SEA-100: Electronics For Non-Engineers

Excerpt: Lesson 1, First Principles

How electrons move through materials

For present purposes, the simplest image of electrons moving through a material is to think of electrons jumping from one atom to the next as depicted in Figure 1-2 (right).

In the illustration, individual electrons (red arrows) are shown jumping from their orbital positions

Figure 1-2: Electron Flow

around one nucleus to another orbit around an adjacent nucleus. Individually, each electron is free to "jump" in any direction and their motion could be aptly described as random or Brownian. Under the influence of a voltage potential (where the right side is positive and the left negative), however, the aggregate direction of movement becomes a flow of electrons from left to right.
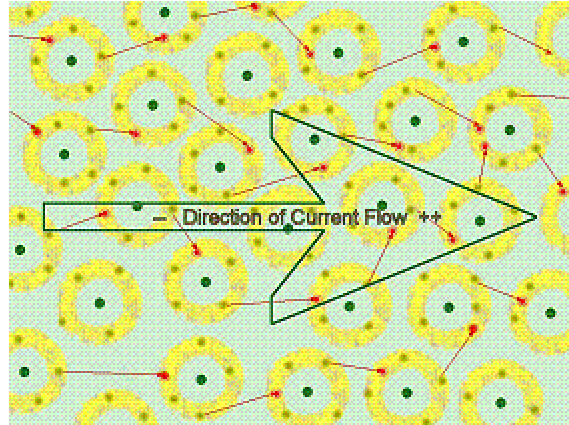
In the actual flow of electrons through a wire or through an electronic component, the specific electron which enters at one end of the circuit is not the same as the electron which exits at the other end. Fortunately, however – just like black cats on a moonless night – all electrons are the same…

Excerpt: Lesson 3, Resistors

Additive Laws / Serial / Parallel

In circuits, resistors are often found in series – one resistor connected to another – or in parallel – two resistors connected to the same two points.

Two (or more) resistors connected in series are additive. That is, the total resistance is the sum of the individual resistances as shown in the first part of Figure 3.2. This is the easiest calculation and the corollary is that the current
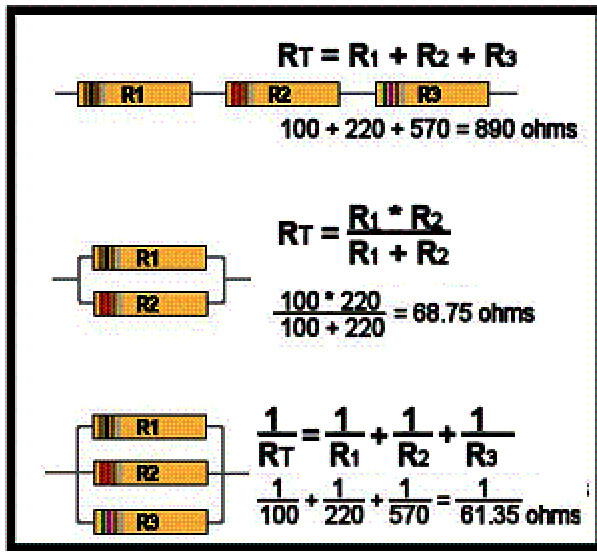
$$R_T = R_1 + R_2 + R_3$$

$$100 + 220 + 570 = 890 \text{ ohms}$$

$$R_T = \frac{R_1 * R_2}{R_1 + R_2}$$

$$\frac{100 * 220}{100 + 220} = 68.75 \text{ ohms}$$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{100} + \frac{1}{220} + \frac{1}{570} = \frac{1}{61.35} \text{ ohms}$$

Figure 3-2 Series / Parallel Resistors

through all of the resistors is the same while the voltage drop across each individual resistor is proportionate to the total.

And, of course, Ohm's Law holds here too and tells us that, where I is the current through any one of the resistors, the voltage drops can be calculated as: $V_1 = R_1 * I$, $V_2 = R_2 * I$, and $V_3 = R_3 * I$.

In a parallel resistor circuit, the voltage drop across each resistor is the same and the total parallel resistance is calculated by adding the current through each resistor.

Calculating currents, however, is not always convenient and, in Figure 3-2 (middle), the simpler case of two resistors in parallel is shown together with the formula for two parallel resistances.

Last, in Figure 3-2 (bottom), three resistors are shown in parallel but the formula for calculation here is a matter of adding reciprocal values to calculate a reciprocal value. In effect, for parallel resistors, we're adding conductance values which are the inverse of resistance.

Excerpt: Lesson 5, Batteries

Variations on a theme
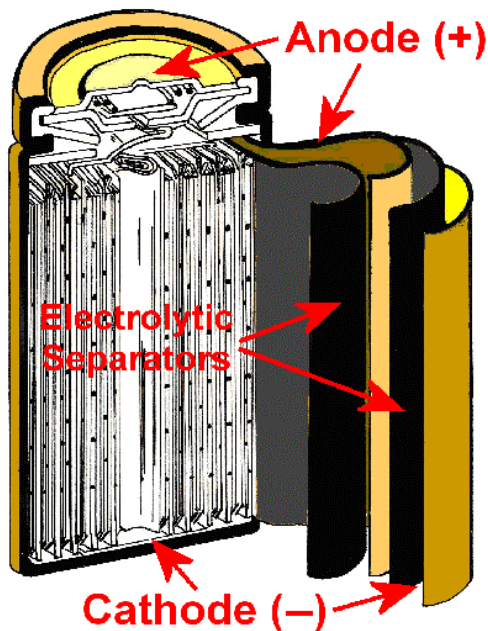
One of the best known rechargeable batteries is, of course, the battery in your car. This is known as a lead-acid battery because it uses lead and lead dioxide plates with sulfuric acid as the electrolyte.

As the battery discharges, the reaction is: $Pb + H_2SO_4 \rightarrow H_2 + PbSO_4$, producing hydrogen gas (most of which remains in solution) and lead sulfate. When the battery is being charged, the reaction is reversed as: $H_2 + PbSO_4 \rightarrow Pb + H_2SO_4$ where hydrogen gas reacts with the lead sulfate, plating the lead out of solution and restoring the sulfuric acid.

A variety of other chemical reactions are used in making batteries, including:

Anode (+)

Electrolytic Separators

Cathode (−)

Figure 5-1: Inside a Battery

➢ zinc & zinc sulfate / copper & copper sulfate

➢ zinc / carbon with an acidic paste is used in dry cells such as those used for flashlights, etc. The disadvantage of dry cell batteries is that the H_2 produced in the reaction is lost and, therefore, the batteries can not be recharged.

➢ alkali batteries – high power but not rechargeable

➢ lithium hydride batteries – popular for phones and other applications where frequent recharges are required.

➢ nickel / metal hydride batteries – another popular rechargeable form

Limitations, Flaws and Problems

There is no such thing as a "perfect" battery and you should be aware that all batteries have an internal resistance which dissipates some power while charging or discharging. Consequently if a battery discharges too rapidly – or charges too rapidly – the battery may overheat and catch fire or cause other physical damage.

Battery Arrangements

When Count Volta was experimenting with his electric piles, he quickly discovered that, by adding additional elements (what we call 'cells' today), he could increase the voltage supplied by the battery.

➢ **Series batteries increase voltage**

There's nothing unusual about placing batteries in series to increase the available voltage. Because a single cell yields approximately 1.5 volts (this can vary depending on the chemistry of the cell) we're quite accustomed to using multiple cells to provide the voltages we actually want.

> **Note**: individual cells, regardless of the chemistry used, normally produce from 1 to 2 volts.

Your car battery, for example, has six cells, each of which yield approximately 2 volts. Since these cells are constructed in series, the battery as a whole yields 12 volts.

The batteries used in flashlights – which have a different chemistry – are commonly 1.5 volts so, for a four-cell flashlight, you need a 6-volt bulb and, for an eight-cell flashlight, you need a 12-volt bulb.

And, if you will notice, the two battery packs included in your experimental kit each take two batteries – which are in series – making them 3-volt packs. Also, many of the projects require both battery packs – in series – to provide a 6-volt source.

> **Note**: the popular 9V batteries actually consist of six 1.5 volt cells in a single package.

➢ Parallel batteries increase current / amp hours

Every battery is limited – by its internal resistance – in how much power (current) it can supply instantly. Where we need more current capacity, we can connect two (or more) batteries in parallel, multiplying the current capacity by the number of units.

Or we can use this same arrangement to increase the total amount of power (amp hours) available.

The disadvantage to a parallel battery arrangement – unless isolation circuitry is used – is that the failure of one battery can drain an entire bank of batteries. For this reason, diode isolation is often used to isolate ganged batteries from each other.

➢ Limited supply life

All batteries deliver decreasing voltage as they discharge. A good battery holds close to its nominal voltage well into its discharge cycle while a poor battery drops off rapidly.

The lead-acid batteries used in vehicles generally drop less than two or three volts before they are pretty well discharged while there are other battery types which drop less (percentage-wise) over their usable range.

Also, as mentioned, all batteries have limits on the maximum current which they can deliver. In circumstances where a very high current is required, capacitors are commonly used as "temporary" batteries, acting as a reservoir to deliver a high instantaneous current which a chemical battery can't readily supply.

Excerpt: Lesson 6, Power Supplies

Smart (Chopping) Power Supplies

Modern power supplies use "switching" technologies to "slice" AC current into smaller segments by turning on and off many, many times per second. These slices of AC – see Figure 6-4 – effectively become high-frequency AC current while the switching circuits adjust their frequency and the width of the "slices"

to match changes in the power requirements.   Advantages of using this chopped, higher-frequency AC are several:

➢ the power supply requires a small transformer or no transformer at all

➢ the higher frequency signal is easier to convert to DC and the higher frequency ripple is easier to filter out

➢ chopping current does not waste power or produce waste heat that will need to be dissipated.

Once the incoming AC has been chopped to the required size, the next step is to rectify the alternating current to become direct current.

A full-wave or brid-ge rectifier works by allowing current to take two separate paths through the bridge. In the first half-cycle shown in Figure 6-2, the current is flowing though D2 and D4 so that the output at ref point **A** is positive (D3 and D1 are reverse biased so current can not flow that way). On the next half-cycle, the current is flowing though D3 and D1, again making the output at ref point **A** positive. And so on.

Figure 6-4: Chopped AC

The choke and two capacitors on the output of the bridge are called a Pi filter because the arrangement of the components (on the schematic) resembles
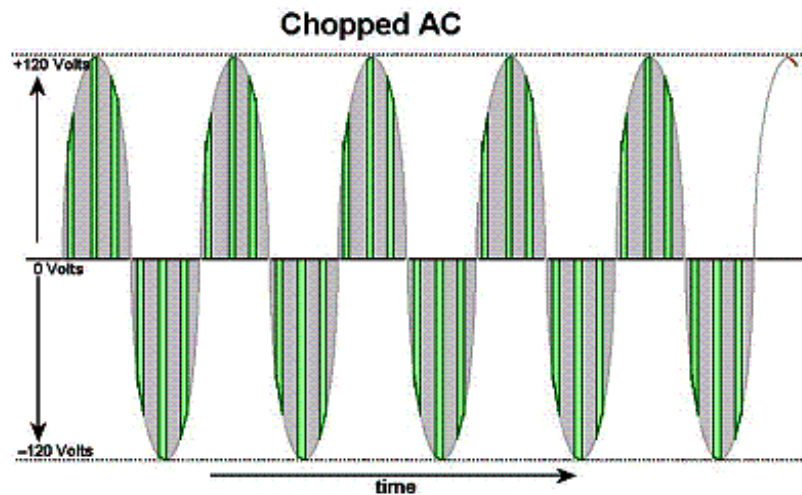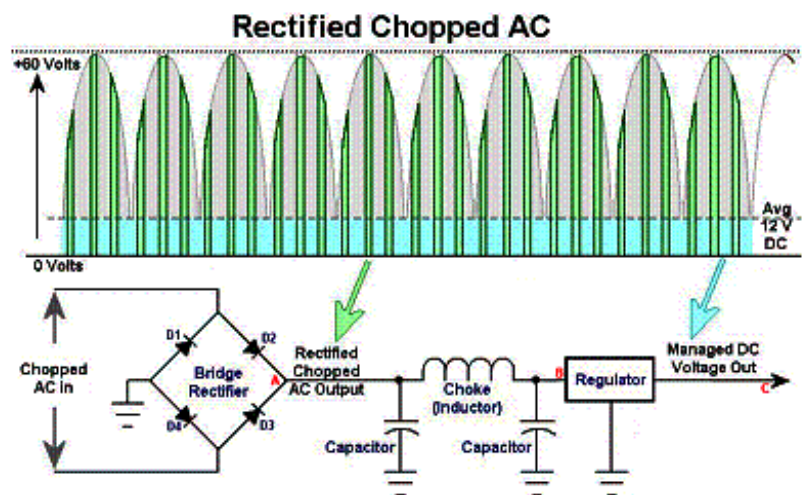

Figure 6-5: Rectified AC becomes DC

the Greek letter Π. There are other arrangements which serve essentially the same purpose but this one is popular and easy to illustrate.

The first step in rectifying any alternating or oscillating current is to pass the current through a rectifier circuit. The circuit shown in Figure 6-4 is called a "full wave rectifier" because the four diodes allow both sides of the current to flow but redirect the current such that it all comes out with the same direction of flow – ergo, becomes direct current although, at this point, the current still has a very heavy ripple. A full-wave or bridge rectifier works by allowing current to take two separate paths through the bridge. In the first half-cycle shown in Figure 6-5, the current is flowing though D2 and D4 so that the output at ref point **A** is positive (D3 and D1 are reverse biased so current can not flow that way). On the next half-cycle, the current is flowing though D3 and D1, again making the output at ref point **A** positive. And so on.

As each spike comes from the bridge, the first (left) capacitor begins to charge but it can't charge instantaneously and, therefore, it begins to flatten the spike. At the same time, the coil (inductor) is resisting a rapid increase in current by building a magnetic field. And last, the second capacitor (right) reacts in the same fashion as the first, providing additional smoothing.

As the spike passes and current decreases, the first capacitor releases electrons (discharges), helping to maintain the current seen by the inductor. But, as the current through the inductor decreases, the magnetic field collapses, inducing current (and maintaining the flow) so that the output current is further maintained and smoothed. And, on the output of the Pi filter, the second cap is further smoothing what ripple remains.

If properly designed, a single Pi filter can produce a very smooth output and the addition of a regulator (aka: voltage regulator) can further smooth the supply voltage.

Elements you should observe in switching power supply are one or more large capacitors which function as temporary batteries as well as further smoothing the current / voltage supplied.

> **Note**: when you are recharging your battery (the capacitors) many hundreds of times each second, you really don't need a very big battery, just an efficient one with minimal losses.

Excerpt: Lesson 9, Diodes and Transistors

Semiconductor Types

Even excluding integrated circuits, we have an almost bewildering assortment of semiconductor type available today so the list following will not be inclusive but we will try to look at the major types.

➢ **Diodes** – single junction devices, basic diodes are use to rectify current but the class of diodes include LEDs, zener diodes for voltage regulation, tunneling diodes and many others. All of these are built around a reverse biased junction but function in a variety of different ways.

➢ **Transistors** – as a class, transistors are referred to as bipolar junction devices (BJT) because they have two junctions instead of a diode's single junction. There are, however, such exotics as unijunction transistors (with a single junction) and FETs which have no real junction at all. However, regardless of the number of junctions, all transistors use a small forward current (gate) to control a large current flow. In junction transistors, this is done by upsetting the reversed junction; in other types, a different principle applies and we will look at these in a moment. However, the basic principle remains that a small current controls a large current which, by definition, makes the transistor a switch.

➢ **Unijunction transistors** – often used as pulse generators, these devices do have only one junction but still use a small current to control the flow through the body of the device.

➢ **FETs / MOSFETs** – these transistors also violate the simple definition by having no real junction at all. They do, however, use a small signal to moderate and control a very high current flow and are particularly useful in power handling with
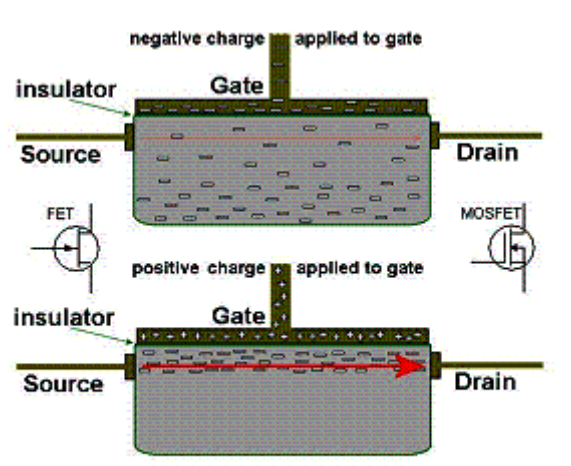

Fig 9-4: FET Transistors

minimal losses (and, therefore, minimal heat produced).

Illustrated in Figure 9-4, a typical FET remains non-conductive until a charge applied to the gate attracts and concentrates electrons to the region between the source and drain, permitting a very high current flow. Because the gate is insulated from both the source and drain portions of the FET, there is very minimal current flow through the gate and gate circuits … which is a major advantage.

> There is also a type of FET called a dual-gate FET which uses two gates in a cascade arrangement such that the first gate drives the second. These are popular for high frequency amps, mixers, and oscillators.

Excerpt: Lesson 13, RF Circuits

RF Limitations

RF signals – depending on the frequency – have various limitations and advantages. One of the best known advantages – and the reason that AM radio broadcasts can (literally) reach around the world – is the reflective effect of the Heaviside layer (named for Oliver Heaviside). The Heaviside layer is a conductive layer in the upper atmosphere which acts as a reflector or mirror for radio waves within certain frequency ranges.

Figure 13-5 illustrates using the Heaviside layer to reflect a transmission so that it reaches receivers which, because of the curvature of the Earth, are out of sight from the transmitter.

Alternately, the FM radio frequencies are purely line of sight and simply penetrate the Heaviside layer rather than being reflected.
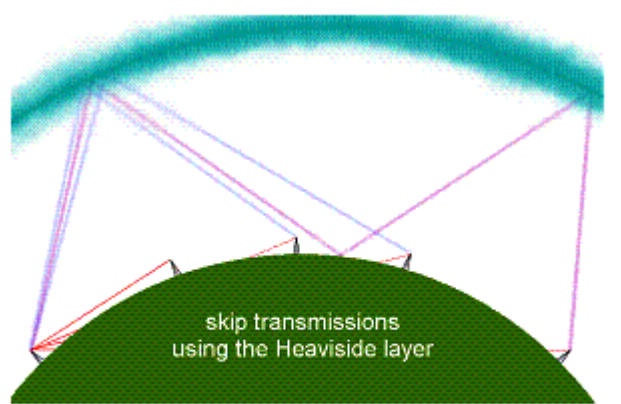

skip transmissions using the Heaviside layer

Figure 13-5 Heaviside Layer

> **Note**: the first radio broadcasts were AM (amplitude modulated) and the frequencies selected were chosen because they could be reflected

by the Heaviside layer. FM, which was developed later, was allocated a different portion of the RF spectrum which is only usable over line of sight. (See Bandwidth and Frequencies, following.)

The remaining principal RF limitation is simply noise. Because we use electricity in so many forms and so many applications, we create a tremendous amount of radio noise and it has been claimed that this planet (our civilization) produces more RF output than many stars. Some of this 'noise' – noise is like a weed, simply something that isn't wanted where it is – is intentional, produced by other equipment for other purposes but interfering with our immediate application / equipment. Other RF noise is simply a byproduct of something which is malfunctioning or just functioning poorly. A good example is the RF waste noise produced by florescent light fixtures; another is simply any heavy electrical machinery or motor.

Excerpt: Lesson 14, Binary Operations

Simple Math

In this lesson, we'll introduce a number of simple mathematical operations showing the numbers in binary format and referring to the operations (visually) necessary to produce a correct result. (At the end of this lesson, there will be a test.)

Addition

Figure 14-9 shows two examples of addition: 5 + 10, which is easy, and 4 + 4, which is a bit harder.

```
   5 = 00000101
  10 = 00001010
        00001111 = 15

   4 = 00000100
   4 = 00000100
        00001000 = 8
```

Figure 14-9: Addition

To add 5 plus 10 (top), all we need to do is add each column to produce the sum. Since no 1s appear in both rows for the same column, there's nothing to carry.

To add 4 plus 4 (bottom), we do the same thing but, this time, we have two 1s in the same column and have to carry a 1 to the next column to the left. Of course, this is essentially what you learned to do in grade school when adding up columns of numbers so it shouldn't be that strange to you.

Subtraction

Figure 14-8 shows two examples of subtraction: 15 – 5, which is easy, and 14 – 7, which is a bit harder.

```
15 = 00001111
-5 = 00000101
     00001010 = 10

14 = 00001110
-7 = 00000111
     00000111 = 7
```
Figure 14-10: Subtraction

In the first example, when a 1 is subtracted from a 1, the result is a 0 and, for a 0 subtracted from a 1, the result is 1.

In the second example, we need to borrow from the columns to the left in order to perform operations in each column. This should also be a familiar practice to you because it is one which you learned in grade school when you learned basic subtraction.

Excerpt: Lesson 15, Digital Operations 2

More About ADCs

ADCs have a variety of applications and designs but the purpose in all cases is to turn an analog signal into digital data. Figure 15-3 (left) shows an analog signal (waveform) as a voltage varying between a +10 maxima and a –10 minima (the units are irrelevant here).
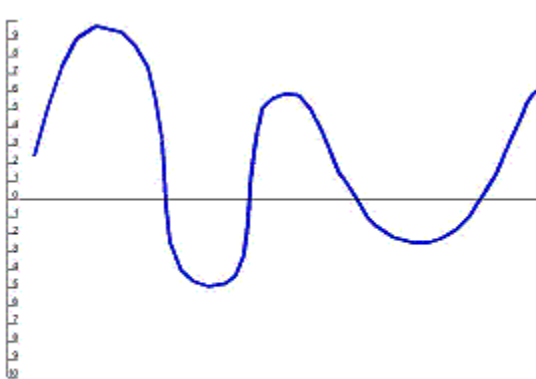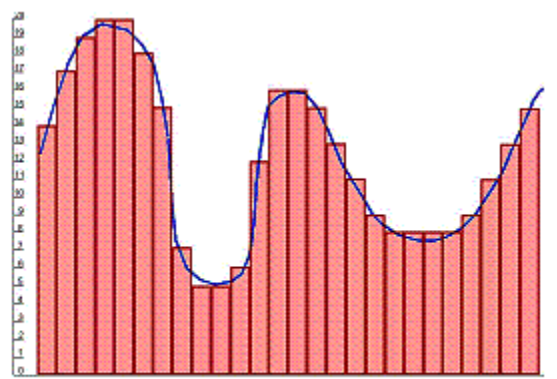

Figure 15-3: An analog signal

Figure 15-4: Sampling the signal

On the right, in Figure 15-4, this same signal has been shifted to put it entirely in a positive region since we really don't want to record negative numbers where we can avoid them without loss. Next, to digitize the signal, samples –

shown by the red bars – are taken to record the average voltage during each sample period.

There are two factors to consider here: accuracy and sampling rates. In Figure 15-4, as shown by the red bars, the fit to the curve is not very accurate. Sometimes the recorded level is obviously above or sometimes below the actual average of the curve during the sample period. This is an artifact of the sampling accuracy because, in the illustration, all of the bars align with the scale marks at the left – a rather course resolution in terms of measured voltages from point to point.

Figure 15-5: Higher resolution sampling

And the second factor – the sampling rate – is also rather course and the results are not a good fit to the actual waveform.

Therefore, in Figure 15-5, we've increased the sampling rate and we've also increased the resolution (accuracy) of the recorded measurements and the result – the left half of the sampled waveform – is a much better fit than the sampling shown at the right.
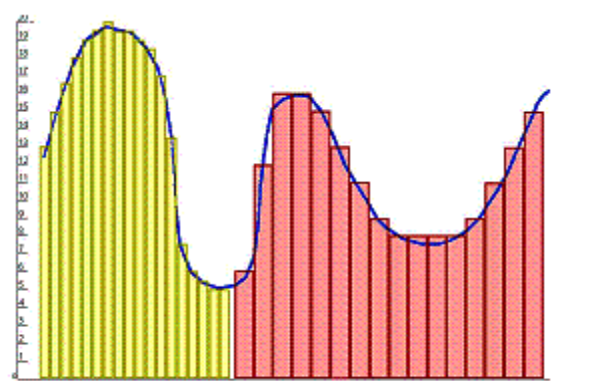

Figure 15-5: Higher resolution sampling

Ideally, since computer geeks are always idealists and most engineers are also, we would chose our ADC to have a much higher sampling rate than the approximate frequency of the input and we would also choose as high a resolution (accuracy) as possible … or, at least, as high as practical.

The qualifier – practical – isn't intended as a cop-out; it's just that the resolution we actually need depends on the application, not just on what we think would be nice.

For audio – either voice or music – we're going to choose a very high sampling rate and a high accuracy in sampling levels. Two factors govern this decision. The sampling rate is determined by the fact that we will be sampling high-frequency wave forms and that we want to pickup (and later reproduce) overtones and subtle variations, not just pure sine waves. And the accuracy requirement stems from the same consideration – that we need to map subtle

changes in the waveforms and this means a very fine increment in our measurements.

On the other hand, if we're monitoring a transmission line for AC power, we can use a much, much coarser resolution for both time and increments. At this point, we know we're monitoring 60-cycle current so a time resolution of a few hundred increments per second should be more than adequate and we can probably get by with a voltage resolution in one volt increments (or even less). (In actual fact, we could perform monitoring with even less information by using custom circuits to 'watch for' and report only abnormalities in the current.)

And we also need to take into consideration the sheer amount of data which we're going to generate during sampling. Are we going to store this information for later reproduction (as music for example) or are we gathering this data only for analysis (as in the power line) and only keeping a record of anomalous events? And, if we're transmitting the data to another location for analysis, what is the capability of our transmission channel? How much information can we pass along and process?

Excerpt: Lesson 16, Computers and Computer Components

Communications with peripherals

To send communications to peripheral devices – and to receive information back – we originally relied on two types of port: parallel and serial, both of which are being rapidly supplanted by the USB port.

A parallel port – once popular for computer printers – was a port which sent eight-bits of data at a time through eight separate lines. While this was a good way of transferring larger amounts of data through a slow port, it also require bulky cables and connectors and, as port speeds increased, the primary impetus for the parallel port design began to lose relevance even though many computers still provide legacy support for parallel port devices.

A serial port, in contrast, handles only one bit of data at a time but, using a faster communication port protocol (and faster hardware), the actual amount of data passed is greater than using a parallel port.

Infrared (IR) connections are a version of serial ports using infrared transmitters and receivers to transfer data short distances when both devices can see each other. These normally function at distances less than ten feet.

Wireless communications – both BlueTooth and 802.11b/g – are special cases for networking and lie beyond the scope of the present topic.

USB – Universal Serial Buss – is the new method of data communications and has a variety of advantages. With USB 2.0, communication rates are equal to or higher than Firewire, the cables required are light and flexible and, unlike conventional serial ports, USB ports can be expanded (using hubs) to allow as many as 127 devices to connect to a single computer. (Serial ports required separate hardware for each connection and supported a maximum of sixteen ports.)

> The $100 laptop computer which is being developed for use in India and other poorer countries has the ability to create an ad-hoc network by simply connecting multiple units with USB cables.

The $100 laptop computer which is being developed for use in India and other poorer countries has the ability to create an ad-hoc network by simply connecting multiple units with USB cables.

Today, almost any peripheral you can name will offer a USB connection, including printers, scanners, mice, joysticks, digital cameras, speakers and even network connections and external storage devices.