Memory devices

Resources and methods for learning about these subjects (list a few here, in preparation for your research):

Question 1

When Digital Audio Tape (DAT) was first introduced to the American public, it was touted as delivering superior sound quality. Most importantly, this high quality of sound was not supposed to degrade over time like standard (analog) audio cassette tape recordings.

The magnetic media from which DAT was manufactured was basically the same stuff used to make *analog* audio tape. Explain why the encoding of audio data *digitally* on the same media would provide superior resistance to degradation over analog recordings even though the recording media was the same. Also, explain how this is significant to modern digital data storage technologies such as those used to store photographic images and numerical data.

<u>file 01441</u>

Answer 1

The answer to why digital recordings retain their quality longer lies in the bivalent nature of digital data, being comprised of either "high" or "low" states, with nothing in between. Consider a sine wave, directly recorded in analog form on magnetic tape, versus a *digitized* representation of a sine wave, recorded as a series of 1's and 0's on the same type of tape. Now introduce some "noise" to each of the signals, and consider the results upon playback.

Notes 1

Challenge students to come up with some *disadvantages* of digital recordings, now that they understand the difference between analog and digital data storage. While digital technology certainly enjoys some advantages over analog, it is not necessarily superior in all aspects!

Question 2

Define the following terms, as they relate to digital memory devices:

- RAM:
- ROM:
- Volatile:
- Nonvolatile:

In particular, explain why "RAM" is a misleading term.

<u>file 01439</u>

Answer 2

ROM stands for Read-Only Memory, which means it can only be written to once. *Volatile* and *Nonvolatile* refer to whether or not stored data is lost when the device is powered down.

Technically, *RAM* means Random-Access Memory, where data stored in memory may be accessed without having to "sift through" all the other bits of data in sequential order. In practice, however, the term RAM is used to designate the volatile electronic memory inside a computer, which just happens to be randomly accessible.

Notes 2

The mis-use of the acronym "RAM" is another unfortunate entry in the lexicon of electronics. Your students are sure to have questions about this term, so be prepared to discuss it with them!

Question 3

Determine whether the following recording devices are *random access* or *sequential access*, and discuss the advantage(s) of one type of access over the other:

- DVD (disk)
- Audio tape cassette
- CD-ROM (disk)
- ROM memory chip
- Vinyl phonograph record
- Video tape cassette
- Magnetic "hard" drive
- Magnetic bubble memory
- Paper tape (a long strip of tape with holes punched in it)
- RAM memory chip

file 01440

Answer 3

- DVD (disk) – *random access*
- Audio tape cassette – *sequential access*
- CD-ROM (disk) – *random access*
- ROM memory chip – *random access*
- Vinyl phonograph record – *random access*
- Video tape cassette – *sequential access*
- Magnetic "hard" drive – *random access*
- Magnetic bubble memory – *sequential access*
- Paper tape (a long strip of tape with holes punched in it) – *sequential access*
- RAM memory chip – *random access*

Be prepared to discuss how each of these recording technologies works, and *why* each one is either random or sequential access.

Notes 3

One of the purposes of this question is to get students to realize that "RAM" memory (solid-state, volatile memory "chips" in a computer) is not the only type of data storage device capable of randomly accessing its contents, and that the term "RAM" as it is commonly used is something of a misnomer.

Question 4

Define the following acronyms:

- ROM:
- PROM:
- EPROM:
- EEPROM:
- UVEPROM:

Be prepared to explain a few things about each of these memory technologies: how they work, what applications they might be found in, advantages and disadvantages of each.

file 01449

Answer 4

- ROM: *Read-Only Memory*
- PROM: *Programmable Read-Only Memory*
- EPROM: *Erasable Programmable Read-Only Memory*
- EEPROM: *Electrically Erasable Programmable Read-Only Memory*
- UVEPROM: *UltraViolet Erasable Programmable Read-Only Memory*

Notes 4

ROM designations are another set of misnomers that have crept into the electronics lexicon. I mean really, how can anything be both *erasable* and *programmable*, but still be *read-only*?

Question 5

Explain the difference between *static* RAM ("SRAM") and *dynamic* RAM ("DRAM") memory technologies. Which type of memory technology provides faster access of data, and why? Which type of memory technology provides the greatest storage density, and why?

file 01442

Answer 5

Static RAM provides the fastest access, while dynamic RAM provides the greatest amount of memory per physical volume (storage density).

Follow-up question: how is *refreshing* provided for dynamic RAM chips? Is this something taken care of internal to the chip, or must the circuit designer provide external circuitry to refresh the dynamic RAM chip's memory cells?

Notes 5

Ask your students where they obtained their information on static versus dynamic RAM technologies. Extra credit for consulting datasheets!

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Question 6

Flash memory is a nonvolatile memory technology, offering greater density than either SRAM or DRAM, and faster erasure than standard EPROMs. At first, it would seem Flash memory outperforms all other memory types, but it doesn't. What are some of the *disadvantages* of Flash memory, and what kind of applications is it best suited for?

file 01452

Answer 6

Flash memories can only be erased or re-programmed in *blocks*, rather than single words at a time. Also, their cycle life is quite a bit less than either SRAM or DRAM technology.

Notes 6

Discuss with your students some of the different applications of Flash memory technology. Talk about how those applications fit the capabilities (and weaknesses) of Flash technology well.

Question 7

Two very important concepts to understand when working with digital memory devices are *address* and *data*. Define each of these terms in your own words.

file 01444

Answer 7

I'll let you research these terms on your own! There are many technical references available on digital memory technology, so finding definitions for "address" and "data" should not be difficult.

Notes 7

Analogies are often helpful to communicate the concepts of "address" and "data" to new students. I like to use the example of post office boxes (lots of addressed boxes, each containing different items) when I explain address and data.

Question 8

A ROM memory chip is rated at 4k × 8 bits. What, exactly, does this designation mean? How many addresses are there inside this memory chip? How many bits of storage are there, total, in this memory chip? How many address bits are there, and how many data bits are there?

file 01443

Answer 8

There are 4096 addresses inside this ROM chip, for a total of 32768 bits of data storage. This chip will have twelve address bits and eight data bits.

Notes 8

Discuss with your students why there are not 4000 (exactly) addresses in a "4k" memory chip.

Question 9

Suppose you need to store a text message in digital memory, consisting of 7500 ASCII characters. What is the most logical memory organization (addresses × data lines) to do this? How many address bits would be needed to store these 7500 characters?
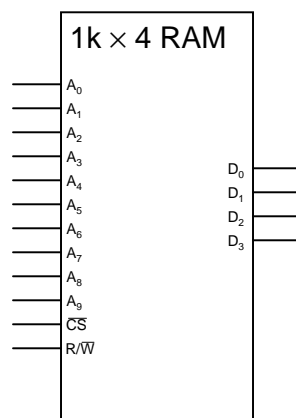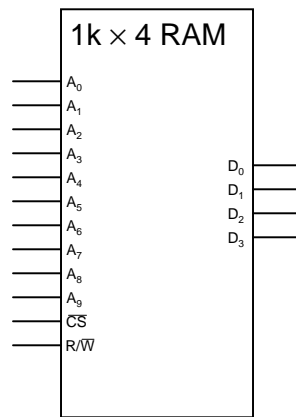
file 01445

Answer 9

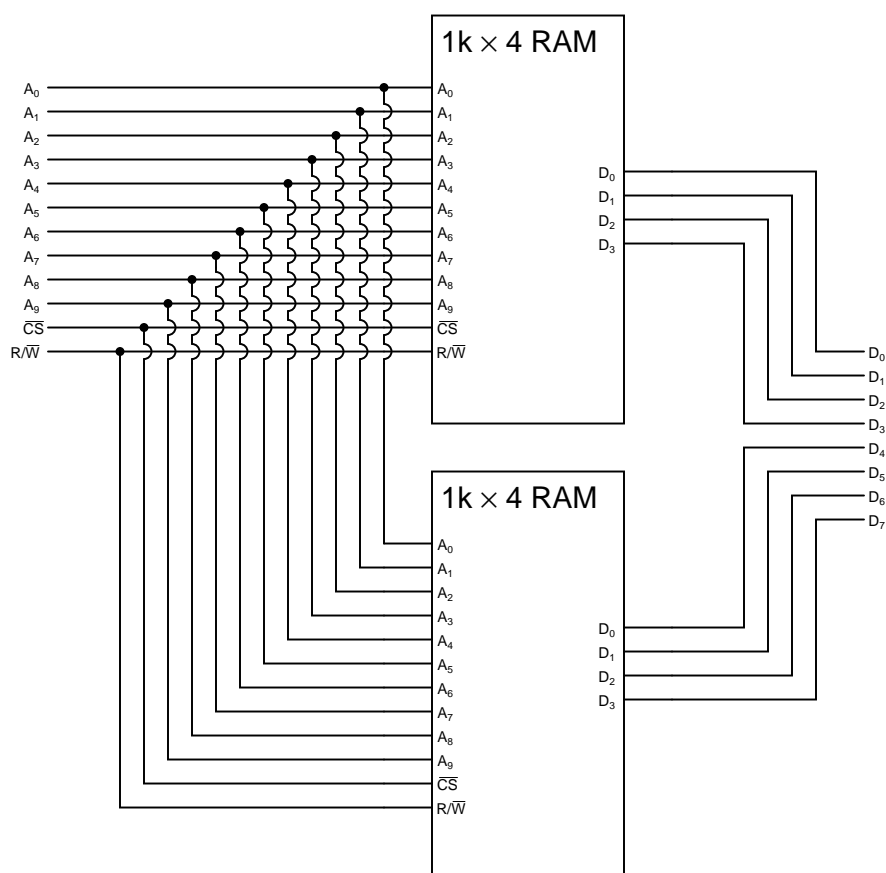Ideal memory organization: 8k × 8, thirteen address bits required.

Notes 9

Be sure to ask your students *how* they calculated 13 bits for the address. Of course, there is the trial-and-error method of trying different powers of two, but there is a much more elegant solution involving logarithms to find the requisite number of bits.

Question 10

Suppose you need a memory array with 1k × 8 organization, but all you have on hand are 1k × 4 memory chips. Show how you could connect two of them to form the desired array:

1k × 4 RAM

A_0
A_1
A_2
A_3
A_4 D_0
A_5 D_1
A_6 D_2
A_7 D_3
A_8
A_9
$\overline{CS}$
$R/\overline{W}$

1k × 4 RAM

A_0
A_1
A_2
A_3
A_4 D_0
A_5 D_1
A_6 D_2
A_7 D_3
A_8
A_9
$\overline{CS}$
$R/\overline{W}$

file 01446

Follow-up question: a common mistake made by students when they "expand" the data bus width of a memory array is to parallel the output lines (in the same way that the address lines are shown paralleled here). Why would this be wrong to do? What might happen to the memory chip(s) if their data lines were paralleled?
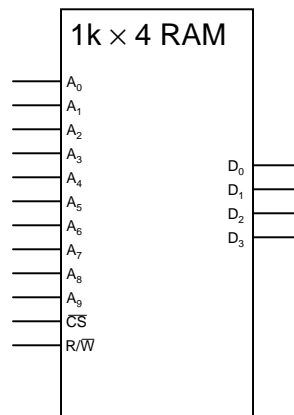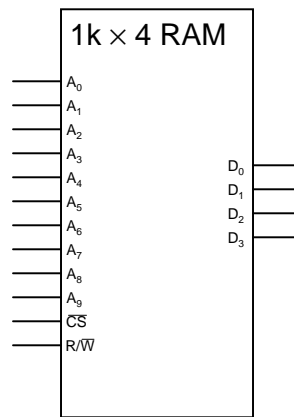
Notes 10

Be sure to spend some time discussing the common mistake referenced in the follow-up question. This is something I've seen more than once, and it reveals a fundamental gap in understanding on the part of the mistaken student. What students are prone to do is try to *memorize* the sequence of connections rather than really understand *why* memory array expansion works, which leads to errors such as this.
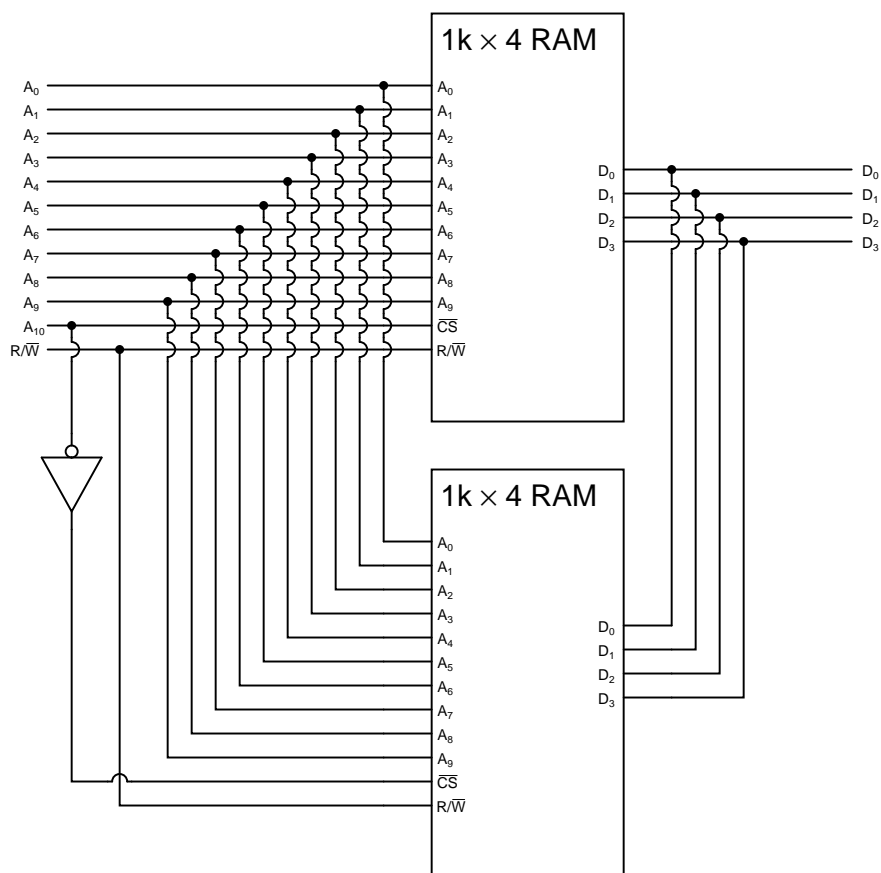
Note that the answer to "what might happen" depends on whether the first operation is a *read*, or a *write*.

Question 11

Suppose you need a memory array with 2k × 4 organization, but all you have on hand are 1k × 4 memory chips. Show how you could connect two of them to form the desired array:

1k × 4 RAM

A_0
A_1
A_2
A_3
A_4
A_5
A_6
A_7
A_8
A_9
$\overline{CS}$
$R/\overline{W}$

D_0
D_1
D_2
D_3

1k × 4 RAM

A_0
A_1
A_2
A_3
A_4
A_5
A_6
A_7
A_8
A_9
$\overline{CS}$
$R/\overline{W}$

D_0
D_1
D_2
D_3

file 01447

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Answer 11

Follow-up question: which of the two memory chips shown here stores the first 1024 addresses, and which one stores the next 1024 addresses? How can you tell?

Challenge question: as you can see, the expansion in addresses comes at the expense of losing the ability to simultaneously disable *both* memory chips. Add whatever logic gates are necessary to this circuit to provide a "global" $\overline{CS}$ line for the 2k $\times$ 4 memory array.

Notes 11

Be sure to spend some time discussing the follow-up question. Once again, I've noticed students are prone to memorizing the connection pattern rather than take the time to figure out *why* the chips are connected as they are.

Question 12

Suppose you need a memory array with 4k × 4 organization, but all you have on hand are 1k × 4 memory chips. Explain how you could build a memory array of this size using multiple 1k × 4 chips.

file 01448

Answer 12

Use four memory chips: parallel the ten address lines from each 1k × 4 memory chip, then connect the $\overline{CS}$ line of each chip to the output of a 2-line to 4-line decoder. The two decoder input lines will then become address lines A_{10} and A_{11} of the 4k × 4 memory array.

Notes 12

Although no schematic is given here in the answer, I expect my students to be able to draw one on their own.

Question 13

Dynamic RAM chips often contain more addresses than they have address lines to select them with. For example, the MCM516100 DRAM chip has an organization of 16M × 1, yet it only has twelve address lines.

Explain how it is possible to select one out of 16 *million* unique addresses while using only twelve address lines. Hint: the technique is known as *address multiplexing*. Be sure to refer to one or more dynamic RAM datasheets when doing your research!

file 01451

Answer 13

With address multiplexing, the address lines going in to the memory chip are used *twice* to select any arbitrary address, bringing in 12 bits worth of the 24-bit address at a time.

Follow-up question: explain how the memory chip "knows" which 12 bits of the address are being read at any given time.

Notes 13

Explain to your students that address multiplexing is not technically limited to application in *dynamic* RAM chips only, but that it is usually applied there because of the high address density afforded by dynamic RAM technology. Most static RAMS, by contrast, are not dense enough to require address lines serve double-duty!

Question 14

After a ROM memory has been programmed with data, it is good to verify that the data now stored is okay, and not corrupted with any errors. A popular method of doing this is to calculate a *checksum* on the stored data, and compare that against the checksum for the original data. If the checksum numbers are identical, chances are there are no corruptions in the stored data.

Explain exactly what checksum is, and how it works as an error-detection strategy.

file 01450

Answer 14

One way to think about checksum is to recall the error-detection strategy of *parity bits*. At root, the two processes are very similar. As for the details of what checksum is and how it is calculated, I leave that for you to research!

Notes 14

Once again, there is little I can reveal in the answer without giving everything away. There are enough resources available for students to learn about checksum on their own, that you should not have to supply additional information.

Question 15

An important use for read-only semiconductor memories is as *look-up tables*. Describe what a "look-up table" is, and what one might be used for.

file 01477

Answer 15

A *look-up table* is a set of data programmed into a memory device, used to map a function of some kind: for each unique input (address), there is an output (data) that means something to the system in which it is installed.

An example of a look-up table is an EBCDIC-to-ASCII code converter, where an EBCDIC code input to the address lines of a ROM chip "looks up" the equivalent ASCII character value from memory, and outputs it as the result through the ROM chip's data lines.

Notes 15

The EBCDIC-to-ASCII code converter concept is not hypothetical! I actually designed and helped build such a circuit to allow standard personal computers to "talk" to an obsolete CNC machine tool control computer which didn't understand ASCII data, only EBCDIC. A look-up table implemented in a UVEPROM served as a neat way to implement this function, without a lot of complex circuitry.

Question 16

Suppose an automobile manufacturer was designing a new car engine design, and they needed a memory chip to store *look-up tables* for the engine's control computer, holding data such as optimum fuel/air ratios for different engine loads which the computer would then consult to maintain best performance, or economy, or emissions. What type of memory chip would you recommend for the task, and why? Choose from the following list:

- Static RAM (SRAM)
- Mask ROM
- PROM
- Dynamic RAM (DRAM)
- EPROM
- Magnetic core

file 04049

Answer 16

EPROM would probably be the best choice. I'll let you discuss this with your classmates and with your instructor, though!

Notes 16

This question is multi-faceted. Students must consider volatility and ease of updating (the data), as well as simply applying the concept of a look-up table to a car's engine control computer, in order to intelligently answer this question.

Question 17

Research datasheets for the 74LS184 and 74LS185 integrated circuits, and then explain how read-only memory technology is used to perform the BCD/binary conversion functions.

file 02991

Answer 17

These integrated circuits are really just read-only memory chips programmed with *look-up tables* for converting BCD to binary (74LS184) and binary to BCD (74LS185).

Notes 17

Discuss with your students why someone would choose to implement these functions in a look-up table instead of using combinational logic or a microprocessor/microcontroller. What advantage(s) might be realized with the look-up table approach?

Question 18

Don't just sit there! Build something!!

Learning to analyze digital circuits requires much study and practice. Typically, students practice by working through lots of sample problems and checking their answers against those provided by the textbook or the instructor. While this is good, there is a much better way.

You will learn much more by actually *building and analyzing real circuits*, letting your test equipment provide the "answers" instead of a book or another person. For successful circuit-building exercises, follow these steps:

1. Draw the schematic diagram for the digital circuit to be analyzed.
2. Carefully build this circuit on a breadboard or other convenient medium.
3. Check the accuracy of the circuit's construction, following each wire to each connection point, and verifying these elements one-by-one on the diagram.
4. Analyze the circuit, determining all output logic states for given input conditions.
5. Carefully measure those logic states, to verify the accuracy of your analysis.
6. If there are any errors, carefully check your circuit's construction against the diagram, then carefully re-analyze the circuit and re-measure.

Always be sure that the power supply voltage levels are within specification for the logic circuits you plan to use. If TTL, the power supply *must* be a 5-volt regulated supply, adjusted to a value as close to 5.0 volts DC as possible.

One way you can save time and reduce the possibility of error is to begin with a very simple circuit and incrementally add components to increase its complexity after each analysis, rather than building a whole new circuit for each practice problem. Another time-saving technique is to re-use the same components in a variety of different circuit configurations. This way, you won't have to measure any component's value more than once.

file 00805

Answer 18

Let the electrons themselves give you the answers to your own "practice problems"!

It has been my experience that students require much practice with circuit analysis to become proficient. To this end, instructors usually provide their students with lots of practice problems to work through, and provide answers for students to check their work against. While this approach makes students proficient in circuit theory, it fails to fully educate them.

Students don't just need mathematical practice. They also need real, hands-on practice building circuits and using test equipment. So, I suggest the following alternative approach: students should *build* their own "practice problems" with real components, and try to predict the various logic states. This way, the digital theory "comes alive," and students gain practical proficiency they wouldn't gain merely by solving Boolean equations or simplifying Karnaugh maps.

Another reason for following this method of practice is to teach students *scientific method*: the process of testing a hypothesis (in this case, logic state predictions) by performing a real experiment. Students will also develop real troubleshooting skills as they occasionally make circuit construction errors.

Spend a few moments of time with your class to review some of the "rules" for building circuits before they begin. Discuss these issues with your students in the same Socratic manner you would normally discuss the worksheet questions, rather than simply telling them what they should and should not do. I never cease to be amazed at how poorly students grasp instructions when presented in a typical lecture (instructor monologue) format!

I highly recommend CMOS logic circuitry for at-home experiments, where students may not have access to a 5-volt regulated power supply. Modern CMOS circuitry is far more rugged with regard to static discharge than the first CMOS circuits, so fears of students harming these devices by not having a "proper" laboratory set up at home are largely unfounded.

A note to those instructors who may complain about the "wasted" time required to have students build real circuits instead of just mathematically analyzing theoretical circuits:

What is the purpose of students taking your course?

If your students will be working with real circuits, then they should learn on real circuits whenever possible. If your goal is to educate theoretical physicists, then stick with abstract analysis, by all means! But most of us plan for our students to do something in the real world with the education we give them. The "wasted" time spent building real circuits will pay huge dividends when it comes time for them to apply their knowledge to practical problems.

Furthermore, having students build their own practice problems teaches them how to perform *primary research*, thus empowering them to continue their electrical/electronics education autonomously.

In most sciences, realistic experiments are much more difficult and expensive to set up than electrical circuits. Nuclear physics, biology, geology, and chemistry professors would just love to be able to have their students apply advanced mathematics to real experiments posing no safety hazard and costing less than a textbook. They can't, but you can. Exploit the convenience inherent to your science, and *get those students of yours practicing their math on lots of real circuits!*