A Miniature Surveillance 8-40 GHz Radar Detector -The Milestone Project of the Institute for Applied Physics in 1978

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Abstract: – **The paper presents the concept, the design and the obtained results of the microwave surveillance radar detector for 8-40GHz range. The detector was realized in 1978 on soft dielectric substrate using gold epoxy bonding for microwave components mounting. The detector consists of three units: two microwave integrated modules, covering two ranges (8-18 GHz and 18-40GHz), and the signal processing unit. The sensitivity (TSS) for the first module (8-18GHz) is between -60 and -68dBm/cm^2 (average power density), and between -52 and -66dBm/cm^2 for the second one (18-40GHz). Total sensitivity, after signal processing is 20dB better than TSS achieving from -80 to -88dBm/cm^2 for 8-18 GHz module, and from -72 to -86dBm/cm^2 for 18-40GHz module. The beam width in H-plane is between 20° and 45°, and in E-plane between 50° and 80°.**

I. INTRODUCTION

This work presents main results of research and development of a miniature surveillance radar detector for 8-40GHz band. This research was financed by the former Yugoslav Army through the Project PRD-01, 26 years ago (in 1978). At that time microwave radar detectors were designed in waveguide technology and among them a very popular one was TAPIRON produced by Thomson, France, also used by the NATO.

Former Yugoslav People's Army initiated development of the Yugoslav version of the detector with companies of *Iskra*, Slovenia and *Rudi Cajevec*, Bosnia and Hercegovina. They tried to make a copy of TAPIRON, but probably due to technological problems, their copy had degraded characteristics in comparison to the original equipment.

At that time, the Institute for Applied Physics presented its first detector modules, with fully original integrated solutions. Microwave modules consisted of wideband printed antenna, PIN modulator, very sensitive detector and feeding network between them. Compared to the well-known conventional solutions, these modules had considerably smaller weight and dimensions: 55×30×10mm, for the 8-18GHz range and 42×20×6mm, for the 18-40GHz range. The dimensions of the whole device were Ø120mm×100mm. The high sensitivity of the detectors enabled the radar signals detection within much longer distance than those of radar detection. All microwave parts including antenna array were realized in printed technology on soft dielectric substrates and the microwave components were epoxy bonded. At that time, application of soft substrates at millimeter ranges was not yet accepted nor it was epoxy bonding of components in military solutions that were to fulfill strict climatic and mechanical standards.

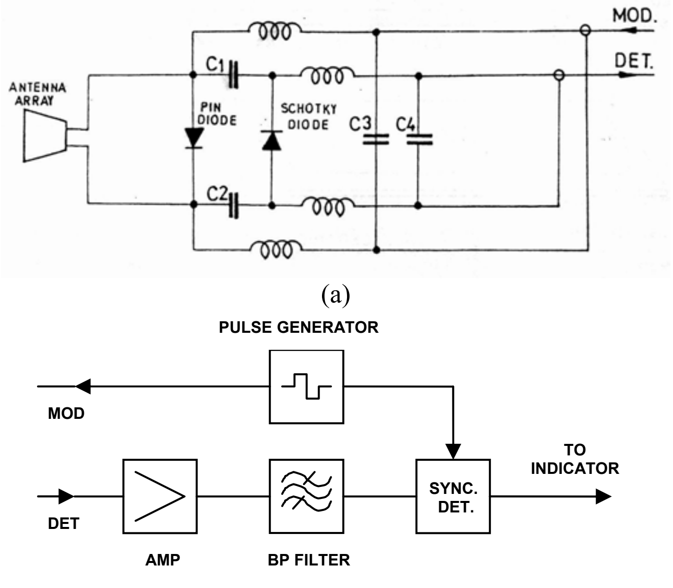
However, military technical experts were doubtful about feasibility of suggested solution since they had no references (it never existed before) in the literature. Finally, in June 1978 the Main Military and Technical Council, which included five high-ranking generals, accepted the solution of Portable Radar Detector (PRD) in 8-40GHz frequency range offered by the Institute of Applied Physics, despite of disagreement with the representatives of Military Technical Institute. It was a milestone in acknowledging the Institute of Applied Physics among the most respectable research institutions by the military authorities.

The research team that was engaged in this project included Aleksandar Nesic, head of the project, Branka Jokanovic, Radoslav Rakar, Dusan Bozovic and Momcilo Tasic. In spring 1979 the radar detector passed rigorous climatic and mechanical tests at the Military Technical and Experimental Center and was included as a regular part of the armament of the Yugoslav People's Army. Technological development of the detector was led by Nenad Popovic. A large number of these radar detectors were produced at the factory of *Prvi decembar* at Pljevlja.

II. PRINCIPLES OF OPERATION

The microwave signals from printed antenna array go to pulse modulator and after modulation to microwave detector. Before it is detected by synchronous detector obtained pulse signal is led to the amplifier and a very selective band–pass filter.

For modulation we are using PIN diodes and for microwave detecting sensitive Schottky diodes. Equivalent circuit of the microwave module is shown in Fig.1a. The layout of the same circuit is shown in Fig. 3, while its photo is shown in Fig. 4b.



(a)

(b)

Fig.1. (a) Equivalent circuit of the microwave module; (b) Block diagram of the signal processor.

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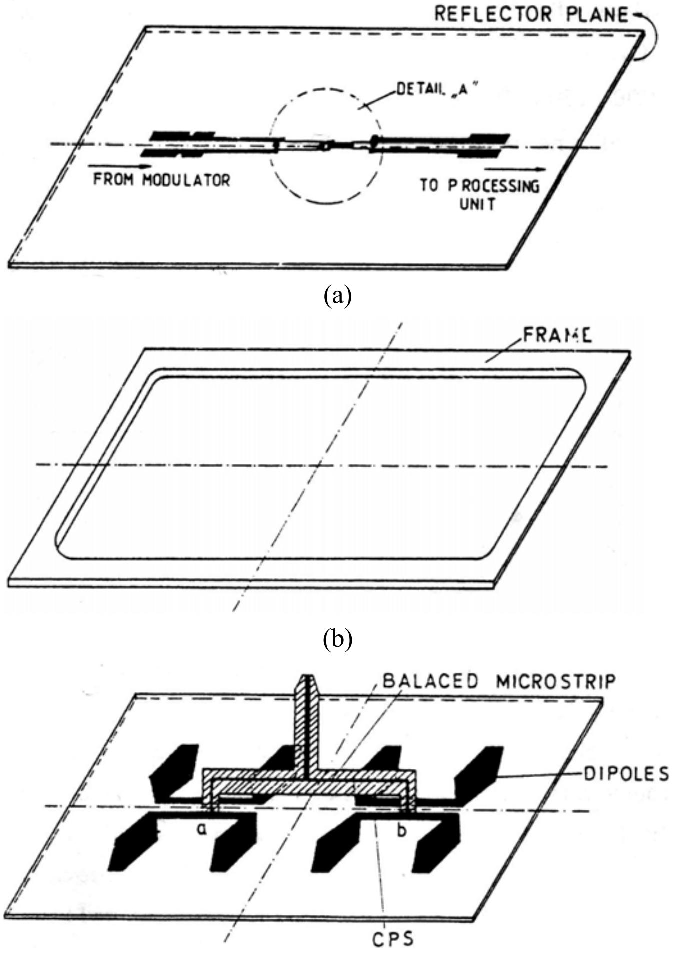
III. THE MICROWAVE MODULES

Both microwave modules (for 8–18GHz and 18–40GHz ranges) are designed using the same concept.

One of the main problems is concept of printed antennas with frequency range beyond one octave. In reference [1], the author of this paper explained the solution for printed wideband antenna in frequency range between 8GHz and 18GHz. Gain of the antenna had variation from 6dBi to 10.5dBi, including losses in transitions between symmetrical and unsymmetrical microstip (bal-un) and coaxial connector. VSWR was between 1.2 and 2.2.



(a)

(b)

(c)

Fig.2. Exploded view of the microwave module with: (a) reflector plane with modulator and microwave detector on the opposite side of the dielectric substrate; (b) frame (between antenna array and reflector plane); (c) antenna array with feeding network;

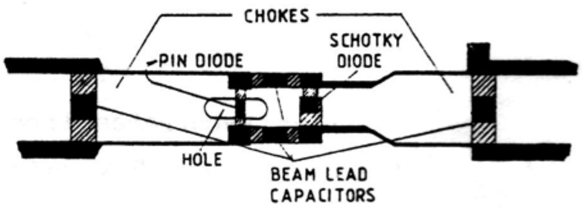
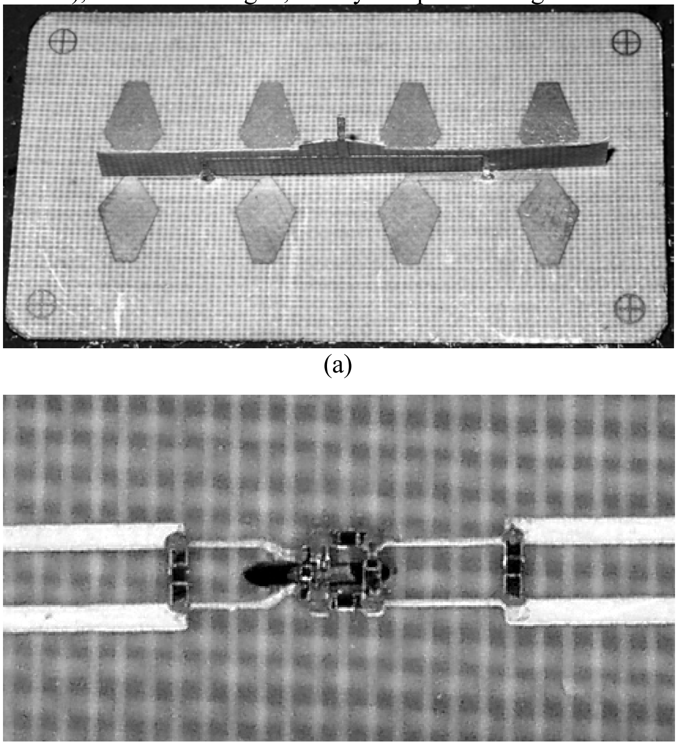


Fig. 3. Detail "A" of the modulator and microwave detector.

Antennas for microwave detector were practically the same to the antenna in reference [1] (but without bal-un) and consisted of two pairs of dipoles of pentagonal shape printed on Teflon-fiberglass substrate. The pair of dipoles were coupled by coplanar strips (CPS) placed on the same side of the dielectric substrate. The medium impedance of the printed pentagonal dipoles (in corresponding frequency range) was near to the characteristic impedance of the coplanar strips (200 ohms). Pentagonal dipoles worked in the second resonance.

The feeding network for both pairs of dipoles was accomplished with a symmetrical (balanced) microstrip on a different board, which was mounted perpendicularly on the antenna plate. The feeding network consisted of T–junction between two balanced microstrip lines with characteristic impedance (Zc) of 100Ω and main feeding line with Zc=50Ω, Fig.2c and Fig.3a. The transition from the balanced microstrip to CPS was accomplished by soldering in points **a** and **b**, Fig. 2c. In such a way the synphase supply of the microwave dipoles is accomplished.

The metallization on one side of the dielectric substrate, placed behind the antenna plane played the role of reflector plane, while the other side of the reflector plane was used for mounting of PIN modulators (with MA 47301 beam-lead diodes) and Schottky detectors (with DDB 4504 beam-lead diodes), as shown in Fig. 3, and by the photo in Fig. 4b.



(a)

(b)

Fig. 4. (a) Photo of antenna array with feeding network; (b) modulator and microwave detector.

The symmetrical (balanced) microstip line from antenna array penetrated through the hole of the reflector plane and coupled with PIN modulator circuit, Fig. 3 and Fig.4b. The coupling with the detector circuit was designed using two beam lead capacitors with small capacitance (8.2 pF) in order to isolate Schotky diode from the modulation signal, Fig 3 and Fig 1a. All microstrip circuits are designed using approximate methods [2, 3]. The input modulation signal was applied via symmetrical thin microstrip lines which figured as chokes, Fig. 3. The same solution was used for output of detected signals. In order to operate in the highest sensitivity the bias current for the Schottky diode was 50 µA. The modulator input and detector output ends were blocked by beam-lead 8.2 pF capacitors.

Fig. 5. shows assembled microwave module for frequency range from 18 to 40 GHz.

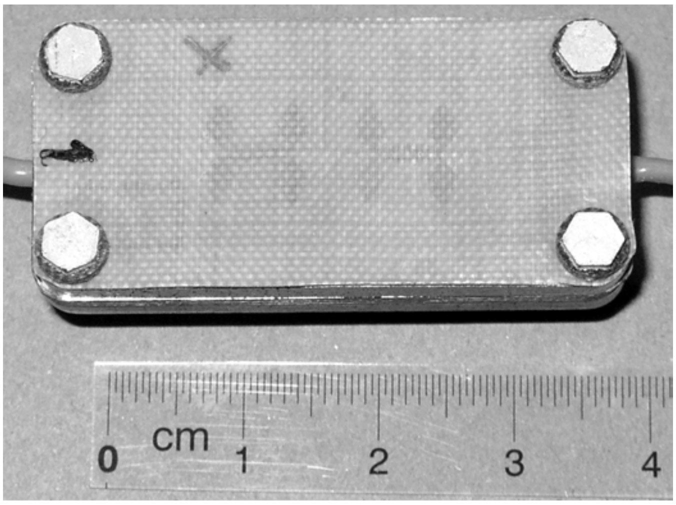


Fig. 5. Module for 18-40 GHz frequency range

IV. OBTAINED CHARACTERISTICS

Measurements are performed with a set of calibrated horn antennas that cover the range from 8GHz to 40GHz and are placed at 4m distance (far zone). Threshold of detector's sensitivity is defined by the average power density (expressed in dBm/cm^2), which is necessary to activate the detector's inductor.

TABLE 1
OBTAINED CHARACTERISTICS OF THE MICROWAVE/MILLIMETER WAVE DETECTOR

	8-18 GHz Module	18-40 GHz Module
Beam width in H-plane	20º to 40º	20º to 45º
Beam width in E-plane	50º to 70º	50º to 60º
Power density for TSS [dBm/cm2]	-60 to -68	-52 to -66
Average power density for the detect. threshold w/process. unit [dBm/cm^2]	-80 to -88	-72 to -86

V. SUPPLEMENT

At the time of research and development of this microwave detector there was any program for computer-aided design of microwave circuits. Shape and size of printed dipoles were determined partly experimentally. Also CPS modulator and microwave detector were determined using approximate methods. This supplement presents characteristics of antenna from ref. [1], measured 26 years ago and simulations of model shown on Fig. 6. obtained by 3D electromagnetic solver WIPL-D Pro [4] that includes losses in metallization and in dielectric substrate. Fig. 7. and Fig. 8. show WIPL-D simulations of VSWR at the input of the feeding network and of the total gain of antenna array respectively.

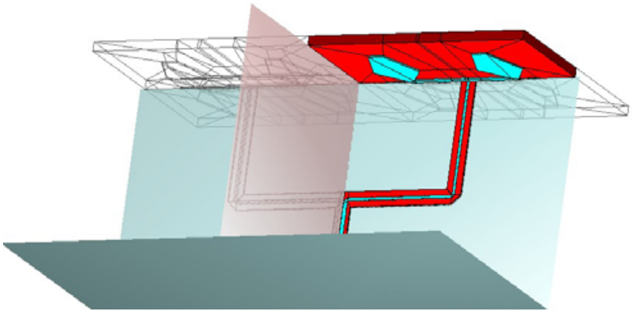


Fig. 6. Preview of WIPL-D model with two symmetry planes and a reflector plate. (Note: The length of the feeding network is extended for better visibility)

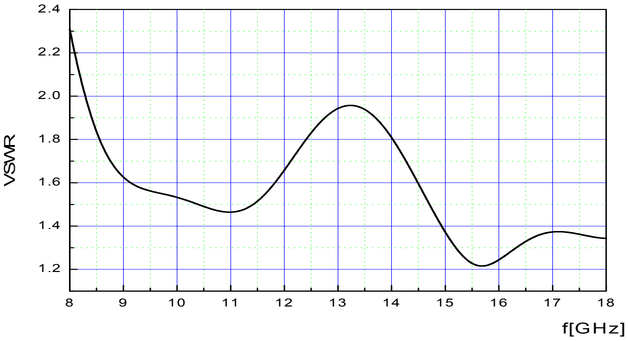


Fig. 7. Simulated VSWR at the input of the feeding network

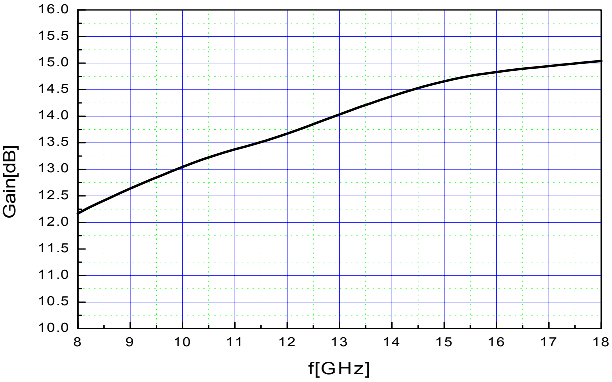


Fig. 8. Simulated Gain of the antenna array

It can be seen from Fig.9.-Fig.12. that there is a good agreement between measured and simulated side lobe levels at all frequencies. A good agreement is also observed in the position of nulls, although simulated radiation pattern has deeper nulls due to the influence of the plastic frame that was not included in simulation. Noticed, comparatively small, distortion of the radiation pattern is a consequence of measurement of the antenna array with incorrectly realized bal-un. As a matter of fact, the feeding network of the antenna array in the microwave module is coupled with modulator and detector (which are symmetrical) through symmetrical (balanced) microstrip line, so that no bal-un is needed.

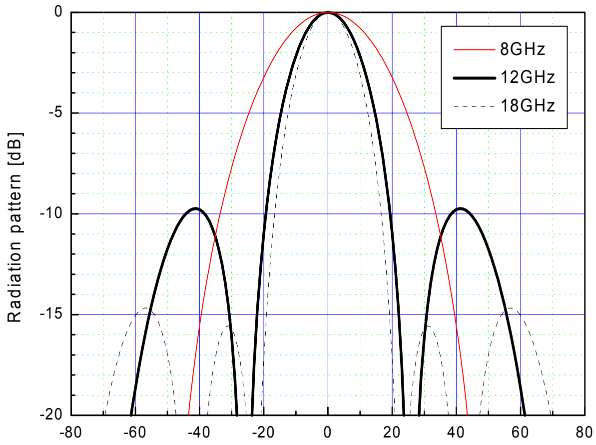


Fig. 9. Simulated H-plane radiation pattern vs. θ[º]

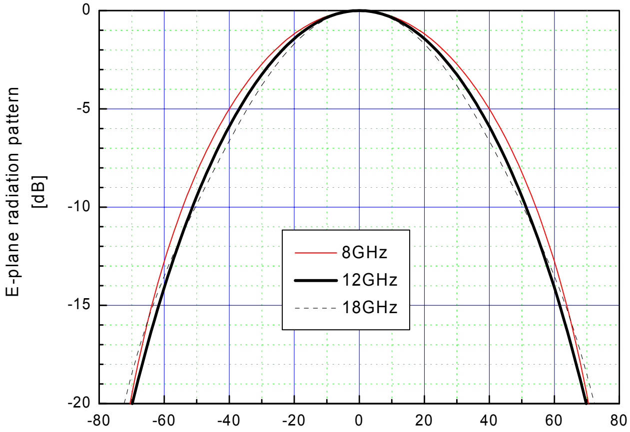


Fig. 10. Simulated E-plane radiation pattern vs. θ[º]

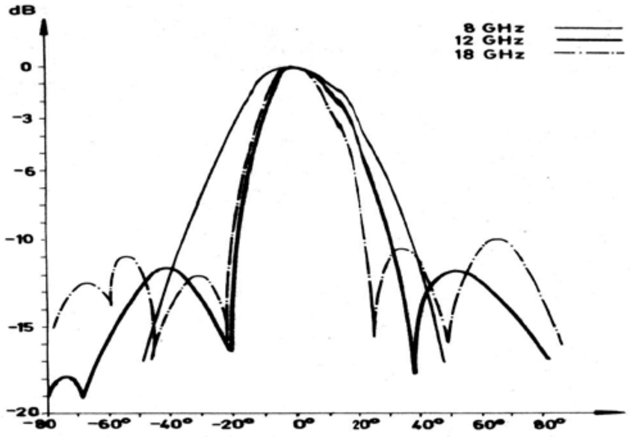


Fig. 11. Measured H-plane radiation pattern vs. θ[º] (June 1978)

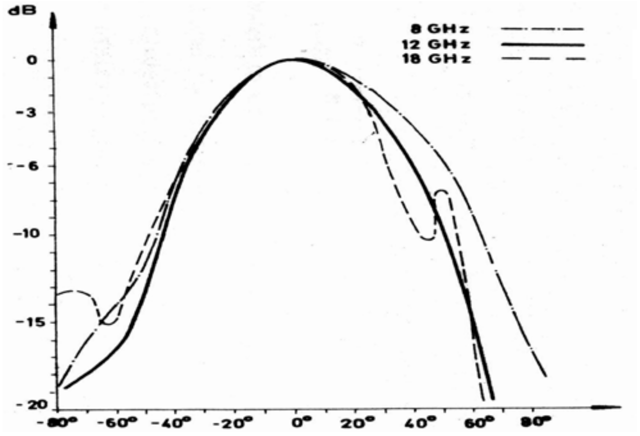


Fig. 12. Measured H-plane radiation pattern vs. θ[º] (June 1978)

VI. CONCLUSION

The miniature surveillance radar detector for the 8-40 GHz frequency range, realized in 1978 (26 year ago) has been presented. There are two basic detector units – microwave modules for two frequency bands: 8-18 GHz and 18-40 GHz. Both modules are designed using the same concept and consist of: wideband antenna array, feeding network, PIN modulator and microwave detector. Antenna arrays and all other microwave circuits are designed in printed techniques on soft dielectric substrate. All microwave components were epoxy bonded. Modules are rotated 45 degrees in detector case due to receiving both linear and circular polarization. Sensitivity threshold in the whole frequency range was between -72dB/cm^2 and -88dB/cm^2. The overall sensitivity is 20 dB better then TSS (tangential sensitivity) because we have used signal processor with synchronous detector. The advantages of the presented solutions, comparing to the conventional ones, at that time (1978) were: high reproducibility, small dimensions and smaller weight.

The antenna array of pentagonal dipoles printed on dielectric substrate with feeding network was designed by approximation and experimental methods, without using any computer-aided design.

This paper has also demonstrated radiation pattern of antenna array measured 26 years ago and simulated now by use of WIPL-D Pro program package. In order to simulate antenna array with complete feeding network we spent two days now, in a difference to months of hard work that we spent 26 years ago to design, measure and correct detector modules.

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