UHF SiGe HBT AMPLIFIER: PARAMETERS AND NOISE CHARACTERISTICS

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This work presents a description of CAD using Harmonica v.8 of UHF two-stage amplifier consisting SiGe transistor type BFP640. High values of S_{21} (28dB), regime stability and low noise factor (NF=1.6-1.9 dB) are reached. The frequency dependencies of S_{11}, S_{12}, S_{21} and S_{22} of the amplifier are presented in graphic forms.

1. THEORETICAL SECTION

One of the first requirements in any amplifier design is to choose the transistor, which is best, suited for the job. Two of the most important considerations, in choosing a transistor for use in any amplifier design are its stability and its maximum available gain (MAG). Stability is a measure of the transistor's tendency toward oscillation.

MAG is a type of figure-of-merit for the transistor, which indicates the maximum theoretical power gain we can expect to obtain from the device when it is conjugate matched to its source and load impedance. The MAG is never actually reached in practice; nevertheless, it is quite useful in gauging the capabilities of a transistor.

RF transistor's characteristics can be completely characterized by their s-parameters. With these parameters, it is possible to calculate potential instabilities, maximum available gain, input and output impedances, and transducer gain. It is also possible to calculate optimum source and load impedances for simultaneous conjugate matching.

S-parameters vary with frequency and bias level. Therefore, we must first choose a transistor, select a stable operating point, and determine its s-parameters at that operating point.

1.1. Stability

To calculate the stability of a transistor with s-parameters, we must first calculate the intermediate quantity Ds:

$$D_S = S_{11}.\ S_{22} - S_{12}.\ S_{21} \quad (1)$$

The Rollett stability factor (K) is then calculated as:

$$K = (1+|\ D_S|^2 - |\ S_{11}|^2 - |\ S_{22}|^2) / (2|\ S_{21}|.\ |\ S_{12}|) \quad (2)$$

If K>1, then the device will be unconditionally stable for any combination of source and load impedance.

If K<1, the device is potentially unstable and will most likely oscillate with certain combinations of source and load impedance.

We must be extremely careful in choosing source and load impedance for the transistor. It does not mean that the transistor cannot be used for our application; it merely indicates that the transistor will be more difficult to use.

1.2. MAG

The maximum gain we could ever hope to achieve from a transistor under conjugate matched conditions is called the maximum available gain.

$$MAG = 10 \lg (|S_{21}| / | S_{12} |) + 10 \lg | K \pm SQRT(K^2 - 1)|, \quad (3)$$

where the sign before the radical determines from the sign of B_1" intermediate quantity": $B_1 = 1 + | S_{11}|^2 - | S_{22} |^2 -| D_S |^2$ (4)

K-is the stability factor calculated using equation (2).

Note that K must be greater than 1(unconditionally stable) or equation (2) will be undefined. That is, for K<1 the radical in the equation will produce an imaginary number and the MAG calculation is no longer valid.

1.3. Design procedures

Once a suitable transistor has been found, and its gain capabilities have been found to match our requirements, we can proceed with the design.

The following design procedures will result in load and source reflection coefficients, which will provide a conjugate match for the actual output and input impedances, respectively, of the transistor.

a) The magnitude of the reflection coefficient is found from the equation:

$$| \Gamma_L| = B_2 \pm SQRT (B_2^2 - 4 | C_2|^2) / 2 | C_2 |, \text{ where:} \quad (5)$$

$$B_2 = 1 + | S_{22} |^2 - | S_{11}|^2 -| D_S |^2 \quad (6)$$

$$C_2 = S_{22} + (D_S. S_{11}^*) \quad (7)$$

The asterisk indicates the complex conjugate of S_{11}.the sign preceding the radical ist he opposite of the sign of B_2.The angle of the load reflection coefficient is simply the negative of the angle of C_2.

b) Load impedance Z_L calculated from : $\Gamma_L = (Z_L - Z_O) / (Z_L + Z_O)$ (8)

c) With the desired load-reflection coefficient specified, we can now calculate the source-reflection coefficient that is needed to properly terminate the transistor's input: $\Gamma_S = [(S_{11} + S_{12}. S_{21}. \Gamma_L) / (1 - \Gamma_L .| S_{22})]^*$ (9)

The asterisk again indicates that we should take the conjugate of the quantity inbrackets.

d) Input matching network with series and shunt component:

-Series C-component: $C = 1/ (\omega. X.N)$ (10)

Where: $\omega = 2\pi f$; X=the reactance as read from the chart; N=the number used tonormalize the original impedances that are to be matched.

-Series L-component: $L = X.N / \omega$ (11)

-Shunt C-component: $C = B/ (\omega. N)$ (12)

Where B=the susceptance as read from the chart.

-Shunt L-component: $L = N / (\omega. B)$ (13)

e) The transducer gain is the actual gain of an amplifier stage including the effects of input and output matching and device gain

$G_T = [|S_{12}|^2 . (1- | \Gamma_S |^2 . (1-| \Gamma_L |^2] / |1- S_{11} . \Gamma_S). (1- S_{22} . \Gamma_L) - S_{12} S_{21} \Gamma_L \Gamma_S |^2$ (14)

Calculation of G_T is a useful method of checking the power gain of an amplifier. Notice, that the transducer gain calculates to be very close to the MAG.

2. EXPEREMENTAL SECTION:

Let's try to design a wideband amplifier (WB amp.) (4,6) With 50 ÷ 60 mW power, working in 0,5 ÷ 3 GHz frequency range with gain G_T >24 dB and noise figure NF < 2,5 dB.

First we chose a transistor, which will meet these requirements. We direct our attention to a transistor of the Infineon Tech® Firm (Siemens Department on RF discrete devices and Integrated Circuits), according to the firm's catalog data (7), there is a good deal of information about ultra high frequencies (UHF) and noise characteristics of the transistors and the devices themselves differ little one from another in relation to DC parameters and, which is very important on AC parameters. We chose a two-stage amplifier's construction. The simulation of the abovementioned (WB amp) in frequency band dc ÷ 5 GHz is performed by Serenada version8 software, which is considered for the design of RF (radio frequency) amplifiers.

For the needs of the WB amplifier we chose BFP 520 type transistor with plastic case SOT 343 designed for amplifiers with high amplification and low noise (NF = 0,95 dB at f =1,86 GHz, Ic / Uce = 2 mA/2v. Main DC parameters as follows: U_{CEO} = 2,5 ÷ 3,5 v, U_{CBO} = 10 ÷ 11 v, h_{FE} = 70 ÷ 200. AC parameters, as follows: f_T = 45 GHz, C_{CB} (C_{TC}) = 60 fF, $|s_{21}|^2$ = 21 dB at $Z_S = Z_L$ = 50 Ω. The values of S_{11},S_{22} , S_{12},$S_{21}$are shown at - common emitters connecting scheme for frequency range0,01 ÷ 6 GHz. Data are presented for noise parameters –scheme common-emitter, as follows: NFmin , G_a , Γ_{Sopt}, R_N [Ω]; $F_{50\Omega}$, $| S_{21}|^2$ at $Z_S = Z_L$ = 50Ω. Frequency amplifying dependence is the following:

f [GHz]	1	2	3	4	5
G [dB]	26	20.5	17.5	15	13

Increasing the frequency f in the range 1 ÷ 5 GHz, the power gain linearly decreases with the frequency. G as a function of Ic increases in the range Ic = 2 ÷ 10mA, and after that remains almost constant. G = f (U_{CE}): the gain increases when U_{CE} rises up to1.5 v, after that remains constant. NF frequency dependence is:

f [GHz]	1	1.5	2	3	4
NF[dB]	0.85	1	1.15	1.3	1.42

The electric scheme of the WB amplifier with its input and output matching and converging calculated elements (the so-called ideal amplifier) is shown on Fig. 1.

The frequency dependence of the Rolett stability coefficient "K" and the coefficient "B" (unconditionally stable amplifier is that with K > 1 and potentially unstable is that with K<1, B>0) is shown on Fig.2.

It is seen that K>1 at f ≤ 4,4 GHz, as at f > 0,4 GHz "K" linearly decreases with the frequency, B>0 for the whole frequency range.

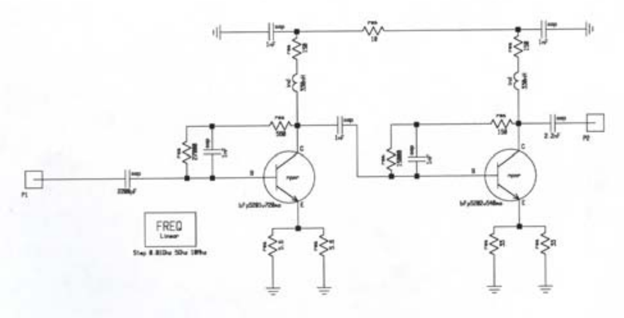

Fig.1

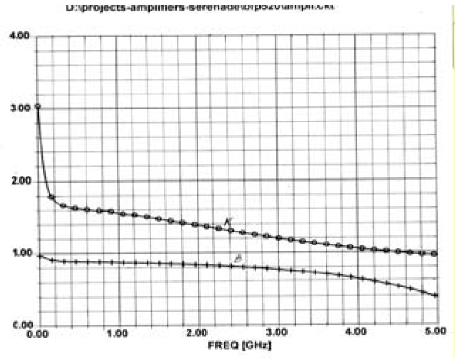

Fig.2

On Fig.3 is shown the frequency dependence of s-parameters for the ideal amplifier.

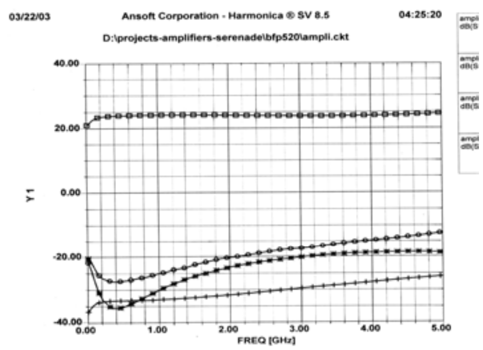

Fig.3

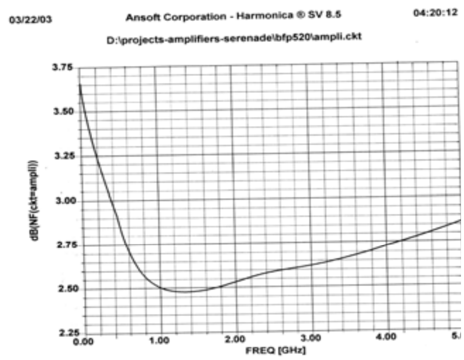

Fig.4

S_{21} at f>0,2 GHz is almost constant with value 24 ÷ 25 dB. S_{11} and S_{22} have well outlined minimums respectively –27 dB and –36 dB at f = 0,3 ÷ 0,6 GHz, after that S_{22} increases almost linearly in the frequency range up to 2 GHz and remains almost constant at f = 2 ÷ 5 GHz with value ≈ -20 dB. S_{11} monotonously increases in the frequency range 1 ÷ 5 GHz; while at 1 ÷ 4 GHz it changes from –25 dB to –15 dB.

S_{12} slightly increases in the range 1,4 ÷ 3,6 GHz it changes with 15 % (from –33 dB to –28 dB).

The frequency dependence of NF of the amplifier is shown on Fig.4 In the frequency range 0,8 ÷ 3,6 GHz, NF changes from 2,57 dB to 2,68 dB with minimum 2,47 dB at f = 1,2 ÷ 1,6 GHz.

The frequency dependence of S-parameters of the real WB amplifier is shown on Fig.5.

In comparison with Fig.3 (frequency dependence of the same parameters for the ideal amplifier), we can see the following:

-As a result of multiple optimization is compensated to a certain extent the continuous increase of S_{11} and S_{22} - S_{22} remains almost constant (-20 ÷ -25 dB) in frequency range 1,4 ÷ 3,8 GHz, while at 3 ÷ 4 GHz even a slight decrease is seen. S_{11} at 1<f<4 GHz decreases its value from –21 dB to –37 dB.

- S_{12} corresponds by value to the reverse amplification of the ideal WB amplifier.

The frequency dependence of NF on Fig.6 is very disagreeable.

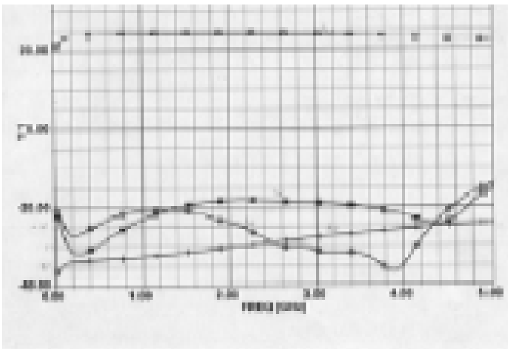

Fig.5

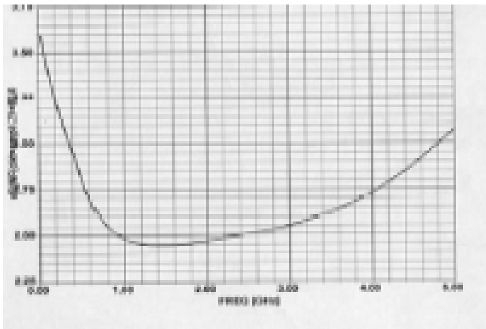

Fig.6

NF<2,6 dB at 0,8 < f <3 GHz. At f > 3 GHz, a great increase of the noise level is observed, which to a great extent worsens the amplifier's efficiency. There are two reasons for that: transistors operate at $I_C >> I_{Copt}$ (20 mA and 40 mA, instead of 3 ÷ 5 mA) and great frequency dependence of NF, see the above mentioned catalog data for BFP 520 transistor).

The conclusion is that when BFP 520 transistor is used, the problems to be solved with WB amplifier are two, as follows:

-NF as a whole has high level (min value 2,4 ÷ 2,47 dB), while the value of noise factor at f>3 GHz makes disputable the amplifier's usage; the reason, as it was indicated is the working point of the transistors, which is far away from the optimal one and the strong frequency dependence of NF of the transistor;

-Comparatively low S_{21} (24÷24,5) dB.

The amplifier can operate in the frequency range 0,8 ÷ 3 GHz, while with optimization of NF – possibly from 0,4 up to 3 GHz.

The above mentioned problems are eliminated changing of BFP 520 - transistor with BFP 640 - transistor. BFP 640 - transistor with SiGe base, designed for low noise UHF amplifiers: f_T = 70 GHz, NF = 0,65 dB $|_{f=1,86\ GHz}$, NF = 1,3 dB $|_{f=6\ GHz}$, I_C/U_{CE} = 2,5 mA/ 2v.

The frequency dependence of s- parameters of the real WB amplifier with RF transistor type BFP 640 is shown on Fig.7.

It is seen the following:

a) S_{21} has a high value 27 – 29 dB, almost unchanged in the frequency range 0,2 - 5GHz.

b) $S_{11}$is constant in the range 0,2 ÷ 4 GHz with value - 16 ÷ -17 dB, after which it decreases up to –28 dB at f>4 GHz. S_{22}has minimum value at f=0,2 GHz (-34 dB) and f=4,2 GHz (-25 dB) and is with almost constant value (-17 ÷ - 20 dB) in the range 1 ÷ 3,6 GHz.

c) S_{12} monotonously increases in value in the whole frequency range –37 ÷ -29 dB.

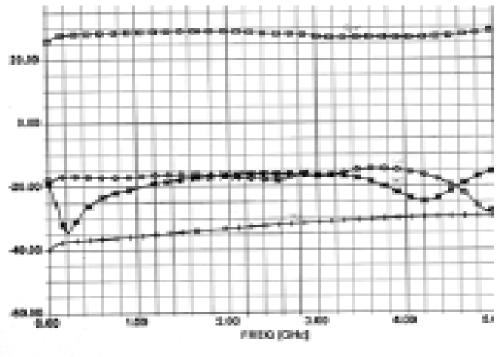

Fig.7

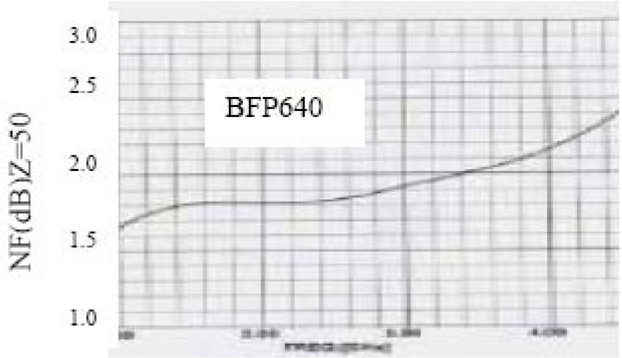

Fig.8

It is seen on Fig.7 that one of the aims S_{21} improvement is achieved.

On Fig.8 is shown the relation NF=f (f) for the real WB amplifier with transistor type BFP 640. It is seen that in frequency range up to 4 GHz, NF <2,15 dB. In the frequency range 1 ÷ 3 GHz, NF≈constant (1,65 ÷ 1,9 dB); NF $|_{5GHz}$ = 2,7 dB (against 3,15 dB for WB amplifier with transistor type BFP 520) , provided the working point of Tr2 transistor is 40 mA/2v at optimal value of Ic=2 ÷3 mA. In the frequency range 0,8 ÷ 5 GHz NF vary according to the following equation $NF = 1,66 + 0,52 \ln f – 1,07 (\ln f)^2$ at $r^2 = 0,9998$.

The WB amplifier with heterojunction bipolar transistor HBT with SiGe base type BFP 640 can be used effectively in the frequency range 0,4 ÷ 4 GHz with possible optimization aiming the decrease of S_{11} and S_{22}.

3. CONCLUSIONS:

1. Methods are described for defining UHF parameters of low-signal RF amplifier (operation stability, maximum available gain (MAG), G, conjugated matching towards source and load etc.), using scattering parameters (s-parameters) of UHF transistor.

2. The particular design characteristics of RF amplifiers with low noise level are described.

3. The characteristics of the two-stage wideband amplifier that is designed by the help of Serenada version8 software are shown. Special attention is paid to the stable operation of the amplifier, the high power gain and low noise level in wide frequency range.

4. REFERENCES

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