Active Microwave Filters based on the Combined Dynamic Negatrons


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Abstract—Representation of the FET as generalized immitance converters is considered, that has allowed constructing new elements on its basis. Schemes of analogues of inductive elements (with low-Q inductor and inductor-less) based on the common-drain scheme are developed. Schemes are developed for active microwave filters, suitable for development as a hybrid or integrated microcircuits.

I. INTRODUCTION

Continuous process of complication of radio-electronic systems and their use on microwave frequency has put before implementators of the equipment two problems of vital importance: increase of dependability and reduction of overall dimensions at preservation of high electric parameters. At the decision of these problems the most significant difficulties have arisen at a stage of creation of frequency-selective filters in an integrated-circuit form. Frequency discrimination of filters depends on Q-factor of their elements. With increase of frequency Q-factor of reactive elements decreases, that conducts to deterioration of discrimination. Q-factor of inductors especially strongly decreases; for its increase it is necessary to increase the sizes, but it complicates miniaturization of LC-filters. To overcome these difficulties it is possible by creation of the digital filters which characterized by high stability and accuracy, simplicity of adjustment and an opportunity of use as adaptive systems, or analog active filters, for example based on gyrators, amplifiers with the limited transmission gain, operating amplifiers and others. The range of application of such filters is limited by frequencies on which it is possible to neglect frequency dependence of current gain of the transistor (up to hundreds megahertz). In a microwave band high-selective miniature filters are manufactured on the micro-strip lines, spiral resonators and ferro-electric elements. Each of these filter’s groups possesses the specific advantages. But all these filters have two important limitations:

• Decrease of Q-factor with reduction geometrical size
• Presence of signal losses in a pass-band.

Hence, for miniaturization of microwave-range filters expediently use of methods and construction tools of filters, which electric parameters (Q-factor) would not depend on the elements geometrical sizes. To such requirements the active filters based on negatrons are correspond. Now they are manufactured on two basic schemes. In the first scheme the passive filter joins the semiconductor element with negative dynamic resistance. It allows raising Q-factor of filter tank, due to indemnification losses. As such devices uses tunnel and avalanche transit time diodes. A limitation of Esaki diodes is their small saturation level that narrows a dynamic band of the filter. Avalanche transit time diodes possess the raised level of noise.

The schemes using generalized immitance converters (GIC) based on the transistors [1], [2] concern to the second group of microwave active filter.

At creation of microwave active filter dependence of a current transmission gain of the transistor and influence of feedback in the transistor uses. It allows using in a wide frequency band the transistor as GIC for synthesis high-Q reactive and negative active dynamic resistance. In comparison with passive microwave filters active filters possess greater Q-factor, the best size characteristics and the expanded functionality.

The important advantage of these filters is the opportunity of their realization not only as hybrid microcircuits, but also kind of monolithic microcircuits based on GaAs-structures with Shottki’s gate.

The purpose of this work is use of field-effect transistor for synthesis of high-Q analogues of the inductor and active microwave filters based on it.

II. MICROWAVE ACTIVE FILTERS MODELLING AND RESEARCH

To research FET as GIC we must use small-signal equivalent circuit of field effect transistor. The common direct extraction procedure of small-signal equivalent circuit parameter should lead to frequency-independent values. With increasing frequency, however, often a decreasing real part of the output admittance $Y_{ds}$ is obtained and may become negative. The effect can be explained by stationary Gunn domain. It is nucleating at the drain side of the gate when the maximum electric field exceeds the threshold value for the negative differential mobility in GaAs. Authors in [3] suggest an extended equivalent circuit with negative resistance in the output part. This modification improves model accuracy over the entire range of operation conditions.

Using this small-signal equivalent circuit (Fig. [1]) was modeling dependence invariant stability factor over frequency of a signal for common source, common drain and common gate schemes has been lead. The analysis of results has shown, that the widest area of potential unstable stability have common drain and common gate schemes. This defines expediency of
use these schemes as GIC at creation of microwave active filters possess. The common-drain circuit is the immitance converter. This means that inclusion on the scheme’s input terminal of the inductor (Fig. 2(a)) allow realize on an scheme’s output inductive resistance with negative active component. At inclusion on the scheme’s input terminal resistor (Fig. 2(b)), on output of the scheme we receive inductive element with positive ohmic resistance. Q-factor of such inductor will be $Q \approx 1$. Cascade interconnection of two common-drain field-effect transistors with inclusion on an input terminal of the resistor (Fig. 5), will allow to realize on the output of the scheme inductor-less high-Q analogue of the inductor. Use of such scheme allows realizing active microwave filters without inductors. The analysis of modeling results shows, that common drain scheme with the inductor on an input terminal allows to realize the inductive element with negative output impedance up to $-400$ Ohm on frequency 12 Ghz (see Fig. 3). Common drain scheme with the ohmic resistance included on an input terminal allows to realize analogue low-Q ($Q \approx 1$) inductivity with resistance $R \approx X = 200$ Ohm on the frequency 5 Ghz (see Fig. 4).

Cascade inclusion of these two schemes allow to realize transistor analogue of the high-Q inductor-less element that allows to manufacture it as monolithic microcircuit. This scheme allow realized in a frequency band 10–16 Ghz possesses inductive $X = 500$ Ohm and negative $R = -120$ Ohm differential resistance (see Fig. 5).

Using this schemes of inductor were development active band-pass and stop-band microwave filters, suitable to manu-

![Fig. 1. Small-signal FET equivalent circuit](image1)

![Fig. 2. Shema of active microwave inductor with low-Q coil (a) and with inductor-less active inductor (b)](image2)

![Fig. 3. Output impedance of active inductor with low-Q coil](image3)

![Fig. 4. Output impedance of low-Q inductor-less active inductor](image4)

![Fig. 5. High-Q inductor-less active inductor](image5)

![Fig. 6. Output impedance of high-Q inductor-less active inductor](image6)
Facture as a hybrid or the monolithic microcircuit.

Example in which the principle of transformation low-Q inductors in active high-Q inductor is realized was band-pass and stop-band filters schemes (Fig. 7, 8, 9, 10). In these filters as the inductive element using microstrip inductor with Q-factor less then 10 units. Results of modelling (see Fig. 11, 12, 13, 14) using such low-Q inductor with GIC allow to realize high signal rejection outside passband (−40 dB and −60 dB accordingly for band-pass filter) and a small signal amplification in a passband (+3 dB) on the frequency $f = 10 \text{ Ghz}$. For single-resonator stop-band filter signal rejection was −42 dB, for two-resonator −73 dB. These filters are designed for realization as a hybrid microcircuit.

Fig. 7. One-pole bandpass active filter with low-Q inductor

Fig. 8. Two-pole bandpass active filter with low-Q inductor

Fig. 9. One-pole bandstop active filter with low-Q inductor

Use of the inductor-less active inductor (see Fig. 5) allows to construct active bandpass (Fig. 15, 16) and bandstop filter (Fig. 17, 18) with following parameters: for single-resonator band-pass filter (Fig. 19) signal attenuation outside a passband −30 dB; for two-resonator band-pass filter (Fig. 20) signal attenuation outside a passband −60 dB; for single-resonator stop-band filter signal signal attenuation −24 dB; for two-resonator stop-band filter (Fig. 21) −47 dB. The analysis

Fig. 10. Two-pole bandstop active filter with low-Q inductor

Fig. 11. Simulation results of one-pole bandpass active filter with low-Q inductor

Fig. 12. Simulation results of two-pole bandpass active filter with low-Q inductor

Fig. 13. Simulation results of one-pole bandstop active filter with low-Q inductor
of results enables to approve about perspectivity of developing inductor-less active inductors analogues and an opportunity of realization on it of active microwave filters as hybrid, and monolithic microcircuits of a large-scale integration.

### III. Dual-Gate FET Active Filter

Using dual-gate FET allow realize two-resonator active filter on the single chip. This allow to get better temperature stability, decrease consumed power and size. This filter consist of two equivalent circuit: common drain circuit with included on an input terminal inductor element and common source circuit with included inductor between gate and drain. As a dual-gate FET can be represent as connection of two single-gate FET with couple first FET drain and second FET source. There is a manufactured dual-gate FET with addition noise-suppressing terminal, connected to the point of couple first
FET drain and second FET source. Shematic and result of simulation of such filter are shown on Fig. 22 and Fig. 23.

The analysis of results shown that such filter can reduce

\[ C_1 \ C_2 \ C_3 \ L_1 \ L_2 \ C_4 \ C_5 \ PORTZ=50 \text{ Ohm} \]
\[ PORTP=2Z=50 \text{ Ohm} \]

Fig. 22. Two-pole bandpass dual-gate inductor-less active filter (without bias circuit)

![Two-pole bandpass dual-gate inductor-less active filter](image)

For two-pole band-pass dual-gate FET active filter signal attenuation outside a passband \(-60\) dB, and a small signal amplification in a passband (+3 dB) on the frequency \(f = 2.8\) Ghz.

Fig. 23. Simulation results of two-pole bandpass dual-gate inductor-less active filter

![Simulation results](image)

geometrical size of hybrid IC.

IV. Conclusion

Experimental researches of schemes of FET inclusion by criterion of stability have allowed choosing the common-drain circuit as base scheme GIC for active microwave filters, as the most high-frequency and possessing properties of the immitance converter.

Modelling of output impedance for the common-drain circuit with included on an input terminal inductor element and ohmic resistance has enabled to realize high-Q \(Q \gg 1\) and low-Q \(Q \approx 1\) inductor analogues. Result of synthesis of these schemes became analogue of high-Q active inductivity without inductive elements.

Carried out research of the generalized immitance converter based on the field-effect transistor has allowed to realize based on the common-drain GIC schemes of band-pass and stop-band active microwave filters suitable for manufacture as a hybrid or monolithic microcircuits. As a result of modelling following parameters are received:

- For filters with inductive elements - for single-resonator band-pass filter signal attenuation outside a passband \(-40\) dB; for two-resonator band-pass filter signal attenuation outside a passband \(-60\) dB; for single-resonator stop-band filter signal attenuation was \(-42\) dB, for two-resonator stop-band filter \(-73\) dB;
- For inductor-less filters - for single-resonator band-pass filter signal attenuation outside a passband \(-30\) dB; for two-resonator band-pass filter signal attenuation outside a passband \(-60\) dB; for single-resonator stop-band filter signal attenuation \(-24\) dB; for two-resonator stop-band filter \(-47\) dB.

REFERENCES

