CRITERIA OF LOGICAL CIRCUITS BASED ON CHANGE OF IMPEDANCE, WITH SPECIAL REGARD TO COS/MOS TECHNIQUE

By

J. GÁL

Institute of Transport Engineering and Organization, Technical University, Budapest

Received May 5, 1977

Presented by Prof. Dr. T. KELEMEN

The COS/MOS logical system has a number of particular characteristic which are fundamentally new in the electronic switching technique. At the same time, however, these particular characteristics can be treated separately from the system and can be generalized for other realizations, too.

The aims of this paper are

1) to justify the truth of the latter statement;
2) to synthetize the main characteristics of the COS/MOS system from the point of view of switching technique;
3) to draw some conclusions likely of use in the design and development work.

1. In examining the COS/MOS system from the aspects above, the author takes himself a high degree of freedom in the fields of denomination and representation in order to increase the abstraction.

Statements

a) In the logical circuits of the COS/MOS system the unipolar transistors constitute a logical network and their only function is to act as variable resistances adjustable to a low or a high value depending on the control signal.
b) The resistances constitute pair-wise an elementary switching unit, an inverter in itself. Considering their momentary values the resistances are complementary pairs.
c) The complementary resistance pairs belong together in the control, in the logical network, however, they are to be separated. Namely, because of the control conditions, the p- and n-type MOS transistors regarded as resistances are not neutral concerning the direction of current flowing in them.

Discussion

In Fig. 1 the known arrangement for the NOR logical function is seen. In Fig. 2 the NOR gate seen in Fig. 1 is represented by resistance symbols in accordance with statements under a), b) and c). For the same purpose an even simpler method of representation is shown in Fig. 3 where at the same time the initial condition of the two possible conditions of the resistances constituting the network is given. This condition will be assigned to value 0 of the control signal. The resistances having low values in initial condition are designated

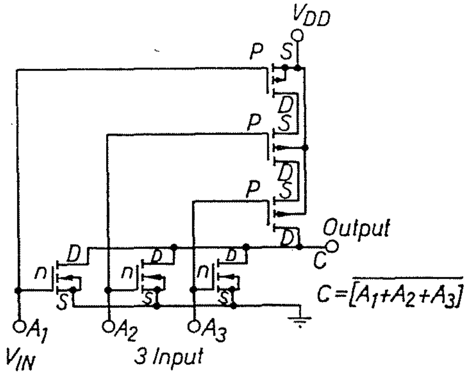


Fig. 1. 3 input nor gate

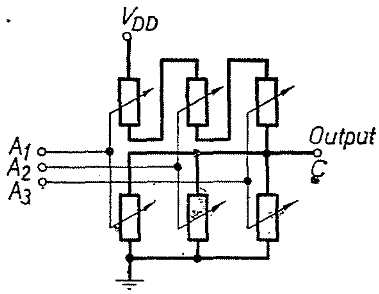


Fig. 2. Nor gate represented by resistance symbols

by a line drawn along the longitudinal axis of the resistance symbol. The others have high resistance in their initial conditions. When the value of the control signal changes, also the resistances change their values in the opposite sense.

The arrangement of the resistances in Fig. 3 emphasizes the network character of the logical circuit in which the output signal is determined by the arrangement and momentary value, i.e. by the conditions of the resistances. Due to the design solution, the control signals determining the conditions of the resistances cannot mix with the output signal.

The elementary switching unit — the inverter — is shown in Fig. 4. In the inverter the two complementary resistances are connected together and their common terminals constitute the output. In more complicated logical

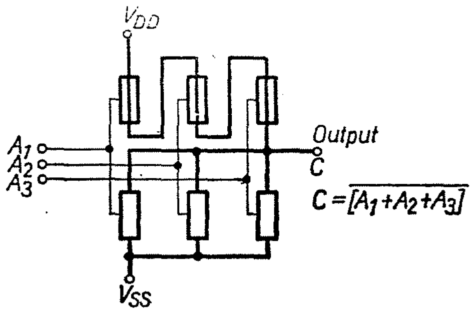


Fig. 3. Nor gate represented by resistance symbols given the initial conditions

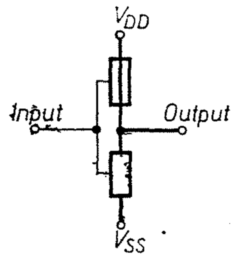


Fig. 4. Elementary switching unit

networks, however, such as the NOR gate, from among the complementary resistance pairs belonging together, only those adjacent to the output keep their arrangement in the inverter. Because of their control conditions and conduction properties the other pairs are separated from each other, although they will belong together both by logical function and control.

Statements

d) In the presented conception the elementary switching unit is simply a controllable potential divider predominated across its intermediate branch — the output — at any moment by the voltage value predominantly obtained across the low resistance of the divider pair.

e) The logical network formed in realizing any logical function is also a potential divider regarding its resultant arrangement.

f) In the arrangement of the resultant potential divider consists of the complementary resistance pairs as elementary components of the logical network. Their values and arrangement determine in final account the two resultant components of the resultant potential divider.

g) The two resultant resistance components of the resultant potential divider also constitute a complementary resistance pair. The more favourable their ratio the more favourable is the same ratio in the elementary switching unit itself.

h) The voltage level of the output is determined by the ratio of the two resultant resistance components.

i) The value and ratio of the two resistance components of the resultant potential divider have a combined effect on the number and time of operation of actuated switching units.

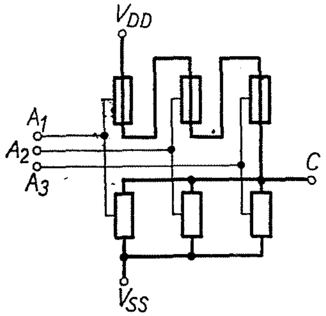
k) In the COS/MOS elementary switching unit the ratio of the high to low resistance values ranges over about four orders of magnitude. Under these conditions all logical functions that may arise in practice can be realized i.e. the number of variables need not be limited. Namely the resistance ratio is never less than two orders of magnitude in the potential divider even in the most complicated practical cases.

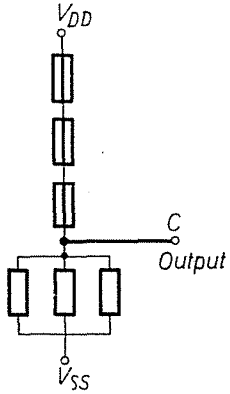
l) Even in the most critical cases there is a possibility to actuate as many elementary switching units from the output of a logical network as needed as a maximum in practical cases.

Discussion

The truth of the statements under d) to g) is obvious from Figs 4 and 5. The arrangement of the resultant potential divider is shown on the inverter in Fig. 4 for the case of the elementary switching unit, while the same is illustrated in the middle of Fig. 5 in case of the NOR gate.

The statements under h) to l) refer to the characteristics of the resultant potential divider with special regard to the voltage level of the output and to the ratio of the two resultant resistanence components. Referring to the potential





A_1	A_2	A_3	C
0	0	0	1
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	0

Fig. 5. Nor gate as potential divider

divider in Fig. 5, a NOR gate containing 10 variables has to be kept in mind as against the present 3 ones. Consequently this NOR gate contains on one hand 10 low-value resistances connected in series, on the other hand 10 high-value resistances connected in parallel in the potential divider. It can be checked that in this case the voltage level of the output will be lower by two orders of magnitude than for the elementary switching unit.

Hence even in case of a NOR gate of 10 inputs there will be only 1% difference between the nominal voltage and the actual output voltage.

Statements

m) Both the elementary witching unit and the logical circuit of many variables built up from the units constitute a so-called three-pole logical network. These three-poles have two inputs and one output.

n) Each three-pole network is composed of two two-pole (Fig. 6) logical resistance networks between the two inputs and the output. The two logical resistance networks are the negatives of each other.

o) Voltage levels of logical values of 1 and 0 appear across the two inputs of the three-pole logical networks, while one of them appears across the output depending on the condition of the two resistance networks.

p) In the two-pole logical resistance networks the series and parallel arrangement of the p- and n-typ MOS transistors — as resistance elements — is a connecting method analogous to the series and parallel connection of the relays' contacts. At the same time the low resistance corresponds to a breaking contact, the high resistance to a making one, in conformity with the operating and inoperating conditions of the relay (Fig. 7).

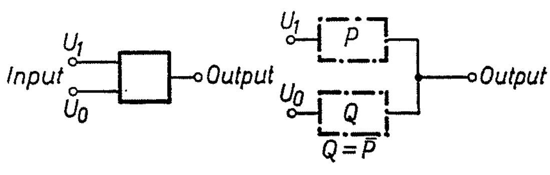


Fig. 6. Structure of a three-pole logical network

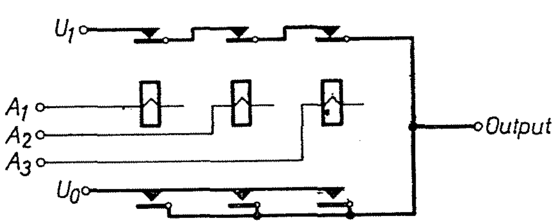


Fig. 7. Three-pole contact network

Discussions

The statements under m) to p) are closely related to the previous ones and do not contain additional statement. The emphasis on the three-pole character and the reference to the relationship of the two-pole resistance networks and to the analogy with relay circuits are of importance from the point of view of subsequent considerations.

2. The switching pecularities in the COS/MOS technique can be synthetized in a general constructional and logical connection structure. This system

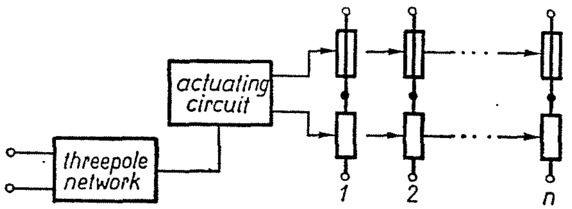


Fig. 8. Structure of a switching set

will be termed a voltage-switching logical system on the basis of its characteristics enumerated below.

According to Fig. 8 the main characteristics of the switching arrangement are:

- a smaller or larger group of the elementary switching units (potential dividers) constitutes a so-called complex switching unit controlled by a common actuating circuit;
- the initial condition of the potential dividers belongs to the initial condition, while their operating condition to the operating condition of the actuating circuit;
- the actuating circuit operates simultaneously every elementary switching unit relating to it;
- the elementary switching units are complementary impedance pairs (represented by the previous resistance symbol);
- both the ohmic and the inductive components may take part in changing the impedance values;
- the impedance elements are neutral from the point of view of voltage polarity and current direction, consequently the two impedance elements may be connected at one of their terminals;
- both the elementary switching units and the complex networks composed of them have voltage-switching characteristics because they transfer one of the input voltage levels to the output;
- the voltage-switching networks both in elementary and in complex form constitute a three-pole network;

— the actuating circuit will be driven by the output signal of such three-pole voltage-switching logical networks;
— the most favourable arrangement of the complex switching unit will be that where the control signal of the operating circuit can directly be used for controlling the elementary switching units; in this case the actuating circuit will be omitted; this is a feature of the COS/MOS system;
— in the symbolic representation the indication of the initial conditions of the elementary switching units may be advantageous.

Characteristics of the comprehensive logical switching arrangement are:
— voltage-switching networks realizing any logical function can be constructed from the elementary three-poles of the complex switching unit by observing the simple rules valid for contact networks;
— in realizing voltage-switching logical networks it is of importance to settle the initial conditions of the elementary switching units and the series and parallel connection of the three-poles;
— in settling the initial condition of the elementary switching units it is not irrelevant to which one of the two inputs to connect the high-level and to which one the low-level signal;
— in connecting any two three-poles in series, the output of the first one is to be connected to the high-level input of the second one, at the same time the low-level inputs of the two three-poles are to be joined;
— in connecting any two three-poles in parallel, the output of the first one is to be connected to the low-level input of the second one, at the same time the high-level inputs of the two three-poles are to be joined.

In Fig. 9 the realization of three logical functions by respecting the above rules is represented. (In case of realizations with neutral impedance elements — in addition to minimizing the logical functions — there is a possibility of simplification also in the network itself.)

Note. — By using inductive potential divider pairs behaving neutrally according to the principles described, the author designed in 1963 a so-called magneto-electronic relay and used it successfully for controlling a telephone exchange (see Fig. 10). The potential divider pairs consisted of tiny coils with iron cores the impedance of which could be changed by pre-magnetization. Consequently the logical networks were supplied by a.c. voltage. The actuating circuit of the complex switching unit consisted of a Smitt trigger, also supplied by a.c. voltage through suitable rectifier elements. At the same time also the constructional and switching criteria of the voltage-switching logical system had been elaborated.

Furthermore it must be emphasized that both the structural arrangement presented and the switching principles are satisfied by the electromagnetic relay the contacts of which may be regarded as ideal potential dividers.

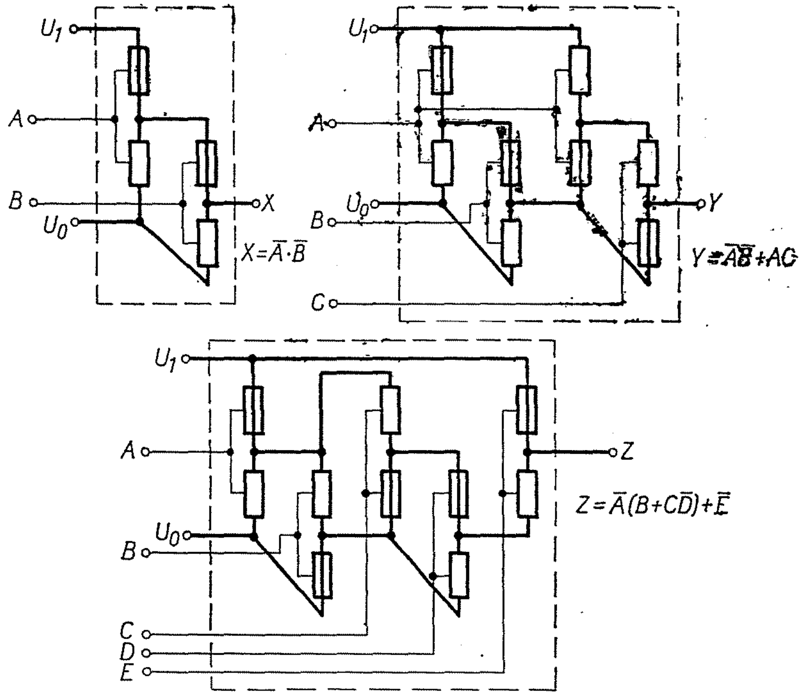


Fig. 9. Three pole networks

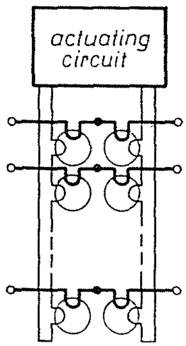


Fig. 10. Magneto-electronic relay arrangement

The realization in form of a contact network of the logical function given in Fig. 9 is shown in Fig. 11.

3. Presentation of the voltage-switching logical circuits imposes some conclusions to be drawn on the COS/MOS technique.

a) The COS/MOS system permits the voltage-switching circuits to be constructed on the latest principles, in spite of the other than neutral behaviour of its operative switching elements. The fact that no common driving-

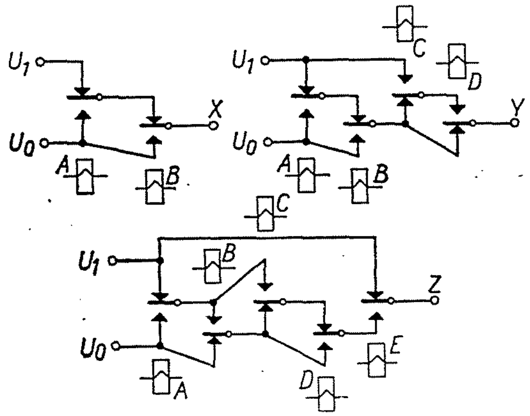


Fig. 11. Logical functions of Fig. 9. realised by contact networks

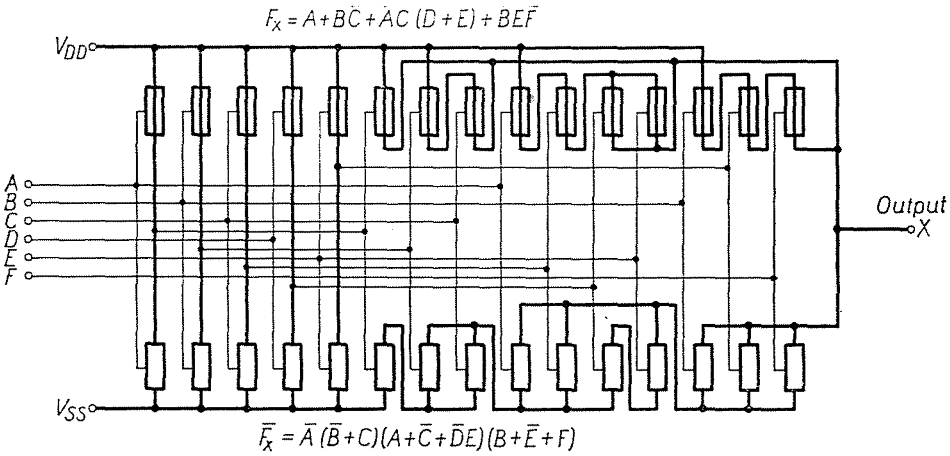


Fig. 12. Realisation of a complicated logical function

actuating-operating circuit is necessary for building complex switching units presents a unique advantage in the realization and in many respects counterbalances the lack of neutral elementary switches.

b) Design in the COS/MOS system may in some cases take advantage from the previously discussed conception that the COS/MOS circuits can be handled as logical networks involving the conventional design methods and achievements of the relay technique. The handling of the logical networks is greatly facilitated by the indication of the initial condition of the switching elements and by their arrangement in series-parallel connection. These advantages are completed by the possibility of using speculative design methods. Realization of a rather complicated logical function is shown in Fig. 12.

c) The manufacturing technology of the COS/MOS integrated circuits permits a high degree of integration. Units of complete circuits for intricate functions are being manufactured and subject to further development. In this business, great many advantages may result from analogies with existing systems.
d) The constructional and switching criteria of the voltage-switching logical circuits offer possibilities for developing further procedures in the techniques and technology of integrated electronic circuits.

Summary

The logical switching method based on complementary MOS transistors and applied in COS/MOS devices seems to incarnate an originally new conception never used in switching technics. This note analyzes the system and explains that these particular characteristics can be treated separately from the system and can be generalized for other realizations.

References

GÁL, J.: Magneto-electronic relay and its switching technique. — Doctor Techn. Thesis. 1963.
SAH: Characteristics of MOS Transistors. — IEEE Transactions, July 1964.
MEDWIN, A. H.—ZUK, B.: Using MOS transistors in integrated switching circuits. — Electronic Design, November 1964.
GÁL, J.: A New Method for the Realisation of Logical Circuits Free of Moving Elements.* Híradástechnika, No. 10. 1965, 302—308.
GÁL, J.: Design of Voltage Switching Logical Circuits. — Híradástechnika, No. 12, 1965.
HOOVER, M. V.: An introduction to COS/MOS integrated circuits and their applications in digital circuits systems. Alfred Neye — Enatechnik Quickborn — Hamburg, 1971.
GÁL, J.: Relay Circuits Operated by Capacitive Currents.* — Híradástechnika, No. 12, 1975, p. 258—262.

Dr. József GÁL 1031 Budapest, Csalma u. 1. Hungary

* In Hungarian.