# A 3.8 - 30.0 GHz YIG OSCILLATOR - THEORY AND DESIGN

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## ABSTRACT

A YIG oscillator tunable over 3.8 -30.GHz band has been developed. The aim of the paper is to analyze the oscillator and to discuss those of its properties which are critical for wide-band and high frequency performance. The paper consists of two parts: in the first one the methods of small signal analysis are used for wide-band design, the second part is focused on nonlinear properties of the oscillations.

## OSCILLATOR CIRCUIT

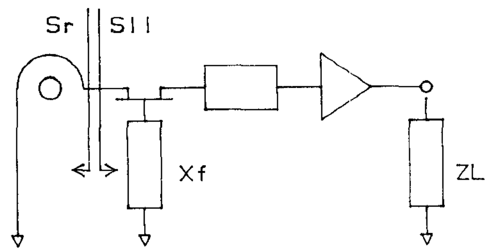
The oscillator shown in Fig.1a has been built as a hybrid microstrip circuit. Choice of active devices and YIG spheres has been critical for oscillator performance.

We have used commercially available MESFET's and HEMT's of 0.25μm and 0.3μm gate-length. The oscillator transistor was selected for high transconductance and the first amplifier transistor for matching properties.

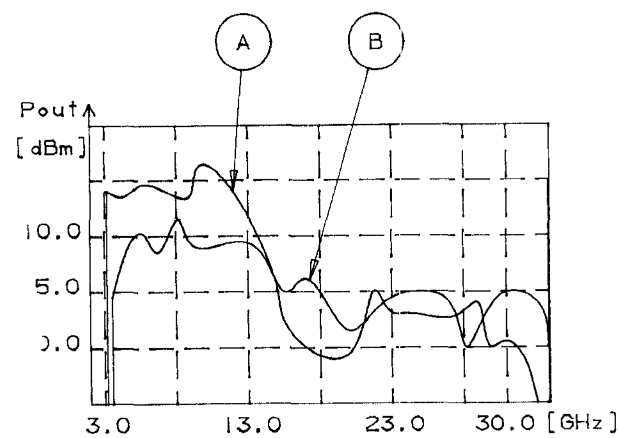
The choice of YIG sphere involved trade-offs between bandwidth (which improves with strong coupling) and suppression of higher order modes (which requires weak coupling). Moreover, sphere dimensions are limited by gap size which in turn is constrained by tuning linearity and overall size of the device.

## SMALL SIGNAL DESIGN

The standard oscillator design methods [4,5,6] consist of analyzing the stability circles for the oscillator circuit and designing the load that assures oscillations in the desired band. Similarly if one works with a fixed load one can also use stability circles to design the feedback circuit (Xf in Fig.1a ) for the required band.




a) YIG oscillator




b) power spectra for different YIG spheres:[A] 3.2-31. GHz, [B] 3.8-32.GHz, measured to 30. GHz

Fig. 1.

The above analysis has simple interpretation in terms of reflection coefficients.

$$|Sr \cdot S11| > 1 \qquad (1)$$

Namely the circuit can oscillate if and only if the inequality (1) holds.

Our first task is to obtain the widest possible instability regions and to design the load that fits those regions (over the band). We achieve this by careful choice of the YIG sphere and proper coupling, then by the wide-band impedance matching.

## SMALL vs. LARGE SIGNAL DESIGN

The stability circles approach gives us important information about oscillations conditions (circuit stability) and consequently the oscillator's band. Moreover, the method is relatively simple. Restriction to "small signals", however, that makes the method simple, renders it useless for analysis of the steady state oscillations which are intrinsically nonlinear.

The next design task is to predict properties of steady state oscillations, in particular to estimate signal power, harmonic content, frequency stability, and resonances which appear over the band.

When the condition (1) is satisfied, then oscillations in the system will grow causing the decrease of S11 until

$$Sr \cdot S11 = 1 \qquad (2)$$

Clearly the designer's aim is to find the widest possible band in which the condition (1),and consequently the condition (2),holds. That was by this method that the 3.8-30 GHz band was achieved.

Equations (1) and (2) have simple geometrical interpretation shown in Fig.2. Let us note that in the neighborhood of resonance frequency the reflection coefficient S11 remains almost constant in frequency ( at least when compared to Sr ). Therefore the variables in equation (2) can be separated.

$$Sr(w) \cdot S11(A) = 1 \qquad (3)$$

consequently the amplitude and frequency of oscillations become simple to determine.

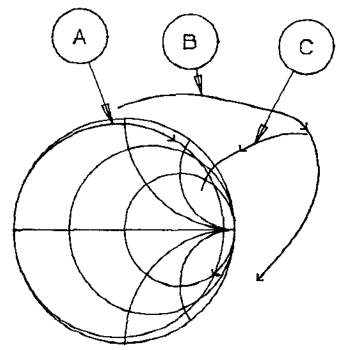



Fig.2. Illustration to equations (1),(2),(3)
[A] Sr(w) which is linear
[B] small signal S11(w)
[C] Variation of S11(A) for fixed w.

The equation (1) describes oscillations of growing amplitude while equation (2) and (3) describe a steady state sinusoidal oscillations.

## LARGE SIGNAL ANALYSIS AND THEORY

Let us specify the precise meaning of "large signal" analysis or "large signal" S-parameters.

1. Harmonic balance.

The best known and closely related to phasor method is the method of harmonic balance. Consider the system shown in Fig.3. If the system possesses periodic oscillations, then, in the steady state, it can be represented by an infinite system of equations

$$x_n = H(jnw)\ f_n(x_o, x_1, x_2, \ldots) \qquad (4)$$

where $n = 0, +1, +2, \ldots$

$x(t) = \Sigma x_n \exp(jnwt)$ represents the oscillations

$f_n(x_o, x_1, x_2, \ldots)$ represents n-th Fourier coefficient of $f(x(t))$.

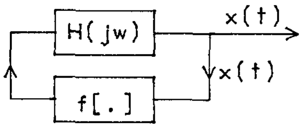



Fig.3. Block diagram of the oscillator

The method is based on assumption that the oscillations are close to sinusoidal i.e. $x(t) = A\cos(wt+p)$ and their amplitude and frequency can be found from HARMONIC BALANCE equation

$$H(jw)\ F(A)/A = 1 \qquad (5)$$

where F(A) is the first harmonic of $f(A\cos(wt))$.

One can prove [7] that if the equation (5) possesses a "regular" solution and if the "filter" H(jw) is selective enough, then the original system (4) possesses oscillations that are close to the ones obtained from (5). Let us note that the expression $H(jw)F(A)/A$ in eq.(5) plays the role of the "large signal" gain ( physical interpretation of eq.(5) is that the gain around the feedback loop is equal to one). The expression can be easily translated into "large signal" S-parameters and can be also easily expressed in terms of FET model characteristics and YIG sphere parameters. Consequently we can choose devices and specify bias to achieve the desirable oscillator properties.

2. Methods of averaging and integral manifolds.

The method of harmonic balance is applicable only to steady state oscillations, for transient analysis of nonlinear oscillatory systems the methods of averaging and integral manifolds are very effective[8]. They consist of looking for a signal in the form $x(t) = A(t)\cos(wt+p(t)) + y(t)$ where y(t) is "small" and A(t),p(t) are slowly time varying. One proves [9,10] that A(t) and p(t) can be determined from the second order autonomous equation of the form:

$$dA/dt = \varepsilon\, g(A,p)$$
$$dp/dt = \varepsilon\, h(A,p) \qquad (6)$$

where $\varepsilon$ is "small"

In many cases the problem can be further simplified, namely one can predict the shape of oscillation's amplitude which reduces the problem to that of simple motion on a surface in state space (the so called integral manifold).

The justification of the methods is quite involved, the results, however, have clear physical and geometrical interpretation, and the method can be effectively applied to analysis of synchronization, squegging and existence of almost periodic (spurious) oscillations. One also proves that the constant solutions of (6) coincide with those obtained by the harmonic balance method.

## CONCLUSIONS

The YIG oscillator band is limited by resonant properties of the YIG sphere on the low end, and by FET parameters (gate length) on the high end.

A multi-octave oscillator covering 3.8 to 30GHz band has been developed. Design effort consisted of two tasks:

1. Extension of oscillator band (up to fundamental limits), achieved via small signal analysis.

2. Optimization of the nonlinear steady state oscillations. The methods of "large signal" S-parameters, harmonic balance, averaging, and integral manifolds were compared and rigorously justified.

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