USB—Packet oriented, time-division multiplexed under the host's control.

USB transactions each consist of a sequence of packet transmissions under state-machine control.
- Token packet: From host to everyone (Addressing information, read or write—data payload direction)
- Payload: as prescribed by token (The data to be communicated. This packet is optional!)
- Status packet: Receiving device acknowledges error-free reception. This packet is not always present.

Each of the three packet types have a sequence of bits, much like an Ethernet frame
- Sync: opportunity for receiver clock to lock onto the transmitter's clock
- Packet ID: Defines the protocol for the remaining packets
- Data: the actual token, payload, or status information
- Address and endpoint: destination of the packet, distribution of the packet within the destination
- CRC: error detections (retry the whole transaction if there was an error)
- EOP: flags the end of the packet

https://microchipdeveloper.com/usb:device-classes

1

USB—Types of "transactions."

A transaction is a sequence of packets sent for a particular purpose

Control transaction
- Mainly for device enumeration
- May also be used for such status matters as, "printer out of paper."

Interrupt transaction
- Not what it seems. In USB there is no way for a device to grab the attention of the host 🙁
- Scheduled polling—host periodically polls the device
- Typically used for low-speed HID devices: A character was typed, or the mouse moved, etc.
- If the device has an interrupt request, that gets communicated when the device is polled.
- There is a bound on the latency. (But it is nowhere as short as a hardware interrupt can produce.)

Isochronous transaction
- Intended for media transmission—smooth motion and sound are needed
- Time-slotted packets provide guaranteed bandwidth (bit-rate)
- Bounded latency—keeps up with "real time."
- Error detection. If an error, discard the packet. No retry. Receiver must "make up" something.
- Not available in low speed.

Bulk transaction
- Intended for file transfer: A burst of data as fast as possible, then long intervals of silence.
- Error detection with retry as much as needed for 100% valid transfer of data
- packets have lowest priority relative to above types. No guarantee of bandwidth or latency.
- Unidirectional, not available in low speed.

2

USB—Dynamic Attachment and Removal, a.k.a. Hot-plugging

We are so used to it that this hardly seems to be a “feature.”
When you insert a USB plug (anywhere) or pull one out something sensible happens!
Things do not “crash” when you pull a USB plug—only the device associated with the plug stops working.
Believe it or not, this was a first with USB.
Interfaces of the 1990’s era and earlier were subject to capricious behavior if the hardware connection was lost.

Typical bad behavior of earlier data communications:
- E.g. if you unplug the printer the printer driver starts filling up memory with pages to print.
- Eventually the system’s memory fills up
- Eventually the operating system can no longer work.
- The whole system, every user, every program in progress, crashes.

What we want:
- The printer’s USB cable gets unplugged for some reason.
- The printer driver starts fills up, but it is given only a limited segment of memory
- This printer driver recognizes its memory is full and signals all programs that write to it—offline.
- Problem is limited, other than printer services, nothing else is impacted.
- This “good” behavior is **designed into the “class drivers.”**
- **This good behavior is required by the USB standard.**

Still, hot-plugging is not recommended. E.g. you are writing to a USB thumb drive while you unplug it. This could leave behind corrupted data. I rare cases it could even brick the thumb drive. (Brick: Cause the lost of internal programming so that it will for all practical purposes never be useful again.) Use the “safely remove USB device” (“unmount” in Unix, Linux) option of your OS.

3

USB—Dynamic Attachment and Removal, a.k.a. Hot-plugging

Q: Why couldn’t earlier interfaces, say RS-232, *always* allow hot-plugging?

A: The device driver (in USB the “class driver”) requires information about the status of the hardware connection.
Earlier interfaces could not provide that information to the driver.
To some extent the status of the hardware connection could be inferred, say be using a time-out or a ping, etc.
But inferring status of the hardware connection is awkward.

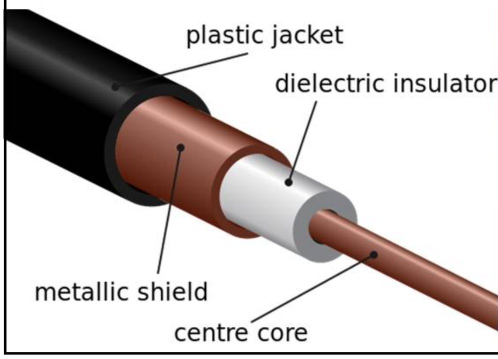
USB hosts and hubs actively detect an open port or a newly attached device.
Class drivers are given direct information—programmers are empowered to use the information.
Programmers generally do a very good job of using the port status information wisely,
but even if not, the USB hosts and ports themselves will never mistake “no connection” for “logic-0” or something like that.

4

Transmission lines
In the context of electric power or analog signals.

Not part of this course. See EGR 360,
Introduction to Power Systems Analysis

Signals are treated as sinusoids
or sums of sinusoids

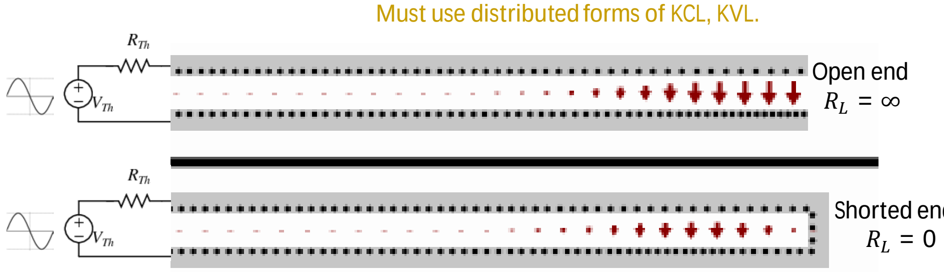


5

<u>In EGR 220 we treated wire as if it was a node</u>
We had a careful definition of a node: All locations of the node at the same voltage with respect to the reference node.
No storage of charge within the node. If one e^- goes in, it pushes another out.

Sorry to disappoint you, but it just ain't so! It is only approximately true, valid for "small" nodes.

When a wire gets long we model it as a transmission line, not a node.
Notice: *node* and *transmission line* are mathematical models, abstractions of reality.
In a transmission line voltages vary with distance,
Charge storage happens. KCL, KVL? Can't use them here in the way used in EGR 220.
Must use distributed forms of KCL, KVL.



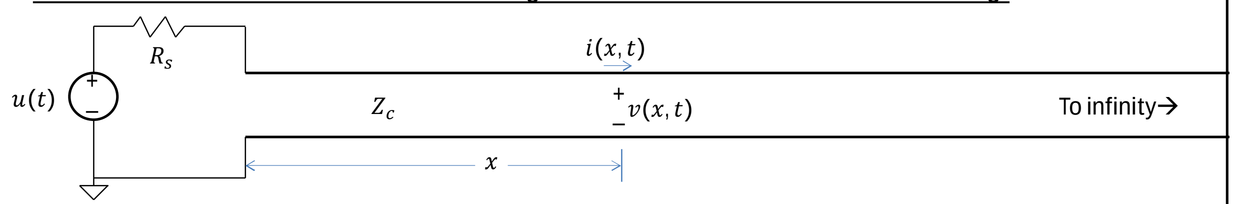
Black dots represent positive charges (dense areas have + charge relative to non-dense areas).
Red arrows represent voltage magnitude and polarity (arrowtip is +).

See animation at: https://commons.wikimedia.org/wiki/File:Transmission_line_pulse_reflections.gif

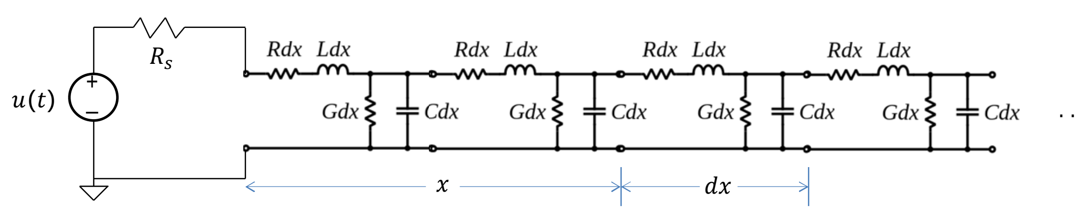
6

7

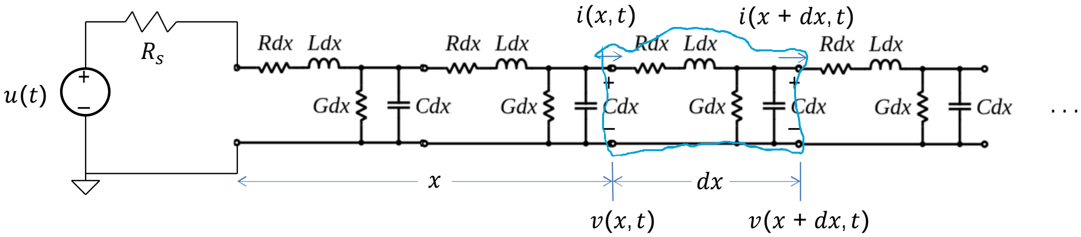
Transmission Lines in the context of digital communication and networking.



Consider applying a step function to an infinitely long transmission line.
We will model this as a sequence of $RLGC$ circuit elements taken in the limit as Δx goes to zero (which is what dx means)
Note that R, L, G, and C must all be specified per unit length. E.g. $L = 33\ \mu$H/m.
At every point along the T-line and at every time there is a voltage and a current, $v(x,t)$ and $i(x,t)$.

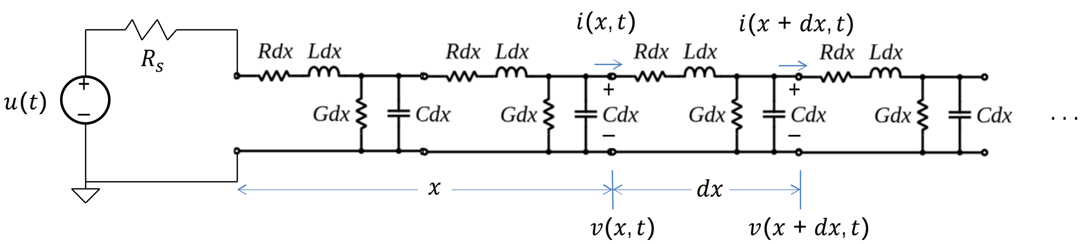


8



$$v(x+dx) = v(x,t) - Ri(x,t)dx - L\frac{\partial i(x,t)}{\partial t}dx \qquad i(x+dx) = i(x,t) - Gv(x,t)dx - C\frac{\partial v(x,t)}{\partial t}dx$$

9



$$v(x+dx) = v(x,t) - Ri(x,t)dx - L\frac{\partial i(x,t)}{\partial t}dx \qquad i(x+dx) = i(x,t) - Gv(x,t)dx - C\frac{\partial v(x,t)}{\partial t}dx$$

$$v(x+dx) - v(x,t) = -Ri(x,t)dx - L\frac{\partial i(x,t)}{\partial t}dx \qquad i(x+dx) - i(x,t) = -Gv(x,t)dx - C\frac{\partial v(x,t)}{\partial t}dx$$

Definition of the derivative:

$$\frac{df(t)}{dt} \triangleq \lim_{dt\to 0}\frac{f(t+dt) - f(t)}{dt}$$

$$\frac{\partial v(x,t)}{\partial x} = -Ri(x,t) - L\frac{\partial i(x,t)}{\partial t} \qquad \frac{\partial i(x,t)}{\partial x} = -Gv(x,t) - C\frac{\partial v(x,t)}{\partial t}$$

10

$$\frac{\partial v(x,t)}{\partial x} = -Ri(x,t) - L\frac{\partial i(x,t)}{\partial t}$$

Take partial w.r.t x

$$\frac{\partial^2 v(x,t)}{\partial x^2} = -R\frac{\partial i(x,t)}{\partial x} - L\frac{\partial^2 i(x,t)}{\partial x \partial t}$$

$$\frac{\partial i(x,t)}{\partial x} = -Gv(x,t) - C\frac{\partial v(x,t)}{\partial t}$$

Take partial w.r.t x

$$\frac{\partial^2 i(x,t)}{\partial x^2} = -G\frac{\partial v(x,t)}{\partial x} - C\frac{\partial^2 v(x,t)}{\partial x \partial t}$$

11

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Take partial w.r.t x

$$\frac{\partial^2 i(x,t)}{\partial x^2} = -G\frac{\partial v(x,t)}{\partial x} - C\frac{\partial^2 v(x,t)}{\partial x \partial t}$$

Take partial w.r.t t

$$\frac{\partial^2 i(x,t)}{\partial x \partial t} = -G\frac{\partial v(x,t)}{\partial t} - C\frac{\partial^2 v(x,t)}{\partial^2 t}$$

12

$$\frac{\partial v(x,t)}{\partial x} = -Ri(x,t) - L\frac{\partial i(x,t)}{\partial t}$$

Take partial w.r.t x

$$\frac{\partial^2 v(x,t)}{\partial x^2} = -R\frac{\partial i(x,t)}{\partial x} - L\frac{\partial^2 i(x,t)}{\partial x \partial t}$$

$$\frac{\partial i(x,t)}{\partial x} = -Gv(x,t) - C\frac{\partial v(x,t)}{\partial t}$$

Take partial w.r.t x

$$\frac{\partial^2 i(x,t)}{\partial x^2} = -G\frac{\partial v(x,t)}{\partial x} - C\frac{\partial^2 v(x,t)}{\partial x \partial t}$$

Take partial w.r.t t

$$\frac{\partial^2 i(x,t)}{\partial x \partial t} = -G\frac{\partial v(x,t)}{\partial t} - C\frac{\partial^2 v(x,t)}{\partial^2 t}$$

Hmm. . . Some terms are getting replicated here.

13

$$\frac{\partial v(x,t)}{\partial x} = -Ri(x,t) - L\frac{\partial i(x,t)}{\partial t}$$

Take partial w.r.t x

$$\frac{\partial^2 v(x,t)}{\partial x^2} = -R\frac{\partial i(x,t)}{\partial x} - L\frac{\partial^2 i(x,t)}{\partial x \partial t}$$

$$\frac{\partial i(x,t)}{\partial x} = -Gv(x,t) - C\frac{\partial v(x,t)}{\partial t}$$

Take partial w.r.t x

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Take partial w.r.t t

$$\frac{\partial^2 i(x,t)}{\partial x \partial t} = -G\frac{\partial v(x,t)}{\partial t} - C\frac{\partial^2 v(x,t)}{\partial^2 t}$$

Hmm. . . Some terms are getting replicated here.

Let's re-write the $\frac{\partial^2 v(x,t)}{\partial x^2}$ term using the expanded terms on the right.

14

$$\frac{\partial v(x,t)}{\partial x} = -Ri(x,t) - L\frac{\partial i(x,t)}{\partial t}$$

Take partial w.r.t x

$$\frac{\partial^2 v(x,t)}{\partial x^2} = -R\frac{\partial i(x,t)}{\partial x} - L\frac{\partial^2 i(x,t)}{\partial x \partial t}$$

$$\frac{\partial i(x,t)}{\partial x} = \underbrace{-Gv(x,t) - C\frac{\partial v(x,t)}{\partial t}}$$

Take partial w.r.t x

$$\frac{\partial^2 i(x,t)}{\partial x^2} = -G\frac{\partial v(x,t)}{\partial x} - C\frac{\partial^2 v(x,t)}{\partial x \partial t}$$

Take partial w.r.t t

$$\frac{\partial^2 i(x,t)}{\partial x \partial t} = \underbrace{-G\frac{\partial v(x,t)}{\partial t} - C\frac{\partial^2 v(x,t)}{\partial^2 t}}$$

$$\frac{\partial^2 v(x,t)}{\partial x^2} = R\overbrace{\left[Gv(x,t) + C\frac{\partial v(x,t)}{\partial t}\right]} + L\overbrace{\left[G\frac{\partial v(x,t)}{\partial t} + C\frac{\partial^2 v(x,t)}{\partial^2 t}\right]}$$

15

$$\frac{\partial v(x,t)}{\partial x} = -Ri(x,t) - L\frac{\partial i(x,t)}{\partial t}$$

Take partial w.r.t x

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$$\frac{\partial^2 v(x,t)}{\partial x^2} = R\left[Gv(x,t) + C\frac{\partial v(x,t)}{\partial t}\right] + L\left[G\frac{\partial v(x,t)}{\partial t} + C\frac{\partial^2 v(x,t)}{\partial^2 t}\right]$$

$$\frac{\partial^2 v(x,t)}{\partial x^2} = LC\frac{\partial^2 v(x,t)}{\partial^2 t} + (LG + CR)\frac{\partial v(x,t)}{\partial t} + RGv(x,t)$$

And clean it up to write it as a standard-form 2nd order partial D.E.

16

$$\frac{\partial v(x,t)}{\partial x} = -Ri(x,t) - L\frac{\partial i(x,t)}{\partial t}$$

Take partial w.r.t x

$$\frac{\partial^2 v(x,t)}{\partial x^2} = -R\frac{\partial i(x,t)}{\partial x} - L\frac{\partial^2 i(x,t)}{\partial x \partial t}$$

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$$\frac{\partial^2 v(x,t)}{\partial x^2} = LC\frac{\partial^2 v(x,t)}{\partial^2 t} + (LG + CR)\frac{\partial v(x,t)}{\partial t} + RGv(x,t)$$ voltage equation

Hold that partial result in your memory for a time.

17

$$\frac{\partial v(x,t)}{\partial x} = -Ri(x,t) - L\frac{\partial i(x,t)}{\partial t}$$

Take partial w.r.t x

$$\frac{\partial^2 v(x,t)}{\partial x^2} = -R\frac{\partial i(x,t)}{\partial x} - L\frac{\partial^2 i(x,t)}{\partial x \partial t}$$

What would have happened if we took the 2nd partial on the left equation instead?

$$\frac{\partial i(x,t)}{\partial x} = -Gv(x,t) - C\frac{\partial v(x,t)}{\partial t}$$

Take partial w.r.t x

$$\frac{\partial^2 i(x,t)}{\partial x^2} = -G\frac{\partial v(x,t)}{\partial x} - C\frac{\partial^2 v(x,t)}{\partial x \partial t}$$

Take partial w.r.t t

$$\frac{\partial^2 i(x,t)}{\partial x \partial t} = -G\frac{\partial v(x,t)}{\partial t} - C\frac{\partial^2 v(x,t)}{\partial^2 t}$$

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18

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current equation

$$\frac{\partial^2 i(x,t)}{\partial x^2} = LC\frac{\partial^2 i(x,t)}{\partial^2 t} + (LG + CR)\frac{\partial i(x,t)}{\partial t} + RGi(x,t)$$

19

The two equations we have derived are called the Telegrapher's Equations

$$\frac{\partial^2 v(x,t)}{\partial x^2} = LC\frac{\partial^2 v(x,t)}{\partial^2 t} + (LG + CR)\frac{\partial v(x,t)}{\partial t} + RGv(x,t)$$

$$\frac{\partial^2 i(x,t)}{\partial x^2} = LC\frac{\partial^2 i(x,t)}{\partial^2 t} + (LG + CR)\frac{\partial i(x,t)}{\partial t} + RGi(x,t)$$

For short transmission lines such as are usually encountered in microcontroller situations we can assume that the transmission line is lossless. That is, $R = 0$ and $G = 0$.

$$\left.\begin{aligned}\frac{\partial^2 v(x,t)}{\partial x^2} &= LC\frac{\partial^2 v(x,t)}{\partial^2 t}\\ \frac{\partial^2 i(x,t)}{\partial x^2} &= LC\frac{\partial^2 i(x,t)}{\partial^2 t}\end{aligned}\right\}\ \text{Wave Equations}$$

20

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$$\frac{\partial^2 v(x,t)}{\partial x^2} = LC\frac{\partial^2 v(x,t)}{\partial^2 t} + (LG + CR)\frac{\partial v(x,t)}{\partial t} + RGv(x,t)$$

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Let $v(x,t) = \cos(\omega(t - x/V_P))$ where ω = frequency (rad/sec) and V_P = propagation speed (m/s)

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