The Supermodulator

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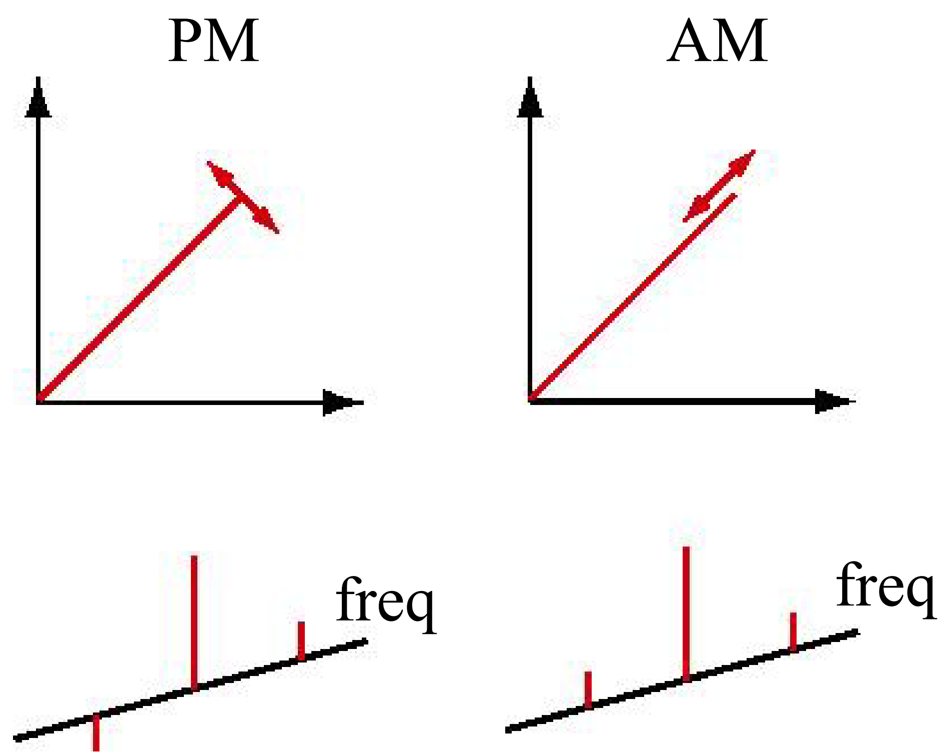
What is a “Super”-modulator?

- Take an **electro-optic amplitude modulator** and re-wire it:
  - AM has one electrode connected to 2 crystals
  - SM has 2 independent connections to crystals
- Supermodulator can do amplitude and phase modulation at once
- GW use: offset locking

Phase and Amplitude Modulation (Let's go back a few steps…)

- Depict laser light with:
- Phasor diagrams
  - "Carrier" rotates at ω
  - Oscillation at ω_m
  - PM: Angle oscillation
  - AM: Length oscillation
- Frequency Vector dgms
  - Carrier at ω
  - "Sidebands" at $\omega \pm \omega_m$
  - Sidebands rotate at $\pm \omega_m$
  - Link between diagrams…

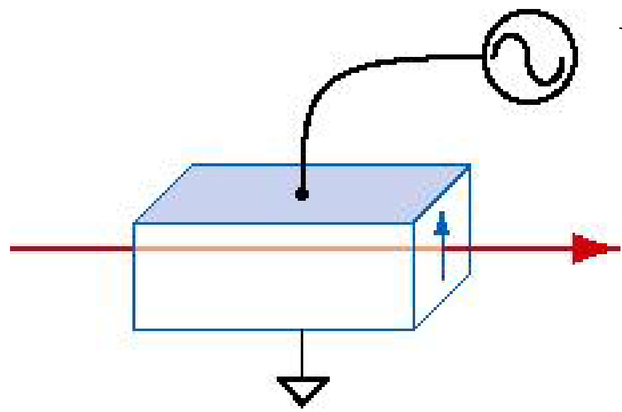


The electro-optic phase modulator

- Crystal with volt-controlled refractive index
  - Pockel's effect: $n(V) = n_0 + n_1 V$ (in one axis)

$V = V_0 \cos(\omega_m t)$

$E = E_0 e^{i\omega t}$

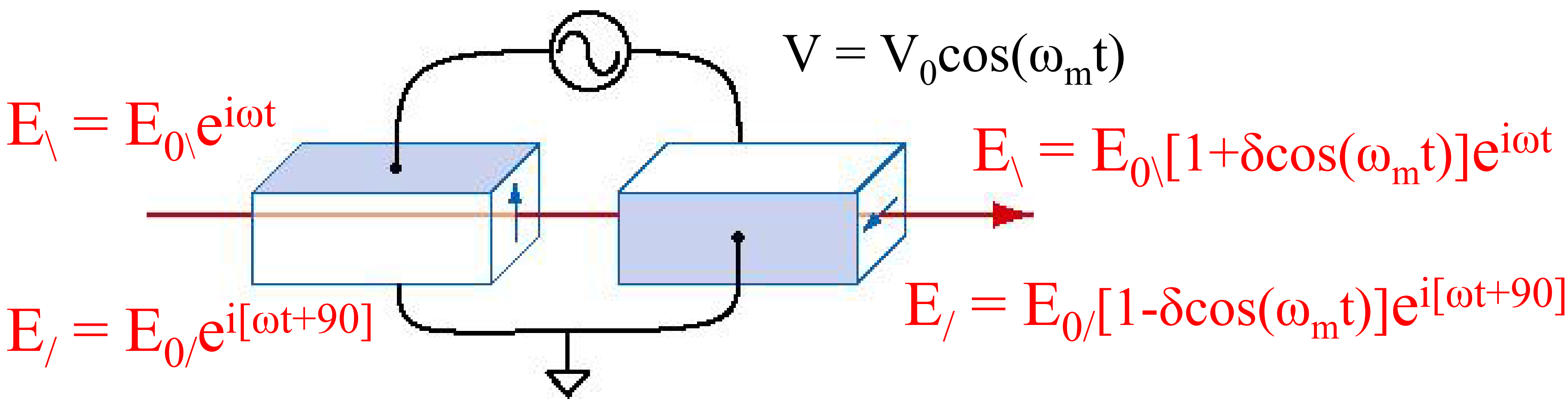


$E = E_0 e^{i[\omega t + \delta \cos(\omega_m t)]}$

  - Sinusoidal voltage → sinusoidal optic path length
  - Phase of laser advanced and retarded alternately
- → Phase Modulation

Electro-optic amplitude modulator

- Use two PM crystals, optic axes at 90°
  - Circular polarised light required, look at comp’ts



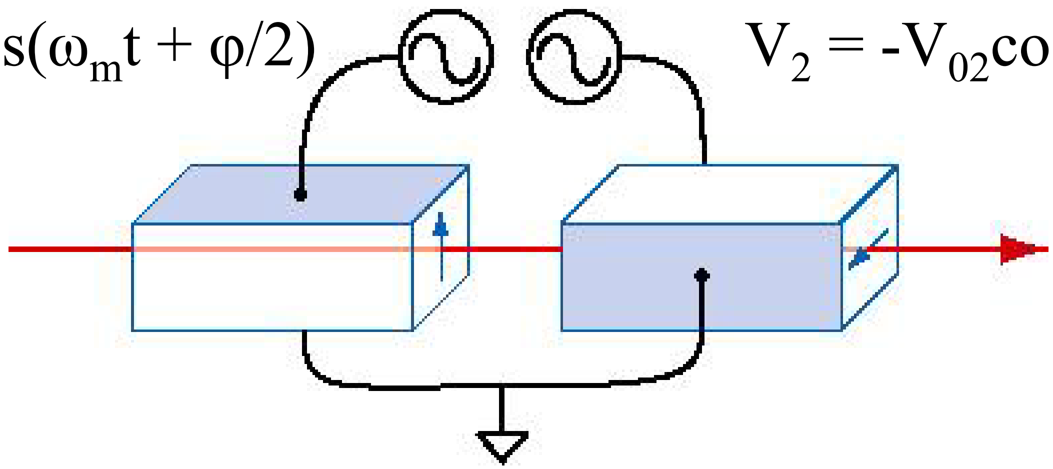
  - Crystals wired with opposite polarity
  - Get AM by removing one pol’n (energy conserv.)

Electro-optic Supermodulator

- Same as AM but use 2 separate voltages

$V_1 = V_{01}\cos(\omega_m t + \varphi/2)$

$V_2 = -V_{02}\cos(\omega_m t - \varphi/2)$



$$E = E_0[1+A_I\cos(\omega_m t)+A_Q\sin(\omega_m t)+P_I i\cos(\omega_m t)+P_Q i\sin(\omega_m t)]$$

- 3 independent degrees of freedom
  - Amount of AM, amount of PM, phase difference

Some operating points of interest

- Six sets of $\{V_1, V_2, \varphi\}$ are significant:
- If $V_1 = V_2$, $\varphi = 0$ → Pure PM
  - crystals modulating in phase, similar to PM device
- If $V_1 = V_2$, $\varphi = 180°$ → Pure AM
  - exactly the same as unmodified AM device
- If $V_1 = V_2$, $\varphi = 90°$ or $270°$ → SingleSideBand
  - crystals modulated in quadrature cancel one SB
- If either $V_1 = 0$ or $V_2 = 0$ → half AM, half PM
  - AM, PM are in phase, so expect equal SB heights

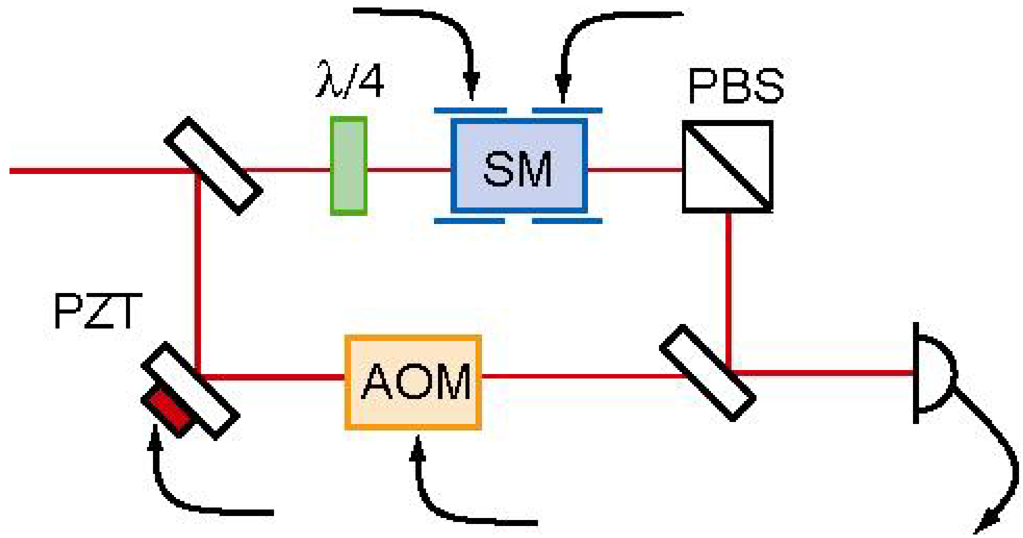
Now I can answer the question: Why?

- Can use SM to offset lock cavity or Michelson
  - PDH lock the device;
  - inject small amount of AM (along with PDH PM);
  - device overcompensates, lock point moves
  - tune lock point in real time, tunable GW detector?
- Bonus: Single Sideband modulation
- So, what am I trying to do with the device?
  - A: Demonstrate 6 operating points at max quality
  - B: Demonstrate stability and predictability of device while “naively” tuning between op. points

Experiment to Characterise SM device

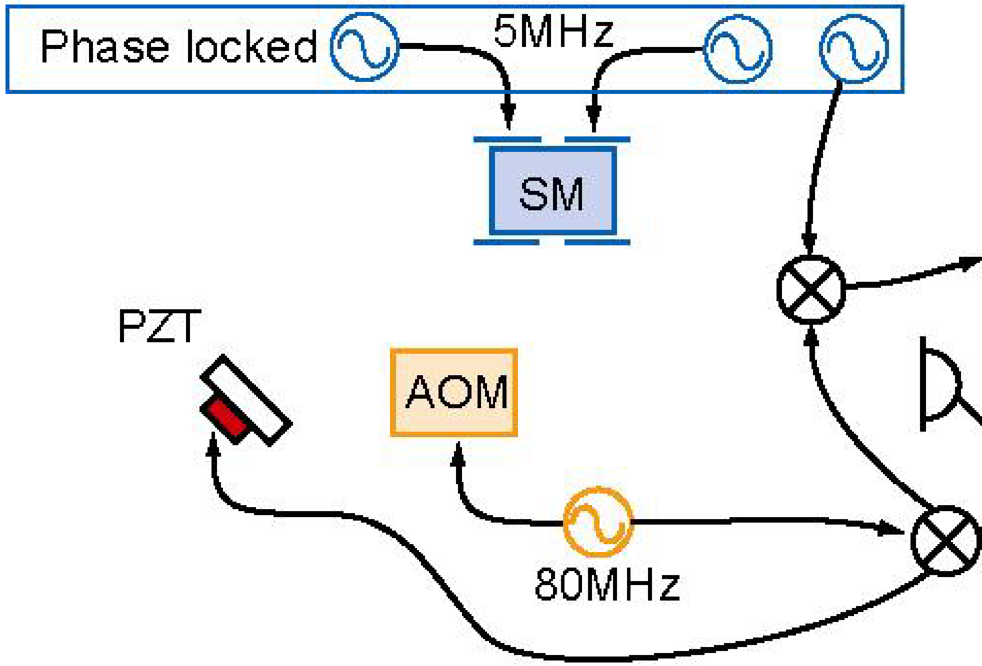
- Need to measure 3 dof: AM, PM, phase rel.
- Experiment incorporates 3 types of measure:
  - 1. Directly detect AM beat (spectrum analyser)
  - 2. Heterodyne measurement of sidebands (s.a.)
  - 3. Double demodulation of heterodyne detected sidebands, can measure magn. and phase of PM
- Total of 5 measurables → redundancy
- 1. and 3. make orthogonal set of measures
- 2. provides cross checking

Experimental Layout: Optical



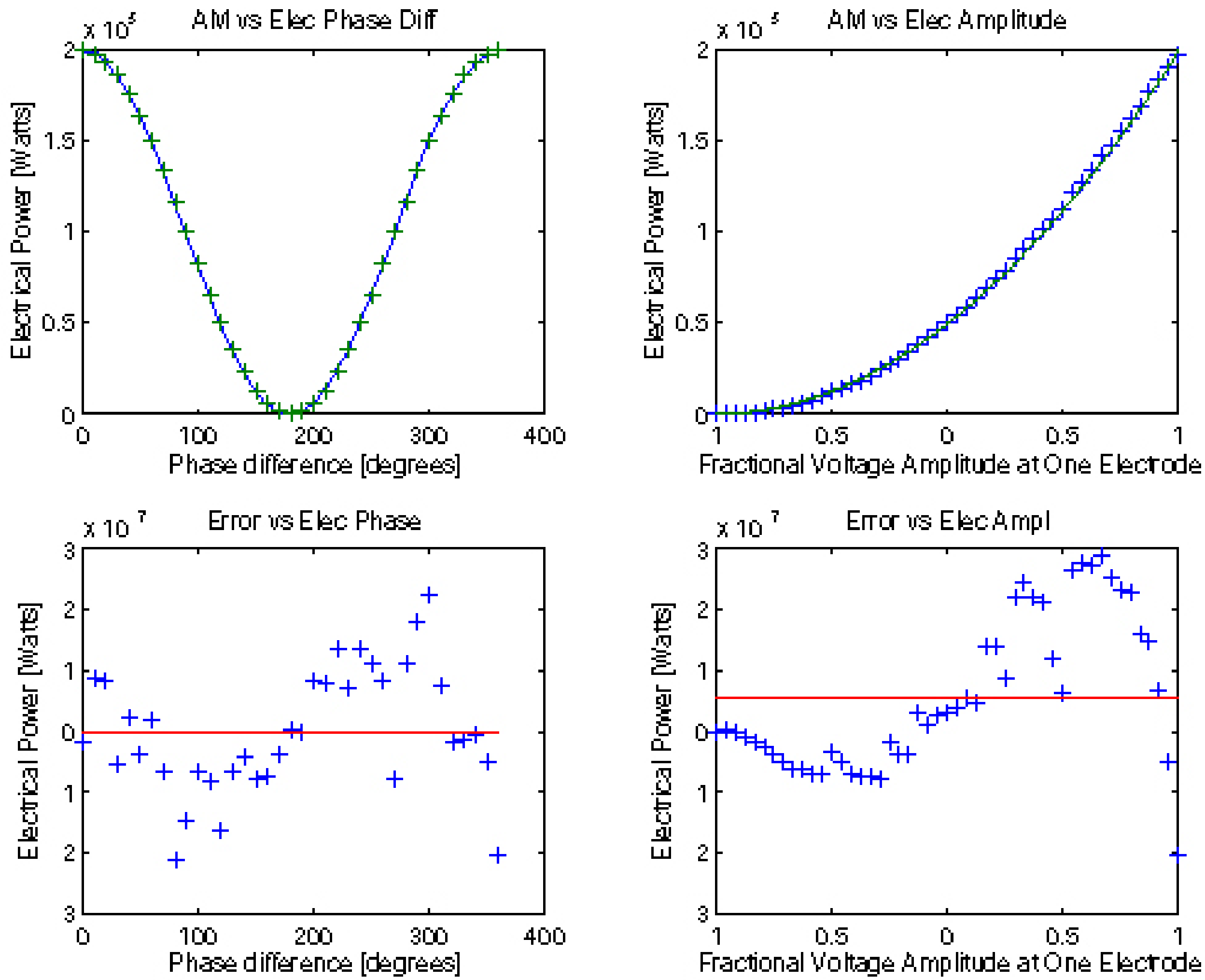
- Circular pol'n into SM; tap off vert. with PBS
- AOM in Mach-Zehnder provides heterodyne
- Feedback to PZT to control recomb. phase
- 2 sines to SM, 1 sine to AOM

Experimental Layout: Electronic

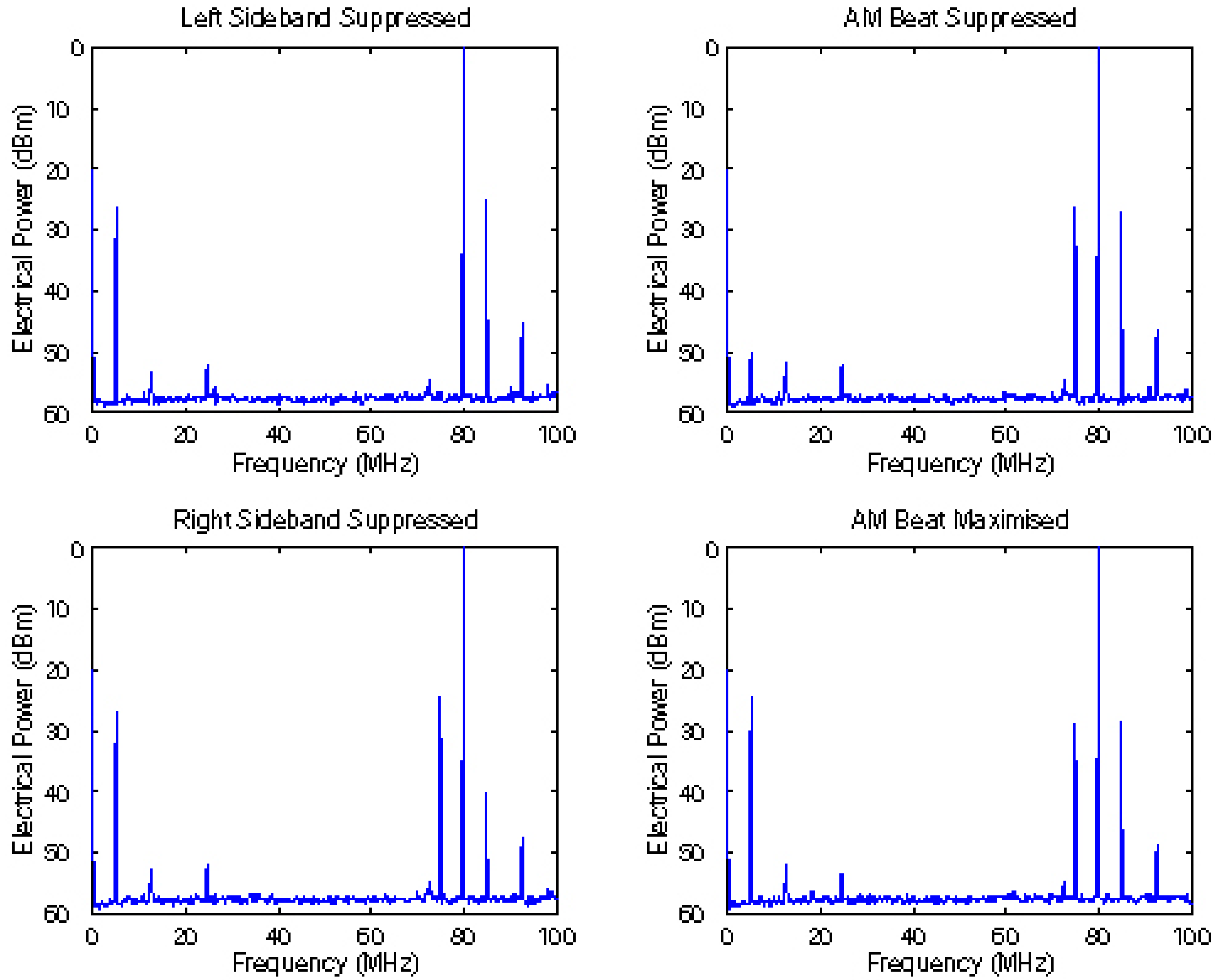


- SM signal generators have definite phase rel.
- Double demodulation "mixes down" signal to baseband → measure PM as DC offset
- Frequency vector description …

Some Experimental Results: AM Beat



More Results: Heterodyne Frequencies



Problems to deal with

- SM has birefringence offset, compensate with non-circular input polarisation state
- "Spatialness" of polarisation transfer function
  - ~1% impurity of polarisation state
- Sideband height mismatch occurs for single crystal modulation; still no mechanism for this
  - Heterodyne detection implicated, suggests spatial
- Have quality goal of < 1dB SB height mismatch, should achieve soon

Future ideas

- Use Supermodulator to do offset locking experiments: Cavity, Michelson, coupled sys.
- Look at “Simplermodulator”: rotate axis of ordinary PM crystal, get in-phase AM
  - Simpler idea to offset lock a cavity,less power loss
- Generalised polarisation modulation
  - Model on Poincare sphere
- Look at effects on higher order harmonics