Effect of Frequency Division in Microwave Magnetron Devices

Frequency multiplication is widely used in low and medium power microwave solid state [1] and medium, high and superhigh power microwave vacuum devices [2,3]. There are several purposes for frequency multiplication at microwaves: mastering the new ranges of higher frequencies, obtaining the more stable output signal frequency by the use of quartz stabilized generator as an input signal source, simultaneous application of several higher temporal harmonics of convection current for creation multichannel devices [4] especially desirable in communication and radiolocation systems etc.

But it is impossible to solve the first two problems by microwave frequency division. Therefore, from practical point of view, microwave frequency dividers may be used as one of convenient means that allows to increase a number of radiocommunication and radiolocation channels. In this case the same signal from reference signal generator is fed into multichannel frequency multiplier and multichannel frequency divider [5]. Such a microprocessor – controlled module let not only increase the number of channels but also rise the reliability of confidential communication and secret ranging significantly. Wide choice in types and laws of modulation, in algorithms and codes of channels switching let avoid of unwanted users of confident information and back reaction from the object to be ranged.

The effect of microwave frequency division has been earlier obtained in O – type devices, such as klystron and travelling wave tube [6]. This confirmed a possibility to use the temporal subharmonics of prebunched electron stream for getting microwave signal with n times lower frequency. However, in the microwave devices of M – type such an opportunity of application of subharmonics in order to generate the signals with lower multiple frequencies was until now physically not obvious. Thus, the generation of subharmonics in magnetron type devices is important as a physical phenomenon itself.

Structure of magnetron frequency divider

We have not been successful in a search for data published neither in periodical editions nor in monographs dealing with application of M type devices for microwave frequency division. Therefore as a basic model of a new device we chose two-cascade resonant magnetron frequency multiplier [2].

The main advantage that distinguishes such type of devices from another ones is separation of the processes of electron grouping into spokes in a first cascade by the input signal and transformation of the spokes injected into output cascade as well as amplification of the signal on a frequency of working subharmonic.

![Diagram](image_url)
frequency of the temporal subharmonic, the device should operate as an amplifier of subharmonic signal controlled by input signal (regenerative regime of frequency divider). In the case when input cascade works in a regime of selfoscillation and output one in a regime of synchronised generation the device will be oscillator of subharmonics. The first regime gives much more opportunities when frequency divider is used in communication and radiolocation systems because it ensures not only manipulation with the parameters of input signal but also guarantees wide enough control on the parameters of output signal. The second – allows to lessen the number of independent oscillators in a multichannel system of communication because in this case only one feeding system and only one electron stream ensure completely the existence of several channels using different subharmonics.

Principal scheme of two-cascade resonant, cylindrical magnetron frequency divider is given in Fig. 1. The main elements of the device are as follows: cathode, negative electrode, resonant SWSs of input and output cascades, electron stream, energy inlet and outlet, collector, diaphragm and sources of permanent electric and magnetic fields. Funnel – shaped SWS of the input cascade together with conoidal cathode makes up active magnetron gun. It’s mission is of two kinds: to bunch a tube – shaped electron stream and to inject it into interaction space of the output cascade. In the output cascade electron spokes are transformed in such a way that their new shape would correspond to the structure of high frequencies field (HFF) in the interaction space of the cascade. If the axial length of the cascade is large enough the subharmonic signal in a self – timing field of SWS may be amplified until magnitude to be desired. Therefore, the gain of the divider may be as high as a coefficient of amplification of crossed-field amplifier [7] using main harmonic and may reach several decades of decibels. Here \((P_{\text{out}1})_{\nu}/P_{\nu}1\) and \((P_{\nu}n)\) - powers of the output and input signals. Theoretical calculations [5, 8] and mentioned below experimental results confirmed the reality of such possibility.

Resonant type of a device was chosen because of it’s structure simplicity and because of possibility to use the 16-cavity anode block of standard magnetron of 10 cm wavelength range. The expected frequency bandwidth of the divider of about 1% satisfy the demands that are made for signal sources used in radiocommunication and radiolocation systems.

The angle of declination of the SWS surface of the active magnetron gun with respect to the symmetry axes of the device has been chosen on a base of calculation carried out for magnetron frequency multiplier [2] and was adjacent to 1°.

At a development of the device under investigation it would be necessary to optimise this parameter both theoretically and experimentally with the devices having different angles of declination.

\[
\eta = \frac{(P_{\text{out}})_{\nu}/n}{P_{0}},
\]

where \(P_{0}\) – power of the direct current feeding source.

Though in this divider the 4-th subharmonic of the input signal is used, multivacity systems of input and output cascades are separated by metallic diaphragm. It is necessary for prevention of penetration of higher HFF harmonics from output interaction space to the input one.

For the output cascade there was designed special cylindrical anode block with four cavities and doubled straps. In this block as well as is an input one \(\pi\)-type oscillations are used.

Calculations presented in an article [5] show that in a case when strength of permanent electric fields in the interaction spaces of the first and second cascades are the same \((E_{01}=E_{02}=E_{0})\) and magnetic flux densities are equal to one another \((B_{1}=B_{2}=B)\), at a condition of synchronism between electron stream and travelling wave \((v_{0}=v_{0})\), coefficient of frequency division (number of working subharmonic \(n\)) in the case of equality radii of the electron stream in both cascades \((r_{1}=r_{2})\) is equal to:

\[
n = \frac{N_{1}}{N_{2}},
\]

where \(N_{1}\) and \(N_{2}\) – number of cavities (HFF gaps) in the first and second blocks correspondingly.

In the divider there is foreseen an opportunity to change a collector. The electrons voltage in order to recuperate energy of the possibility of independent change in anode voltages of the first and second anode blocks \(U_{a1}\) and \(U_{a2}\) is also foreseen. This is very valuable property which allows to investigate current distribution between different electrodes of the device and optimise their voltages.

Amplitudinal characteristics of frequency divider

High enough number of working harmonic \(n=N_{1}/N_{2}=4\) was chosen because it let demonstrate not only physical effect of frequency division in a crossed – field device itself but also produce a device which could be applied in real radio systems.

![Fig. 2. Dependence of output signal power \((P_{\text{out}1})_{\nu}\) of the divider and output signal power of the first cascade \((P_{\text{out}1})_{\nu}\) on the input signal power. 1 and 4 – \(U_a=15kV\); 2 – \(U_a=10kV\); 3 – \(U_a=20kV\)](image)

This paper deals with the amplitudinal characteristics of resonant two – cascade magnetron frequency divider operating on the fourth subharmonic of the input signal.
frequency with the wavelength of about 10 cm. Dependences of output signal power \(P_{\text{out}}\) and power of the signal that had been amplified in an input cascade \(P_{\text{in}}\), on an input signal power \(P_{\text{in}}\), at different values of anode voltage represents Fig. 2. One can see from this graph that, at optimal magnetic flux density \((B=0.23\, \text{T})\), output signal power becomes maximum \(((P_{\text{out}})_{\text{max}})=10\, \text{kW}\) when anode voltage reaches about 15kV.

At the increase or decrease of anode voltage of about 30\% (curves 2 and 3) output signal power reduces about twice. It is also important to notice that sharp increase of power \((P_{\text{out}})_{\text{max}}\) begins at the moment when output signal power of the device \((P_{\text{out}})_{\text{max}}\) approaches their maximum value. This shows that at this moment electron spokes, bunched in an input cascade, have the greatest extent of harmonization because further increase in an input signal power \((P_{\text{in}})\) does not increase neither \((P_{\text{out}})\), nor \((P_{\text{out}})_{\text{max}}\).

The graphs of a gain of frequency divider \(K\) (see(1)) and coefficient of amplification of the first cascade
\[
K_1 = 10 \log \left(\frac{P_{\text{out}}}{P_{\text{in}}^2}\right)_{\text{dB}}
\]
against input signal power and anode voltage are shown in Fig. 4 and 5. Character of curves in Fig. 2 and 3 let expect that relationships \(K=f(P_{\text{in}})\) and \(K_1=f(P_{\text{in}})\) will be sufficiently flat. The flatness of characteristics causes stabile enough amplification both input and subharmonic signals in a broad range of values of input signal power. The broadest range of nearly constant amplification, as it might be expected, is characteristic to optimal values of anode voltages and magnetic flux density. And on the contrary, as one can see from Fig. 5, frequency divider is more sensitive with respect to the change in anode voltage.

Values of a gain achieved in a resonant frequency divider operating on the 4-th subharmonic testify a high effectivity of a mechanism of frequency division in crossed – field microwave devices. Optimisation of the parameters of interaction space and electrical regime allows to expect significant increase in the main parameters – gain and efficiency – of a magnetron frequency divider under investigation.

Conclusions

1. For the first time in the world is frequency division effect in a microwave crossed – field device realized.
2. Designed, produced and investigated experimentally two-cascade magnetron resonant frequency divider operating in 10cm wavelength range having 16 cavities in the input anode block and 4-in the output one and using the 4-th subharmonic of frequency of the input signal.
3. Amplitudinal characteristics of the frequency divider testify that maximum output signal power \((P_{\text{out}})_{\text{max}}\approx 10\, \text{kW}\) corresponds to the maximum gain of the

The effect of microwave frequency division has been earlier obtained in O – type devices, such as a klystron and travelling wave tube. This confirmed a possibility to use the temporal subharmonics of prebunched electron stream for getting microwave signals with n times lower frequency. By the application of sectioned structure used in magnetron frequency multipliers there was designed, produced and investigated both theoretically and experimentally unique microwave electron device – two – cascade magnetron frequency divider which allowed to obtain, for the first time the world, in 2000, the effect of frequency division in crossed field devices at microwaves. Paper represents structure and main experimental characteristics of the device. The divider operates on a frequency of the 4 – th subharmonic of the input signal which is chosen in 10 cm wavelength range. Maximum output signal power reaches 10 kW at a maximum gain of about 25 dB. Ill. 5, bibl. 8 (in English; summaries in Lithuanian, English, Russian). 9 pt normal


Dažnio dalijimo efektas mikrobanginiuose magnetroniniuose prietaisuose yra gautas O tipo prietaisuose, klystrone ir bėgančiosios bangos lempose. Tai patvirtina galimybę panaudoti sugrupuotų elektronų pluošto konvekcinei srovės laiko subharmonikas n kartų žemesnio dažnio mikrobangiiniuose signalams gauti. Panaudojant subharmonikų dažniams suderintų magnetroninių pakopų sekcionavimo idėją buvo suprojektuotas, pagamintas ir praktiškai išbandytas unikalas prietaisas – dvių pakopų magnetroninis dažnio dalytuvas, kurio ir pirmą kartą pasaulinėje praktikoje 2000 metais buvo gautas mikrobanginio signalo dažnio dalijimo efektas kryžmų lauko prietaise. Straipsnyje aprašoma prietaiso struktūra ir pateikiamos pagrindinės eksperimentinės charakteristikos. Keturios 10 cm bangos ilgio subharmoniką naudojantio dalytuvų isėjimo signalo galia siekė 10 kW, o didžiausia galios transformacijos koeficiento vertė – 25 dB. Il. 5, bibl. 8 (anglų kalba; santraukos lietuvių, anglų ir rusų k.).