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# MPPT Charge Controller Design in a Solar PV System under Rapidly Changing Climate Condition

By Mostafizur Rahman & Md. Mahmudur Rahman

*Daffodil International University*

**Abstract-** This paper presents a detailed theoretical study of photovoltaic (PV) systems and their operation using the MPPT (Maximum Power Point Tracking) method and presents the simulation of photovoltaic modules validated by computer software simulation followed by an experimental setup of MATLAB R2017a. The first approach to build the performance of a photovoltaic solar panel is to use a maximum power point tracker in rapidly changing climatic conditions and use a DC-DC converter to maximize the output power. This framework can operate at the maximum power point MPP and produces its highest power in different irradiance conditions when the solar panels are partially shaded. The main perspectives is design and simulation of a simple but efficient charge controller by utilizing maximum power point tracker for photovoltaic system and analysis results show that this MPPT system with perturb & observe (P&O) method and the DC-DC Boost converter can significantly increase the efficiency and the performance of PV.

**Keywords:** photovoltaic (pv), perturb and observe (p & o) method, maximum power point tracking (MPPT), dc-dc converter, boost converter.

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# MPPT Charge Controller Design in a Solar PV System under Rapidly Changing Climate Condition

Mostafizur Rahman <sup>α</sup> & Md. Mahmudur Rahman <sup>ο</sup>

**Abstract-** This paper presents a detailed theoretical study of photovoltaic (PV) systems and their operation using the MPPT (Maximum Power Point Tracking) method and presents the simulation of photovoltaic modules validated by computer software simulation followed by an experimental setup of MATLAB R2017a. The first approach to build the performance of a photovoltaic solar panel is to use a maximum power point tracker in rapidly changing climatic conditions and use a DC-DC converter to maximize the output power. This framework can operate at the maximum power point MPP and produces its highest power in different irradiance conditions when the solar panels are partially shaded. The main perspectives is design and simulation of a simple but efficient charge controller by utilizing maximum power point tracker for photovoltaic system and analysis results show that this MPPT system with perturb & observe (P&O) method and the DC-DC Boost converter can significantly increase the efficiency and the performance of PV.

**Keywords:** photovoltaic (pv), perturb and observe (p&o) method, maximum power point tracking (mppt), dc-dc converter, boost converter.

## I. INTRODUCTION

Global temperature changes have become a major problem in global warming in recent years. In addition to energy demand, there is also an exponential increase. This increase in demand causes concern about the global energy crisis and environmental threats. Many countries are concerned to reduce their ozone-damaging emissions and to continue their efforts to improve the energy system. Renewable energy sources see how these problems are solved. In 2017, an estimated 17 countries generated more than 90% of their electricity from renewable sources [1]. Solar energy is considered to be one of the most important renewable sources available in abundance, free of pollution and free of charge in remote areas where there is still no electricity. [2]-[3].

Solar power extracted from solar photovoltaic (PV) cells delivers low efficiency [4]. Because of these problems, it is important to extract maximum power from solar photovoltaic cells and improve efficiency in different weather and temperature conditions. An MPPT

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or Maximum Power Point Tracking is an electronic tracking device usually digital DC to DC converter which is connected between solar panels and battery or the utility grid that optimizes the match between the solar array (PV panels), and the battery bank or utility grid. It monitors the PV array for the maximum power point and tries to use this information not only to control the output voltage of the PV array but also to control the current. Typically, this means that the voltage is reduced while the current is increased and most of the overall output power is maintained. In this research with the MPPT controller, we used P&O algorithm that has a conversion efficiency of 95%. Output gain varies greatly due to partial shading, bad weather condition, temperature effect, battery charging state, and other consideration.

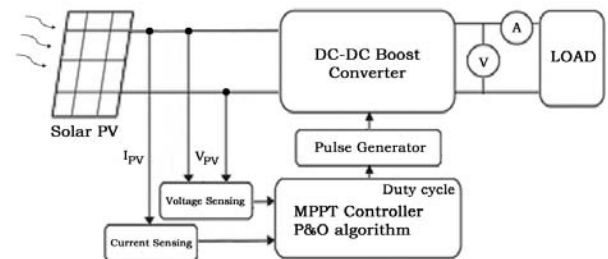


Fig. 1: Maximum power point tracking controller

## II. METHODOLOGY OF PV SYSTEM

A typical MPPT and PV system consists of photovoltaic array modules. The designing ideas first come from the Photovoltaic cell (PV cell) or solar cell which can absorb light from the sun and that transmitted to the absorber layer and converted into electrical energy, the process known as the photoelectric effect. An electrical circuit that contains only a current source ( $I_L$ ) and a diode (D) can represent an ideal solar cell. In real life, however, there is no ideal solar cell so that with the proposed model there is series and shunt resistance ( $R_S$ ,  $R_{SH}$ ) added.

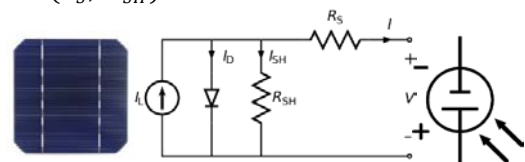


Fig. 2: Photovoltaic Cell, Equivalent circuit and Schematic representation

### a) Characteristic Curve of PV Cell

IV-curve which represents the performance of a solar cell demonstrated by measuring its current and voltage employed on the device and defined for a unique set of temperature and irradiance conditions. For example, if the irradiance (G) increases, the IV curve improves, but the temperature (T) increase leads to a worse IV curve and vice versa[5].

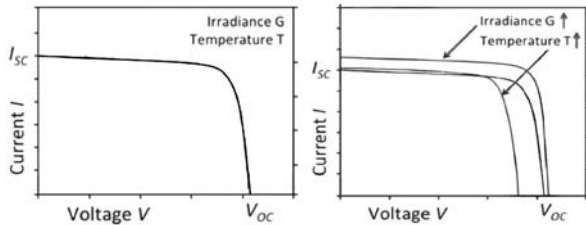


Fig. 3: Simple IV-Characteristic curve (Left), At different Irradiance and Temperature condition

There are three important points:

- Open circuit voltage ( $V_{OC}$ ), Output to the cell is open circuit. The cell generates voltage only, but the current is zero ( $I=0$ ). On IV-curve the point ( $V_{OC}$ , 0) can be found on the horizontal axis of the graph that meets the current axis.
- Short circuit current ( $I_{SC}$ ), External circuit of the cell is shorted. Therefore, producing short circuit current but the voltage is zero ( $V=0$ ). Looking back at the IV-curve the point (0,  $I_{SC}$ ), on the vertical axis that meets the voltage axis.
- Maximum power point,  $P_{MPP}(V_{MPP}, I_{MPP})$  The power generated and supplied to the rest of the PV system and the load eventually. If the open circuit voltage at point  $V_{MPP}$  and the short circuit current at point  $I_{MPP}$  known, we can find out the Maximum Power Point ( $P_{MPP} = V_{MPP} \times I_{MPP}$ ).

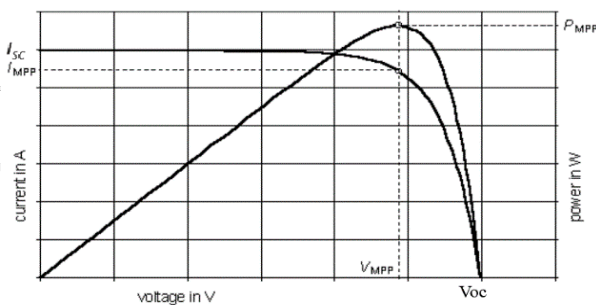


Fig. 4: IV and PV-Characteristic curve of a Solar

### b) Characteristic Equation of PV Cell

The current (I) generated by the solar cell from the equivalent circuit,

$$I = I_L - I_D - I_{SH} \quad (1)$$

The diode current is controlled by the voltage,

$$V_D = V + IR_S \quad (2)$$

The current through the diode is diverted by the equation of the Shockley diode:

$$I_D = I_0 \left[ \exp \left( \frac{V_D}{nV_T} \right) - 1 \right] \quad (3)$$

In accordance with Ohm's law, the current of shunt resistor ( $I_{SH}$ ):

$$I_{SH} = \frac{V_D}{R_{SH}} \quad (4)$$

The characteristic equation of a solar cell by replacing them with equation (1):

$$I = I_L - I_0 \left[ \exp \left( \frac{V + IR_S}{nV_T} \right) - 1 \right] - \frac{V + IR_S}{R_{SH}}$$

Where,

- $I_0$  Reverse saturation current of the diode
- $R_S$  Series resistance of a solar cell
- $R_{SH}$  Parallel resistance of a solar cell
- $V_T$  Thermal voltage,  $V_T = \frac{kT}{q}$ , [at 25°C,  $V_T$  approx. 0.0259]
- T Junction temperature in Kelvin (K)
- K Boltzmann constant ( $1.38 \times 10^{-23}$  J/K)
- Q Electron charge ( $1.6 \times 10^{-19}$  C)
- N Diode ideality factor (1 for the ideal diode)

### c) Photovoltaic Module

A single solar cell cannot deliver the necessary output. The required number of such cells is therefore combined and forms a photovoltaic module or solar module [4]. Connecting cells in serial circuits, the total circuit current remains the same, but the output voltage increases and the output current increases in parallel, but the voltage remains the same.

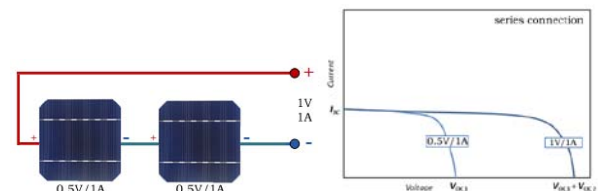


Fig. 5: PV Module & its I-V Characteristics curve (series connected)

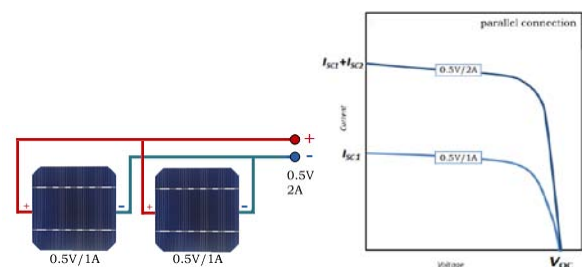


Fig. 6: PV Module & its I-V Characteristics curve (parallel connected)

### d) Photovoltaic Array

A group of PV panels is connected to a large array in series and parallel known as Photovoltaic Array [4]. For higher voltage requirement photovoltaic panel

are wired in series but for higher current wired in parallel. The Photovoltaic array VI-characteristic equation can be expressed as,

$$I = N_p \times I_L - N_p \times I_0 \left[ \exp \left( \frac{V + I \times \left( \frac{N_s}{N_p} \right) \times R_s}{N_s \times n \times V_T} \right) - 1 \right] - \frac{V + I \times \left( \frac{N_s}{N_p} \right) \times R_s}{\left( \frac{N_s}{N_p} \right) \times R_{SH}}$$

Where,

$N_s$  Number of PV modules connected in series  
 $N_p$  Number of PV modules connected in parallel

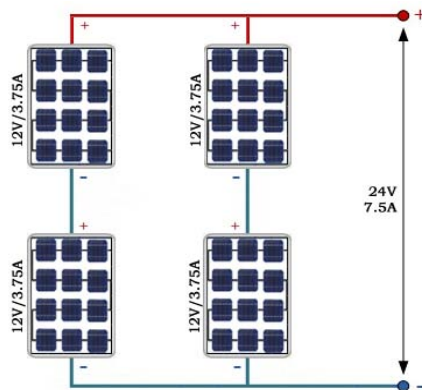


Fig. 7: Photovoltaic Array Connection (Series & Parallel combination)

The output voltage of the array:

$$V_{out} = ((12V | 12V) || (12V | 12V)) = (24V || 24V) = 24V$$

The output current ( $I_T$ ) is equal to the total of the parallel branch currents:

$$I_T = (3.75A | 3.75A) || (3.75A | 3.75A) = (3.75A || 3.75A) = 7.5A$$

The maximum power of the PV array can be calculated as:

$$P_{out} = V_{out} \times I_T = 24 \times 7.5 = 180W$$

The maximum output of 180 watts in full sun. The actual output is usually much lower than the calculated 180 watts due to different radiation level, temperature effect, electrical losses, and other factors.

\*Note: | symbol represents connected in series and || represents connected in parallel.

#### e) Bypass & blocking diodes in photovoltaic arrays

Due to shading and reverse current flow excessive heat and power loss occurs in the PV system. To prevent heat and power losses there two types of diode diodes are used, Bypass diodes and Blocking diode. The same type of diode, Schottky barrier diode is used for both but what's makes it different is, how it can be wired and what it does.

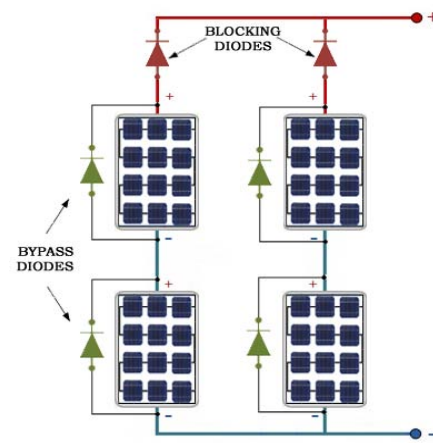


Fig. 8: Bypass diode with photovoltaic Array

Bypass diodes reduce power loss due to shading effect [5] (caused by dust, leaves, trees, buildings etc.) in solar panel and may generate excessive heat. The diode is wired parallel to the cells so that current can flow through the diode even the cell not operate or damage.

During night time there is a high possibility to discharge battery due to reverse current flow from the battery into the solar panel because of lower solar panel voltage. The series blocking diode prevents reverse flow and only allows the power to enter the battery and prevent from being discharged.

### III. IMPLEMENT & DESIGN OF STEP-UP/BOOST CONVERTER

A fundamental DC-DC boost converter (step-up converter) arranged that step-up the input voltage so that the output (load) is higher than the input [6].

#### a) Implementation of Boost Converter

Fig.9.Boost converter circuit containing an inductor, a transistor, a diode, and a capacitor. The connection of the transistor behaves similarly to a switch which can turn on or off by controlling transistor gate voltage. If we close the switch DC voltage appears across the inductor and continue increasing so long as the switch is closed. The current through an inductor cannot change instantaneously [7] therefore the moment we open the switch the inductor will create a force causing the current to continue flowing towards output circuit.

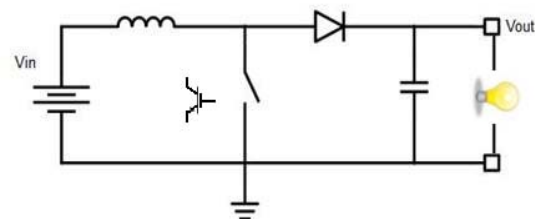


Fig. 9: Basic schematic of step-up/Boost converter with load.

### i. Continuous switch on and off

We can control DC output voltage by controlling the percentage of time that turning the switch on and off.

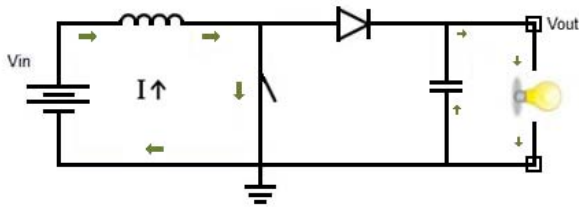


Fig. 10: Step-up/Boost converter (switch on for D% duty cycle)

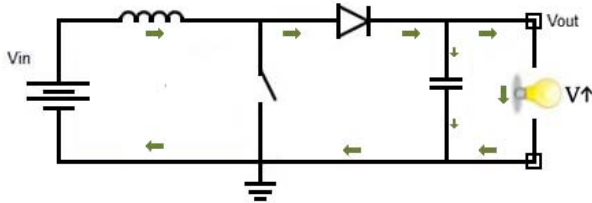


Fig. 11: Step-up/Boost converter (switch off for D% duty cycle)

### ii. Switch off (0% duty cycle)

If we leave the switch turn off 100% of the time, the output voltage will equal to the battery voltage.

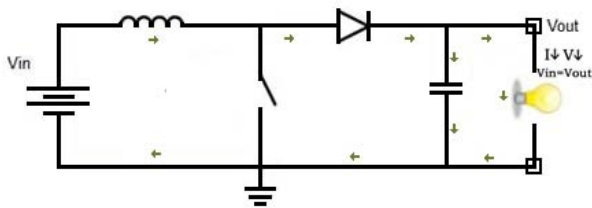


Fig. 12: Step-up/Boost converter (switch off for 100% duty cycle)

### iii. Switch on (100% duty cycle)

If we leave the switch always on 100% of the time, the current will theoretically keep increasing to infinity and overcurrent flow can generate an excess amount of heat which can cause damage the entire circuit.

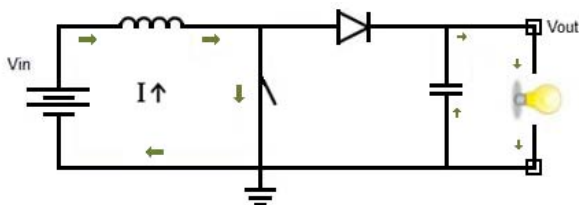


Fig. 13: Step-up/Boost converter (switch on for 100% duty cycle)

### b) Simulation Model of Boost Converter

The SIMULINK and MATLAB model shown in Fig. 14 represents a DC voltage source connected to a resistive load through a DC-DC boost converter with an IGBT (switching device), where the duty cycle is manually updated to attain maximum power. Using

Pulse Generator here we are controlling duty cycle. Duty cycle is the ratio or percentage of the period of time for which the switch is activated.

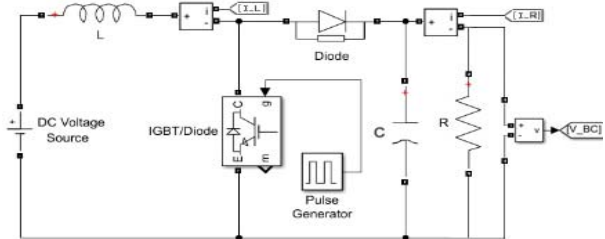


Fig. 14: Block diagram of modeled Boost Converter

Parameters of DC-DC boost converter as given in Table 1. The performance of the boost converter circuit without PV module conditions as given in Table 2& Table 3.

Table 1: Parameters of Boost Converter

S. No.	Name of the Parameter	Values
1	Load Resistance (R)	50 $\Omega$
2	Inductor(L)	10 Mh
3	Frequency	10 kHz
4	Capacitor (C)	1000 $\mu$ F
5	No of Diode	1
6	No of Switch (IGBT)	1
7	Pulse Generator	1

When a 6V and 10V DC voltage source connected, at 53% duty cycle efficiency shows a maximum 96% and at 52% duty cycle efficiency from the boost converter is 97.5%.Irradiance and temperature effect neglected in both cases.



Table 2: Varying Duty Cycle for 6V DC-Efficiency in %

Voltage Source ( $V_{DC}$ )	$I_L$ (A)	$P_{in} = V_{DC} \times I_L$ (W)	Output Voltage ( $V_{BC}$ )	$I_R$ (A)	$P_{out} = V_{BC} \times I_R$ (W)	$\eta = \frac{P_{out}}{P_{in}}$ (%)
6	2.5	15	12	1.2	14.4	96
6	2.4	14.4	11.7	1.1	12.87	89.3
6	2.3	13.8	11.4	1.1	12.54	90.8
6	2.2	13.2	11.2	1.1	12.32	93.3
6	2.1	12.6	11	1.1	12.1	96

Table 3: Varying Duty Cycle for 10V DC-Efficiency in%

Voltage Source ( $V_{DC}$ )	$I_L$ (A)	$P_{in} = V_{DC} \times I_L$ (W)	Output Voltage ( $V_{BC}$ )	$I_R$ (A)	$P_{out} = V_{BC} \times I_R$ (W)	$\eta = \frac{P_{out}}{P_{in}}$ (%)	Duty Cycle (%)
10	4.3	43	20.4	2	40.8	94.8	53
10	4.1	41	20	2	40	97.5	52
10	4	40	19.6	1.9	37.24	93	51
10	3.8	38	19.2	1.9	36.48	96	50
10	3.6	36	18.8	1.8	33.84	94	49

#### IV. PRINCIPLE AND RESEARCH OF THE MPPT

The Maximum power point tracking, MPPT charge controller examine the output power of the PV panel and compare it with battery voltage then maximizes the output in all different conditions [8]. The output gain varies considerably due to partial shading, bad weather, temperature, battery charging and other factors [8]-[9]. The SunPower SPR-305-WHT is rated at 5.58 amps at 54.7 volts.

The maximum power can, therefore, be extracted from the PV panel,  $(54.7 \times 5.58) = 305$  w

Output of PV without MPPT,  $(12 \times 5.58) = 66.96$  w

Loss of Power,  $(305 - 66.96) = 238.04$  w

Because the panel and the battery are poorly matched, we lose 238 watts. However, at 5.58 amps, MPPT takes 54.7 volts and converts them to 10.8 amps at 12 volts.

$25.4 \times 12 = 304.8$  watts. So the power loss is nearly 0 watt.

A range of methods for tracking the maximum power point (MPPT) was proposed [10]. Among different MPPT algorithms, a detailed study of the P&O algorithm and its comparison of the advantages, deficiencies, and efficiency has been shown.

##### a) MPPT- Perturb and Observe (P&O) Method

Perturb and Observe (P&O) method provides perturbation of the PV module or array voltage. This

would mean an increase in power or a decrease. If the operating point is to the left of the maximum power point and therefore further voltage perturbation to the right is required to reach the maximum power point [11]. Conversely, if the voltage increase leads to a decrease in power, the current operating point is to the right of the maximum power point and further perturbation of the left voltage is necessary to reach the maximum power point. The algorithm thus converges over the various perturbation to the maximum power point.

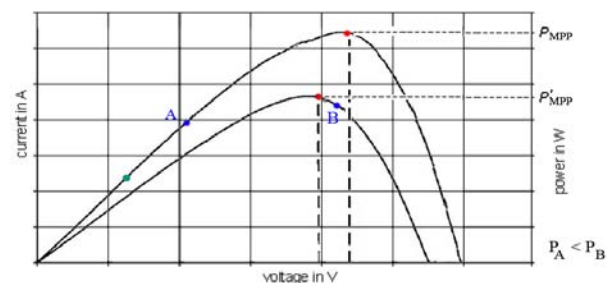


Fig.15: MPPT techniques – Perturb and Observe (P&O) method

The operating point of the MPPT is not constant, so the algorithm struggles with rapidly changing climatic conditions that have a serious effect on the efficiency of the algorithms [12]. The P&O algorithm flowchart is shown in Fig. 16.

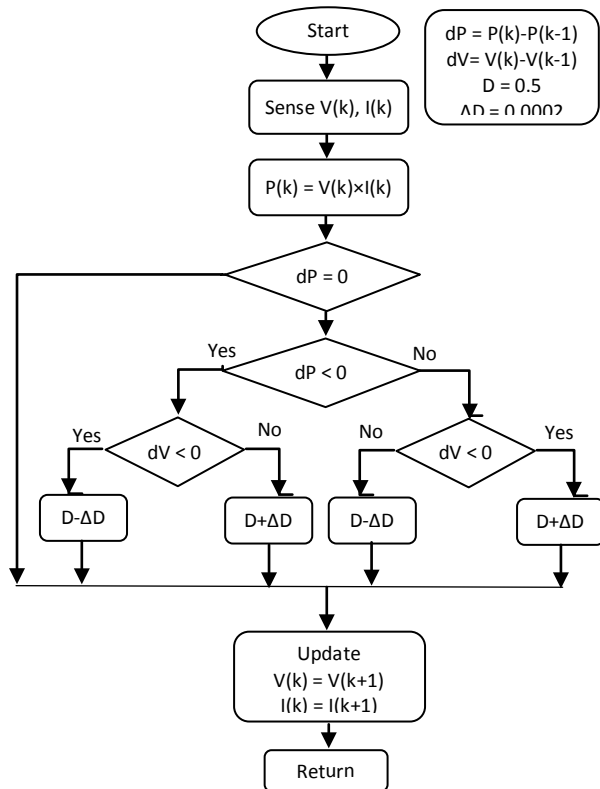


Fig. 16: Flowchart of Perturb & Observe (P&O) Algorithm

b) Simulation of PV Model using MATLAB/SIMULINK

The SIMULINK and MATLAB model of PV system shown in Fig.17 SunPower SPR-305-WHT solar panel with 96 cells connected in series tested at 25°C temperature. The output connected to the resistive load with a MPPT controller via DC-DC boost converter.

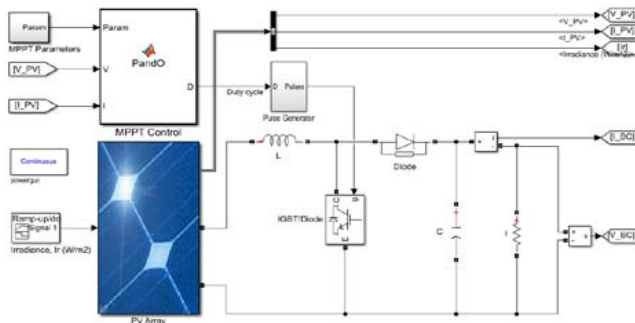


Fig. 17: Simulation Model of PV System with MPPT Controller

Table 4: Parameters of PV Panel (SunPower SPR-305-WHT)

S. No.	Name of the Parameter	Values
1	Open Circuit Voltage (Voc)	64.2 V
2	Short-circuit Current (Isc)	5.96 A
3	PV Panel Max. Power characteristics	305 W
4	Maximum Power Voltage (Vmp)	54.7 V
5	Maximum Power Current (Imp)	5.58 A
6	No of cell per module	96
7	No of series-connected module	1
8	No of parallel string	1
9	Temperature (T)	25°C

The MPPT Controller and Pulse Generator subsystem is shown in Fig.18. The MPPT controller has PV Solar Panel voltage and current input. MPPT parameters Initial duty cycle, Dint and Increment value used to increase/decrease the duty cycle,  $\Delta D$  connected also to "Param" input port. The MPPT controller output is connected to the pulses.

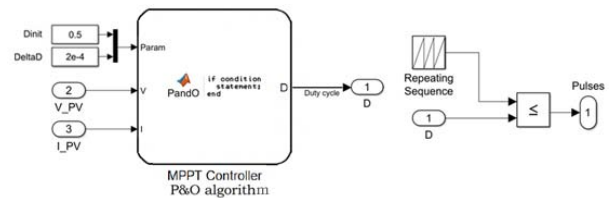


Fig. 18: Simulation Model of MPPT Controller & Pulse generator

c) Simulation Result and Discussion

The MPPT P&O algorithm was tested in the first step for a change in the irradiance level of 1000w/m<sup>2</sup> and then again for different irradiance conditions. All results are showing four plots. The first shows the irradiation, the second shows the voltage, the third shows the current and the fourth shows the output power.

The result from Fig.19showing with a fixed irradiance of 1000 w/m<sup>2</sup>.There are two voltages plot V\_PV and V\_BC represents in Fig.20, two currents plot I\_PV and I\_BC in Fig.21 and two power plot P\_PV and P\_BC in Fig.22 which represent the output plot of PV module and boost converter. PV output showing cyan and the load output showing red so that it can clearly be understood.

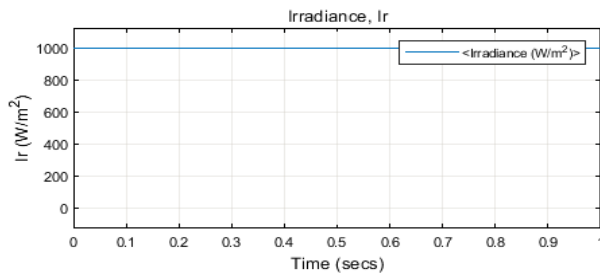


Fig. 19: Irradiation (1000W/m<sup>2</sup>) of input for PV Panel

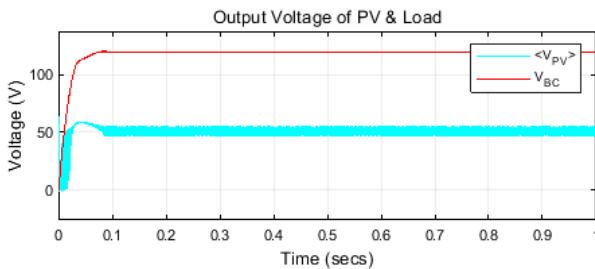


Fig. 20: Performance of PV and boost converter output voltage

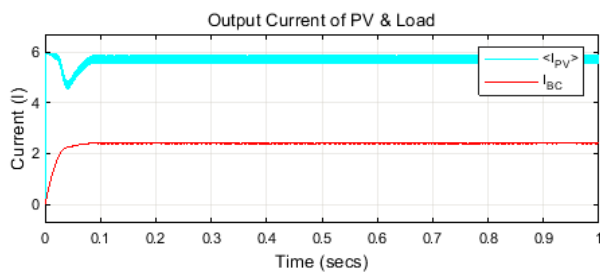


Fig. 21: Performance of PV and boost converter output current

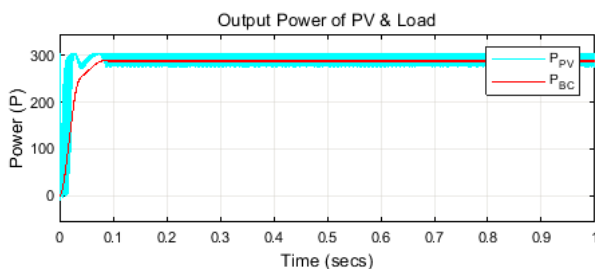


Fig. 22: Performance of PV and boost converter output power

Tabl 5: Efficiency of the P&O algorithm at 1000w/m<sup>2</sup> irradiance level

$I_r$ (W/m <sup>2</sup> )	$V_{BC}$ (V)	$I_{BC}$ (A)	$P_{BC}$ (W)	$\eta = \frac{P_{out}}{P_{max}} \%$	%D
1000	35.58	0.71	25.26	8.3	47.6
	114.1	2.28	260.15	85.3	50.6
	118	2.36	278.48	91.3	54.8
	119	2.38	283.22	93.8	56.5
	120	2.41	289.6	94.9	56.9

Table 5. showing due to the adjustment of the duty cycle to maximize output power, efficiency ranges

from 94.4 percent to 8.3 percent. PV Panel Max. Power characteristics = 305 w

Power output at load,  $P_{BC} = 289.6$  w

Efficiency,  $\eta = (289.6/305) \times 100 = 94.95\%$

The MPPT P&O algorithm was tested for a change in the different level of irradiance shown in Fig.23, PV and Boost Converter output voltage in Fig.24, output current in Fig.25 and represent output power in Fig.26. The model simulation has been completed in one second.

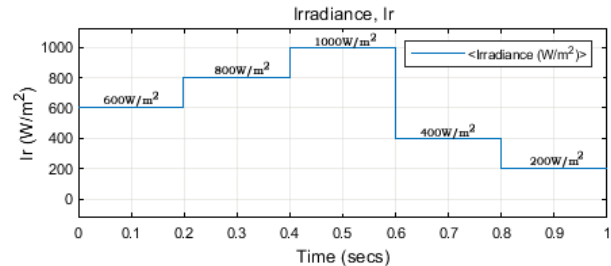


Fig. 23: Different Irradiation level of input for PV panel

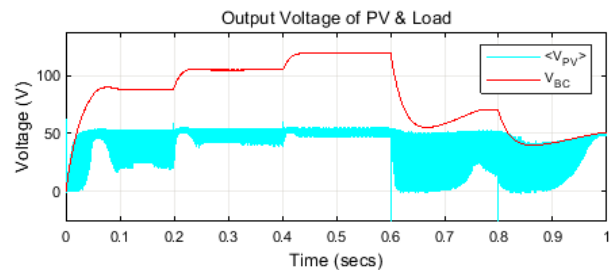


Fig. 24: Performance of PV and boost converter output voltage at different Irradiation level

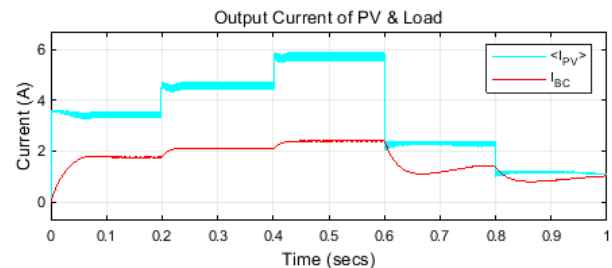


Fig. 25: Performance of PV and boost converter output current at different Irradiation level

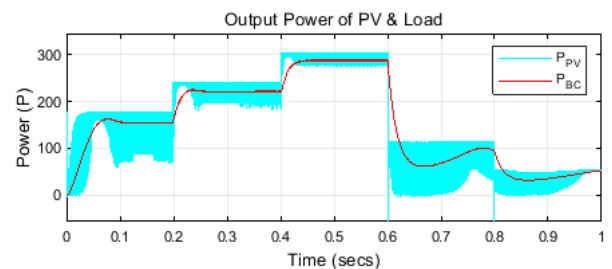


Fig. 26: Performance of PV and boost converter output power at different Irradiation level

**Table 6:** Efficiency of the P&O algorithm at different irradiance level

$I_r$ (W/m <sup>2</sup> )	With MPPT		Without MPPT		$\eta$ (%)
	$P_{PV}$ (W)	$P_{BC}$ (W)	$P_{PV}$ (W)	$P_{BC}$ (W)	
200	53.24	52.13	51.67	49.86	2.27
400	78.43	96.80	68.54	67.59	29.21
600	149.5	161.3	73.78	72.79	88.51
800	208.7	220	77.34	76	144
1000	278.9	289.6	79.29	78.29	211.31

Table 6. Showing the efficiency of the output power varies when the simulation runs at the same irradiance level without the MPPT controller. For a solar irradiation value of 1000W/m<sup>2</sup>, the power obtained from a load of 289.6 watts greater than the output value of  $P_{BC}$  without a MPPT PV system. Similarly, it shows maximum output with MPPT controller at different irradiance levels.

## V. CONCLUSIONS

This paper presents perturbation and observation method which implemented with the PV module and MPPT controller, which works at rapidly changing irradiance levels, temperature effect and partially shaded solar panel. PV system and Simulation of PV Model analyzed using MATLAB/SIMULINK. In addition, this is important that the efficiency of the algorithm had to be as high as possible, and the MPPT had to have an efficiency of at least (93-95) %. It has tested and verified that the MPPT controller and the algorithms implemented with it works properly. After implementing MPPT with Boost Converter, the controller can select the maximum power point and efficiency for rapidly changing irradiance levels, temperature effect and partial shading of the solar panels. In addition, result shows that MPPT P&O method increased and gives at least 95% efficiency.

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## Novel Microstrip Patch Antenna with Modified Ground Plane for 5G Wideband Applications

By Sadiya Afrin Swarna, Salma Faria, Sakhawat Hussain & Anis Ahmed

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**Keywords:** 5G wide-band wireless communication, rectangular slot-loaded microstrip patch antenna, ground modified bi-directional antenna.

**GJRE-F Classification:** FOR Code: 100501



NOVEL MICROSTRIP PATCH ANTENNA WITH MODIFIED GROUND PLANE FOR 5G WIDE BAND APPLICATIONS

*Strictly as per the compliance and regulations of:*



# Novel Microstrip Patch Antenna with Modified Ground Plane for 5G Wideband Applications

Sadiya Afrin Swarna <sup>α</sup>, Salma Faria <sup>ο</sup>, Sakhawat Hussain <sup>ρ</sup> & Anis Ahmed <sup>ω</sup>

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**Keywords:** 5G wide-band wireless communication, rectangular slot-loaded microstrip patch antenna, ground modified bi-directional antenna.

## I. INTRODUCTION

A revolution has occurred in the world of wireless communication systems with the introduction of 5G network. It provides high speed data transmission rates more than 1Gbps to broadcast live events, high definition video streaming, autonomous driving, robotics, aviation, health care applications, etc. This 5G wireless technology is nearly capable of the wired fiber optic internet connection. Another feature of 5G is that it can transfer both voice and high-speed data at the same time more efficiently than the other conventional mobile cellular technologies. Depending on the implementation policy of 5G in various countries, the lower and higher end of the fifth generation frequency spectrum are approximately 3-5 GHz and 24-71 GHz, respectively [1]. To interconnect the existing mobile devices and various sensors, sub-6 GHz frequencies are being used by 5G technology. For

maintaining high speed transmission and reception, high-gain wideband antennas are needed for reliable wireless communication. Recently use of a wideband antenna for multichannel transmission and reception has become more popular. Besides, low-profile antennas are preferable for mobile base station, intra-satellite communication purposes, missiles and so on. For these application areas, microstrip patch antennas (MPAs) are better choice over the other types of antennas. Some of the advantages of MPA are light weight, smaller size, low fabrication cost, easy installation, mechanical robustness and freedom of design [2-3]. They also minimize the excitation of other undesired modes [4]. Due to the miniaturized structure of MPAs, they feasibly can be used in smaller electronic devices to improve the portability and efficiency [5]. But they are not widely used antennas because of their low gain, narrow bandwidth, low directivity, low power handling capacity, distorted radiation pattern and multiple resonances [6-7]. So the target of the research on MPA is to increase the bandwidth, gain, and desired radiation pattern for various sorts of 5G applications. Antenna characteristics can be improved by introducing slots of different shapes, defected ground plane, metamaterial, and shorting pins. etc. [7-10]. Besides by increasing the substrate height, and lowering the dielectric constant, antenna characteristics can also be increased [11]. Moreover feeding techniques affect some important antenna parameters such as bandwidth, return loss, VSWR etc. [12].

In this paper we proposed a microstrip patch antenna having 6 rectangular slots placed symmetrically on both sides the feed line. The introduction of slots on the patch changes the resonance characteristics from conventional multiband to a single resonant one. The ground plane is modified with a new structure to increase bandwidth. The bandwidth of the slot loaded MPA with modified ground plane is increased approximately 18 times than that of the conventional MPA. The design and simulation process of the MPA are done by CST software. The radiation pattern and  $S_{11}$  of the fabricated antenna are measured using Vector Network Analyser (Rohde & Schwarz-ZVH8) and Wave and Antenna Training System (Man and TEL Co.).

## II. DESIGN OF THE PROPOSED MPA

The proposed MPA is a rectangular inset feed patch antenna as shown in Fig. 1. To enhance the

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resonance characteristics at a single frequency, slots are introduced in the patch (see Fig. 1(a)). The patch is placed in the middle of the substrate. Three slots of different sizes are placed symmetrically on both sides of the microstrip feed line. The width and length of patch are represented by  $W$  and  $L$ . In general, the width and length of substrate are taken 1.5 times than that of patch dimensions. The width, gap and length of inset feed microstrip line are denoted by  $W_f$ ,  $G_f$  and  $F_i$ , respectively.

The slots are denoted by 'a', 'b' and 'c' as shown in Fig. 1(b). The widths and lengths of slots are represented by  $W_i$  and  $L_i$ , where  $i = 1, 2, 3$  corresponds to the slots 'a', 'b' and 'c', respectively. The position of each slot is very sensitive to the patch characteristics. For example, the distances of slot 'c' from the bottom edge, side edge and top edge of the patch are denoted by  $c_1$ ,  $c_2$  and  $c_3$ , respectively (see Fig. 1(b)). Similarly the positions of slot 'a' and 'b' are taken as  $a_i$  and  $b_i$  ( $i = 1, 2, 3$ ).

Figure 1 (c) shows the modified ground structure of the proposed MPA. To increase the bandwidth of patch antenna, the ground side is modified to form a helipad-like structure. Three English letter 'I' are made along the length of patch. All 3 I-structures are connected at the middle. The middle I has larger width than the other two Is. This middle I also has a rectangular slot in the middle and two side-slots at the top and bottom edges. The hatched part in ground plane represents the existence of copper layer and the rest regions are etched out. The widths of the side I and central I are expressed by  $G_1$  and  $G_2$ , respectively. The distance between the outer edges of 2 side I's is denoted by  $G_3$  which is taken 10 times of the width of each side I i.e.  $G_3 = 10 \times G_1$ . The whole ground plane has been finally appeared as a helipad-like structure.

For the analysis, the substrate is considered FR4 whose dielectric constant,  $\epsilon_r$ , is 4.3 with a thickness  $h = 1.6$  mm. The effective dielectric constant  $\epsilon_{reff}$  is expressed as [8]

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \left[ \frac{\epsilon_r - 1}{2} \right] \left[ \left( 1 + \frac{12h}{W} \right)^{-\frac{1}{2}} \right] \quad (1)$$

The width  $W$  of the patch is calculated for the resonant frequency  $f_r$  at 3 GHz using the following equation

$$W = \frac{v_0}{2 \times f_r} \times \sqrt{\frac{2}{\epsilon_r + 1}} \quad (2)$$

where  $v_0$  is the speed of light in free space.

The relation between the actual length  $L$  and the effective length  $L_{eff}$  is

$$L = L_{eff} - 2\Delta L \quad (3)$$

Where  $\Delta L$  is the fringing correction factor and is expressed as

$$\Delta L = 0.412h \times \frac{(\epsilon_{reff} + 0.3) \left( \frac{W}{h} + 0.264 \right)}{(\epsilon_{reff} - 0.258) \left( \frac{W}{h} + 0.8 \right)} \quad (4)$$

The expression for the effective length  $L_{eff}$  is

$$L_{eff} = \frac{v_0}{2 \times f_r \times \sqrt{\epsilon_{reff}}} \quad (5)$$

Microstrip transmission line width  $W_f$  has been varied from  $W/5$  to  $W/15$  to achieve the best result through simulation. The value is found to be 3.06 mm for the best antenna characteristics.

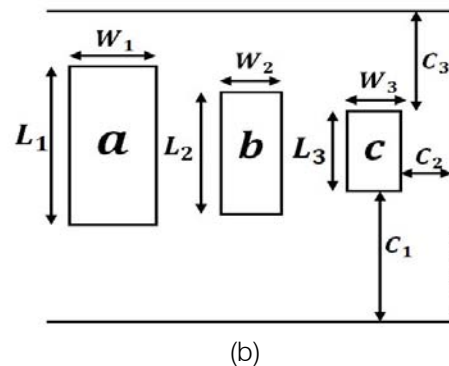
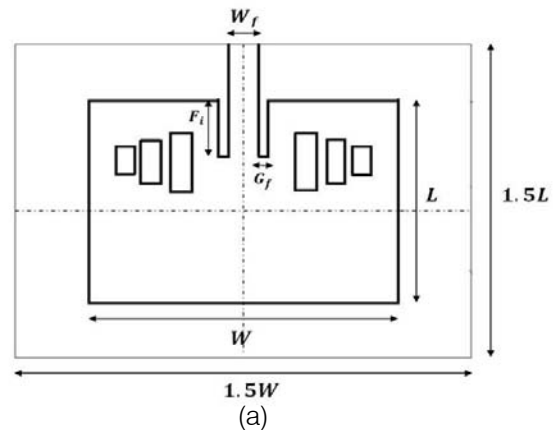
The equation used for determining the exact length of inset feed  $F_i$  for thin dielectric substrate to achieve an input impedance of  $50\Omega$  is as follows [13]:

$$F_i = 10^{-4} (F_{c7}\epsilon_r^7 + F_{c6}\epsilon_r^6 - F_{c5}\epsilon_r^5 + F_{c4}\epsilon_r^4 - F_{c3}\epsilon_r^3 + F_{c2}\epsilon_r^2 - F_{c1}\epsilon_r + F_{c0})L/2 \quad (6)$$

Where

$$F_{c7} = 0.001699, F_{c6} = 0.13761, F_{c5} = 6.1783, F_{c4} = 93.187, F_{c3} = 682.93, F_{c2} = 2561.9, F_{c1} = 4043 \text{ and } F_{c0} = 6697, \text{ respectively.}$$

Using the above stated equations, all the parameters (such as  $\epsilon_{reff}$ ,  $L$ ,  $W$ ,  $F_i$ ) are calculated for  $f_r = 3$  GHz. These calculated values are used to design a conventional MPA as well as the proposed MPA using CST software. It is found that the calculated values of different parameters are slightly modified to obtain the optimized values which give better antenna characteristics. The gap between the patch and the inset-feed microstrip line  $G_f$  has been changed from 0.5 to 3.5 mm to get the best result. It is found that  $G_f = 0.95$  mm gives the satisfactory result.



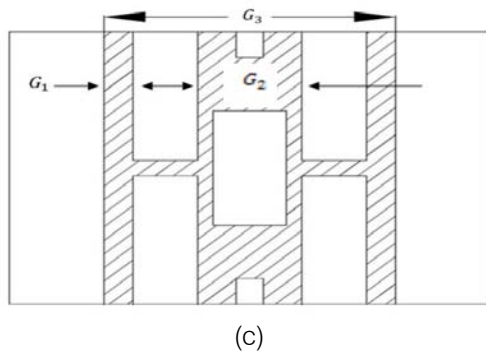


Fig. 1: Structure of the proposed MPA; (a) slotted patch side, (b) enlarged view of slots with dimensions and (c) modified ground plane side.

The length  $L_3$  and width  $W_3$  of the smallest 'c' slot are found 3.2 mm and 1.9 mm, respectively. Two smallest 'c' slots are placed symmetrically on both sides of the feed line. Each smallest 'c' slot is positioned at

distances  $c_1 = 14.605$  mm,  $c_2 = 2.745$  mm and  $c_3 = 5.205$  mm away from the bottom edge, side edge and top edge of the patch antenna, respectively. The dimensions of medium type 'b' pair of slots are  $L_2 = 5$  mm and  $W_2 = 1.9$  mm. These 'b' slots are positioned at  $b_1 = 13.505$  mm,  $b_2 = 5.345$  mm and  $b_3 = 4.505$  mm apart from the bottom edge, side edge and top edge of the patch, respectively. The length and width of the biggest two symmetrical rectangular 'a' slots are  $L_1 = 6.5$  mm and  $W_1 = 2.2$  mm, respectively. The slots are positioned at  $a_3 = 3.805$  mm,  $a_2 = 8.245$  mm and  $a_1 = 12.705$  mm apart from the top edge, side edge and bottom edge of the patch, respectively. The positions and dimensions of the slots are determined using trial and error method to get good antenna characteristics such as S-parameter, radiation pattern, bandwidth, directivity etc. All the optimized structural parameters of the proposed MPA are given in Table 1.

Table 1

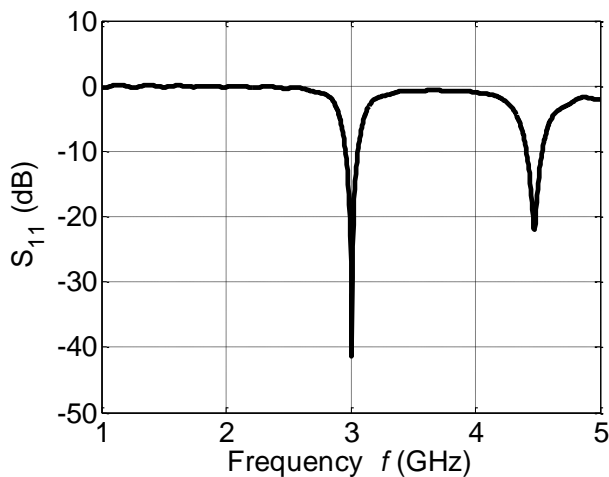
Parameters	Optimized value	Parameters	Optimized value
Frequency, $f_r$ (GHz)	3	$W_1$ (mm)	$2.2(\cong 0.022\lambda)$
Wavelength, $\lambda$ (mm)	100	$W_2$ (mm)	$1.9(\cong 0.019\lambda)$
Dielectric constant, $\epsilon_r$	4.3	$W_3$ (mm)	$1.6(\cong 0.016\lambda)$
Substrate Height, $h$ (mm)	1.6	$a_1$ (mm)	$12.705(\cong 0.127\lambda)$
Patch Width, $W$ (mm)	$31.29(\cong 0.313\lambda)$	$a_2$ (mm)	$8.245(\cong 0.082\lambda)$
Patch Length, $L$ (mm)	$23.01(\cong 0.23\lambda)$	$a_3$ (mm)	$3.805(\cong 0.038\lambda)$
Substrate Width, $1.5W$ (mm)	$46.04(\cong 0.46\lambda)$	$b_1$ (mm)	$13.505(\cong 0.135\lambda)$
Substrate Length, $1.5L$ (mm)	$35.52(\cong 0.355\lambda)$	$b_2$ (mm)	$5.345(\cong 0.053\lambda)$
Microstrip Transmission Line Width, $W_f$ (mm)	$3.06(\cong 0.0306\lambda)$	$b_3$ (mm)	$4.505(\cong 0.045\lambda)$
Microstrip Line Inset Feed Length, $F_i$ (mm)	$6.5(\cong 0.065\lambda)$	$c_1$ (mm)	$14.605(\cong 0.146\lambda)$
Gap between patch and feed line, $G_f$ (mm)	$0.95(\cong 0.009\lambda)$	$c_2$ (mm)	$2.745(\cong 0.027\lambda)$
Thickness of Copper Layer, $M_t$ (mm)	0.035	$c_3$ (mm)	$5.205(\cong 0.052\lambda)$
$L_1$ (mm)	$L_1 = 2.0L_3$ $6.5(\cong 0.065\lambda)$	$G_1$ (mm)	$2.8(\cong 0.028\lambda)$
$L_2$ (mm)	$L_2 = 1.5L_3$ $5(\cong 0.05\lambda)$	$G_2$ (mm)	$G_2 \cong 3.6G_1$ $10(0.1\lambda)$
$L_3$ (mm)	$3.2(\cong 0.032\lambda)$	$G_3$ (mm)	$(G_3 = 10G_1)$ $28(= 0.28\lambda)$

### III. SIMULATION RESULTS

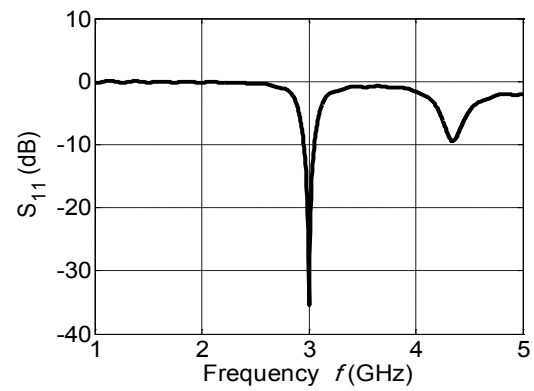
To observe the effects of slots and ground modification, we have designed two types of MPAs using CST simulation software. A conventional MPA has also been designed to compare the improvement of characteristics of the proposed MPA. The substrate is taken FR4 with a copper cladding thickness of  $35\ \mu\text{m}$  and the final dimension of the MPAs is  $40.1 \times 35.5\ \text{mm}$ . Obtained return losses ( $S_{11}$ ) and far-field radiation patterns of three types of MPAs are shown in Figs. 2 and 3, respectively.

We have shown the return loss ( $S_{11}$ ) of the conventional MPA (without slot and with full ground plane) in Fig.2 (a). We have seen that there are two resonant peaks at 3.008 GHz and 4.48 GHz with the magnitudes of  $-41.35\ \text{dB}$  and  $-22.04\ \text{dB}$ , respectively. The corresponding bandwidths of these two frequencies are 100 MHz and 120 MHz, respectively. Introducing slots in the patch with the full ground as conventional one, the magnitude of  $S_{11}$  is found to be  $-35.32\ \text{dB}$  at 3.00 GHz which is very close to the designed resonant frequency of 3 GHz (see Fig.2 (b)). We have eliminated the second resonant peak of the conventional antenna by incorporating six slots on the patch. We have gradually decreased the size of the slots from middle to the patch-edge. The bandwidth of the resonant peak at 3.00 GHz is found 100 MHz which is similar to the conventional one.

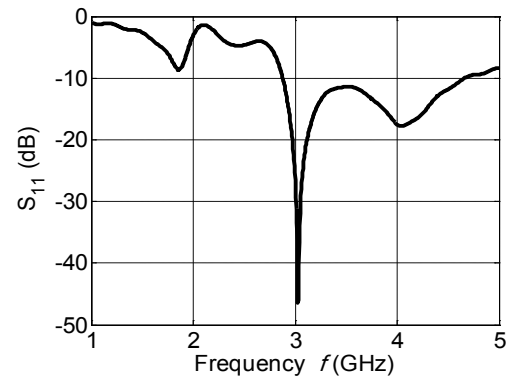
To increase the bandwidth, the ground plane is modified to form a helipad-like structure keeping slots in the patch. The obtained  $S_{11}$  is shown in Fig. 2(c). The bandwidth and minimum return loss of the final proposed MPA are 1.77 GHz and  $-46.5\ \text{dB}$  at 3.028 GHz, respectively. Thus the bandwidth has been increased remarkably, and our proposed MPA is appropriate for wideband applications.



(a)



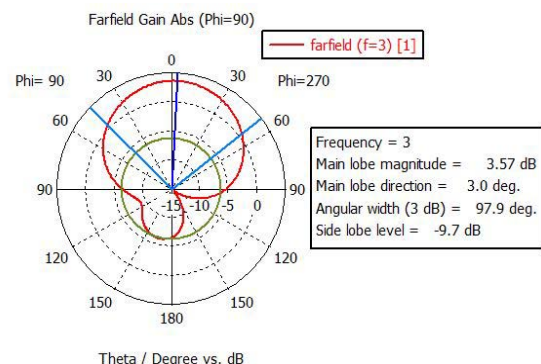
(b)



(c)

Fig.2: Variation of  $S_{11}$  with frequency for (a) Conventional MPA (b) MPA with slotted-patch and the full ground plane (c) Proposed MPA (slotted-patch with modified ground plane).

We have shown the far-field radiation patterns of the conventional and the proposed MPAs in Fig.3 (a) and 3(b), respectively. The radiation pattern of the conventional one is hemispherical as a theoretical one. But the radiation pattern of the proposed MPA is bi-directional and symmetric. Such a bidirectional antenna is suitable for WLAN, intra-satellite communication and beam forming applications [14-16]. The main lobe magnitude of the proposed MPA is found to be 1.89 dB. We have found VSWR  $1.5 \pm 0.2$  in the whole bandwidth range of 2.8 to 4.6 GHz for the final proposed MPA.



(a)



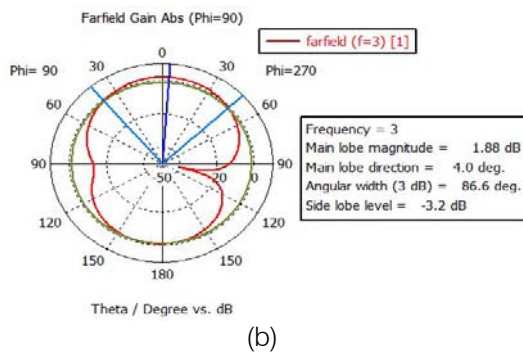


Fig.3: Far-field radiation of MPA: (a) Conventional MPA (without slot with modified ground plane) and (b) Proposed MPA (slotted-patch with modified ground plane).

#### IV. MEASURED RESULTS

The conventional and the proposed MPAs are fabricated in our laboratory by liquid etching technique. First of all, Copper substrate has been cut into rectangular pieces with the dimensions according to the optimized values shown in Table-1. Then the patch and ground sides of the MPA are masked using photo resist. Ferric Chloride solution is used to chemically etch out the unwanted copper to get the desired portions of the patch and ground plane. After cleaning up the mask with Ethanol, SMA connectors are fixed on the mount at the antenna port. In Fig. 4, the photograph of the patch side (left) and the ground plane (right) of the proposed MPA are shown.

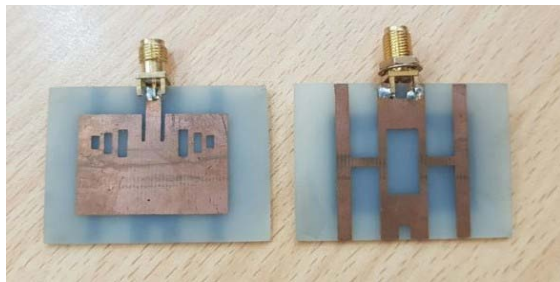


Fig. 4: Patch side and ground plane of fabricated proposed MPA

The measured scattering parameters of the conventional and the proposed MPA in Fig. 5(a) and 5(b), respectively. There are two resonant peaks for conventional MPA. The magnitudes of the resonant peaks are  $-13.74$  dB and  $-8.5$  dB at  $2.98$  GHz and  $4.3$  GHz, respectively (see Fig. 5(a)). The bandwidth of the resonant peak at  $2.98$  GHz is found  $80$  MHz. For conventional MPA, the measured return loss is found very similar to the simulated one. Finally the measured  $S_{11}$  of the proposed MPA is shown in Fig. 5(b). The bandwidth is increased with a fraction bandwidth increment of  $14\%$  and found to be  $380$  MHz which is almost  $5$  times larger than the bandwidth of conventional MPA. The magnitude of  $S_{11}$  is found to be

$-36.48$  dB at the resonant peak of  $2.76$  GHz. May be due to the fabrication and measurement (without anechoic chamber) inaccuracy, the obtained results of measurement have some deviation from that of simulation.

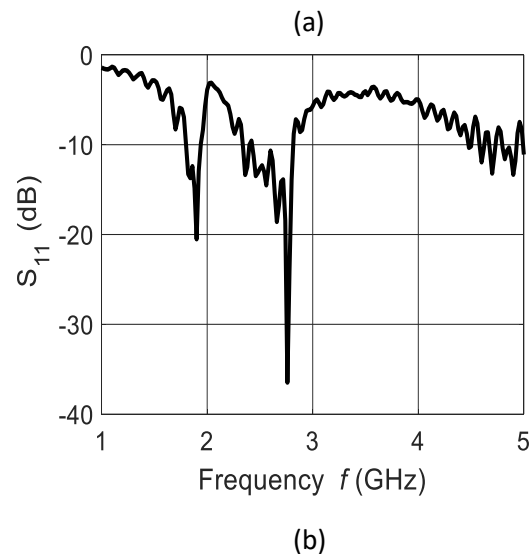
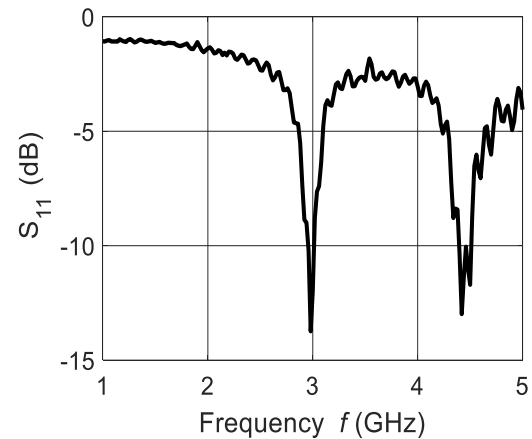
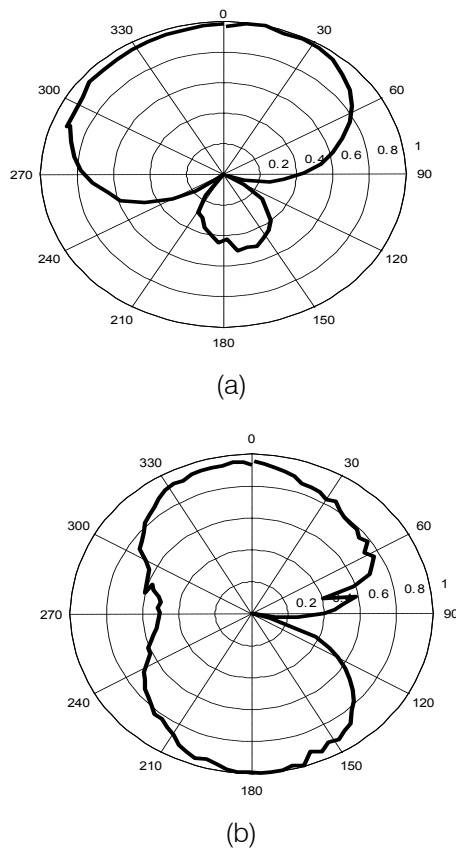


Fig.5: Experimental measured results of  $S_{11}$  of fabricated two types of MPA: (a) conventional rectangular MPA (b) Proposed MPA (slotted-patch with modified ground plane)

The measured far field radiation pattern of the conventional MPA is shown in Fig.6 (a). The radiation pattern has a hemispherical main lobe and a small back lobe. By comparing Figs. 3(a) and 6(a) it is seen that the measured radiation pattern is almost same as the radiation pattern obtained from simulation. Figure6 (b) shows the characteristics of measured radiation pattern for the proposed MPA with modified ground plane. This result also agrees very well with the simulated one. Since bandwidth of our proposed MPA has increased remarkably, the gain has reduced. The measured radiation pattern of our proposed MPA is also found bi-directional pattern which is similar to that of simulated one.





**Fig. 6:** Measured radiation patterns of (a) conventional MPA and (b) proposed MPA

## V. CONCLUSION

A new slot-loaded patch antenna with ground modification has been designed to enhance the resonance characteristics with improved bandwidth. The antenna works at the resonance frequency in S-band i.e. at 3 GHz. The return loss magnitude of the proposed MPA is found quite satisfactory than the conventional structure. The simulated return loss bandwidth of the proposed MPA has been increased from 100 MHz to 1.77 GHz compared to the convention MPA. The measured return loss characteristics and radiation pattern of the proposed antenna match well with the simulated results. The bandwidth of the measured MPA is found 380 MHz, a reduced bandwidth value due to the inaccuracy of fabrication and measurement in our laboratory without anechoic chamber. The far field gain and directivity of the fabricated antenna are quite satisfactory. The radiation pattern of the proposed MPA is bi-directional and is suitable for WLAN, intra-satellite communication and beam forming applications.

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# The Problem Solving Algorithm Time-Frequency Signals Analysis based on Behavior Functions and Arithmetic Series

By Victor Bocharnikov

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**Keywords:** *time series, time-frequency analysis,  $p$ -adic numbers, system behavior functions, measure of possibility, fuzzy set, system analysis, identification, arithmetic series, frequency spectra.*

**GJRE-F Classification:** *FOR Code: 090699*



*Strictly as per the compliance and regulations of:*



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## I. INTRODUCTION

Any space-time signal can be described by a set of basic functions [1]. This allows us to obtain a signal spectrum that reflects the basis functions proportion of the content in the original signal. Such a decomposition is often useful for signal analysis. For example, the spectral representation is effective for analyzing the compressibility of signals, the synthesis of compression algorithms with minimal losses, the signals filtering problems solving, the synthesis of optimal regulators, etc.

The transition to the spectrum can be carried out using orthogonal and unitary transformations. Most often, to obtain a spectrum, the decomposition in orthogonal functions is used [2]. For example, the spectra obtained on the basis of decomposition into a Fourier series [3] (with harmonic basis), Walsh series [4] (using a non-harmonic orthogonal system of rectangular functions with values of  $\pm 1$ ), wavelet transform [5, 6], etc. In [7], a new approach to the time-frequency analysis of non-stationary signals was proposed. In this paper, we consider an algorithm implementing the approach developed in [7] and present the results of its application to the time-frequency analysis of non-stationary signals.

## II. RESEARCH AND PUBLICATIONS ANALYSIS AND THE PROBLEM STATEMENT

A detailed analysis of existing approaches to the spectral-temporal analysis of signals is given in [7]. From the analysis it follows that the following elements are common to all the main approaches:

1. Arbitrary of the function  $\varphi(t)$  tend to be decomposed into a set of basis functions  $\{\Phi(k, t)\}$ . Such functions form, as a rule, an orthogonal basis. Each function from this system conditionally plays the role of a coordinates axis.

2. To determine the projection on such an coordinates axis, the integral convolution is used  $c_k = \int_0^T [\varphi(t) \cdot \Phi(k, t)] dt$ , where  $c_k$  are decomposition coefficients determining the degree of coincidence of the original function  $\varphi(t)$  and  $\Phi(k, t)$ . The values of  $c_k$  are perceived as coordinates on the respective axes of the basis orthogonal functions. Thus, the convolution integral or its discrete analogue is perceived as a measure of the similarity of the original function  $\varphi(t)$  and the function  $\Phi(k, t)$ .

3. To study non-stationary signals and obtain the time-frequency decomposition of a signal a “window” is used, which is “cutting out” a portion of the function  $\varphi(t)$  over a certain time interval. For each time interval, a measure of similarity with the basis functions  $\Phi(k, t)$  is found.

4. Window accounting when analyzing the original function can be carried out explicitly or implicitly. In the first case, the window function  $\varpi(t)$  is explicitly introduced into the expression for integral convolution. This function may have various forms, for example, in the form of a Gaussian function. In the second case, the window is accounted for by direct selection of the basis orthogonal functions, which are called bursts or wavelets. The use of wavelets allows to further determine the frequency localization.

5. Depending on the selected basic orthogonal functions and window functions, different time-frequency localization is obtained (Fig. 1). In any case, such localization is determined in advance before the beginning of the analysis and affects its result.

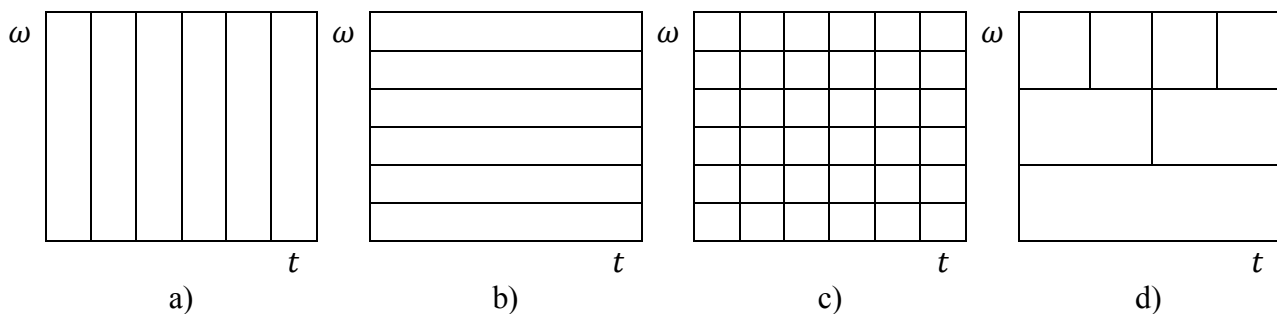


Fig. 1: Time-frequency localization for various approaches:

- Time Localization at Shannon signal discretization;
- Frequency localization during Fourier transform;
- Window transformations of the instantaneous spectrum methods [8] (D. Gabor, J. Ville etc.)
- Wavelet transform [9] (I. Daubechies, Y. Meyer, R. Coifman, etc.)

Analysis of existing approaches to the frequency-time analysis of signals revealed a number of important points:

1. The “grid” of the time-frequency localization superimposed on the original signal may not “coincide” with the characteristics of the original function  $\varphi(t)$ , which leads to distortions of the time-frequency signal evaluation. That is why in the existing approaches special attention is paid to the selection of basic functions and window modeling functions.

2. In some cases, such as when using wavelet transforms, the time window has fuzzy boundaries, which leads to distortions of the time-frequency estimate due to the windows overlapping.

3. The choice of functions integral convolution instrument as a measure of their similarity affects the assessment of initial and basic functions coincidence degree. The measure of similarity can be constructed in other ways and be more effective. In addition, in practice, the use of integral convolution introduces its own errors, which are associated with numerical integration methods.

4. The rigid “grid” of time-frequency localization used in existing approaches is not adaptive. It does not take into account the behavior of the non-stationary function of the signal. At present, localization is more effective, which is used in wavelet transforms (Fig. 1d). However, it is also rigid, which leads to the need for a more careful selection of wavelet basis functions. Selection of basic functions adapted to a signal is used in the method of signal analysis proposed by N. Huang (Huang-Hilbert Transform) [10]. However, studies have shown that this approach also has several disadvantages [11].

5. It can be assumed that if the function  $\varphi(t)$  behaves not stationary, then the time-frequency localization should be adaptive and adapt to the behavior of the signal under study (Fig. 2).



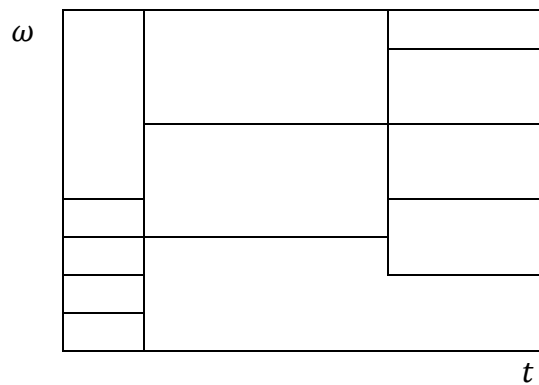


Fig. 2: Adaptive time-frequency localization

Thus, to ensure the adaptation of the time-frequency signal localization, it is necessary to determine the local areas of stationary behavior for the system that generates the signal. These areas are defined as a locally-invariant constraints on system behavior.

Earlier, theoretical studies were presented in [7], which allow us to obtain estimates of the frequency spectrum of a signal in an adaptive version. The approach is based on the fact that the behavior of the system has locally invariant sections, in which the signal spectrum is relatively stable. To identify these sections, it was proposed to use a behavior functions change in the system [12]. This behavior function is proposed to build using the mathematical basis of the  $p$ -adic calculus in the form of possibility measure distribution. The moments of the behavior function change allow us to determine the coordinates of the impulse function that models the original signal. It is noteworthy that periodic functions (for example, harmonic) are described by impulse functions, in which the coordinates of the pulses correspond to the members of arithmetic progressions. In the above presented work, an approach is proposed to determine the current signal spectrum estimates based on the coincidence degree of the impulse functions of this signal and the harmonic signals of the basis functions. To ensure the effectiveness of the approach, it is necessary to develop an algorithm for solving the problem and test its workability for non-stationary signals.

### III. THE PURPOSE AND TASKS OF THE STUDY

The purpose of the study, the results of which are presented in the article, was to develop an algorithm for solving the problem of frequency-time analysis of signals, which implements the approach proposed in [7], as well as testing the efficiency of the algorithm based on a model example of a non-stationary signal. To achieve the goal, three tasks were solved:

1. Development of a time-frequency analysis algorithm for signals based on behavior functions and arithmetic series.
2. Determination of the signal spectrum under study based on the algorithm, comparison of the results obtained with the ideal spectrum of the model signal and errors estimation.
3. Estimation of the error in the restoration of the original signal based on the obtained spectra.

### IV. RESEARCH METHODS

To solve these problems the following methods were used: the theory of fuzzy sets and fuzzy measures; system analysis based on changes in system behavior;  $p$ -adic analysis; linear programming; discrete signal modeling; spectral analysis

## V. RESEARCH RESULTS

Based on the approach proposed in [7], an algorithm for time-frequency analysis of non-stationary signals was developed. The algorithm allows to obtain the spectrum of the signal at each point in time when observing the signal. The delay in estimating the spectrum is determined by the time for the formation of the observation window. Below is the synthesized algorithm for solving the problem:

### Step. 1. Initial data set:

1. The observation time  $W$  and the sampling interval of the signal (for example, in seconds).
2. The set of basis functions of impulse sines [7]  $\Phi = \{si_k(t)\}, k = \overline{1, N}, t \in W$ . Pulse sines are called impulse functions, in which the coordinates of the pulses are determined by the formula of an arithmetic progression:

$$a_m^k = a_1^k + (m - 1) \cdot d_k,$$

where  $a_m^k \in W$ ,  $k$  – index  $k$ -th sinusoid,  $d_k = const$  – is a step of arithmetic progression. In fact, the functions  $si_k(t)$  are given by two parameters  $a_1^k$  and  $d_k$ , which determine the phase and frequency of the harmonic signal, respectively.

3. The basis of the  $p$  - adic number ( $p \geq 2$ ), as well as the number of  $L$  observation channel blocks [13] to represent the data that describe the signal. The number of blocks is usually from 3 to 9.
4. The set of shift parameters  $\rho_k \in Z, k = \overline{1, |M|}$  is determined for the whole set of sample variables  $M$  [14] describing the signal.
5. The set of cut-off thresholds  $\{\Delta_u\}, \Delta_u \in [0; 1]$  to determine the impulse function. Thresholds are chosen at regular intervals in the range 0.12 – 0.25 in the amount of 10 – 15.
6. The algorithm parameter for determining the pulses coordinates for the impulse function of the studied series: an integer  $m \geq 1$ .
7. Select the type of window. There are four options:
  - a. Asymmetrical window. The boundaries of the window lie in the middle between the coordinates of nearby pulses of the signal that is being studied. Calculation of the window using the formula:

$$LR_n = [\tau_n - \varepsilon_L(n); \tau_n + \varepsilon_R(n)] \subseteq W.$$

where  $\varepsilon_L(n) = 0.5 \cdot (\tau_n - \tau_{n-1})$ ,  $\varepsilon_R(n) = 0.5 \cdot (\tau_{n+1} - \tau_n)$ ,  $\tau_n$  – pulse coordinate of the signal under study;

- b. Minimum window. Calculation of the window  $LR_n$  from the condition:

$$\varepsilon_L(n) = \varepsilon_R(n) = \varepsilon(n) = \min\{\varepsilon_L(n); \varepsilon_R(n)\};$$

- c. Maximum window. Calculation of the window  $LR_n$  from the condition:

$$\varepsilon_L(n) = \varepsilon_R(n) = \varepsilon(n) = \max\{\varepsilon_L(n); \varepsilon_R(n)\};$$

- d. Window with averaged deviation values. Calculation of the window using the formula:

$$LR_n = [\tau_n - 0.25 \cdot (\tau_{n+1} - \tau_{n-1}); \tau_n + 0.25 \cdot (\tau_{n+1} - \tau_{n-1})] \subseteq W.$$

8. A method is chosen for determining the influence degrees of the  $k$ -th impulse sine function from a set of basis functions  $\Phi$  for building the signal spectrum: method 1 - based on optimization (linear programming); method 2 - on the basis of an approximate approach.

**Step 2.** The maximum normalizing integer for the time series is determined on the basis of the  $p$ -adic number formula of the form [15]:

$$b_{max} = \sum_{l=0}^L \alpha_l \cdot p^l,$$

where  $\forall l \in \{0, \dots, L\} \alpha_l = p - 1$ .

**Step 3.** All values of the time series of the signal under study  $\varphi_n$  are normalized so that the minimum value of the series is 0, and the maximum value of the series  $b_{max}$ . The resulting values are rounded to integers.

**Step 4.** Each value of the series is decomposed into  $p$ -adic number and is represented in canonical form [16]:  $b(t) = \{\alpha_0, \alpha_1, \dots, \alpha_l, \dots, \alpha_L\}$ . In fact, this is a representation of a number in the  $p$ -adic number system. If  $p = 2$ , then these are binary numbers. The value of  $\alpha_l$  determines the value of the  $l$ -th variable.

**Step 5.** For each point in time, the confidence distribution is calculated for each system variable describing the signal. Let the value of the system variable  $v_i \in V_i$ , be determined on the set of states  $V_i = \{v_{i1}, \dots, v_{i,L+1}\}$ , where  $v_{ij} = \alpha_{l+1}$ ,  $j = l + 1, l = \overline{0, L}$ . Then the state of the system for this variable for  $t \in W$  is determined by the distribution function of the possibility  $\mu_t(v_{ij}): W \times V_i \rightarrow [0,1]$ , which is given on the basis of  $p$ -adic number  $b(t)$  in the form:

$$\mu_t(v_{ij}) = \alpha_{l+1}(t) \cdot \left( \max_{l=\overline{0, L}} \alpha_l(t) \right)^{-1},$$

where  $\alpha_l(t)$  – value of  $l$ -th element of canonical form  $p$ -adic number with  $t \in W$ .

**Step 6.** A set of sample variables that determine the current state of the signal is defined. Sample variables are given by the relation  $s_{k,t} = v_{i,\zeta_k(t)} \in V_i \equiv S_k$ , where  $s_{k,t}$  is the state of the  $k$ -th sample variable with the parameter  $t \in W$ ,  $v_{i,\zeta_k(t)} \in V_i$  – the state of the variable  $v_i \in V_i$  when the value of the parameter  $\zeta_k(t) = t + \rho_k$ ,  $\rho_k \in Z$ . The full set of signal states will be defined as  $C = S_1 \times S_2 \times \dots \times S_{|M|}$ , where  $|M|$  – the power of the set of sample variables. The distribution of the possibility on the set of values of the sample variable is defined as  $\mu_t(s_{k,j}) = \mu_{\zeta_k(t)}(v_{i,j}) \in [0,1]$ .

**Step 7.** The pulses coordinate of the time series of the signal under study  $\varphi_n$  are determined. The algorithm is calculated for all thresholds  $\{\Delta_u\}$ . It is carried out iteratively on the basis of the metasystem identification subalgorithm described below:

**Step 7.1.** At the first step, the initial conditions for the parameter  $t = 1$  and the coefficient of the algorithm  $k = 1$  are accepted.

**Step 7.2.** For the data subset  $[t, t + m]$ , the behavior function  $f_1(c)$  is defined as the distribution of the possibility by the formula:

$$f(c) = \left\{ \sum_{t \in \Delta W} f_t(c) \right\} \cdot \left\{ \max_{e \in C} \sum_{t \in \Delta W} f_t(e) \right\}^{-1}.$$

where

$$f_t(c) = \min_{k=1, |M|} \{ \mu_t(s_k[c]) \},$$

where  $c \in C$  is the system state. The specific sample variable  $s_k$  in the state  $c \in C$  takes the value  $s_k[c] \in S_k \equiv V_i$ .  $\mu_t(s_k[c])$  - the possibility to observe the state  $c \in C$  with the sample variable  $s_k$  at the time  $t \in W$ .

**Step 7.3.** The index value of generating fuzziness of the system [17]  $U(f_1(c))$  is calculated by the formula:

$$U(f(c)) = \sum_{j=1}^{|C|} (f(c_j) - f(c_{j+1})) \cdot \log_2(j),$$

where  $f(c)$  is ordered by descending of  $\forall j, f(c_j) \geq f(c_{j+1})$  behavior function with a fictitious element  $f(c_{|C|+1}) = 0$ ,  $|C|$  - power set of states.

**Step 7.4.**  $k = k + 1$ . is given.  $t + k \cdot m \notin W$ , then go to step 7.7.

**Step 7.5.** The behavior function  $f_k(c)$  is determined for the data subset  $[t, t + k \cdot m] \subseteq W$  and the generating fuzziness  $U(f_k(c))$  is determined.

**Step 7.6.** If  $|U(f_k(c)) - U(f_{k-1}(c))| / \max(U(f_k(c)), U(f_{k-1}(c))) < \Delta_u$ , then go to Step 7.4. If the condition is not satisfied, then the point  $t + (k - 1) \cdot m \in W$  is taken as an approximation of the replacement point of the metasystem elements. For this point, the value  $k = 1$  is assumed and the transition to Step 7.2 is performed.

**Step 7.7.** Stop. At the moments of change in the behavior of the system, single impulses form. For a fixed threshold  $\Delta_u \in [0, 1], u = \overline{1, N_\Delta}$  for discrete moments  $t \in W$ , we obtain a two-dimensional impulse function:

$$r(u, t) = \begin{cases} 1, & t = \tau_n; \\ 0, & t \neq \tau_n. \end{cases}$$

**Step 8.** There is a generalized impulse function of the signal under study by the formula:

$$g(t) = \sum_{\Delta_u \in \{\Delta\}} \Delta_u \cdot r(u, t),$$

where  $r(u, t)$  is the impulse function for the threshold  $\Delta_u$  of the metasystem identification algorithm.

The time coordinates  $\tau_n \in W$  of the approximating impulse function  $r(t)$  for the signal under study are defined as the local maxima of the function  $g(t)$ . The coordinates  $\tau_n$  will specify a numeric sequence with variable step  $d(j)$ . The total number of pulses of the function under study  $N$ . Thus, there will be  $N$  local intervals, where the original signal has relatively stable frequency characteristics.

**Step.9.** For each pulse  $\tau_n$ , a window  $LR_n \subseteq W$  is determined based on the selected window type in accordance with Step 1.

**Step 10.** For each pulse of the signal under investigation with the coordinate  $\tau_n$ , for each basis function of the pulse sines, the coefficients of the balance equation [7] are determined by the formula:

$$\Lambda_k(\tau_n) = \{\beta_k(\tau_n) \cdot \tau_n - S_k(LR_n)\},$$

where the coefficient  $\beta_k(\tau_n) = \sum_{a_m^k \in LR_n} (-1)^{m-1} \in \{-1, 0, 1\}$ .  $S_k(LR_n)$  – is the partial sum of the sign-variable number series obtained from the arithmetic progression for the pulse sine  $si_k(t)$ :

$$\sum_{a_m^k \in LR_n} (-1)^{m-1} \cdot a_m^k = S_k(LR_n),$$

where  $LR_n \subseteq W$  is the time window near the pulse coordinate  $\tau_n$  of the function under study. The partial sum  $S_k(LR_n)$  takes into account the influence of all the pulses of the function  $si_k(t)$  falling into the window  $LR_n$ .

**Step 9.** For each  $k$ -th impulse sine function, the degree of its influence on the formation of the resulting impulse  $r(\tau_n)$  is determined. For each pulse  $r(\tau_n)$  the determination of the coefficients of the influence degrees  $x_k(\tau_n) \in [0, 1]$  is found either by the optimization method (method 1) or by the approximate method (method 2).

According to method 1, the coefficients  $x_k(\tau_n) \in [0, 1]$  are found from the solution of an optimization linear programming problem based on the simplex method [18]:

$$\begin{cases} \sum_{k=1}^K x_k(\tau_n) \cdot \Lambda_k(\tau_n) \rightarrow \min_{\{x_k(\tau_n)\}} \\ \sum_{k=1}^K x_k(\tau_n) = 1, \forall k, x_k(\tau_n) \geq 0, \end{cases}$$

According to method 2, the coefficients  $x_k(\tau_n) \in [0, 1]$  are found by the formula:

$$x_k(\tau_n) = \begin{cases} |\beta_k(\tau_n)| \cdot \left[ 1 - \frac{2 \cdot |\Lambda_k(\tau_n)|}{(\varepsilon_R(n) + \varepsilon_L(n))} \right], & S_k(LR_n) \neq 0, \\ x_k(\tau_n) = \lambda_k \cdot x(\tau_{n-1}), & S_k(LR_n) = 0, \lambda_k \in [0, 1]. \end{cases}$$

where  $\varepsilon_R(n)$  and  $\varepsilon_L(n)$  are the right and left deviations from the coordinate of the pulse  $\tau_n$ . Coefficient  $\lambda_k \in [0, 1]$  is determined from the correct consideration condition of the low-frequency components of the signal spectrum:

$$\lambda_k = \begin{cases} 0, & \left| \tau_n > \max_{\cup_{j \in \{1, n-1\}} LR_j} (a_m^k) + d_k \right. \\ 1, & \left| \tau_n \leq \max_{\cup_{j \in \{1, n-1\}} LR_j} (a_m^k) + d_k \right. \\ [0,45; 0,55] & \left| \begin{array}{l} \tau_n \leq \max_{\cup_{j \in \{1, n-1\}} LR_j} (a_m^k) + d_k, \\ \nexists k', \{S_{k'}(LR_n) \neq 0\} \wedge \{\Lambda_{k'}(\tau_n) = 0\}. \end{array} \right. \end{cases}$$

For all pulses of the signal under study, in the vicinity of the coordinates  $\tau_n$ , a function of the conditional instantaneous spectral density  $\omega_n(k): \Phi \rightarrow [0,1]$  is formed, where  $\omega_n(k) = x_k(\tau_n)$ .

**Step 10.** Spectrum estimates are determined based on fuzzy filtering. The estimated spectrum is determined by the fuzzy filter formula [19, 20]. In the simplest case, a filter is used in the form

$$\hat{\omega}_n(k) = \hat{\omega}_{n-1}(k) + \alpha \cdot \{\omega_n(k) - \hat{\omega}_{n-1}(k)\},$$

where  $\alpha \in [0,1]$  is the gain of a fuzzy filter [21].

**Step 11.** Stop.

The function  $\hat{\omega}_n(k)$  is taken as the basis for the time-frequency analysis of the signal under study. It is also used to restore the original signal. In this case, the reconstructed signal is found as the sum of sinusoidal functions, which determine the set of basis functions  $\Phi$  with amplitudes multiplied by the value  $\hat{\omega}_n(k)$ . The accuracy of the algorithm is checked by the error criterion, which is calculated, for example, by the degree of correlation [22] between two functions. To test the performance of the algorithm, studies were performed on a model example of a non-stationary signal.

## VI. THE DISCUSSION OF THE RESULTS

To substantiate the performance of the proposed algorithm for time-frequency analysis of non-stationary signals, it is necessary to solve two classical interrelated tasks:

1. To determine the spectrum of the investigated signal. Compare the results obtained with the actual signal spectrum. Estimate the errors of the proposed algorithm.
2. Based on the obtained spectra, restore the signal and compare it with the original signal. Rate the error.

For the study of the algorithm, a non-stationary signal  $\varphi_n$  with a sampling interval of 0.1 s was chosen. The observation time of the signal  $W = 10$  s. The source signal is considered as a discrete representation of the addition of sinusoidal signals  $f_n^i, i = \overline{1,4}$  at frequencies of 0.159 Hz, 0.334 Hz, 0.446 Hz, 0.637 Hz with different amplitudes at subintervals  $W_1 = [0; 5]$  s and  $W_2 = [5; 10]$  s. The values of amplitude-frequency characteristics for signals  $f_n^i$  in the intervals  $W_1$  and  $W_2$  are shown in Fig. 3



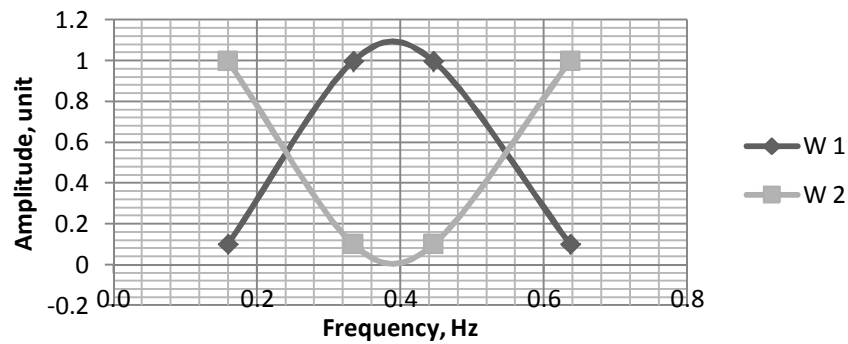


Fig. 3: Graphs of amplitude-frequency characteristics for signals  $f_n^i$

Time series graphs of the of the signal under study and its components  $f_n^i, i = \overline{1,4}$ . are shown in Fig 4

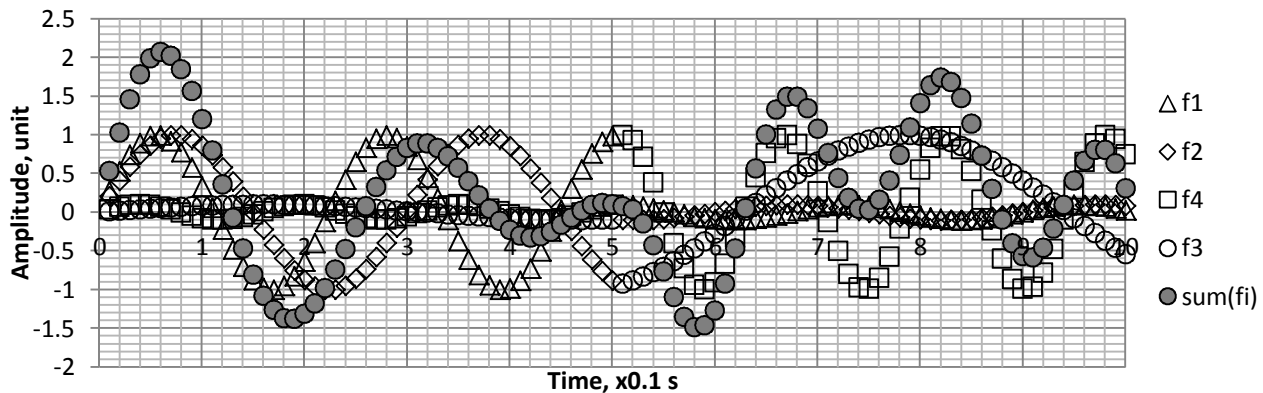


Fig. 4: Time series of the investigated signal and its components

The following parameters were chosen as initial data for the algorithm investigation:

1. In the set of basic functions, sinusoidal functions are considered, represented by impulse sines of the form:

$$\Phi = \{ si_k(t|a_1^k, d_k) \} = \{ si_1(t|0; 15); si_2(t|0; 11); si_3(t|0; 20); si_4(t|0; 5); \}, k = \overline{1,4}.$$

2. We will assume that quantization by level of the signal under study provides the power of the set of signal values  $Card(Z_{ts}) = 128$ . To represent the signal value, we will use  $p$ -adic numbers with  $p = 2$ . In this case, to represent one data in the data system, the number of blocks of the observation channel will be  $L = 7$ .

3. To determine the set of sample variables and build the function of the system behavior, we will use the simplest mask with the shift parameter  $\rho = 0$  for all variables of the system  $v_{i, \zeta_k(t)} \in V_i$ . In the metasystem identification algorithm, the set of cut-off threshold values  $\{\Delta_u\}$  is presented in Table 1.

Table 1: The set of cut-off thresholds taken in the study

$u$	1	2	3	4	5	6	7	8	9	10	11
$\Delta_u$	0.205	0.202	0.199	0.196	0.193	0.19	0.187	0.184	0.181	0.178	0.175

4. In the balance equations, we will use a symmetric window  $LR_n$  with the averaged deviation  $\varepsilon(n) = 0.5 \cdot (\varepsilon_L(n) + \varepsilon_R(n))$ .

5. To test the algorithm performance in determining the influence degrees of the  $k$ -th impulse sine function  $x_k(\tau_n)$  from the set of basis functions  $\Phi$ , we will use an approximate approach.

Based on the initial data, as a result of applying the algorithm proposed above, the data system  $D$  was obtained for the signal under study. Data system  $D$  is a matrix  $V \times W$  with a dimension of  $7 \times 100$ . In Table 2 shows a fragment of this matrix for a time subset up to  $t \in [0; 1]$  s.

Table 2: Fragment of the data matrix for the time series under study

$t$	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
$v_1$	1	1	1	1	1	1	1	1	1	1
$v_2$	0	1	1	1	1	1	1	1	1	1
$v_3$	1	0	0	1	1	1	1	1	1	0
$v_4$	0	0	1	0	1	1	1	1	0	0
$v_5$	0	0	1	1	1	1	1	0	0	1
$v_6$	0	0	0	1	0	1	0	0	0	0
$v_7$	1	0	1	0	1	1	1	0	0	1

As a result of using the metasystem identification algorithm, the full two-dimensional impulse function  $r(u, t)$  was obtained (Fig. 5). Based on this function, a generalized impulse function  $g(t)$  was obtained (Fig. 6).

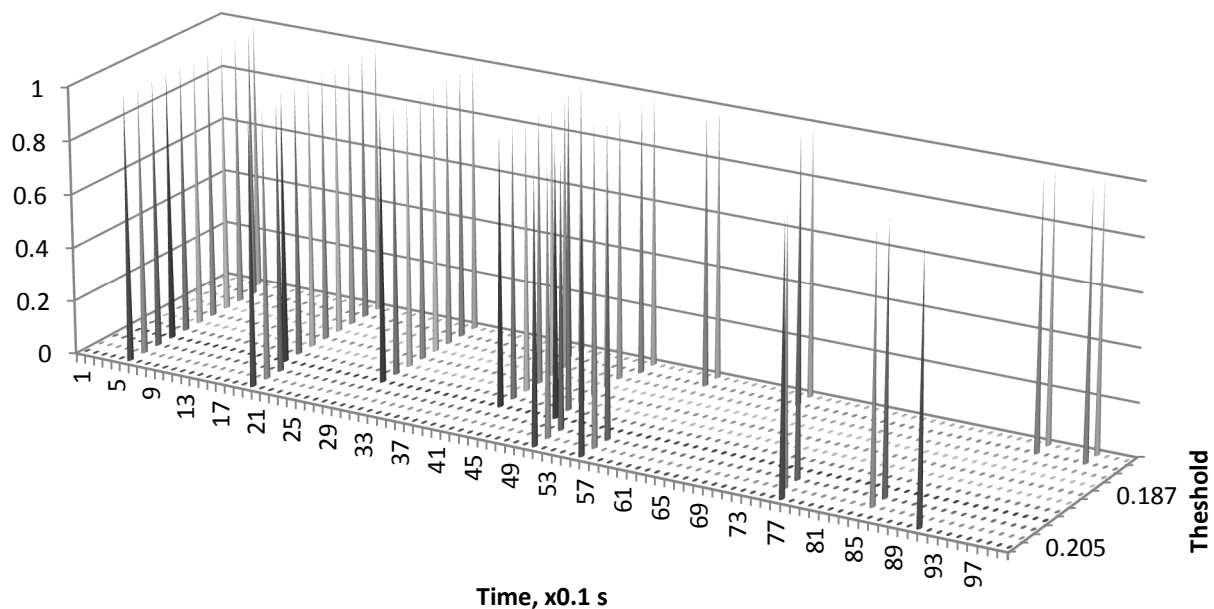


Fig. 5: Full two-dimensional pulse function  $r(u, t)$  for the signal

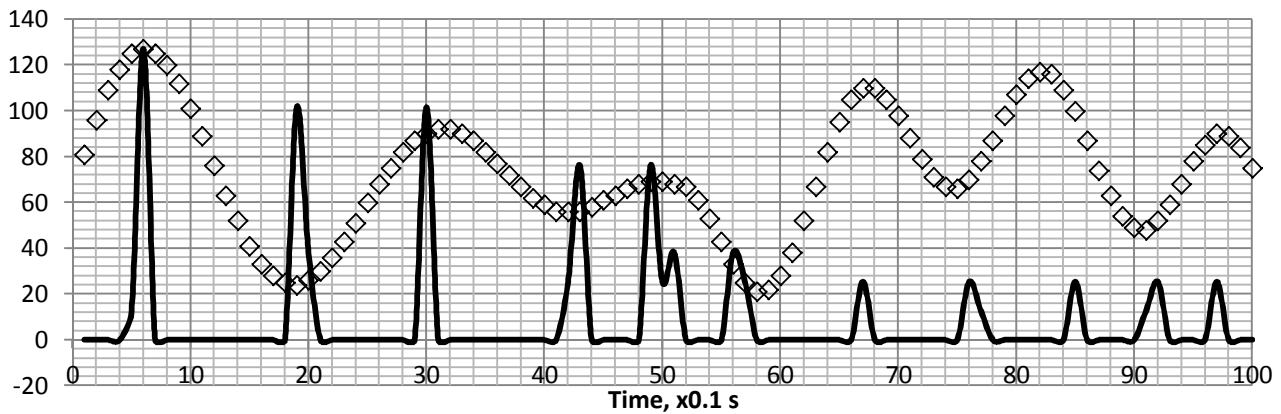


Fig. 6: The time series of the signal under study and the corresponding generalized impulse function  $g(t)$  (normalized to the maximum value of the series under study)

The function  $g(t)$  allows to obtain the impulse function of the signal under study  $r(\tau_n)$ . The coordinates of the pulses  $\tau_n$  were determined as the local extrema coordinates of the function  $g(t)$  (Fig. 7).

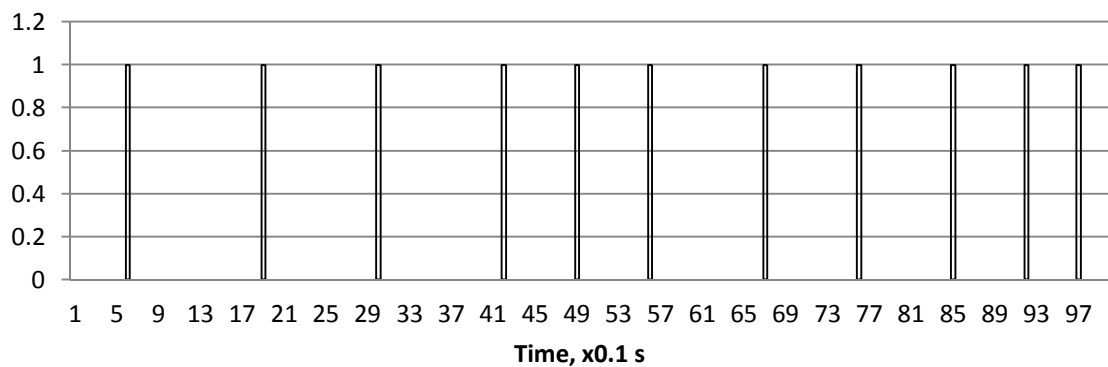


Fig. 7: Pulse function of the signal under study  $r(\tau_n)$

Based on the obtained impulse function  $r(\tau_n)$  for a given set of impulse functions  $\Phi = \{si_k(t)\}, k = \overline{1,4}$ , we obtained the coefficients of the balance equation for all coordinates of the impulses  $\tau_n, n = \overline{1, N}$ . For example, for the coordinate  $\tau_2 = 19$  and for the average deviation, the window will be defined as:

$$LR_n = [\tau_2 - 0.25 \cdot (\tau_3 - \tau_1); \tau_2 + 0.25 \cdot (\tau_3 - \tau_1)] = [19 - 0.25 \cdot (30 - 6); 19 + 0.25 \cdot (30 - 6)] = [13; 25] \subseteq W.$$

In this case, the value of the partial sum for the pulse sine function  $si_1(t|0;15)$  will be:  $S_1(LR_2) = -21$ , and the coefficient  $\beta_1(\tau_2) = (-1)^{2-1} = -1$ . Then the coefficient  $\Lambda_1(\tau_2)$  for the balance equation will take the value:

$$\Lambda_1(\tau_2) = \{\beta_1(\tau_2) \cdot \tau_2 - S_1(LR_2)\} = -1 \cdot 19 - (-21) = 2.$$

Similarly, the coefficients of the balance equation are calculated for all basis functions and coordinates  $\tau_n, n = \overline{1, N}$ . (Table 3).

*Table 3:* The coefficients of balance equations

$\tau_n$	$\Lambda_1$	$\Lambda_2$	$\Lambda_3$	$\Lambda_4$
19	2	-2	-	5
30	-	2	-4	5
43	-	4	3	5
49	2	-1	-	2
56	-	-	-	0
67	1	-	-1	5
76	-	-	-	0
85	-	2	-1	-1
92	-	2	-	-1

In Table 4 estimates of the coefficients  $x_k(\tau_n)$  (normalized to unity) obtained using the direct approximate approach to their definition are presented. Table 4a presents the directly obtained estimates of the coefficients  $x_k(\tau_n)$ , and in Table 4b are estimates of the coefficients  $x_k(\tau_n)$  after filtering with the gain  $\alpha = 0.53$ .

*Table 4:* Estimates of the coefficients  $x_k(\tau_n)$  of the signal spectrum, obtained by the approximate method

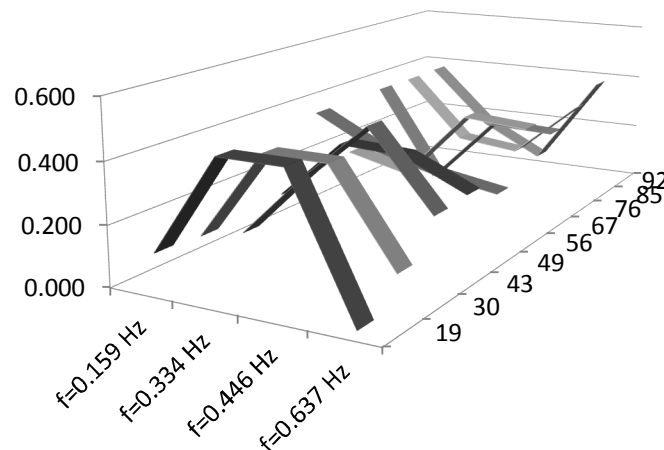
Table 4a

$\tau_n$	$x_4(\tau_n)$	$x_2(\tau_n)$	$x_1(\tau_n)$	$x_3(\tau_n)$
19	0.167	0.667	0.667	0.000
30	0.167	0.667	0.667	0.333
43	0.000	0.200	0.667	0.400
49	0.333	0.667	0.333	0.400
56	1.000	0.333	0.167	0.200
67	0.000	0.000	0.800	0.800
76	1.000	0.000	0.400	0.400
85	0.750	0.500	0.000	0.750
92	0.667	0.333	0.000	0.750

Table 4b

$\tau_n$	$x_4(\tau_n)$	$x_2(\tau_n)$	$x_1(\tau_n)$	$x_3(\tau_n)$
19	0.111	0.444	0.444	0.000
30	0.100	0.402	0.402	0.096
43	0.047	0.272	0.468	0.213
49	0.124	0.332	0.322	0.222
56	0.370	0.260	0.203	0.167
67	0.174	0.122	0.360	0.343
76	0.376	0.057	0.287	0.279
85	0.376	0.159	0.135	0.330
92	0.378	0.176	0.063	0.382

The change in the  $x_k(\tau_n)$  coefficients of the signal spectrum over time is shown below (Fig.8).



*Fig. 8:* Change dynamics of the  $x_k(\tau_n)$  coefficients of the signal spectrum

From Fig. 8, it follows that the algorithm provides the correct spectrum estimate for a non-stationary signal. In Fig. 9 a comparison of the true and estimated signal spectrum at the initial and final measurement interval is shown.

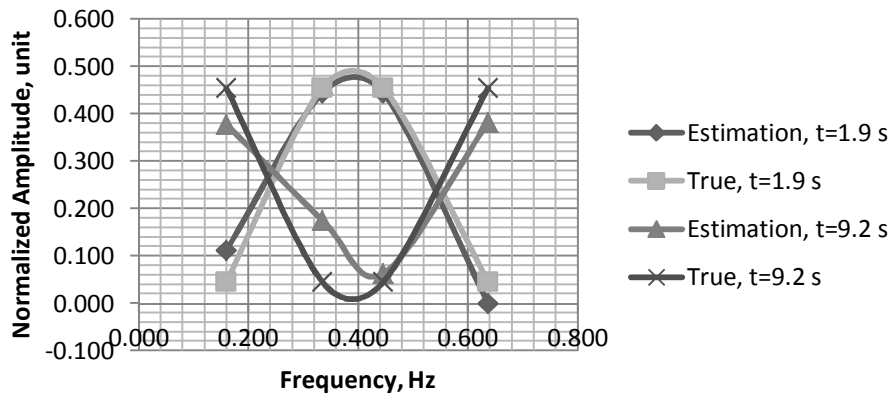


Fig. 9: Comparison of the true and estimated spectrum

At the same time, over the entire observation interval, the degree of correlation between the spectra at each frequency remains high (more than 0.7, Fig. 10).

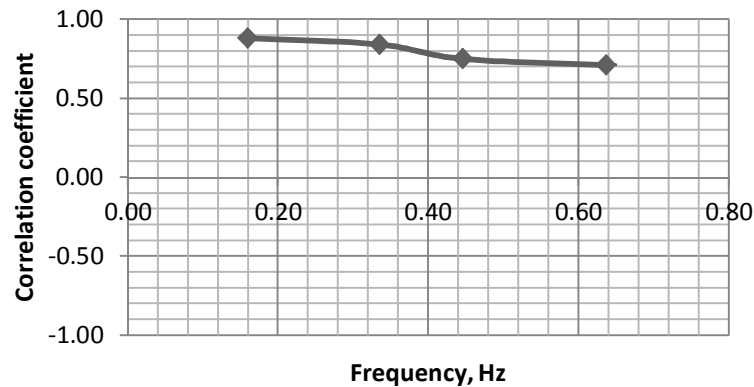


Fig. 10: The correlation coefficient between the spectra for each frequency over the entire time interval

The change in the value of the correlation coefficient between the true and estimated spectra over the entire time interval is shown in Fig. 11.

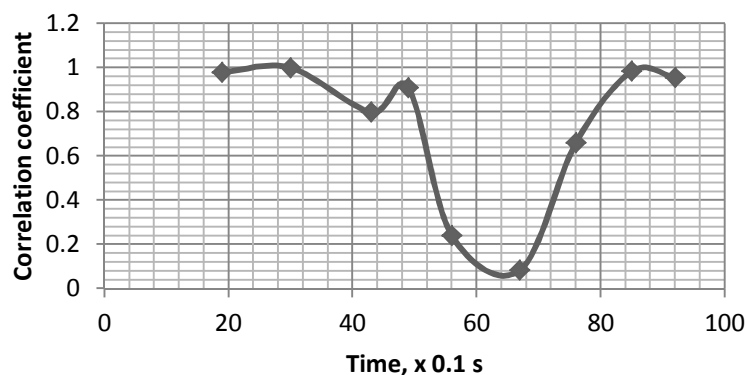


Fig. 11: Change in the correlation coefficient between the true and estimated spectra

The correlation degree of the spectra at the stationary parts of the signal refers to a high one (the correlation coefficient is more than 0.7). At the moment of changing the spectra of a true signal, the algorithm provides fast adaptation to a new signal spectrum (within 1 - 2 pulses of an impulse function simulating a true signal). Thus, with a large number of measurements, the algorithm will provide an increase in the accuracy of estimation of the current signal spectrum.

Based on the estimated spectra in each  $LR_n$  windows, the estimated signal is easily restored. In this case, the coefficients  $x_k(\tau_n)$  as amplitudes of the sinusoidal signals normalized to one are used. These sinusoidal signals correspond to the impulse sines  $si_k(t|a_1^k, d_k)$  from the set of basis functions  $\Phi$ . Fig. 12 shows the true and reconstructed signals from the estimated spectrum.

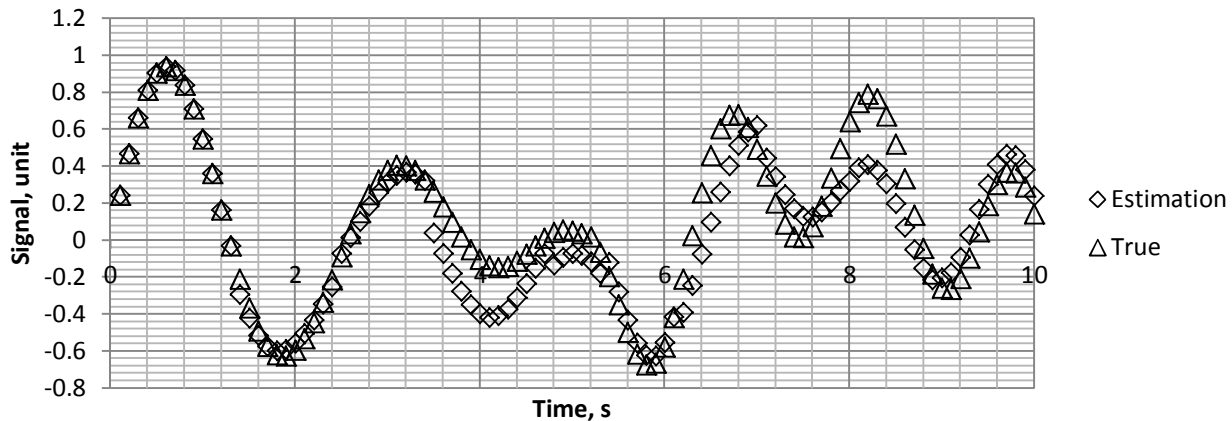


Fig. 12: True and reconstructed signals from the estimated spectrum.

The correlation coefficient of the signals is 0.933, which corresponds to a high level of correlation between the true and reconstructed signals. The average error for the Hamming distance is about 0.1 for the entire observation interval of the signal, taking into account the sharp change in its spectrum. From the graph it is seen that after a sharp change of the signal spectrum, there is an error in its recovery. However, by the 9th second the signals almost coincide. Thus, a relatively high degree of adaptation of the spectrum estimation algorithm for a non-stationary signal can be made.

## VII. CONCLUSIONS

The developed algorithm based on the results given in article [7] allows to reduce the problem of estimating the signal spectrum to the solution of a system of linear equations. These equations are based on the use of arithmetic progressions. In this case, the task of calculating the integral convolutions of functions that introduce additional errors in the definition of the signal spectrum is excluded. Additionally algorithm provides adaptive time-frequency localization which is linked to the measured signal. This reduces errors at the borders of the windows when determining the current spectra. These results were made possible due to the properties of the system behavior functions. These functions are the distribution of the possibility measure on a set of system states.

Studies of the algorithm have shown that the accuracy of determining the current signal spectrum will depend on the set of its parameters. In particular, the accuracy will depend on the signal discretization conditions, on parameters of the construction algorithm of behavioral functions, on algorithm for identifying the metasytem, on the choice of window, on the gain of the fuzzy filter, and other parameters. These parameters are the algorithm settings. The study of the



algorithm on the example of a non-stationary signal with a sharp change in the spectrum showed the efficiency of using the algorithm and a high degree of correlation between the estimated and true signal spectra. Estimates of the signal spectra, which are obtained using the algorithm, make it possible to recover the true signal with a high degree of correlation (with a correlation coefficient higher than 0.9).

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# Evaluation of the Effectiveness of the Integrity Control Algorithm Integrated Satellite Navigation System and the Functioning of the Inertial Navigation System

By Oleh Dmitriiev, Nadiia Kushnerova & Stanislav Profatilov

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**Methods:** Methods of experimental research and mathematical modeling.

**Results:** A project for an application software package has been developed that allows for a full-cycle simulation of the operation of the algorithm for monitoring the integrity of the SNS and monitoring the correctness of the INS operation.

**Discussion:** Based on the results of the study, it is proposed to simulate various situations from the point of view of assessing the integrity of the SNS and the correct functioning of the INS at different stages of the flight of the aircraft with different constellations of satellites.

**Keywords:** *satellite navigation system and inertial navigation system, integration, integrity, operation.*

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## I. INTRODUCTION

When flying along a route, the allowable error levels for determining the coordinates are quite high, which may facilitate the use of satellite navigation system (SNS) as the main means of navigation. During the approach phase, the integrity requirements are significantly increased, and the control parameters, which are calculated using the built-in monitoring method, can exceed the marginal error levels, which can lead to a decrease in the level of integrity evaluation functions.

Significantly improve the work of the integrated monitoring of the integrity of the SNS is possible not only with the help of functional add ons, but also through integrated use with other on board navigation systems, namely the INS.

To solve such problems, the construction of mathematical models of components within the structure of the navigation system of an aircraft (AC) is of great importance, since the adequacy of the models ensures the quality of the system in general.

Thus, the tasks of synthesis and modeling of the integration algorithms for mixed sources and motion control are important and relevant.

This article analyzes the effectiveness of assessing the integrity of an integrated satellite navigation system and the functioning of an inertial navigation system using computer simulation.

## II. ANALYSIS OF LATEST RESEARCH AND PUBLICATIONS

Due to the widespread use of satellite navigation technology, the integrity of navigation systems is becoming an important issue, especially to improve safety in air transport. [1-3]. Receiver Autonomous Integrity Monitoring (RAIM) is an important technology developed to assess and maintain the integrity of a GPS system.

The main requirements for ensuring integrity control are set out in the main guidelines [4,5]. According to the specified requirements, the satellite indicator should form control parameters that allow to make a conclusion about the compliance with the requirements for the integrity of the navigation system for a given flight phase of the aircraft and issue warning signals.

The high efficiency of RAIM depends on a sufficient number of visible satellites and their geometrical configuration. Usually, RAIM requires at least five satellites. In addition, the level of protection that is determined by the geometric configuration must be less than the warning limit.

Unfortunately, at the stage of take-off and landing errors and interferences can lead to a loss of signal. In this case, the detection efficiency of RAIM defects is greatly reduced [6-8].

The loss of functions to assess the integrity of the satellite radio navigation system can also occur with insufficient measurement redundancy, with unfavorable mutual geometry of the working constellation of navigation satellites, aircraft and high measurement interferences [9].

The search for algorithms that monitor the integrity of the SNS using navigation information is the

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subject of [10–12] works. In research [13], an algorithm was proposed for monitoring the integrity of the SNS and monitoring the correctness of the operation of the INS. However, in these works there is no construction of mathematical models of the components included in the structure of the navigation complex of the aircraft.

### III. RESEARCH TASKS

The purpose of this study is to develop an application software package for the integrated effectiveness of the algorithm for monitoring the integrity of the SNS and assessing the correctness of the operation of the INS.

### IV. ANALYSIS THE EFFECTIVENESS OF ASSESSING THE INTEGRITY OF AN INTEGRATED SATELLITE NAVIGATION SYSTEM AND THE FUNCTIONING OF AN INERTIAL NAVIGATION SYSTEM

To find out the effectiveness of the proposed algorithm [13] for autonomous monitoring of the integrity of the SNS and assessing the correctness of the operation of the INS, a project of the applied software was developed. This software package allows you to simulate the work of the entire complex of functions performed in the module of secondary processing of the SNS computer, taking into account the operating hindrance measurements of pseudoranges.

The graphic device developed as part of this software package allows you to directly observe the current parameters of key software modules that implement the developed algorithm for monitoring the integrity of the SNS and monitoring the correct functioning of the INS directly in the course of modeling.





Consider the work of the software package (Fig. 1).

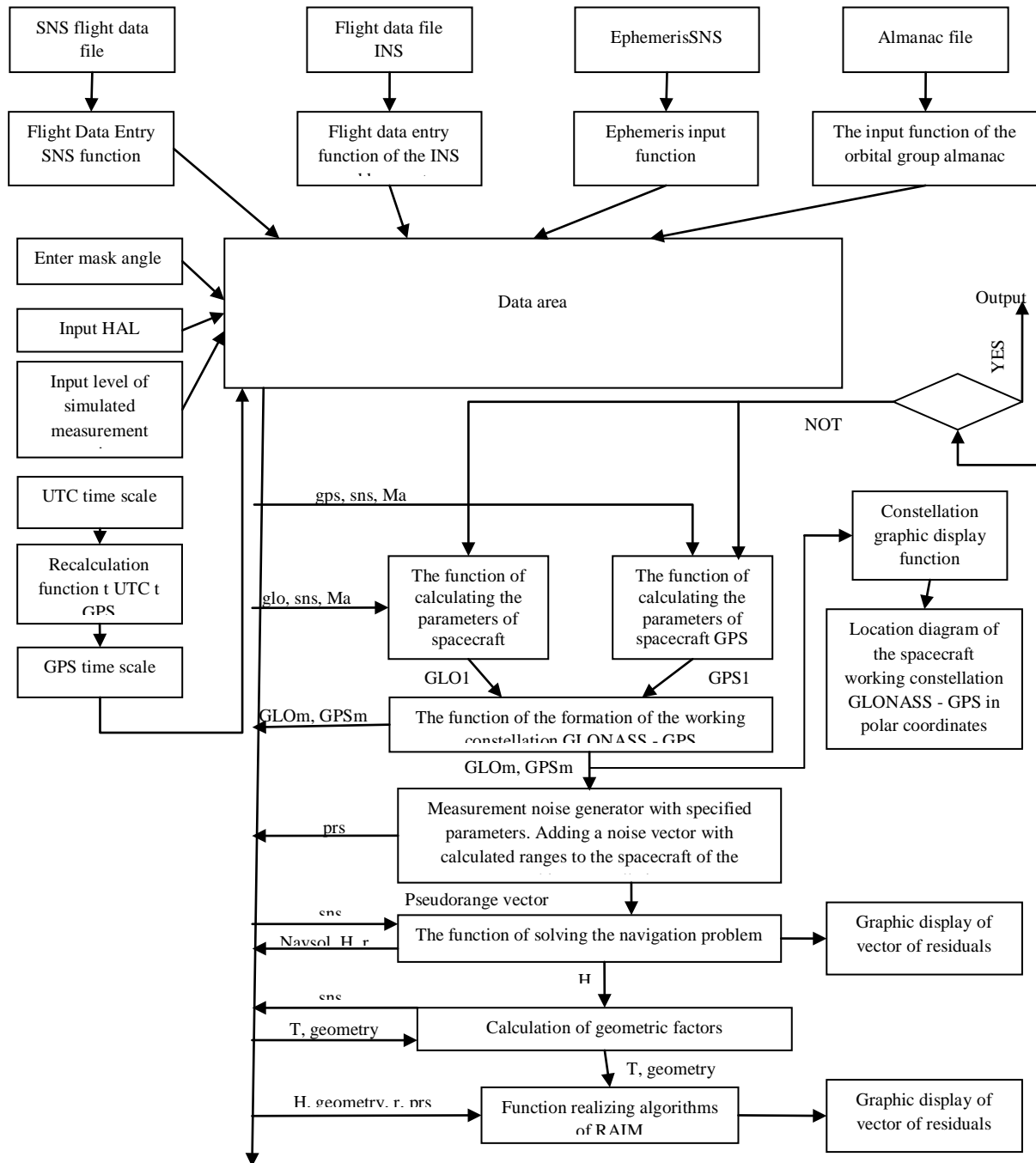


Figure 1: Structural diagram of an application software package for studying the effectiveness of the algorithm for monitoring the integrity of the SNS and evaluating the correctness of the operation of the INS at a given stage of the flight of the aircraft

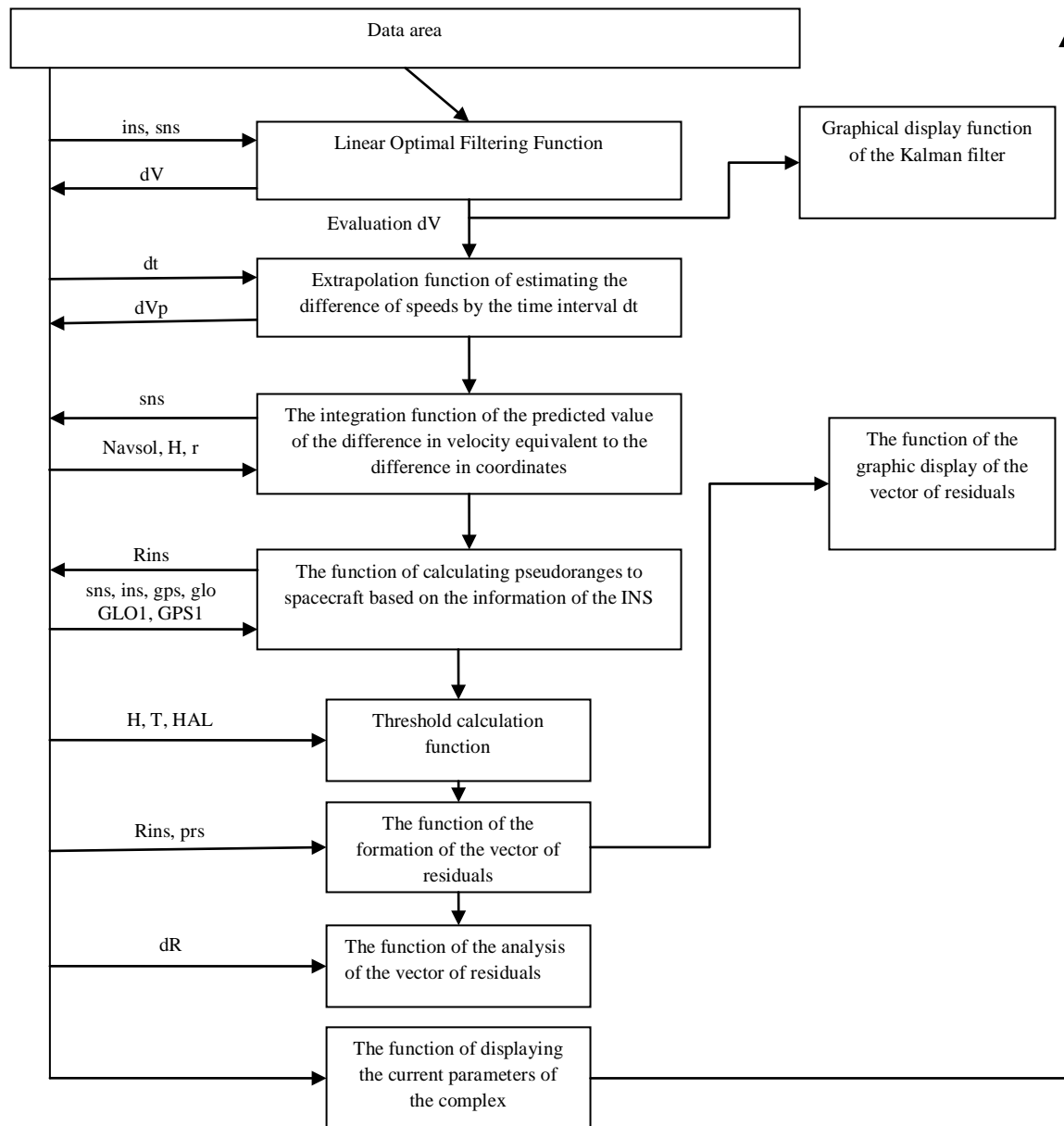


Figure 2: Structural diagram of the application software package for studying the effectiveness of the algorithm for monitoring the integrity of the SNS and evaluating the correctness of the operation of the INS at a given stage of the flight of the aircraft (continued)

Input parameters are databases of flight navigation data received from receiver-indicators (RI) of the SNS, INS and barometric altimeter. The format of the navigation data can be represented as:

$$SNS = \begin{bmatrix} \phi_1^{SNS} & \lambda_1^{SNS} & h_1^{SNS} & V_{N1}^{SNS} & V_{E1}^{SNS} & V_{h1}^{SNS} \\ \phi_2^{SNS} & \lambda_2^{SNS} & h_2^{SNS} & V_{N2}^{SNS} & V_{E2}^{SNS} & V_{h2}^{SNS} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \phi_i^{SNS} & \lambda_i^{SNS} & h_i^{SNS} & V_{Ni}^{SNS} & V_{Ei}^{SNS} & V_{hi}^{SNS} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \phi_N^{SNS} & \lambda_N^{SNS} & h_N^{SNS} & V_{NN}^{SNS} & V_{EN}^{SNS} & V_{hN}^{SNS} \end{bmatrix}.$$

$$INS = \begin{bmatrix} \phi_1^{INS} & \lambda_1^{INS} & h_1^{BARO} & V_{N1}^{INS} & V_{E1}^{INS} & V_{h1}^{BARO} \\ \phi_2^{INS} & \lambda_2^{INS} & h_2^{BARO} & V_{N2}^{INS} & V_{E2}^{INS} & V_{h2}^{BARO} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \phi_i^{INS} & \lambda_i^{INS} & h_i^{BARO} & V_{Ni}^{INS} & V_{Ei}^{INS} & V_{hi}^{BARO} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \phi_N^{INS} & \lambda_N^{INS} & h_N^{BARO} & V_{NN}^{INS} & V_{EN}^{INS} & V_{hN}^{BARO} \end{bmatrix}.$$

The length N of arrays of the SNS and INS is determined by the duration of the flights of the aircraft  $N = \frac{T_{flight}}{0.1}$ . Accumulated flight material contains arrays of length  $N = (2 \div 4) \times 10^6$ .

All calculations are made in the time scale of the GPS system, formed by recalculating computer time, synchronized with the UTC time scale (Fig. 1).

At the time  $t_{gps1}$ , the parameters of all spacecraft of orbital groupings are calculated, for which the orbital elements in the almanac are determined. The satellite coordinates are calculated according to the algorithms given in the interface control documents of these systems [14, 15].

As a result of the work of the functions of calculating the parameters of navigation spacecraft

(NSC), the matrices GLO1 and GPS1 are formed, corresponding to the NSC GLONASS and GPS. The matrices contain the same type of data, the format of which can be represented as:  $[N, NSC, A, E, R, X, Y, Z]$ , where  $A$  is the azimuth of NSC,  $E$  is the elevation angle of NSC,  $R$  is the geometric range to NSC,  $[X, Y, Z]$  - coordinates of satellites in the geocentric coordinate system.

Calculation of parameters  $A, E, R$  is made according to the algorithm

$$A = \arctan\left(\frac{E}{N}\right),$$

$$E = \arctan\left(\frac{H}{\sqrt{N^2 + E^2}}\right),$$

$$R = \sqrt{(X - x)^2 + (Y - y)^2 + (Z - z)^2},$$
(1)

where  $\begin{bmatrix} N \\ E \\ H \end{bmatrix} = T_1 \begin{bmatrix} (X - x) \\ (Y - y) \\ (Z - z) \end{bmatrix}$ ,  $x, y, z$  - geocentric coordinates of the aircraft.  $T_1$  matrix is defined in  $H_{NEH} = H_{XEZ} \cdot T^T$

Thus, at the time  $t_{gps1}$ , the parameters of all the NSCs of the existing SNS are known. The working constellation is determined by selecting the NSC whose elevation angle  $A$  is more than or equal to the specified angle of the mask  $Ma$ . This procedure is performed by the function `configure_constellation`. This function also makes it possible to exclude or, on the contrary, include NSCs of interest from the solution of the navigation problem directly in the modeling process, which provides an analysis of the operation of the algorithm under study with the desired geometric factors of GDOP.

To simulate the noise accompanying the pseudorange measurement process in real RI SNS, a random vector  $\xi_{t\_gps}$  is formed in the software package at each time instant, representing the Markov process with standard deviation =  $s_0$ , the value of which can be specified directly during the simulation.

The expression for the vector of pseudoranges can be written as

$$H_x = \begin{bmatrix} \frac{X_{gps}^1 - x_{t\_gps} - 1}{prs(l)_{t\_gps}^{GPS}} & \frac{Y_{gps}^1 - y_{t\_gps} - 1}{prs(l)_{t\_gps}^{GPS}} & \frac{Z_{gps}^1 - z_{t\_gps} - 1}{prs(l)_{t\_gps}^{GPS}} & 1 & 1 \\ \frac{X_{gps}^1 - x_{t\_gps} - 1}{prs(i)_{t\_gps}^{GPS}} & \frac{Y_{gps}^1 - y_{t\_gps} - 1}{prs(i)_{t\_gps}^{GPS}} & \frac{Z_{gps}^1 - z_{t\_gps} - 1}{prs(i)_{t\_gps}^{GPS}} & 1 & 1 \\ \frac{X_{glo}^1 - x_{t\_gps} - 1}{prs(l)_{t\_gps}^{GLO}} & \frac{Y_{glo}^1 - y_{t\_gps} - 1}{prs(l)_{t\_gps}^{GLO}} & \frac{Z_{glo}^1 - z_{t\_gps} - 1}{prs(l)_{t\_gps}^{GLO}} & 1 & 0 \\ \frac{X_{glo}^1 - x_{t\_gps} - 1}{prs(k)_{t\_gps}^{GLO}} & \frac{Y_{glo}^1 - y_{t\_gps} - 1}{prs(k)_{t\_gps}^{GLO}} & \frac{Z_{glo}^1 - z_{t\_gps} - 1}{prs(k)_{t\_gps}^{GLO}} & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} x_{t\_gps} - 1 \\ y_{t\_gps} - 1 \\ z_{t\_gps} - 1 \\ cdy_{t\_gps} - 1 \\ cdy'_{t\_gps} - 1 \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} \hat{x}_{t\_gps} \\ \hat{y}_{t\_gps} \\ \hat{z}_{t\_gps} \\ c\hat{d}t_{t\_gps} \\ c\hat{d}t'_{t\_gps} \end{bmatrix} = (H^T H)^{-1} H^T prs,$$

$$prs(j)_{t\_gps} = R(j)_{t\_gps} + \xi(j)_{t\_gps} \quad (2)$$

The failure of the  $j$ -th NCA is formed by entering an additional value  $e$  into the  $j$ -th component of the pseudorange vector  $prs$ :

$$prs(j)_{ei\_gps} = prs(j)_{t\_gps} + e. \quad (3)$$

The software package allows you to simulate the failure of any of the NSC of the visible constellation by selecting the appropriate number on the graphic console of the pseudorange determination process control console.

After the formation of databases of GLOm, GPSm, containing the coordinates of the NSC, as well as the vector of pseudoranges  $prs$ , all the necessary data for solving the navigation problem are prepared.

In the case of determining the coordinates when using measurements carried out on the NSC of two SNS, which takes place in the developed software package, the algorithm can be written as

$$\begin{aligned}x_{t_{gps}} &= x_{t_{gps}-1} + \hat{x}_{t_{gps}}, \\y_{t_{gps}} &= y_{t_{gps}-1} + \hat{y}_{t_{gps}}, \\z_{t_{gps}} &= z_{t_{gps}-1} + \hat{z}_{t_{gps}}.\end{aligned}\quad (5)$$

Covariance matrix  $\Sigma_{\Gamma CK} = (H^T H)^{-1}$  carries information about the error of the estimate of coordinates, which takes place at the current mutual geometrical arrangement of the NSC and AC:

$$\Sigma_{GSK} = \begin{bmatrix} \sigma_X^2 & \sigma_{XY} & \sigma_{XZ} & |\sigma_{X,cdt} & \sigma_{X,cdt'} \\ \sigma_{XY} & \sigma_Y^2 & \sigma_{YZ} & |\sigma_{Y,cdt} & \sigma_{Y,cdt'} \\ \sigma_{ZY} & \sigma_{ZY} & \sigma_Z^2 & |\sigma_{Z,cdt} & \sigma_{Z,cdt'} \\ - & - & - & - & - \\ \sigma_{cdt,X} & \sigma_{cdt,Y} & \sigma_{cdt,Z} & |\sigma_{cdt}^2 & \sigma_{cdt',cdt} \\ \sigma_{cdt',X} & \sigma_{cdt',Y} & \sigma_{cdt',Z} & \sigma_{cdt,cdt'} & \sigma_{cdt'}^2 \end{bmatrix}. \quad (6)$$

To calculate the geometric factors, the  $\Sigma_{GSK}$  matrix, defined in the geocentric coordinate system, must be transformed into the local coordinate system NEH. Designating the matrix block (6), which determines the deterioration of the coordinate determination accuracy as

$$S = \begin{bmatrix} \sigma_X^2 & \sigma_{XY} & \sigma_{XZ} \\ \sigma_{XY} & \sigma_Y^2 & \sigma_{YZ} \\ \sigma_{ZX} & \sigma_{ZY} & \sigma_Z^2 \end{bmatrix},$$

we write the expression for the covariance matrix in the local coordinate system:

$$\Sigma_{NEH} = \begin{bmatrix} \sigma_N^2 & \sigma_{NE} & \sigma_{NH} \\ \sigma_{NE} & \sigma_E^2 & \sigma_{EH} \\ \sigma_{HN} & \sigma_{HE} & \sigma_H^2 \end{bmatrix} = T_1^T \Sigma_{\Gamma CK} (3 \times 3) T_1. \quad (7)$$

Having determined the  $\Sigma_{NEH}$  matrix, we can find the corresponding degradation of accuracy for the two-system RI SNS:

$$\text{geometrical: } GDOP = \sqrt{\sigma_N^2 + \sigma_E^2 + \sigma_H^2 + \sigma_{edt}^2 + \sigma_{edt'}^2} \quad (8)$$

$$\text{horizontal: } HDOP = \sqrt{\sigma_N^2 + \sigma_E^2} \quad (9)$$

$$\text{coordinates: } PDOP = \sqrt{\sigma_N^2 + \sigma_E^2 + \sigma_H^2} \quad (10)$$

$$\text{heights: } HDOP = \sigma_H \quad (11)$$

$$\text{time: } TDOP = \sigma_{edt} \quad (12)$$

Integration of information from RI SNS and INS occurs in the software block displaying the work of the Kalman filter. The result of the function is an optimal linear estimate of the velocity difference  $\Delta \hat{v}_{t_{gps}}$ .

The predicted velocity difference vector  $dV_p$  is calculated by the method of numerical integrated one into the equivalent value of the predicted divergence of the coordinates of the PI SNS and INS.

The next step in the algorithm for monitoring the integrity of the SNS and assessing the correct operation of the INS is the calculation of the pseudoranges  $R_{ins}$  to the NSC of the working constellation based on the current navigation information of the INS.

After calculating the threshold for detecting and localizing anomalous measurements, the vector of pseudorange residuals is formed, measured in the SNS and calculated on the basis of the INS navigation definitions. Next, the vector of residuals is transmitted as an input parameter and the following possible solutions are made:

- The decision on the presence of an anomalous measurement in the vector of measured pseudoranges RI SNS.
- The decision to detect the malfunction of the INS.

The considered software package allows you to simulate a failure in the INS directly in the simulation process by entering an additional  $x_e^{IHC}$  error into the INS coordinate vector:

$$\begin{aligned}\phi_{t_{gps}}^{INS} &= \phi_{t_{gps}}^{INS} + \phi_e \\ \lambda_{t_{gps}}^{INS} &= \lambda_{t_{gps}}^{INS} + \lambda_e.\end{aligned}$$

At the final stage, the current parameters of the studied algorithm are output to the information console. At the next time point  $t_{gps2}$ , if the sign of completion of the simulation is not established, a new cycle of calculations begins in the sequence described.

## V. CONCLUSIONS

In order to determine the effectiveness of the proposed algorithm [13], a project of an applied

software complex was developed that allows performing a full cycle of modeling the operation of an algorithm at a given AC flight stage using the orbital parameters of the existing SNS groupings, as well as experimental navigation definitions of the SNS and INS receiver and indexer, registered during the AC flights.

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You may join as member of the Editorial Board of Global Journals Incorporation (USA) after successful completion of three years as Fellow and as Peer Reviewer. In addition, it is also desirable that you should organize seminar/symposium/conference at least once.

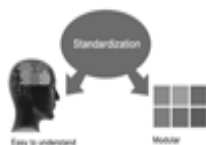
We shall provide you intimation regarding launching of e-version of journal of your stream time to time.This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.





The FARSE can go through standards of OARS. You can also play vital role if you have any suggestions so that proper amendment can take place to improve the same for the benefit of entire research community.

As FARSE, you will be given a renowned, secure and free professional email address with 100 GB of space e.g. johnhall@globaljournals.org. This will include Webmail, Spam Assassin, Email Forwarders, Auto-Responders, Email Delivery Route tracing, etc.



The FARSE will be eligible for a free application of standardization of their researches. Standardization of research will be subject to acceptability within stipulated norms as the next step after publishing in a journal. We shall depute a team of specialized research professionals who will render their services for elevating your researches to next higher level, which is worldwide open standardization.

The FARSE member can apply for grading and certification of standards of their educational and Institutional Degrees to Open Association of Research, Society U.S.A. Once you are designated as FARSE, you may send us a scanned copy of all of your credentials. OARS will verify, grade and certify them. This will be based on your academic records, quality of research papers published by you, and some more criteria. After certification of all your credentials by OARS, they will be published on your Fellow Profile link on website <https://associationofresearch.org> which will be helpful to upgrade the dignity.



The FARSE members can avail the benefits of free research podcasting in Global Research Radio with their research documents. After publishing the work, (including published elsewhere worldwide with proper authorization) you can upload your research paper with your recorded voice or you can utilize chargeable services of our professional RJs to record your paper in their voice on request.

The FARSE member also entitled to get the benefits of free research podcasting of their research documents through video clips. We can also streamline your conference videos and display your slides/ online slides and online research video clips at reasonable charges, on request.





The FARSE is eligible to earn from sales proceeds of his/her researches/reference/review Books or literature, while publishing with Global Journals. The FARSE can decide whether he/she would like to publish his/her research in a closed manner. In this case, whenever readers purchase that individual research paper for reading, maximum 60% of its profit earned as royalty by Global Journals, will be credited to his/her bank account. The entire entitled amount will be credited to his/her bank account exceeding limit of minimum fixed balance. There is no minimum time limit for collection. The FARSE member can decide its price and we can help in making the right decision.

The FARSE member is eligible to join as a paid peer reviewer at Global Journals Incorporation (USA) and can get remuneration of 15% of author fees, taken from the author of a respective paper. After reviewing 5 or more papers you can request to transfer the amount to your bank account.



## MEMBER OF ASSOCIATION OF RESEARCH SOCIETY IN ENGINEERING (MARSE)

The 'MARSE' title is accorded to a selected professional after the approval of the Editor-in-Chief / Editorial Board Members/Dean.

The "MARSE" is a dignified ornament which is accorded to a person's name viz. Dr. John E. Hall, Ph.D., MARSE or William Walldroff, M.S., MARSE.



MARSE accrediting is an honor. It authenticates your research activities. After becoming MARSE, you can add 'MARSE' title with your name as you use this recognition as additional suffix to your status. This will definitely enhance and add more value and repute to your name. You may use it on your professional Counseling Materials such as CV, Resume, Visiting Card and Name Plate etc.

*The following benefits can be availed by you only for next three years from the date of certification.*



MARSE designated members are entitled to avail a 25% discount while publishing their research papers (of a single author) in Global Journals Inc., if the same is accepted by our Editorial Board and Peer Reviewers. If you are a main author or co-author of a group of authors, you will get discount of 10%.

As MARSE, you will be given a renowned, secure and free professional email address with 30 GB of space e.g. johnhall@globaljournals.org. This will include Webmail, Spam Assassin, Email Forwarders, Auto-Responders, Email Delivery Route tracing, etc.





We shall provide you intimation regarding launching of e-version of journal of your stream time to time. This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.

The MARSE member can apply for approval, grading and certification of standards of their educational and Institutional Degrees to Open Association of Research, Society U.S.A.



Once you are designated as MARSE, you may send us a scanned copy of all of your credentials. OARS will verify, grade and certify them. This will be based on your academic records, quality of research papers published by you, and some more criteria.

It is mandatory to read all terms and conditions carefully.



## AUXILIARY MEMBERSHIPS

### Institutional Fellow of Open Association of Research Society (USA)-OARS (USA)

Global Journals Incorporation (USA) is accredited by Open Association of Research Society, U.S.A (OARS) and in turn, affiliates research institutions as “Institutional Fellow of Open Association of Research Society” (IFOARS).

The “FARSC” is a dignified title which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., FARSC or William Walldroff, M.S., FARSC.



The IFOARS institution is entitled to form a Board comprised of one Chairperson and three to five board members preferably from different streams. The Board will be recognized as “Institutional Board of Open Association of Research Society”-(IBOARS).

*The Institute will be entitled to following benefits:*



The IBOARS can initially review research papers of their institute and recommend them to publish with respective journal of Global Journals. It can also review the papers of other institutions after obtaining our consent. The second review will be done by peer reviewer of Global Journals Incorporation (USA). The Board is at liberty to appoint a peer reviewer with the approval of chairperson after consulting us.

The author fees of such paper may be waived off up to 40%.

The Global Journals Incorporation (USA) at its discretion can also refer double blind peer reviewed paper at their end to the board for the verification and to get recommendation for final stage of acceptance of publication.



The IBOARS can organize symposium/seminar/conference in their country on behalf of Global Journals Incorporation (USA)-OARS (USA). The terms and conditions can be discussed separately.

The Board can also play vital role by exploring and giving valuable suggestions regarding the Standards of “Open Association of Research Society, U.S.A (OARS)” so that proper amendment can take place for the benefit of entire research community. We shall provide details of particular standard only on receipt of request from the Board.



Journals Research  
inducing researches

The board members can also join us as Individual Fellow with 40% discount on total fees applicable to Individual Fellow. They will be entitled to avail all the benefits as declared. Please visit Individual Fellow-sub menu of GlobalJournals.org to have more relevant details.



We shall provide you intimation regarding launching of e-version of journal of your stream time to time. This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.



After nomination of your institution as “Institutional Fellow” and constantly functioning successfully for one year, we can consider giving recognition to your institute to function as Regional/Zonal office on our behalf.

The board can also take up the additional allied activities for betterment after our consultation.

### **The following entitlements are applicable to individual Fellows:**

Open Association of Research Society, U.S.A (OARS) By-laws states that an individual Fellow may use the designations as applicable, or the corresponding initials. The Credentials of individual Fellow and Associate designations signify that the individual has gained knowledge of the fundamental concepts. One is magnanimous and proficient in an expertise course covering the professional code of conduct, and follows recognized standards of practice.



Open Association of Research Society (US)/ Global Journals Incorporation (USA), as described in Corporate Statements, are educational, research publishing and professional membership organizations. Achieving our individual Fellow or Associate status is based mainly on meeting stated educational research requirements.

Disbursement of 40% Royalty earned through Global Journals : Researcher = 50%, Peer Reviewer = 37.50%, Institution = 12.50% E.g. Out of 40%, the 20% benefit should be passed on to researcher, 15 % benefit towards remuneration should be given to a reviewer and remaining 5% is to be retained by the institution.



We shall provide print version of 12 issues of any three journals [as per your requirement] out of our 38 journals worth \$ 2376 USD.

### **Other:**

**The individual Fellow and Associate designations accredited by Open Association of Research Society (US) credentials signify guarantees following achievements:**

- The professional accredited with Fellow honor, is entitled to various benefits viz. name, fame, honor, regular flow of income, secured bright future, social status etc.





- In addition to above, if one is single author, then entitled to 40% discount on publishing research paper and can get 10% discount if one is co-author or main author among group of authors.
- The Fellow can organize symposium/seminar/conference on behalf of Global Journals Incorporation (USA) and he/she can also attend the same organized by other institutes on behalf of Global Journals.
- The Fellow can become member of Editorial Board Member after completing 3yrs.
- The Fellow can earn 60% of sales proceeds from the sale of reference/review books/literature/publishing of research paper.
- Fellow can also join as paid peer reviewer and earn 15% remuneration of author charges and can also get an opportunity to join as member of the Editorial Board of Global Journals Incorporation (USA)
- • This individual has learned the basic methods of applying those concepts and techniques to common challenging situations. This individual has further demonstrated an in-depth understanding of the application of suitable techniques to a particular area of research practice.

## Note :

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- In future, if the board feels the necessity to change any board member, the same can be done with the consent of the chairperson along with anyone board member without our approval.
- In case, the chairperson needs to be replaced then consent of 2/3rd board members are required and they are also required to jointly pass the resolution copy of which should be sent to us. In such case, it will be compulsory to obtain our approval before replacement.
- In case of “Difference of Opinion [if any]” among the Board members, our decision will be final and binding to everyone.

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## PREFERRED AUTHOR GUIDELINES

### **We accept the manuscript submissions in any standard (generic) format.**

We typeset manuscripts using advanced typesetting tools like Adobe In Design, CorelDraw, TeXnicCenter, and TeXStudio. We usually recommend authors submit their research using any standard format they are comfortable with, and let Global Journals do the rest.

Alternatively, you can download our basic template from <https://globaljournals.org/Template.zip>

Authors should submit their complete paper/article, including text illustrations, graphics, conclusions, artwork, and tables. Authors who are not able to submit manuscript using the form above can email the manuscript department at [submit@globaljournals.org](mailto:submit@globaljournals.org) or get in touch with [chiefeditor@globaljournals.org](mailto:chiefeditor@globaljournals.org) if they wish to send the abstract before submission.

### BEFORE AND DURING SUBMISSION

Authors must ensure the information provided during the submission of a paper is authentic. Please go through the following checklist before submitting:

1. Authors must go through the complete author guideline and understand and *agree to Global Journals' ethics and code of conduct*, along with author responsibilities.
2. Authors must accept the privacy policy, terms, and conditions of Global Journals.
3. Ensure corresponding author's email address and postal address are accurate and reachable.
4. Manuscript to be submitted must include keywords, an abstract, a paper title, co-author(s) names and details (email address, name, phone number, and institution), figures and illustrations in vector format including appropriate captions, tables, including titles and footnotes, a conclusion, results, acknowledgments and references.
5. Authors should submit paper in a ZIP archive if any supplementary files are required along with the paper.
6. Proper permissions must be acquired for the use of any copyrighted material.
7. Manuscript submitted *must not have been submitted or published elsewhere* and all authors must be aware of the submission.

### **Declaration of Conflicts of Interest**

It is required for authors to declare all financial, institutional, and personal relationships with other individuals and organizations that could influence (bias) their research.

### POLICY ON PLAGIARISM

Plagiarism is not acceptable in Global Journals submissions at all.

Plagiarized content will not be considered for publication. We reserve the right to inform authors' institutions about plagiarism detected either before or after publication. If plagiarism is identified, we will follow COPE guidelines:

Authors are solely responsible for all the plagiarism that is found. The author must not fabricate, falsify or plagiarize existing research data. The following, if copied, will be considered plagiarism:

- Words (language)
- Ideas
- Findings
- Writings
- Diagrams
- Graphs
- Illustrations
- Lectures



- Printed material
- Graphic representations
- Computer programs
- Electronic material
- Any other original work

## AUTHORSHIP POLICIES

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1. Substantial contributions to the conception and acquisition of data, analysis, and interpretation of findings.
2. Drafting the paper and revising it critically regarding important academic content.
3. Final approval of the version of the paper to be published.

### Changes in Authorship

The corresponding author should mention the name and complete details of all co-authors during submission and in manuscript. We support addition, rearrangement, manipulation, and deletions in authors list till the early view publication of the journal. We expect that corresponding author will notify all co-authors of submission. We follow COPE guidelines for changes in authorship.

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### Appealing Decisions

Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

### Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

### Declaration of funding sources

Global Journals is in partnership with various universities, laboratories, and other institutions worldwide in the research domain. Authors are requested to disclose their source of funding during every stage of their research, such as making analysis, performing laboratory operations, computing data, and using institutional resources, from writing an article to its submission. This will also help authors to get reimbursements by requesting an open access publication letter from Global Journals and submitting to the respective funding source.

## PREPARING YOUR MANUSCRIPT

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.



### ***Manuscript Style Instruction (Optional)***

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

### ***Structure and Format of Manuscript***

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

- a) A title which should be relevant to the theme of the paper.
- b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
- c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
- d) An introduction, giving fundamental background objectives.
- e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
- f) Results which should be presented concisely by well-designed tables and figures.
- g) Suitable statistical data should also be given.
- h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

- i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
- j) There should be brief acknowledgments.
- k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.



## FORMAT STRUCTURE

***It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.***

All manuscripts submitted to Global Journals should include:

### **Title**

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

### **Author details**

The full postal address of any related author(s) must be specified.

### **Abstract**

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

### **Keywords**

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

### **Numerical Methods**

Numerical methods used should be transparent and, where appropriate, supported by references.

### **Abbreviations**

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

### **Formulas and equations**

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

### **Tables, Figures, and Figure Legends**

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.



## Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

## PREPARATION OF ELETRONIC FIGURES FOR PUBLICATION

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

## TIPS FOR WRITING A GOOD QUALITY ENGINEERING RESEARCH PAPER

Techniques for writing a good quality engineering research paper:

**1. Choosing the topic:** In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

**2. Think like evaluators:** If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

**3. Ask your guides:** If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

**4. Use of computer is recommended:** As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

**5. Use the internet for help:** An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow [here](#).





**6. Bookmarks are useful:** When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

**7. Revise what you wrote:** When you write anything, always read it, summarize it, and then finalize it.

**8. Make every effort:** Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

**9. Produce good diagrams of your own:** Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

**10. Use proper verb tense:** Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

**11. Pick a good study spot:** Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

**12. Know what you know:** Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

**13. Use good grammar:** Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

**14. Arrangement of information:** Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

**15. Never start at the last minute:** Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

**16. Multitasking in research is not good:** Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

**17. Never copy others' work:** Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

**18. Go to seminars:** Attend seminars if the topic is relevant to your research area. Utilize all your resources.

**19. Refresh your mind after intervals:** Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

**20. Think technically:** Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.



**21. Adding unnecessary information:** Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

**22. Report concluded results:** Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

**23. Upon conclusion:** Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium through which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

## INFORMAL GUIDELINES OF RESEARCH PAPER WRITING

### Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

### Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

*The introduction:* This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

### The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

### General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

**To make a paper clear:** Adhere to recommended page limits.

### Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.



- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

#### **Title page:**

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

**Abstract:** This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

*Reason for writing the article—theory, overall issue, purpose.*

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

#### **Approach:**

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

#### **Introduction:**

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

*The following approach can create a valuable beginning:*

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.



**Approach:**

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

**Procedures (methods and materials):**

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

**Materials:**

*Materials may be reported in part of a section or else they may be recognized along with your measures.*

**Methods:**

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

**Approach:**

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

**What to keep away from:**

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

**Results:**

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.



**Content:**

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

**What to stay away from:**

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

**Approach:**

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

**Figures and tables:**

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

**Discussion:**

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.



**Approach:**

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

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Topics	Grades		
	A-B	C-D	E-F
<i>Abstract</i>	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
<i>Introduction</i>	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
<i>Methods and Procedures</i>	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
<i>Result</i>	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
<i>Discussion</i>	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
<i>References</i>	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring





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