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INFORMATION TRANSMISSION BY TIME-PROGRAMMED MULTIPLEXING

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I. Assumptions:

1. Only primary equipment in beam tunnel

2. Ordinary cabling (except Teflon) OK in radiation areas

3. Secondary equipment gathered in 36 houses around main ring

4. Additional houses at linac and booster, experimental areas, etc. total about 50.

5. All equipment to be autonomous-i.e., can operate independently of central nervous system of machine. Equipment manufacturers provides terminals for input and output of information.

6. Essential interlocks and safeties are within equipment. (This may imply rather complicated logic in some cases. Perhaps it suggests a small computer as part of the equipment—but this would be a special-purpose, wired-program device.)

7. Analog programming of equipment is normally admissible. (E.g., the desired magnet program can be transmitted as an analog waveform.)

II. Objectives:

1. Central control of machine to be computer oriented.

   (a. Machine not to be completely dead without the computer.

   b. Equipment to be capable of local control even if control computer is turned off.)

2. Communication between houses and central control to be economical, flexible, and of non-limiting capacity.

   (a. Format to be "human-friendly" when possible --some diagnostics or displays without intermediary of computer.)

3. Status signals and commands to be digital.

4. Analog variables to be digitized locally only if high precision in transmission is essential. Other variables (5% resolution)

can be transmitted as analog signals.

5. Commands to be carried out without noticeable delay.

6. Major operations (magnet power on/off, personnel safety circuits) to be handled by conventional wire and relay systems- i.e., provide a small, separate, inviolate environment for these.

III. Method:

We attempt to minimize cost and complexity of each house by having no computer (soft programmed processor) there. At locations requiring computers because of equipment demands (RF, extraction, linac) such computers can be provided; they will communicate with central control on interrupt basis. This link is considered a separate system.

Information is transmitted on a predetermined time cycle, whether needed or not. Choice of cycle is somewhat arbitrary, but a skeleton outline might be like this:

a.) At each house there are 8 successive time slots, each 200 μs These are available for
   (i) 8 versions of a particular variable at 8 nearby places around the magnet ring (e.g. vacuum pressure)
   or (ii) 8 digits for a digital representation of a variable (or of a few variables):
   or (iii) 8 digits for 8 separate or correlated status signals or commands.

b. The groups of 8 slots for successive houses are sequenced so that we finally have 50 x 8 400 contiguous slots. Cycle time is 80 ms. Oscilloscope display of a cycle shows tolerable flicker for direct viewing.

Commands are coded by sending a pulse in the appropriate time slot *. Information is similarly coded, both for digital and analog formats. Each signal cable thus serves 400 possible addresses; coincidence gates sort out the address by comparison with the timing pulses available at the houses.

Most signals will be carried over single-conductor coaxial cables. (28 such coax cables in a single jacket about 3/4" diameter cost about 50 ¢ per foot.)

Information which cannot be time coded conveniently (e.g. video beam pickup signals) will be carried over a small number of high-quality cables, balanced to ground. Selection of which signal is injected out which cable is by reed relay. The relays are controlled by time-coded pulses in the usual manner.

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* For the digital circuits, subdivision of each time slot into four possible subchannels is envisaged; this permits extra capacity to be obtained for certain selected functions. The basic 200 μ's slot is kept long to facilitate handling of the analog signals in long cables.

IV Details:

A. Time cycle:

This is established by a shift register (or its equivalent) which is distributed among the houses (Fig. 1). 8 stages are located in the first house; when the pulse shifts out from the last stage, it enters a carry line and starts the first stage in the next house. Shifts occur at 200μs intervals as dictated by a clock line. Verification of correct operation is continuous. Repeater amplifiers are used between houses to renormalize signals. (Attenuation for a terminated cable might be to 70% in 800 ft.) Subchannel marker signals are made available on two separate cables.

B. Digital commands:

(i) Momentary commands (e.g. pushbuttons): a pulse with the timing of the desired address is sent down one cable. (Fig. 2). At the appropriate location, a coincidence with a timing pulse occurs. This sets a binary element, which is cleared just before the occurrence of the next cycle, 80 ms later. The binary is the output; it might drive a relay. The relay contacts are a reproduction of the original pushbutton contacts, with 80 ms time quantization.

(ii) Holding commands (Fig. 3): two subchannels of time slots are allocated to such a command. A pulse in the first subchannel sets the binary element, and a pulse in the second subchannel

is required to reset it. The binary memory is thus of indefinite duration, while for the momentary system it was limited to 80 ms. To transmit and memorize an N - digit binary number, N cables can be used; this makes available 8 addresses for such a number within each house. Alternatively, with only one address at the house, 8 digits can be transmitted over a single cable.

C. Digital Monitor: (Fig. 4)

These can be status signals (e. g. interlock contacts) or digits of a binary number. A signal cable can handle 8 such digits at each house-8 elements of an interlock chain, or combinations of fewer elements in several chains. For ease of display and interpretation it is nice not to mix many uncorrelated signals on one cable. Thus we might be generous with cables.

D. Analog Monitor: Rough analog signals may be transmitted as pulse amplitudes. The variable would first be coded into a voltage (Fig. 5). A gating system driven by the timing pulses then injects a sample of this voltage onto the cable, the combination ultimately resulting in a histogram waveform. This can be displayed directly at central control, or digitized and processed. The analog display might be useful for quick diagnostics, e. g. in the vacuum system.

E. Cable properties

Small coaxial cable of the type proposed (about 1/8" diameter, about 50 Ω impedance) will have an attenuation of about 30% in 800 feet, if terminated. Thus insertion of repeater units is desirable. Risetime problems with our long pulses are not anticipated. Transmission delays are significant (≈ 20μs around the main ring); all signals should propagate along the same paths in the same direction to take account of this.

The cable is terminated at 50 locations. Simple crimp fittings are suitable and to be preferred to connecters and sockets. Terminations can be installed by machine.

F. Video system

A few (8) high-quality cables will provide links for selectable video signal transmission (beam pickups, TV pictures).

G. Video programming

Programming analog signals should not need μs risetimes and can thus be handled by the small cables.

H. Signal listings

Some types of signals to be handled:

1. Digital commands

3 Vacuum: Pump ON/Off
Pump START
Gate valve OPEN/CLOSE... + other functions

7 Correction magnets: ON/OFF
DC correction level: 6 bits

4 Video addressing: multiplex address on one cable identifies signal source (e.g. 8 possible beam pick-up) connection to one of 8 cables coded signals on 3 more lines.

4 Ring magnet power supply: (8 commands per cable)

2. Digital monitors

5 Interlock chains at house

1 starter signal for magnet power

4 Ring magnet power supply starter signals (8 per cable)

2 vacuum starter (one for OK per pump, one for valving)

1 Magnet voltage and temperature (preprocessed at house)

7 DC correction levels (response)

4 Video address, verification

3. Analog monitors

3 Beam pickups (I, R, Z)

1 Magnet currect verification

2 Ring magnet power supply monitors

4 Misc. histogram plots for fun

4. Service cables

1 Clock

1 Carry

2 Subchannel sequencing

4 internal verifications

10 systems communications (local controls)

70

Providing 4 x 28 = 112 cables should be adequate.

Assume 18 analog channels, the remainder digital.

I. Cost Guess

I. Costs associated solely with multiplex transmission system; boundaries are at central control computer's interface and at terminals in houses where external equipment connects. (Cables from house to tunnel not included).

Cable:	4 28-conductor shielded	
	4 x 30 Kft = 120 Kft x $0.5	$60 K
	1 19-conductor twisted pair for service, communication 25 Kft x $0.3	8
	Installation	32
		100 K

Equipment in house:

Repeaters-analog (3 x 6 channels, $100 / cond.	300
-digital (8 x 12 channels, $100 / cond.	800

Timing circuits	100
Digital commands (30 lines, average of 4 addresses each, 8 per cond., $50/cond.	750
Digital monitors (40 lines, $50/cond. etc.)	1000
Analog monitors (18 lines, etc.)	500
A/D converter (1 channel)	400
Subchannel distr.(for video address)	100
Conductor racks, sockets	500
Power supplies	500
Relays (50 at $5)	250
Rack and hardware, terminals	300
Assembly (1 man, week)	500
	6000
50 x 6000 300 K	
Central equipment(clocks, service and testing, scope, local controls)	30 K
	430 K

So about 1/2 million should buy and install the multiplex system, which would make a viable control and monitoring device even without a computer. Linking to the control computer could be an adiabatic procedure.

2. Cost of video transmission system: cables etc.,assuming control of reed relays to be available already (multiplex or competitive system)

Cable 8 x 30 Kft 240 Kft x $.1	$ 24 K
Relays: 40 per house, 2000 x $20 installed with cable connectors etc.	40 K
	64 K

3. Cabling from houses to tunnel (as per meeting of August 30, 1967)

$ 250 K

This looks like a high estimate if it does not include the beam pickups, cable and devices, etc.

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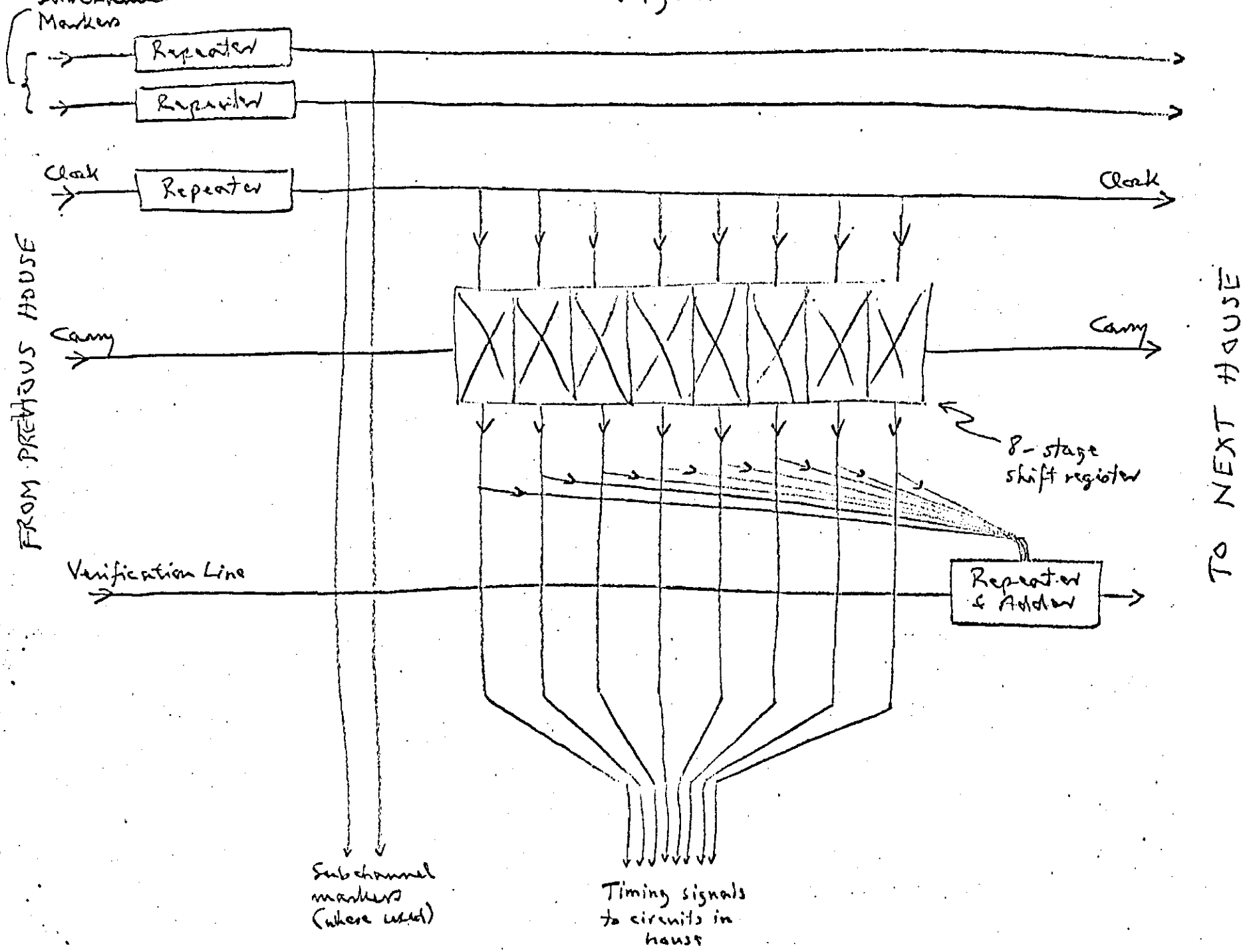
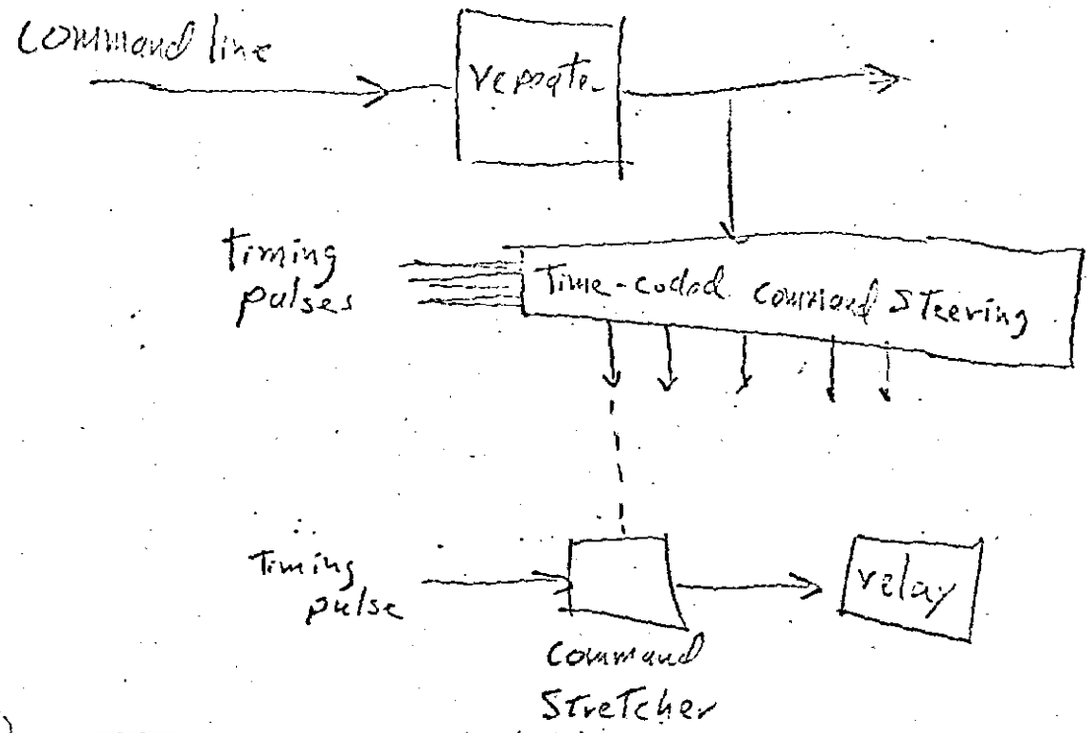
Fig. 1.



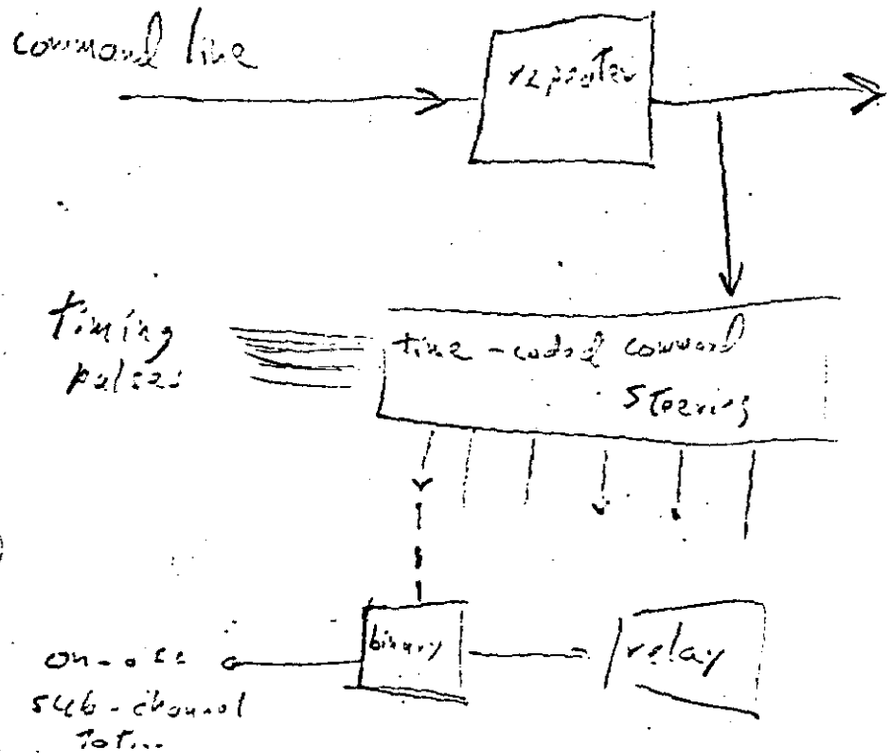
Digital commands (momentary)

(Fig. 2)

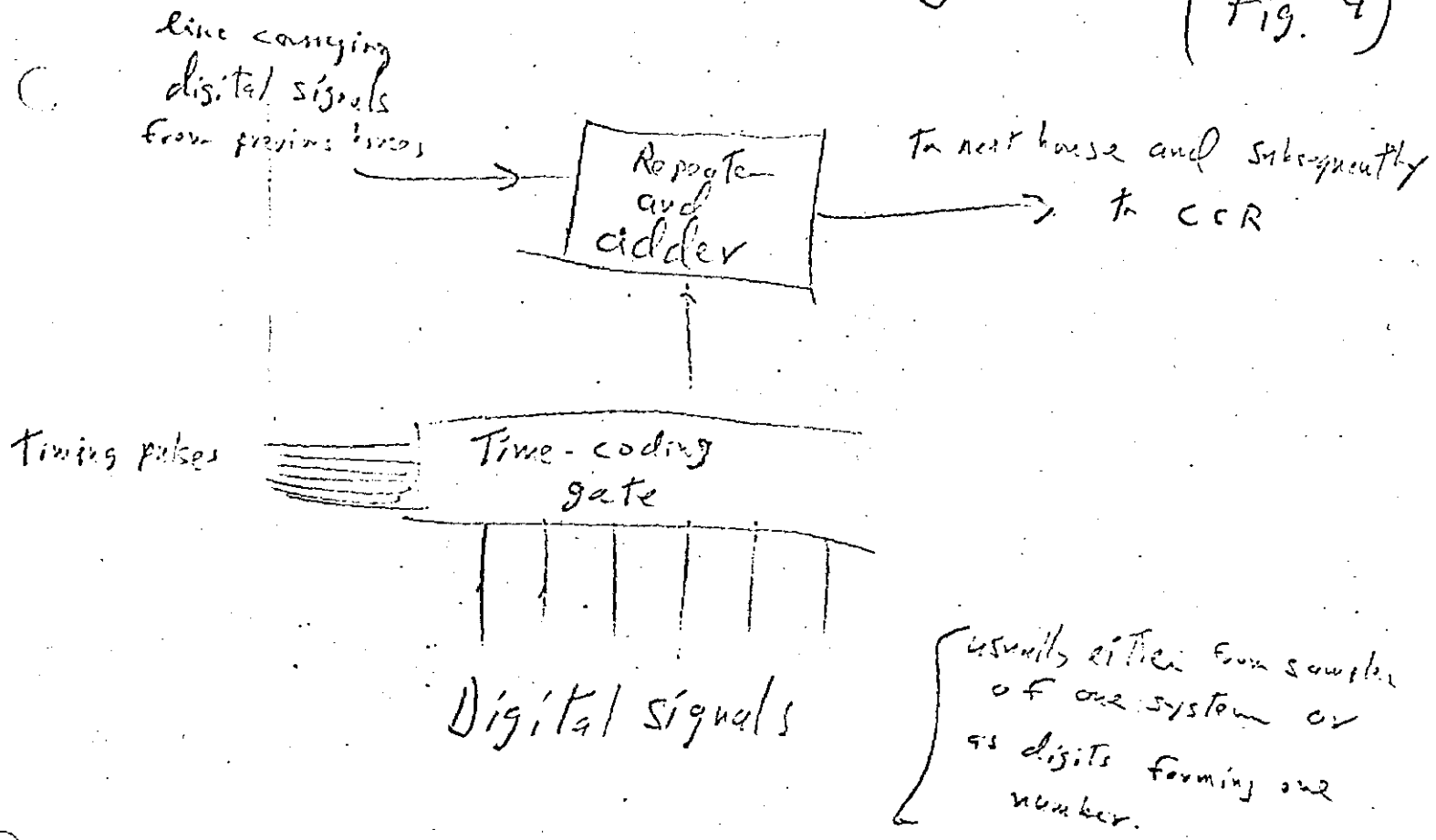
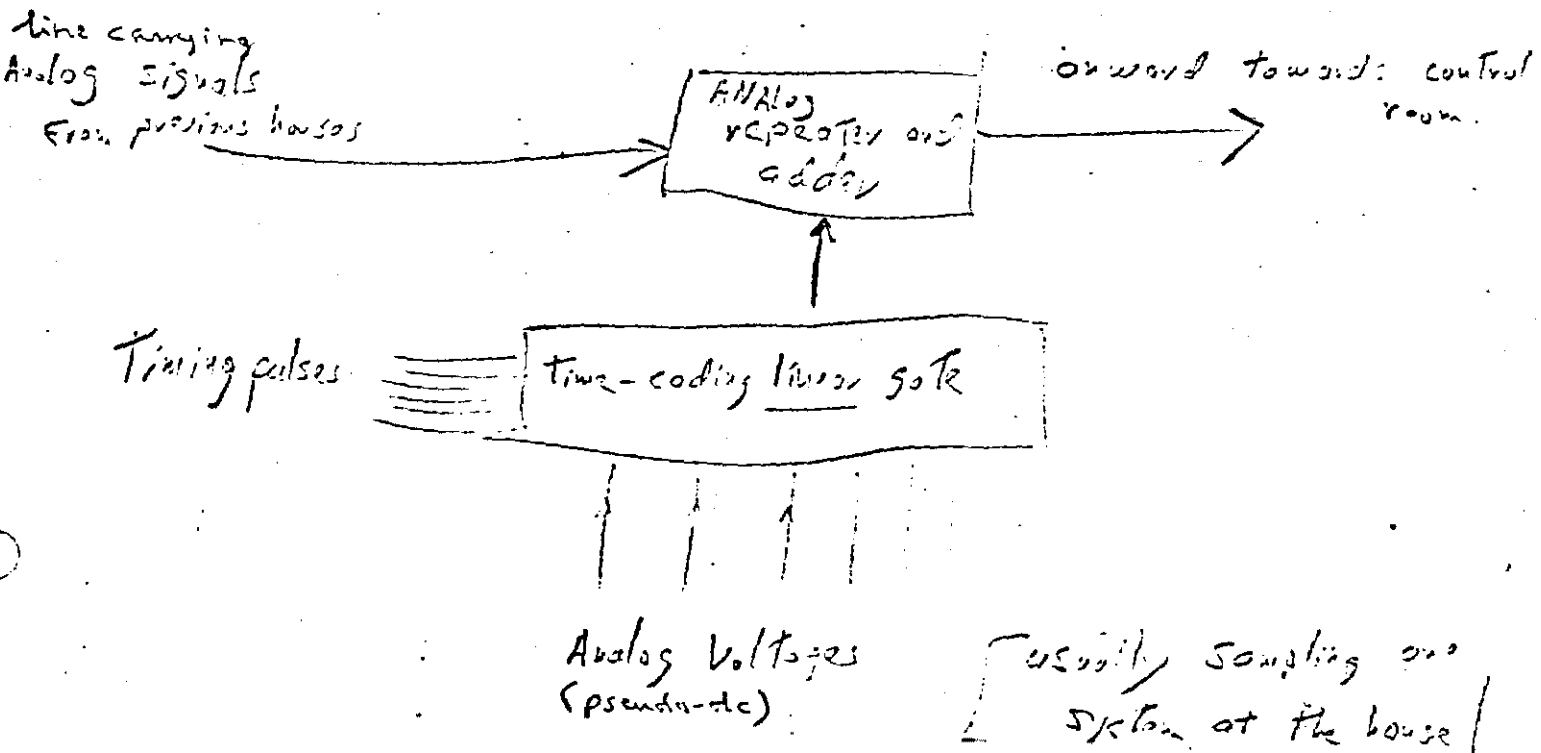


Digital Commands (holding)

(Fig. 3)



Digital Monitoring (Fig. 4)



Analog Monitoring (Fig. 5)