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VACUUM MICROWAVE INTEGRATED CIRCUITS AS A TOOL FOR PROTECTION OF RADAR AND COMMUNICATION RECEIVERS AGAINST HIGH POWER EMI AND IONIZING RADIATION

KONSTANTIN A. LUKIN

Vacuum microwave integrated circuits (VMIC) has been suggested for design of radar front-end to provide its high resistance against ionizing radiation and high power electromagnetic impulse radiations. We describe general approach to the suggested VMIC design and give preliminary results of its possible implementation and future applications.

Keywords: vacuum microwave integrated circuits, noise radar front-end, electromagnetic impulse, ionizing radiation.

1. INTRODUCTION

Semiconductor based technology dominates in nowadays radar and telecommunication systems, in particular, in their receiver units since they are designed on the basis of semiconductor chips, diodes, transistors and microwave integrated circuits (MMIC). However, all semiconductor based devices are rather sensitive to exposure of both ionizing radiation and high power electromagnetic signals [1]. The latter is especially important nowadays in the antiterrorism context. To enhance resistance of radar and communication systems against both ionizing radiation and high power electromagnetic impulse (EMI) radiation the idea of Vacuum Microwave Integrated Circuits (VMIC) design has been suggested [2] for application in radar front-end. It is worth of noting that this is a *new* application of microwave vacuum electronics. It is well known that vacuum electronic devices are much more resistant against ionizing radiation and high power electromagnetic fields. Actually the idea of devising vacuum microelectronic devices is a very old one [3]. As it was noticed in [3], about 40 years ago, K.R. Shoulders of Stanford Research Institute (SRI) presented a device concept in his article entitled "Microelectronics using electron-beam-activated machining techniques" [4]. At that time, the known today micro fabrication technology did not exist. Nevertheless, K. R. Shoulders, proposed "to devise vacuum tunnel effect devices of micron sizes with switching times in 0.1ns that (i) operate at 50 V, (ii) have high input impedance, (iii) are insensitive to temperature effects up to 1000 °C, (iv) are insensitive to ionizing radiation effects up to the limits of the best known dielectric materials, and (v) have a useful lifetime of many hundreds of years." However absence of mature technology for micro fabrication of vacuum devices and appearance at the same year (!) of the first results on semiconductor integrated circuits (IC) and further great success in their developments has blocked elaboration of that idea and did not draw proper attention to that paper. At the same time, nowadays Vacuum Microelectronics demonstrates significant achievements in the areas of both field emission cathodes and microwave devices exploiting these cathodes. The results obtained encourage researchers to extend applications areas for Vacuum Microelectronics.

Recently a new gate-insulated *vacuum* channel transistor has been designed, fabricated and tested [11], which combined advantages of the vacuum tube and transistor and showed significant potential of nowadays technology for vacuum microwave integrated circuit design.

In the paper we describe general approach to design and feasibility study of VMIC for radar and communication applications.

2. VMIC FOR CW RADAR

Usually, application of vacuum electron devices is associated with generation of high power microwave signals by vacuum electron devices, such as magnetron, klystron, gyrotron, BWO, FEL. We suggested a new area of vacuum microelectronics application where high power of the generated signals is NOT required, but vacuum electronics technology is needed. We suggest design of VMIC for Radar and Communication applications.

The main idea of the VMIC consists in substitution of all semiconductor components in radar RF front-end with their vacuum analogues and use microminiaturized waveguides and/or co-axial lines for electromagnetic signals propagation between all active devices and VMIC Input/Output connectors. In this way, VMIC for radar RF front-end will require to use only two RF vacuum isolated Inputs for the reference and radar returns; two Intermediate Frequency (IF) outputs for IF copies of the reference and radar returns and certain number of DC inputs to deliver the required voltage to the active electronic devices inside the VMIC.

To the active devices needed for design of radar RF front-end we may relate the following: Local Oscillator for the frequency down conversion of both the reference signal and radar returns; mixing diodes, triodes or transistors; Low Noise Amplifier; IF amplifier, etc. Design of the VMIC will also require a set of passive components, such as: waveguides; co-axial lines, RF and IF filters; 3dB splitters; ferrite isolators and circulators; waveguide flanges; vacuum isolation components; vacuum DC voltage connectors, etc.

The most appropriate candidates for Local Oscillator are miniaturized low voltage Reflecting Klystron or Diffraction Radiation Oscillator (Orotron). Vacuum transistor [11] may be used for design of LO as well provided mature technology being available. A Travelling Wave Tube or Backward Wave Oscillator may be used as a good basis for design of miniaturized Low Noise Amplifier, while vacuum diode or triode may serve as the basis for design of RF signal mixers. Field emission cathodes are to be used as a source of electron beams for the above active devices. We suppose application of available etching technology for fabrication of waveguide filters, RF power splitters, and other passive components when implementing the VMIC. Important issues of DC power supply and VMIC cooling are much easier to solve in the case of VMIC compared to the case of high power vacuum devices. This is because successful operation of VMIC radar front-end may be performed with rather low level of RF signals and therefore one has to use reasonably low currents which make the cooling problem much easier provided negligible electrons interception by the miniaturized vacuum devices electrodes. At the same time in case of the need in cooling both water and air cooling may be readily implemented.

As an example of VMIC design we present description of coherent double channel frequency down converter for Continuous Wave (CW) Noise Radar [5, 6]. Its block-diagram is shown in Fig.1.

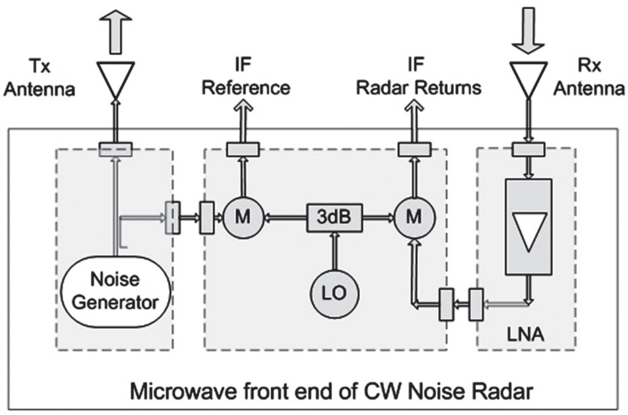

Fig. 1. Schematic of microwave front-end of CW Noise Radar: LNA is Low Noise Amplifier; LO is Local Oscillator; M is mixer

The microwave front-end for CW Noise Radar may be implemented as a single circuit on the basis of microwave vacuum electronics and deep-etch X-ray lithography [7]. Reflecting klystron [8] should be used for design of Local Oscillator (Fig.2 and Fig.3).

Nonlinear vacuum triodes [9] may be used as RF signal Mixers for down conversion of the frequencies of radar returns and reference signals. Weak Resonant BWO [10] is a good candidate for Noise Generator design, while miniaturized TWT is to be used for design of Low Noise Amplifier. In all devices the carbon nanotube cathodes should be preferably used to produce electron beams required. However at the first stage of VMIC design well studied thermo cathodes may be also used. Moreover these types of cathodes demonstrate higher current stability as compared to carbon nanotube cathodes.

The required transmissions of microwave signals between those devices are to be done via miniaturized waveguides. To increase the working frequency bandwidth and avoid cut-off frequencies we may use vacuum coaxial transmission lines rather than rectangular waveguides.

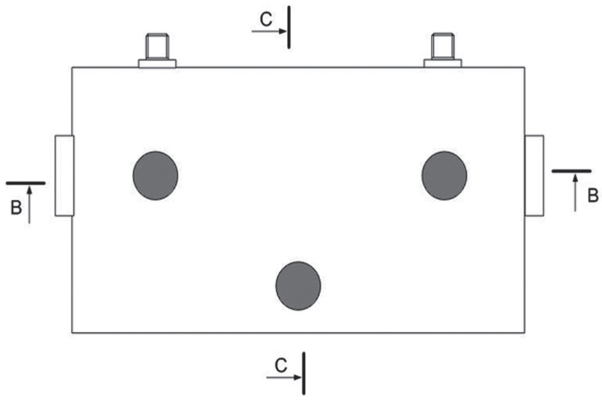

Fig. 2. Appearance of vacuum microwave integrated circuit for CW Noise Radar Frequency Down Converter: dark circles and rectangles show miniature focusing magnets

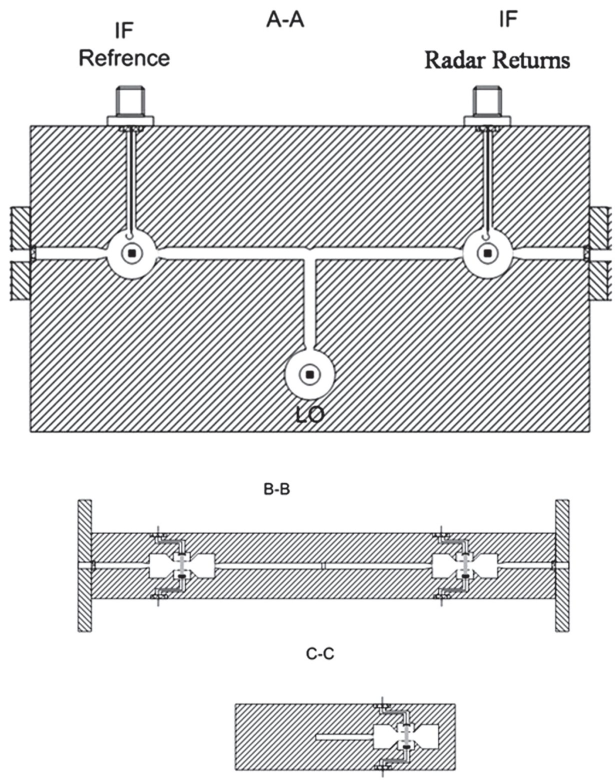

Fig. 3. Three cross-sections (indicated in Fig.2) of vacuum microwave front-end for CW Noise Radar Frequency Down Converter

In this way, it is feasible to implement microwave front-end for CW Noise Radar as a single vacuum circuit containing all the required active electron devices, transmission lines and connectors, which may be called as suggested: ***Vacuum Microwave Integrated Circuit (VMIC).***

We see the following particular areas of future applications for VMIC in Radar:

- RF front-end of Radar and Communication receivers designed for operation in hostile environment, such as high level of ionizing radiation (e.g. after nuclear bomb explosion) or High Power Electromagnetic radiation.
- RF front-end of Radar and Communication receivers capable to resist a terroristic attack by electromagnetic impulse generated with the help of Magnetic Cumulative Generators (MCG).
- Microminiaturized RF front-end for Radar Sensor and Navigation equipment mounted in Unmanned Robotic Vehicles, in particular Unmanned Combat Aerial Vehicle (UCAV).
- Imaging Radar with signal processing at carrier frequency based upon VMIC "generator+ phase modulator" arrays.
- Design of Radar front-end for systems operating in sub-THz and THz frequency bands on the basis of VMIC with oversized quasi-open transmission lines and resonators.

3. CONCLUSIONS

We suggest innovative application of vacuum microwave electron devices, namely for design of miniaturized radar front-end rather than its application as a sources of high power microwave radiation. It has the advantage of high resistance against both ionizing radiation and high power EMI radiation compared to semiconductor based radar RF front-end. Brief description of general design of the VMIC suggested is presented. Besides in the future paper we shall describe in more detail design of the miniaturized vacuum microwave devices such as klystrons, DRO, triodes, transistors and will give preliminary results of its feasibility study and possible implementation.

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Konstantin Lukin, Dr. of Sci., Professor, Fellow IEEE; Head of the Laboratory for Nonlinear Dynamics of Electronic Systems, Usikov Institute for Radiophysics and Electronics NAS of Ukraine; ICTP Senior Associate; Head of the Task Group on "Capabilities of Noise Radar" at the RTO/NATO. Research interests: Dynamical Chaos in electronic systems; noise generators; random signal processing; Software Defined Radar; Noise Radar; Ground Based Noise Waveform SAR for remote sensing and pre-catastrophic stage detection.

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Вакуумные микроволновые интегральные схемы как средство защиты радаров и приемников связи от мощного электромагнитного излучения и ионизирующей радиации / К.А. Лукин // Прикладная радиоэлектроника: науч.-техн. журнал. – 2012. – Том 11. – № 4. – С. 498–500.

Вакуумные микроволновые интегральные схемы (ВМИС) были предложены для применения в высокочастотной части радаров, чтобы обеспечить их высокую устойчивость к ионизирующей радиации и мощному электромагнитному излучению. Мы описываем общий подход к проектированию предложенных ВМИС и приводим предварительные результаты их реализации и перспективы будущих применений.

Ключевые слова: вакуумные микроволновые интегральные схемы, микроволновая часть шумового радара, электромагнитный импульс, ионизирующее излучение.

Ил. 3. Библиогр.: 11 назв.

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Вакуумні мікрохвильові інтегральні схеми як засіб захисту радарів і приймачів зв'язку від потужного електромагнітного випромінювання та іонізуючої радіації / К.О. Лукін // Прикладна радіоелектроніка: наук.-техн. журнал. – 2012. – Том 11. – № 4. – С. 498–500.

Вакуумні мікрохвильові інтегральні схеми (ВМІС) були запропоновані для застосування у високочастотній частини радарів, щоб забезпечити їх високу стійкість до іонізуючої радіації та потужного електромагнітного випромінювання. Ми описуємо загальний підхід до проектування запропонованих ВМІС і наводимо попередні результати їх реалізації і перспективи майбутніх застосувань.

Ключові слова: вакуумні мікрохвильові інтегральні схеми, мікрохвильова частина шумового радару, електромагнітний імпульс, іонізуюче випромінювання.

Іл. 3. Бібліогр.: 11 найм.