Superconducting Antenna Concept for Gravitational Wave Radiation

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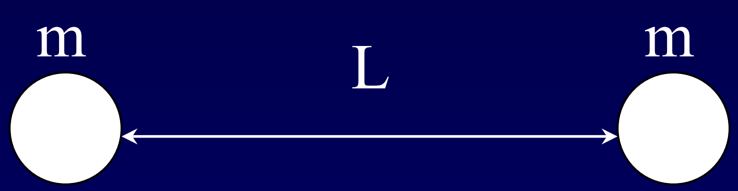
Executive Summary

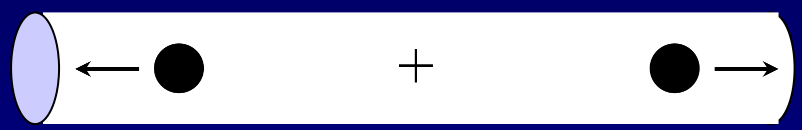
- A novel concept of superconducting GW antenna.
- Non-resonant, applicable to wide spectrum of sources.
- Highly sensitive: $h_0 \sim 10^{-26}$ at 10^2Hz; $h_0 \sim 10^{-23}$ at 10^2 mHz.
- Moderate volume: 10 m lateral size.
- Passive cooling below critical temperature of superconducting components far from the Sun.
- Very little energy consumption at operation.
- Easy to orient.
- Virtually unrestricted operational time.

Starting Point

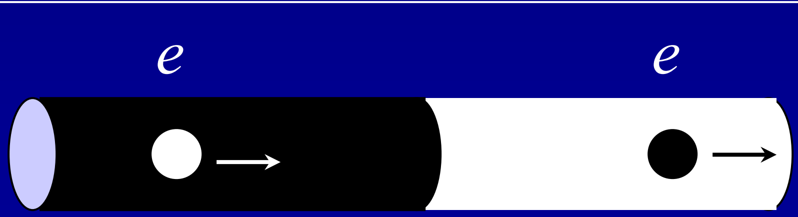


$\Delta L = L h_0 \sin \omega t$

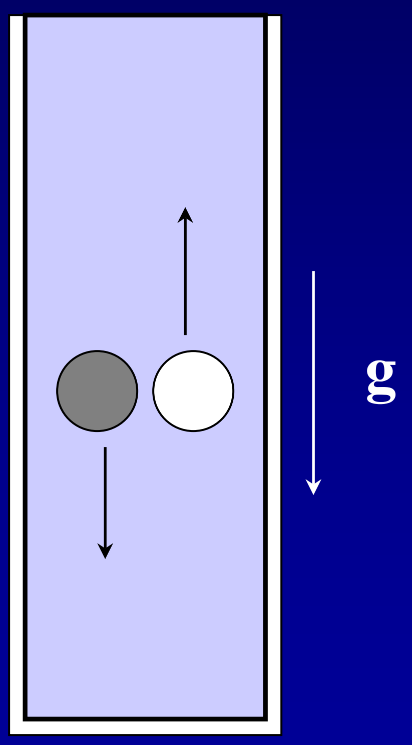
Next step: metallic bar



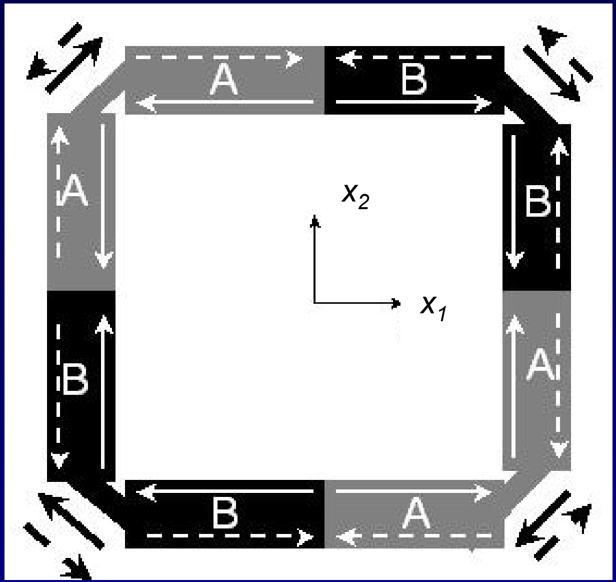
Tidal force tends to accelerate back and forth from CG.
Exchange interaction prohibits ionic motion.
Coulomb interaction prohibits electronic motion.



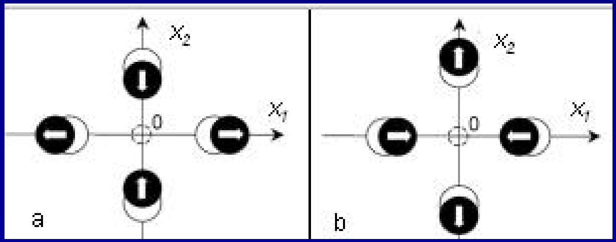
Bimetallic bar, negative m_{eff}



Next Step: Closing Current Trajectory



This design breaks Coulomb blockade: during two half-periods electrons will now move clockwise and counter-clockwise



Why superconductivity?

Why Superconductivity

Motion of electrons in semiconductors and normal metals, though sometimes called “free”, is Aristotelian: it persists while the force is acting. Ohms law: j~v~eE~F,

v~F , *i.e.*, velocity in response to force

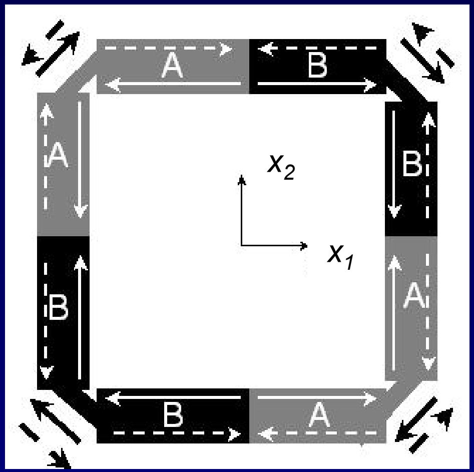
In superconductors $dv/dt \sim E$, *i.e.*, motion is Newtonian!

This difference has crucial consequences: in S/C current response is greater by a factor $(\omega\tau)^{-1} \sim 10^{10+}$.

Ten or more orders of magnitude more than justify SC.

Price to pay: no negative masses for SC. Cooper pairs have positive mass.

Next Step Forward



What if $m^{A}_{eff} > m^{B}_{eff} > 0$?

Tidal force is $\sim m_0$.

Acceleration $\sim m_{eff}^{-1}$.

Torque ~ $n^{A(B)}$, density of carriers.

Subject to electroneutrality (which imposes $n_A v_A = n_B v_B$, at *S*=const), the electric current is:

$$I = jS = en_S^A v_A S = e(n_S^A - n_S^B)\frac{m_0}{m_{eff}^A + m_{eff}^B}\frac{LS\omega h}{8}$$

Here *L* –side length of antenna, S is its cross section.

Estimates of Antenna Response

At $L=10^3 cm$, $S=10^2 cm^2$ the resultant current is about femtoampere for a wave with amplitude $h_0=10^{-26}$ and frequency *100 Hz*. It will be the same for a given value of ωh_0. For example, at 100mHz, *1 fA* yields at $h_0 \sim 10^{-23}$, etc.

This looks encouraging, however, there is still a problem we will address next.

Inductance (Magnetic Energy)

$$E_{mag} \sim \mu_0 L I^2$$

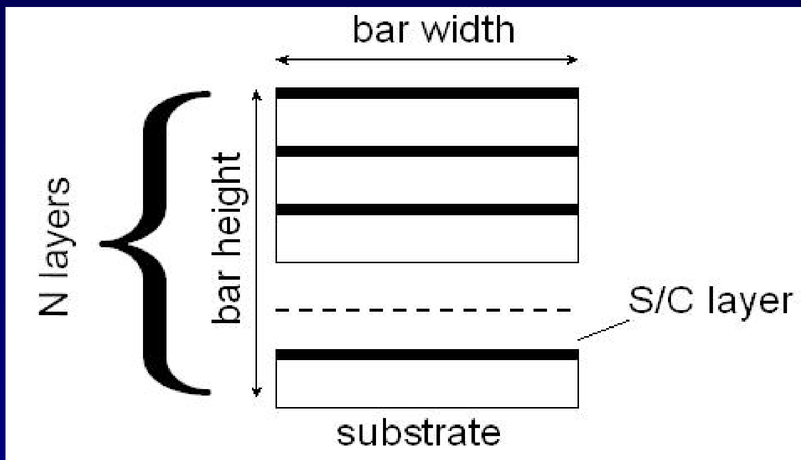
$$E_{kin} = LS(n_S^A m_{eff}^A v_A^2 + n_S^B m_{eff}^B v_B^2)$$

if $m_{eff} \sim m_0$, $n_B << n_A$, and $n_B \sim 10^{22} cm^{-3}$:

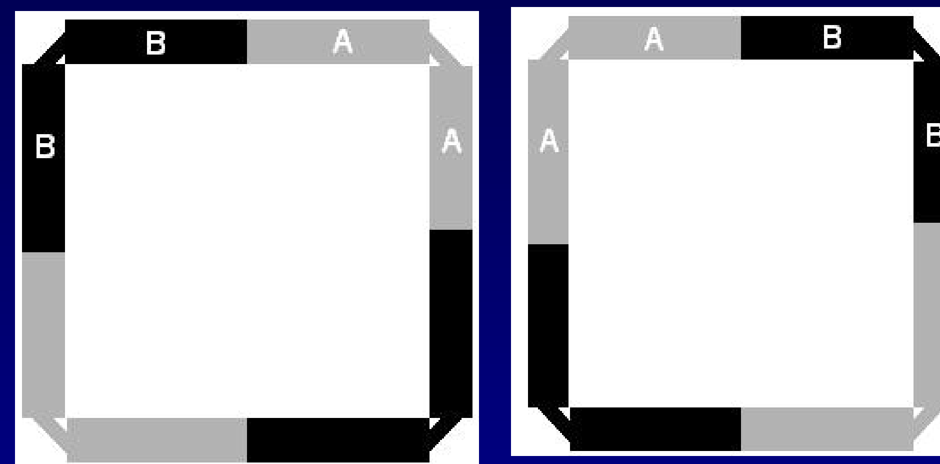
$$\frac{E_{mag}}{E_{kin}} \sim \mu_0 e^2 S \frac{n_S^B}{m_{eff}^B} \sim 10^{12}$$

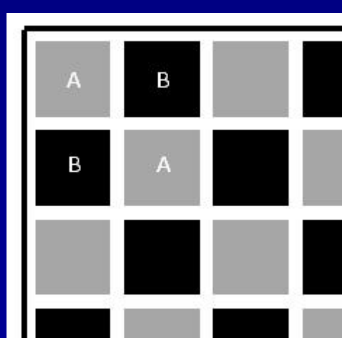
How to neutralize magnetic field?

"Spaghetti" Structure



layers with A and B swapped

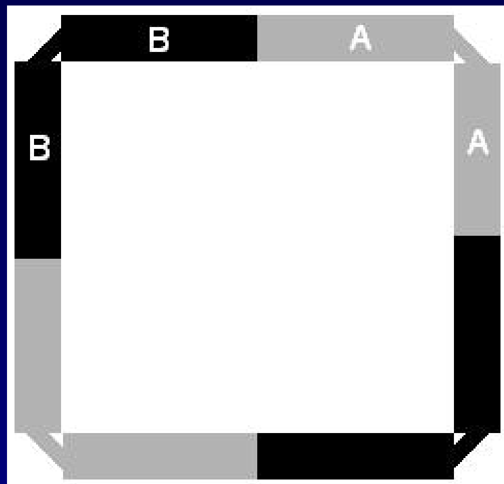


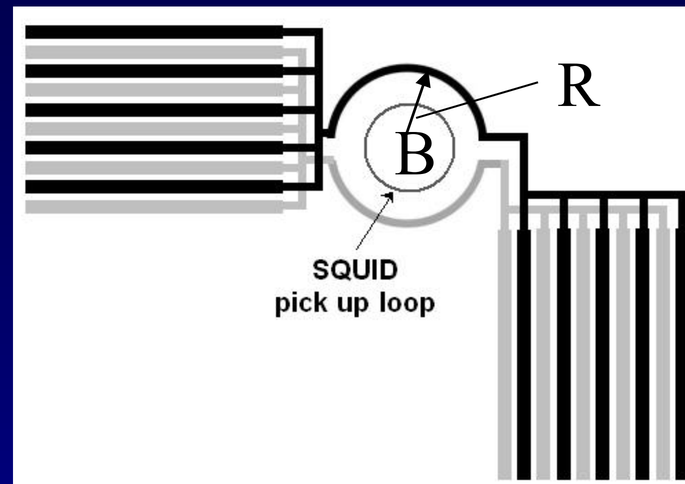


cross section

- Currents move in opposite directions and cancel the magnetic field.
- The number of spaghetti depends on geometry; large but realistic.

Readout





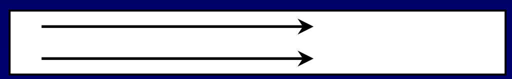
At $I=1$ *fA* and $R=5\mu m$, $B=\mu_0 I/(2R) \sim 10^{-16}$ *T*.

SQUID noise floor $3fT/Hz^{1/2}$: 10^{-17} *T* /1 day of measurement.
Freedom to exploit, say, *10* SQUIDs for different groups of layers, and/or get to weaker GW source detection, and/or reduce the observation time.

Noise Floor of the Detector

- Real noise floor of this antenna is due to normal resistance

I_n, I_S



$$\langle I_n^2 \rangle = 4(k_B T / R_n)\delta\nu$$

- Two notes are important here:

1) at low *T* the normal fluid (and its influence) dies out exponentially;
2) bandwidth $\delta\nu$ can be made narrow for periodic signals (large integration time).

Our estimates indicate that achievable noise floor is about *10 fA/Hz*$^{1/2}$, which inspires optimism.

Conclusions

•We elaborated a novel concept of the GW antenna. We see no showstopper for this concept and would welcome experts opinion on its viability.

•Hopefully, in parallel to other large-scale efforts, such as the LIGO approach and LISA mission or NANO gravitational initiative, the suggested concept will become useful for one of the most challenging experiments – the detection of gravitational waves.

•We cannot build it, but NASA can!