A trip down memory lane

Rolfe Bozier

16-Sep-2015

(or, all about core memory)

Agenda

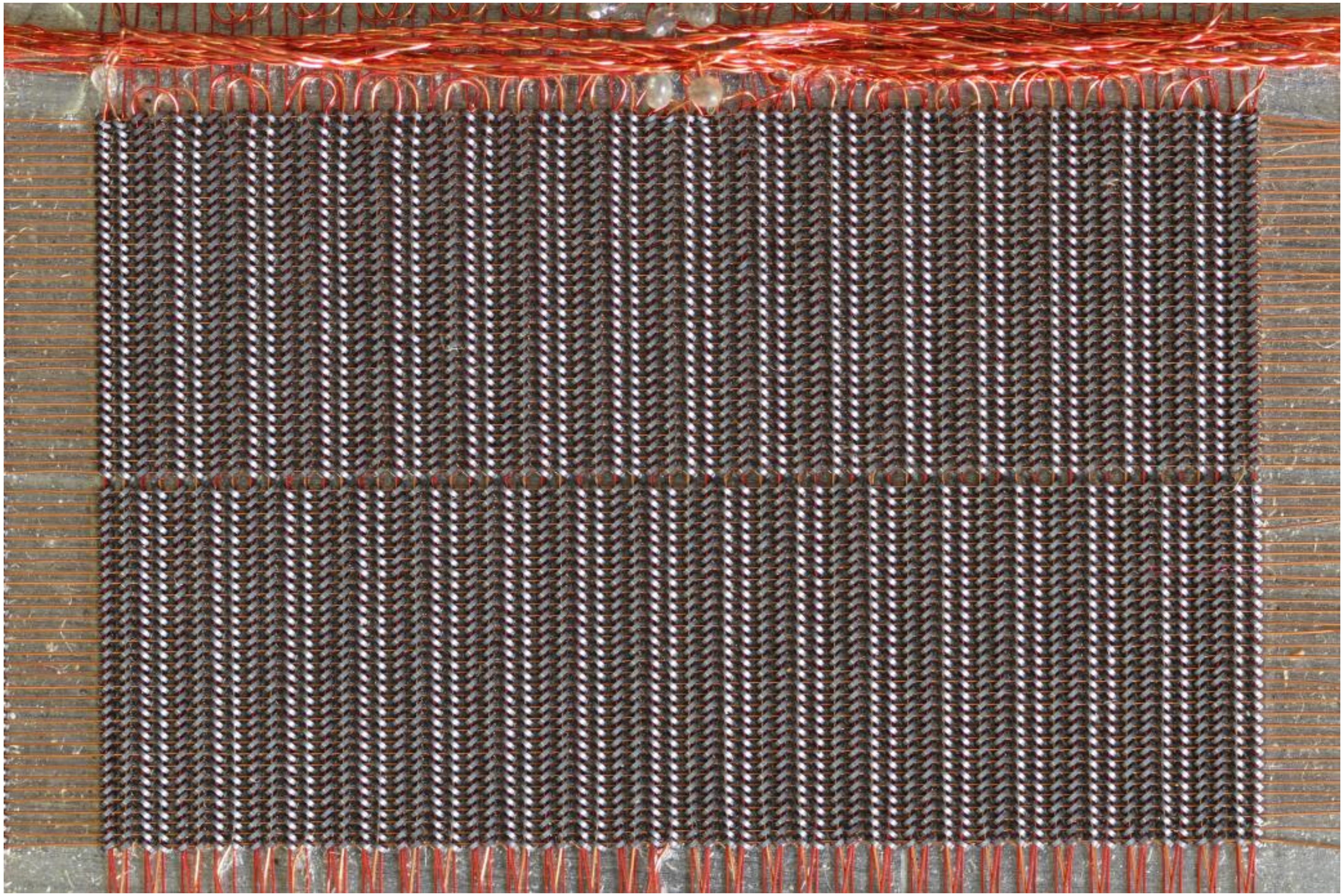
- What did core memory look like?
- Its place in computing history
- How did it work?
- A proof-of-concept

What does core memory look like?

- 1 bit stored in a small ferrite ring
- This array:
  - 16 kwords = 32 kbytes
  - 294,912 cores
  - 72 sub-blocks of 4 kbits
- Separate driver board
- Manufactured around 1977
  - General Automation Inc

What does core memory look like?

- Sub-block:



A brief history of computer memory

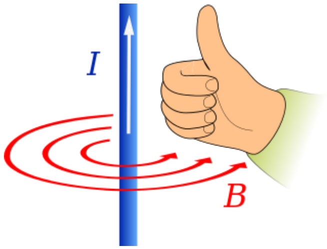
- Before core memory
  - Relays
    - 10-100s of bits
  - Rotating magnetic drums (1932 – 1960s)
    - Up to 100s kbits
    - Sequential access
    - Ancestor of floppy / hard disks
  - Williams tube (1947 - mid 1950s)
    - 1-2 kbits
    - Random access
  - Delay lines (1947 – mid 1950s (and beyond))
    - 1 kbit
    - Sequential access
- After core memory
  - Semiconductor integrated circuits (early 1970s – now)

A brief history of computer memory

1946	ENIAC
1947	
1948	
1949	EDSAC
1950	ERA 1101 - 1st commercial computer
1951	
1952	
1953	IBM 701, IBM's 1st computer
1954	
1955	
1956	
1957	
1958	
1959	IBM Stretch, IBM's 1st transistorised computer
1960	DEC PDP-1
1961	
1962	
1963	
1964	CDC 6600 super-computer
1965	DEC PDP-8, 1st commercial minicomputer
1966	
1967	
1968	Apollo guidance computer
1969	
1970	
1971	
1972	HP-35 portable calculator
1973	
1974	Xerox Alto workstation
1975	
1976	Apple 1, Cray I
1977	TRS-80, Commodore Pet
1978	VAX 11/780

The lifetime of core memory, around 20 years

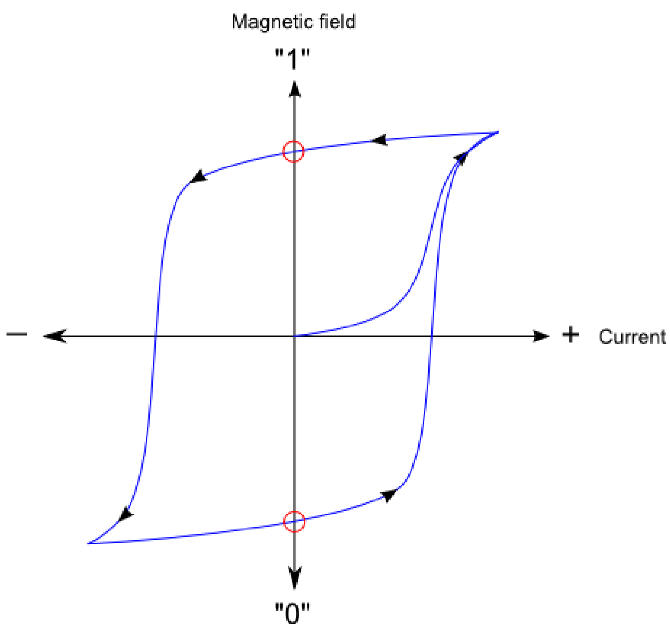
How did it work?



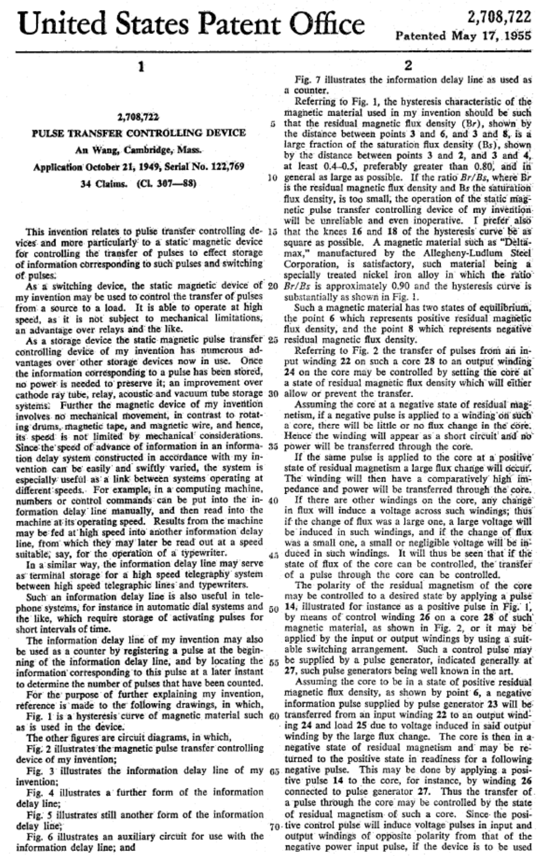
- Ampere’s Law: A current generates a magnetic field encircling the wire
- Place a ferromagnetic ring around the wire and the magnetic field can induce a permanent magnetic field in the ring
  - Clockwise = 0
  - Anti-clockwise = 1
- So we can store 0 and 1 values in a ferrite ring, but how can we read the value back?

US 2,708,722 – An Wang

- Magnetic field in the ring is not proportional to the current



- Faraday's Law: change in magnetic field induces a current in a nearby conductor
  - Add a second "sense" wire through the ring
  - Sense wire detects the flip as a pulse



United States Patent Office

2,708,722
Patented May 17, 1955

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2,708,722

PULSE TRANSFER CONTROLLING DEVICE

An Wang, Cambridge, Mass.

Application October 21, 1949, Serial No. 122,769

34 Claims. (Cl. 307—88)

This invention relates to pulse transfer controlling devices and more particularly to a static magnetic device for controlling the transfer of pulses to effect storage of information corresponding to such pulses and switching of pulses.

As a switching device, the static magnetic device of my invention may be used to control the transfer of pulses from a source to a load. It is able to operate at high speed, as it is not subject to mechanical limitations, an advantage over relays and the like.

As a storage device the static magnetic pulse transfer controlling device of my invention has numerous advantages over other storage devices now in use. Once the information corresponding to a pulse has been stored, no power is needed to preserve it; an improvement over cathode ray tube, relay, acoustic and vacuum tube storage systems. Further the magnetic device of my invention involves no mechanical movement, in contrast to rotating drums, magnetic tape, and magnetic wire, and hence, its speed is not limited by mechanical considerations. Since the speed of advance of information in an information delay system constructed in accordance with my invention can be easily and swiftly varied, the system is especially useful as a link between systems operating at different speeds. For example, in a computing machine, numbers or control commands can be put into the information delay line manually, and then read into the machine at its operating speed. Results from the machine may be fed at high speed into another information delay line, from which they may later be read out at a speed suitable, say, for the operation of a typewriter.

In a similar way, the information delay line may serve as terminal storage for a high speed telegraphy system between high speed telegraphic lines and typewriters.

Such an information delay line is also useful in telephone systems, for instance in automatic dial systems and the like, which require storage of activating pulses for short intervals of time.

The information delay line of my invention may also be used as a counter by registering a pulse at the beginning of the information delay line, and by locating the information corresponding to this pulse at a later instant to determine the number of pulses that have been counted.

For the purpose of further explaining my invention, reference is made to the following drawings, in which,

Fig. 1 is a hysteresis curve of magnetic material such as is used in the device.

The other figures are circuit diagrams, in which,

Fig. 2 illustrates the magnetic pulse transfer controlling device of my invention;

Fig. 3 illustrates the information delay line of my invention;

Fig. 4 illustrates a further form of the information delay line;

Fig. 5 illustrates still another form of the information delay line;

Fig. 6 illustrates an auxiliary circuit for use with the information delay line; and

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Fig. 7 illustrates the information delay line as used as a counter.

Referring to Fig. 1, the hysteresis characteristic of the magnetic material used in my invention should be such that the residual magnetic flux density (Br), shown by the distance between points 3 and 6, and 3 and 8, is a large fraction of the saturation flux density (Bs), shown by the distance between points 3 and 2, and 3 and 4, at least 0.4–0.5, preferably greater than 0.80, and in general as large as possible. If the ratio Br/Bs, where Br is the residual magnetic flux density and Bs the saturation flux density, is too small, the operation of the static magnetic pulse transfer controlling device of my invention will be unreliable and even inoperative. I prefer also that the knees 16 and 18 of the hysteresis curve be as square as possible. A magnetic material such as "Deltamax," manufactured by the Allegheny-Ludlum Steel Corporation, is satisfactory, such material being a specially treated nickel iron alloy in which the ratio Br/Bs is approximately 0.90 and the hysteresis curve is substantially as shown in Fig. 1.

Such a magnetic material has two states of equilibrium, the point 6 which represents positive residual magnetic flux density, and the point 8 which represents negative residual magnetic flux density.

Referring to Fig. 2 the transfer of pulses from an input winding 22 on such a core 28 to an output winding 24 on the core may be controlled by setting the core at a state of residual magnetic flux density which will either allow or prevent the transfer.

Assuming the core at a negative state of residual magnetism, if a negative pulse is applied to a winding on such a core, there will be little or no flux change in the core. Hence the winding will appear as a short circuit and no power will be transferred through the core.

If the same pulse is applied to the core at a positive state of residual magnetism a large flux change will occur. The winding will then have a comparatively high impedance and power will be transferred through the core.

If there are other windings on the core, any change in flux will induce a voltage across such windings; thus if the change of flux was a large one, a large voltage will be induced in such windings, and if the change of flux was a small one, a small or negligible voltage will be induced in such windings. It will thus be seen that if the state of flux of the core can be controlled, the transfer of a pulse through the core can be controlled.

The polarity of the residual magnetism of the core may be controlled to a desired state by applying a pulse 14, illustrated for instance as a positive pulse in Fig. 1, by means of control winding 26 on a core 28 of such magnetic material, as shown in Fig. 2, or it may be applied by the input or output windings by using a suitable switching arrangement. Such a control pulse may be supplied by a pulse generator, indicated generally at 27, such pulse generators being well known in the art.

Assuming the core to be in a state of positive residual magnetic flux density, as shown by point 6, a negative information pulse supplied by pulse generator 23 will be transferred from an input winding 22 to an output winding 24 and load 25 due to voltage induced in said output winding by the large flux change. The core is then in a negative state of residual magnetism and may be returned to the positive state in readiness for a following negative pulse. This may be done by applying a positive pulse 14 to the core, for instance, by winding 26 connected to pulse generator 27. Thus the transfer of a pulse through the core may be controlled by the state of residual magnetism of such a core. Since the positive control pulse will induce voltage pulses in input and output windings of opposite polarity from that of the negative power input pulse, if the device is to be used

US 2,708,722 – An Wang

- Destructive read:
  - Write “0” value
  - If sense wire detects a flip,
    - The previous value was “1”
    - Rewrite the “1” value back
  - otherwise, do nothing
  - Wang created a 50-bit shift register form of memory using this technique
- In 1955, Wang sold the patent to IBM for $500,000
  - That’s about $4.5M in today’s money…
  - Wang went on to form Wang Laboratories and revolutionise office computing

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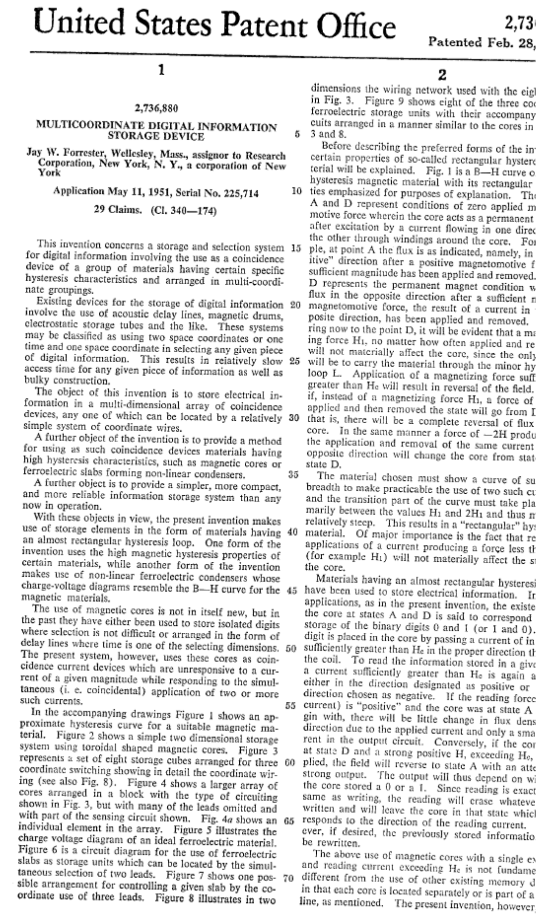
US 2,736,880 – Jay Forrester

- Split the current through a ring across 2 wires; total current = threshold value
- Arranges cores in an X/Y array
  - Pass half the current through 1 column
  - Pass half the current through 1 row
  - Only the core at the intersection gets the right amount of current
- Only need $2\sqrt{n}$ address lines
- 1 sense wire going through all cores
- Random access
- In 1964, MIT sold the patent to IBM for $13,000,000
  - That's about $100M in today's money



United States Patent Office

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2,736,880

MULTICOORDINATE DIGITAL INFORMATION STORAGE DEVICE

Jay W. Forrester, Wellesley, Mass., assignor to Research Corporation, New York, N. Y., a corporation of New York

Application May 11, 1951, Serial No. 225,714

29 Claims. (Cl. 340—174)

This invention concerns a storage and selection system for digital information involving the use as a coincidence device of a group of materials having certain specific hysteresis characteristics and arranged in multi-coordinate groupings.

Existing devices for the storage of digital information involve the use of acoustic delay lines, magnetic drums, electrostatic storage tubes and the like. These systems may be classified as using two space coordinates or one time and one space coordinate in selecting any given piece of digital information. This results in relatively slow access time for any given piece of information as well as bulky construction.

The object of this invention is to store electrical information in a multi-dimensional array of coincidence devices, any one of which can be located by a relatively simple system of coordinate wires.

A further object of the invention is to provide a method for using as such coincidence devices materials having high hysteresis characteristics, such as magnetic cores or ferroelectric slabs forming non-linear condensers.

A further object is to provide a simpler, more compact, and more reliable information storage system than any now in operation.

With these objects in view, the present invention makes use of storage elements in the form of materials having an almost rectangular hysteresis loop. One form of the invention uses the high magnetic hysteresis properties of certain materials, while another form of the invention makes use of non-linear ferroelectric condensers whose charge-voltage diagrams resemble the B—H curve for the magnetic materials.

The use of magnetic cores is not in itself new, but in the past they have either been used to store isolated digits where selection is not difficult or arranged in the form of delay lines where time is one of the selecting dimensions. The present system, however, uses these cores as coincidence current devices which are unresponsive to a current of a given magnitude while responding to the simultaneous (i. e. coincidental) application of two or more such currents.

In the accompanying drawings Figure 1 shows an approximate hysteresis curve for a suitable magnetic material. Figure 2 shows a simple two dimensional storage system using toroidal shaped magnetic cores. Figure 3 represents a set of eight storage cubes arranged for three coordinate switching showing in detail the coordinate wiring (see also Fig. 8). Figure 4 shows a larger array of cores arranged in a block with the type of circuiting shown in Fig. 3, but with many of the leads omitted and with part of the sensing circuit shown. Fig. 4*a* shows an individual element in the array. Figure 5 illustrates the charge voltage diagram of an ideal ferroelectric material. Figure 6 is a circuit diagram for the use of ferroelectric slabs as storage units which can be located by the simultaneous selection of two leads. Figure 7 shows one possible arrangement for controlling a given slab by the coordinate use of three leads. Figure 8 illustrates in two

Into the third dimension

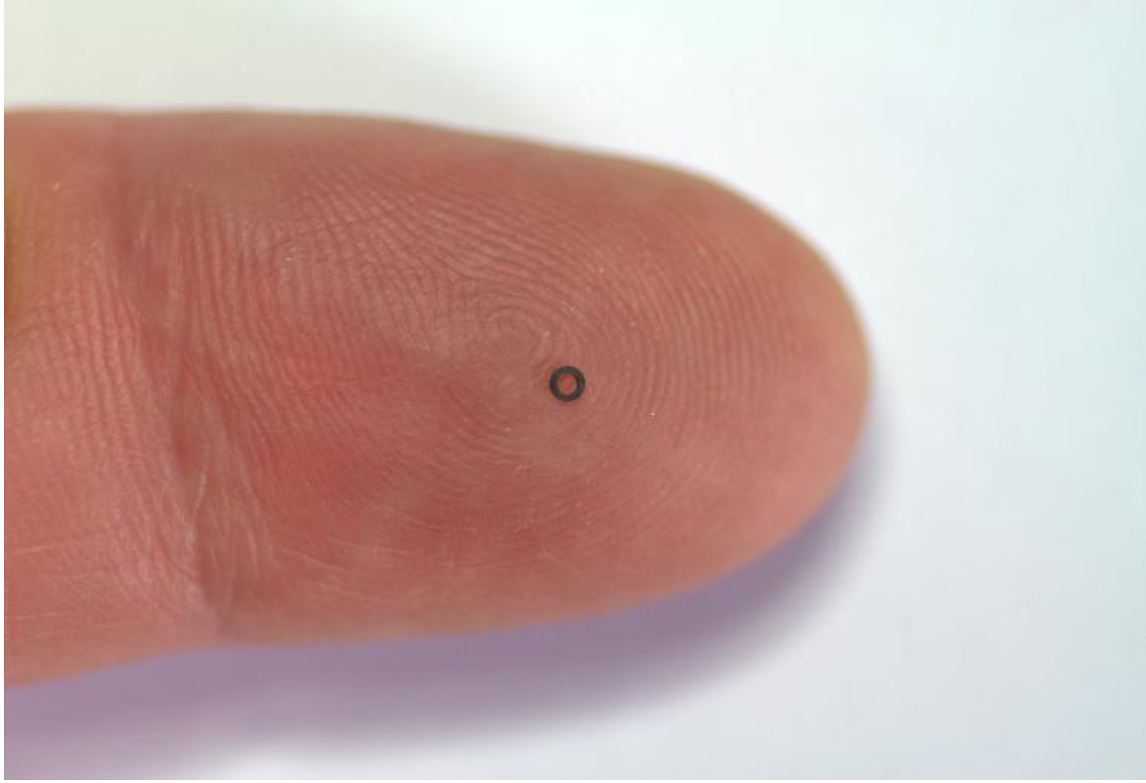
- You can't keep making arrays bigger and bigger
- Stacking them makes sense
  - Expand the address space by using extra bits to address each plane
  - Store each bit of a word in a separate plane
- The inhibit wire was added to make this easier
  - Goes through each for in the plane (like the sense wire)
  - All planes share the same address lines
  - If you don't want to write to a plane, put some reverse current through the inhibit line, so the net current is below the threshold

Performance

- Performance
  - 10s of kBytes per plane
  - Access time < 1µs (clock rate > 1MHz)
  - Random access
  - Non-volatile
  - Power-hungry
- Assembly
  - Manual at first
  - Eventually jigs were created for semi-manual assembly
    - Shaking, vacuum tables
    - Wires threaded with special needles
  - “Ferrite Core Planes and Arrays: IBM’s Manufacturing Evolution”
    - http://ibm-1401.info/IBMCoreArraysIEEEMagnetics1969.pdf

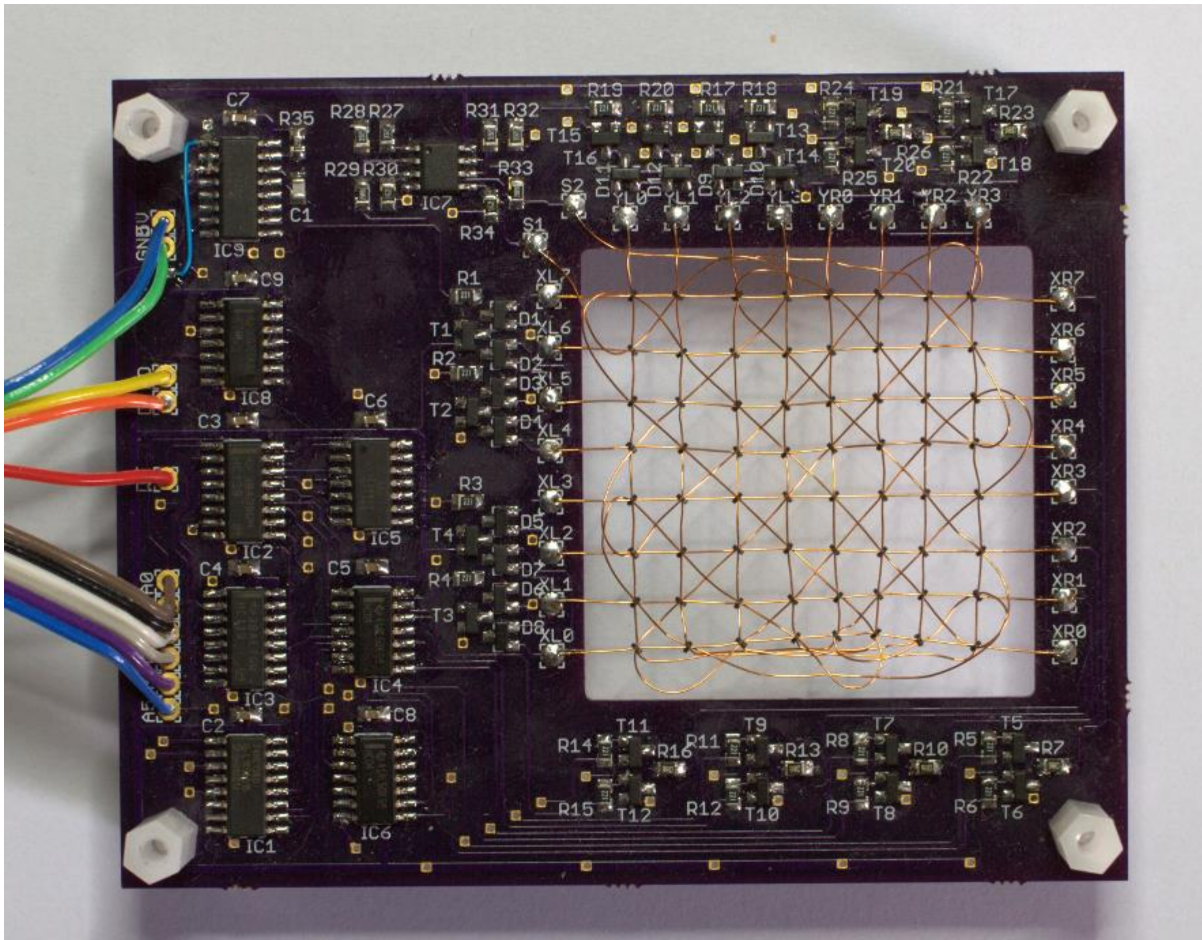
Proof-of-concept

- You can buy ferrite cores on eBay:



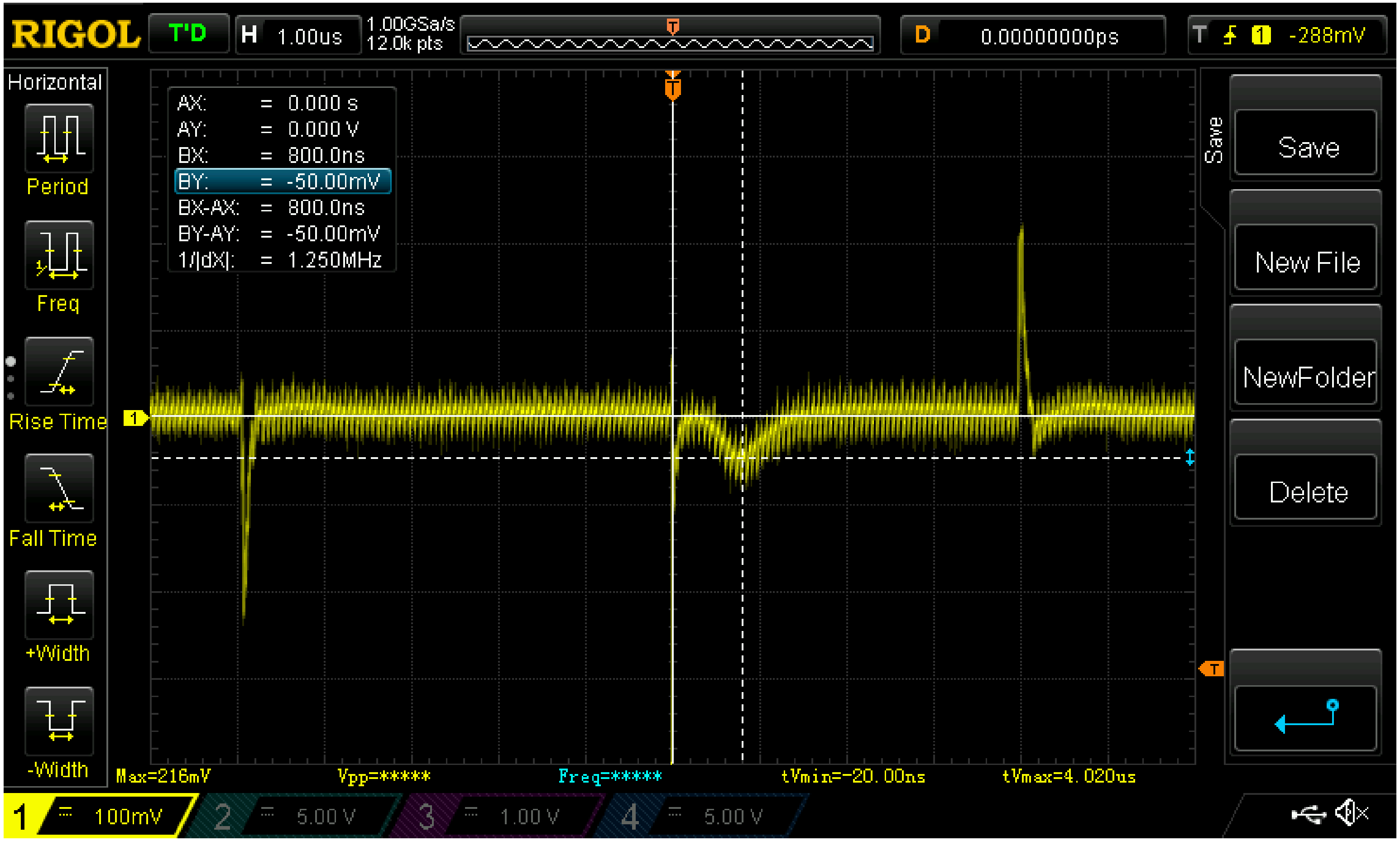
Proof-of-concept

- An 8 byte memory board:



Proof-of-concept

- Detecting the sense line pulse:



Questions?

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