Coordination of the microwave module used in the Doppler meter of the velocity vector components

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Abstract: The article describes a method for coordinating the microwave path and verifying the microwave module of the DMVC. The method for coordinating and adjusting the microwave module helps measure and evaluate characteristics of the device to confirm compliance with the DMVC requirements.

1. Introduction

One of the significant radio navigation devices of the onboard equipment is the Doppler meter of the velocity vector components (DMVC) [1-3]. As a rule, the DMVC includes a transceiver module of superhigh frequencies (microwave), which determines most of the characteristics and measured parameters of the device.

Microwave modules operating in the range from 3 GHz to 30 GHz are implemented as devices connected by transmission lines. The part of the system located between the initial and terminal devices is the microwave path or the microwave circuit. Such a path transmits electromagnetic energy from the transmitter to the antenna or from the antenna to the receiver, provides the required operating mode of the output and input circuits of the transmitter, performs the frequency and polarization separation of transmitted signals, etc. The most common elements of microwave circuits are transmission lines, transition and butt nodes between lines, matching and tuning elements, adders, power dividers and couplers [4].

Coordination of transmission lines is required to suppress waves reflected from the load under the equal load and wave resistance of the transmission line[5].

In case of full coordination of all elements of the transmission line and the supply generator in the transmission line, the reflected wave is absent (the traveling wave mode), the reflection coefficient is 0, and the standing wave coefficient is 1.

If the load is not consistent with the transmission line, a number of undesirable effects occur [6-9] 1) frequency and power of the generator change due to the pulling effect; 2) power supplied to the load decreases; 3) the limit value of the transmitted power decreases due to the electrical breakdown in the path; 4) the broadband transmission path decreases; 5) active losses in the transmission line increase.

It is clear that coordination in the transmission line is one of the most common and important tasks of the microwave technology.
The authors developed a method for coordinating the microwave path and verifying the microwave module of the DMVC. The method for coordinating and adjusting the microwave module helps measure and evaluate characteristics of the device to confirm compliance with the DMVC requirements.

2 Consideration of basic characteristics when coordinating microwave devices

The main source of losses is standing waves [10]. They appear in circuits when the wave encounters changes in wave resistance [11]. In order to prevent standing waves and achieve the maximum value of the power flow in the circuit, it is necessary to coordinate the load with the transmission line.

Let us consider the main characteristics that must be taken into account when coordinating microwave devices with different wave resistances.

The wave resistance $Z$ ($\Omega$) is the resistance that an electromagnetic wave encounters when propagating inside a homogeneous line without reflection, i.e., provided that the transmission process is not affected by inconsistencies at the ends of the line. The wave resistance is a parameter that depends only on physical parameters of the line, such as sections, conductor shapes, thickness, material, etc.).

The reflection coefficient $G$ shows how much of the radiation is reflected from the inhomogeneity in the propagation medium, for example, the junction of two lines with different wave impedances. It can be calculated by formula:

$$ G = \frac{Z_g - Z_l}{Z_g + Z_l}, $$

where $Z_g$ and $Z_l$ – wave resistance and load of the generator, respectively.

The standing wave coefficient (SWC) characterizes the degree of coordination of the device. In real devices, reflected waves are always present in the transmission line, which indicates that part of the energy is reflected and does not reach the load [12]. The reflected energy is not only “lost” in the transmission line, but can cause the overheating of the entire microwave device. This can significantly change its characteristics and lead to greater reflections. The SWC is calculated by formula:

$$ \text{SWC} = \frac{U_i + U_r}{U_i - U_r}, $$

where $U_i$ and $U_r$ - the amplitude of incident and reflected electromagnetic waves. The SWC should be equal to 1, which corresponds to the absence of reflected waves, matching in the traveling wave mode. With a purely standing wave, the SWC tends to infinity. The admissible SWC is up to 1.5.

3. The method for coordinating the microwave path

The microwave module consists of a low-frequency part and a high-frequency part, which are structurally separated by the module housing (Figure 1).
In the high-frequency part, there is a circulator (Figure 2).

Fig. 2. Assembly with a circulator.

In the high-frequency part, there is a frequency generator, RF elements and four outputs. In the low-frequency part, there are shapers of the internal power supply ± 6 V and +4 V, a connector for input and output signals, a controller for monitoring the carrier frequency and output power, and a cascade of filters. This microwave module is responsible for formation, amplification and reception of the microwave frequency-modulated (FM) signal and allocation of the Doppler frequency. The module generates, modulates, and transmits a microwave frequency signal to the antenna input with the following parameters:

a) the central operating frequency (\( F_p \)) - (13250-13400) MHz;

b) the type of modulation is continuous frequency with a modulation index of \((3.7 \pm 0.5)\ \text{dB}\).

c) the output power of the module is not less than 8 and not more than 20 dBm.

d) the module must have a level of single-band phase noises of 1000 Hz and no more than 50 dBc / Hz.

d) the module must ensure allocation of the Doppler frequency and its spectrum when receiving and transmitting the signal through the channel with a power of at least 100 dBm with suppression of spurious components with a frequency of 20 dB.

f) the transceiver of the microwave module must have an isolation between the channels of at least 23 dB.

g) the level of quadratures I, Q of the analog output signal at the output of the module should be 0-0.7 V.

The microwave module must have built-in controls for the following parameters:

- excess current consumption in the power circuit (logical "0" corresponds to normal operation, logical "1" - failure);

- the presence of the output power of the amplifier on the antenna key (logical “1” corresponds to normal operation, logical “0” - failure.).

The control results should be issued in the form of digital signals of the LVTTL level. Logical “1” corresponds to a voltage range (2.4 ... 3.6) V, logical “0” corresponds to a voltage range (0 ... 0.4).

The scheme of the workplace for the coordination and debugging of the microwave module is shown in Figure 3.
Before connecting the power source (PS), the value of 6V is set on the channels, the current limit is 0.6 A.

It is necessary to control the value of the consumed current from the PS by the built-in indicator, the current should be no more than 5 mA for each of the three channels. It is necessary to measure the secondary supply voltage (3.30 ± 0.10) V, (5 ± 0.1) V, (minus 5 ± 0.1) V. If the parameters deviate, turn off the power sources, determine and eliminate the cause of the discrepancy by health checks of PS voltage stabilizers and associated circuits.

The procedure for programming the microwave module firmware (software) is carried out. The STM32 controller from STMicroelectronics located in the low-frequency part is programmed. The programmer is connected to the microwave module only when the supply voltage is off. Therefore, it is necessary to remove the supply voltage from the microwave module; to connect the ST-LINK / V2 programmer to the programming socket located in the low-frequency part; to supply voltage to the microwave module; to open the STM32 ST-LINKUtility application; to create a connection to the controller by selecting TARGET - CONNECT in the program menu; in the program window (Figure 3), to select the following menu items "File - Openfile ...".

Fig. 3. Scheme of the workplace for the coordination and debugging of the microwave
Fig. 4. Sample built-in software window

In the dialog window, select the file “SVCHM_Vx.hex” and start the programming process by selecting the following menu items "Target - Program & Verify ...". Wait for the end of the programming process, remove the supply voltage from the transmitter, disconnect the ST-LINK / V2 programmer from the programming connector and reapply the supply voltage.

After the programming stage of the microwave module, install the assembly with the circulator in the high-frequency part. To do this, remove the power from the microwave module. Connect the assembly with the WS1 circulator to the microwave path with IN-00 indium foil 0.1 mm thick with an approximate size of 1 mm * 2 mm (selected locally). The figure shows an assembly with the circulator after connecting to the microwave path. Fix the joints with AK-113 and dry them in accordance with GOST 23832-79 [2] (Fig. 4).

At the next step, it is necessary to measure the carrier frequency at four outputs of the microwave module. To do this, using a torque wrench with a size of 8 mm and a gain of 0.9 N, connect the RF cable with SMA connector to the first output of the microwave module.

Set up the microwave signal analyzer as follows: using the control devices, set FREQ - 13.325 GHz (by pressing FREQ, CENTER), SPAN - 500 kHz, BW - 2 kHz, AMPT - 20 dBm. The spectrum tab should be open (if necessary, press the mode button, select the spectrum mode).

On the microwave control panel, the first channel “1” is selected with the help of a dial switch and the “BP” key is pressed.

On the microwave signal analyzer, the carrier frequency value is read. Check that the carrier frequency is (13250-13400) MHz and meets the specified requirements. If the parameter deviates, check the operation of the 40 MHz reference oscillator and its associated circuits, as well as the correct installation of the frequency synthesizer IC and its associated circuits. These measurements must be carried out for each output channel of the microwave module.
The output power level of each channel of the microwave module is adjusted. The output power level is read using a microwave signal analyzer with the above settings. Before reading the power value, update the reading. Make sure that the output power level is in the range from 8 to 20 dBm, in accordance with the assigned requirements, and the “KVM” indicator is on on the microwave remote control. If the parameter is rejected or the “KVM” indication is not displayed on the microwave remote control, carry out adjustments. Carry out adjustments at the input of the filter or at the input of the microassembly with the circulator, if the previous adjustment was not efficient. Recommended locations for trimming elements are shown in Figure 6.
The tuning element is indium foil 0.1 mm in thickness; the size and shape of the tuning element is determined during the tuning process. It is recommended to start the adjustment with a tuning element 1x1 mm in size. Move and fix the tuning elements with any convenient tool with dielectric properties. The tuning element should fit snugly against the board. After tuning the microwave path, the tuning elements must be fixed on the printed circuit board with AK-113 varnish and dried in accordance with GOST 23832-79 [2]. Recheck the output power level in the steps above. Repeat the check for all microwave channels.

To make further adjustments, install the frames of the receiver, transmitter and assembly with the circulator to regular places and fasten with screws, as shown in Figure 7.

Check for the absence of foreign objects, unused particles of adjusting elements on the high-frequency part of the microwave module and on the faces of the frames before installation.

![Fig. 7. Regular places of the transmitter and microassemblies with a circulator](image)

The next parameter is the modulation index. The analyzer adjusts the center frequency so that the carrier frequency is in the center of the screen. Adjust the REF level so that the carrier peak is located at a distance of half a division from the upper border of the screen. On the generator, according to the operating instructions for the device, set the output waveform to be sinusoidal, frequency of v25 kHz, amplitude of 1.6 V. Install channel 1 on the microwave control panel.

Using the analyzer, the difference between the level of the carrier and the level of the first lateral harmonic is read out as shown in Figure 8.
Fig. 8. Reading the difference between the level of the carrier and the level of the first lateral harmonic

Make sure that the difference is $(3.7 \pm 0.5)$ dB. If the parameter deviates, select the R84 resistor (selection range from 50 to 1000 Ohms).

Phase noise is measured at each microwave module output using an analyzer. On the analyzer, select the phase noise measurement mode by pressing the MODE button and selecting PHASENOISE from the menu, as shown in Figure 9.

Fig. 9. Phase noise measurement mode

Make sure that the level of single-band phase noise is not higher than minus 50 dBc / Hz. The oscillogram is shown in Figure 10.
Fig. 10. Oscillogram of single-band phase noises

If the parameter deviates, check the operation of the 40 MHz reference oscillator and its associated circuits, as well as the installation of the frequency synthesizer IC and its associated circuits. Coordinate the microwave path between the assembly with the circulator and the switch. Adjust the signal analyzer.

Fig. 11. Approximate position of the tuning element
Set the following parameters on the signal analyzer: CENTRAL FREQUENCY - 25 kHz, SPAN - 50 kHz, BW - 200 Hz, AVERAGE - 200 (press TRACE, select TRACE1, AVERAGE in the menu). Connect the generator to the second channel of the microwave module through the attenuator. Set channel 2 on the microwave remote control. On the generator, set the frequency of 23 kHz higher than the previously measured carrier frequency; set the output signal level to minus 65 dBm and apply the microwave power. Apply the power to the microwave module. On the analyzer screen, the difference of the useful signal and noise is at least 20 dB. Adjust the frequency of the generator to achieve the peak (the maximum signal) of 25 kHz. Set the output level to 10 dBm. On the oscilloscope screen, observe quadrature signals. I is the in-phase component, Q is the quadrature component from the output of the microwave control panel. By introducing tuning elements into the microwave line between WS1 and the switch, coordinate the path. The approximate position of the tuning element is shown in Figure 10.

Repeat the check of the output power level as described earlier, turning off the generator. Coordinate the microwave path between the switch and the microwave outputs of the module. The circuits connecting the switch and the contact pads of the output connectors of the microwave module are subject to coordination, depending on the selected channel. The approximate location of the tuning elements is shown in Figure 12.

Fig. 12. Approximate location of tuning elements
Set the frequency of 25.0 kHz. Using an oscilloscope, control the level and phases of signals I and Q. Achieve the difference in amplitudes and the phase shift of 90° of no more than 20% (the time shift between transitions through zero 10ms ± 2ms). The type of signals I, Q before and after adjustment is shown in Figure 12.

![Fig. 13. Type of signals I, Q before and after adjustment](image1)

Monitor the current consumption on the 4V circuit. With the correct adjustment, a decrease in the current consumption should be observed. There should be no indication of “KTM” on the microwave control panel. Repeat the check of the output power level as described earlier, turning off the generator.

Repeat the above steps for output 2, 3 and 4 of the microwave module (alternately connecting the analyzer to the connectors and selecting the “2”, “3”, “4” positions with the microwave remote control switch, respectively).

![Fig. 14. Microwave module workstation assembled with an antenna](image2)
Further adjustment of the microwave module is carried out as an assembly with the antenna. Four outputs of the microwave module must be connected to the antenna and collect the workplace according to Figure 13 for the following adjustment operations.

Install the antenna on the anechoic chamber by positioning the camera mark on the side of the microwave module. Connect the generator to the anechoic chamber. Connect the microwave signal analyzer to input 1 of the antenna through the adapter p/nADSC-A8A8 (female-female).

Set the power level of 0 dBm on the generator. Read the power levels from each input of the antenna. These antenna losses are subject to accounting for further adjustment and measurements.

Disable the microwave signal analyzer. Connect the antenna to input 1 of the microwave remote control. Connect it to the output I_P (Q_P) of the microwave remote control. On the generator, set the power so that the input of the microwave module is minus 100 dBm. On the analyzer, monitor the markers - noise at 25 kHz and useful signal I_P (Q_P). Install additional tuning elements to achieve the maximum difference in the amplitudes of the markers (the difference between the useful signal and noise). The waveform is shown in Figure 15.

![Fig. 15. Oscillogram of the maximum difference in the amplitudes of the markers](image)

Additionally, observe a decrease in the consumption of current along the 4 V circuit. An approximate arrangement of the tuning elements is shown in Figure 16.
The approximate arrangement of tuning elements

Fig. 16. The approximate arrangement of tuning elements

The signal levels of the I_P and Q_P channels (the difference between the useful signal and noise for each quadrature signal) for each channel of the microwave module must differ by no more than 2–3 dBm and be at least 13 dBm.

Repeat the procedure for the remaining channels of the microwave module. If the parameters go beyond the specified limits, repeat the setting.

4. Conclusion
The article presents a method that allows you to rebuild and adjust the microwave module in order to confirm the given requirements.

Indium foil was chosen as the main construction material, which has good adhesion to form the topology and use the "casts" method.

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