Wideband Receiver for Signal Detection in Frequency Range from 15 to 19 GHz

Sinisa P. Jovanovic, Predrag S. Manojlovic, Dragan D. Obradovic and Nemanja M. Mitrovic

***Abstract* – The paper presents the concept, realization and measured results for a receiver prototype designed for signal detection in a frequency range from 15 to 19 GHz. The characteristics of the presented unit are described in detail as well as the enhancements relative to the previously developed laboratory model. As the final result, a compact, dependable, repeatable and inexpensive device is obtained. This receiver is one of the essential parts of the device for detection of radar signals as well as others signal sources from the microwave frequency range.**

***Keywords* – Radar signal detection, receiver, microwave frequency range.**

I. Introduction

Together with the invention of the first radars emerged the need for devices which would, in real time, determine the frequency, intensity and direction of the unknown electromagnetic radiation. In the beginning, those devices, as well as radars, were heavy and complicated facilities primarily intended for use on a strategic level. However, at the same time as the development and increase in the use of radars in the preparation and executing of all sorts of battle operations, the importance of the use of the devices for their detection also increased, as well as the need for their improvement and widespread use so that in the conditions of modern warfare every vehicle or object that is the aim of radar observation could be equipped with them.

II. A Short Description of the Detection Device

Detecting and locating an unknown microwave signal in real time is not an easy task. It requires determining at least three parameters of that signal: the time of appearance, frequency and at least one spatial coordinate-azimuth. In order for the task to be realistically achievable, it is necessary to define certain tradeoffs right at the beginning. For example the observing frequency range needs to be limited to the most interesting frequencies based on experience and available data of the radars' characteristics that are planned to be observed. Also, certain limitations should be established regarding the resolution or accuracy with which the unknown frequency and azimuth are determined. The device discussed in this paper is projected for the detection of an unknown signal in the frequency range from 7 to 19 GHz, which is divided into three sub-ranges: from 7 to 11 GHz, from 11 to 15 GHz and from 15 to 19 GHz, marked on Fig. 1 and Fig. 2 as lower (L), middle (M) and upper (U) frequency ranges respectively. Thanks to that, the construction and the realization of the receiving antennas are significantly simplified by narrowing the frequency working range, of course at the price of tripling the total number of receiving antennas in the system. Another significant convenience is the possibility of using the common local oscillator for all three sub-ranges [1], which is very important considering the complexity and price of this subassembly, as well as the need for the synchronization and control of the whole system.

Fig. 1 shows the schematic of the entire device. Its antenna system is made up of 24 linearly polarized horn antennas, with 8 on every 3 sub ranges. In the azimuth plane, the antennas from the same sub range are spaced by 45°. All antennas have a 3 dB width of the main lob of 60° in both the E and H plane, which allows every antenna to cover a sector of the azimuth 45° in width. Depending on the relative position of the radiation source and radiation pattern and orientation of the receiving antennas, different levels of unknown signal will be received by the antennas of this system, which would be the base for determining the azimuth of the unknown signal by employing a special algorithm [2] in the signal processing block. The measuring accuracy, before everything else, depends on the equalized characteristics of both the horn antennas and the receiving blocks and their components. In order to enable the detection of both the horizontally and the vertically polarized signals, all the antennas are positioned so that the E-plane of their radiation pattern forms a 45° angle with the horizontal plane.

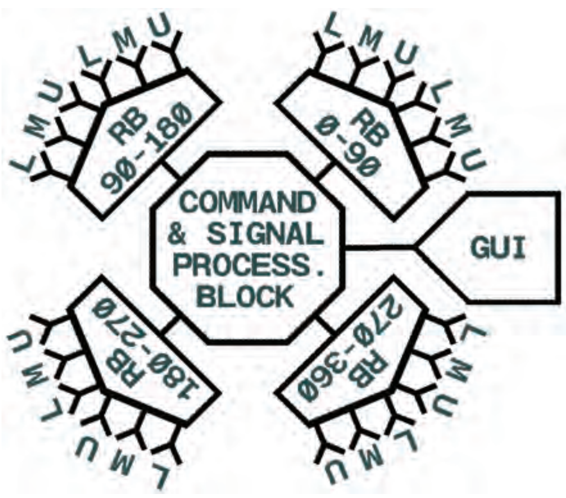

Fig. 1 The block scheme of the device for radar detection
L, M, U- receiving antennas for the Lower, Middle and Upper frequency sub-range respectively; RB xxx-xxx- receiving blocks for the related sectors of the azimuth; GUI – Graphic User Interface

The authors are with the IMTEL Communications, Blvd. M. Pupina 165B, 11070 N. Belgrade, Serbia, E-mail: siki@insimtel.com

Fig.2 shows a schematic of one of the four identical receiving blocks of the detection device, each intended to cover a 90° wide azimuth sector, for which a pair of antennas in each frequency sub range is needed. Each pair is connected to a corresponding receiver via the antenna switch. It is also possible to have a configuration of the receiver block without antennas switches, but it would require twice more of all other subassemblies. The local oscillator generates signals in frequency range from 11 to 15 GHz, with a 100 MHz step, which are divided into three samples and amplified up to the levels required for the normal operation of mixers in all three receivers.

The block for the control and acquisition directs the changes in frequency of the signal of the local oscillator and the work of the antenna switch. This block also reads the analogue values on the exit of the detector of all three receivers and communicates with the command and processing block.

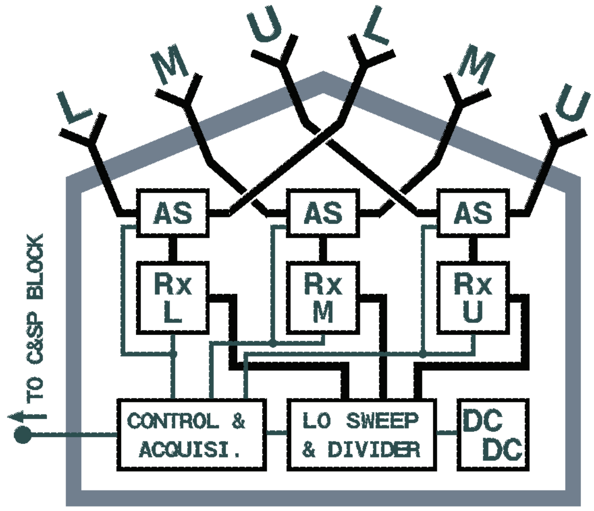

Fig. 2. The block scheme of one receiving block.
AS: antenna switches; DC/DC: power supply;
Rx(L,M,U): receivers for the Lower, Middle and Upper sub-range.

Unlike other, mentioned up to now, parts of the receiver block which are identical or common for all three sub ranges, receivers RxL, RxM and RxU are realized for each sub range separately. Although their configurations are mutually similar, they are different when it comes to working frequencies of the input band-pass RF filters as well as the IF band-pass filters. Since the length of this paper isn't sufficient for the description of all three types of receivers, in the remaining part of this paper only the receiver for the highest (upper) sub range will be presented and described.

III. Laboratory Model of the Receiver

On Fig.3 a block scheme of the laboratory model of the receiver is given, which in that phase of development was projected for a frequency sub range from 15 to 18GHz. The same picture shows an antenna switch and a wideband band-pass filter which are realized in separate housing. The low noise amplifier (LNA) shown on Fig. 4 is realized in a two-stage transistor amplifier using transistors NE3210S01 [3]. The amplifier has a gain of 14 dB with a noise figure of 3 dB.

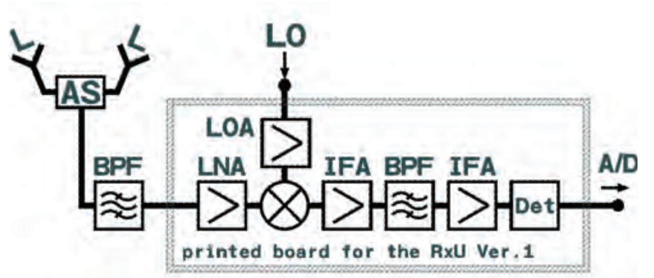

Fig. 3. A block- scheme of the laboratory model of the receiver

The LO signal is amplified with LOA (HMC441) to the level required by the mixer (HMC144) [4]. The obtained signal at intermediate frequency with two ERA1 amplifiers [5] both before and after passing through the narrow band-pass filter (fc=3 GHz, BW_{3dB}=200 MHz) made as a printed filter with slow-wave open-loop resonators [6]. The logarithmic detector [7] (Det) produces a DC signal reversely proportional to the signal level at its input, which is further processed in the control and acquisition block. The photo of the realized laboratory model of the receiver is presented on Fig. 4.

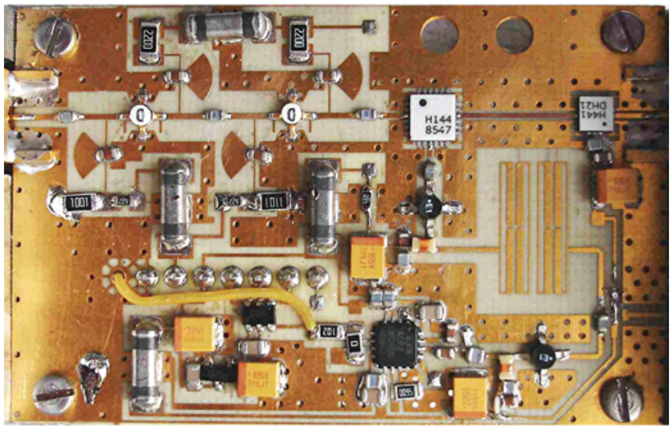
Fig. 4 Photo of the laboratory model of the receiver

The evaluation of the realized receiver usually means the excitation of its entrance with a series of signals of a known level and frequency and the reading and memorizing of the levels of the detected signal at its output. The results obtained in that way are shown on Fig.5.

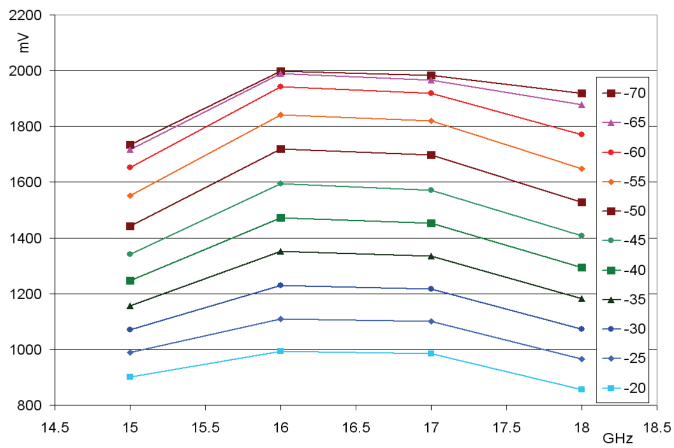

Fig.5: The measured results of the signal at output of the receiver depending on the frequency and level of the input signal

The frequency of input signals has changed from 15 to 18 GHz, with a step of 1 GHz, and level from -70 to -20 dBm, with a step of 5 dB. In the case of the ideal logarithm detector, the obtained curves would be horizontal, parallel and equidistant. The results shown on Fig. 5 reveal a decline of the sensitivity and the overall conversion gain in the centre of the working bandwidth. Comparing the results from Fig. 5 and the characteristics of the logarithmic detector AD8318 shows that this version of the receiver has quite a low overall conversion gain that vary from 0 to 3 dB over working bandwidth.

IV. THE NEW VERSION OF THE RECEIVER

The experiences gathered during the making and evaluation of the laboratory model have led to some significant improvements in the next version. Primarily, the intermediate frequency has been changed from 3 to 4GHz, which has enabled the expansion of the receiver sub range from 15-18 GHz to 15-19 GHz, respectively the expansion of the working frequency range of the whole device for radar detection from 8-18 GHz to 7-19 GHz. The next improvement was the integration of the receiver with the input band pass filter as well as the antenna switch, as shown on Fig. 6.

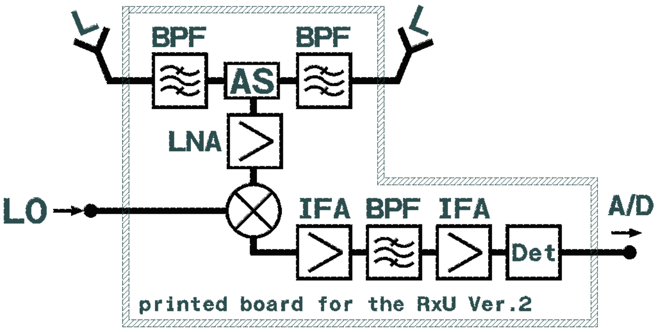

Fig. 6 A block-scheme of the prototype of the receiver

Instead of one filter behind the switch, like on Fig. 3, the new version has two filters, one behind each antenna entry of the receiver, but that hasn't changed the total entrance attenuation, or the noise factor of the receiver, nor has it changed the total size of the plate on which it is realized. The dimensions of the previous version of the receiver were 38 × 58 mm. The new version of the receiver, in spite of having an even bigger number of elements, is realized on only one board with dimensions 30 x 67 mm. All the components, except for the connector for the connection with the motherboard, are installed on one side of the board. The integration of the receiver with a band pass filer and antenna switch has significantly lowered the number of components needed for its connection with the surrounding subassemblies, which is shown in Table 1. This way, next to lowering the production costs, a significantly higher reliability of the entire device is achieved, because the number of connections that could become loose due to mechanical shocks to which the device is exposed in real working conditions is scientifically reduced.

In order for the new version to be suitable for serial production, it was necessary to design printed filters whose characteristics will be stable with variations of projected dimensions typical for available mass production technology. The printed filters which needed to be designed are: the input RF band pass filter with pass-band (1 dB) from 15 to 19 GHz (instead of from 15 to 18 GHz that was required for the previous receiver's version); as well as the IF band-pass filter having fc=4 GHz and relatively narrow (for printed filters) 3 dB-pass-band of about 150 MHz. The filters were designed and realized on substrate RO4350 (h=0.762 mm, εr=3.48, tanδ=0.0037), which is for above requirements more suitable than the substrate used for laboratory model of the receiver RO4003 (h=0.2 mm, εr=3.38, tanδ=0.003) [8]

TABLE I
REQUIRED NUMBER OF COMPONENTS VS RECEIVER'S VERSION

Component type	Receiver's version	
	v1 (lab. model)	v2 (prototype)
SMA connector	20	12
Flat connector	4	2
Semi-rigid cable	6	3
Flat cable	1	0
Mechanical case	3	1

The band pass filter is realized as a standard printed filter with parallel coupled resonators of the fourth order [9], whose dimensions are optimized with a program for electromagnetic simulation [10] to make it resistive to tolerances during production. The chosen version's characteristics stay within specified limits even for realized widths that deviate from the projected ones for ±50 µm, which makes a very big relative error considering that the minimal projected width of the lines or gaps is 120 µm.

Separate test versions of the filters are fabricated in the same time and under the same conditions as the receiver's board containing integrated filters to enable measurements of the filters' characteristics. Fig. 7 shows the measured results of the realized input band-pass test filter. Over the working bandwidth (m1 to m2), the maximum insertion loss is 1.82 dB with a variation lower than 0.5 dB (m1 and m2), while the return loss is better than -18 dB.

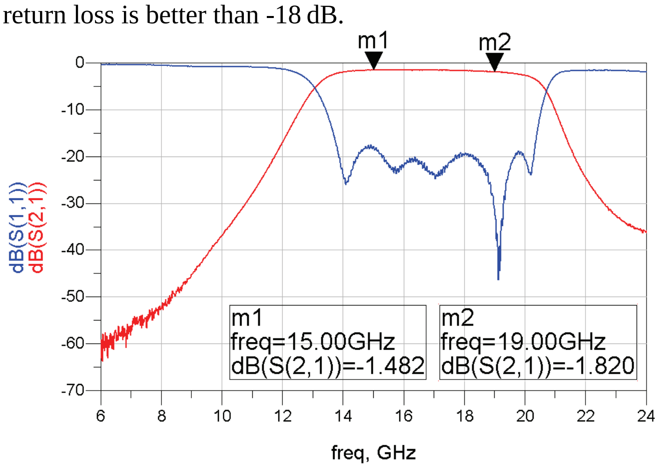

Fig.7 Measured characteristics of the input RF band-pass filter

The 3 dB bandwidth of the IF band-pass filter defines the measuring accuracy of the whole detection device. In the previous version that width amounted to 200 MHz, or 6.6% relative to the central frequency of 3 GHz. During the prototype development phase, one of the basic requirements was the narrowing of its 3dB bandwidth to at least 150 MHz with the central frequency of 4 GHz, which gives a relative bandwidth of 3.75%. Like in the previous version, the filter is realized with four resonators with an open loop [5], but the change of the substrate enabled the required narrowing of the bandwidth.

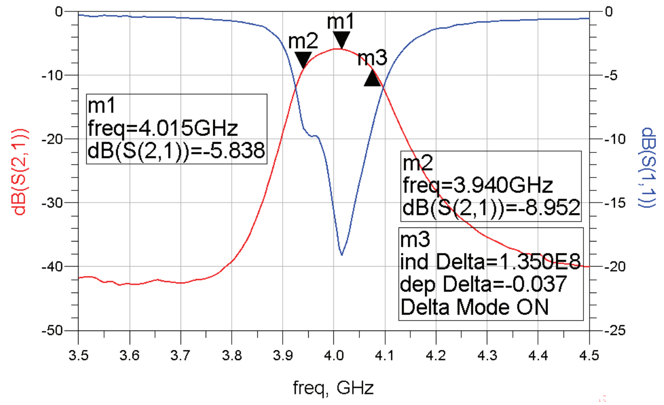

Fig.8 Measured characteristics of the IF band-pass filter

Fig. 8 shows the measured values of the frequency characteristics of this filter realized on a test board. The narrowing of the bandwidth is realized partially at the price of a somewhat bigger insertion loss at the central frequency of about 6 dB (m1). The insertion loss in the band-stop region is about 40 dB, while the 3 dB bandwidth is 135 MHz (m2 to m3).

V. Realization and Measured Results

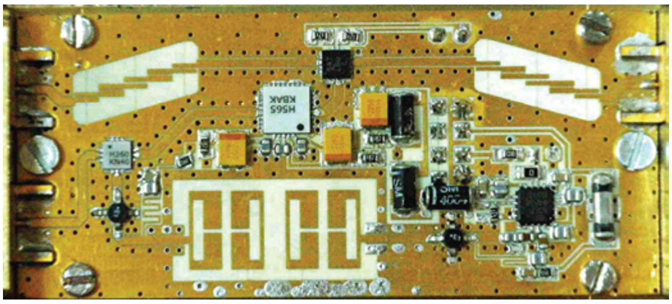

Fig.9 Photo of the prototype version of the receiver

TABLE II
MAJOR CHARACTERISTICS OF BOTH RECEIVERS' VERSIONS

Characteristics	Receiver's version	
	lab. model	prototype
Dimensions [mm]	36×56	30×67
Operating range [GHz]	15-18	15-19
Max conversion gain [dB]	3	16
Min conversion gain [dB]	0	15
Overall noise figure [dB]	12	8
Sensitivity [dBm]	-70[1]	-81
Max RF_{IN} (±1dB error) [dBm]	-5	-16
Dynamic Range [dB]	65	65
Useful dynamic range [dBm] (for max expected RF_{IN} =-30dBm)	40	51

[1]This low sensitivity is caused by low conversion gain so that the input RF signal range wasn't adjusted to the dynamic range of the logarithmic detector

Fig. 9 shows a realized prototype of the receiver, while Table II shows measured results of its major characteristics compared to the previous version.

The major improvement is increasing the conversion gain for 13dB and lowering the overall noise figure (that includes all losses between the horn antenna and the receiver) for 4dB. The higher overall conversion gain is achieved by employing an input amplifier with higher gain (HMC565) and a mixer with lower conversion loss (HMC260) [4], while the lower noise figure is mainly achieved by integration of the components and avoiding unnecessary losses in connecting cables as well as the realization of the input BPF with lower insertion loss.

VI. Conclusion

In this paper two versions of the receiver for the detection of an unknown signal are described in detail. The improvements in the prototype version, which have been achieved based on experiences with the laboratory model, are especially emphasized. The realized prototype version of the receiver has a conversion gain of 16 dB, with a noise figure of 8 dB and a sensitivity of -81 dBm. As a final result a reliable, repeatable, compact and inexpensive subassembly is obtained, which is one of the key elements of the device for the detection of radar radiation and other unknown sources of signals of microwave frequency.

Acknowledgement

The authors wish to thank to Miss Maja Jovanovic for her help in translating this paper into English.

This work is supported by the Ministry of Science and Technological Development of the Republic of Serbia.

References

[1] N. Mitrovic, D. Obradovic, S. Tasic: "High Frequency Low Cost Fast Channel Switching Synthesizer", Proceedings of 9th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Service - TELSIKS, Nis, 7-9 Oct. 2009, pp.48-51.

[2] N. Mitrovic, D. Obradovic, P. Manojlovic: "One Method Source Radiations Azimuth Finding Using Horn Antennas", Proceedings of papers, 53th ETRAN Conference, Vrnjacka Banja, 15.-18. June 2009, paper AP1.2, str.1-4.

[3] www.cel.com/pdf/datasheets/ne3210s1.pdf

[4] www.hittite.com

[5] Hong, J.-S., and Lancaster, M.J.: 'Theory and experiment of novel microstrip slow-wave open-loop resonator filters', IEEE Trans. Microw. Theory Tech., 1997, 45, (12), pp. 2358–2365

[6] www.minicircuits.com/pdfs/ERA-1+.pdf

[7] www.analog.com

[8] www.rogerscorp.com

[9] Ian Hunter: "Theory and Design of Microwave Filters", University Press, Cambridge, 2001.

[10] IE3D User's Manual, Zeland Software Inc.