AEM 617

Electrical Systems

Maxwell's Equations

$$\nabla \cdot E = \frac{\rho}{\epsilon_0}$$ ← The divergence of the electric field depends on the enclosed charge.

$$\nabla \times E = -\frac{\partial B}{\partial t}$$ ← The rate of change of the magnetic field depends on the curl of the electric field

$$c^2 \nabla \times B = \frac{\partial E}{\partial t} + \frac{j}{\epsilon_0}$$ ← The rate of change of the electric field depends on the curl of the magnetic field and the current.

$$\nabla \cdot B = 0$$ ← Magnetic monopoles doen't exist. Every magnet has a N and a south.

$\epsilon_0 \approx 4\pi \cdot 9.0\times10^9 \left[\frac{V \cdot m}{C}\right]$ $\quad c^2 = 3\times10^8 \left[\frac{m}{s}\right]$

The rest is up to our ingenuity! C.f. N. Tesla.

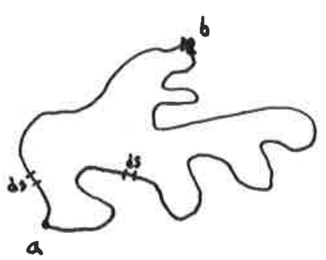
Aside: John Lienhard's "Engines of our Ingenuity" is an excellent engineering resource.

- Statics

When charges and currents are static, E and B are independent.

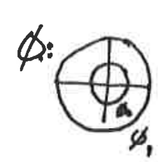
- Fields

E and B are fields: $E = E(x,y,z)$



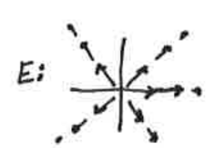
Electrostatic potential $\equiv \phi = -\int_a^b E \cdot ds$

For a charge at $r=0$, $\phi = \frac{q}{4\pi\epsilon_0} \cdot \frac{1}{r}$



The inverse operation is:

$$E = -\nabla\phi$$



Also: $E = -\nabla\phi$ and $\nabla \cdot E = \frac{\rho}{\epsilon_0}$

Thus

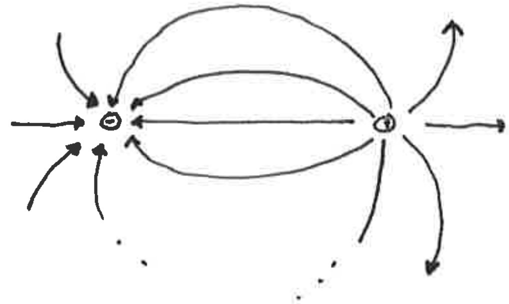
$$\nabla^2\phi = -\frac{\rho}{\epsilon_0}$$

A Poisson Equation!!

Thus $E_{\text{point charge}} = -\nabla\phi = -\frac{\partial\phi}{\partial r}\hat{r} - \frac{1}{r}\frac{\partial f}{\partial\theta}\hat{\theta} = \frac{1}{r^2} \cdot \frac{q}{4\pi\epsilon_0}\hat{r}$

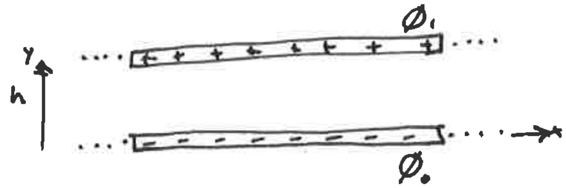
Knowing that $\nabla^2 \phi = -\frac{\rho}{\epsilon_0}$

- 2 pt charges:



$\nabla^2 \phi$ in the control volume not containing charges.

- Capacitor parallel plates



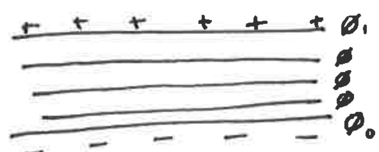
want a function such that

$\phi(h) = \phi_1$ and $\phi(0) = \phi_0$

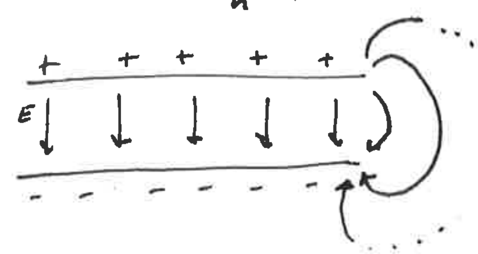
and $\nabla^2 \phi = 0$ and $\frac{d\phi}{dx} = 0$

Voltage is: $V = \phi_1 - \phi_0$

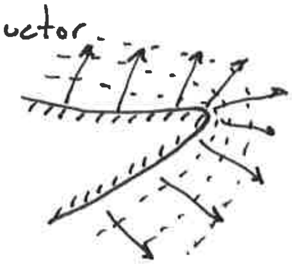
$\phi = Ay + B \Rightarrow \phi = \frac{\phi_1 - \phi_0}{h} y + \phi_0$



and $E = -\nabla \phi$



- Sharp conductor

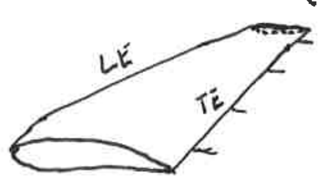


Must have $\nabla^2 \phi = 0$

The electric field near a sharp corner is large. This leads to a break down in the air such that ions flow.

Spark!!

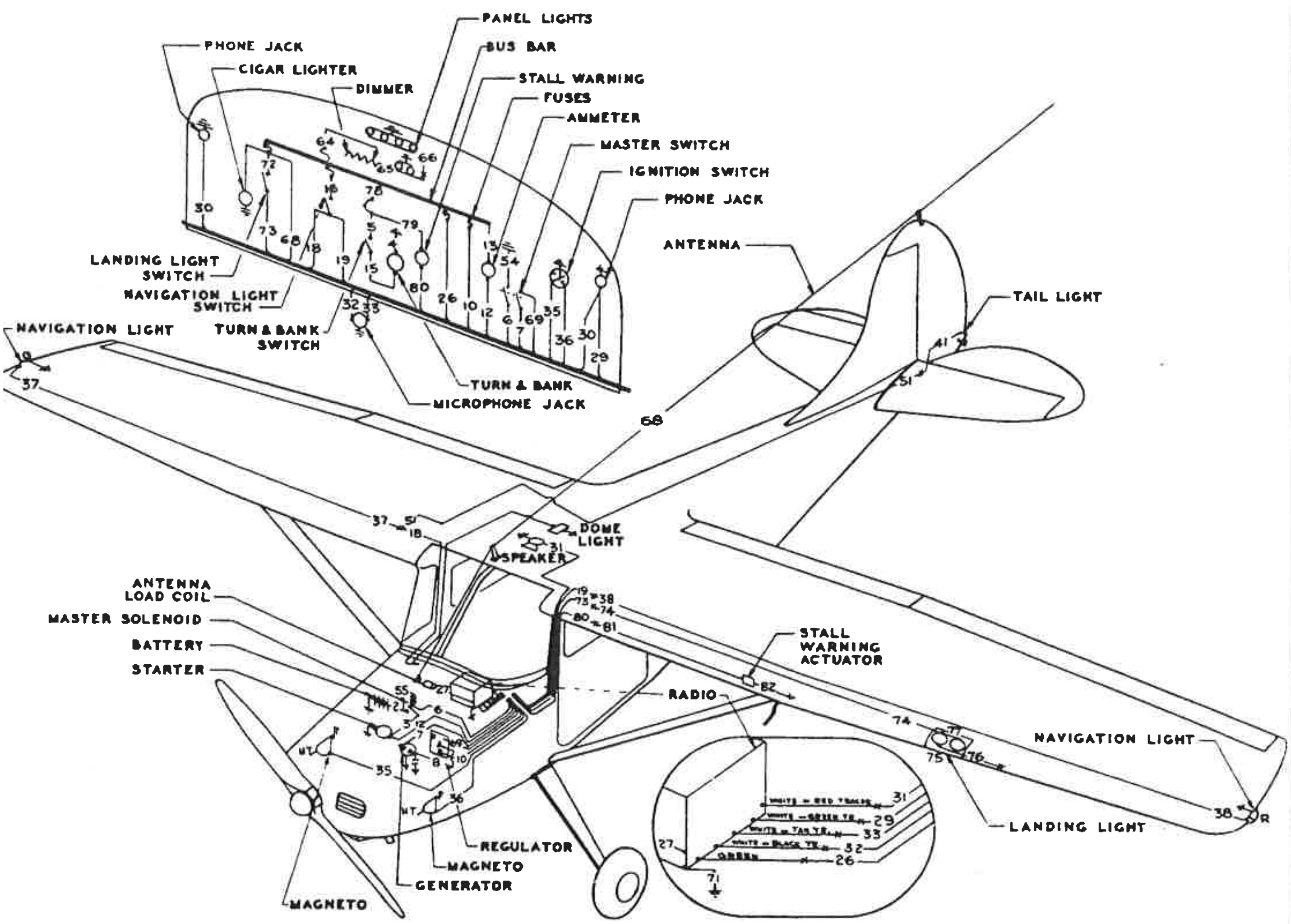
This is why "static wicks" (aka static dischargers) are on aircraft to reduce static noise (DC to 1 GHz) in communications systems



- Sometimes just a flexible wire.
- Sometimes a sharp pointed solid
- Always a conductor

C-170

12 volt System



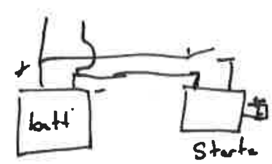


FIGURE 30 - ELECTRICAL WIRING DIAGRAM

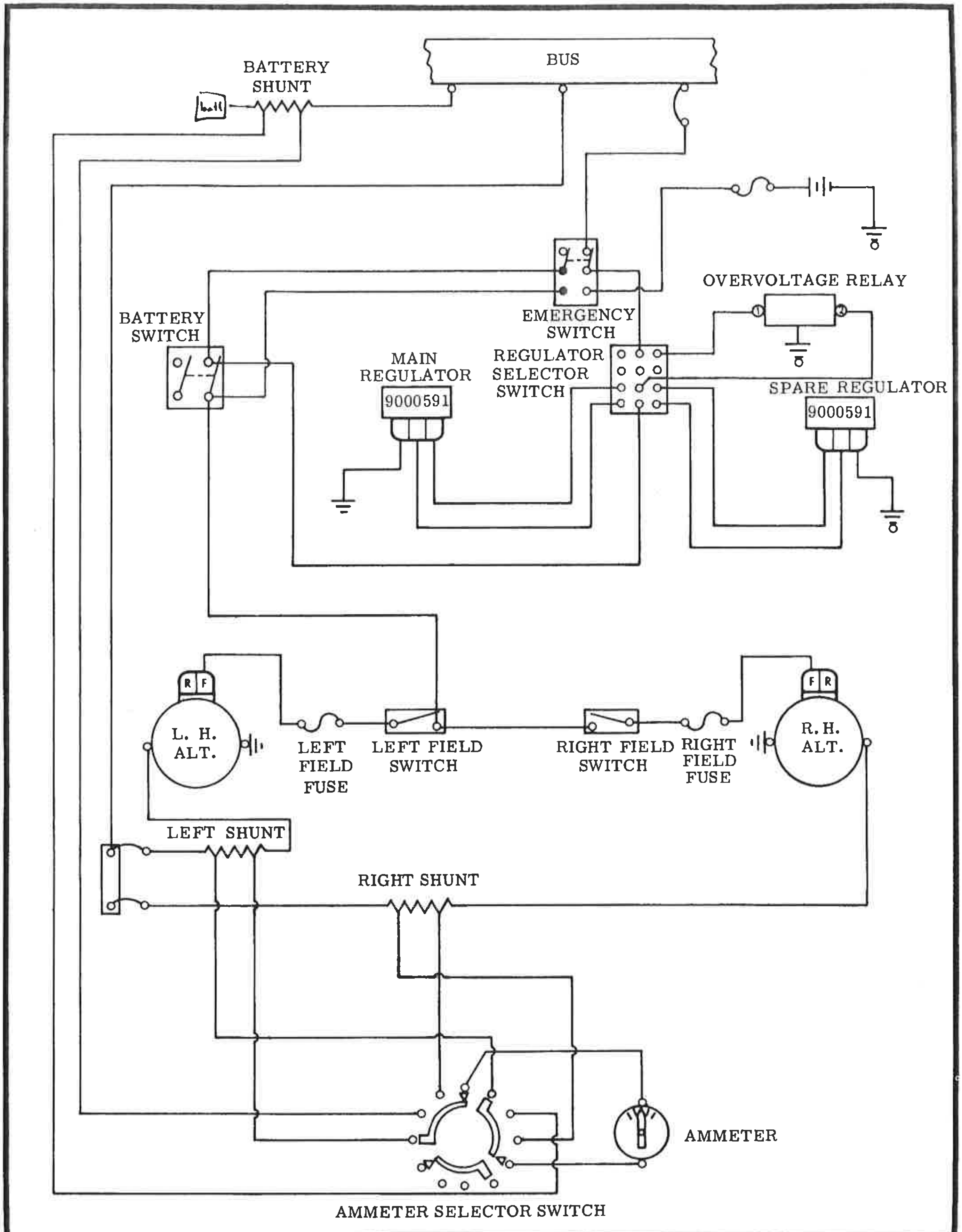


Figure 14-13. Power Distribution Schematic

F-16

Electrical Power Distribution Diagram
Air Defense Fighter

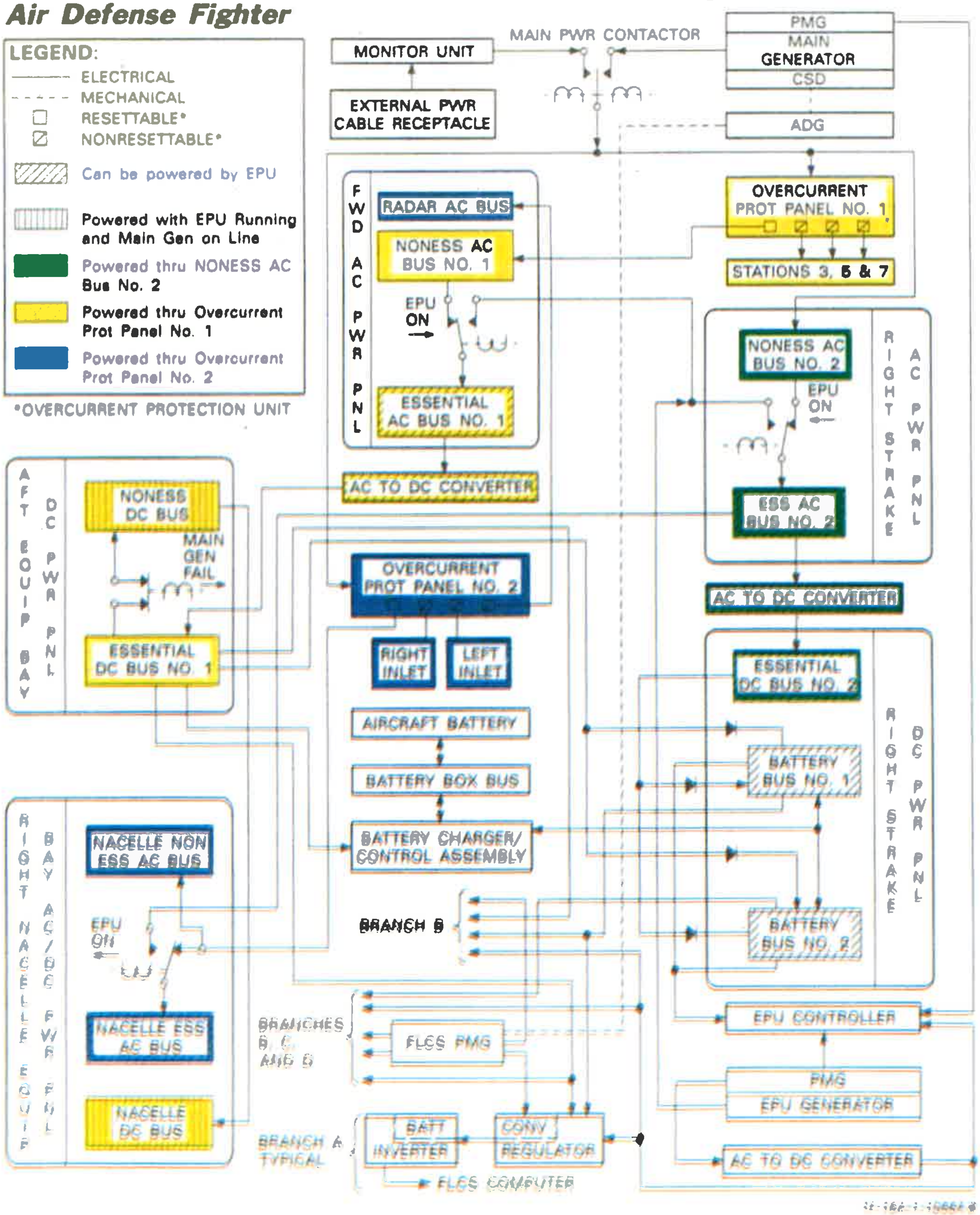


Figure 1-26 (Sheet 3)

AC Power Distribution Diagram
Block 10

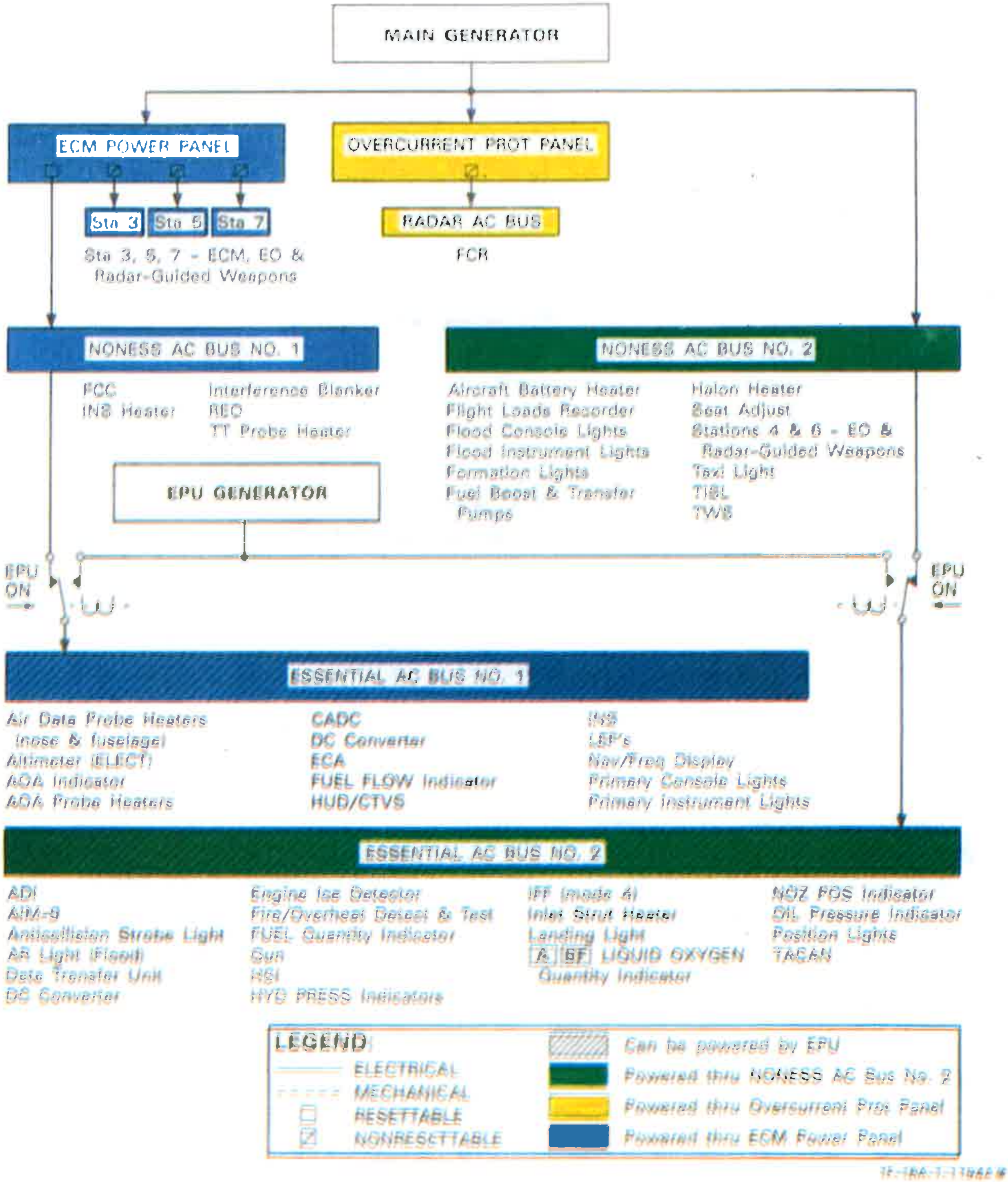


Figure 1-30. (Sheet 1)

Electrical System

Small General Aviation: C-150, C-172, Skipper,
12 volt system

$P = V \cdot A$
$240 = 12 \cdot 20$

General Aviation: DA-40, Most twins, King Air
28 volt system

$\text{power} = V \cdot A = 28^{V} \cdot 400^{\text{Amp}} = 11^{\text{kW}}$

AWG 4/0

!! This would be ≈ two ½ in diameter Cu wires

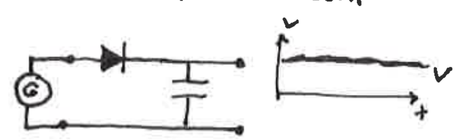
Heavy!

DC Generator

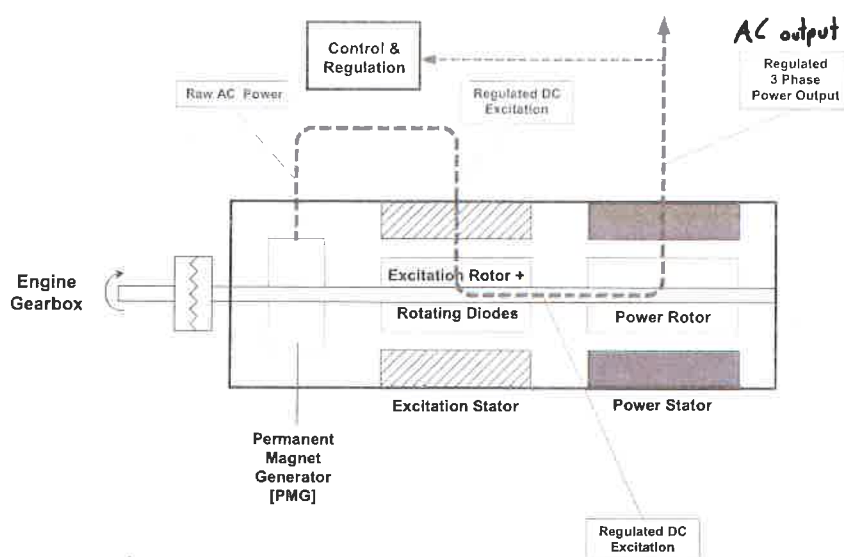
$\nabla \times E = -\frac{\partial B}{\partial t}$ Moving/changing a magnetic field implies an electric field.

Reverse of a motor

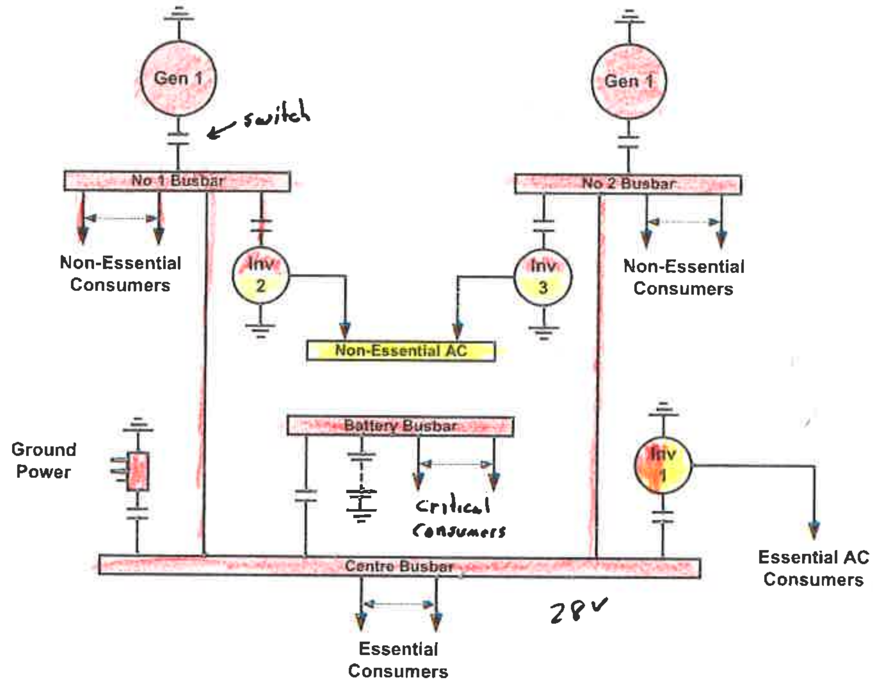
⇒ Rectify and smooth



- Modern generators spin a electromagnet



Typical 28V DC twin bus system



Source: Civil Avionics Systems, Moir + Seabridge

Boeing 767 Electrical System

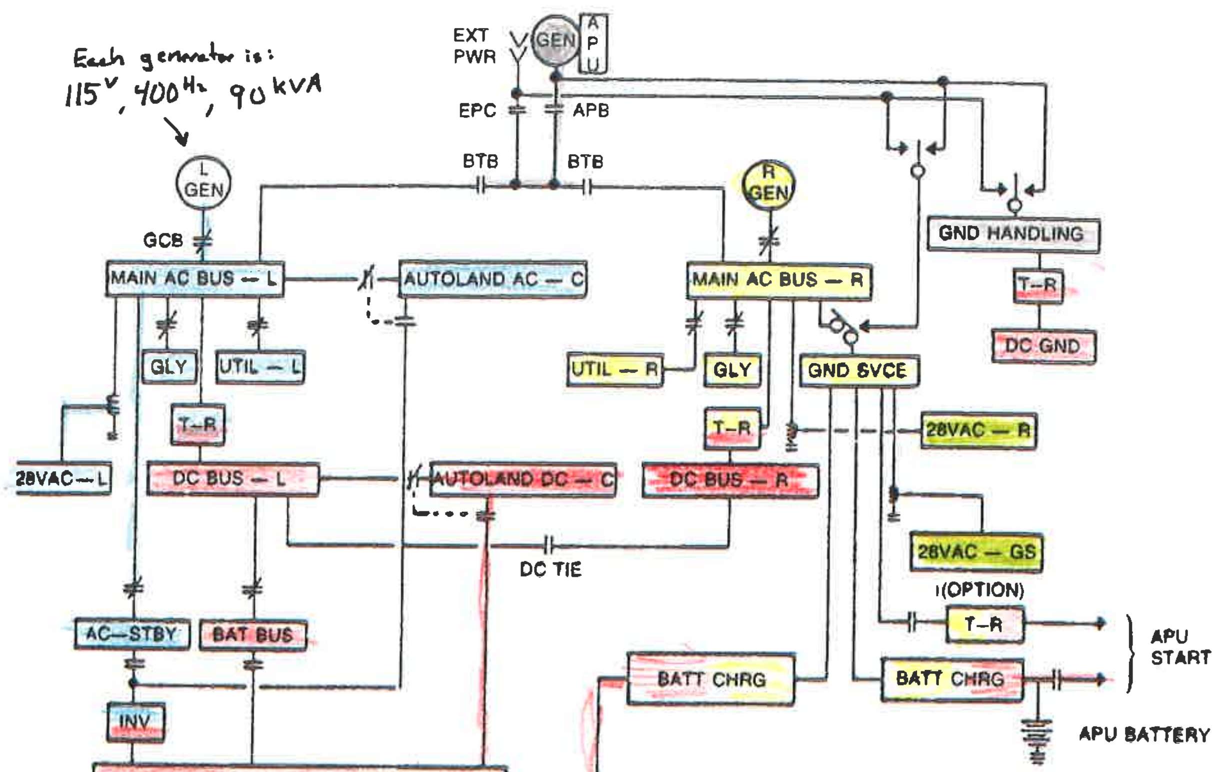
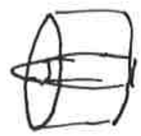


Fig. 4.19 Simplified Boeing 767 electrical power system

Variable Frequency AC systems.



Jet engine "n" revolutions per minute is not fixed

If the generator is directly connected, the output frequency varies as well $\approx$ 2:1

- Hydraulic drive to maintain a constant frequency (!)
- VSCF (Variable speed constant frequency) Cycloconverter

  take a high frequency output and sample down to 400Hz

- Allow VF and let downstream systems "deal" with frequency differences
- AC → DC → AC

270 VDC:

Military push to 270 VDC for high power applications


AIR CANADA

Ram Air Turbine (RAT)

Air Canada Flight 143 Gimli Glider (tiny.cc/AEM617Gimli)

Boeing 767 misfueled:
- 22300 lbs fuel rather than 22300 kg ≈ 50%
- Fuel Quanity Indicator System failed earlier.
- Captain checked fuel loading ... same error!

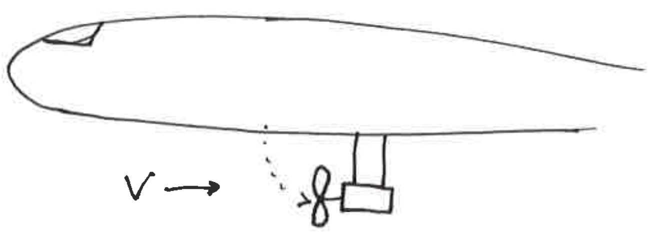
At 41000 ft, the engines fail. (out of fuel)

Failure mode tracking:

No engines → no generator → battery power → Critical <u>only</u>
↘ no hydraulics → No FCS (!)
⇓
RAT (as a function of 8)

Landed on ex-Gimli airfield (then a racetrack)

RAT is a wind turbine powering either electrical or hydraulic systems.



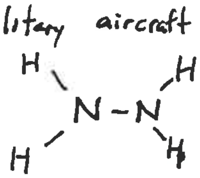
From dimensional analysis, power is proportional to:

$$P = C \cdot n^3 D^5$$

(n ← rpm, D ← diameter)

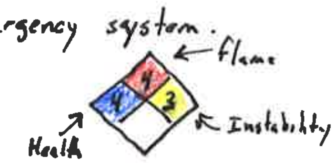
(tiny.cc/AEM617RAT)

Aside: Military aircraft often also have a hydrazine powered emergency system.



Nasty, toxic, unstable, scavenges O_2

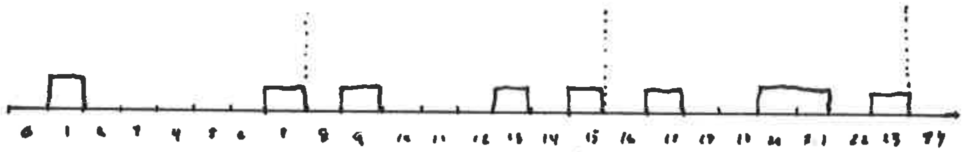
N_2H_4 . $LC_{50} = 260$ ppm



Manchester Coding

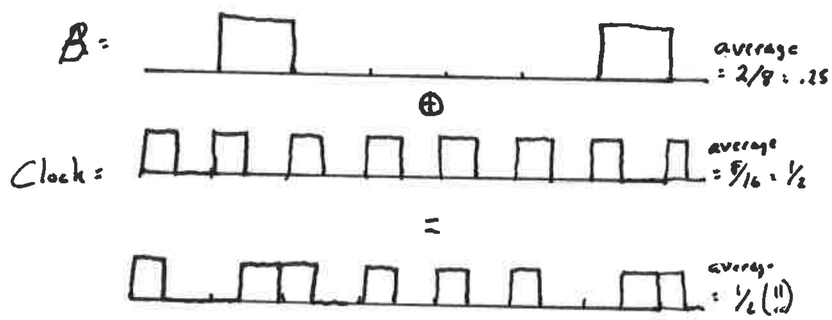
How can one avionics system send information to another system? Assume binary.

AEM → 01000001 01000101 01001101   24 bits



- Average value is 0.375. DC component!
- Clock rate?

Lets take the letter "B" to demonstrate Manchester coding



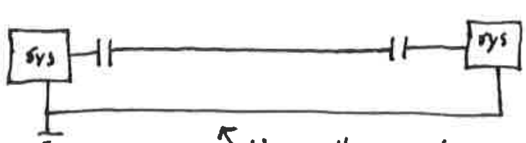
XOR = exclusive OR

a	b	out
0	0	0
1	0	1
0	1	1
1	1	0

Another way to look at this:

high to low = 0
low to high = 1

Advantages:
- Easy to recover the clock signal from data signal.
- Transition indicates data (i.e. not tied to exact clock synchronization)
- No DC component. Isolate systems with inductive or capacitive coupling!



↖ We usually consider "ground" to be the same voltage, but this is not true.