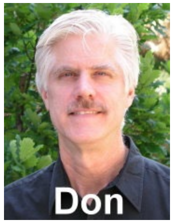
Electronics - PHYS 2371/2



Calendar of Topics Covered

Physics PHYS 2371/2372, Electronics for Scientists

Don Heiman and Hari Kumarakuru
Northeastern University, Fall 2020

Also see **Course Description** and **Syllabus**

This is a schedule of the topics covered, but it may be modified occasionally (10/21/2020).

Week #	Lectures	Weekly Topics (Chs.)	Homework (Ch-Problem)	Lab Experiments (always look for latest version)
VI Oct 14	**Wednesday** Study for EXAM-1	**Study for EXAM-1** **Basics, AC Circuits, Semiconductors, Op-amps**		No Lab
VII Oct 19, 21-23 **MON/WED**	**MONDAY** **EXAM-I**	**Wed Lecture** Magnetoelectronics Magnetic induction/flux Transformers (Ch-11)	11-all	**Lab-6, *Build a Magnetometer***
VIII Oct 28-30	**Wed Lecture** Optoelectronics	Photodiode, LED, laser	none	**Lab-7, *Optoelectronics*** (coupled LED-photodiode)
IX Nov 2, 4-6 **MON/WED**	**Mon/Wed Lectures** MON Digital-1 WED Digital-2	Digital Logic (Ch-19,22), Binary Numbers (Ch-54) Logical Networks (Ch-20)	19-all, 20-all	**Lab-8a, *Digital Circuits*** (truth table, 4-bit decoder)
X Nov 11-13	**Wed Lecture** Pulsed ICs	Lecture: Pulsed ICs Digital Summary	21-1/2	**Lab-8b, *Pulsed Digital*** (Flip-flops, counter, displays)
XI Nov 18-20 **WED EXAM**	**EXAM-II - Wed** Final Project	**EXAM-II: Magnetoelectronics, Optoelectronics, Digital/Pulsed**		***Final Project***
XII Nov 25-27	No Lecture	**Thanksgiving**		No Lab
XIII Dec 2	**Wed Lecture**	Future Electronics		***Project PowerPoint*** **due Monday Dec 2** (EG361 or email file)
XIV Dec 7-9	**No Classes**			

TODAY

Magnetism in Electronics

- **The Electric Grid**
- **Transformer Physics**
- **Faraday's Induction Law**
- **Magnet Solenoid**
- **Impedance Matching**
- ***Build a Magnetometer***

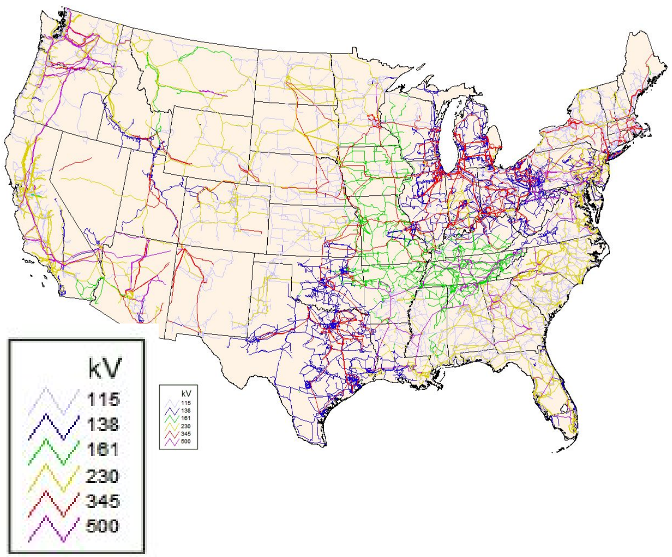
Magnetism in Electronics

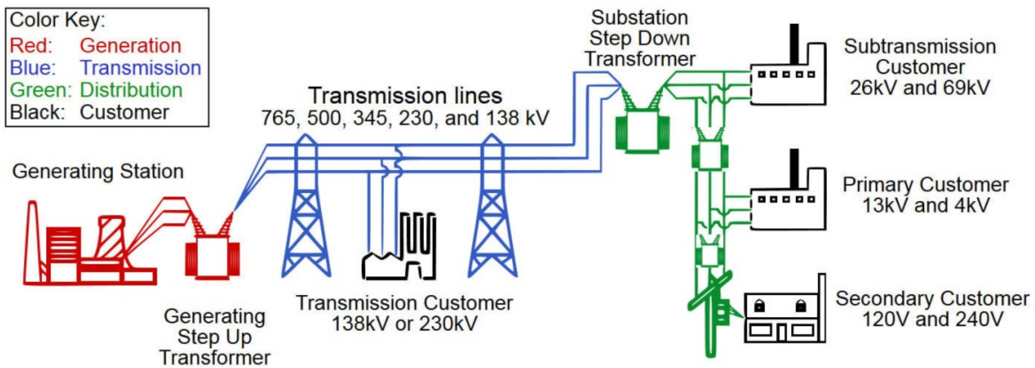
- **The Electric Power Grid**
- **Transformer Physics**, Ch-11
- **Faraday's Induction Law**
- **Magnet Solenoid**
- **Impedance Matching**
- ***Build a Magnetometer*, Lab-6**

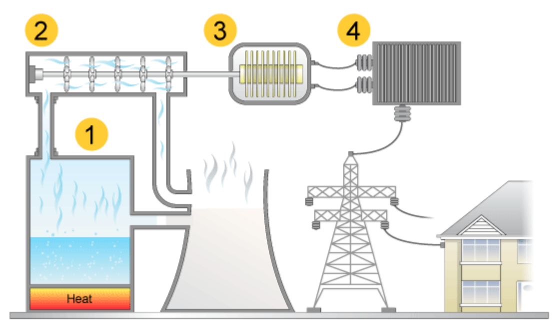
Electric Power Grids

US Power Grid
>160,000 miles of wires

Power Grid
Step-up and step-down Transformers







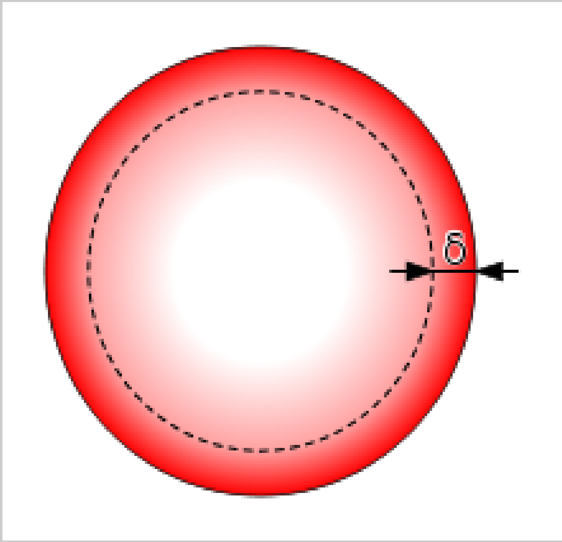
How Does the Power Grid Work? 2:44
UK National Grid **0-2:15** (11:29)
(How the grid works) 4:24

Questions ?

Why HVDC for Ultra-High Voltage Transmission

Skin Effect

AC current flows more on the conductor surface, wasting the inner part of the conductor. HVDC requires less conductor per unit distance than an AC.



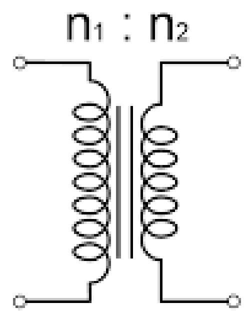
Distribution of current flow in a cylindrical conductor, shown in cross section. For alternating current, most (63%) of the electric current flows between the surface and the skin depth, δ, which depends on the frequency of the current and the electrical and magnetic properties of the conductor.

Advantages of HV DC

- No skin Effect
- Synchronizing AC phase
- Charging/discharging of wire capacitance
- RMS for AC is only about 71% of the peak voltage
- Handles outages better

Transformers

Change Voltage
Step-up Voltage ↗
Step-down Voltage ↘

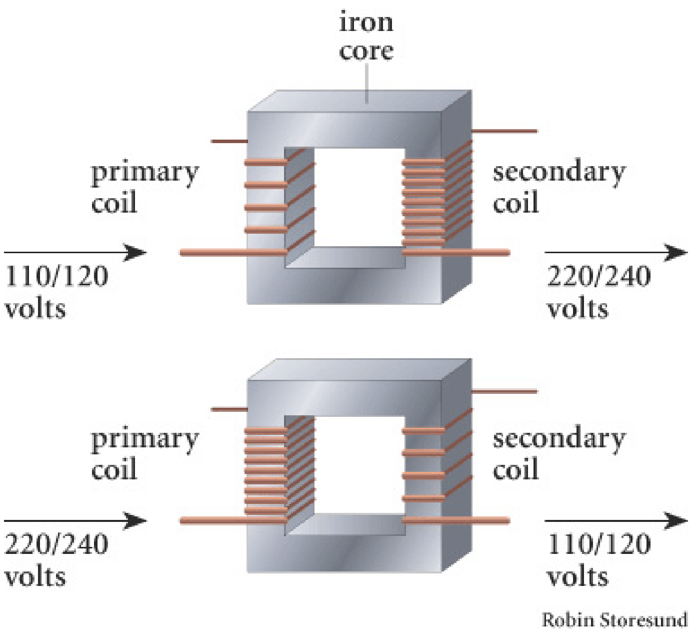


Efficiency ~ > 99.5 %

Energy Loss in US ~ 7 %

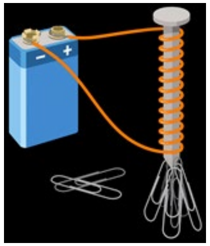
Transformers

2 wire coils around an iron core



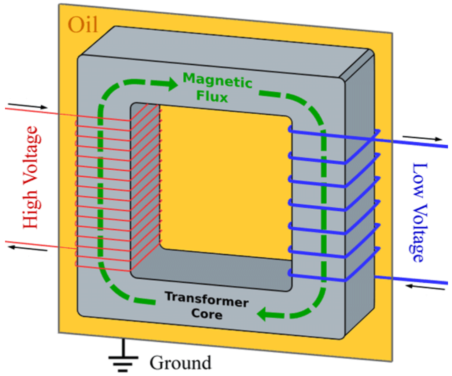
Passive Component
Power is constant P=IV
V up ⟺ I down

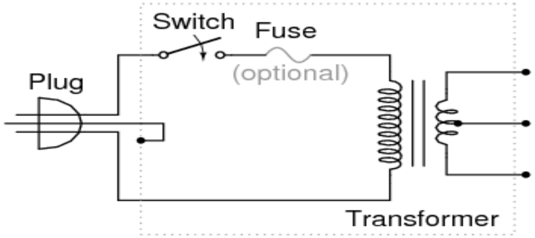
Magnetic Flux produced by current



Flux couples the primary and secondary coils

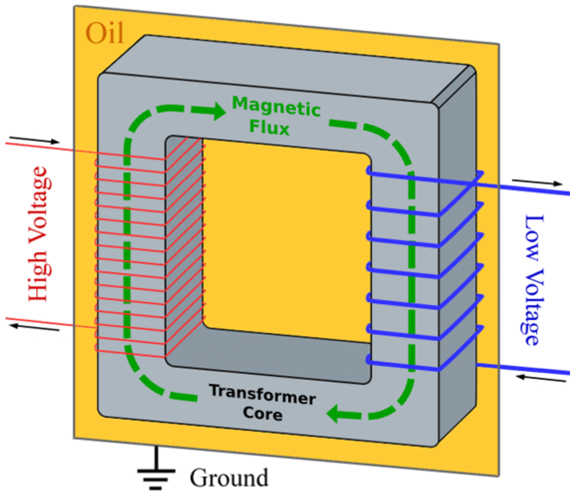
Magnetic flux is trapped in the iron





Physics of Transformers

Transformers
operate to amplify
AC voltage or AC current,
but not both at once.



Transformer Operation

1) Convert AC **current** in a primary coil into magnetic **flux**

2) Transfer the magnetic **flux** to another coil

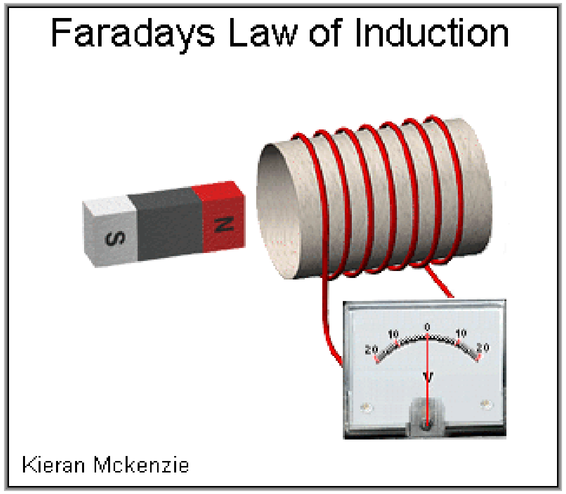
3) Convert the **flux** back into AC **current** in the secondary coil

current ⇨ **flux**
transfer flux
flux ⇨ **current**

Physics:
How do you convert current in a coil into magnetic flux?

How does a Transformer work ? **0-3:00 (**5:47)
(How electrical transformers work **3:38)**

Faraday's Law of Induction



Faraday's Law of Induction

Induced *EMF* in a Loop of Wire
(ElectroMotive Force ~ voltage)

EMF is created by
magnetic flux Φ
changing in time
EMF = $-d\Phi / dt$

Define magnetic flux
$\Phi = \int B \bullet dA = BA\cos(\theta)$

B=magnetic field, A=area

Compute voltage induced in a wire coil from a changing magnetic field.

EMF = $-d\Phi/dt$ for 1 turn
= $-N\, d\Phi/dt$ for N turns
= $-N\, d(BA\cos\theta)/dt$
= $-NA\, d(B\cos\theta)/dt$

Can vary either B or θ with time.
For θ=constant

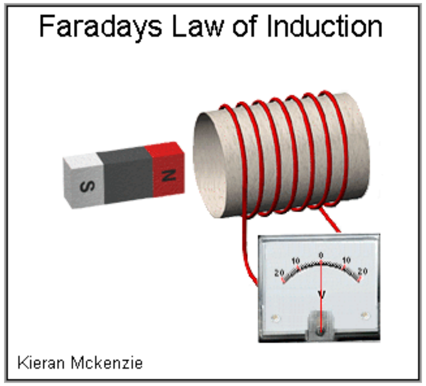
***EMF* = $-$ NA dB/dt**

Consider the magnet and coil on the left.

How do you get a voltage when putting the magnet in looks effortless?

Can you get something for nothing?

Lenz’s Law



Where does the energy coming from to push the magnet in?

Induced current in a closed loop of wire,

*generates a magnetic field in a **direction** that opposes*

the change that produced it.

It takes energy to force the magnet in against the opposing magnetic field.

Heinrich F.E. Lenz

Russian physicist, (1804-1865)

1834 Lenz’s Law

There is an induced current in a closed conducting loop if and only if the magnetic flux through the loop is changing. The direction of the induced current is such that the induced magnetic field always opposes the change in the flux.

Le Chatelier's Principle

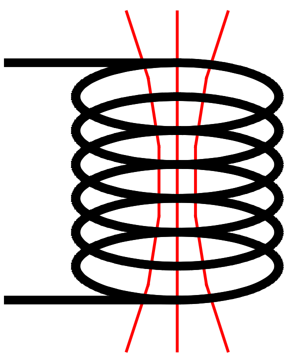
Any change in status quo prompts an opposing reaction in the responding system.

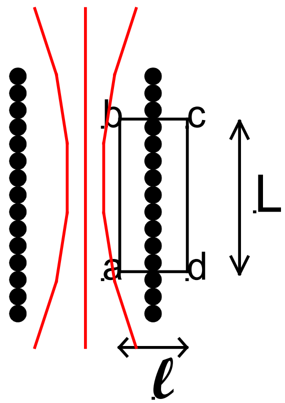
Questions ?

Magnet Solenoid

Compute the magnetic field

wire coil **coil cross section**





Ampere's Law

$$\mu_o I = \int \mathbf{B} \cdot d\mathbf{s}$$

μ_o = 4π x 10^{-7} Tm/A (permeability)

Compute the magnetic field in a solenoid by intgerating Ampere's Law around box.

$$\int B \bullet ds = \quad around\ loop \quad a,b,c,d,a$$

$$\int_a^b B \bullet dL + \int_b^c B \bullet dl + \int_c^d B \bullet dL + \int_d^a B \bullet dl$$

$B \parallel dL \qquad B \perp dl \qquad B = 0 \qquad B \perp dl$

$$\int_a^b B \bullet dL = \mu_o N I, \quad N = \#\ turns$$

$$B L = \mu_o N I$$

$$B = \mu_o I (N / L)$$

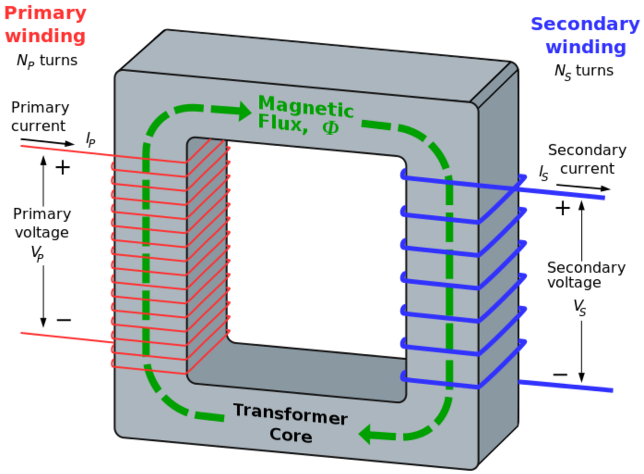
$$\boxed{B = \mu_o I \eta} \qquad \eta = turns / length$$

Physics of Transformers

Ch. 11

Transformer Operation

1) Convert AC current in a primary coil into magnetic flux
2) Transfer the magnetic flux to another coil
3) Convert the flux back into AC current in the secondary coil



Current in coil produces B - field

$B_N = \mu_o \eta I \quad$ *for* η *turns / length*

Now assume $\eta = N$ *(L is fixed)*

B - field produces magnetic flux

$\Phi = B_N A \quad A = area$

Voltage (EMF) produced by change in flux

$V = -N\, d\Phi / dt$

$V_P = -N_P\, d\Phi / dt \quad$ *for primary*

$V_S = -N_S\, d\Phi / dt \quad$ *for secondary*

Suppose N_S *catches all the* N_P *flux*

$$V_S = \frac{N_S}{N_P} V_P \quad \text{looks like gain } G = \frac{N_S}{N_P}$$

Current

$$\Phi_P = (\mu_o N_P I_P) A = \Phi_S = (\mu_o N_S I_S) A$$

$$I_S = \frac{N_P}{N_S} I_P \quad \text{inverse of voltage}$$

Power $P = IV \quad$ *Flux* $\Phi = BA$

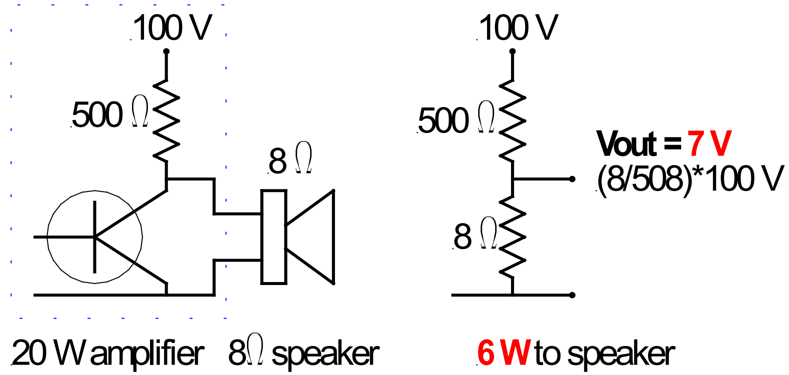
Since $P_P = I_P V_P$ *and* $P_S = I_S V_S$

$P_P = P_S$ *conservation of energy*

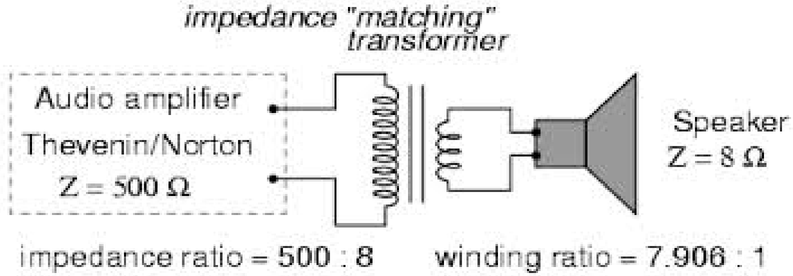
Questions ?

Impedance Matching Transformers

Match Circuit to Output Impedance



Only get 6 W out of a 20 W amplifier because of the impedance mismatch.



Transformer Impedance – *Impedance Matching*

Impedance

$$Z_S = \frac{V_S}{I_S} \quad and \quad Z_P = \frac{V_P}{I_P}$$

$$Z_S = \frac{\frac{N_S}{N_P} V_P}{\frac{N_P}{N_S} I_P} = \left(\frac{N_S}{N_P}\right)^2 \frac{V_P}{I_P}$$

$$Z_S = \left(\frac{N_S}{N_P}\right)^2 Z_p$$

Example – No impedance matching

Function generator $Z_P = 50\Omega$

Speaker $Z_S = 8\Omega$

Voltage Divider

$$V_S = V_{FG}\left(\frac{Z_S}{Z_S + Z_{FG}}\right)$$

$$= V_{FG}\left(\frac{8\Omega}{8\Omega + 50\Omega}\right)$$

$V_S = V_{FG}/7$ only 14% gets to speaker

Example – With impedance matching

Function generator $Z_P = 50\Omega$

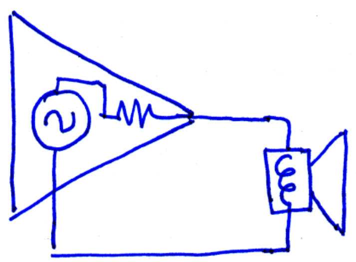
Speaker $Z_S = 8\Omega$

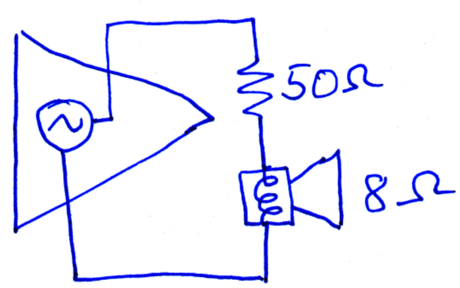
Compute transformer turns ratio

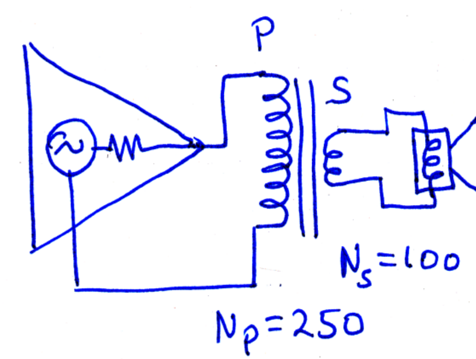
$$\frac{N_S}{N_P} = \sqrt{\frac{Z_S}{Z_P}} = \sqrt{\frac{8\Omega}{50\Omega}}$$

$$\frac{N_S}{N_P} = \frac{1}{2.5}$$

$N_P = 2.5 N_S$ 100% gets to speaker







Questions ?

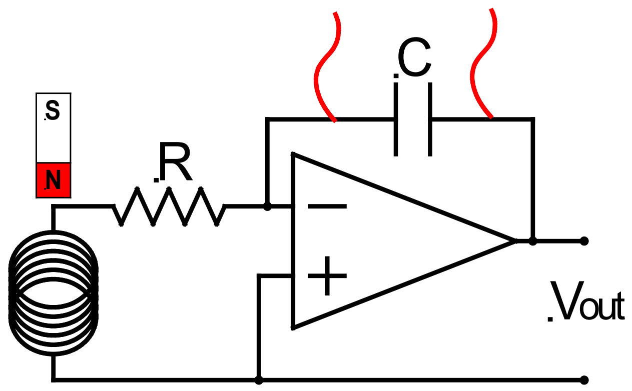
Lab-6

Measure a Magnetic Field

or

Build a Magnetometer

Lab-6 - Measure a Magnetic Field



Recall $V_{out} = -\frac{1}{RC}\int_0^t V_{in}\,dt$

$But \quad V_{in} = EMF = -NA\,{dB}/{dt}$

$So \quad V_{out} = -\frac{1}{RC}\int_0^t (-NA\,{dB}/{dt})\,dt$

$\Delta B \;=\; Integtate\ B\ from\ \infty\ to\ inside\ coil$

$$\Delta V_{out} = \frac{NA}{RC}\Delta B$$

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