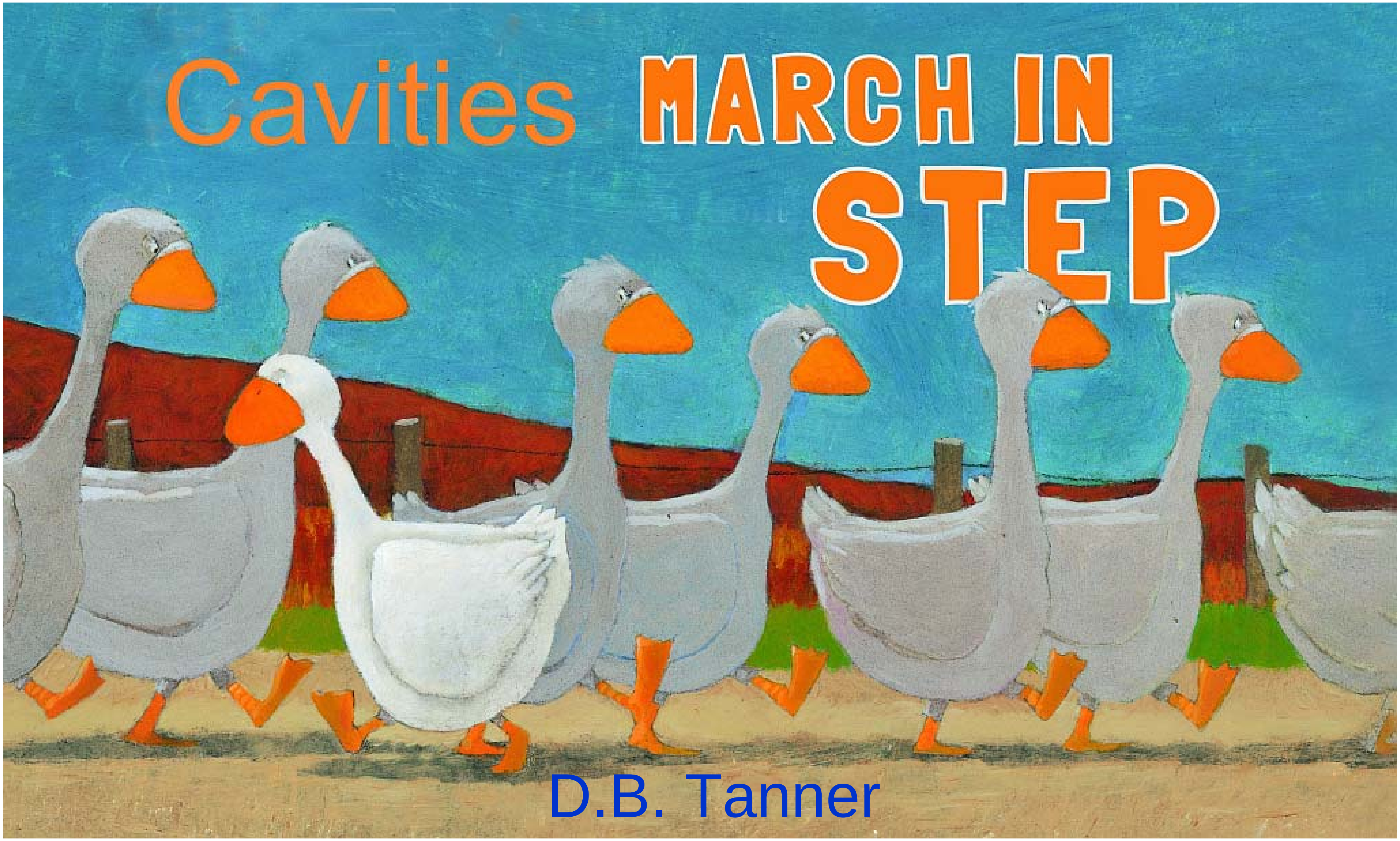
Cavities MARCH IN STEP



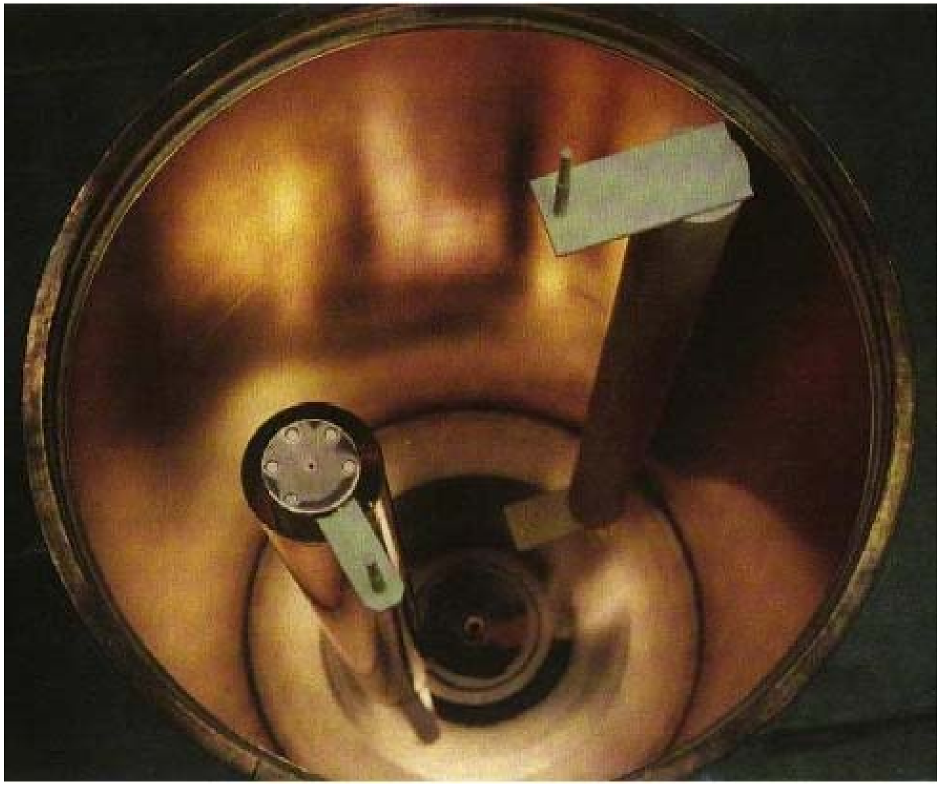
D.B. Tanner

Basic cavity is a right circular cylinder

$$f = \frac{c}{2.61r}$$

Or:

$$\frac{r}{1\ \mathrm{cm}} = \frac{11.5\ \mathrm{GHz}}{f}$$



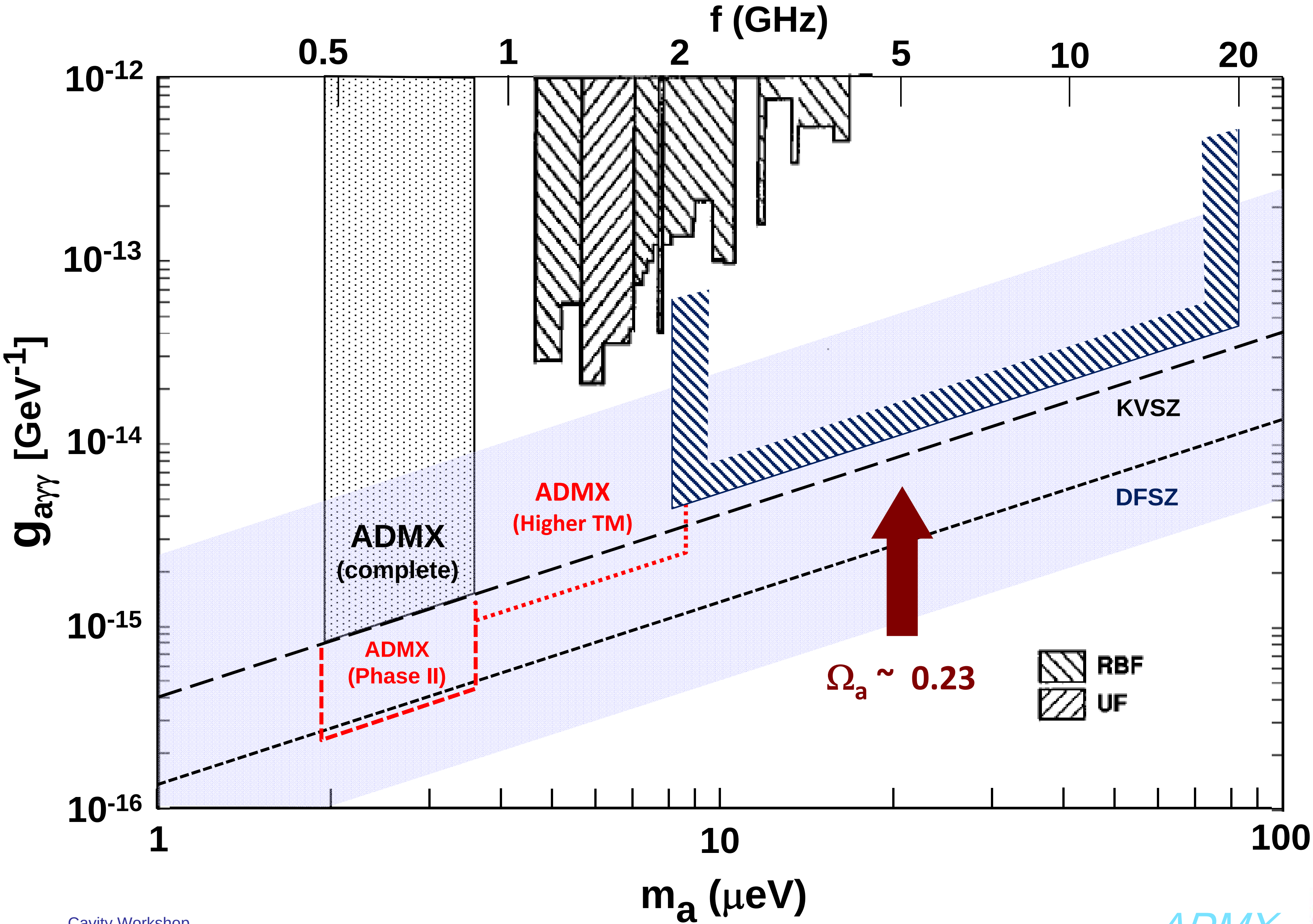
For ADMX,

$$r = 21\ \mathrm{cm}$$

$$\Rightarrow f = 550\ \mathrm{MHz}$$

$$L = 100\ \mathrm{cm}$$

“Sweet spot” is ~ 4-5 GHz



ADMX

Signal strength

- Power from the cavity is

$$P = 4 \cdot 10^{-22}\ \mathrm{W} \left(\frac{V}{200\ \ell}\right)\left(\frac{B_0}{8\ \mathrm{Tesla}}\right)^2 C_{nl}\left(\frac{g_\gamma}{0.97}\right)^2 \cdot$$
$$\left(\frac{\rho_\mathrm{a}}{0.5 \cdot 10^{-24}\ \mathrm{g/cm^3}}\right)\left(\frac{m_\mathrm{a}}{1\ \mathrm{GHz}}\right)\left(\frac{\min(Q_\mathrm{L}, Q_\mathrm{a})}{1 \times 10^5}\right)$$

- Where C is form factor, ρ_a is the halo density, m_a the axion mass, and
- $Q_\mathrm{L} \sim 70000(\mathrm{GHz}/f)^{2/3}$ (ASE); $Q_a \sim 10^6$ are quality factors
- $g_\gamma \sim 0.97$ (KSVZ); $g_\gamma \sim 0.36$ (DFSZ) are coupling strengths
- We use DFSZ; look for ~10^{-22} Watts power

Baseline is a right circular cylinder

$$f = \frac{c}{2.61r}$$

Or:

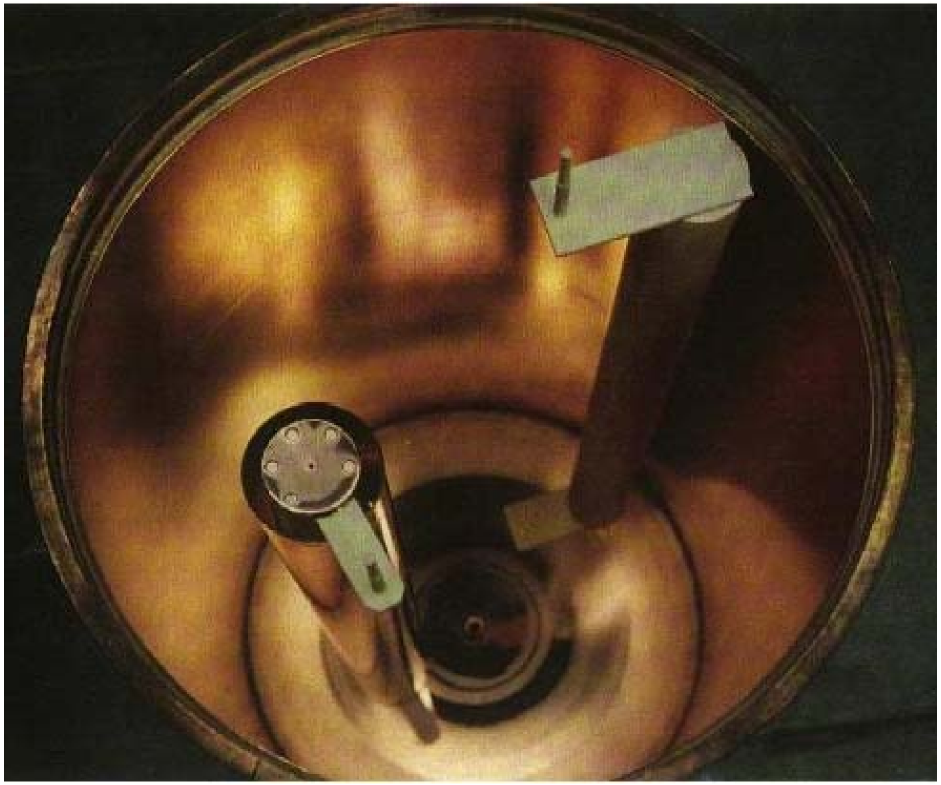
$$\frac{r}{1\ \mathrm{cm}} = \frac{11.5\ \mathrm{GHz}}{f}$$

For Sweet Spot,

$$r = 2.6\ \mathrm{cm}$$

$$\rightarrow f = 4.5\ \mathrm{GHz}$$

$$L = 5.6\ \mathrm{cm}$$

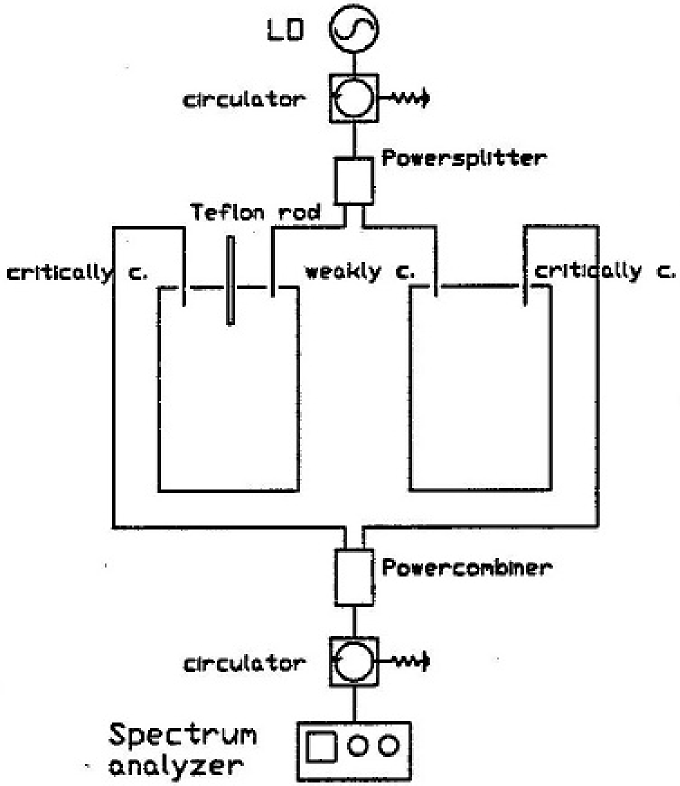


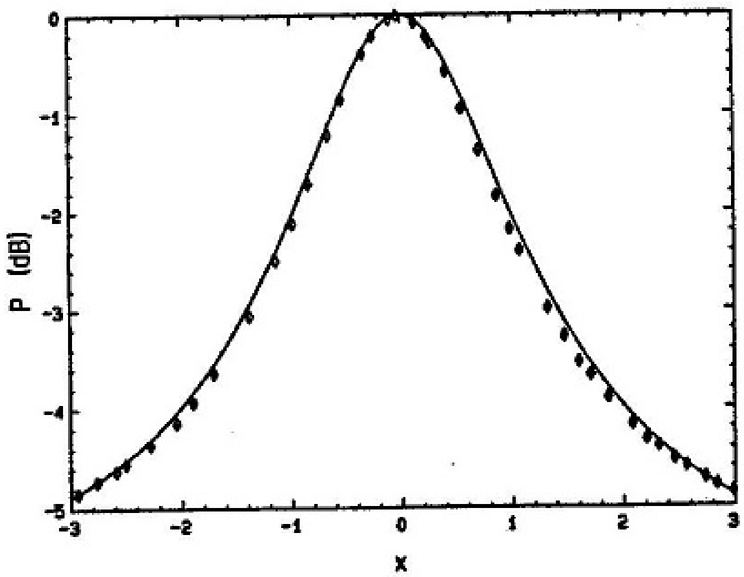
In ADMX magnet, need up to 32 cavities

Cover about 1 decade in axion mass

Cavities No.	Cavities Type	Tuned by	r/R	Pack factr	Res. freq. MHz	Tuning range MHz	Tuning range ueV	Q wall	P W *e-22	1 df / f dt %/wk	Run time Wks
1	O	dielec	1.00	1.00	575	402 - 575	1.7 - 2.4	246000	4	3.6	8
1	O	metal	1.00	1.00	575	575 - 908	2.4 - 3.8	223000	4	3.3	18
2	(|)	metal	1.00	1.00	897	897 - 1417	3.7 - 5.9	154000	4	3.5	16
4	(+)	metal	1.00	1.00	1207	1207 - 1907	5 - 7.9	127000	4	3.9	15
8	O *8	metal	.303	.733	1899	1899 - 3001	7.8 - 12	119000	5	3.1	19
16	(|) *8	metal	.303	.733	2959	2959 - 4675	12 - 19	81000	5	3.3	18
32	(+) *8	metal	.303	.733	3983	3983 - 6293	16 - 26	67000	5	3.7	16

Cavities must be added in phase





Requires them to have identical resonances

- Tune (dead reckoning), measure, adjust…
- Use a servomechanism

Requires them to have identical resonances

- Tune (dead reckoning), measure, adjust…
- Use a servomechanism

- Need a method to bring all resonances to a common frequency
- Method: Pound, Drever, Hall (PDH) reflection locking
- Used by LIGO, VIRGO and other gravity experiments

PDH references

- Electronic Frequency Stabilization of Microwave Oscillators

  R.V. Pound, Rev. Sci. Instrum. **17**, 490 (1946).

- Laser phase and frequency stabilization using an optical resonator

  R.W.P. Drever, J.L. Hall, F.V. Kowalski, J. Hough, G.M. Ford, A.J. Munley, and H. Ward, Appl. Phys. **B31**, 97-105 (1983).

- An introduction to Pound–Drever–Hall laser frequency stabilization

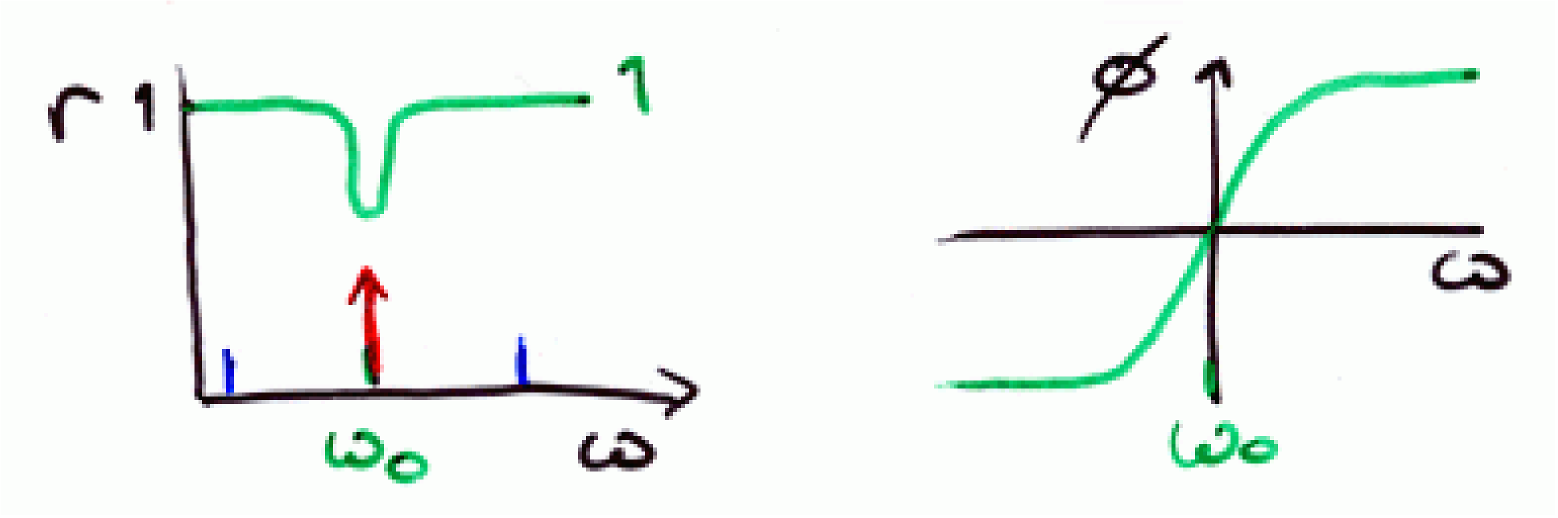
  Eric D. Black, Am. J. Phys. **69**, 79 (2001).

- Understanding Pound-Drever-Hall locking using voltage controlled radio-frequency oscillators: An undergraduate experiment

  C.E. Liekhus-Schmaltz and J.D.D. Martin, Am. J. Phys. **80**, 232 (2012).

Pound Drever-Hall (PDH) reflection locking

- Cavity reflects (promptly) waves that are not on resonance
- Reflection dip at resonance, along with phase change



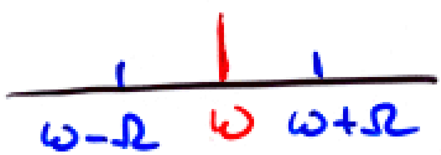
Phase-modulated light

- Phase modulated light

$$E = e^{-i\omega t + i\Gamma \cos \Omega t}$$

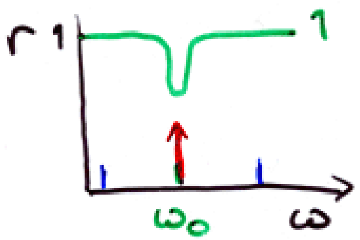
$$= e^{-i\omega t}\left[1 + i\Gamma \cos \Omega t + \cdots\right]$$

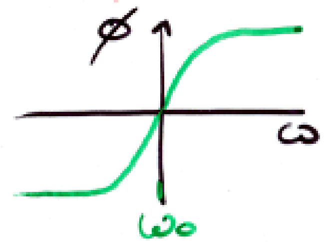
$$= e^{-i\omega t} + \frac{i\Gamma}{2} e^{-i(\omega+\Omega)t} + i\frac{\Gamma}{2} e^{-i(\omega-\Omega)t}$$



As cavity tunes, *phase* of reflected carrier shifts

- Reflect from cavity





$$\phi = \begin{cases} \dfrac{\omega - \omega_0}{\Delta\omega} \equiv \epsilon & \omega \sim \omega_0 \\ \pm\pi & \omega \gg \omega_0,\ \ll \omega_0 \end{cases}$$

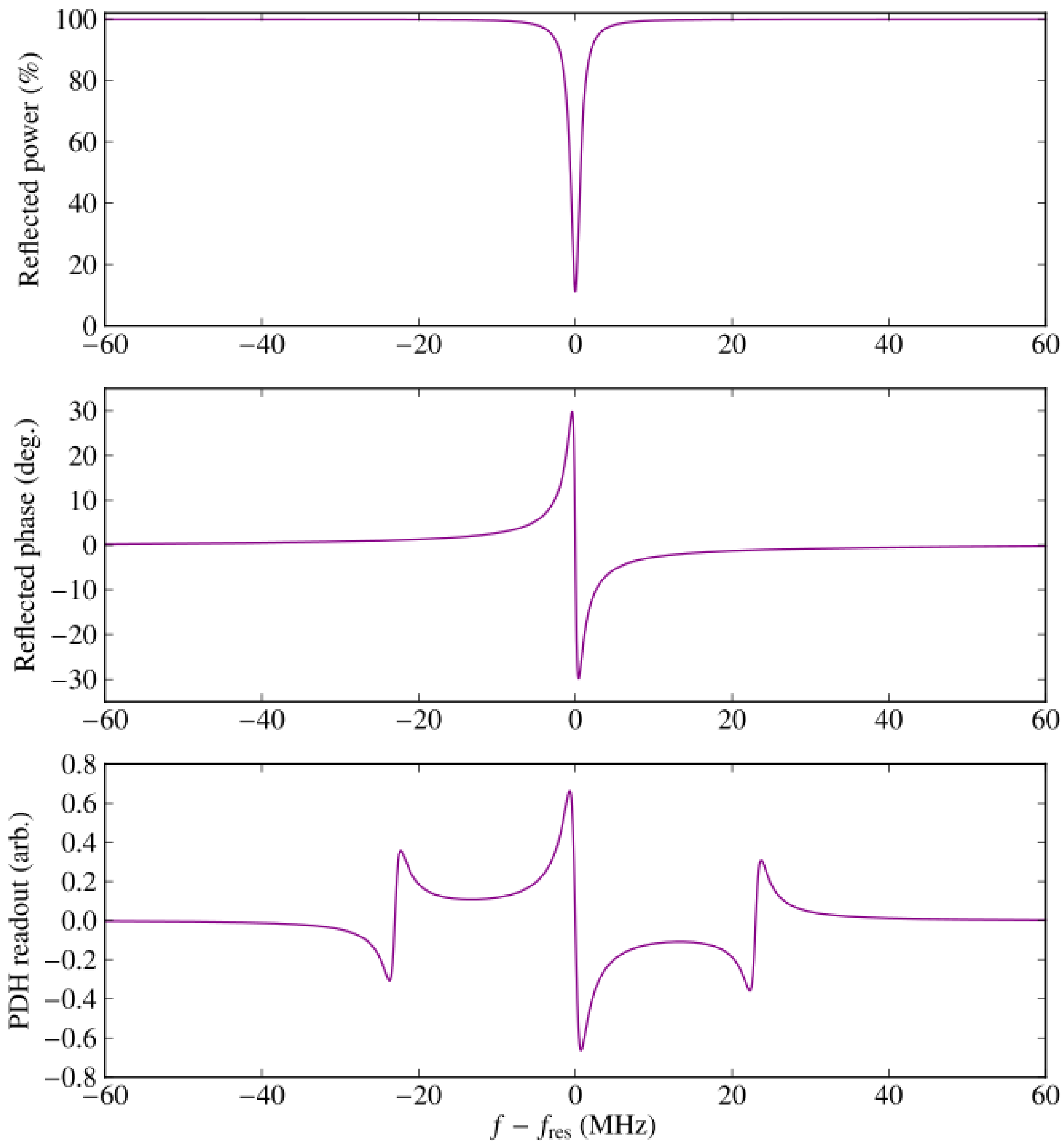
$$E_r = \left(r e^{i\epsilon} - i\Gamma \cos \Omega t\right) e^{-i\omega t}$$

$$I_r = \underbrace{R}_{r^2} + \Gamma^2 \cos^2 \Omega t - 2\Gamma r \sin\epsilon \cos \Omega t$$

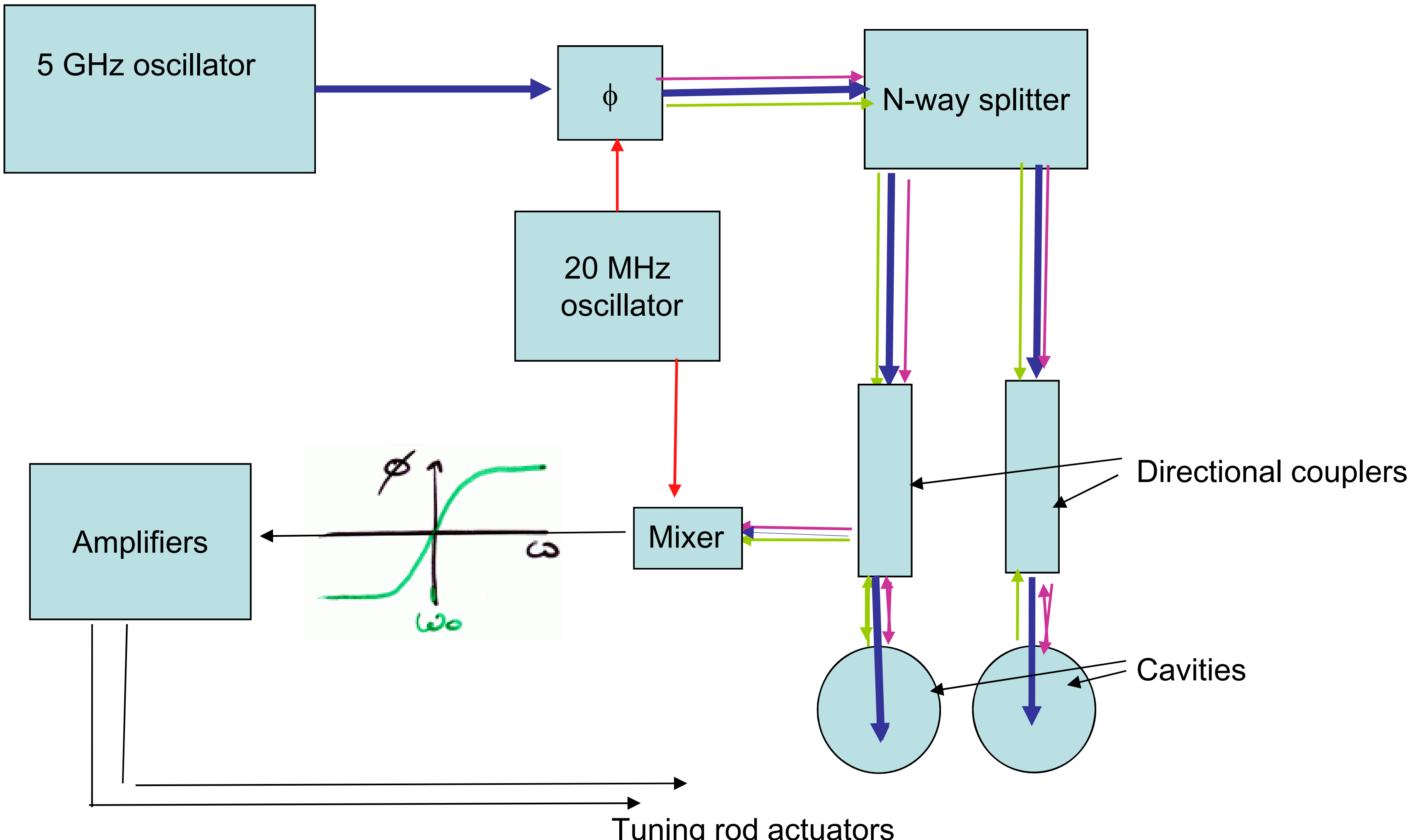
- Demodulate at $\cos \Omega t$ $\quad \langle \cos^2 \rangle = 1/2$

$$\langle I_\Omega \rangle = -\Gamma r \sin \epsilon$$

Simulated PDH signal



Each cavity can be driven to resonance at the carrier



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