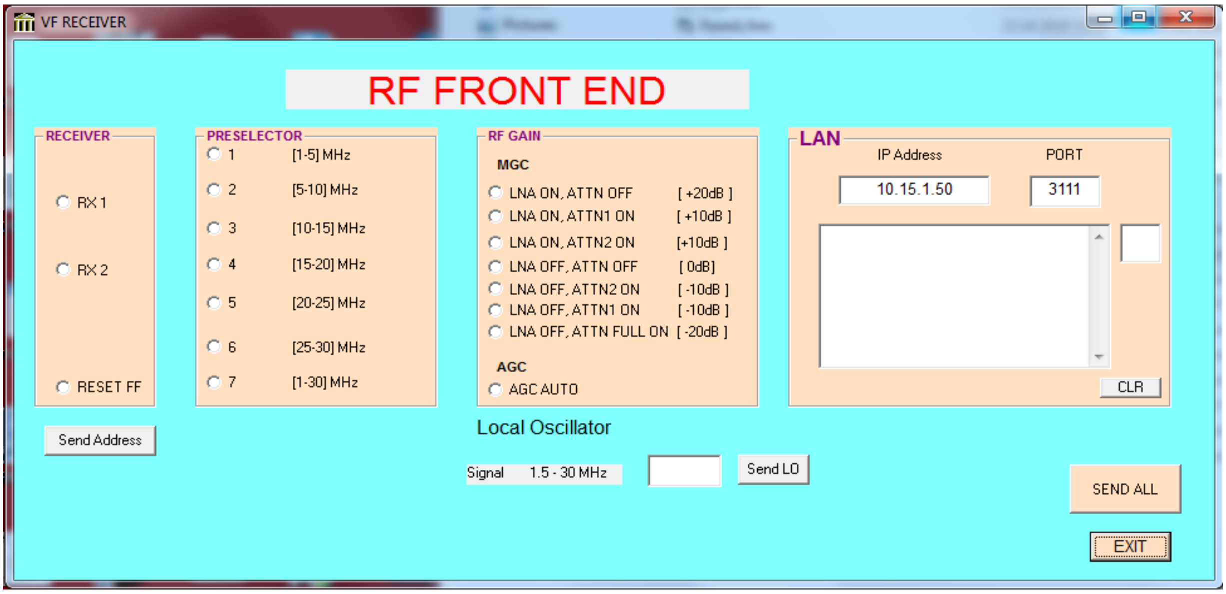



Figure 17. User interface for HF receiver

## VII. Conclusions

The radio surveillance system for high frequency spectrum monitoring and signal processing used in direction finding is presented in this paper. The system is developed using the low cost readily available commercial components. This development is the extension of IRITEL earlier systems in this area [1]–[10], [12]. The highest progress is achieved in demodulator implementation based on COTS component RTL-SDR and associated public domain software packages. Such a strategy has allowed that demodulator solution is open for future development towards easy implementation of additional signal types processing. The principles of software defined radio are implemented in software realization. Implementation of universal software protocol for system remote control allows easily alterable and user friendly programming of the applied system according to the specific needs. User interface is clear, self understandable and there is no need for special training courses to implement it. The achieved electrical characteristics satisfy very strict pre-defined limits, which is illustrated by several examples both for ARK 30 and RF signal receiver. The system is completely approved for the application in real conditions.

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