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## NOISINESS OF THE VIDEO AMPLIFIER MADE BY THE CASCODE CIRCUIT WITH DYNAMIC LOAD

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*Relative influence of active elements on noises of video amplifier cascode circuit at resistive loading and at use of an active element as the cascade dynamic load has been considered. The conclusion is drawn that in both cases the second transistor of the cascode circuit contributes insignificantly into amplifier noises in comparison with the first one. The contribution of active element noises of dynamic load exceeds considerably the contribution of traditional resistive loading of the cascade and doubles practically in capacity the noises conditioned by the first active element.*

Cascode circuit (cascode) was proposed, in due time, in video amplifiers on vacuum electron valves for decreasing the influence of transfer capacitance and increasing amplifier stability connected with it. It represents an amplifying stage where two triodes are connected in series instead of one. The first one is with a common cathode and another is a grounded-grid one. Owing to the fact that the cathode circuit of the second valve is the load of the first one in anode, the signal voltage, as it is known, is only inverted (at similar amplifying elements) and, therefore, the transfer capacitance is only doubled in composition of aggregate equivalent input capacitance of the amplifier while in a general circuit with common cathode it increases in  $(K_u+1)$  times where  $K_u$  is the voltage gain of the first triode.

The cascode circuit is widely used in transistor circuits – both bipolar and field-effect ones [1, 2].

In video amplifiers of TV cameras made on vacuum pickup tubes which are still irreplaceable in some con-

ditions, in input stages the field-effect transistors with a control  $p-n$ -junction are applied as the best ones by noisiness and radiation resistance.

Each time at constructing the unique camera video amplifiers, the question on the influence of the second transistor (a common-gate one) on noises occurs; and applying another transistor as the cascade dynamic load the question on its noise contribution occurs. The information for concrete situations may be found in scientific sources but there is no a cogent fundamental answer for a common case: in spite of the apparent simplicity of a research circuit the analysis is not simple at all.

The aim of the given work is to estimate the relative influence of amplifying elements on the amplifier noises. Therefore, the other amplifier noise sources are not considered.

The first cascade of the video amplifier is often performed by the cascode circuit. Such circuit operation for the case of its performance from the signal current

source with output capacitance (pickup tube) in a frequency band about 10 MHz subject to implementation of a simple noise-balancing correction in video amplifier is considered. This correction consists in increase of active resistance of input circuit and further correction of frequency distortions connected with it.

The cascode circuit with input circuit of video amplifier and a certain schematic dynamic analogue of it are introduced in Fig. 1. The circuit is presented by transistor elements: stray capacitance (input and transfer)  $C_{11}, C_{12}$  and control current source  $SU$ , principle for our case. The signal source – the signal current generator  $i_c$  and the equivalent complex resistance  $Z_C$  in which the bias circuit resistances may be taken into account. The resistance of cascode load –  $R_H$ .  $U_{BblX}$  is the output voltage.  $E$  and  $E_{CM}$  are the supply and bias voltages. Internal resistances of source-sink transistors ( $R_i$ ) are neglected.

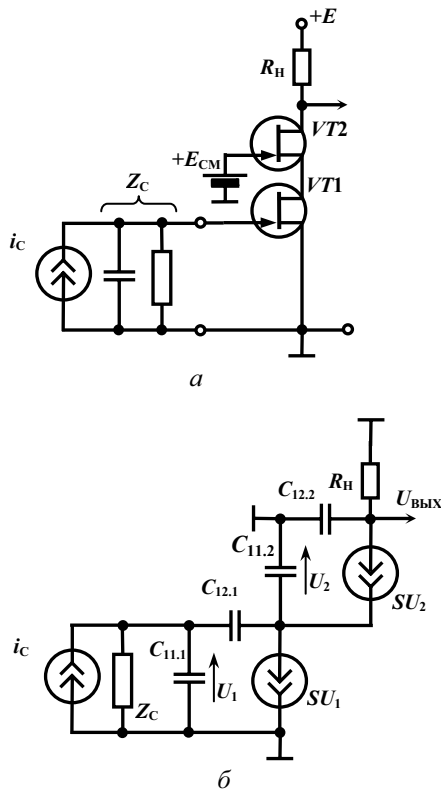


Fig. 1. Cascode gain circuit: a) the basic diagram; b) its equivalent

After a certain ranking the equivalent circuit may be introduced by the Fig. 2 where the sources of the main noises of the field-effect transistors (thermal noises of transistor channel)  $i_{III1}$  connected in parallel to the areas source-sink and load thermal noises  $i_{IIIH}$  are shown as well.

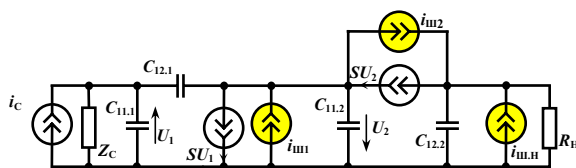


Fig. 2. Noise equivalent circuit of the cascode

The circuit may be more simplified taking into account the fact that for the second amplifying element the first one may be introduced by its equivalent output resistance and noise source. Neglecting the «lost» signal source the element noises may be correlated to each other. The circuit in this case may be introduced by the Fig. 3. The notations occur, in this case:

$$Z_{||} = Z_{BblX.1} || x_{11.2} \text{ и } Z_H = R_H || x_{12.2},$$

where in general case  $x=1/j\omega C$  at compliance of indices of values  $x$  and  $C$ .

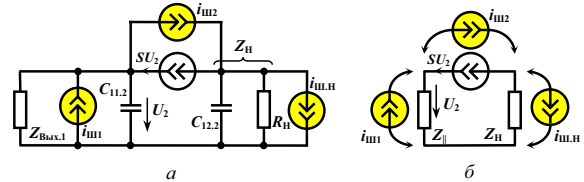


Fig. 3. The transformed cascode circuit: a) the first stage is introduced by the equivalent output resistance and noise source; b) the same circuit at joint resistance connected in parallel

In the Figure of the control current sources  $SU$  the arrow direction has a magnitude and connected with polarity of voltage sources  $U$ .

As a result of transformations (strict, without neglect) the scheme rather simple for analysis is obtained. In order to define the influence of the second transistor noises as well as the cascade load noises it is sufficient to estimate their contribution into ambiguous value of noise determined at the output of the circuit.

For the noises of the first cascode, the ratio

$$(i_{III1} - S_2 U_2) Z_{||} = U_2,$$

may be written down by a superposition principle from the Fig. 3; the input voltage of the upper transistor

$$U_2 = i_{III1} \frac{Z_{||}}{1 + S_2 Z_{||}},$$

is determined from it; whence it follows that the load voltage conditioned by the first transistor noises

$$U_{III1.BblX} = S_2 U_2 \cdot Z_H = i_{III1} S_2 \frac{Z_{||} Z_H}{1 + S_2 Z_{||}}.$$

With the help of the equation

$$(i_{III2} - S_2 U_2) Z_{||} = U_2$$

the output voltage of the second transistor noises may be found in the similar way.

$$U_{III2.BblX} = (i_{III2} - S_2 U_2) Z_H = i_{III2} \frac{Z_H}{1 + S_2 Z_{||}}.$$

The load noise voltage in the same point equals

$$U_{IIIH.BblX} = i_{IIIH} Z_H.$$

Hence, a general mean square value of noise voltage in elementary frequency band at the circuit output:

$$\begin{aligned} \sqrt{dU_{III.BblX}^2} &= \sqrt{\sum_i dU_{III.BblX}^2} = \\ &= \sqrt{\left( \frac{S_2 Z_H Z_{||}}{1 + S_2 Z_{||}} \right)^2 \left\{ di_{III1}^2 + di_{III2}^2 / (S_2 Z_{||})^2 + di_{IIIH}^2 \left( \frac{1 + S_2 Z_{||}}{S_2 Z_{||}} \right)^2 \right\}}. \end{aligned}$$

Not stopping at considering the output noise voltage the note should be taken to the fact that the current square magnitude reduced to the noise current of the first transistor taking into account all the examined noises is written down in curly brackets:

$$\overline{di_{\text{III}\ominus\text{KB}}^2} = \overline{di_{\text{III1}}^2} + \overline{di_{\text{III2}}^2} / (S_2 Z_{\parallel})^2 + \overline{di_{\text{IIIH}}^2} \left( \frac{1 + S_2 Z_{\parallel}}{S_2 Z_{\parallel}} \right)^2. \quad (1)$$

Taking into account the fact that the current square of the load thermal noises

$$\overline{di_{\text{IIIH}}^2} = 4kT \frac{1}{R_{\text{H}}} df$$

and the equivalent noise current of transistor [3]

$$\overline{di_{\text{IIIi}}^2} = S_i^2 \overline{de_i^2} = S_i^2 \cdot 4kT r_{\text{IIIi}} df,$$

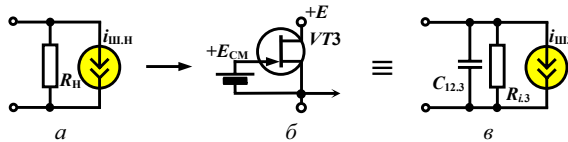
where  $k = 1,38 \text{ J/K}$  is the Boltzmann constant;  $T$  is the absolute temperature, K;  $r_{\text{IIIi}}$  is the equivalent resistance of the  $i$  field-effect transistor, it is not difficult to find the value of the equivalent resistance of noises of the examined circuit from (1)

$$r_{\text{III}\ominus\text{KB}} = r_{\text{III1}} + r_{\text{III2}} / (S_1 Z_{\parallel})^2 + \frac{1}{S_1^2 R_{\text{H}}} \left( \frac{1 + S_2 Z_{\parallel}}{S_2 Z_{\parallel}} \right)^2. \quad (2)$$

Thus, the second amplifying element may be introduced as a noiseless one relative to the noises and influence of its noises as well as the load noises of may be taken into consideration by a correction to the equivalent noise source of the first transistor or to its noise resistance.

Noise contribution can be easily estimated from the expressions (1) and (2). Taking into account the fact that  $Z_{\parallel}$  represents relatively high value (Appendix) the main conclusion may be drawn that the upper transistor of the cascode does not practically add any noise and the load noises introduce the same addition as in the circuit with a common source (fraction value in brackets (2) is close to a unit).

A transistor with gate-source poles, short-circuited by alternating current, is sometimes connected instead of the load resistor (Fig. 4): at the same voltage drop a higher dynamic resistance of the cascade load may be obtained from the power supply. It results in growth of the gain on center frequencies and required increase of depth of parallel negative feedback which is often applied in TV camera video amplifiers. Such dipole is called the dynamic load.



**Fig. 4.** Exchange of a load: a) resistive; b) dynamic; c) equivalent to dynamic

Changing  $R_{\text{H}}$  to  $R_{i,3} \parallel X_{12,3}$  (Fig. 4) the resistance  $R_{i,3} \parallel X_{12,2} \parallel X_{12,3}$  of the elements  $R_{i,3}$ ,  $C_{12,2}$  and  $C_{12,3}$  connected in parallel is connected instead of the resistance  $Z_{\text{H}}$  in Fig. 3.

Then it is not difficult to determine the value of the equivalent noise resistance for the cascode with the dynamic load from the Fig. 3, like the formula (2):

$$r_{\text{III}\ominus\text{KB}} = r_{\text{III1}} + r_{\text{III2}} / (S_1 Z_{\parallel})^2 + r_{\text{III3}} \left( \frac{S_3}{S_1} \right)^2 \left( \frac{1 + S_2 Z_{\parallel}}{S_2 Z_{\parallel}} \right)^2, \quad (3)$$

where index 3 indicates the relation to the third transistor.

The expression (3) shows clearly the noise contributions of all amplifying elements. Nothing has changed for the second transistor noises. The third transistor noises turn out to be significant. For example, at the same parameters of all three transistors, noise resistance of the third transistor is added, at the best, one-to-one to the noise resistance of the first one. The addition depends on the ratio of values  $S_1$  and  $S_3$ .

It should be also noted that the dynamic load noises contributes more in comparison with the resistor applied as a load [compare (2) and (3)]. The latter covers equally the cascode and general common-source circuit.

The examined circuit was simulated in Electronic Workbench medium.

As it was supposed the neglect of inner resistance of transistors  $R_i$  does not qualitatively change the results of investigation as in the first cascade the resistance  $R_i$  is bridged by low input resistance of a part of a diagram loading it (equal approximately  $1/S$ ), and in the second one – the load resistance.

So, even accepting the value of inner resistance  $R_i = 1 \text{ kOhm}$  connected in parallel to the control current sources  $S_i U_i$  in circuits of both transistors in the equivalent circuit we obtain the change of the transfer constant from the equivalent current noises  $i_{\text{III1}}$  and  $i_{\text{III2}}$  at the output of the circuit from 13,5 to 6,5, at the value of the parameters:  $C_c = 10 \text{ pF}$ ,  $S = 10 \text{ mA/V}$ ,  $C_{11} = 5 \text{ pF}$ ,  $C_{12} = 1 \text{ pF}$  (typical for transistor KP341),  $R_{\text{H}} = 1 \text{ kOhm}$  on frequencies to 10 MHz, i.e. the contribution of the noise source of the second active element  $i_{\text{III2}}$  into output voltage is rather lower in comparison with the source  $i_{\text{III1}}$ .

All the ratios are valid for the electron tubes. Noises of bipolar transistors require additional examination as their main noises are introduced by two sources, in base and collector circuits.

Finally, the analysis (4) and simulation show that all the ratios of active element contribution into the amplifier noises remain valid at low resistances of signal source (50 Ohm).

**Appendix.** Output resistance of the cascode bottom step by the Fig. 1.

In order to find out the output resistance, it is more suitable to connect a test generator of alternating current  $I$  at the output of the concerned part of the circuit (Fig. 5), find the response voltage and determine the required resistance by the Ohm law.

Using the superposition principle the apparent equation system

$$\begin{cases} U_{\text{BHX},1} = (I_0 - S_1 U_1)(X_{12,1} + Z_{\text{BX},\Sigma}), \\ U_1 = (I_0 - S_1 U_1)Z_{\text{BX},\Sigma}, \end{cases}$$

may be written down following the Fig. 5, whence the value

$$Z_{\text{BbX},1} = U_{\text{BbX},1} / I_0 = \frac{X_{12,1} + Z_{\text{BbX},\Sigma}}{1 + S_1 Z_{\text{BbX},\Sigma}}, \quad (4)$$

is determined, where  $Z_{\text{BbX},\Sigma} = Z_C \parallel X_{11,1}$  (Fig. 5).

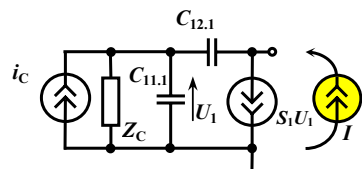


Fig. 5. The part of the circuit of amplifier loaded by the second cascode step

The value  $Z_{\text{BbX},1}$  may be judge by (4). At high frequencies when  $Z_{\text{BbX},\Sigma}$  decreases greatly,  $Z_{\text{BbX},1}$  is comparatively high, about  $|X_{12,1}|$ . At low frequencies, it equals approximately  $(1/S_1)(X_{12,1}/Z_{\text{BbX},\Sigma})$ .

In the circuit in Fig. 3 the resistance of the elements connected in parallel denoted by  $Z_{\text{BbX},1}$  and  $C_{11,2}$  having

rather high resistances is indicated by the variable  $Z_l$ . Bridging the output resistance by the capacitance  $C_{11,2}$  makes no difference. Value  $Z_l$  remains of the same order that  $Z_{\text{BbX},1}$ . Product  $S_2 Z_l$ , met in formulas (2) and (3), is much more than a unit while  $S_2 X_{12,1} \gg 1$ , i.e. while frequency  $f \ll S_2 / 2\pi C_{12,1}$ . So, applying the field-effect transistors of the type KP341 this product can not be less than the ratio  $C_{11}/C_{12}$ , which equals approximately five.

**Summary.** The relative influence of active elements on noises of video amplifier cascode circuit at resistive load and application of active element of as the cascode dynamic load was considered. It was shown that in both cases the second transistor of the cascode circuit contributes insignificantly into the amplifier noises in comparison with the first one (<10 %). Contribution of noises of the dynamic load active element exceeds considerably the contribution of the traditional cascode resistive load and doubles practically in power the noises conditioned by the first active element at uniformity of all three active elements.

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### ACTIVE FREQUENCY-DIVIDING FILTERS

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The method of synthesis of analog frequency-dividing devices on the basis of wave filters has been offered. Various variants of configurations of such filters are considered. It is shown that frequency-dividing filters synthesized according to the offered method, have the minimal order.

Processing and transmitting signals the necessity of using the frequency dividing devices intended for dividing signal spectrum into nonoverlapping parts often occurs. Such devices are called directional filters or multiplexers [1, 2]. The questions of directional filter application in radio systems and devices are examined in detail in monograph [1].

A particular case of multiplexer is two-channel frequency-dividing devices – diplexer. Diplexer implements two transfer functions meeting the condition

$$|H_1(j\omega)|^2 + |H_2(j\omega)|^2 \leq 1.$$

Diplexers are the basic elements at construction of frequency-dividing devices with any amount of channels.

A significant number of works where various aspects of theory and design of the directional filters are discussed indicates the importance of the problems of their synthesis [1, 3–8]. The work [7], where the general technique of calculating the transfer functions of the directional filters with maximum flat gain-frequency characteristics (GFC) and controlled attenuation at frequency of GFC junction is considered, should be especially noted. The question of branching filter implementation on the basis of parallel or series connection of passive LC filters realizing separate transfer functions are examined in [4–6]. Such approach is not optimal as each transfer function is implemented by a certain filter and realizing circuit has a high order. The technique of synthesizing diplexer in the form of reactive six-pole is