



Calhoun: The NPS Institutional Archive

Theses and Dissertations

Thesis Collection

1955

A study of factors limiting the utility of a digital memory system with nondestructive readout

Krohn, Stanley W.

Massachusetts Institute of Technology

http://hdl.handle.net/10945/14659



Calhoun is a project of the Dudley Knox Library at NPS, furthering the precepts and goals of open government and government transparency. All information contained herein has been approved for release by the NPS Public Affairs Officer.

> Dudley Knox Library / Naval Postgraduate School 411 Dyer Road / 1 University Circle Monterey, California USA 93943

http://www.nps.edu/library

A STUDY OF FACTORS LIMITING THE UTILITY OF A DIGITAL MEMORY SYSTEM WITH NONDESTRUCTIVE READOUT

Stanley W. Krohn and Thomas W. Robinson Library U. S. Naval Postgraduate School Monterey, California





A STUDY OF FACTORS LIMITING THE UTILITY OF A

DIGITAL MEMORY SYSTEM WITH NONDESTRUCTIVE READOUT

by N

Stanley W. Krohn U. S. Naval Academy (1950)

and

354Thomas W. Robinson, III5U. S. Naval Academy (1950)

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF NAVAL ENGINEER at the MASSACHUSETTS INSTITUTE OF TECHNOLOGY May 23, 1955

A TO TELLING THE OWNERS LIKETONS OF YOUTS A

TUDGARE SWITCHWIESONON NTEP METERS REGULAR SATISFIC

k -67

Bankey W. Stream

Dec.

Thereas W. R. Diseas, 10

AND ANTETTAD IN PARTIAL PULYILLAND, OF THE REQUIREMENTS FOR THE MODELES OF MAYAL ENCIMIEN, MACHACHORETTS INSTITUTE OF THOMNOLINGY MACHACHORETTS INSTITUTE OF THOMNOLINGY MACHACHORETTS INSTITUTE

A STUDY OF FACTORS LIMITING THE UTILITY OF A

DIGITAL MEMORY SYSTEM WITH NONDESTRUCTIVE READOUT

by

Stanley W. Krohn

Thomas W. Robinson III

(Submitted to the Department of Naval Architecture and Marine Engineering on 23 May 1955, in partial fulfillment of the requirements for the degree of Naval Engineer.)

ABSTRACT

The problem of determining the feasibility of expanding the system designed by General Electronics Laboratories, Inc., into a large practical array involves so many aspects that require concentrated study that this investigation was confined to a study and static analysis of the core and diode matrix scheme.

The immediately obvious problem was diede back leakage current. Whenever large numbers of crystal diodes are connected in parallel, the summation of individual back leakage currents at critical points may cause trouble by destroying stored information in a core, or by sufficiently reducing the net magnetizing force on the selected core so that proper readout is not insured. In addition, leakage currents generate directly on the output winding an unwanted voltage that may indicate wrong information when a core is read out.

To determine the size limitation imposed by the foregoing conditions, the diede matrix was analytically reduced, and the magnitude of total leakage current was calculated as a function of matrix size and read current. The pulse responses of the core used in the model in the "clear", "1", and "0" remanent states were then obtained for currents in the range of interest. The core response data was then correlated with the matrix analysis to find out which condition was the limiting one. Interpretation of the data was made under the assumption that the memory core and diede characteristics were identical.

The results included:

- Leakage current output voltage is a function only of total leakage in a z - plane and is of the same sign as the readout voltage.
- The use of silicon point contact diodes allows a much greater matrix size.
- For small disturbances, the magnitude of the output voltage of the core is independent of the state or the direction of the disturbance.

フェフラノ

A THE WALLEY DAMAGE DOMESTICS, CONTRACT OF THE OWNER, AND

REGITAL PURISH STRUCTURE PRIVE STRUCTURE RELATION.

104

Annulug W. Revine

Dimension, W meaning

An experiment in the Discovery of Diversi Areatimetrics and Marrison Parameter and Angeles and the second statements for a second statement of the respectements for a second statement of the respect sources of the respect sources

TRATILIS.

Who perchase of metrymiting the Accelhics of reputiting the systems destgrad by Germands (Rentzoutch International International

"The boloomitately sholves produces to a state that back bounds contrasts whenever beings members of expected theirs and consected to preain the exercise transfer by destroying states beinges excrement or consected to preain the exact transfer by destroying states before the formation (mode any exact the transfer by destroying states) before and on the state of the restance transfer by destroying states before and on the cores, we by and the integer the set magnetizing inverse in the before whether a cores, we by and the setted to not heavied. In obtigine, isology contrasts prove as the presence the setted of setting in monorability where the rest in the set of the set the setted of setting the rest of the setting the set of the setting of the first setter to the setter of the setting the set of the setting the setters.

To delay the distance has also functioners impossed by the droughing come drifting, the distance massive was analytically restand, and the magnimum of restricted. Instage converse was indecided as a function of matrix also and wat craves. The pulse compares of the core and in the matrix also in the "chait" of belower, the state mapping data on the interview of the test of the range of belower, the test velocit state was the interview of the correct of the range at the test of the core mapping data and the interview of the range of belower, the test velocit state was the interview of the range at the test of the core test the interview of the test of the range at the test of the interview of the interview of the test of the range at the test of the core responded the interview of the test of the range. The provide test of the test which could the interview of the test of the test of the state characteristics were the interview of the test of the test of the state characteristics are the interview of the test of the test of the test of the state of the test of the interview of the interview of the test of the test of the state of the test of the interview.

denbulant attactive bill

- -Stabil Fabril in when noticeast a at spatters inspire interest spatters? (I regardler involves why as again access all the at heat second a at spa
- 11 The was of altitude pulses a containt (Souties attance a mark grouped matrice kine.
 - b) Fee evenil distantions into the suggestance of the option vestage of the care to baspinsten of the side at the distantion of the distantions.

The conclusions and recommendations included:

- Leakage current output voltage is the factor that limits matrix size.
- Good reliable operation may be obtained from a 32 x 32 size s - plane matrix.
- 3) The operation of z 64 x 64 size z plane matrix would be marginal at best.
- 4) The existing device may not be operating under optimum conditions. At the read current value of 100 ma. used, the cores do not give the maximum difference between "1" and "0" readout voltages.
- 5) The use of clipping instead of reference core comparison technique, or the use of a reference core different from the memory core will greatly increase the limit to which the matrix may be extended.
- 6) A complete dynamic analysis should be made to determine if a limit is imposed by diode shunt capacitance and core inductance.

Thesis Supervisor: Thomas F. Jones, Jr.

Title: Associate Professor of Electrical Engineering

designed and other and the second second second second

- b) Lookings measure renew veloce (white is the famous due) Weren particular state.
 - he is he a second an and the similar and the similar is the second of the second secon
 - 3) The equivalence of a full p b6 stmit p platin midole model be many bidd at board.
- 9 The extention thereas arene out he opporting reduct splitunes cause different. All the stand partners value at 110 art, much, the respontion at also the constraint intervals intervals. (1° and 10° readers voltages).
- 9) This as a digiting instant of ordereses warr conjection leads ridges, or the use of a reference core different trees the movement entry entry will greatly hereware the field to within the maintar may be unreased.
 - M. A complete dynamic analysis provid be main in discreteles if a time is interprete by discis eless organizations and they delegance.

There's Supervisent Tamone F. Joorn, St.

Titles Annexima Protecter of Sherinders! Southerston

ACKNOWLEDGMENTS

In bringing this project to a close, it is with pleasure that we express our gratitude to those people who have contributed to the work involved. We are especially grateful to Professor Thomas F. Jones, Jr. for providing the stimulus which initiated this investigation. As thesis supervisor, he was helpful in more ways than can be told here.

We are also indebted to Mr. Bernard Widrow for his technical advice and assistance. His encouragement and foresight were instrumental in helping us to surmount many of the difficult, technical aspects which faced us.

Thanks are due Mr. William Hogan of Sylvania, Inc., Mr. Kenneth Perkins of General Electronics Laboratories, Inc., and to Miss Edith Repshis for her able secretarial assistance.

ATTEMENT OF POLICE

balancedeg this project to a store. It is well, generality granted to be appeare the grantitule in them panyle who have equivilated to the verse involved. We now exposiblly granted in Protectours: Themas 21, itsees, in We now exposibly granted in Protectours: Themas 21, itsees, in We now exposibly granted in Protectours: The best set in the state of the providing the state fact in Protectours: the the three the state of the providing the state fact in the state of the state of the state in the state of the state in the state of th

We are also haldened to this, the passe of blows for the body, sheat advice and analatures, (the announgement and forweight were hartersounds) to helping to in eccentral owney of the differing backs when aspects which there us.

These are the Mit. Witness Higgs of Spiraring, Inc., Mr., Wassett Frykton of Ground Kontentin, Abbrewinning, Inc., and th Mias Billin Beyerkie for her able secreterial assistance.

TABLE OF CONTENTS

Title

Abstract

Acknowledgments

X	Introd	uction.	• •	e o	•	•	\$ •			٠		•	٠	0	3	•		8	1
п	Proce	dure		3 0	(8		n e	•	8	•		ø							5
III	Recult	s	9 0	0 0	v	•	• •	đ	9	\$	٠	•	ъ	•	a		3		6
IV	Discus	ssion of	Resu	lte			• •	•		٠		*			•	•		•	7
V	Conclu	sions.	•••	• •		•			•	•	3	٠	*	٠	Ø		٠	3	15
VI	Recom	menda	tions	• •	•		• •	•	٠		•			3	æ			a de la del	6
VII	Append	dist		• •	• •	•	• •	•	¥		9	0	•		з	•	•	1	.7
	A.,	Detail	s of F	700	ced	lure	Ł .			•	٠	a		19	•	•	•	1	8
	8,	Summ	ary o	f Da	ita	8.19	d C	ale	cul	at	lor		w	•		•		1	24
	C.	Sampl	le Cal	culi	atic	ans	•	•		•	•	9	•		9			2	15
	D.	Supple	ment	al L)is:	cus	sio	M .,	•	G	•	4	•	9	٠	+	9	2	17
	E.	Origin	nal Da	ta.	3	•	•••		9	•	w	•		w	9		•	2	19
	F.	Eiblic	graph	y.											a	•		17	0

Page

LTMU BYOCH RAD BLERAS

	10x2							
	Assessed a							
	wine or the first state of the second state of							
I		5		8	¢	v	-	: :
-			7	n		D	*	~
m	Mandra			æ	~		×	a .
91			л b					,
								2.8
- 4	Newsman Andrews and the second		0 1			,	8	45
ww.		n q	r 6	P	,	3	Q	
	A. Totalia of Pressentions			er	ą,	÷	ð	-
	II. Automoticy of Data and Colombalant	in i	4			,		44
	G. Marghe CalcyleSone	•	• •		í,	7		25
	11. Supplemental Phoneselan		• Å					<u> </u>
	T. Delyine Date	ə 19	9 0	÷	7	ø	1.	25
	N. Stillegradity .							ar.

INTRODUCTION

The basis of the nondestructive readout method developed by General Electronics Labs. Inc., and tested in a sinteen word breadboard model is minor loop permeability. Bozorth (1) shows how minor loop permeability varies for different remanent states. For a stable remanent state near the maximum negative remanent state, the ratio of minor loop permeability to the permeability at the undisturbed zero (maximum positive remanent) state is approximately 2 to 1.

In Fig. I, stable remanent state "A" is defined as a "1". Normally, maximum negative remanence is given this designation, but in order to proceed logically from the work already done on this method, the notations previously established will be continued. If a core in state "1" is pulsed positively to H', the magnitude of the output doublet voltage which appears across secondary windings will be approximately twice the voltage that would appear if the core were in the "0" state. Since state "1" is stable, a readout pulse of magnitude H' may be applied an infinite number of times without destroying the state, and the intelligence stored by the core may be determined by the secondary voltage magnitude. The advantages of this nondestructive readout system over the presently used read - rewrite system of coincident currents is felt not to be a part of the objectives of this investigation.

Two practical ways of differentiating between the '1" and "0" read voltages are clipping and reference core comparison. In the first,

MOSTO DE CUITRE

The bards of the contextension resident context the solution of the solution o

In Fig. 6, enclose respective remeasurer (figur 2, " is automather 2, ", providently, mead-more requires remeasurer is given this finance, we take but is creater to present logically from (in word already date to the mathemat, line measured or providently in 0", the completent, if a datablet voltage which appears remean eccentry withfield of the comp datablet voltage which appears remean eccentry of the engletistic of the approximation of the entire of the vector of the completent of the comp datablet voltage which appears remean eccentry withfield of the comp datablet voltage which appears remean eccentry withfield of the comp data of the entire of the vector of the second second of the comp data of the second of the second of the second of the comp data of the complete of the entire of the second of the comp second of the field of the field of the second of the comp remeted of the field of the termine of the second of the second of the remeted of the termine of the second of the second of the second of the remeted of the termine of the second of the second of the second of the remeted of the termine of the second of the second of the second of the remeted of the second of the second of the second of the remeted of the second of the second of the second of the remeted of the second of the second of the second of the remeted of the second of the second of the second of the remeted of the second of the second of the remeted of the second of the second of the remeted of the second of the

Two prectical ways at Millerensizating belowers the 11" and "6" read work workages are offering and relevance into a comparison, in the first,

Ľ



the maximum "0" output voltage would be determined, and circuits would be designed to exclude all signals below that level. In this manner, the output from a stored one would yield a signal but the output from a stored zero would not.

The second method compares the output of the memory core with that of a reference core which is always in the zero state. The cores are pulsed identically and simultaneously, and the outputs are fed to a difference amplifier. If the memory core holds a zero, the comparison with the reference onre in the difference amplifier will theoretically yield no output, whereas if it holds a set, there will be an output. General Electronics L. b., chose this method in constructing their working model.

To show how a memory matrix may operate on this principle of nondestructive readout, a 4 by 4 by 4 matrix will be used as an illustration. Fig. III is the circuit diagram of the memory. Included on this figure are wiring diagrams for both the reference and memory elements. Fig. II shows the spatial configuration of the matrix.

The matrix capacity is sixteen words of four binary digits per word. The four cores with the same (x, y) coordinates in all four x - planes make up one word. The X and Y drivers work in pairs, so that the selection of drivers X_n and Y_m pulses the word (x_n, y_m) . Each word has a reference core associated with it, and each core has a forward and back diode associated with it.

Pulsing a word through the "clear" circuit sends a 100 ma. pulse through twenty turns on each core in the word, and drives them all into

the manifesta "I" exignit voltage vents he determined, and chevalus maint in designed to contrate off signals before that herein. In this minners, the exignit frace a second we would plath a signed her the cutput draws a marked ways would not.

The second motion compares are separated the compare process were that of a reductory cases which is atomys to the avery sime. The respectance proceed theoretically and simulationsmulp, and the outputs are ded to a difference acquisition. If the processry even boble is more the procession with the reductories to up in the difference and files with the sampachine with the reductors to up in the difference and files with the as theorem and y field on outputs whereas if it holds a test, there will be an everyon. Second Marchender Labo, character the restrict to restricting their warding would be reducted to the second of the restrict to the second test working would be accessed with the second of the restrict to the second their working would be accessed with the second of the restrict to the second test working would be accessed to the second of the restrict to the second test working would be accessed.

Yes along have here a measury nontriticancy spacety on this principle of mandal transition reachest. a 4 by 4 by 4 contents will be need to no Minestra-Here. Why, We the sizeway diagrams of the restorance. Enclosed on this Represence are winted the granter for both the restorance and measurery elements. Why. It shows the spatial configuration of the restorance.

Whe manyth coperity is statemed words of feer binary digits perword. The lists crows with the second (x, y) constituents to all time a - glasses tother up one cance. The X and Y determs work to pains, we that the estection of detects X, and Y, galace the verd (oge Ym). State tweed has a reducence core towardated with the and each core has to ferenced and having distribute another toward to the second to a second to the second to ference and having the second towardated with the and each core has to corrected and having the second towardated with the second core has to the second and having the second towardated with the second core has to core and the second to the second towardated with the second core with the second core has the

Putateg a word through the "stear" streats and a 100 me. pales, meruph tweety terms in such come in the word, and drives them all icos

ĸ



FIGURE III - CIRCUIT DIAGRAM OF REGISTER FOR STORAGE OF 16 4-BIT WORDS



the maximum negative romanent state. At the same time, reversed current connections on the reference core associated with the word drives it into the "0" or positive romanent state. The clear condition, then, is all memory cores in the maximum negative romanent state and the reference core in the "0" state.

To write a "0" into a memory core, the appropriate X, Y, and Z drivers are energized. The X and Y drivers in combination, and the Z driver, each supply 100 ma. through ten turns and switch the designated core into the "0" state. All other cores in the z - plane and all other cores in the word are disturbed from the clear state into the stable "1" state by a magnetizing force of one ampere - turn, since the Z driver selects an entire plane and the X and Y drivers select a whole word. The reference core state is not disturbed because the write - zero pulse is in the positive direction, i.e., in such a direction as to drive it further into the "0" state.

Writing a "1" into a core merely requires that the core be disturbed by 100 ma. through ten turns. Ones are written into whole words at once by selection of appropriate X and Y drivers.

Similarly, in reading out, an entire word is read out at once. Each z - plane has its own output winding which threads all cores in that plane. A selected combination of X and Y drivers pulses z word and its reference core with one ampere - turn. This amplitude read pulse will not disturb cores from their stable states. One core in each z - plane is therefore energized, and the output of each z - plane is

the ministerious segretion concerns one. At the same these, reversed, everyond connections on the treference once associated with the word drives it late the "0" or publics everyons size. The clear condition, then, is all memory cares in the resolution agains revasient state and the redirence care in the '0' state.

e

The writes a "0" bain a mannery case, the symposymbol X, Y, and Z drivers are margined. The X and T drivers is conducting, and the H drivers, and anypity 100 cas, showing ben turns and switch the dasigneted core into the "0" state. All other norms in the a - place and all enter some in the work are disturbed from the clear state into the station "1" state by a conquesticing force of an anyone - bers, since the Z driver selects an ortice place and the X and Y drivers advant whole word. The references over state in the intermined income the state over pales to the positive dimension, i.e., in such a direction as to drive the first the positive dimension, i.e., in such a direction as to drive the fortune the "0" units.

Writing a "1" Late a core marshy requires that the nore to distanted by 168 ma, through test terms. Once are written into whole mores at more by selection of appropriate X and Y drivers.

Much to - plane has be reading and, an antise upped to read not at once, Such to - plane has be own subject whether which clownda all cares is that plane. A selected coordination of it and T detwark putses to wood and the reference core with our acquero - man. This amplitude week palse will not disturb cares from their stable uniter, for ours in carb compared, in a difference amplifier, with the voltage output of the "0" state reference core of the selected word. This readout process may be repeated an infinite number of times without destroying the intelligence on the cores. Reading out and writing cases are identical operations insofar as the drivers are concerned.

For further information concerning the actual circuits and operation of the breadboard model constructed by General Electronics Labs. Inc., see (2).

The Diode Matrix

Fig. III shows that paralleling the core matrix is a diode matrix, the purpose of which is disassociation of the "clear" and "read - write" circuits. Since the diodes are not parfect, some leakage occurs. As the matrix is expanded in size, more back paths through the diodes are put in parallel, increasing the total leakage current. These individual back leakage currents may combine at points in the matrix. If the combined leakage current is sufficiently large, it may cause trouble in three ways. It may disturb the remanent state of a core. It may generate an unwanted voltage directly on the output winding that causes the indication of wrong information. Finally, it may reduce the net magnetizing force on the selected core sufficiently so that its "1" voltage output when readout cannot be differentiated from the "0" output of the reference core.

Longuesed, in a difference amplified, will the relation of the 70 state roleses, are a fifteeness and the set of the ranked irrects a new be repared on tailable product of their vision destroying the familiegrain of the cores. Supply of your will are set in their pass and the first and the transfer to the cores. Supply of your will are set in the set in the set of the transfer.

For Arrange (Arrenting muscrosting the error) chrodiends and spectation at the heaviloant model constructed by Gaucial Theoremics Labor 1st., son (3),

has been merry or a set of second making the party

which the bit with

3%, With the propose of which is the constituting the same builded in a filede matches the perspose of which is these contains of the "time" and "mail " wells" "developed is which is these are an product, some periods blocks. As the materia is essential to the, here well periods, some periods to the part to persibely formation to the, here well periods. These holl which had be persibely formation to the secondars of points in the same holl which had be independent to the secondars of points in the same results. If the same back materia is an exact particularity target, is may annot result to these an events is settinized in the secondars of a first of the same is non-angle. If the formation is a secondary to the the same results for the same result. If the formation is a secondary to the first of a first of the same is a second to the settinization of the secondary is and a first of a first of the same of the state of the secondary is a secondary to the second for the same result of the secondary is a state of a first of a first of the same state of the interval is a second to the secondary is a state of a first of the interval is a state of the state of the secondary is the secondary of the second to the secondary is a state of a first of the interval is a state of the state of the secondary is a state of the secondary of the second the secondary is a state of the secondary of the secondary is a state of the secondary of the secondary of the secondary is a state of the secondary is a state of the secondary of the secondary of the secondary is a state of the secondary of the

of some on the property section and and and a state of the

PROCEDURE

The diode matrix in Fig. III was redrawn in three dimensions without the cores as shown in Fig. IV-A. When the assumption is made that all diodes are identical, it is possible to reduce the three dimensional matrix of Fig. IV-A to the simple parallel circuit of Fig. V-A. Use of this circuit is conjunction with forward and reverse low voltage characteristic curves for the 1N56A (the diode employed by the system under consideration) permitted the calculation of leakage current versus read current for various values of matrix size.

The voltages on core output windings for low ampore - turn inputs were obtained in the laboratory. A continuous spectrum of this leakage voltage was obtained for the three different states in which the core could be, the clear state, the "1" state, and the "0" state.

The matrix leakage paths were analyzed to determine the locations of the "critical" points where all or many of the individual leakage currents combined.

The laboratory data was correlated with the diode matrix analysis and the leakage path analysis to estimate to what approximate size the matrix could be extended before one of the three troubles previously mentioned blocked a further increase in size.

Propagate and a second se

The damin cannot be Yig. 121 year restricts to three damaged on a series of the series

We retrage an over retract static for the surgers - term topers were strated to the informative, 'A continuous developed of the indexing estrates were strated for the firm difference developed of value for and would be the sizes spece, the "E" strate the "e" strate.

The scaleful balatic paths mere analysed to decreased the lates of the

The biosterrowy data was accessively with the Aleke rendering startpath and the backage and analysis to extended bi which approximates start the context pould be redevided before one of the three brechtal previously meetinged bracket a feetber brownes to star.





RESULTS

1) For small ampere - turn magnetizing forces, the magnitude of the voltage output of the core is independent of the state of the core or the direction of the magnetizing force. Fig. VI shows the voltage output curves for a core in the "1", "0", and "clear" states when pulsed positively. The curves are identical up to a value of about .2 ampere - turns.

Leakage current output voltage is a function only of total
leakage current in a z - plane.

3) Leakage current output voltage is of the sense to add to the "1" and "0" output in the z - plane output winding.

 Leakage current output voltage is independent of the "z" direction of expansion.

5) Total leakage current increases with an increase in read current or matrix sizes. See Figs. VII and VIII-A.

6) A selection magnetizing-force current of 1.1 ampere - turns yields a higher "1" to "0" output ratio than 1.0 ampere - turns used in the system. The plot of the output curves for these two remanent states is shown on Fig. VI. Increasing the read current to some higher value will ease the problem of differentiating between the 1" and "0" outputs.

7) Fig. VII shows one curve for silicon diode, Transitron type S-5. The leakage currents computed for a 256 x 256 size matrix using these diodes are less than those in a 50 x 50 size using the 1N56A.

ě.

1) For avoid anyone - term sugnating forces, the maguitode of the volcage compated for ever to independent of the state of the ever as the direction of the meganianty face. Fig. VI shows the voltage anyot curves for a core in the '1', '0', and 'chart' orden when pated positively. The curves are identical up to a value of about .3 anguine - farms.

31 Leakage currant entres volvage is found to a found to all of initial leakage mercant in a - plane.

3) Louisage excession compute voltage is of the sense to add to the "i" and "0" solged in the s - plane subject winding.

*) Lookage current incost voltage in independent of the "s" direction of expansion.

5) Total leakage overend formance with an formance in read ourters as matrix stees. See Figs. VII and VIII-1.

b) A solaction magneticing due correct of \$, \$ impress - ieros platies a higher "1" to "0" sequel ratio than 1, 0 angers - terms tool in the system. The plat of the opped nerved for these term remained in it shows on 3%. We hereasing the rest opped normalise to mode higher value will save the problem of differentiable between the 1 and "0" sequence.

71 Hig. Vil abases can express day eliform iteles. Transitions type 2-5. The instage corrects concepted for a 256 o 256 also vestors taked black Hodes are been itsey three in 57 a 50 also using the 1198.















DISCUSSION OF RESULTS

Matrix Analysis of Leakage Paths

The exact locations of anticipated trouble conditions were established in general terms by analysis of the leakage paths shown in Fig. IV-B.

If the word at (x_1, y_1) was selected to be read, all cores in every x - position on the y_1 line, except the selected core, could have its remanent state sufficiently disturbed so that the output voltage would indicate a "1" when a "0" was actually stored. This is seen by observing that the magnitudes of the leakage currents through the "clear" and "read" windings of cores in positions $(x_2, 3, ..., y_1)$ are approximately equal. The "clear" winding has twice as many turns as the read winding. Therefore, the net effective magnetizing force on the core is from the leakage current in the "clear" winding which tends to disturb the cores toward the negative remanent or "clear" state. If the core is disturbed sufficiently (not necessarily all or even most of the way to the "1" state) its output voltage when read at a later date could be large enough to indicate a "1".

It is also seen that the same magnitude of leakage current in the above "clear" windings also flows in the "clear" winding of the selected core. If this leakage current is sufficiently large, it may reduce the net read magnetizing force to such a value that a "1" output voltage is reduced so that it may not be differentiated from the "0" voltage of the reference core.

TIUS TO TO MOLEUTE

Matthe Assisted to May 1 and a state

The eract locations of anthripated trouble conditions were established in general towars by analysis of the balage paths shows in Fig. IV-m.

If the word at (u₁, y₁) was subscred to be read, all cores in every z + position on the y₁ that, encapt the subscript due antyper voltage have its summanni state sufficiently theorem an that the antyper voltage would indicate a '1' when a "0" was actually stored. This is seen by observing that the magnitudes of the instrage correctes through the "cleaks" and "weat" whether a "0" was actually stored. This is seen by "cleaks" and "weat" whether a "0" was actually stored. This is seen by approximation the magnitudes of the instrage correctes through the asyst actualed winding. The "clear" winding has reter as many turns as the read winding. Therefore, the set affective magnituding force on the cure is from the incharge current in the "clear" winding force tends to disturb the entrop toward the asynthese remained or "clear" tends to disturb the entrop toward the asynthese remained or "clear" and the way to the "(" state) is any to in any to the "(" state) is antiput when any to the "clear" is antiput to indicating to the seconstating a the means of the way to the "(" state) is antiput with a state of the seconstating at a latter (as a gould be intege sound) to indicate a "it approximates a "it and a the state of the way to the "(" state) is a subject with a state of the seconstating at a latter (as a gould be intege sound) to indicate a "it approximates a "it and a the state of the seconstating the intege sound) is antiput with a state of the seconstating the intege sound is a "it approximates a "it approximates as "it approximates" is the state of the state of the state of the intege sound is the intege sound in the intege sound is a state of the intege sound is a state of the state of the

It is a bits above that the move mugatrate of loatage correct in the above "clear" whethaps also flows to the "clear" whethap of the selected cores. If this basings corrects to exclusionshy large, it may reduce the set read magnetizating force to each a value that a "1" maynet woltage is reduced as that it may not be differentiated from the "0" However, if these leakage currents are traced back through their paths, it is established that the sum of both the "clear" and "read" leakage currents at $(x_2, 3...n, y_1)$ flows through read windings at core positions $(x_1, y_2, 3...n)$. The effect of these currents is to generate an unwanted positive voltage on the output winding. If the selected core stores a "0", this leakage current voltage adds to the "0" output voltage from the z - plane and the sum may be sufficiently larger than the reference core "0" voltage to indicate a "1". It is very important to note that this leakage current voltage also adds to a "1" output voltage of the z - plane.

Let I_1 equal the read current, I_2 equal total leakage current, I_c equal leakage current in "clear" winding of the selected core, and n equal linear dimension of matrix size.

Then for n = 75 (75 x 75 matrix), at $I_1 = 100$ ma., $I_2 = 33$ ma. The maximum leakage current in the "clear" winding of the selected

core is
$$\frac{I_2}{2 n-1} = \frac{33}{149} = .2215$$
 ma. The ratio of $\frac{I_1}{I_c} = \frac{100}{.2215} = 452$.

For $\frac{I_1}{I_c} = 100$, the ratio of; $\frac{\text{net magnetizing force on the core}}{\text{magnetizing force from I_1 alone}}$ is .98 (I_c flows through twice as many turns). Since the read H = 1 amp. turn, the net H on the selected core equals .98 amp. -turns. This reduces the magnitude of the "1" output voltage by only $\frac{1}{200}$ of a volt or 5 mv. (from Fig. IX-B). Since the ratio, $\frac{I_1}{I_c}$ for n = 75 is more than four times 100, the ratio of magnetizing forces is even closer to Moreauro, I cheek healengs marrente and that the brough

1

these parties it is notablicated that the sum of both the "disser" and "react" hadings commute all (20, 1, ..., 2, 3) (how dissuph read whilhogs at core positions (10, 9, 3, ..., 1). The allows of baces corrects is to processes in any model plottered voltage on the access stating. If the delected the any model plottered voltage on the access stating. If the delected the astrona is a "0" this indexe correct voltage adds to the "0" black to be reference on "0" this indexe correct voltage adds to the "0" black to a state of the set of the analytic and the set of the subjected of the reference on "0" this indexe with the analytic adds to the "0" black to be a state of the set of the set of the set of the set of adject when the reference on "0" with the set of the set of the set and the set of the set of the faile of the set of the set of the set output voltage for a farmer on the set of the set of the set of the set adjected of the set of the faile of the set of the set of the set of the set adjected of the set of the faile of the set of the set of the set of the set output with a set of the set of

there, the not H an the velocied area rights. If area, endows. This real rests is a rolt real of the rolt of the





Test Equipment Set-Up for determining small **beine** voltages from memory cores.

1.0. A matrix of n = 75 is already past what is considered marginal operation by reason of leakage output voltage. (See Correlation of Core Data with Matrix Analysis). Therefore, it is determined that this situation need not be a consideration in expanding the presently existing system, since its size is already limited by another effect of leakage current.

The leakage current through "clear" windings may destroy information if large enough. Let $I_2 = 33$ ma. (n = 75, $I_1 = 100$ ma.). The H applied to the cores at $(x_2, 3, \dots, y_1)$ from the leakage current in the read winding is: $\frac{I_2}{2 n-1}$ (10 turns). From the clear winding: $\frac{I_2}{2 n-1}$ (-20 turns).

The net H is the sum of the above:

Net H =
$$\frac{I_2}{2 n-1}$$
 (10 - 20) = -2.215 ma. turns.

This is much too small to disturb the remanent state sufficiently to increase the output voltage of a core when read out at a later date. Again matrix size is already limited by another effect of leakage current.

Matrix Analysis of Diodes

Total leakage current was found to be a function of I_1 the selection current, n the linear dimension of matrix size, and the characteristics of the particular diodes used. Forward and reverse low voltage characteristics of the Sylvania 1N56A, the diode used in the system under consideration, obtained from the manufacturer 1.0. A matrix of a = 73 is already gast what is considered marginal operation by reason of habings output roltage. (See Correlation of Core Burn with Matrix Ambiyand). Therefore, it is determined that this simular seed art by a consideration in expanding the presently existing system, since its size is slowedy Undeed by somher effect of lesinge correct.

ę

The leadings current through "clear" windings may destroy to information if hargs suragh. Let lg = 33 res. $(n = 75, 1_1 = 100 \text{ cms.})$. The H synthed to the cores at $(n_2, 3, ..., n^2, y_1)$ from the leadings current in the teaching current in the teaching $(1, 2, 3, ..., n^2, y_1)$ from the clear whethag: It the read winding in: $\frac{1}{12n-1}$ (10 turns). From the clear whethag: $\frac{1}{2}$ (-20 turns).

The nut H in the sum of the above.

This is much too would be disturb the permanent state sufficiently to increase the output voltage of a core when read not at a later date. Agein matrix size is already limited by another edited of leakage current.

subold to already sizes.

"finitel bulkage current was found to in a function of 1, the softenion currents, is the linear description of estimat time, and the characteristics of the particular division and. Forward and reserves for voltage characteristics of the hybridia firsh, the linds used in the system under countiversity, obtained from the manufactures (Figs. X and XI) permitted the calculation of the magnitude of total leakage current for any matrix size and given value of I₁. These results are plotted in several different forms in Figs. VII, VIII, and VIII-A. The curves show both the manner in which total leakage current increases with matrix size and magnitude of read current, as well as the relative absolute magnitudes of total leakage current. A significant system improvement was noted over the germanium diodes with the use of a silicon diode. Transitron type S-5. It was necessary to increase the matrix size to 256 x 256 in order to obtain leakage current magnitudes to permit plotting on the same scale of Fig. VII.

Memory Core Characteristics

Theoretically, core output voltages should depend on the remanent position of the core on its hysterisis loop, being proportional to the incremental permeability at each remanent position. When output data was taken for the three possible remanent states of the cores as used in this system, it was found that the curves of output voltage versus magnetizing force were coincident up to a magnetizing force of about .2 amp.-turns. It is felt that the reason for this lay in the accuracy limitations of the test equipment rather than the actual core characteristics being identical for all three remanent states. In the measurement of the extremely small output voltages from the small magnetizing forces which would result from the magnitudes of leakage currents found in the diode analysis, differences in (Figs. 3 and 33) parminas the calculation of the magnitude of tend hadage current for may restrict size and given value of 1. There senote are plotted in second filter on forme in Figs. Vil. Vil., and Vil.-1. The correst share bolk the manner in which theil here, a observe increasing with manufactions and magnitude of read transport, in wolf as the autointé analise the second magnitudes of tead transport, in anothe the autointé analise size was able to a second all a lange with the one of a affect disc and an added over the permanant disks which the one of a affect disc of 35 a 250 is order to officia toring a because the matrix affect disc a 250 is order to officia toring. Vil.

Manuary Gone Character Letter

The period and the core point valuage should depend on the reasoner peeifour of the core on the hystarials trop, being proportional to the increasents' permetability of tack remained peeblas. When output that was teles for the three perceble concerns return of the cours as used to this optimized for a superiol control the for a wages gos voltage warane magnetized for a vers found that the concerns of set of the taxes of about . 2 are proved that the tenace of the thing for the second return of the test secondities of the thing for the accuracy firstitutions of the test secondities of the lifeting for the accuracy firstitutions of the test secondities the test actual once characterizations of the test second, and the second states the second return of the second result of a second states. In the resourcement of the second result of the states, in the second return of the second result of the states of based return and the test second, and there respect the second one the resourcements of the test second, and there respect states is second return to a second result of the states of based and the second result for a second result to be the second respective test of the second result from the second states of based as a second result of the second which would result from the maps -

 B_{i}^{i}







output voltages between the core states were not measurable. Because of this, and since the output voltage curves appeared to be coincident near the origin, with a constant slope, the assumption was made that any actual differences of output voltage for the remanent states would be negligible up to a magnetizing force of .2 amp.turns.

When the magnetizing force was increased to values near the region of operation, it was found that an appreciably higher "1" output was obtainable. The response of a "1" for a read current of 110 ma. was plotted on Fig. IX-B to illustrate this. Bozorth (1) shows how incremental permeability varies for different remanent states.

Correlation of Core Data with Matrix Analysis

Every core with leakage current in it will generate a voltage on an output winding. A general analysis of the matrix using established magnitudes of leakage current, core voltage output data, the equivalent circuit of Fig. V-E, and the number and direction of core windings, was made to determine a final magnitude of output voltage from leakage current. It was found that all the leakage voltages from cores associated with the two parallel branches cancelled, leaving as the only leakage output voltage that generated by the cores associated with the set of forward diodes in series with the parallel branches of Fig. V-B. These cores, in the case of a selected position of (x_1, y_1) , are at the $(x_1, y_2, 3, ..., n)$ positions previously mentioned. In general outget voltaget hotmeen the cure stairs were not contourbite. Second this, and share the outget voltage curves appeared to be coincident near the origin, with a constant slope, the assumption was made that any actual differences of outget voltage for the ramatents.

When the magneticing force was merased to values near the region of peration, it was found that an appreciably bigher "1" sutput was obtainable. The response of a "1" for a cost current of 210 near was plotted on Fig. Et.-B in (Domrate chis. Braosth (1) shows bow incrumental percendifity varias for different remained states.

Correlation at Core Date - the Matrix Analysia

. Swary core with insings correct to it will generate a voltage on an oniped winding. A general nearly is of the matrix using whelethered magnitudes of leakage correct, core voltage output data, the equivalent directs of Fig. V-2s, and the muscher and direction of core windings, whe made to determine a final massion and direction of core from beamage surrect. If whe finand that all the beamage voltages with the outy temage surrect. If whe finand that all the beamage voltages from still the outy temage surrect. If whe finand that all the beamage voltages drawn the outy temage surrect. If whe finand that all the beamage voltages drawn with the outy temage surrect. If whe finand that the provide of output voltage of the outy temage surrect. If whe finand that all the provide of the survey of the outy temage surrect. If whe finand that all the provide of the survey of the output temage surrect. If whe finand that all the provide of the survey of the output temage is a survey of the provide of the survey of the output temage is a survey of the provide of the survey of the survey of the transform of the survey of the provide of the provide of the output the the transform of the transform of the provide of the provide of the the the test of the survey of the transform of the provide of the provide of the survey of the test of the transform the survey of the provide of the transform of the test of the test of the transform the survey of the provide of the test of the test of the test of the test of the provide of the test of the provide of the test of the t terms, for a selected position of (x_n, y_m) all cores on the x_n line, less the selected core, will generate output voltages from leakage currents.

The magnitudes of leakage output voltages for a series of leakage currents, which were identified with matrix sizes by holding I_1 constant at 100 ma., were calculated and plotted against matrix size in Fig. VI. In addition "1", "0", and "1" - "0" voltage magnitude levels were drawn on the same figure.

As previously noted, the leakage current output voltage is added to both the "1" and "0" output voltage from the memory cores. However, the magnitude of the reference core "0" response is fixed. This means that if a 0" is to be read out of a memory core, leakage current output voltage may add a sufficient amount to the total output voltage to have the sensing amplifier indicate a "1" response. The matrix size 64 x 64 was determined to be marginal by the following somewhat arbitrary reasoning.

This is the size where the "1" - "0" difference voltage is reduced by approximately one half, and it will be reduced even more by statistical variations in core and diode characteristics. Consistent detection of ones and zeros with very small difference voltages requires extremely careful engineering of sensing amplifiers with precision components. This is the major limitation when it is kept in mind that consistent, reliable detection is of paramount importance.

12

forma, for a selected position of (see Tes) all cores on the reliance leas the scienced core, will granters output voltages from helener corrects.

The magnitudes of landings subject welfages for a series of leadents comments, which are blocklind with marrix their the billing is consents at 100 mas, were adjusted and plotted against materia size in Fig. VI. In addition 'I'', '0'', and 'I'' - '0' weights magnitode levels were drawn on the same figure.

As presidently noted, the baskage current ordent voltage to added to here the "1" and "0" only of voltage from the memory cover, forwares, the magnitude of the contractor cars "0" employed to find the mean that it a -0" to to be mad out of a memory cover, tealage creaters of pass the second and a multiplier teal-cate a "1" respond. The scatters she fit a of one determined to be marginal by the total output restricts she fit a of one determined to be marginal by the total comparison and the second second of the teal of the total output scatters also fit a of one determined to be marginal by the total comparison and the second second of the second to be total output scatters also fit a of one determined to be marginal by the total comparison and the second of the second of the total output

This is the size where we "I" - """ with reason without is to make a by approximately one walf, and to we be reduced wreen and a by stabilitient warkstions to care and finds characterization. Consistent detection of some and assue with very locally difference web ages required detection of some and assue with very locally difference web ages required detection. This is the mation of security any total difference with principles components. This is the mation localed to show it is have in a build the components. This is the mation in advised as when it is have in a build the components. The de the mation is advised as when it is have in a build the components.

Noise Voltage Considerations

It should be noted that these leakage output voltages are predictable to the extent that the diode and core characteristics are identical. Random, unpredictable voltages, commonly known as "noise" voltages, will exist in this system and may ultimately limit the matrix size.

Several possible sources of noise voltage exist. A diode may change its characteristics after a period of operation and permit more leakage current in a leakage path. This means that there may be incomplete cancellation of the leakage voltages generated in the matrix positions other than cores on the selected x - line, y positions. These are random because the effect could be any of the ones discussed previously, depending on the particular diode that is bad.

Cores will undoubtedly be individually tested (automatic or otherwise) to obtain as nearly uniform responses as possible. Nevertheless, small differences will exist simply because obtaining exactly identical cores in large numbers is a tremendously difficult problem. The differences in core responses will again result in incomplete leakage current output voltage cancellation, even if all diodes are exactly identical. As before, these uncancelled leakage output voltages are random and unpredictable.

There is always the possibility of spurious voltages being

Meter V State Constant to a

It should be attent that these leafes, o the voltage act predicted to the extern that the distance of core characteristics are theodoric. Angura, we endersity without, our and your are theodoric. Angura, we endersity without, our and our a "enter walker with end it is but systems and our all monty limits the matrix size.

Reversi possible sources of value voltage and it. A Gole way change its characteristics where a partial of operation and porecit meres balage corrections in a balance pain. This content that there is a be income into cancelistics of the balance with gos preserved it its matrix possibles cancelistics of the balance with gos preserved it its postfilm. These are readers become the advected of a line, y to any discussed previously, depending in the particular during the is balance is the readers become the advected of a line with the bala.

Career will and address or publication proposed (and and a second a second to black as valed y address proposed to possible. Nowerwheten, and differences will address imply account durating rearry featured views to barge numbers to a transmission (address) prior bifeatured views to barge numbers to a transmission (address) prior of the difference to rave respondent to a transmission (address) prior taken difference to rave respondent with again reason to all difference taken converse adjust valing reason definitions are to all difference matches to reason output valing reason to all difference to a second black of the prior of the second black are to all difference are prior and a second black prior and the second black of the second prior and a second black of the second black of the second prior and a second black of the second black of the second prior and a second black of the second black of the second prior and a second black of the second prior are set of the second prior of the second black of the second prior and the second prior of the second black of the second prior of the second prior and second black of the second prior of the second prior and the second prior of the second prior of the second prior of the second second prior and second prior of the second prior of the second prior of the second prior and second prior of the second prior of the second prior of the second prior of the second prior and second prior of the seco

These a states an statisty of a pairing an entrance we have a

2

generated from air leakage flux, and other energy fields from external sources.

It is obvious that as matrix size increases, the opportunities for generation of noise voltages will increase. No quantitative estimates or predictions can be made except by measurements as larger and larger matrices are operated. generated (New Ale Leticage Suc. and other energy Selds from

54

Hi ha devices that as mairies size herroases, the opportunities for generatics of solve witheges will increase. No quantizative estimates or predictions can be made encept by measurements as 'argies and herger metrices are scended.

CONCLUSIONS

1) In the range of matrix sizes investigated, magnitudes of leakage current are too small to be the limiting effect by preventing proper readout of the selected core or destroying stored information. The present system, then, is limited in size by the leakage current output voltage which adds to the 0" readout to indicate a "1".

2) Expansion of the present system to a 32 by 32 matrix is feasible since at this matrix size, the leakage current output voltage is only 15 percent of the "1" - "0" output voltage difference. At 64 by 64, however, the percentage is more than 50 percent, and operation is marginal at best.

3) The system may not be operating at its optimum point, since 100 ma. read current does not yield the maximum "1" to "0" output ratio. For each value of matrix size, the read current value must be optimized to give the maximum "1" - "0" output voltage difference with minimum leakage current. 15
1) To the range of maleria time investigated, magnitules of lettings correct are too small to be the limiting effort to preventing proper readent of the selected core or destroying stewed information. The proper readent of the selected core or destroying stewed information.

20 Expandence of the provent system to a 31 by 52 matrix is feasible time at bbs maining size, the bainge correct merged voltage is only 15 percent of the "1" - "0" andput withge difference. At 64 by 64, becaver, the percentage is more than 50 percent, and operation is marginal at lest.

3) The systems may not be operating at the spikesme judgel, since 100 rms, read convent does ant pulsition estadownes "1" to "0" subpat satio. For each value of matrix also, the read correct estan manet be optimized to give the socialization "1" - "0" output roltage diffingence with minimum labor environ.

RECOMMENDATIONS

1) In the existing system, there always will be a difference between the "0" readout voltage and the reference core output voltage. This difference is the leakage voltage. If a core larger than the memory core is used as reference, the voltage output of the reference will be larger and may be used to compensate for the leakage voltage. Overcompensation, or designing the reference output to lie between the "1" and "0" readout voltages, will ease the problem of subsequent amplification of the output difference.

2) The use of clipping to differentiate between the "1" and "0" output should also be thoroughly investigated.

3) The system should be operated at a point of maximum "1" to "0" output voltage difference, and input turns (read current magnitude) should be adjusted within practical limits for minimum leakage current.

4) The use of smaller memory cores may greatly reduce the problem of winding the cores by reducing the number of windings. This, however, may reduce the "1" to "0" output difference, thereby making differentiation between the two signals more difficult.

5) It is of the utmost importance that a dynamic analysis of the system be made. The further limitations imposed by stray capacitance, diode shunt capacitance, and other dynamic factors may be extreme.

6) The use of silicon point-contact diodes is highly recommended.

A) In the selecting syndromy there always with as a datherence setween the "0" publicat voltage and the redevance core integral valiage. This difference is the Janiage voltage. If a core integra vitation the memory can a later as deferrence, the voltage empth of the seterence with the hereic and mary the association compared to age voltage. Overconversation, or designing the setarement output to the between the "1" and "0" respond veltages, with easy the problem af esteres and and "0" respond veltages, with easy the problem.

3) The ask of Spping in differentiate servers the "3" and "0" orages should stop be thereesplicy investigated.

3) The spectrum closeld on operatively at a point of maximum "1" to "5" output voltage difference, and inexis inerva (even or magnirade) absold be adjusted within practical jumits for minimum leakage rearrant.

Q The peed of muchles manney cares may preasity reduce the problem of wholing the cares by patienting (to some of visitings). This, however, may reduct the '1' to '1' empty difference, thereby making sitterestability between the rest signally same difference.

5) It is and the conserve to particulation that a optimizate analysis of the system, by reads. This continue (holistiched on proved by every copyristement, chain about representation, and place dynamic instore many be waiteens.

W . The use of stillout polater polater diodes is highly encontained.

APPENDIX



APPENDIX A

DETAILS OF PRO CEDURE

Analysis of the Diode Matrix

Fig. IV-A, the three dimensional view of the diode matrix, can be reduced to Fig. V-A or V-B. By showing that points "A" and "B" on Fig. V-B are always at the same potential, the points may be connected for the purposes of static analysis. This reduction is valid, if the assumption of identical diodes is made, because the ratio of the number of back diodes to forward diodes in each of the two parallel leakage paths of Fig. V-B is the same.

It is obvious that as the matrix size is increased, more diodes are paralleled, lowering the ratio of the leakage path resistance to the read path resistance. Consequently, as N is increased, for a fixed readout current, the leakage paths take more and more of the total driver current. One important feature of memory design is design of the drivers, which, besides supplying readout current, must supply the leakage current. An important parameter for driver design is the ratio of leakage current (I_2) to readout current (I_1) as a function of matrix size. This curve was obtained using Sylvania-supplied low voltage characteristics for the diode IN56A (Figs. X and XI) in conjunction with Fig. V-A.

The method used is as follows:

1. Assume a value of N.

18

A X316X94LA

LI RECENT DELL'ENC

statute about and a completera

Why, Wooks the Star of Star and coal year of the disks marries, easy by restanced to Star Vert as Well. By starwing that putchs 'A' but "B' as Nur, YeB are absorpt to the same pricestal, the prices may be consisted for the pergeners of staric instigate. This reduction is waited, it the accuractions of the staric instigate. This reduction is react of the member of herebell fields in math, because the react of the member of herebell fields to forward distar the two persists trainings putto, of Star. Ye is to the vacuation of the

It is abolious that as the same is the barrensei, more divides are particletial. Knowning the ratio is the barrense parts weekshare to the reach parts enstations. Consequently, so if is forcement, for a fixed reachest current, the barrense parts the score and more of the band deliver variants. The barrense parts the score and more of the basing of the training of the important batters of memory design is sugging the training currense. As barrenses parameters for frienders is upply the training currense the barrense parameters for free there design is the matter also of barrense the barrense parameters for free there also working attempt and the data and the score and the score is the same also in the currense the barrenses parameter for free thermales at matter also. This currense the to be parameters and an are the first data is the state of formation and the first high is the score and the parameter also. This currense the first high is the state of the top of the top is an action of the first high is the score and the first high as a state with the first of the the first high is the score and the parameter with the first of the first high is the score of the section.

Dies stadfank waad in to reflorers

Z. ANTORNA IN TEADS OF P.

ŕ

- 2. Assume a value of leakage current.
- 3. In each of the three diode sections of the leakage path, divide the current in accordance with the number of parallel diodes. The voltage drop across the section is then the voltage across one diode in that section.
- Using Fig. X and Fig. XI, add up the voltage drops in the leakage path. This voltage sum is the drop across the read diode.
- 5. I₁ is equal to (voltage drop across the read diode .75) X (58.5) ma. This equation represents the slope and intercept of the forward characteristic curve of the diode. Published curves do not extend to the region of interest and they had to be extrapolated, but the diodes are usually stable up to 300 ma. D.C. and probably much higher for low duty cycles.
- Calculate the desired ratios and the value of leakage current.

Leakage Current Voltage Analysis

As mentioned previously, all the cores in a z - plane are linked by the same output winding. When a word is read out, one core in that z - plane impresses on the output winding a voltage which is dependent upon the core state. Other cores in that z - plane, however, are pulsed by leakage currents, and they too impress a voltage

- . Averages a value of lashings tury cont.
- 1. In oneth of the UniversetLods methods of the feature para, disting the correct is an accordence with the manipus of gravital diadas. The vertices from ectors the methor is the theorith voltage service can diada to these section.
- 4. Diskag Fig. 2 and Fig. VI, and up the rollings drops for the bouldage park. This voltage aver is the drop moreas (her read thedu.)
- 5. If is equal to (wellings they across the stage and shods * .73) X (50. 4) has. This equation represents the stage and hads. avera of the burrent characteristic over all the shods.
 3. Indiduded correct correct is the rest over all the state over the state of the state over the state o
 - Galerders the deckred ratios and the value of leanage current.

Lorgent ratio best in a shall

An existing provisionly, and the course is it is a plane by the set of the pare one of wheth c. When a word is reach only that every is then a spinne increases in the only a whether is collered which is dependent time to corr when a finite course to the test of a soliar or over, are plane for bottom to corr when a finite course to the test of a soliar or over, are plane by bottom to corr when a finite course to the test of the test of the soliar of the corr when a soliar course to the test of the test of the soliar of the corr when a soliar course to the test of the test of the test of the test plane by bottom course when a soliar of the test of test of the test of test of

γŧ.

on the output winding. This leakage voltage appeared to be dependent upon the state of the core in the leakage circuit. The system under consideration allows the cores to be in any one of three states, "clear", "1", and "0" so that it became necessary to obtain in the laboratory the response of the core to small currents when the core was in all three states. Fig. IX-A shows a block diagram of the apparatus used.

A. The "0" State.

Driver #2 was disconnected. The output of driver #1 was raised sufficiently to put a test core in the "0" state, then was reduced to zero. The output was raised in small increments and for each increment, the core output voltage and the voltage across the metering resistor were recorded. Metering resistance voltage is proportional to the current pulsing the core, so that a spectrum of output voltage versus input current for a positively pulsed "0" was obtained. Ten windings were used on the input and twenty windings were used on the output. The input windings were then reversed and the same procedure followed to get the data for a negatively driven "clear".

B. The "l" State.

Driver #2 was disconnected after it was used to put the core in the clear state. Driver #1 output was raised to 100 ma.. and the pulpote wheelding. "This basings wellings appeared to be dependent agent for insta of the core to the basings deviate. "The equines areas according obtained for some to be to the instance of bores alsoes." "Share", "The dash "The worked to be set in any means bores alsoes." In the contains the supplement of the core to book sets and a set of the set of the supplement of the core to book sets and sets of the set of all there as a state of the core to book sets and a set of the set of all there as a state of the core to book sets and the set of a state of the set of all there as a state of the core to book a block of a state of the sets and to all there as a state of the core to book a block of a state of the set of the state of the state of the core in the state of a state of the set of the state of the state of the core in the state of the state of a state of the sets and to all the state of the state of the state of the state of a state of the sets and the state of a state of the sets as a state of the state of the state of the state of the state of a state of the state o

A. The "O" State.

by type 12 years the construction of the construct of the part of the part of the part of the part of the core of

NAMES OF TAXABLE

Diritere 12 min disconsected attac is one version for put the

and then reduced to zero. The core was now in the 1" state. Driver #1 output was raised in small increments to 100 ma. and data was taken in the same manner as previously. The output was then raised to 110 ma. and the process repeated for the stable remanent state resulting from a 110 ma. positive pulse. Fig. IX-B is a plot of the data obtained in the laboratory.

Correlation of the Diode Matrix Analysis with Leakage Voltage Analysis

In analyzing the diode matrix, Fig. V-A was derived by connecting equipotential points A and "B in Fig. V-B, with the ultimate goal of computing total leakage current as a function of N. In a leakage voltage analysis, the important criterian is the current in the individual diodes and their related cores, and it is not immediately obvious that the total leakage current in the matrix of Fig. V-A will produce the same effect. Consequently, the two leakage paths were kept separate, and Fig. V-B was used as a basis for this calculation.

In Fig. V-B, the number in brackets indicates the number of turns on the associated core through which the leakage current passes, and the sign indicates whether the output voltage tends to add or subtract from a read voltage. The resistances of the two leakage paths are in a ratio of N to (N-1). This is based on the assumption that for large matrices the currents in the two leakage branches and hence forward and back resistances in these branches are approximately equal. and there reduced to entry. The core was some in the " state, firthway it output was raised in small barroments to 100 ma, and data was taken in the same mammer as provincely. The sampair was then extend to 110 min, and the provincely. The for the static remeasure state recutifing from a 119 ma, postdry palses. Fig. Di-11 is a plot of the date obtained to the fabrication.

Correlation of the Dioda Matrix Analysis with Louisage Voltage Analysis

In analysing the dioks maintin, Fig. V-A was declored by commenting equipotential solute A, and B is Fig. V-E, win the vittemake goal of computing total backness correct as a function of N. In a leakage voltage analysis, the important enformm is the correct to the individual diokap and their estande curses, and it is not incoedinately abvious that the total because correct is the matrice of Fig. V-A will produce the same placet. Consequently, the two leakage paths were been as a back the total because correctly, the two leakage paths were produce the same placet. Consequently, the two leaks for this contract has been appreciate, and Fig. V-B was used as a bank for this contraction.

In Fig. 7-B, the purches in broches indicates the number of tures on the associated cases dravagh which the balage correctly passes, and the sign indicates relative the asignt writege bench to add or subtract items a reach voltage. The realistances of the two holes paths are to a value of M to (N-1). (Side to based on the association that her here here the voltages in the two falles and a submark and here the voltages is then to the set of procedule and here ward and here the voltages is the two falles are supremented by a contact in the set of the test of the test of the set of the test of the set of the test of the set of the test of the set of t One important result of the core data is that for small disturbances the voltage output of the core may be assumed to be independent of the state (see Fig. IX-B). This greatly simplified the computation of leakage current output voltage as a function of matrix size.

The leakage voltage in one parallel section of diodes is equal to the product of:

- 1. The current in one diode in that section.
- The number of turns on the core through which this small leakage current passes.
- The slope of the leakage current output voltage curve in volts per ampere-turn.
- 4. The number of diodes in that section.

However, the product of one and four yields the total leakage current in that section. The leakage voltage, then, is independent of the number of diodes in each section, and is dependent only on the leakage current. This establishes the conclusion that there is complete cancellation of leakage voltage in each parallel branch of Fig. V-B, which leaves a net leakage voltage of $I_2(N-1)(10)$.

In computing the leakage voltage as a function of N, the following procedure was followed:

 I₂, the leakage current at 100 ma. read current, was recorded for each N curve shown on Fig. VII. The Emperated reality of the case data to the food for analy determined the veloce wided of the door only be normalied to be independent of the main (ask Fig. Th-Th. The press), whey then the compression of the lange operation anges where the standard of the compression of the second of the second of the second of the second to the second of the second of the second of the second of the second to the second of the second of the second of the second of the second to the second of the seco

1.5

"The Decision velocity to doe percent a section of distance to equal-

- 1. The curvess is use dische in this success.
- The consist of threat on the core through which this enait leasing two and passed.
 - This shape al the balance excesses origins voltage extra in volta per amuent-furto.
 - A. The moders of discharts in this of the

Moreover, the product of the set for the list the first total backing statem is the settion. The backage with providers, is inferreduct at the combur at divise in and a settion, and is dependent only as the basings coprast. This saturblicase the constants will there to outs place cancellation of backage jamage to each presided backs of Fig. 7-B.

In congretied the heighter voltage to bolicond of N. Hee following procedure was delivered.

is the state way is a low to see a set of

JTY AT STREET STREET COLUMN TARGET

 Leakage voltage equals I₂(10)(.0963) where .0963 is the slope of the leakage current output voltage curve at small ampere-turn driving forces. 3. Loskage voltage orgalls T₁(40%, 0963) where, 0963 is the slope of the leakage carrent couput voltage carve at eralt incource-ture ditatog for the.

APPENDIX B

SUMMARY OF DATA AND CALCULATIONS

Figure VII shows the result of the diode matrix analysis. In addition to indicating at what read current the ratio of leakage current to read current is a minimum for a given value of N, it indicates the upward trend in the ratio as matrix size is increased. The silicon diode curve also clearly illustrates the advantages to be gained by its use.

To bring out trends more clearly, Figs. VIII and VIII-A were drawn from computed data. Fig. VIII shows what portion of the total driver current is taken by the leakage paths, and Fig. VIII-A shows how total leakage current increases with both matrix size and read current.

Fig.IX-B presents the laboratory data of the response of the core to small magnetizing forces. Two positions of the "1" state were used in order to investigate the possibility of improvement by choosing a better remanent point to store a "1".

Fig. VI shows the variation of leakage voltage with matrix size for a read current of 100 ma. Superimposed on this plot are the "1" and "0" output voltages for the system as it now operates.

REPERDENCE 3

Nigere VII shows the routh of the divide matrix analysts. In addition to redicating at what read current the ratio of halonge cerrent to read current is a minimum for a given value of N. it indicates the upward trund in the ratio as mairies also be increased. The silicon dials surve also cherrip timevestes the advantages to be galand by the stat.

We being out treate many charachy, 24gs, VIII and VIII-A were drame from from compaind date. Fig. VIII shows when poreius of the solul defect correct to tables by the bology parks, and Fig. VIII-A shows how cotal lantage current seconsect with both marks the and yeak correct.

Fig. 13-8 provents the theoreticy data of the comprove of the core to annih magnetizing forces. Two possidem of the "1" state very shall in Ardes to Investigate the possibility of improvement by choosing a botton resummers point to stars a. T.

Fig. We shows the variation of bulance valtage with matrix eiter in read corrects of 100 min. Expectionwell on this play ave the "2" and "0" output rollages for the the syriess as it care quenties.

24

APPENDIX C

SAMPLE CALCULATIONS

Analysis of the Diode Matrix

TABLE I

iz	ñ	(a -1)	12 (m -1)	Na	(2n ~1)(n ~1)
60ma	100	99	606	. 25 ^v	19700
				-	
$\frac{i_2}{(2\pi - 1)(\pi - 1)}$	(back)	(2m -1)	ⁱ 2 (2n -1)	Ne	N
3.1	2.5	199	300	.195 ^V	2.95 ^V
11	1 _T	1 ₂ /1 _T	12/11		
129ma	189ma	. 318	. 465		

The values of v_a and v_c were obtained from Fig. X at points "A" and "C". The value of v_b was similarly obtained from Fig. XI at point B. The resultant point, $I_2/I_1 = .465$ at $I_1 = 129$ ma. for N = 100, is plotted on Fig. VII as point D. Values of I_2 were chosen so as to cover the region between 100ma. and the minimum of the resultant curve.

3 Lana Sill

BANYLE GALOULATION

			ANK CAT		
	i canadigan di				-
(1- =)(1-=3)	7	13	- (l- =)	-	t ₂
19706	v _{ell} .	404	86	06J	6.0Houk
and and			eres.		
77,	°С,	1 1-=5)	(1- 10)	N.	(1 = m)(1 = mL)
V 87 23	Vora.	984	101	P	
		manager.	a 0.7 °	440 (1000) N. N	
		12/II	1. I.	T.L.	1ª
	-	2011	5×5.	am (2.1	antes

The values of v₀ and v₀ errors abstitued from Vi0. It at priots "A" and "C . The value of v₀ error signification discover inter Fig. 73 at poles 3. The two base poles, 2g/l₀ = 1005 at l₁ = 1.07 min, for H = 100, 14 platted no Fig. VII at point D. Values of 3g wars choose at as to errors the region between 100mm, and the minimum of the routhant clarge.

Calculation of Leakage Voltage

- 1. For N = 75 at $I_1 = 100$ ma., from Fig. VII, $I_2 = 33$ ma.
- 2. Leakage voltage = 33×10^{-3} (10)(.0963) = .0318 volts.

This result is plotted on Fig. VI.

allow ones to with inchas

- 2. Lashage voltage = 13 x 10"3 (10)(. 0963) = . 0316 velse.

This result is platted on Fig. VI.

APPENDIX D

SUPPLEMENTAL DISCUSSION

Although all the previous work was predicated on an analysis of the static case, this by no means infers that the dynamic response of the system is of no importance. On the contrary, the dynamic case may impose even more stringent limitations on the expansion of the matrix, and before definite conclusions can be reached, this analysis should be carried out. Even without being mathematically rigorous, several general trends can be predicted.

Each leakage section in Fig. V-A can be replaced by an inductance in series with the parallel combination of a diode and a capacitance where :

- The diode represents the resistance of all the parallel diodes in that section.
- The capacitance represents the parallel combination of all diode shunt capacitance in that section.
- The inductance represents the inductance of the cores through which the leakage current in that section passes.

The forward diode resistance and capacitance can be neglected, but the reverse diode resistance and capacitance is significant. Thus the entire leakage path can be represented by one inductance in series with the parallel combination of the net reverse diode resistance and the sum of the reverse diode capacitances. The read path can be

CONTRACTOR OF

HOLESSON IN TATILLARDAD UNS

Although all the privious work was producited on an analysis of the statte zame, this by no means index the dynamic response of the symmet is of no importance. On the contrary, the dynamic case may impose even more emisgent limitations on the organization of the matrix, and before deficite constructions on the resolute, this analysis should be caseded on. Some which their mathematically we grows, errored grownik immike can be produced to an

Thick leatings section in Fig. V-A can be replaced by an haloctence is series with the parallel cambination of a diade and a capacilage where :

- The diode sequeness the restorence of all the parallel diodes in that section.
- The capacitance represents the particlel combination of all disks show capacitance in that section.
 - The Inductories represents the induction of the cores.
 Strongb which the Instage correct in third section parset.

The learness disks restatence and experiments in argument, but the resorres disks restations and argumentance is eignificant. That the antine basings path can be expressed by see Eiderstate in series with the parallel combinizion of the set reverse disks residences and the two of the reverse disks experiments. The read pith can be represented by the inductance of the core being read out, plus a series forward diode.

The core is driven by the current through its windings. For small matrices, C is small and may be considered an open circuit. Because of the high back resistance in the leakage circuit, the major portion of the driver current initially fires through the read path, reading out the core. As N is increased, there is a threefold effect:

1. Net back resistance decreases.

2. Net shunt capacity increases,

3. The net inductance in the leakage path decreases, The read path circuit parameters are independent of N.

All three effects mentioned above are detrimental to the proper operation of the circuit, since they all tend to shunt more initial current through the leakage path, and thus reduce the carrent in the read path.

A mathematically rigorous analysis is impossible to do without laboratory data correlation because the shunt capacitance is variable with the back voltage across the diode. However, if the read path current rises too slowly, the core might not be read out. Generally speaking, if the rate of change of current in the read path is not equal to or greater than that in the leakage path, the system probably will not operate properly. represented by the induction of We where being rand out, plan a series

Whe case is driven by the current through its similars. Are areadly matrices, if is amult and may be conditioned as open simult. Produces of the block marketance in the labrage circuit, the mator portion of the driver current followity from through the road path.

1. Not back youlsvanke decreasion,

2. Net almost engacity increases,

The patt infortance in the lashings path decreases.
 The read path effects preventions are informations of N.

All three effects massioned above use detrimental to the preper operators of the elecuit, since they all tead in show more initial current through the balance path, and then reduce the current in the read path.

A muthematically sign one analysis is impounded as a without laboratory data correlation because the share combilitance he vertable with the back votings scross the disks. Nonever, if the youd geth cverses these to showly, the ones might out he vest one finnevally aposhing, if the mean is charge of screeps is the work for probably to be presser that the to be cause of screeps is the work probably and and questin property.

85

APPENDIX E

ORIGINAL DATA

See Figure IX-A for block diagram of apparatus.

Metering Resistors	=	53 ohms	Pulse length = 2 microsecends
Input Turns	=	10	E1 : Voltage across metering resistor
Output Turns	4	20	E = Voltage at output winding I ₁ = Input Current E ₁
			- 53

"O State		"1 ' State (110ma.)			Clear State				
E ₁ (Volts)	1 ₁ (ma)	E ₀ (Volts)	El (Volts)	1 (ma)	E ₀ (Volte)	E ₁ (Volts)	I ₁ (ma)	E ₀ (Volts)	
. 2.25	4.24	.10	1.12	21.1	.45	. 23	4.33	. 09	
. 35	6.6	.15	2.25	42.4	1.05	. 65	17.93	. 25	
. 65	12.27	. 25	3.52	66.4	1.95	. 675	12.74	. 27	
. 85	16.04	. 30	4.66	87.3	2.90	. 80	15.1	. 29	
1.4	26.4	. 50	5.25	99.0	3, 45	1.4	26.4	. 50	
1.5	28.3	. 50	6.0	113.2	4.12	1.5	28.3	. 55	
2.0	37.7	.75	6.9	130.2	5.25	2.7	32.1	. 64	
2.5	47.2	. 95				2.1	39.6	. 75	
2.95	55.7	1.02			pearsocarrood and an and a range (capable in	2.35	44.3	. 85	
4.2	79.3	1.50				3.0	56.6	1.15	
5.5	103.8	1.95				4.05	76.4	1.65	
6.0	113.2	2.20	"1" Sta	te (100	ma.)	5.04	95.1	2.3	
7.0	132.0	2.75	. 54	10.2	. 25	5.85	110.5	3.0	
7.5	141.5	3.0	1.40	26.4	. 56	6.6	124.5	3.75	
8.0	151.0	3.3	2.40	45.3	1.00	7.5	141.5	4.75	
8.5	160.5	3.5	3.46	65.3	1.60	8.25	155.8	6.3	
10.4	196.3	4.5	4.30	81.2	2.16	8.75	165.0	11.0	
13.5	255	5.0	5.10	96.2	2.79				
			\$ 60	105 8	3 20				

11 11	Sta	te (120 1	na.)
0	925	17.46	. 40
1.	70	32.10	. 85
1.	80	34.0	. 90
3.	08	58.1	1.70
4.	45	83.9	2.85
6.	35	119.8	4.75
6.	37	120.1	4. 80

A DRENDARD A PORTAGE A

ATAS JAROSKO

some lies light for block disgrams of apparatus,

 A subsensesconde 	Talse Leager,	America (1 a an	Mentering Realeston
Contract to 2' of the state of the	Callo V = 1ª	4L =	LEWT SHAL
geNindw Jorgico 26	master V = 2	131 2	Galgati Yama
Pl. Lawrence	C Lloci = 14		
and the second s	and the second s		

"A" many (11 Branks) " Olezze States						winter of		
nile (wolim)	1 ² (acr.)	E1 (Volta)	(422.07)	(mar)) (11. (11. (11. (11. (11. (11. (11. (11	Q.II mile V)	(==0	i≡ (sille∀)
秋日. 秋日. 秋日. 秋日. 秋日. 秋日. 秋日. 秋日. 秋日. 秋日.	4.13 17.03 12.14 15.1 15.1 15.1 15.1 15.1 15.1 15.1	45. 81. 178. 1.1 1.1	20,1 20,1 20,1 20,1 20,1 20,1 20,1 20,1	42.4 42.4 65.4 65.4 97.9 97.9 213.2 213.2	「「「「「「「」」」」	DI. 11. 11. 11. 12. 0E. 0E. 0E. 0E. 0E. 0E. 0E. 0E	林市田村市 日下 日	1115. 86. 86. 8. 8. 8. 8. 8. 8. 8. 8. 8. 8. 8. 8. 8.
M. HI.I NA.I NA.I NA.I NA.I NA.I NA.I NA.I N	44,3 94,6 94,6 94,5 10,1 14,0 14,0 14,0 14,0 14,0 14,0 14,0	11.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1.1	1.400 25. 32. 32. 00. 1 04. 1 01. 2 07.3	10000 m 10000 m 10000000000	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	1.50 1.50 1.50 1.50 1.50 1.50 1.50 1.50	1031.0 1031.0 1131.4 11	

	-1 5.85		11	5	100
	and a state	25	a h		e estatus - esta -
20		8	a EA F	1	-
10.0	w.	1		08	7 3
() Sa		5	.107	66	S.
1 P.	.=		.1.0	25	
25	2		in and	- g	. all
.08.	4 4	1	.611	1	

5,40 185.8 5.30

25

APPENDIX F

BIBLIOGRAPHY

- 1. Bozorth, R.M., Ferromagnetism. D. Van Nostrand Company, Inc., New York, 1951, pages 539-543.
- Final Development Report for Static Magnetic Storage with Nondestructive Readout. W.O. #800-36177. 15 December 1954, Contract NObsr 63348, General Electronics Laboratories, Inc., Cambridge, Mass.
- Rajchman, J. A., <u>A Myriabit Magnetic-Core Matrix Memory</u>, Proceedings I.R.E., October 1953, Computer Issue, pages 1407-1421.
- Freeman, J. R., Pulse Responses of Ferrite Memory Cores, Engineering Memorandum M-2568-1, Division 6, Lincoln Laboratory.

APPENDING I

TOTAL COLLEGE

- Beword's R.M., Teconomycontrue, D. Van Kowarah Company. In., New Teck, 1951, pages 5194343.
- E. Etted Development Report for Jostic Magnetic Description (1998). Wesdistructive Readent. W. O. \$500-Juliv. 18 Descripted 1998. Fontruct NOber 53146. Generatic Electronics Laborations, her. Electronics.
- Rajohenan, J. A., <u>A Myrinka Magnetic-Corp Mainteenry</u>.
 Freesedings 1. 3. 4., Oxioher 1935, Competer Savia, pages
 1607-1623.
 - Farmenta, J. R., Faine Leoparns of Ferrin Listers' Core., Inclineating Memories and L. Monthly, David on 6, Marcha E.Gornanya.



L.

.

.


