1971

A driver-assisting control system

Roger Allen Hayes

A DRIVER-ASSISTING CONTROL SYSTEM

BY

ROGER ALLEN HAYES, 1949-

A THESIS

Presented to the Faculty of the Graduate School of the

UNIVERSITY OF MISSOURI-ROLLA

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

1971

Approved by

(Advisor)

ABSTRACT

The material presented here explains the electronics of a magnetic guidance control system. The system is based on magnets embedded in the center of the roadway. If a vehicle passes near a magnet, fluxgate magnetometers sense the presence of the magnets and guidance pulses are developed and processed. The end result is a visual output which indicates the direction the driver must steer the vehicle for proper positioning on the roadway.

The paper presents a solution to the detection problem caused by the sensor output being a function of the earth's field as well as the field of the guidance magnets. Specific circuits and component values are developed for the circuit which solve the above problem and for all other circuits used in the system.

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to Dr. K.R. Dunipace for his guidance during the project, Dr. F.J. Kern for assistance in circuit applications, and to Delco Electronics Division of General Motors Corporation for financial assistance.

The author also wishes to express his gratitude to his wife for her patience and encouragement and for typing the manuscript.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

This thesis concerns a problem in transportation research currently being studied at the University of Missouri-Rolla[1]. The over-all project intends to reduce the number of automobile accidents by increasing the ability of the driver to manuever his vehicle and consequently to stay on the roadway. The system will eventually provide a visual or tactile indication as to the direction the vehicle should be steered for proper positioning in the driving lane. The system will also provide digitally encoded data describing conditions of the oncoming roadway.

Basically, the system presently works as follows: Sensitive magnetic field sensors called fluxgate-magnetometers mounted on the undercarriage of the vehicle sense the presence of magnets embedded in the center of the driving lane. If the vehicle does not pass directly over a magnet, signals detected by the sensors will be unequal and the difference is used to provide a steering error signal which is processed, then displayed visually. Thus driving over each magnet provides updated data as to the vehicle's position, while driving over a series of magnets provides digital data about the oncoming roadway. Eventually processing circuits will estimate the lateral velocity and acceleration of the vehicle path for compensation of the feedlock signal to the driver.

II. REVIEW OF THE LITERATURE

Controlling the position of a vehicle on a roadway is not a recent development. As early as 1931 Adler was concerned with apparatus to aid the driver in manuevering his vehicle[2]. More recent developments in the vehicle guidance field include a system by Harned and Marchewitz designed around a cable buried in the roadway[3]. The cable conducts an alternating current which induces a voltage into specially placed sensor coils. An error signal is developed and applied to the power steering system. This system has two disadvantages: 1) the expense of burying the cable, and 2) conducting an alternating current through the cable. Several other guidance systems have been devised; however, they also use considerable length of cable buried in the roadway, the installation of which would be quite expensive[4,5].

The systems thus far considered have made modifications to existing roadways and vehicles. Another class of systems has recently been receiving considerable attention[6,7]. Typically, these systems are not capable of operating on existing roadways. As an example, one such system studied by Wilkie uses magnetically levitated vehicles[8]. This system requires high levitation currents and a special track for vehicles to follow, neither of which now exists to any great extent.

A great many circuits which typify the needs of the system exist in the literature. Only a few of the books and articles are cited here which contain circuit information pertaining to this project. Sevin[9] and Naylor[10] provide Peak-Hold and Sample-Hold circuits using operational amplifiers and FET's which are popular today. Burr-Brown[11] considers many circuits involving operational amplifiers. Rekoff[12] considers the implementation of simple transfer functions. There is no evidence of previous application to the vehicle guidance problems discussed here.

III. DEFINITION OF THE PROBLEM

Figure 1 is a simplified block diagram of an early configuration of the system. Embedded magnets produced peaks in the magnetic field which were sensed by the magnetometers. These sensed pulses were converted to pulses of a usable form by the sensor electronics. The signal processing circuitry produced a continuous signal from a pulse which was capable of driving a visual display.

The magnetometers are sensitive not only to embedded magnets, but any metal object capable of generating a magnetic field. The magnetometers also sense the earth's ambient field. For example, magnetometers sense the presence of bridges, culverts, railroads, metal sign posts, and the ambient earth's magnetic field. The guidance system is based on the relative strength of the pulses produced from sensing embedded magnets. If some other metal object was sensed, a pulse would be produced causing erroneous output of the signal processing block.

The earth's ambient field appears at the output of the sensor electronics as a slowly varying direct current voltage when the vehicle is being driven along a roadway. This voltage was as much as 2 volts in peaks of the ambient magnetic field. Such output voltages cause erroneous output in the signal processing circuitry.

The purpose of this thesis is twofold: 1) develop a circuit which alleviates the effects of metallic objects and reduces the sensor electronics output to zero with no input pulses, and 2) develop circuits to be used as the signal processing block in Figure 1.

Before attacking a solution for the ambient field problem, it is necessary to define some characteristics of the signal which is under consideration: 1) the signal pulse width is inversely proportional to the vehicle's speed, 2) most ambient field signals have a much narrower frequency spectrum than the magnetic pulses, 3) metal objects in or near the roadway are capable of producing pulses very similar to the magnet pulses. The ambient field's comparatively low frequency spectrum suggests that a high pass filter might provide a simple solution to the problem; however, the varying pulse width of the magnet pulse precludes such a solution.

A feedback network has been investigated which samples the output of the sensor electronics and feeds a compensating signal back to the magnetometers as shown in Figure 2. The feedback signal should be proportional to the ambient signal at the output of the sensor electronics and connect to the magnetometers so as to oppose the ambient field, thus cancelling the effect of the ambient field.

The purpose of the network is to feed back the slowly varying D.C. voltage appearing at the output of the sensor electronics to oppose the ambient field signal, thus

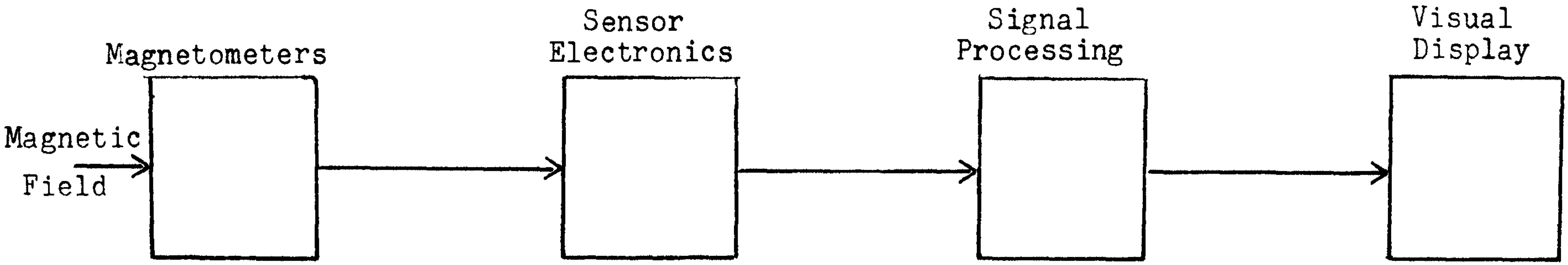


Figure 1. Early System Block Diagram

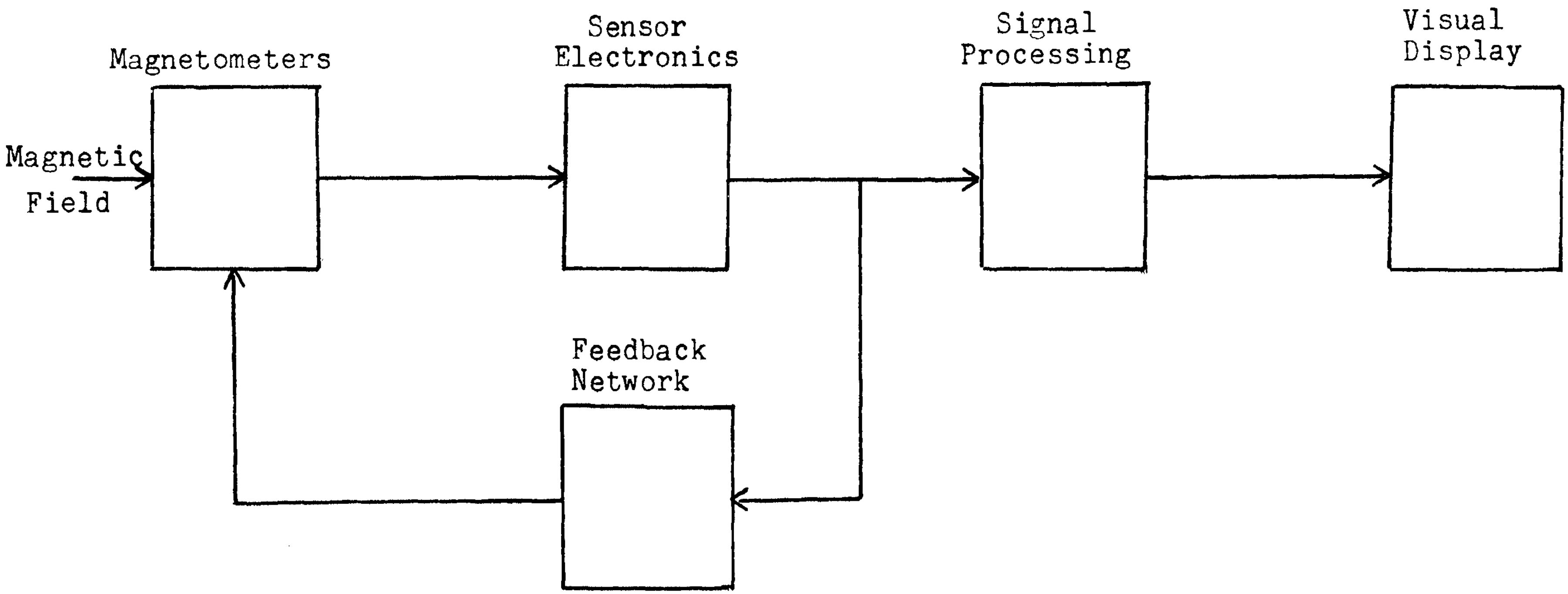


Figure 2. Present System Block Diagram

resulting in a cancellation. Yet, the network must not pass the magnet pulses. Theoretically, the feedback network will eliminate the slowly varying D.C. voltage at the output of the sensor electronics.

The feedback network must be basically a low pass configuration whose cutoff frequency contains the smallest possible portion of the pulse spectrum so that the magnetic pulse will not be fed back to the magnetometers and result in a self-cancellation. The higher frequency pulses which are obtained by traveling at a higher rate of speed offer no problems with respect to the feedback network because the high frequency components are much greater than the cutoff frequency of the feedback network. It is the low frequency pulses, which result from the slowest vehicle speed at which the system is to operate, which will determine the low frequency cutoff for the feedback network. At the other extreme, all frequency components of any ambient fields present should be passed by the feedback network. It is advantageous to feedback as much of the extraneous signals as possible to reduce the effect of extraneous signals on the system.

Because of the similarity between some metallic object pulses and the magnet pulses, such signals will be processed through the system; however, it is desirable to minimize the effect of such pulses.

From these basic requirements, an expontially-weighted time averaging filter was chosen which has an open circuit voltage transfer characteristic of $T(s) = \frac{K}{s(s+a)}$. The selection and design of this filter constituted the first part of the work leading to this thesis.

The second portion of this thesis concerns the circuit following the sensor electronics, labeled "Signal Processing" in Figure 2. The purpose of these circuits is to convert pulses from the sensor electronics to continuous signals capable of driving a visual or tactile display. The signal must be continuous in a practical sense and indicative of required steering correction. A simplified block diagram of this "Signal Processing" section is shown in Figure 3.

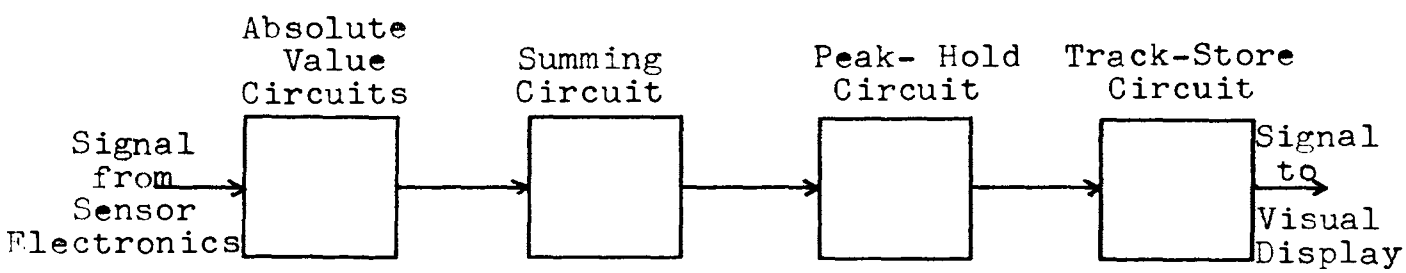


Figure 3. Block Diagram of Signal Processing

The circuits for this part of the system are developed in Section V.

IV. DEVELOPMENT OF THE FEEDBACK NETWORK

This section describes the deedback network development by first deriving the filter parameters, then discussing advantages and disadvantages of various synthesis procedures.

A. Determination of Filter Constants

This section develops the original values of the constants K and a selected for the filter. A simplified model of the feedback system involving the filter is shown in Figure 4. Previously the compensation coil has not appeared in the block diagram form, but was considered to be an integral part of the magnetometers. For analysis to determine K and a it must be shown external to the magnetometers.

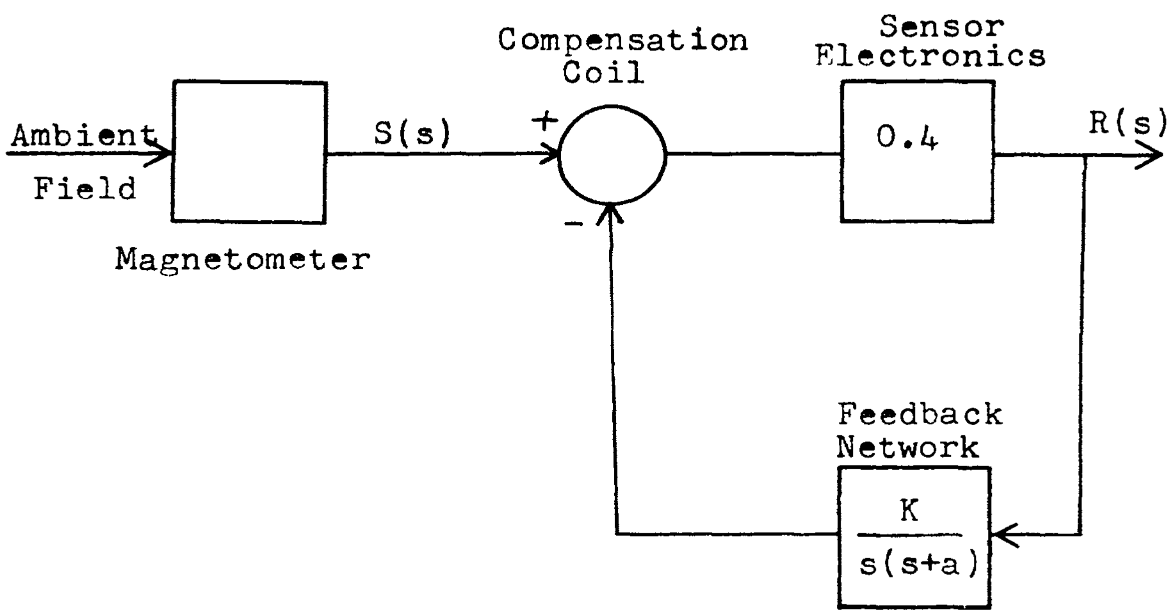


Figure 4. Block Diagram Involving Feedback Network

The sensor electronics circuitry constant K was found experimentally[13]. The open loop gain was found to be approximately 4 volts/oersted. The earth's magnetic field is approximately 0.5 oersted which provides a static open loop voltage output of approximately 2 volts, due to the earth's magnetic field. Experimentally, it was determined that a current of approximately 2 ma connected so as to oppose the earth's field, would result in zero output. Thus the detection circuitry constant is determined to be 0.4 volts/ma.

The transfer function for the second order system of Figure 4 is:

$$\frac{R(s)}{S(s)} = T_1(s) = \frac{G(s)}{1 + G(s)H(s)}$$

where s is the Laplace Transform Variable, G(s) is the forward path transfer function and H(s) is the feedback transfer function

$$T_1(s) = \frac{G(s)}{1 + G(s)H(s)} = \frac{0.4}{1 + (0.4)\left(\frac{K}{S(s+a)}\right)}$$

Let F(s) be the characteristic equation:

$$F(s) = 1 + G(s)H(s) = 0$$

$$1 + (0.4)\left(\frac{K}{s(s+a)}\right) = 0$$

$$s^2 + sa + 0.4k = 0 \qquad (1)$$

$$s^2 + 2dW_n + W_n{}^2 = 0 \qquad (2)$$

d and W_n are the damping ratio and natural radian frequency of the second order system. d was picked arbitrarily for a small overshoot: d = 0.7. W_n is calculated using two assumptions 1) the magnet spacing is 15 ft. and 2) the operating range for the system is between 20 and 80 M.P.H. The system is basically a high-pass system; therefore the low frequency cutoff, W_n, is calculated using the 20 M.P.H. extreme.

20 M.P.H. 30 ft/sec

The time between magnets equals

$$\frac{15 \text{ ft/magnet}}{30 \text{ ft/sec}} = 0.5 \text{ sec/magnet}$$

From experimental data taken from the simulated roadway, it was found that a pulse occupies approximately 20 per cent of the time. Thus a pulse width of 0.1 sec should be the maximum pulse length. Let t = 0.1

$$W_n = \frac{1}{dt} = \frac{1}{(0.7)(.1)} = \frac{1}{0.07} = 14.3 \text{ RAD/sec}$$

Equation (2) becomes $s^2 + 2(0.7)(14.3) + 204 = 0$

Equating coefficient of Equation (1):

$$a = 2dW_n = 2(.7)(14.3) = \underline{\underline{20}}$$

$$6.4K = W_n^2$$

$$K = \frac{W_n^2}{0.4} = \frac{204}{0.4} = \underline{\underline{510}}$$

These values were used for the initial choice of components.

B. Synthesis of $\frac{K}{s(s+a)}$

Four different synthesis procedures were considered for the realization of the transfer function $\frac{K}{s(s+a)}$. The two gyrator procedures produced non-realizable component values and parameters K and a could not be varied easily in the NIC realization. The State Variable method provided exceptional results in several respects: 1) easy controllability, 2) low output impedance, 3) high input impedance, 4) simplicity and economy of components, and 5) minimal number of capacitors. The State Variable method was chosen for the realization.

Circuit specifications must be considered before synthesis procedures can be appraised. The most important criterion in the present developmental stage of the system is that of controllability of the parameters K and a. Experimental on-the-road results have proven that the approximating models used for the magnetometers and sensor electronics to calculate the original values for the parameters K and a were not ideal. Another specification to be considered is that of input-output impedances. Because of the marginal output impedance of the sensors, a relatively high input impedance is necessary, although the output stage of the sensors is an emitter follower. A low output impedance will be used to help eliminate loading effects on the following stage. These were the major specifications considered; however, with consideration of future production, two other criteria should be considered: 1) the minimization of components, and 2) the sensitivity of the transfer function with respect to a given component.

Gyrator Realization

This section discusses two attempts at gyrator realizations. The results both methods yielded were unexpected nonrealizable circuits; however, an important fact is proven about passive realization in this section. No problem was anticipated in these synthesis procedures; however, the pole of the transfer function at zero frequency proved to be the limiting factor.

Before synthesis procedures can be considered, a suitable gyrator realization must be found. A simple gyrator realization is shown in Figure 5.

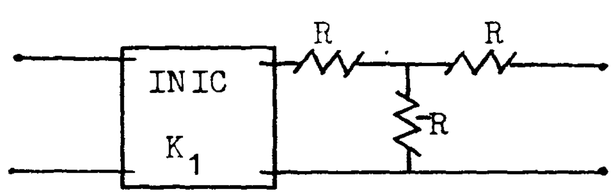


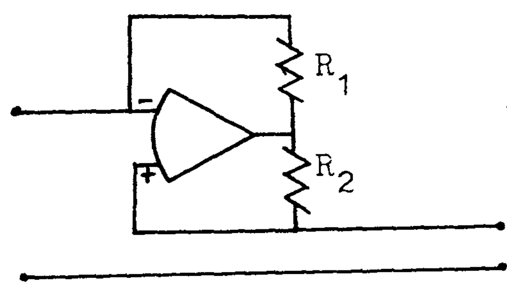
Figure 5. Gyrator Realization Using NIC

This realization has a Y-parameter set of:

$$\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} = \begin{bmatrix} 0 & -G \\ -G/K_1 & 0 \end{bmatrix}$$

Where $G = 1/R$, K_1 = current gain factor.

An operational amplifier realization of the INIC consists of the following circuit



$K_1 = R_1/R_2$

Two operational amplifiers are required to realize Figure 4; one operational amplifier to construct the INIC, another to realize the -R element.

Having found a suitable gyrator realization, the next step is the synthesis of $V_2/V_1 = \frac{K}{s(s+a)}$

The first synthesis procedure considered was that of Mitra[14]. This procedure yields two networks, one Z_{RC} driving point, and the other Y_{RC} driving point, which are placed at the gyrator's ports. The success of this method is dependent upon the ability to decompose the transfer function denominator. Calahan[15] proved two necessary and sufficient requirements for decomposition, such that the end result would yield realizable driving point functions. The transfer function $V_2/V_1 = K/S(s+a)$ violates one of the two requirements necessary for polynominal decomposition, that condition being all real roots must be negative. Thus a pole at the origin violates this condition. As a result, this method was abandoned.

A second method for gyrator synthesis is suggested by Newcomb[16]. This method synthesizes a lossless two-port using gyrators with termination impedances, which are resistive. The network is shown in Figure 6.

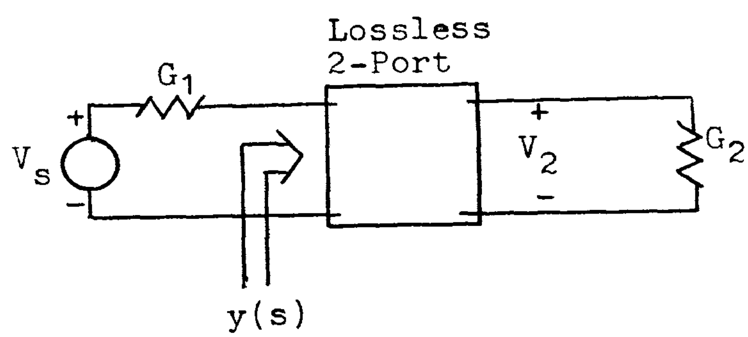


Figure 6. 2-Port Synthesis Diagram

From this network the following equation can be derived.

$$\left| \frac{G_1 - y(jw)}{G_1 + y(jw)} \right|^2 = 1 - 4\frac{G_2}{G_1} \left| \frac{V_2(jw)}{V_s(jw)} \right|^2$$

This equation leads to the inequality

$$4\,\frac{G_2}{G_1}\left|\frac{V_2(jw)}{V_s(jw)}\right|^2 < 1 \qquad \text{for all} \quad w \geqslant 0$$

$$\left|\frac{V_2(jw)}{V_s(jw)}\right|^2 < \frac{G_1}{4G_2}$$

substituting the desired transfer function

$$\left|\frac{K}{jw(jw+a)}\right|^2 = \frac{K_2}{w^4+w^2a^2} < \frac{G_1}{4G_2}$$

At w = 0, the function is unbounded, therefore this type of synthesis is not applicable to the required transfer-function.

The derivation not only eliminates this particular gyrator procedure, but also eliminates any LC synthesis terminated in resistive loads. In fact, if the transfer function is examined at w = 0, the circuit must have infinite gain, which is impossible for any passive circuit. Hence the conclusion that the required transfer function can not be synthesized using passive synthesis techniques, and the limiting factor has been the pole at w = 0.

NIC Realization

With the advent of the operational amplifier, practical realizations of negative impedance converters are now possible. Huelsman offers a simple NIC realization using an operational amplifier and two resistors shown in Figure 7.

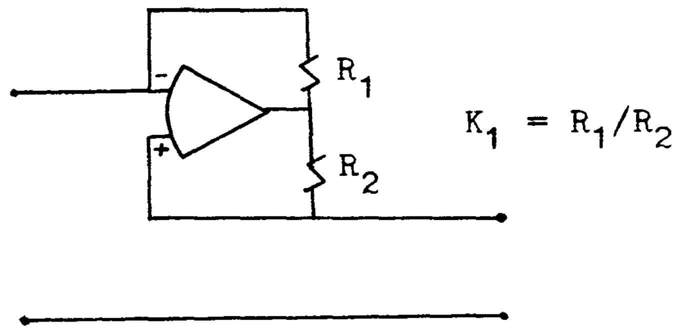


Figure 7. NIC Realization

A synthesis procedure based upon the NIC shown in Figure 7 was tried using the Yanagisawa method[16].

$$\frac{V_2}{V_1} = \frac{N/P}{D/P} = \frac{-y_a + kY_a}{(-y_a + kY_a) + (-y_b + kY_b)} \qquad \frac{K_1}{s(s + a)}$$

where N = numerator = K_1

D = denominator = $s(s + a)$

P = polynominal = $s + b$

$$\frac{N}{P} = kY_a - y_a = \frac{K_1}{s+b} = K_1 - \frac{sK_1}{s+b}$$

$$\frac{D-N}{P} = kY_b - y_b = \frac{s^2 + sa - K_1}{s + b} = s + (a-b) - \frac{K_1 + (ab-b^2)}{s + b}$$

$$= s + \frac{as + ab - K_1 - ab + b^2}{s + b}$$

$$= s + \frac{as + b^2 - K_1}{s + b} \qquad -b$$

if $b^2 = K_1 \; \frac{a\,s}{s+b}$ can be realized as an Y_{RC}

$$kY_b - y_b = s + \frac{a\,s}{s+b} - b$$

The realization for this procedure is shown in Figure 8. This procedure yielded a poor circuit with respect to controllability of the parameters K and a. Recalling that b was chosen with respect to K_1, seven external elements are required; five elements are functions of K_1 and two elements are dependent. Another disadvantage for this circuit is its non-minimal number of capacitors.

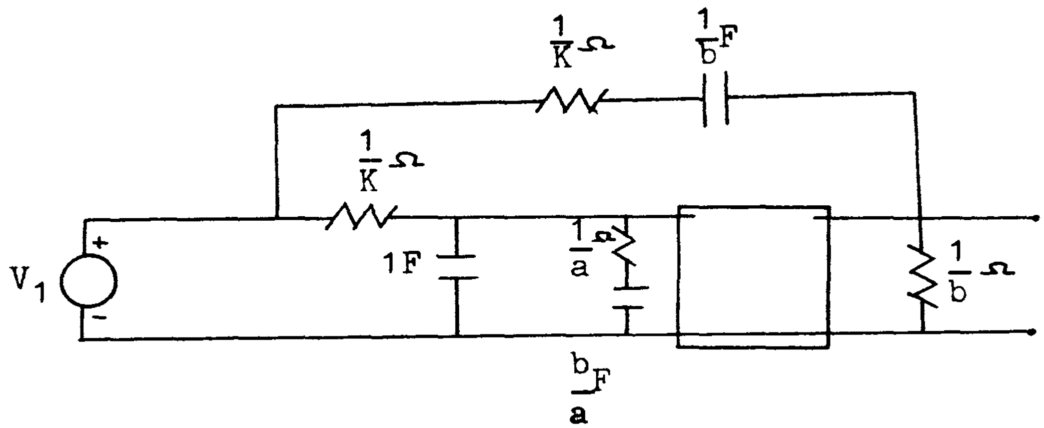


Figure 8. NIC Synthesis Realization

State Variable Realization For $\dfrac{K}{s(s+a)}$

State variable synthesis will be considered as it lends itself to easy circuit realization as well as having high input and low output impedances when using operational amplifiers. By using the cascade approach to State variable synthesis the parameters K and a can be easily controlled.

By Partial Fraction Expansion

$$\frac{K}{s(s+a)} = \frac{K_0}{s} + \frac{K_1}{s+a} \qquad (1)$$

where

$$K_0 = \frac{K}{a}, \text{ and } K_1 = -\frac{K}{a}$$

$$= \frac{K_0 s + K_0 a + K_1 s}{s(s+a)} \qquad (2)$$

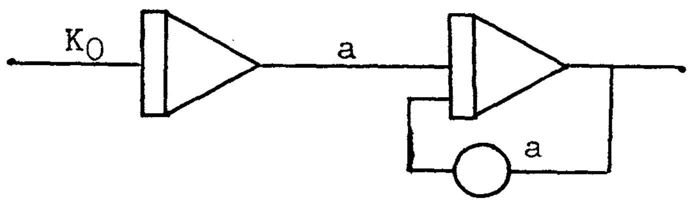
but

$$K_0 = -K_1$$

$$= \frac{K_0 a}{s(s+a)} \qquad (3)$$

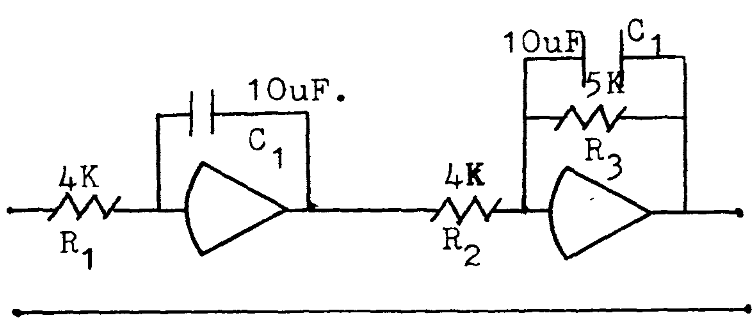
From Equation No. 3, it can be seen that the parameter K can be independently controlled by the gain K_0, while changing the parameter a changes the D.C. gain as well as the pole position.

An analog simulation of the left side of Equation No. 1 is shown below.



State variable synthesis has many circuit realizations but only one has been shown. Another cascade realization was tried and the results are discussed in the conclusion.

An operational amplifier realization of the transfer function $\frac{V_2}{V_1} = \frac{K}{s(s+a)} = \frac{510}{s(s+20)}$ is the following:



Capacitors were chosen at 10 uF.

$$\frac{1}{sRC} = \frac{K/a}{s} = \frac{510/20}{s} = \frac{1}{s\ Rx10uF.}$$

R 4K

$$\frac{K/a}{s+a} = \frac{\frac{1}{R_2C}}{s + \frac{1}{R_3C}}$$

$$R_3 = \frac{1}{a\ C} = \frac{1}{20 \times 10^{-5}} = 5K$$

$$R_2 = \frac{a}{K\ C} = \frac{20}{510 \times 10^{-5}} = 4K$$

The change in parameters with respect to a given change in component values should be checked after a realization has been found. As an example, with the parameter $a = \frac{1}{RC}$, it can be shown that the per cent change in a equals $- \frac{x}{1 + x}$ 100 per cent where x equals the fractional change in R or C. A one per cent change in R would cause a -0.99 per cent change in a. Thus, small variations in R or C will cause small variations in a. A similar relationship can be shown for the parameter K.

V. SIGNAL PROCESSING ELECTRONICS

This section discusses the circuits following the sensors. The output of these circuits should be capable of driving a visual indicator. A block diagram of this part of the system is shown in Figure 9.

The system works as follows. The sensor signals are subtracted, a difference of zero indicating that the vehicle is being driven directly over the magnets. If the left sensor is receiving a stronger signal than the right the difference is positive, indicating the vehicle is positioned too far to the right. The output stage should indicate to the driver that the vehicle should be turned to the left for correction. On the other hand, if the right sensor receives a stronger signal than the left the difference has a negative value, thus indicating the right sensor is close to the magnet and the output indicator should direct the driver to the right.

The absolute value circuits are used to convert signals of either polarity to monopolar signals in order that differencing may take place for steering. In addition, magnets of either polarity may then be used for steering and polarity may be used to encode digital information.

If the difference output is non-zero, then the Peak-Hold circuit holds the peak of the pulse for the duration of the clock pulse. The Peak-Hold circuit is triggered so that

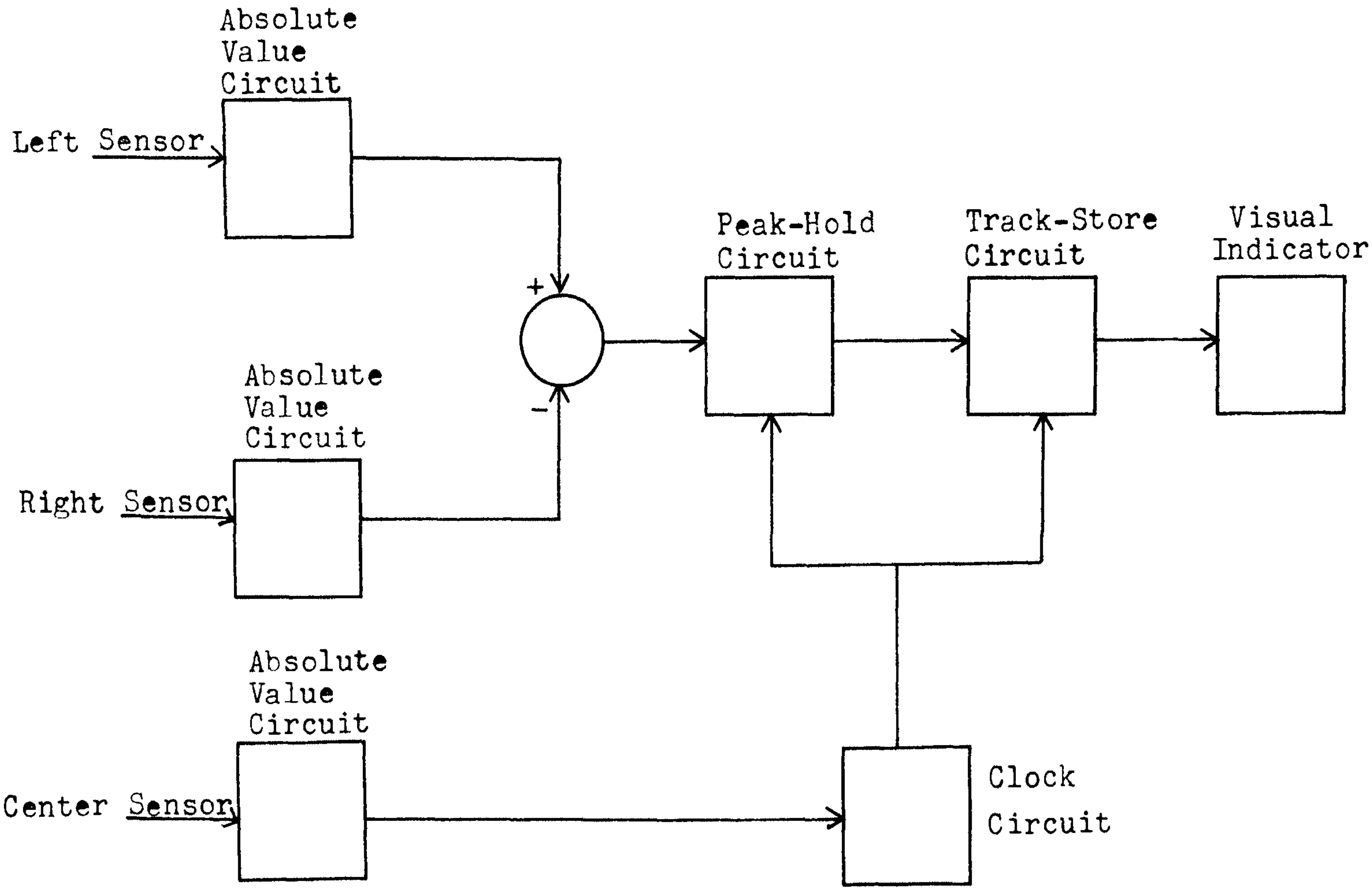


Figure 9. Block Diagram of Signal Processing

it completes one cycle during the pulse and is in the reset mode between pulses. The Track-Store circuit is triggered simultaneously with the Peak-Hold circuit with the Track-Store circuit in "track" mode during the pulse duration and in "store" mode between pulses. The Track-Store circuit will hold the peak of the pulse until reset at the beginning of the next pulse. This type of signal is adequate to drive a meter movement in a smooth manner. Figure 10 shows the progression of a pulse through this part of the system.

Circuit Realization

The first realization of the absolute value circuit, shown in Figure 11, took advantage of the phase inversion in a transistor amplifier

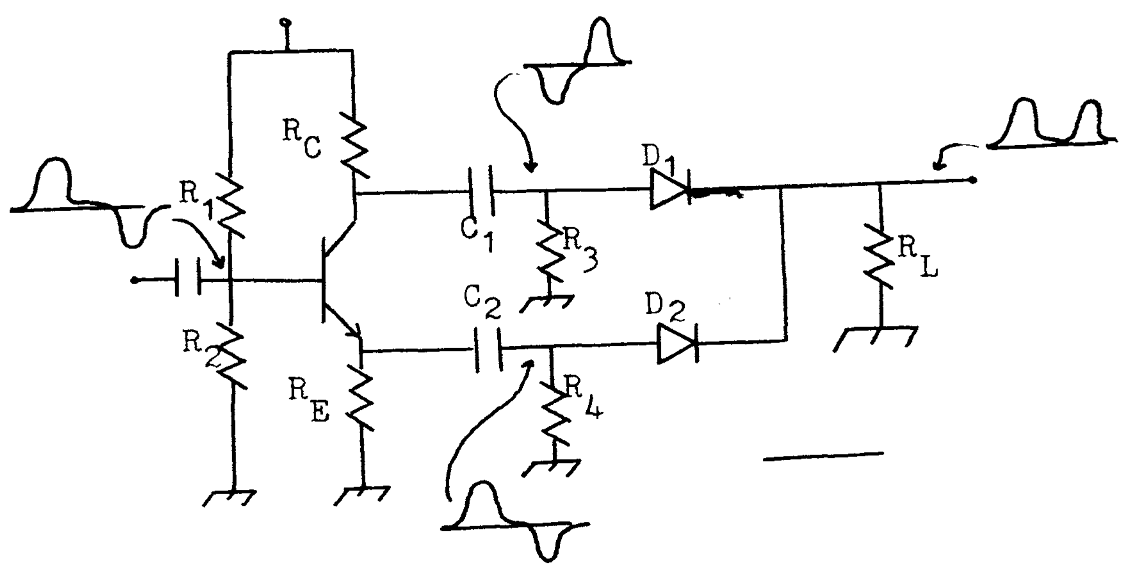


Figure 11. Transistor Absolute Value Circuit

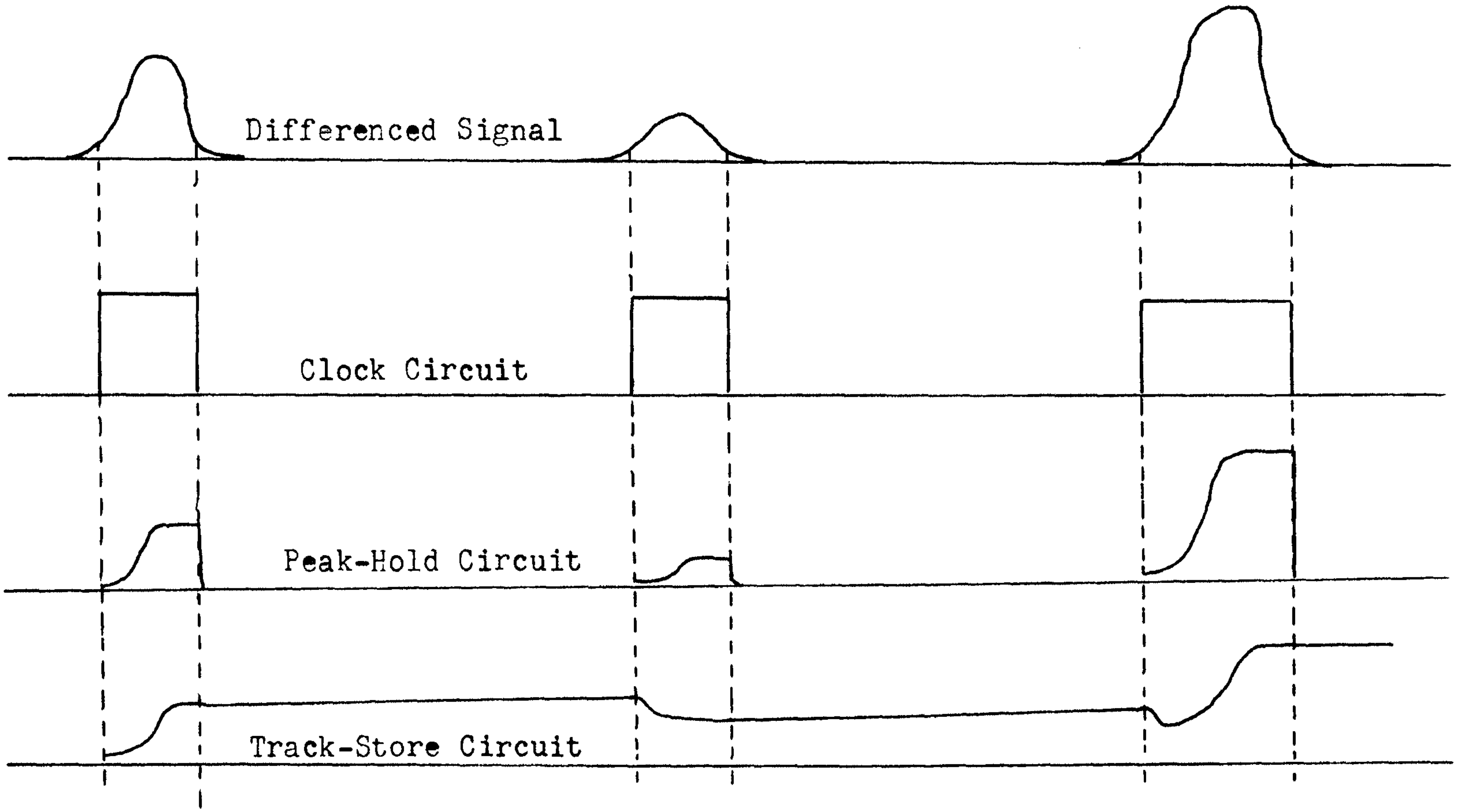


Figure 10. Pulse Progression

The circuit is essentially a full wave rectifier with a transistor used as a phase splitter. The circuit performed quite well at frequencies above 50 Hz with $C_1 = C_2$ 100 F; however, where pulses of 20 to 200 msec. duration were applied, the capacitors had to be greatly increased in value for proper operation. At this point, it became more economical to use an operational amplifier circuit which required no capacitors than to use a transistor circuit requiring two quite large capacitors.

The absolute value circuit presently used is shown in Figure 12 and is an operational amplifier full wave rectifier.

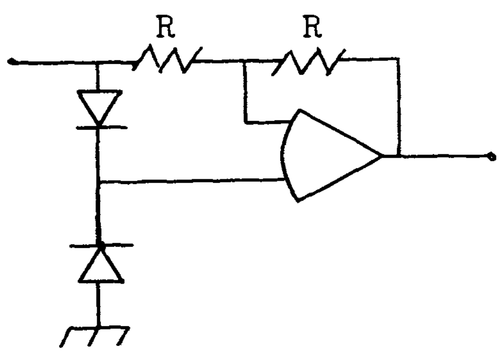


Figure 12. Absolute Value Circuit

The difference stage (Figure 9) is a simple operational amplifier used as a summing amplifier. The diodes in one of the absolute value circuits are (Figure 13) reversed, making it possible to obtain the difference signal from the summing amplifier, and to reduce the number of components required.

The Peak-Hold circuit is a standard series diode and shunt capacitor plus a transistor used to reset the circuit. The circuit is shown in Figure 14. Two branches are required to handle pulses of either polarity.

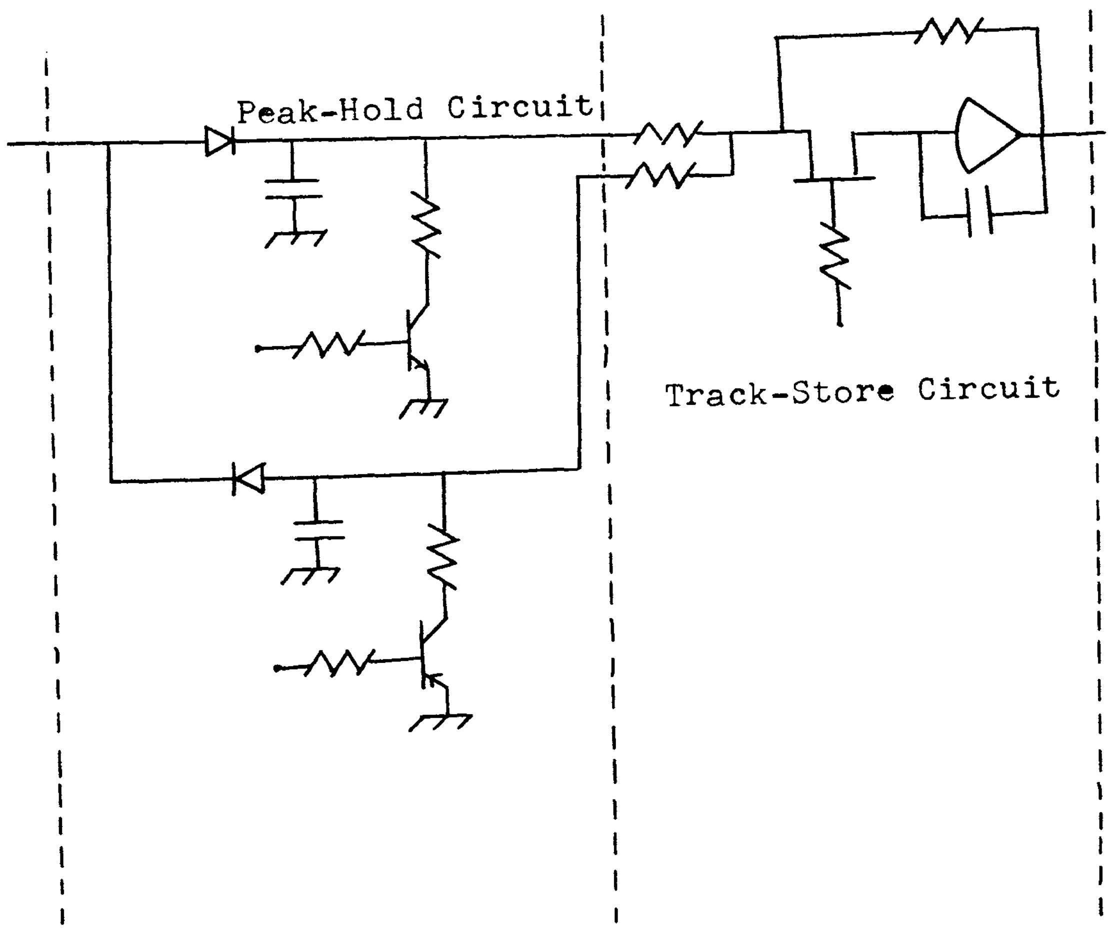


Figure 14. Peak-Hold Circuit

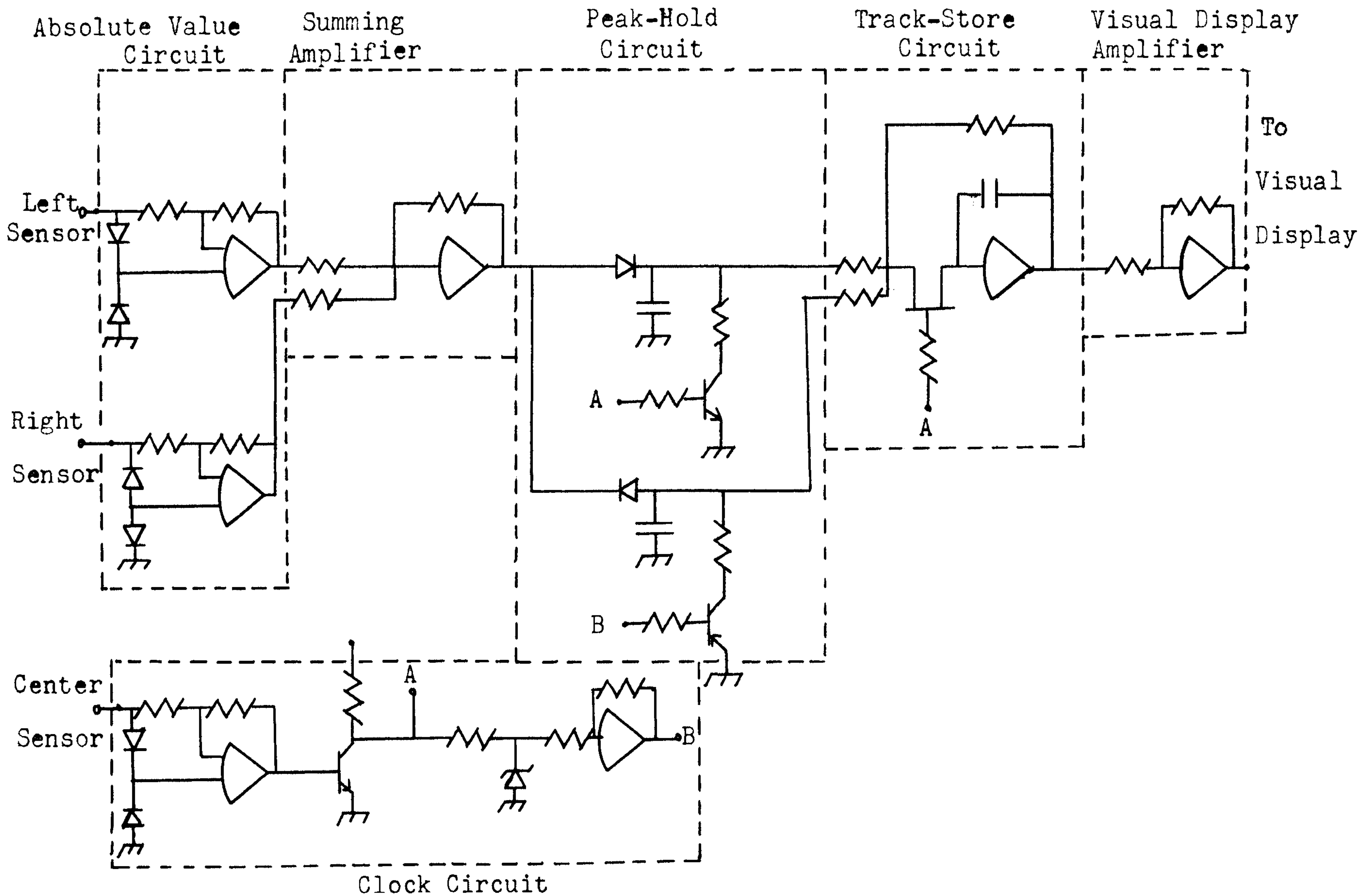


Figure 13. Signal Processing Electronics

The Track-Store unit is a simple operational amplifier circuit using an FET switch[10]. As in the previous circuit, this one must also be bipolar. The circuit is shown in Figure 14.

With the FET switch closed and in "track" mode, the circuit acts an an amplifier with a relatively fast time constant. As the FET switch opens, the capacitor clamps the output at the voltage held by the capacitor just before switching. ("Store" mode)

The capacitor value must be large enough so that there is little discharge current while in the "store" mode; but, at the same time, small enough to allow only a small delay when acting as an amplifier.

The interconnection of the Signal Processing circuits is shown in Figure 13.

Optical Electronics

At the present time the visual indicator consists of a meter mounted in a box[17,18]. Illuminating lights reflect an image of the needle through an optical lens. A meter deflection one-half of full scale deflection will indicate that the vehicle is moving in the correct direction, that is, directly over the magnets. As seen from the previous discussion, the output of the summing amplifier will be zero when the vehicle is directly over the magnets. Therefore, it will be necessary to provide an offset voltage to the input of the output operational amplifier. With this offset properly adjusted, a negative voltage at the output of the summing amplifier will deflect the needle one direction while a positive signal at the same point will deflect the needle in the opposite direction.

VI. CONCLUSION

Four basic types of synthesis procedures were examined for the realization of $\frac{K}{s(s+a)}$. The State Variable approach was chosen for several reasons: 1) controllability of the K and a, 2) simplicity of the realized circuit, 3) high input impedance, 4) low output impedance, 5) economy of realization, 6) minimum number of capacitors.

The limiting factor in the gyrator procedure, and in any passive procedure, is the pole of the transfer function at $s = 0$. This requires a gain of infinity at D.C. which is impossible for passive physically realizable circuits.

The voltage at the output of the sensor electronics reached peaks as high as 2 volts before installation of the feedback network. After the network was inserted, maximum peaks were no more than one-half a volt, which only occurred directly following a pulse.

The cascade approach of State Variable synthesis used for transfer function synthesis in Section IV is not unique. Another cascade realization was tried and the end result was that the $\frac{K_1}{s}$ and $\frac{K_2}{s+a}$ blocks were interchanged. Using this realization, that is $\frac{K_1}{s}$ block following the $\frac{K_2}{s+a}$ block, resulted in saturation of the output operational amplifier. The integrator could not handle the signal level from the $\frac{K_2}{s+a}$ block without saturation. On the present circuit, which has the $\frac{K_1}{s}$ block followed by the $\frac{K_2}{s+a}$, there are no saturation problems.

The cascade approach was considered more favorable than other realizations such as "parallel" and "canonical" because of the number of operational amplifiers required. Typically, such realizations require a summing junction, which takes the form of an operational amplifier, in addition to the minimum number of required operational amplifiers. Thus, in the interest of economy, realizations requiring only two operational amplifiers were considered more desirable than circuits with three operational amplifiers.

The system presented in this thesis has been assembled in a prototype model. An automobile has been manuevered on a roadway using only the output from the summing amplifier (Figure 13) for steering correction. The circuits have not been optimized as the system is in the developmental stages.

A feature of this system which has not been discussed is that of sensing encoded data from the magnets[19]. Magnetometers are capable of detecting the polarity of the magnet over which the vehicle passes.

The pulses need only be gated through saturation inverters or Schmidt triggers for pulse shaping and then fed into logic circuits for decoding. A variety of data may be stored in the embedded magnets for system decoding, data such as the conditions of the oncoming roadway.

Further Work

Several simplifications could be made to the electronics of the system. With a proper choice of components, the Peak-Hold and Track-Store circuits can be combined into a configuration similar to that shown in Figure 15.

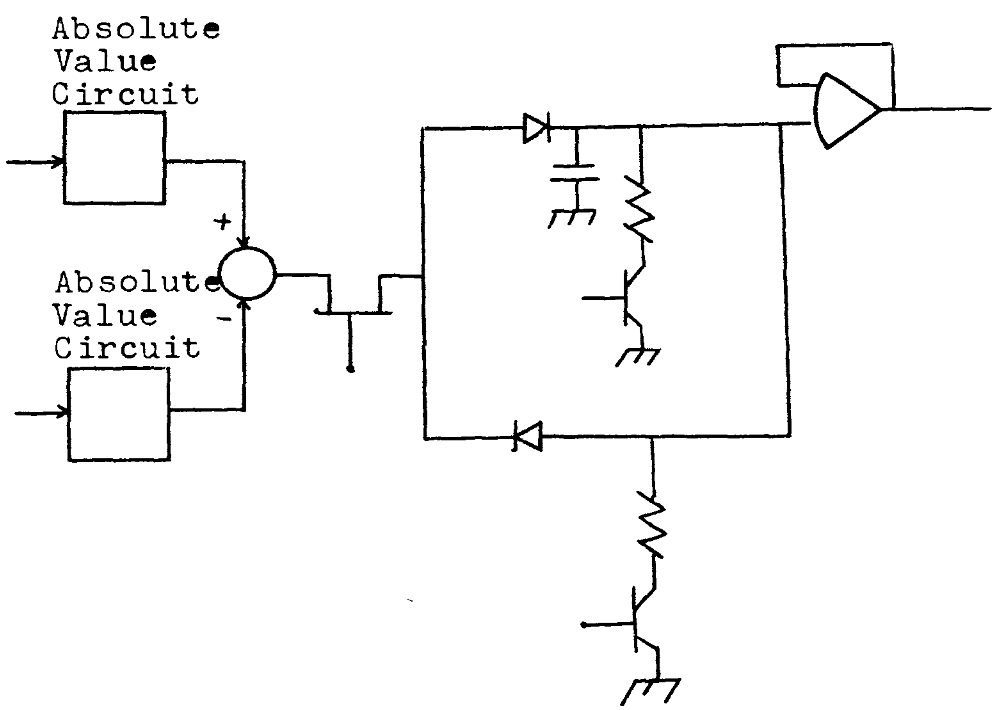


Figure 15. Proposed Signal Processing

With this circuit configuration, the FET switch is triggered so that it is closed during the pulse and open between pulses. The capacitors charge to the peak-pulse value and hold until reset. The reset pulse comes from a fast monostable oscillator triggered on the leading edge of each pulse. Output loading effects are minimized by using an operational amplifier.

This circuit will have only slightly inferior performance when compared with the original design, and use fewer components.

BIBLIOGRAPHY

1. Dunipace, K.R., "A Driver-Assisting Magnetic Field Control System for Highway Vehicles," Research Proposal at University of Missouri-Rolla, May 5, 1970.

2. Adler, Charles Jr., "Automatic Signal for Automobiles," April 28, 1931, United States Patent Office.

3. Harned, John L., and Eugene J. Marchewitz, "Vehicle Guidance System," May 8, 1962, United States Patent Office.

4. Reed, S.F., "Automatic Pilot for Motor Vehicles," November 14, 1961, United States Patent Office.

5. Krieger, H.B., "Steering Control System for Unmanned Vehicles," December 9, 1969, United States Patent Office.

6. Breuning, S.M., "Automated Highways: What is the Dream and How do We Reach It?," Technology Review, February, 1969.

7. Ross, H.R., "The Future of the Automobile," Science and Technology, August, 1908.

8. Wilkie, D.F., "Stability and Control Problems Associated with Magnetically Levitated High Speed Vehicles," Ninth Annual Allerton Conference on Circuit Theory and System Theory, 1971.

9. Sevin, Leonce J., Field Effect Transistor, McGraw-Hill, 1966.

10. "Digital and Analog Applications of Operational Amplifiers," Spectrum (IEEE) Vol. 8, No. 6, June, 1971.

11. Jobey, G.E., J.B. Graeme, and Lawrence P. Huelsman (ed.) Operational Amplifiers - Design and Application, McGraw-Hill, 1971.

12. Rekoff, Michael G. Jr., Analog Computer Programming, Merrill Books, Inc., 1967.

13. Marshall, Stanley V., Private Communication.

14. Mitra, Sanjit K., Analysis and Synthesis of Linear Active Networks, Wiley & Sons, 1969. pp. 381-389.

15. Calahan, D.A., "Restrictions on the Natural Frequencies of a RC-RL Network," Journal of the Franklin Institute, August, 1961.

16. Newcomb, R.W., Active Integrated Circuit Synthesis, Prentice-Hall, 1968.

17. Heyl, J., "Steering Error Optical System," Unpublished work, May 1971.

18. Parker, B., "Experimentation With and Mounting the Steering Error Optical Projector," Unpublished work, July 30, 1971.

19. Edwards, D., "Binary Coded Messages for U.M.R. Transportation Project Demonstration., Unpublished work, May, 1971.

VITA

Roger Allen Hayes was born in Harrisonville, Missouri, on May 6, 1949. He received his primary education in Maysville and Warrensburg, Missouri. After graduating from Warrensburg High School, Warrensburg, Missouri, in 1967, he attended Central Missouri State College for one term, then transferred to the University of Missouri-Rolla. He graduated from the University of Missouri-Rolla in May, 1971, with a Bachelor of Science in Electrical Engineering. As an undergraduate he was a member of Kappa Mu Epsilon and Eta Kappa Nu honor fraternities.

On December 19, 1970, he married Shari Lynne White, a graduate of Central Missouri State College at Warrensburg, Missouri.

He has been enrolled in Graduate School at the University of Missouri-Rolla since June, 1971. He has held a graduate teaching assistantship.