Transmitter for small-size aircraft based on direct digital carrier modulation

Shestakova T.
Department Electronic Systems and Devices
Technical University of Moldova
Chisinau, Republic of Moldova
t.sestacova@mail.ru

Sorokin G.
Department Electronic Systems and Devices
Technical University of Moldova
Chisinau, Republic of Moldova
ger_sor@mail.ru

Abstract: **The work deals with the principles of construction and structural - circuit solutions of the transmitting device on the basis of direct digital modulation of the carrier oscillation. Structural and schematic diagrams of the transmitting device of phase - manipulated signals in the C - range are presenting. Results of simulation of thermal modes of the developed device with the help of the program "Hyper Lynx" are given.**

Keywords: **direct digital carrier modulation, "six-port" architecture, direct digital phase shifter, modulator.**

I. Introduction

Unmanned aerial vehicles (UAV) and their complexes are widely used in the fields of both military and civilian applications. Particular attention in recent years has been given to lightweight unmanned aerial vehicles (LWUAV).

They are used to obtain information on forest fires, detection and research of objects with harmful emissions, monitoring of traffic, monitoring the state of oil and gas pipelines, etc. At the same time, they can be equipped with video and photo equipment and special sensors for detecting electromagnetic and thermal radiation.

The information, which received by on-board monitoring facilities, should be transmitted in real time to the control point for processing and making adequate decisions.

The limitation of the frequency range from below is determined by the screening action of the ionosphere, and from above by the absorption in the troposphere. These two factors limit the range of operating frequencies from 40 MHz up to 40 GHz. Currently, the range from 1 to 12 GHz has the greatest application in satellite and mobile communication lines, in the radio control lines of unmanned aerial vehicles for military and civilian applications. This is due to the fact that, if the wavelength decreases, then the mass - dimensional parameters of the antenna-feeder systems also decrease. It is especially important for LWUAVs.

However, the condition for the preservation of basic functions requires the search for new technologies for the creation of miniature, highly functional devices that allow solving the tasks assigned to the UAV.

II. Main Part

The LWUAVs transmitters for reduce power consumption and overall dimensions are mostly often designed using direct digital carrier modulation (DDCM) schemes. It is worth noting that DDCM is understood not as a specific technology, but the principle of the formation of a modulated signal. In DDCM, the transmitted digital information is used to modulate carrier frequency of signal directly.

This can be achieved by the action of a digital data stream on the radio frequency carrier generation device, or the modulated signal is generated entirely on the carrier frequency in digital form and then converted using a high-speed DAC. As a result, many analog components of the transmission path (mixer, intermediate frequency (IF) path, modulator and, in some cases, the output power amplifier) become unnecessary.

The transmission path becomes more stable, compact, economical and cheap. The possibilities to form any kinds of modulation become practically limitless. They are restraining only by the computing power of the digital part. The linearity of the characteristics of the device is improving, so there are no parasitic signals of the local oscillator in the output spectrum.

As a device that can be using to generate manipulated signals in the main frequency band, a "six-port" architecture is using, which is discussed in [3].

The concept of "six-port" architecture was firstly used by G. Engen in the 1960-70s of the last century to measure the complex reflection coefficients of microwave devices and was supplemented by R.G. Bosisio.

With the help of the "six-port" architecture, it became possible to use direct digital phase shift keying of carrier, and the absence of non-linear elements allows to extend the range of applied frequencies up to the millimeter wave band.

The scheme of a direct QPSK modulator using the "six-port" architecture has the following form (Fig.1.1).

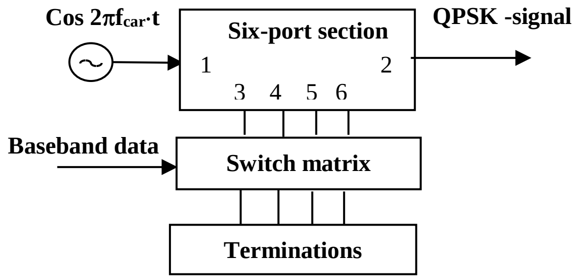


Fig.1.1. QPSK modulator based on the "six-port" section

The modulator contains the "six-port" section, the switch matrix and terminations that can be in two states - open and closed. The principle of operation of the device is as follows: the signal from the carrier generator arrives to the "1" input of the "six-port" section and through 3, 4, 5 and 6 inputs arrives to different terminations (phase shifters) through the switch matrix that is controlled by input binary sequences. The signals passed through the respective phase shifters are summed and arrived to the "2" output of the "six-port" section, forming the output phase-manipulated signal.

According to the structure of the "six-port" circuit, the transfer function of the modulator between the "1" and "2" ports can be representing in the following form:

$$H(f) = 0{,}707 \exp[-j\,(\varphi_1 + 3\varphi_2 + 2\theta + 45^0 + i90^0)] \qquad (1.1)$$

where $i = 0, 1, 2, 3$;

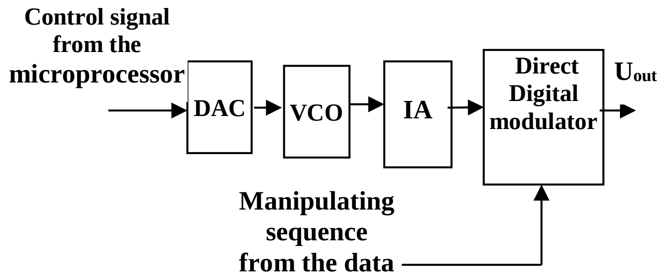
$\varphi1$, $\varphi2$ and θ - phase shifts in the power divider, couplers and transmission lines, respectively;

"i" - corresponds to the "i" configuration of four different phase shifter.

For a signal with a carrier frequency, the phase shifts $\varphi1$, $\varphi2$ and θ are constant, depending on the characteristics of the power divider, the hybrid couplers and the transmission lines. Therefore, this total phase shift $\varphi = \varphi1 + 3\varphi2 + 2\theta$ is undesirable. Therefore, in the elaboration of phase modulators it is necessary to take measures to ensure that these phase shifts do not affect the signal constellation be forming.

The latest advances in the technology of microwave components, their circuitry, have made it possible to create transmitters with direct, digital manipulation of the carrier in monolithic microwave integrated circuit (MMIC) [1, 2, 4, 5].

Typically, the signal level generated by the carrier oscillator is insufficient for the normal operation of the direct modulator. Therefore, between the digital phase modulator and the carrier oscillator it is necessary to install an intermediate C-band amplifier matched to the input and output. In addition to obtain the necessary carrier signal gain and matching, the intermediate amplifier must also have a large dynamic range, small own phase noise. Therefore, the block diagram of the C-band radio transmitter may have the following form (Fig. 1.2):



The control signal from the microprocessor (in digital form) is arriving to the DAC.

Fig.1.2. The block diagram of the C-band radio transmitter

The DAC generates the voltage level necessary to obtain the required frequency of VCO (5.8 GHz) (in cases where it is not necessary to reconfigure the carrier frequency, instead of the DAC a constant precision resistor is included).

The company "Hittite" produces the chip HMC649LP6 (Fig.1.3), which is a six-bit digital phase modulator and is designed to operate in the range from 3 to 6 GHz. This chip is designed for use in military (weather & military radar) and satellite communications equipment. Six - bit control provides to obtain phase shifts ($\Delta\varphi$min ≈ 6°) in the range from 0° to 360°. The phase of the carrier wave in the modulator is changed by the TTL - logic signals (0B / + 5B).

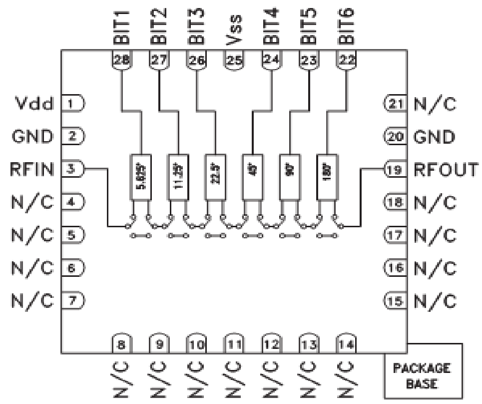


Fig.1.3. Functional diagram of HMC649LP6 modulator

The truth table of the modulator is presenting in Fig. 1.4

If the input bit sequence has the form - 000100, 000110, 000101, 000111, a quadrature phase-shifted signal (QPSK) is forming at the output of the modulator.

The level of the carrier signal when compressed at 1 dB is at least 29 dBm. To obtain the required level of the signal at the input of the modulator, a one-watt power amplifier is included between the carrier oscillator and the modulator. For this purpose, the single-watt power amplifier of the company "Hittite" HMC408LP3 (Fig.1.5), operating in the range 5.1 ÷ 5.9 GHz and made in GaAs PHEMT technology in monolithic microwave version (MMIC), is used.

Truth Table

Control Voltage Input						Phase Shift (Degrees) RFIN - RFOUT
Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	
0	0	0	0	0	0	Reference*
1	0	0	0	0	0	5.625
0	1	0	0	0	0	11.25
0	0	1	0	0	0	22.5
0	0	0	1	0	0	45.0
0	0	0	0	1	0	90.0
0	0	0	0	0	1	180.0
1	1	1	1	1	1	354.375

Fig.1.4.The truth table of the HMC649LP6 modulator

Thus, depending on the number of bit of the input sequence the modulator, in general, may form an M-PSK signal ($M = 2^6$).

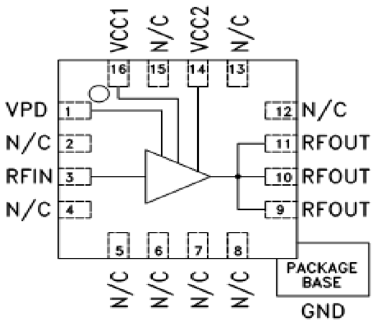


Fig.1.5. Functional diagram of the NMS408LP3 chip

The amplifier has internal input matching circuits for an input impedance of 50 ohms and requires a minimum number of external elements to match the output. An important design feature of this amplifier is that it has a special output (Vpd), used to determine the operating mode of the amplifier, which is especially important for satellite (remote) devices. By the magnitude of the DC voltage at the "1" pin of the IC it can be known the value of the output signal power, the gain factor, the current consumed.

The voltage controlled oscillator (carrier oscillator) is implemented on a chip HMC358MS8G. The chip is made on the basis of a bipolar transistor with heterojunctions based on GaAs InGaP semiconductors, which allow to work in the frequency range 5.8÷6.8 GHz. The generator is made according to MMIC technology, which allows reliable operation under shock and vibration external influences. Volumetric integrated resonators, a circuit with a negative internal resistance and a varactor diode provide a very high Q - factor of the oscillatory system. The functional diagram of the generator is presented in Fig.1.6.

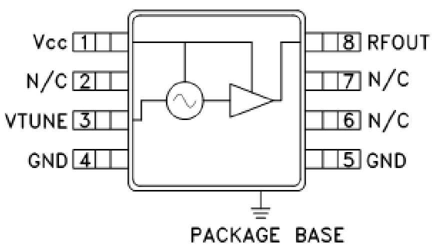


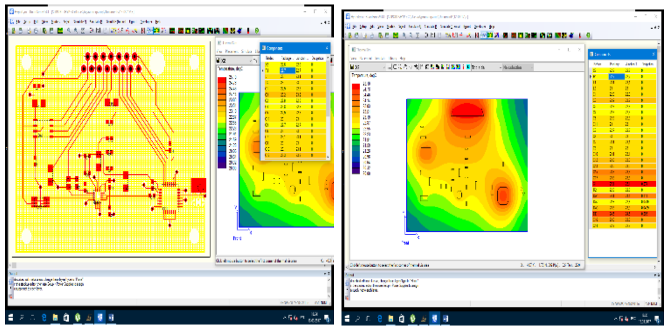
Fig.1.6. Functional diagram of the generator HMC358MS8G

The use of a buffer amplifier, that eliminates the effect of external connected circuits on the operation of the oscillating system, also provides a high stability of the frequency of the generated oscillations.

The scheme of the transmitting device of phase-manipulated signals, which operates in the C-band, was developed on the basis of the above-discussed microcircuits.

III. Conclusion

The printed circuit board of the C-band transmitter was developed. Thermal modes of the PCB were simulated using the "Hyper Lynix" program, developed by the company "Mentor Graphics". The modeling results are presented in Fig. 1.7.



a) b)

Fig.1.7. The print circuit board of the transmitting device (a) and its temperature image (b)

The simulation results show that the most heated zones of the printed circuit board are the connector, to which the supply voltage of the circuit is applied, and the output amplifier of the transmitting device. However, the maximum temperature of the heated zone does not exceed 26°C, which confirms the correctness of the selected modes of operation of all blocks of the transmitting device. This generator can be used as a separate unit or can be combined on the one motherboard along with the control and navigation board.

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