The search of new diagnosing and predicting methods to the thermomechanical and strength characteristics of the component base of control systems for unmanned vehicles of the “smart city” based on 5G technologies

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Abstract. The data transfer rate which in the near future will be provided by the 5G standard will allow to combine thousands of drones (unmanned aerial vehicles, UAV) in real time into a common network, capable of tracking any situation in the territory of a large metropolis (within the SmartCity project). The large number of UAVs which are in continuous operation in the airspace will lead to a situation where a variety of adverse climatic factors (high humidity, sudden gusts of wind, lightning minutes, electromagnetic fields, electron-ion irradiation, infrared heating, electrostatic discharge, corona discharge in the atmosphere, etc.) will influence on these UAVs. This can lead to systematic failure of this type of device which will lead to additional costs and deterioration of the quality of the system in general. Implementation in the drone-construction some systems similar to systems for protecting aircraft from lightning strikes (for example, the Faraday grille in the body) will lead to a significant increase in the costs of devices. Therefore, a develop proposals for measures to protect drones from such an impact, at the present stage of development, the diagnostic and prediction of the thermo-mechanical and strength characteristics of the component base of control systems of unmanned vehicles of a “smart city” using 5G technology when exposed to external electrical effects of considerable amplitude is of practical value.

1. Introduction

It would not be an exaggeration to say that 5G technology (which should provide higher bandwidth compared to 4G technologies and it will ensure greater availability of broadband mobile communications, as well as the use of device-to-device modes or direct connection between subscribers; ultra-reliable large-scale communication systems between devices, as well as less time lag, Internet speeds of 1-2 Gbits per second, lower battery power consumption than 4G equipment as part of the development of the Internet of Things) — this is the admission ticket in the future, providing its owners happy enormous technological lead over the competition. In this case, we are not talking about the next increase in the speed of data transfer, even if it is so impressive, namely, 100 times higher compared to the current 4G standard, and also not about the ability to download a 4K video in a couple of seconds.
It is not even about Smart Home technology and not about Internet of Things which will receive different quality scope and development in the 5G environment. The new communication protocol will give the go-ahead for launching such incredible things as Smart City and, more broadly, Smart State.

The data transfer rate provided by the 5G standard will allow for real-time merging into a common network thousands of drones (UAV) capable of tracking any situation on the territory of a large metropolis (and in the future — country): control over city traffic, tracking public order, suppression offenses, rescue activities, localization of fires and their rapid elimination, delivery of mail, food and medicine, monitoring the weather.

5G technology will coordinate the movement of all unmanned vehicles in the city (from taxis to trucks), in principle, excluding the possibility of an accident. With the help of 5G, it will be possible to organize mass monitoring of the health status of an unlimited number of people. This whole flight of fantasy is only a small part of the possibilities that are opening up with the introduction of the new data exchange standard.

The main elements of the 5G-network in the framework of the project “smart city” and “smart country” are unmanned aerial vehicles (hereafter referred to as UAV) or “drones”. It would be more accurate to say about a system of several thousand, and even hundreds of thousands of such UAVs which will continuously be in the airspace under any climatic conditions. This will be a significant difference from modern devices of this type. Since modern even better sample UAV hardly anyone uses in such an extreme mode. In this regard, the design of drones for networks of “smart” cities should be subject to special conditions for their design, safety for the environment and reliability.

Identification of important features in the performance of such UAVs (including the electronics of these devices) in adverse weather conditions, in critical operating modes (for example, when lightning strikes) is an important task in the search for new methods for diagnosing and predicting the thermo-mechanical and strength characteristics of the component base of UAV control systems of the “smart city” using 5G technology.

The analysis of the current state of research in this area should be started with a description of the object of study. In this regard, we consider the design of the drone in more detail. Formally, such a UAV is an unmanned flying robot that can be remotely controlled, and can fly autonomously with the help of onboard sensors and GPS systems.

The large demand for commercial and private drones has also caused a number of security problems regarding the effects of a collision and loss of control. In this regard, many countries at the legislative level have introduced a number of amendments to the air codex.

Despite the fact that the internal structure of the drone may differ from model to model, its basic components are always the same. In general, the following components can be distinguished in each drone:

- engines;
- speed controllers;
- propellers;
- flight controller;
- rama.

In the context of this work, the main object of the UAV research is the flight controller (figure 1). It consists of various complex electronic components. The flight controller is the drone “brain”. It is programmed to process various signals from the operator’s remote control and the sensors installed on it. The more signals the controller can handle, the more versatile the drone is. Using a loop, the flight controller is connected to each of the four engines, which allows you to send control signals to them (programmed commands).
Since the stability of the entire flight depends on the operation of the flight controller, when creating drones, developers actively use various methods that allow these elements to be vibration-proof to the maximum. As a rule, the better the controller is vibroisolated, the more stable the drone will fly. Recently, high-class flight controllers are already produced with built-in vibration isolation.

A set of various sensors (GPS, gyroscopes, barometer, accelerometer, etc.) are connected to the flight controller, which transmit to it their readings. Feedback from the operator is carried out through a special transmitter mounted on the housing. Depending on the readings obtained, the operator changes the parameters of the drone's flight. If the flight controller of the drone is sufficiently “smart”, then, based on the readings of the sensors and algorithms of the program sewn into it, it can independently change the flight parameters of the drone without resorting to the assistance of the operator.

The final composition of the flight controller depends on the cost of the drone. The simplest drones can only control the rotation of the engines, depending on the incoming commands, while the most advanced ones can, for example, return to the starting point on their own. The basic composition of the flight controller is as follows:

- the main processor — is responsible for processing commands;
- gyro-sensor determining the position of the drone in space;
- barometer — a device that determines the height of the apparatus;
- an accelerometer is a device that analyzes an accelerating device in three planes (x, y, z);
- direction arrow — indicates the direction in which the drone should fly (located at one corner of the base plate);
- GPS Navigator — determine the location of the drone;
- Wi-Fi — to communicate with external devices (tablet, smartphone, PC) RAM.

The electronic printed circuit plates that are part of the processor, GPS-navigator and Wi-Fi-module are an aggregate of metal contact tracks and electronic components (resistance, capacitance, transformers, chokes, relays) placed on a dielectric plate. Modern unmanned aerial vehicle completely depends on the quality of functioning of this electronics.

But external factors can be an obstacle to its smooth operation. Such as, for example, high humidity, sudden gusts of wind, lightning strikes, electromagnetic fields, electron-ion irradiation, infrared heating, electrostatic discharge, corona discharge in the atmosphere.

Consider the passage of lightning through a UAV. The electronic impulse moves along the conductive parts of the device and enters the electrical appliances. Because of this, all the electronics burn out with microchips. The pulse discharge burns semiconductor elements (resistors, thyristors, etc.) (figure 2). As a rule, electronics after this is no longer suitable for repair.
Figure 2. View on the electronic board after the impact of critical currents impulse (lightning discharge).

Also, it is worth noting that with a decrease in the cross-section of the interconnecting conductors (and, consequently, an increase in the working current density) in the UAV printed circuits, there are a number of other problems: the probability of electric-transfer-processes increases, the transitional resistance of ohmic contacts increases significantly, including the problem of creating non-penetrating contacts (in case of using “small” \( p-n \)-transitions).

2. Experimental methods
A number of researchers see the solution of problems associated with “thermal overloads” in pulsed modes of operation in the choice of parameters of pulses that prevent the onset of degradation processes both in the metal film itself and at its boundaries [1]. Another approach is to search for new metallization systems with lower specific resistivity values (than the classical materials Ag, Cu, Al, etc.). This is the development of film composite materials, for example, using nanotubes [2-4]. However, the aspects mentioned are far from finishing and need further study.

In this regard, the subject of the project related to solving the problem of increasing the thermal stability of the metallization systems for ultra-large-scale-integration circuits (ULSI), including the diagnostics of thermal overloads of the metallization systems, as well as the search for new composite metallization systems based on copper with carbon nanotubes, is highly relevant.

3. Results and discussion
The goal of the project is to search for new methods for diagnosing and predicting the thermomechanical and strength characteristics of the component base of control systems for unmanned vehicles of the “smart city” using 5G technology. The main tasks were:

- to develop a methodology for diagnosing thermal overloads of the metallization systems of modern drones;
- to create a hardware-software complex and special test structures of metallization systems for recording thermal “overloads” of metallization systems;
- to conduct experiments on the use of composite metallization systems based on copper with carbon nanotubes.

As the most important results one can possible to highlight the following:

- development of the technology of spraying thin film structures and formation of test structures including composite structures with CNT (in collaboration with the Institute of nanotechnologies of microelectronics of the Russian Academy of Sciences, Moscow).
necessary experimental equipment for the creation of a software and hardware complex has been selected and all experimental techniques have been developed;

• theoretically studied temperature fields created on the surface of the silicon wafer with rectangular sections of the metallization layer when it is heated by rectangular current pulses. A mathematical model for calculating the thermal conditions of the metal-semiconductor contact pair has been constructed;

• the processes of formation of acoustic responses in semiconductor structures under the influence of rectangular current pulses are considered. The determining moments of the generation of mechanical oscillations associated with the on and off of current pulses are established;

• the mechanism of contact melting of metal-semiconductor structures is partially studied; the pulse effect of high-density currents \( j > 5 \times 10^{10} \text{ A/m}^2 \) and heat treatment modes on metal-semiconductor structures is analyzed.

• from the analysis of the thermoelastic stresses of the silicon substrate, the nucleation of surface dislocations along the perimeter of the metallization track is predicted and detected. Experimentally determined conditions for the formation of linear and bulk defects near the source of thermal shock.

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