ANALOG SWITCH FOR VIDEO SIGNALS

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Abstract

The paper is devoted to the development of the analog electronic switch for video signals. The simple linear equivalent diagram of the integrated circuit CMOS 4066 on the basis of measurements its transfer characteristics was designed. Consequently the connection of the double switch was designed and experimentally verified. Its properties (parameters) (especially the attenuation in the transmission and suppressed band, non-linear distortion, frequency band etc.) are quite suitable for video signals processing.

Keywords

switching, analog electronic switch, linear model, video signal

1. Introduction

First-switch for analog video signals must have a small attenuation in the transmission band on the contrary large attenuation in the suppressed band, small non-linear distortion in wide frequency range (at least up to 10 MHz). It is possible to used this designed switching circuit for different applications in the video or measuring technique (for example in the cutting or connections units in TV studio etc.).

Required technical specifications:

attenuation in the transmission band	$b_{ON} \leq 0{,}5$ dB
attenuation in the suppressed band	$b_{OFF} \geq 26$ dB
frequency band	$B = 0 \div 10$ MHz
distortion of differential gain	$k_A \leq 5$ %
distortion of differential phase	$\Delta\varphi \leq 10°$
delay time in the face of a control signal U_C	t_{ON}, $t_{OFF} \leq 50$ ns
output resistance	$R_{out} = 75\ \Omega$

The cheap and usually accessible integrated CMOS circuit 4066 was selected for this purpose. This circuit contains four independent bilateral analog switches, every one has two input/output (Y,Z) and one control input (E) - see Fig. 1a.

2. Transfer Properties of the Switching Circuit CMOS 4066

The simple linear equivalent diagram of the one switch of integrated circuit 4066 was devised and values of all elements was determined so that its transfer characteristics are in accordance with the results of the measurements. Analysis was performed by means of the software Micro cap IV.

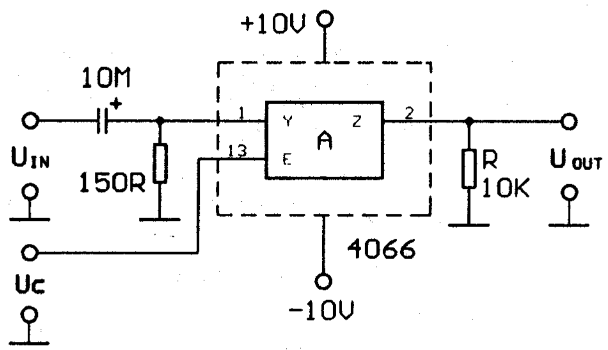
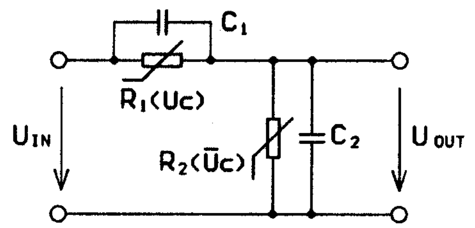


Fig.1 a) Schematic diagram of the one switch of the integrated circuit 4066



$R_{1\,ON} = 351\ \Omega$, $R_{2\,ON} = 1\ M\Omega$, $C_1 = 1.24$ pF
$R_{1\,OFF} = 10.6\ M\Omega$, $R_{2\,OFF} = 10\ K\Omega$, $C_2 = 18$ pF

b) Equivalent diagram of this switch

By measurements on the real switch was demonstrated, that the simple linear model, shown in Fig. 1b, can be used for signal levels up to 1,5 V (the DC-transfer characteristics in the transmission band showed the distortion of differential gain above 4%). The emitter follower was added after the switch to secure that the input capacities of measuring instruments did not influence results of measurements on high frequency. It is especially very important to acquirement required output resistance (75 Ω). The transfer characteristics of emitter follower don't practically influence properties of analog switch.

At Fig. 2 are shown transfer characteristics of circuit according to Fig. 1.

It is obvious, from transfer characteristics at Fig. 2, that the linear model corresponds with a reality well. The analog switch has not required attenuation in the suppressed band on high part of frequency band ($b_{OFF} \approx 24$ dB < 26 dB for $f = 10$ MHz).

The element values of linear model are written in Fig. 1b. They were calculated by [1], from values of voltage transfer real switch, measured on a few frequency points. These results are used for analysing double switch below.

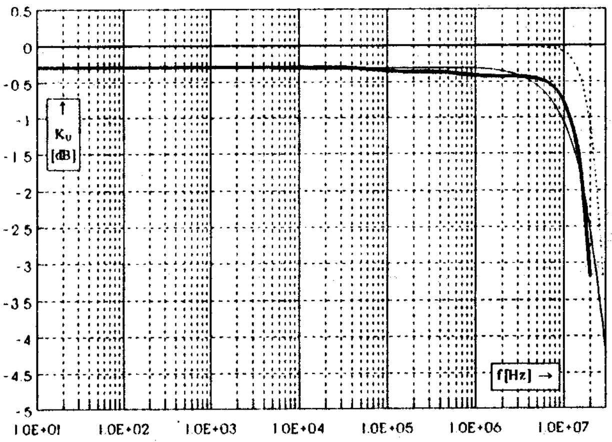
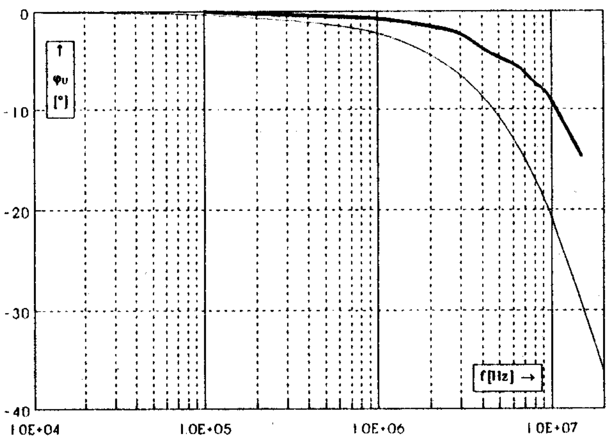
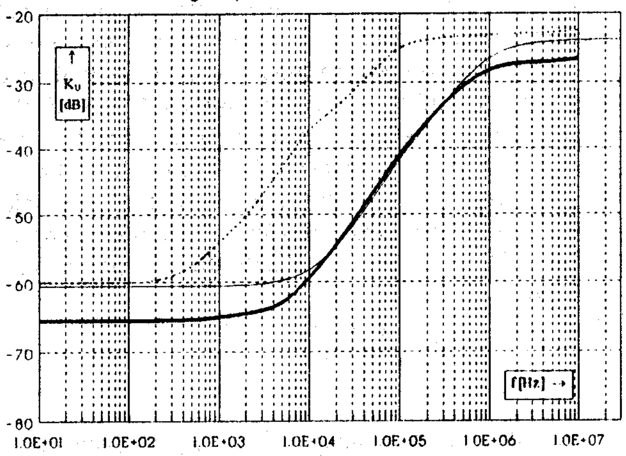


Fig.2 a) Amplitude-frequency characteristics of switch according to Fig. 1 in the switched-ON state
(—— theoretical characteristics of linear model according to Fig. 1b,
▬▬ measured characteristics of circuit according to Fig. 1a (R = 10 kΩ),
······ measured characteristics of circuit according to Fig. 1a (R → ∞))



b) Phase-frequency characteristics of switch according to Fig. 1 in the switched-ON state
(—— theoretical characteristics of linear model according to Fig. 1b,
▬▬ measured characteristics of circuit according to Fig. 1a)



c) Amplitude-frequency characteristics of switch according to Fig. 1 in the switched-OFF state
(—— theoretical characteristics of linear model according to Fig. 1b,
▬▬ measured characteristics of circuit according to Fig. 1a (R = 10 kΩ),
······ measured characteristics of circuit according to Fig. 1a (R → ∞))

The elements at linear model (Fig. 1b):

R_1 is transmission resistance of the analog switch in switched-ON state ($R_{1\,ON}$) or suppressed resistance of the analog switch in switched-OFF state ($R_{1\,OFF}$). R_2 is output resistance with respect to common clamp of the analog switch in switched-ON ($R_{2\,ON}$) or switched-OFF state ($R_{2\,OFF}$). C_1 and C_2 are spurious capacities of the analog switch.

Phase-frequency characteristic of circuit according to Fig. 1a in switched-ON state was not measured, because the output signal level was too small. This characteristic is not essential for evaluating function of analog switch. There are obvious influence of load resistance R = 10 kΩ connected at the output of the analog switch from Fig. 2. The distortion of differential gain and phase was determined from DC-transfer characteristics ($u_2 = F_1(u_1)$, $\Delta\varphi = F_2(u_1)$) of analog switch according to Fig. 1a, which was measured in range 0-1 V. This distortion of differential gain was calculated by expression:

$$k_A = \left(1 - \frac{\left(\frac{du_2}{du_1} \right)_{\min}}{\left(\frac{du_2}{du_1} \right)_{\max}} \right) \cdot 100 = 4{,}5\,\% \qquad (1)$$

and distortion of differential phase:

$$\Delta\varphi = \varphi_{\max} - \varphi_{\min} \approx 8^\circ \qquad (2)$$

Both values of the differential gains are in compliance with requirements of the assignment.

Function of the switching circuit CMOS 4066 was checked, without emitter follower on the output, by oscilloscope and pulse generator with output signal 500 kHz and mark-to-space ratio 1:1 in the time domain. The results of measured rise times were corrected to rise time of the generator ($t_r = 5$ ns) and rise time of the oscilloscope ($t_r = 3$ ns). The rise times after correction are $t_r = 17$ ns (for $R \rightarrow \infty$) and $t_r = 14$ ns (for $R = 10\ k\Omega$). These values are in relationship with the threshold frequencies of transfer characteristics of the analog switch in switched-ON state (see Fig. 2) according to approximate expression:

$$f_t = \frac{0{,}35}{t_r} \qquad (3)$$

The time delay of output signal u_2 was measured towards control signal U_C, which had a pulse wave with frequency 15 kHz and mark-to-space ratio 1:1. The input voltage $U_1 = 1$ V was constant during measurements. The analog switch was altered between switched-ON and switched-OFF state. The output signal u_2 of the analog switch was checked by oscilloscope and the time delay was measured at output signal level $u_2 = 0{,}5$ V by calibrated time base of the oscilloscope. The time delay of switching-ON Δt_{ON} and switching-OFF Δt_{OFF} measured on the analog switch, with $R \rightarrow \infty$, did not exceed 20 ns. This result suits to requirements of the assignment.

The time delay of signal pushing through the analog switch is maximal 20 ns.

The analog switch can be connected symmetrically into a circuit (then a symmetrical power supply is required) or non-symmetrically. For non-symmetrical connection is necessary to set a DC-bias of switched signal, which must fit into range defined by used power supply. This requirement can be fulfilled by connecting a input buffer amplifier in a common emitter circuit, which performs impedance matching of input of the analog switch.

3. Double Analog Switch

The transfer characteristics of the single analog switch 4066 according to Fig. 1 don't suit to requirements of the analog switch at OFF-state ($b_{OFF} < 26$ dB - see Fig. 2c), therefore was designed the double analog switch as connection of two single analog switches 4066 (Fig. 3).

The resistor R, which was used in single switch, was replaced by inversely controlled switch (next switch from the same package). This arrangement makes possible the increase of attenuation in switched-OFF state and also shorting the transient time from ON to OFF state (discharging the input capacitance of input emitter follower).

It is very important to keep DC operating conditions. When the double switch works in non-symmetrical operation, it is necessary to connect the second switch (switch D at Fig. 3a) between output of first switch (switch C at Fig. 3a) and the same DC level as those in the output of input buffer amplifier (instead to common connector - ground at Fig. 3a).

The control signal U_C is parameter for switching R_{A1} (and R_{B2}) and the inversion control signal $\overline{U}_C$ is parameter for switching R_{B1} (and R_{A2}).

The simplified linear model of double switch (see Fig. 3b) does not contain R_{A2} and R_{B2}, because they cannot influence properties of linear model at the next simulation.

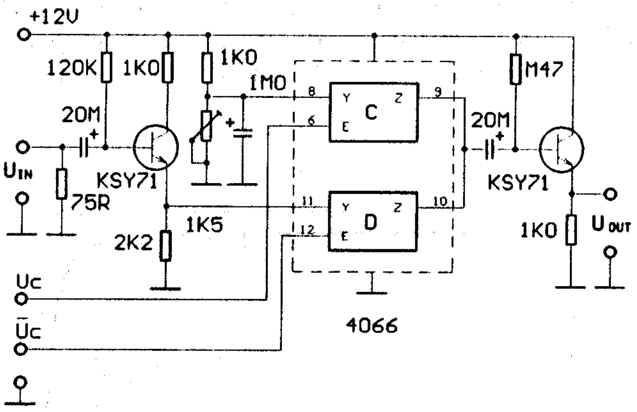
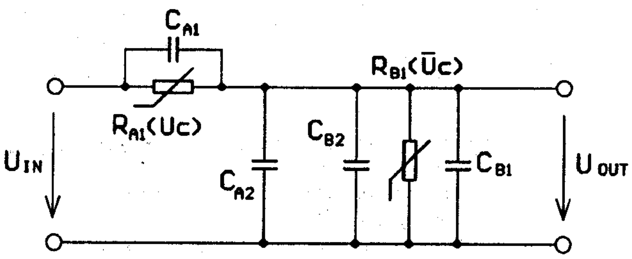


Fig.3 a) Double analog switch 4066 with input and output emitter follower



b) Simplified linear model of double analog switch (the values of components are same as at Fig. 1b)

Similar measurements was performed as on a single analog switch on a double analog switch. The results are at Fig. 4.

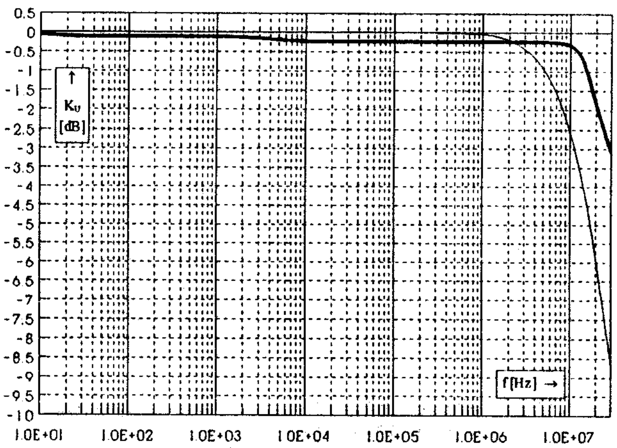
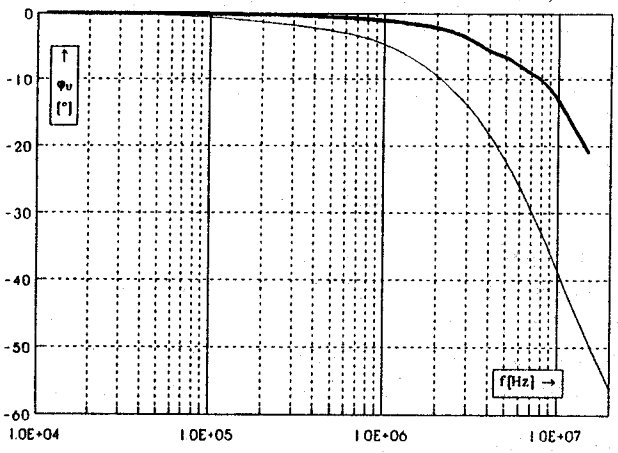
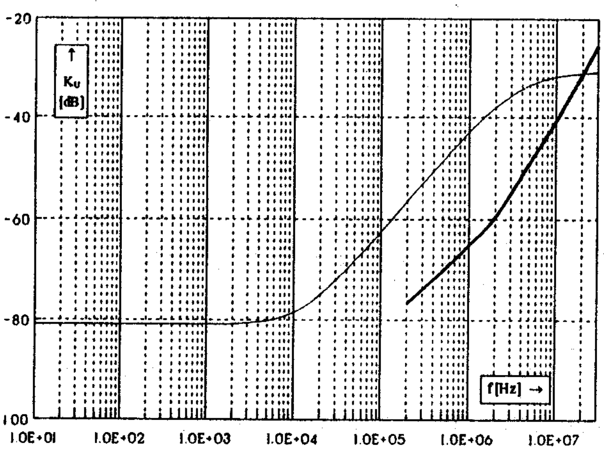


Fig.4 a) Amplitude-frequency characteristics of double switch according to Fig. 3 in the switched-ON state
(—— theoretical characteristics of linear model according to Fig. 3b,
▬▬ measured characteristics of circuit according to Fig. 3a)



b) Phase-frequency characteristics of double switch according to Fig. 3 in the switched-ON state
(—— theoretical characteristics of linear model according to Fig. 3b,
▬▬ measured characteristics of circuit according to Fig. 3a)



c) Amplitude-frequency characteristics of double switch according to Fig. 3 in the switched-OFF state
(—— theoretical characteristics of linear model according to Fig. 3b,
▬▬ measured characteristics of circuit according to Fig. 3a)

Theoretical properties of linear model of double switch according to Fig. 3b were determined by means of software Micro cap IV:

for $f \rightarrow 0$ Hz: $b_{ON} \approx 0$ dB, $b_{OFF} = 89{,}6$ dB

for $f = 10$ MHz: $b_{ON} = 2{,}4$ dB, $b_{OFF} = 33{,}6$ dB, $\varphi_{ON} = -38°$

At Fig. 4 are shown transfer characteristics of circuit according to Fig. 3a. Phase-frequency characteristics of circuit in switched-OFF state were not measured, so it is not essential for evaluating function of switch.

4. Conclusion

It was proved, that the double switch 4066, connected according to Fig. 3 (including input and output emitter follower), fulfils requirements of assignment from paragraph 1 in all parameters, by experimental verifying and determining in frequency and time domain. However, it was very important to keep totally synchronous switching control of both switches by control signal U_C and $\overline{U}_C$. This condition is able to ensure by controlling from direct and inverse output of the control logic circuits, which controls the double switch. However, it is necessary to perform arrangement of logic levels (TTL or CMOS) to reach suitable levels for controlling of the analog switch (it depended on used power supply).

From measured characteristics and results of measurement were determined the fundamental parameters of double switch according to Fig. 3a:

attenuation in the transmission band	$b_{ON} \leq 0{,}24$ dB
attenuation in the suppressed band	$b_{OFF} \geq 41$ dB
phase in range 10 Hz ÷ 10 MHz	$\varphi = 0 \div 13°$
frequency band	$B = 10 \div 30$ MHz
distortion of differential gain	$k_A \leq 4{,}5$ %
distortion of differential phase	$\Delta\varphi \leq 8°$
rise time of pulse	$t_{rise} \leq 20$ ns
delay time in the face of a control signal U_C	$t_{ON}, t_{OFF} \leq 20$ ns
delay time of signal goes through the switch	$t_{delay} \leq 20$ ns

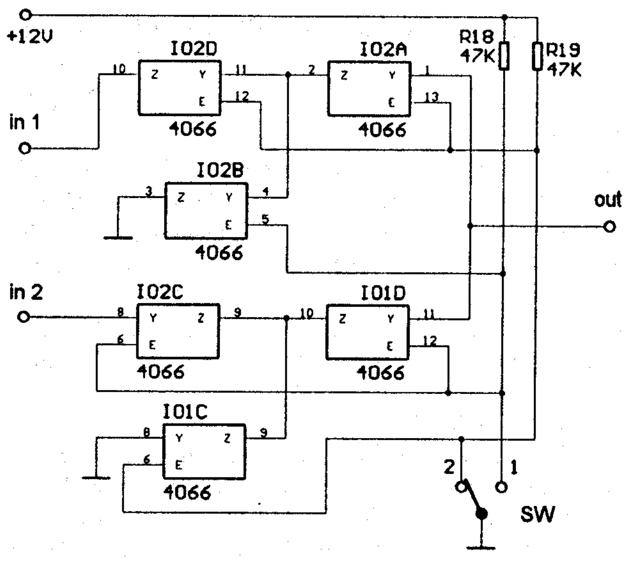


Fig.5 Analog demultiplexer with double switches 4066

As similar as the double switch can be realized a demultiplexer (contains two double switches) see Fig. 5. There are two signal branches in the demultiplexer. A single switch is connected on output of each signal branch. The single switches are used for each other buffering of signal branches and the control connectors of switches are connected to control connectors of switch in corresponding continuous branch.

The parameters of the demultiplexer are similar to parameters of the double switch. By simulation of demultiplexer linear model was determined, all parameters of which fulfilled requirement of the assignment from paragraph 1, without frequency band. The frequency band is finite up to 8 MHz. It is caused by the above mentioned buffering single analog switches in signal branches. Therefore analog demultiplexer is applicable for less demanding applications.

References

[1] PIŠTĚK,M.: Adaptér k osciloskopu pro výběr obrazového signálu zvoleného řádku, Diploma work, FEE CS TU Brno, 1995

[2] DATA HANDBOOK, Integrated circuits, HEF 4000B logic family CMOS, BOOK ICO4 1990.

[3] SVATOŠ,J.: Elektronika televizních zařízení, skriptum, FEL ČVUT Praha 1990

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CONTENTS OF ELECTRICAL ENGINEERING JOURNAL

(Issued by the Faculty of Electrical Engineering and Informatics, Slovak Technical University, Bratislava).

No. 11-12, 1996