WAVE ANALYSIS OF TUNABLE MAGNETOSTATIC WAVE OSCILLATOR

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ABSTRACT

This paper is devoted to theoretical analysis of tunable magnetostatic wave (MSW) oscillator. It based on the loop oscillator model consisting of amplifier, MSW frequency determinating element (FDE) (resonator or/and delay line (DL)), coupling line and coupler. And authors took to account electromagnetic wave reflection. The calculations of output power of MSW oscillator took to account variations of G and loss in feedback α_{fb} over the band as well as influence of reflections in oscillator's loop were executed. Experimental check of calculation's results with sample of tunable MSW oscillator was executed too.

INTRODUCTION

Electrically tunable microwave oscillators are composite parts of radio communication systems, radio location stations, radio navigation, satellite and cable TV, a number of radio-measuring devices. Due to multiple special properties (low level of phase noises, wide band of electrical tuning, advanced technology of manufacturing, low zero signal plate current and power consumption in control mode) magnetostatic wave oscillators (MSW-oscillators) don't have competitors in the frequency band from 0,5 up to 20 GHz. The application in this oscillators of frequency fixing MSW-units, based on the epitaxial ferrite films, provides more advanced technology, better electrical features and as a result ability to compete with the nearest analog like oscillators, based on Yttrium Iron Garnet (YIG) spheres. The design of new devices on YIG base such as optimization it's characteristics make a need of theoretical analysis whole devises as well as it's partial elements.

This paper is advance of the earlier executed theoretical analysis of tunable MSW oscillator But that analysis didn't take to account a wave nature of oscillator's circuits, particularly reflections in oscillator loop, i.e. the elements of oscillators were assumed as matched. However, in number of cases, especially with significant reflection from input and output sections of MSW oscillator's elements, existing of reflected waves can effect oscillator's characteristics. Therefore the authors made theoretical analysis of MSW oscillator with discount of electromagnetic wave reflection.

CALCULATION METHOD

Calculations based on the loop oscillator model consisting of amplifier, MSW frequency determinating element (FDE) (resonator or/and delay line (DL)), coupling line and coupler. This model took to account all features of such oscillators: nonlinearity, dispersion and additional delay time in the amplifier and coupling lines (t_y). Let's break the oscillator's loop in our imagination for discount of reflected waves. Then oscillator's elements were considered as two cascaded two-port devices. Two-port device A has scattering matrix [S^A] and describes SHF amplifier. Two-port device B has scattering matrix [S^B] and describes MSW FDE (it may be resonator, DL or filter). Such division is proper in case FDE, that consist from MSW resonator and DL placed in the same magnetic system, too. This two-port devices contain coupling lines the same length as oscillator's ones. Designating scattering matrix of cascade of these two-port devices as [S^{AB}] it is possible to write down an amplitude balance condition and a phase balance condition as following:

$$\left| S_{21}^{AB} + \frac{S_{11}^{AB} * S_{22}^{AB}}{1 - S_{12}^{AB}} \right| \geq 1 \qquad (1)$$

$$Arg\left| S_{21}^{AB} + \frac{S_{11}^{AB} * S_{22}^{AB}}{1 - S_{12}^{AB}} \right| = 2\pi n; \qquad (2)$$

where: $S_{11}^{AB}, S_{22}^{AB}, S_{12}^{AB}, S_{21}^{AB}$ - matrix elements, n – whole number.

Whence, taking to account known formulas [1] for cascaded two-port devices:

$$\left[S^{AB}\right]=\begin{bmatrix} S_{11}^{A}+\dfrac{S_{12}^{A}*S_{11}^{B}*S_{21}^{A}}{1-S_{22}^{A}*S_{11}^{B}}; & \dfrac{S_{12}^{A}*S_{12}^{B}}{1-S_{22}^{A}*S_{11}^{B}} \\ \dfrac{S_{21}^{A}*S_{21}^{B}}{1-S_{22}^{A}*S_{11}^{B}} & S_{22}^{B}+\dfrac{S_{21}^{B}*S_{12}^{B}*S_{22}^{A}}{1-S_{22}^{A}*S_{11}^{B}} \end{bmatrix}, \tag{3}$$

and assuming $S_{12}^{A}\approx 0$ (since SHF amplifier has back gain $S_{12}^{A}<<S_{21}^{A},S_{11}^{A},S_{22}^{B}$), the selfexcitation conditions can be written as following:

$$\left|\frac{S_{21}^{A}*S_{21}^{B}}{1-S_{22}^{A}*S_{11}^{A}}+S_{11}^{A}*S_{22}^{B}+\frac{S_{21}^{B}*S_{12}^{B}*S_{11}^{A}*S_{22}^{A}}{1-S_{22}^{A}*S_{11}^{B}}\right|\geq 1 \tag{4}$$

$$Arg\left[\frac{S_{21}^{A}*S_{21}^{B}}{1-S_{22}^{A}*S_{11}^{B}}+S_{11}^{A}*\left(S_{22}^{B}+\frac{S_{21}^{B}*S_{12}^{B}S_{22}^{A}}{1-S_{22}^{A}S_{11}^{B}}\right)\right]=2\pi n \tag{5}$$

The condition (5) is an phase balance condition, that allow to find own frequencies of system $\omega_n(H_e)$ (frequencies where phase balance condition is valid) with discount of wave processes in oscillator's loop. Analysis of this equation revealed that magnitudes of own frequencies determinate with (5) will differ unessentially from determinate earlier without taking to account a wave processes. Course of this is a high slope of phase frequency characteristic of MSW FDE and different will only few MHz. Hence calculation of it isn't interesting since the MSW oscillators are tunable above broad band and it's difficult since the phases of reflectivity and transfer rate of all elements often aren't known. Considering amplitude balance condition (4) more carefully the loop gains (gain of one pass through the oscillator's loop) for the best (K_{max}) and worst (K_{min}) combinations of reflectivity phases were found.

$$K_{\max}=\frac{\left|S_{21}^{A}\right|*\left|S_{21}^{B}\right|+\left|S_{11}^{A}\right|*\left|S_{21}^{B}\right|*\left|S_{12}^{B}\right|\left|S_{22}^{A}\right|}{1-\left|S_{22}^{A}\right|\left|S_{11}^{B}\right|}+\left|S_{11}^{A}\right|*\left|S_{22}^{B}\right| \tag{6}$$

$$K_{\min}=\frac{\left|S_{21}^{A}\right|*\left|S_{21}^{B}\right|-\left|S_{11}^{A}\right|*\left|S_{21}^{B}\right|*\left|S_{12}^{B}\right|\left|S_{22}^{A}\right|}{1+\left|S_{22}^{A}\right|\left|S_{11}^{B}\right|}-\left|S_{11}^{A}\right|*\left|S_{22}^{B}\right| \tag{7}$$

These gains determine scope of possible magnitudes of loop gain. After change of matrix elements on parameters measuring by equipment we can write down:

$$K_{\max,\min}=\frac{G*\alpha_f\pm\alpha_f*\alpha_b*\left(\dfrac{r_1^A-1}{r_1^A+1}\right)*\left(\dfrac{r_2^A-1}{r_2^A+1}\right)}{1\mp\left(\dfrac{r_2^A-1}{r_2^A+1}\right)\left(\dfrac{r_1^B-1}{r_1^B+1}\right)}\pm\left(\frac{r_1^A-1}{r_1^A+1}\right)*\left(\frac{r_2^B-1}{r_2^B+1}\right) \tag{8}$$

where: G – gain of SHF amplifier in small signal mode; α_f and α_b - absolute volume of forward and back transfer functions of two-port device B, respectively; $r_{1,2}^{A},r_{1,2}^{B}$ - SWRV of input and output ports of dual-port devices A and B.

Using results of above analysis the minimum amplifier gain G_{min} that is necessary for executing of self-excitation condition over the all oscillator's band was calculated:

$$G_{\min}=\frac{1}{\alpha_f}*\left[1+\left(\frac{r_1^A-1}{r_1^A+1}\right)\left(\frac{r_2^B-1}{r_2^B+1}\right)\right]\left[1+\left(\frac{r_2^A-1}{r_2^A+1}\right)\left(\frac{r_1^B-1}{r_1^B+1}\right)\right]+\alpha_b\left(\frac{r_1^A-1}{r_1^A+1}\right)\left(\frac{r_2^A-1}{r_2^A+1}\right) \tag{7}$$

This parameter's magnitude is impotent during MSW oscillator design with given FDE for SHF amplifier choice that has minimal but enough gain. The results of calculations with according to above method are shown on fig.1 and 2. Fig.1 shows influence of SWRVof FDE on loop gain for different volumes of G. It reveals that even with gain exceeding loses in FDE there is possibility of absent of generation if FDE has SWRV >2. If SWRV of FDE is equal 3 then scope of loop gain (K_{max} - K_{min}) reaches 4.5÷5 dB. It leads to significant variations of MSW oscillator's output power during tuning.

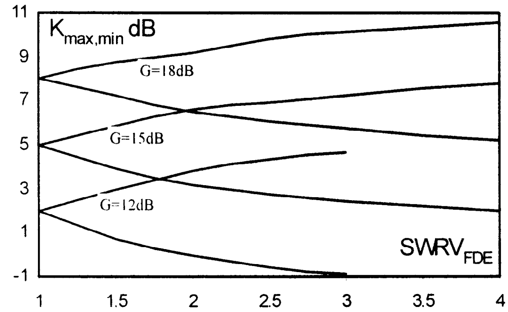

Fig.1. Influence of SWRVof FDE on loop gain

Unmatching of oscillator's contour elements with coupling line's impedance influent on self-excitation conditions. Fig.2 shows calculated volumes of gain stock (G-α) that is necessary for MSW oscillator excitation over the all band with dependent on amplifier's and FDE's SWRV. (There curve 1 correspond $SWRV_{amplifier}$=1.5, curve 2 - $SWRV_{amplifier}$=2, curve 3 - $SWRV_{amplifier}$=2.5). The significant reflectivity of amplifier and FDE (SWRV≥2.5) demand an increasing of gain G that undesirable.

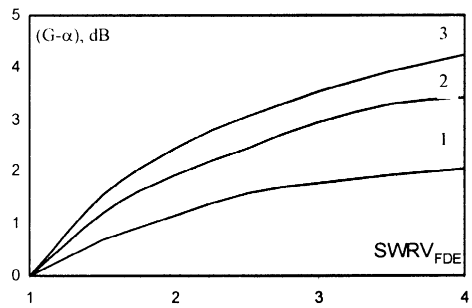

Fig.2. Gain stock (G-α) for excitation of MSW oscillator over the all band

Calculations of output power of MSW oscillator took to account variations of G and loses in feedback α_{fb} over the band as well as influence of reflections in oscillator's loop were executed with numerical method [2]. The results of these calculations (curves 2 and 3) and measured frequency pattern of oscillator's output power (curve 1) are shown on fig. 3.

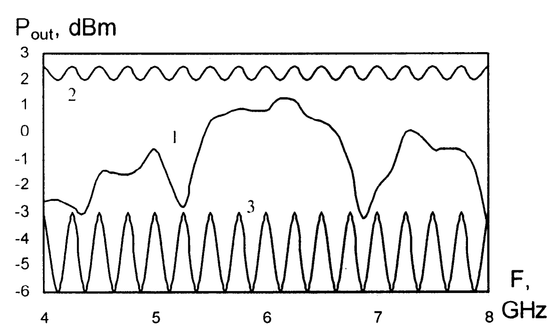

Fig.3. Output power of MSW oscillator

The experimental check of obtained results was executed with sample of tunable MSW oscillator. It involved: SHF amplifier with G=45.76, FDE designed on basis of coupled MSW-resonators. The passband of such FDE was ΔF=4.5 MHz and phase increment over passband was $\Delta\varphi$=340°. It had equal Q-factor Q=4000 on frequency F=6GHz [3]. The composite magnetic system was used. In it the magnetic field H_{e0}=3740 E that corresponds initial oscillator's frequency at middle of band F_0=5.6GHz, was provided by SmCo permanent magnet. And frequency control was executed by current I_c in a coil.
Maximal variation of output power over the all tuning band is 5.5 dB and it don't come out the calculated margins.

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