ings and bit rate are shown in Fig. 1. Assumptions used in the calculation are as follows: (1) An avalanche photodiode excess noise factor less than 0·7, quantum efficiency greater than 80%, and dark current negligible. (2) Average optical power of -5 dBm is coupled into a monomode fibre or multimode fibre. (3) Splicing point is every 2 km. Misalignment of fibre core at splicing points is within 1 μm. (4) Required error rate is less than 10^{-11}. (5) A 4 dB degradation is allocated for the repeater. Under these assumptions, allowable transmission-line loss is 31·4 dB at 1 Gb/s. (6) Average full half-power width of the laser emission spectrum is 2 nm. (7) Total loss of a graded-index multimode fibre, consisting of P_2O_5-SiO_2 cladding and GeO_2-P_2O_5-SiO_2 core, is 0·33 dB/km. Its baseband width B_0 is 1·5 GHz km and the length dependency factor of baseband width is 0·85, that is, $B(L) = B_0 L^{-0.85}$. The L is the fibre length in km and $B(L)$ is the baseband width at L. (8) OH concentration is 30 p.p.b.

Baseband transmission width is limited first by modal dispersion due to multimode propagation through a fibre, and then by mode partition noise[3] due to multi-longitudinal-mode oscillation of a laser, as shown in Fig. 1. Therefore, it seems important to use a single-mode laser (a single-longitudinal and single-transversal mode laser) as well as a monomode fibre, to broaden the baseband width. In fact, if a laser oscillates in a multi-longitudinal-mode, the repeater spacing attainable practically at 1·55 μm using fibre II is comparable to that attained by using fibre I at 1·29 μm, as shown in Fig. 1. As a result, the transmission system at 1·55 μm using fibre II cannot make good use of ultimate low loss. This fact does not change with slight modification of parameters or dopants for fibre I or II.

Conclusion: A practically attainable repeater spacing has been calculated, and systems in the 1·3 μm and 1·55 μm wavelength regions have been compared. If a multi-longitudinal-mode laser is used, attainable repeater spacings in the 1·3 μm and the 1·55 μm wavelength regions have no significant difference. If a single-mode laser is usable, a repeater spacing becomes maximum in the 1·55 μm wavelength region, and a monomode fibre with $\Delta \approx 0.2\%$ and $\lambda_c \approx 1.2$ μm is applicable to both wavelength regions.

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TRANSITION MATRICES IN MULTIPLE PRESET EXPERIMENTS AND INITIAL STATE IDENTIFICATION OF SYNCHRONOUS SEQUENTIAL MACHINES

Indexing terms: Identification, Sequential machines

Recently, in connection with the measurement and control of synchronous sequential machines, Das et al. proposed an approach to the solution of the problems using the transition matrix representation of the machine and its higher-order forms. In the proposed approach, however, the authors restricted themselves to only simple and preset experiments. Generally speaking, a simple preset experiment is rather easy to implement, though it suffers from the disadvantage that it tends to be lengthy, and sometimes does not provide the experimenter with the desired information. The letter develops a new approach to the solution of the initial state identification problem or diagnosing problem, which happens to be an important measurement problem in sequential machines through multiple preset experimentation, using the transition-matrix representation of the machine and other related concepts as provided in the paper by Das et al. The present approach, like the one suggested before, is also very systematic and completely algorithmic, and thus lends itself to easy computer implementation.

Introduction: The response of a nontrivial sequential machine to specified excitations becomes unpredictable if the state of the machine is unknown. On the other hand, the response of the machine can always be predicted if the initial state is known. Hence one of the basic problems in the study of sequential machines is to identify the state of the machine under investigation.[1-6] Once the state is identified, the behaviour of the machine under all future circumstances becomes predictable, and definite steps may then be taken to force the machine into various modes of operation at the discretion of the investigator. The former class of problems comes under the broad category usually termed *measurement problems*, whereas the latter problem is commonly known as the *control problem* in sequential machines.[3] In a recent paper, Das et al.,[7] instead of resorting to the conventional procedure of using the transition table and the corresponding response tree, made use of the transition-matrix representation of the machine and its higher-order forms to solve the measurement and control

problems in sequential machines. The approach the authors developed is not only simple but also very systematic and completely algorithmic, and thus lends itself to easy computer implementation. However, the authors in their study restricted themselves exclusively to *simple preset experiments*, that is, the authors assumed that the experiments were conducted on a single copy of the machine, and further, the input sequences to be applied to the machine were supposed to be fixed in advance. One of the obvious shortcomings of such simple experiments is that they are inherently destructive. When only a single copy of a given machine is available, there may be no way, in general, of knowingly recovering the initial state of the machine for conducting a new experiment, in case the previous experiment proves to be a failure. If, however, a sufficient number of copies of the given machine are available, it becomes possible to conduct a number of experiments, each of which by itself may be unable to solve the *initial state identification problem* or *diagnosing problem*, but all of which jointly may supply sufficient information to identify the initial state of the machine. As an illustration, consider the case of machine M of Table 1. There is no simple experiment which solves the diagnosing problem for machine M with *admissible set*[2] S_1, S_2, S_3, S_4. We shall see later that the diagnosing problem for machine M and admissible set S_1, S_2, S_3, S_4 is readily solvable by a *multiple preset experiment* of *multiplicity* 2 and *length* 3. In general, for every minimal machine M, there does not exist a simple preset or adaptive experiment to solve the diagnosing problem.[1-5] Rather a preset or an adaptive multiple experiment may have to be required. Thus every minimal machine M, even if it does not possess a single input sequence as its diagnosing sequence, does possess a set of input se-

Table 1 MEALY MACHINE M

Input State	0	1
S_1	$S_2, 0$	$S_4, 0$
S_2	$S_1, 0$	$S_2, 0$
S_3	$S_4, 1$	$S_1, 0$
S_4	$S_4, 1$	$S_3, 0$

quences, termed the *characterising sequences*,[4,7] that can be used for the identification of the unknown initial state of the machine. A graphical exhaustive search procedure that makes use of the state-response tree can be utilised to solve the characterising problem for any given sequential machine, just like the diagnosing problem. In this letter the authors extend the transition matrix and other related concepts of Das *et al.* as developed for simple preset experiments to the case of multiple preset experiments, and propose a new approach to the solution of the initial state identification problem in synchronous sequential machines. The suggested approach is simple, extremely systematic and completely algorithmic, and hence can be very readily implemented on a computer as well.

Assumptions and basic concepts: Consider a finite, deterministic, completely specified, synchronous sequential machine M defined by the quintuple $M = \langle I, S, O, f, g \rangle$, where $I = I_1$, $I_2, \ldots, I_u$ denotes the input alphabet, $S = S_1, S_2, \ldots, S_v$ denotes the state alphabet, and $O = O_1, O_2, \ldots, O_w$ the output alphabet, and f and g denote the two *characterising functions* of machine M given by $S_{N+1} = f(I_N, S_N)$, and $O_N = g(I_N, S_N)$. For a Mealy machine, O_N is the corresponding output of I_N, and (I_N, O_N) forms an *input-output pair*, whereas for a Moore machine[1] the output corresponding to I_N is O_{N+1} and (I_N, O_{N+1}) forms an *input-output pair*. An *input sequence* $I_i = I_{i1}I_{i2} \ldots I_{iL}$, of *length L*, is a series of L inputs successively applied to the machine M in a certain initial state S_j. An *output sequence* $O_k = O_{k1}O_{k2} \ldots O_{kL'}$, of *length L'*, is a series of L' outputs successively produced by the machine M when an input sequence is applied. An output sequence O_k is called the *corresponding output sequence* of an input sequence I_i if and only if $L = L'$, and (I_{ih}, O_{kh}), $h = 1, 2, \ldots, L$, is an input-output pair.[6] We assume further that the machine M under consideration is a minimal machine. If we now allow I_i to represent any possible input sequence of M, we can always evaluate the functions $f(I_i, S_r)$ and $g(I_i, S_r)$ for every state S_r in the state set S, $f(I_i, S_r)$ denoting the terminal state reached, and $g(I_i, S_r)$ denoting the output sequence produced, on application of I_i at S_r of M.

A transition matrix is viewed as the mathematical counterpart of the transition diagram of a sequential machine. For a v-state machine M, the *transition matrix* is composed of v rows and v columns, and is denoted by $[M]$. For ease of understanding, it is usual to attach the label of the kth state S_k to the kth row and kth column, and refer to the row and column as *row S_k* and *column S_k*, respectively. The (i, j) entry, that is, the entry common to the ith row and jth column of $[M]$, is b_{ij} if and only if there exists an input that takes the machine M from the state S_i to the state S_j in the transition diagram of M, and is zero otherwise. For a Mealy machine M, $b_{ij} = \sum_k (I_N, O_N)$, where I_N is the present input that takes M from S_i to S_j, and O_N is its corresponding present output, whereas for a Moore machine M, $b_{ij} = \sum_k (I_N, O_{N+1})$, where I_N is the present input that takes M from S_i to S_j as before, but O_{N+1}, its corresponding output, is the next output, the summation being in either case over all such input-output pairs. The transition matrix $[M]$, corresponding to the Mealy machine M of Table 1, is shown in eqn. 1.

$$[M] = \begin{matrix} & 1 & 2 & 3 & 4 \\ 1 \\ 2 \\ 3 \\ 4 \end{matrix} \begin{bmatrix} 0 & (0,0) & 0 & (1,0) \\ (0,0) & (1,0) & 0 & 0 \\ (1,0) & 0 & 0 & (0,1) \\ 0 & 0 & (1,0) & (0,1) \end{bmatrix} \quad (1)$$

For transition matrices, multiplication is defined in the usual way. If $[M]$ represents the transition matrix of a v-state sequential machine M, with (i, j) entry b_{ij}, then the (i, j) entry of the *rth-order transition matrix*, denoted by $[M]^r$, is given by

$$b'_{ij} = \sum_{k1, k2, \ldots, k(r-1) = 1}^{v} b_{ik1} b_{k1k2} \ldots b_{k(r-1)j}$$

which vanishes if some of the b_{pq} are zero. The rows and columns of $[M]^r$ are also labelled as in $[M]$. Notice that $[M]^1$ is simply $[M]$.

Given the kth-order transition matrix $[M]^k$, the next higher-order transition matrix $[M]^{k+1}$ can be formed as: $[M]^{k+1} = [M][M]^k$. The second-order transition matrix $[M]^2 = [M][M]$, corresponding to machine M in Table 1, is shown in eqn. 2.

$$[M]^2 = \begin{matrix} & 1 & 2 & 3 & 4 \\ 1 \\ 2 \\ 3 \\ 4 \end{matrix} \begin{bmatrix} (00,00) & (01,00) & (11,00) & (10,01) \\ (10,00) & \begin{matrix}(00,00)\\+(11,00)\end{matrix} & 0 & (01,00) \\ 0 & (10,00) & (01,10) & \begin{matrix}(11,00)\\+(00,11)\end{matrix} \\ (11,00) & 0 & (01,10) & \begin{matrix}(10,01)\\+(00,11)\end{matrix} \end{bmatrix}$$

$$(2)$$

Multiple preset experimentation and characterising sequences for initial state identification: The initial state identification problem in a sequential machine consists of finding the unknown initial state of the machine from external observation. In solving the initial state identification problem for a machine that does not possess diagnosing sequences, through multiple preset experimentation, we need to find a set of input sequences $I_{k\beta}$, $\beta = 1, 2, \ldots, h$, such that there exists a unique relationship between the observed output sequences $g(I_{k\beta}, S_j)$, $\beta = 1, 2, \ldots, h$, and the unknown initial state of the machine S_j. To solve the problem by using transition matrix representations, we make use of the following theorems.

Theorem 1: A set of input sequences $I_{k1}, I_{k2}, \ldots, I_{kh}$ of lengths $r_1, r_2, \ldots, r_h$, respectively, represents a characterising sequence for a sequential machine M with admissible set $A(M) = S_{a1}$, $S_{a2}, \ldots, S_{ak} \subseteq S$, the set of states of M, provided in each of the $a\theta$ rows, $\theta = 1, 2, \ldots, k$, of all of the r_αth-order transition matrices $[M]^{r_\alpha}$, $\alpha = 1, 2, \ldots, h$, wherever the input sequences $I_{k\beta}$, $\beta = 1, 2, \ldots, h$, appear in the entries of some columns j, $1 \leq j \leq v$, the corresponding output sequences of $I_{k\beta}$, $\beta = 1, 2, \ldots, h$, in the entries of all those columns of all the matrices constitute a distinct set.

Theorem 2: A set of input sequences $I_{k1}, I_{k2}, \ldots, I_{kh}$ of lengths $r_1, r_2, \ldots, r_h$, respectively, represents a characterising sequence for a sequential machine M with admissible set $A(M) = S_{a1}$, $S_{a2}, \ldots, S_{ak} \subseteq S$, the set of states of M, if and only if $I_{k1}, I_{k2}, \ldots, I_{kh}$ define partitions $\pi_1, \pi_2, \ldots, \pi_h$ based on output responses on the set of admissible states $A(M)$ in the matrices $[M]^{r_1}$, $[M]^{r_2}, \ldots, [M]^{r_h}$, respectively, such that the product of these partitions $\pi_1, \pi_2, \ldots, \pi_h = \phi$, the trivial partition in which there are ak blocks, each block containing exactly one state of $A(M)$.

The above theorems readily follow from the definition of characterising sequences, and theorem 13, and corollaries 13.1, 13.2 of Das *et al.* We next state the following important theorem.[2,7]

Theorem 3: The initial state identification problem for a v-state sequential machine M with k admissible states is always solvable by a multiple preset experiment of length L_s and multiplicity C_s, where $L_s \leq (v-1)(k-1)$ and $C_s \leq k-1$.

A formal algorithm for finding the characterising sequences for initial state identification in sequential machines is given next.

Algorithm: (a) Given the transition table of a minimal v-state synchronous sequential machine M, form the corresponding transition matrix $[M]$ for M. (b) Check the entries in different rows and columns of the transition matrix $[M]$ as obtained. Select an input symbol I_s such that I_s defines a partition π on the admissible set of states $A(M)$ of machine M having a maximum number of blocks, each block b_i corresponding to a distinct output. For a machine M with the size of its output alphabet w, the number of such partition blocks $n_i \leq w$. (c) Form the second-order transition matrix $[M]^2 = [M][M]$. (d) Check the entries in different rows and columns of $[M]^2$, and select an input sequence that defines partitions on the state sets

of a maximum number of blocks in π and simultaneously for each such block b_i, partitions its set of elements into a maximum number of disjoint subsets, based on output responses. Stop if every block b_j of π is partitioned into single element sets. If not, form successively higher-order transition matrices $[M]^3 = [M][M]^2, \ldots$, and in each case continue with (d), until for some $[M]^r$ the process terminates, yielding the desired characterising sequence (or sequences).

Example: Consider the machine M in Table 1. From the transition matrix $[M]$ of machine M in eqn. 1, we can select the input symbol 0, while from the second-order transition matrix $[M]^2$ in eqn. 2, we can select the input sequence 10, giving a characterising sequence for the machine with admissible set S_1, S_2, S_3, S_4 as: 0, 10, as observed before.

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TRAP LOCALISATION IN THE ACTIVE LAYER OF GaAs MICROWAVE F.E.T.S

Indexing terms: Electron traps, Hole traps, Schottky-gate field-effect transistors, Solid-state microwave devices

The localisation of traps in the active layer of GaAs microwave m.e.s.f.e.t.s has been effected for two different epitaxial materials. The method used in this work was a transient measurement of source-drain voltage associated with a simple theoretical model. Our results indicate that electron traps are localised in the bulk of the epilayer whereas hole traps are localised at the epilayer/buffer-layer interface.

The realisation of reliable GaAs microwave field-effect transistors necessitates not only reliable metallisation but also high-quality material. A difficulty frequently encountered has been the existence of deep-level impurities in the active layers grown on semi-insulating GaAs. The insertion of a buffer layer[1] can reduce these parasitic effects but does not entirely eliminate them, since the results of d.c. and pulsed drain-current characterisation are often quite different and some devices are still light-sensitive.

The trap characterisation of the different m.e.s.f.e.t. epitaxial layers grown in our laboratories has been performed using a d.l.t.s. method[2] directly on our microwave f.e.t.s.[3] All the epitaxial material used in our work has been v.p.e. $AsCl_3$ grown with buffer layers.

We have characterised two materials, each having one predominant trap. The first one (hole trap, $E_a = 0.53$ eV and $\sigma = 2 \times 10^{-15}$ cm^2) was obtained on conventional v.p.e. material (Ga source, deposition temperature $T_D = 750°C$),[4] and the second one (electron trap, $E_a = 0.43$ eV and $\sigma = 2 \times 10^{-17}$ cm^2) was obtained on low temperature v.p.e. material (GaAs source, $T_D = 650°C$).[5]

In each case, the preceding values of energy level and capture cross-section do not agree with previously published results. We believe this is due to the high doping level causing a tunnelling effect, and consequently modifying values of E_a and σ.[6]
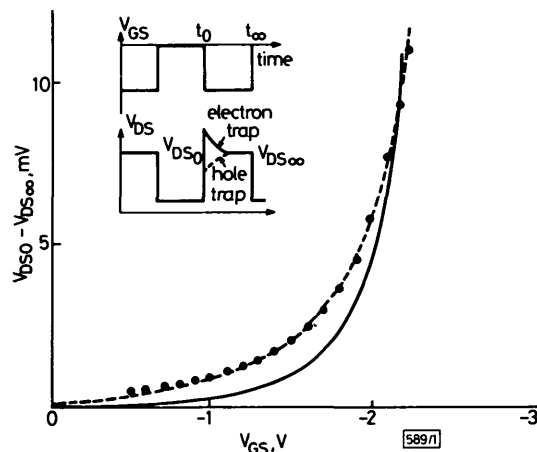
Fig. 1 *Difference between V_{DSO} and $V_{DS\infty}$ as a function of V_{GS} for hole trap. The dots correspond to experimental measurements, the full line to the simulated bulk trap model, and the broken line to the simulated interface trap model*

Insert: V_{DS} voltage transient with corresponding gate pulse

We have therefore tried to localise the position of these two traps in the epilayer. During this process of localisation, the temperature has been kept constant and we have recorded the source-drain voltage transient for different values of gate voltage pulse (see insert in Fig. 1). If the active layer contains traps, the V_{DS} voltage will not immediately return to its equilibrium value ($V_{DS\infty}$) after the following edge of the gate pulse, but will take another value (V_{DSO}) whose amplitude and position relative to $V_{DS\infty}$ depend on the density and nature of traps.

The amplitude of the gate pulses has been chosen such that the source-drain voltage can be represented by the Shockley equations for the linear region of the f.e.t.s static characteristics. Thus, after some calculations:

$$V_{DSO} - V_{DS\infty}$$

$$= KId \left(\frac{\sqrt{N_0}}{\sqrt{V_{p0}} - \sqrt{(V_{bi} - V_G)}} - \frac{\sqrt{N_\infty}}{\sqrt{V_p} - \sqrt{(V_{bi} - V_G)}} \right)$$

K is a constant depending on the geometrical and physical parameters of the device, N_0, N_∞ are the doping levels at $t = 0$ and $t = \infty$ (each doping level is to be considered constant in the active layer) and V_{p0} and $V_{p\infty}$ are the corresponding pinch-off voltages.

The following two cases have been considered:

(a) Density of traps is constant in the active layer, which has a fixed thickness. Then, in the above equation, N_0 can be expressed as:

$$N_0 = N_\infty \pm \Delta N$$