The Method of Modeling of VCO Based on SPICE Simulation

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Paper abstract:
The method of VCO simulation, based of modern SPICE models of semiconductor units, is offered. This method allows calculate basic parameters of VCO with high-Q oscillatory systems of any type. Results of calculations and experiments on measurement of voltage-frequency control characteristics and regime instability are brought. Practical worth of this method consists in significant development phase abbreviation of real VCO and possibilities of accomplish multifactor analysis of the developed circuits.

SIMULATION METHOD OF VOLTAGE-CONTROLLED OSCILLATORS

RESEARCH OF PROBLEMS

To voltage-controlled oscillators (VCO), working in systems of a phase locking of frequency of the radio-transmitting and radio receivers of band VHF and UHF contradictory enough demands are made:

1. A high rated frequency - (150 - 450) MHz;
2. A wide tuning frequency range;
3. High linearity of frequency control performance;
4. Uniqueness of output frequency VCO to a control voltage (lack of stray frequency jumps on a tune band edges);
5. High linearity of a drive characteristic for VCOs, used in FM modulators;
6. A high regime stability of frequency and, therefore, high enough purity of a spectrum of output oscillation;
7. Low parametric sensitivity to dispersion of circuit components values.

Existing methods of the analysis of steady conditions VCO, based on analytical methods and the simplified models of driven elements, in practice do not give good approximation to a reality. The methods of circuit simulation based on SPICE-models of transistors and used in a transient analysis regime, demand the major expenditures of a computer time because of presence of high-Q vibrating systems in VCO circuits. Outcomes of a transient analysis calculation (meaning of amplitude of oscillation and their frequency) do not take an immediate estimate of correspondence of the circuit to the demands resulted above. A measurement accuracy of frequency is thus insufficient the amount of the gained information is not enough for a circuit qualitative analysis. Therefore quality of circuitry VCO often depends on talent, intuition of engineers-developers and directly from a time spent for device breadboarding.

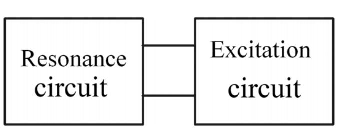

Fig.1. Model of oscillator

METHOD SUBSTANTIATION

The offered method of VCO analysis is a logical development of a quartz oscillators analysis method described in [1,2,3]. Abstracting from concrete structure of the oscillator circuit and from concrete sort of a feedback, the oscillator can be presented in the form of system of two units: passive, high-Q resonance circuit, and active, compensating energy loss [4]. Irrespective of real circuit complexity, a passive and active part of the self-oscillator may consider as the linear two-terminal networks and presented by certain characteristic parameters. In this representation (fig. 1) properties, both a vibrating system, and it excitation circuits, may be described based only on relations between signals on exterior outputs, i.e. using macromodels. Properties of a vibrating system easily express through its linear macromodel. For the high-Q oscillating circuit a current through it (for a serial outline) or the voltage on it (for a shunt circuit) during period of oscillations practically does not differ from pure sinusoidal, that gives the ability to neglect higher harmonics and to characterize the feed circuit only relations between amplitudes of first harmonics of currents and voltage on its poles and to use harmonically linearized parameters (to create the linearized macromodel of the excitation circuit). Therefore, for two-pole representation the feed circuit can be completely described by the complex impedance averaged on a first harmonic (for the serial oscillating circuit) or the complex admittance averaged on a first harmonic (for the parallel oscillating circuit). Autoexcitation condition of the circuit thus is excess of the energy generated by the active two-terminal network, over an energy loss in a vibrating system at small (zero) amplitude of oscillation. The steady conditions of operation of the oscillator are characterized by balance of energies (consumed in a vibrating system and the selected feed circuit).

To produce of all sorts of the analysis observed next, the program of circuit simulation Micro-Cap used. In a drive index point when the signal amplitude is close to null, VCO behaves as a linear circuit, therefore this point can be spotted in a circuit design regime on an alternate current (AC Analysis). Examinations [1-3] have shown that at the signal magnitude variation basically there is a modification of a real part of a linearized resistance or conductance, and their imaginary part practically does not vary. At analysis VCO where the oscillation frequency strongly depends on the control voltage value, little change of an imaginary part of a linearized resistance of

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the oscillator can be neglected practically lost-free exactitudes of accounts. Therefore for sufficing it is enough to purposes of research problems to be restricted to determination of requirements of autoexcitation. Possibilities of program Micro-Cap allow yielding in regime AC measuring of all enumerated above parameters VCO.

At representation of the oscillator in the form of the joint of two-terminal networks (fig. 1) it is obvious, that through outputs of these two-terminal networks the same current, therefore the second Kirchhoff's law for an outline derivated by these two-terminal networks leaks, for a steady conditions of oscillations it is possible to write in sort: $I\cdot Zk+I\cdot Zg=0$, where I - a steady conditions current, Zg - a linearized resistance of the generating two-terminal network, Zk - a resistance of the two-terminal network of a vibrating system. After abbreviation on I we gain a balance equation of resistances in a steady conditions: $Zk+Zg=0$. This equation it is possible to write through so-called «a balance resistance» Zb in the form of $Zb = 0$, where $Zb = Zk+Zg$.

It is possible to write also the equation for a steady conditions on the first Kirchhoff's law: $U\cdot Yk+U\cdot Yg=0$, where U - a potential difference on outputs of two-terminal networks, Yg - linearized conductance of the oscillator, Yk - conductance of a vibrating system. After abbreviation on U we gain a balance equation of conductivities in steady conditions: $Yk+Yg=0$. This equation it is possible to write through so-called «balance conductance» Yb in the form of $Yb = 0$, where $Yb = Yk+Yg$.

Sampling of sort of the equation (balance of resistances or balance of conductivities) depends on vibrating system and feed circuit type: from the point of view of program accounts it is necessary to select such parameters which autoexcitation on frequency do not tend to infinity. For example, if the vibrating system represents the parallel oscillating circuit it is necessary to select a balance equation expressed through conductivities as the resistance of the parallel oscillating circuit at approximation to frequency of a resonance tends to infinity. For the serial oscillating circuit, on the contrary, it is necessary to select a balance equation of resistances.

As the balance resistance is complex the equality to its null actually matches to two equations: for a real part and for an imaginary part. The equality to null of a real part is equivalent to concept «balance of amplitudes», and equality to null of an imaginary part is equivalent to concept «balance of phases». It is necessary to mark, that the balance of resistances occurs only in the installed functional mode of the oscillator. In that case when there is a process of a build-up of amplitude (for example, at powerup) or when there is a process of its decrease (for example, at voltage excursion of an automatic gain control or at feed turn off), real part Zb can be distinct from null. The imaginary part of this resistance is equal to null always irrespective of, the amplitude of oscillation was installed, or not. The autoexcitation requirement can be written in sort: $Re\ (Zb) <0$.

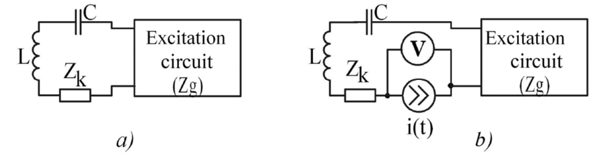


Fig. 2. Oscillator model with a consecutive tank circuit

Analogous reasoning can be led and for balancing conductance; the autoexcitation requirement can be noted in a view: $Re\ (Yb) <0$.

In some circuits of oscillators where the vibrating system is complicated, sometimes it is difficultly to identify its type on frequency of autoexcitation. In this case it is possible to lead both sorts of the analysis, and then to choose in what the balancing parameter has no disrupters.

THE OSCILLATOR WITH A SEQUENTIAL TANK CIRCUIT

Let's spot requirements of autoexcitation for the oscillator with the sequential tank circuit shown on fig. 2a. Proceeding from the reasons resulted above we sample a balance equation of resistances. For measuring Zb the oscillator-contour is switched on in a break in a circuit an ideal radiant of a harmonic current $i\ (t) =I\cdot sin\ (\omega t)$, and metered on it a voltage (fig. 2b). In regime AC the program uses an individual value of amplitude of a current, therefore a voltage on the current source to equally value Zb. The balance of phases can be spotted from requirement $Im\ (Zb) =0$, therefore frequency of autoexcitation is easily spotted as an intersection point of the diagram of imaginary part Zb with an axis of frequencies. Autoexcitation requirements are spotted on this frequency as performance of inequality $Re\ (Zb) <0$. It is necessary to note, that in that case when diagram $Im\ (Zb)$ recuts an axis of frequencies some times, and possible driving frequencies match to points where the diagram has the plus derivative. If the derivative in an intersection point is subzero, such point is unstable (so-called fixing ability of the circuit [5] here is subzero), and drive on this frequency is impossible.

If at the oscillator analysis it has been gained more than one possible point of autoexcitation, and autoexcitation requirements in these points are fulfilled (i.e. in these points $Re\ (Zb) <0$) it means, that in the given oscillator jumps of frequency from one point in another are possible, i.e. the given circuit of the oscillator demands modification. It is necessary to make variations, at which in undesirable points of autoexcitation requirement $Re\ (Zb) <0$ would cease to be satisfied.

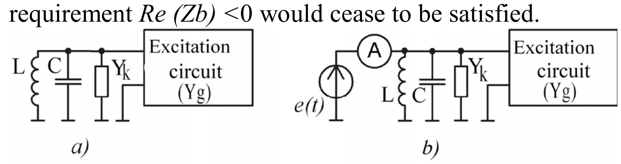


Fig. 3. Oscillator model with a parallel tank circuit

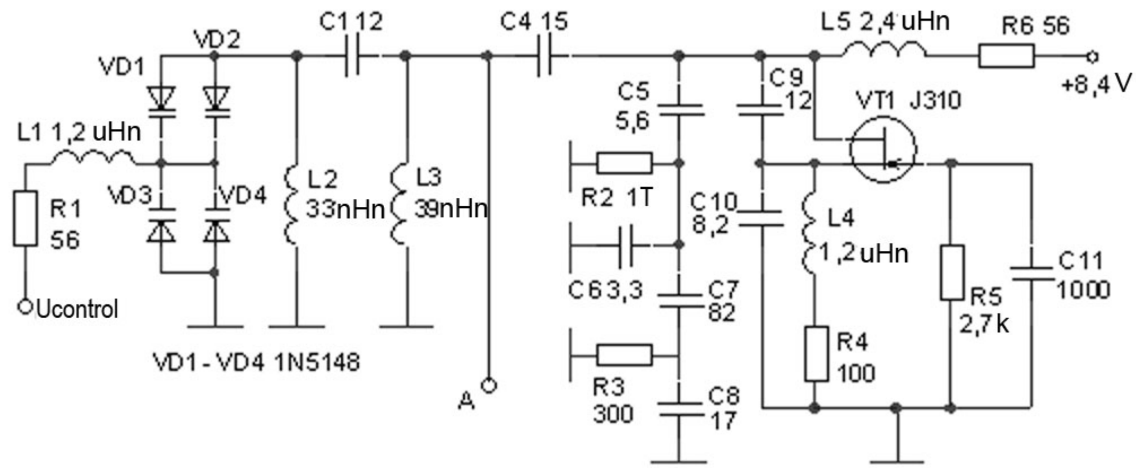


Fig. 4. The basic circuit VCO of professional radio station VHF - range "Motorola CM-140"

THE OSCILLATOR WITH A PARALLEL TANK CIRCUIT

The oscillator with a parallel tank circuit is figured on fig. 3a. Here for determination of a regime of autoexcitation we sample a balance equation of conductance. For determination *Yb* it is parallel to a circuit the oscillator-contour we will hook up an ideal radiant of a harmonic voltage $u(t) = U \cdot \sin(\omega t)$, and we will metre a current through it (fig. 3b). In regime AC the program uses an individual value of voltage amplitude; therefore the EMF source current is equal to value *Yb.* The balance of phases can be spotted from requirement $Im(Yb) = 0$, therefore frequency of autoexcitation is easily spotted as an intersection point of the diagram of imaginary part *Yb* with an axis of frequencies. Autoexcitation requirements are spotted on this frequency as performance of inequality $Re(Yb) < 0$. In the same way, as well as in the previous case, possible driving frequencies match to those intersection points of diagram *Im (Yb)* with an axis of frequencies where the derivative is plus.

EXPERIMENTAL RESEARCHES

Modeling of oscillators with the serial oscillating circuit (in the capacity of an outline the crystal vibrator used) and matching of outcomes of modeling with experimental data is resulted in [1. 3].

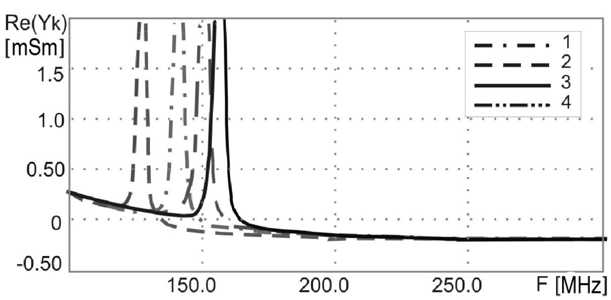
Modeling VCO with the parallel oscillating circuit and experimental researches were carried out on the basis of circuit diagram VCO of professional radio set VHF - a band "Motorola CM-140" (fig. 4). The point A matches to the selected place of hooking up of a radiant of EMF of a signal. Outcome of measuring in the form of graphs real (dashed line) and imaginary parts (solid line) of balance conductance *Yb* in a regime the EXPERT are resulted on fig. 5. From comparison of these graphs it is visible, that for possible three driving frequencies (a point of balance of phases) autoexcitation requirements are fulfilled only

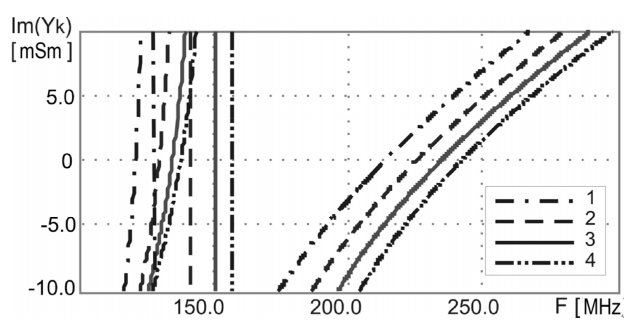
Fig. 5. The diagram of Re(Yk)/F

of measuring of the set of graphs of real and imaginary part *Yb* in a regime the EXPERT are resulted on fig. 6 for a number of meanings of a control voltage (1 - Ucontr = 2 In, 2 - Ucontr = 4 In, 3 - Ucontr = 6 In, 4 - Ucontr = 8). The analysis of graphs shows, that autoexcitation requirements are fulfilled over the range frequencies from 215 to 245 MHz.

For practical verification of outcomes of account of a dot frequency of balance of phases by means of function X_Level (from menu Performance Windows) have been transferred on the diagram of association of a driving frequency from the control voltage value (fig. 7, the graph 1).

Association of a driving frequency on a supply voltage (performance of regime instability) on fig. 9 (the graph 1) has been similarly gained. As at presence in the circuit of a modulation entry, it is possible to gain the drive





characteristic graph.

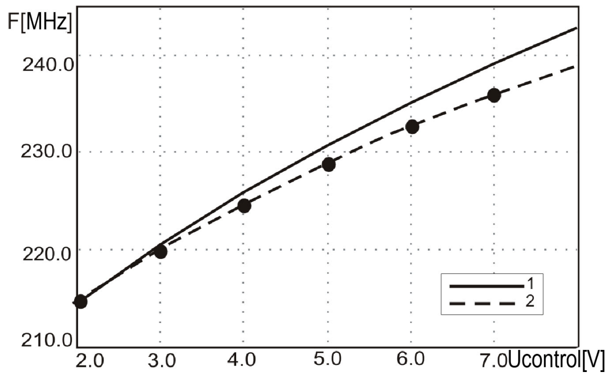


Fig. 7. The diagram F/Ucontrol

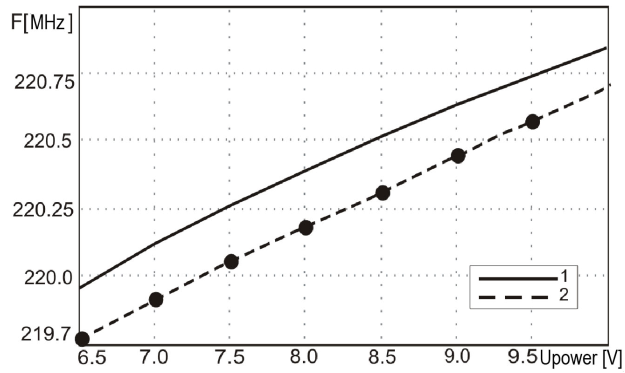


Fig. 9. The diagram F/Upower

In figures 7 and 9 (the graph 2) is shown outcomes of the observational measuring. It is visible, that observed data and outcomes of modeling will well agree among themselves. Difference of outcomes (within 5 %) is called by assemblage of not considered factors, such, as parasitic capacities of builders, difference of parameters of models of semiconductor electronic parts from real meanings. At conducting of rated experiments it has been noted, that for the given circuit the main contribution to a lapse of determination of performances VCO is imported by parameters of inductors L2, L3, L5. Rise of exactitude of accounts can be gained, using data of corporations-manufacturers which are resulted in the form of tables of S-parameters.

Inference

The stated procedure of modeling of oscillators gives to development engineers the powerful instrument for the analysis of their properties and detection of the builders most responsible for quality indicators VCO. The offered method allows to depart from the approximate analytical approaches of the theory of a generating, and to transfer to the analysis of properties of oscillators on the basis of the most exact by the current moment SPICE models of semiconductor units. In the literature devoted to accounts of parameters of the radio electronic arrangements, there are completed expositions of design procedures of oscillators on the basis of SPICE no models of builders.

Procedures of modeling of the oscillators, stated in [1. 3] have been dilated on the wide class-room of oscillators with sound vibrating systems of any type. Outcomes of experiments proved correctness of the stated approach.

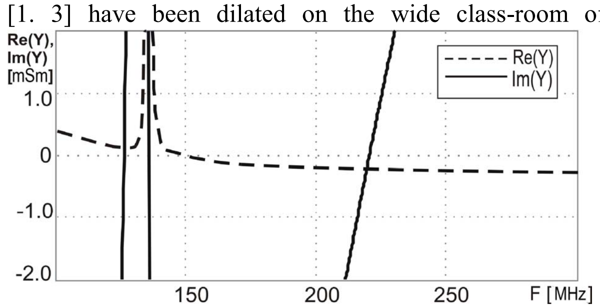


Fig. 8. The diagram Re(Yk), Im(Yk)/F

Practical worth of a method consists in the considerable abbreviation of a time of development real VCO and possibilities of conducting of multicomponent analysis of the developed circuits.

The given procedure can be used at any firms of the radio engineering profile in which the radio-receiving develop, the radio-transmitting, or other arrangements containing VCO

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