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Received on 14.05.2007

UDC 621.372.852

MODELING OF ATTENUATOR STRUCTURES ON FIELD EFFECT TRANSISTORS WITH MINIMAL PHASE SHIFT AT ATTENUATION REGULATION

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Controlled absorbing attenuators on Schottky-gate FETs: T-circuit, T-shaped bridge circuit and transistor attenuator in the mode with controlled slope of voltage-current characteristic have been considered. Attenuator phase-frequency characteristics were modeled. The main difference of the circuits from the known ones consists in introduction of equalizers that conditions broadband feature and large attenuation range where minimum of the phase shift is achieved at regulation. As a result, the optimal parameters of adjusting circuits in attenuators are founded. It is shown that the least phase shift is provided in attenuators on transistor with controlled volt-ampere characteristic steepness. The comparative estimation of the considered base structures was given.

The requirement of phase shift constancy at transfer constant adjustment is made to modules of active phase lattices, systems of automatic phasing in transmitters, precise wide-band amplifiers, attenuators with smooth variation of attenuation and other devices with adjustable characteristics of signal transmission. Change of phase shift or group delay is conditioned by the influence of parasitic reactivity of elements with controlled resistance. There is a certain process limit in decreasing parasitic parameters. Therefore, one of the most important tasks is a balance of parasitic reactivities of the controlled elements by circuit solutions.

1. The problem of phase shift invariance

Electrically controlled attenuators (ECA) are intended for smooth change of signal level in a circuit. For a number of practical tasks, for example, CDMA of communication systems, phased arrays, surface radars etc., the excess requirement is made to attenuators; the requirement to phase shift stability of output signal relative to the input one at adjustment of transfer constant [1]. This aim is complicated at system operation in a wide band, in general case from zero to several GHz. Phase variation is conditioned by the influence of parasitic reactivities of the controlled elements. They may be decreased technologically only to a certain limit, especially in super-wide band. Therefore, the only method of supporting phase shift invariance to attenuation is the balance of parasitic reactivities of controlled elements by a circuit way. In particular, the equalizers included specially into the base structure find wide application in absorbing attenuators.

The methods of phase correction are developed best of all for ECA on *p-i-n* diodes [1]. Schottky-gate FETs (SFET) have a number of advantages although diodes gain in maximum power of controlled signal. In particular, the advantage is in switching time, decoupling between signal transmission circuit and control paths. Availability of using SFETs conditioned by low values of parasitic reactivities simplifies considerably the problem of constructing wide band ECA in microwave range.

The aim of the work is the investigation and simulation of circuit design characteristics for ECA on FETs, search for perspective circuit methods of phase shift correction and comparison of the obtained results with known characteristics of base diode and transistor structures.

2. Selection of transistor operating conditions in a circuit

SFETs represent a semiconductor substrate with two ohmic contacts (drain and source) and rectifying junction metal-conductor used as a gate [2]. Usually SFETs are characterized by current-voltage input, output and transfer dependences reflecting physical processes occurring in transistor at its different states. So, without bias voltages on the gate and drain the transistor is in thermodynamic equilibrium and all currents equal zero. This state of transistor is boundary for the transfer processes occurring in SFET channel. Channel resistance at fixed voltage gate-source may be determined by the Ohm law. But the channel effective section changes depending on the value of drain-source voltage at fixed gate voltage, as well as because of voltage drop in transistor sub-gate area at drain current flow. It is obvious that the channel resistance depends on thickness of sub-gate area depletion layer. Therefore, field-effect transistor may be considered as a voltage controlled resistor. And such resistor is not sensitive to the effects of minority carrier accumulation and has higher control velocity; application of reversed-biased junction with low saturation current requires minor power consumption for controlling transistor.

High operating speed of control devices as well as low value of power consumption allows obtaining passive mode of transistor connection. SFET application in passive mode allows controlling efficiently the decay in attenuators. SFET use is bounded by the absence of characteristics and parameters required for design. This is the reason for additional and labor-consuming measurements. The adjusting characteristic is the main one for estimation of control efficiency. It is determined by minimum and maximum transistor resistances as well as by the law of variation of SFET channel resistance from voltage on its gate. Therefore, the issue of selecting SFET consists in determining its channel resistance without voltage between the transistor source and drain.

At transistor manufacturing there are process errors resulting finally in deviation of the implemented characteristics from the expected ones. The range of their deviation is not known beforehand, as a rule; therefore, the comparison of the results of calculations by the fixed electrophysical parameters of SFET with the results of measuring single samples of transistors is illegal. At the same time, use of transistors with different characteristics in control devices of microwave range results in nonidentity of their frequency characteristics. Therefore, definition of parameters of average transistor as well as the value of their deviations from the most probable magnitude for the applied type of SFET is one of the most important tasks of designing control devices.

Let us examine some peculiarities of studying SFET in devices of controlling signal amplitude in the mode with the controlled slope of voltage-current characteristic which depends on voltage of gate-source or gate-drain shift. Transistors are usually connected by the common-source circuit, i.e. the attenuator represents a usual single-stage amplifier. The adjustable signal and control voltage are supplied to transistor gate. Current-voltage characteristic slope of transistor decreases at increase of negative blanking voltage at the gate that results in signal attenuation.

3. Circuit designs of transistor attenuators

Circuit of T-shaped attenuator is given in Fig. 1. The attenuator consists of two transistors in series arm and one transistor in parallel arm connected in the mode of controlled resistance. Two voltages $U_{упр}$, entering the transistor gates are required for attenuator control. If negative blanking voltage is supplied to the gates *VT*1 and *VT*2 then the resistance of drain-source channels increases and therefore, the decay introduced by attenuator raises. If the blanking voltage is supplied to the gate *VT*3 then attenuation decreases. Gate voltages enter through the filters consisting of elements *C*2, *L*3, *R*3 and *C*3, *L*1, *L*2, *R*4.

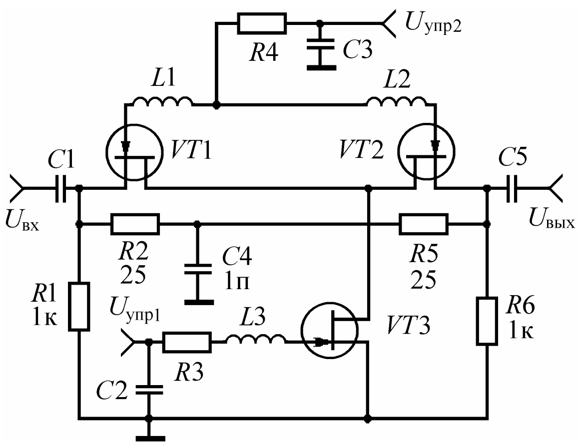

Fig. 1. *Circuit of T-shaped controlled attenuator*

Attenuator characteristics were modeled by application package WorkBench 5.12 and transistor Philips BSJ110 from the built-in library of the elements. In order to decrease the phase shift at attenuation adjustment the correcting *RC*-circuit *R*2, *R*5, *C*4 was applied. The correcting element rates should be selected so that the circuit impacts the shape of AFC and PFC only on upper frequencies.

Dependences of phase shift change on frequency and attenuation obtained by simulation and constructed in program Statistica 6.0 are given in Fig. 2 and 3.

In compensated attenuator the phase shift change does not exceed 10° in attenuation range 2,5...8,2 dB and in frequency band 0,05...4,0 GHz while it equals 26° in attenuator without correction.

Similar results were obtained in T-shaped compensated bridge attenuator consisting of two transistors connected in the mode with controlled resistance (Fig. 4). In comparison with usual T-shaped connection it supports lower range of input signal adjustment, however, its advantage is minor initial attenuation. The correcting circuit consists of resistors *R*2*R*4*C*3. Its principle of operation is like the operation of correcting circuit of the T-shaped attenuator. The difference consists in the fact that transistor *VT*2 controls the influence of correcting elements on the attenuator characteristics.

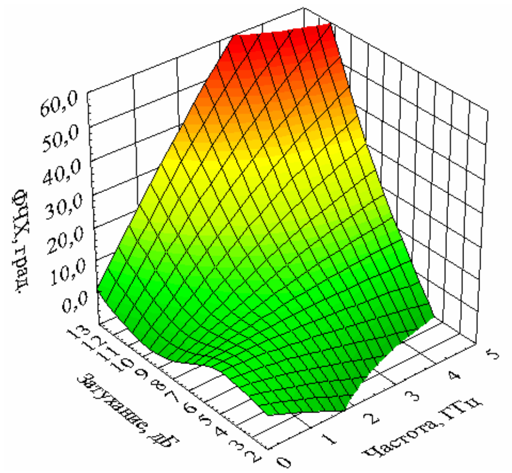

Fig. 2. *Change of phase shift depending on frequency and attenuation for uncompensated attenuator*

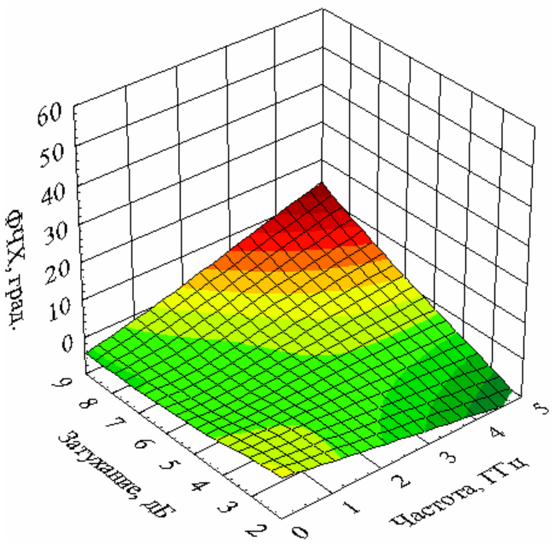

Fig. 3. *Change of phase shift depending on frequency and attenuation for compensated attenuator*

Let us compare the obtained results with the attenuator characteristics from the work [3]. The attenuator represents a bridge of resistive sections switched by the field-effect transistors in passive mode. The initial loss of attenuator amount to 2,5 dB, peak attenuation is 17 dB, phase shift change at adjustment equals 30° in frequency range 0...4 GHz. Thus, the simplified model used in this article is rather adequate to the experimental results from [3].

The results of simulation show that in P-shaped circuit of attenuator a minor change of phase shift could not be achieved at attenuation adjustment than in T-shaped circuit just the same as in diode attenuators.

SFET attenuator with controlled slope of current-voltage characteristic represents a usual single-stage amplifier where transistor is connected by a common-source circuit. Adjustable signal is supplied to the gate; control is fulfilled by the gate or by the gate and drain simultaneously. Increasing negative voltage on the gate the current-voltage slope decreases, so, signal amplitude at the output decreases as well. The disadvantage of the examined circuit is the absence of isolation between the adjustable signal and control signal. The attenuator circuit is given in Fig. 5.

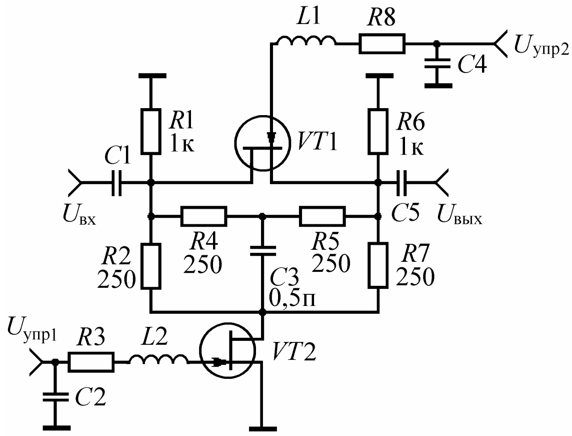

Fig. 4. *Circuit of T-shaped bridge attenuator*

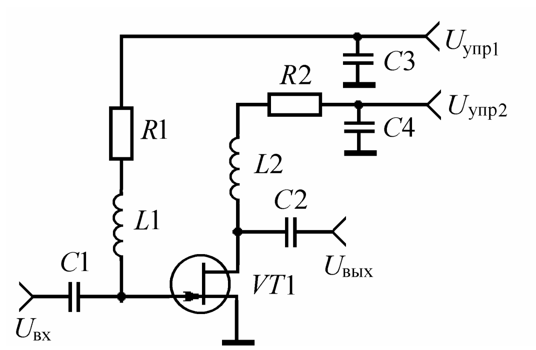

Fig. 5. *Attenuator on transistor with adjustable slope*

If voltage is adjusted simultaneously on the gate and drain so that the gate-drain voltage remains constant then only a gate-source capacity decreases. This causes minor changes of PFC then at adjustment only by the gate (Fig. 6). PFC change does not exceed 5° in the whole range of frequencies and attenuations.

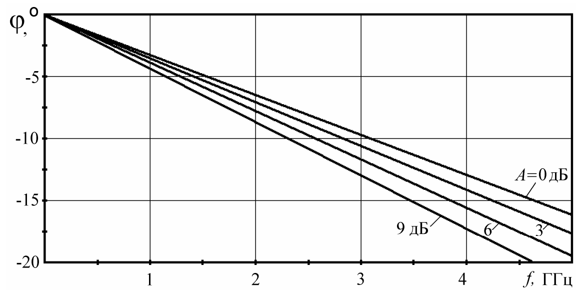

Fig. 6. *Attenuator PFC (Fig. 5) with adjustment by the gate and drain*

4. Conclusion

Model phase-frequency characteristics of attenuators controlled by voltage, carried out on Schottky field-effect transistors: T-shaped, T-shaped bridge circuits and attenuator on transistor in the mode with controlled slope of current-voltage characteristic were examined.

It is shown that use of correcting circuits allows achieving phase shift uniformity at adjustment of power attenuation. It is assigned that in modified T-shaped attenuator the phase shift change does not exceed 10° in attenuation range 2,5...8,2 dB in frequency band 0,05...4,0 GHz; it is almost in 2,6 times lower than in attenuator without correction. In comparison with diode attenuators, the T-shaped bridge circuit does not give considerable advantages from the point of view of phase shift minimum.

In attenuator in the mode with adjusted slope of current-voltage characteristic a minor change of phase shift – to 5° in the same range of frequencies and attenuations may be achieved. The obtained results are close to the experimentally observed values.

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Received on 07.12.2006

UDC 621.3

SIMULATOR OF FUEL CELLS CHARACTERISTICS ON THE BASIS OF THE SEMICONDUCTOR CONVERTER

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The results of development and research of the simulator of fuel cells characteristics based on the operated pulse converter with direct current and digital alarm processor have been considered. The electrochemical model of fuel cell considering its static and dynamic characteristics is incorporated in the algorithm of the processor work. The specified simulator has on loading terminals the same characteristics of output capacity as a real system. It allows abandoning the use of both the elements and expensive accompanying systems at stages of research, design and realization of independent systems of power supply on the basis of fuel cells.

Introduction

In order to provide competitiveness with independent feed systems on the basis of well known sources of electric energy, the systems on the basis of fuel cells (FC) should operate with comparable efficiency [1]. Such systems behavior in transients is one of the key issues at the stage of their design [2]. Simulator of FC characteristics is the device having at loading terminals the same characteristics of output power as the real system. In order to develop the simulator of FC characteristics the mathematical model of electrochemical generator directed to the analysis of the system by techniques of automatic control theory and electrical engineering should be designed.

Currently, the investigations in this field, introduced in domestic and foreign sources, may be conditionally divided into two directions: the first one (given in the majority of works) is the investigation in the field of electrochemistry the aim of which is the development of the FC components (electrolytes, gas-diffusion electrodes etc.) and selection of optimal work areas on current-voltage, parametric and other curves. Such models are based on laws of electrochemistry of porous structures, thermodynamics and mechanics of gaseous and liquid media [3, 4]. They are not suitable for analysis of transients in FC system by the techniques of automatic control theory and electrical engineering.

Another direction is the investigation in the field of electronics and microprocessor engineering allowing modeling FC characteristics [5]. However, insufficient coverage of these questions in scientific literature resulted in necessity of developing mathematical model of closed-loop control of FC, designing physical model computer control simulator of FC characteristics for experimental investigations of its characteristics; as well as developing the control system allowing providing the specified characteristics of the transients.

The authors proposed a new device on the basis of computer controlled pulse converter of direct current on the basis of FC electrochemical model (software) included in it. The simulator on the basis of the mentioned converter has on its loading terminals the same dependence of output continuous stress on load current as the real FC [6, 7].