

Study of a Universally Tunable Electro-Optic Modulator

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Universally Tunable Modulator

- Our UTM = modified Amplitude Modulator
 - New Focus 4104
 - Re-wire to have separate control of two crystals
- UTM is capable of PM and AM with selectable phase relation

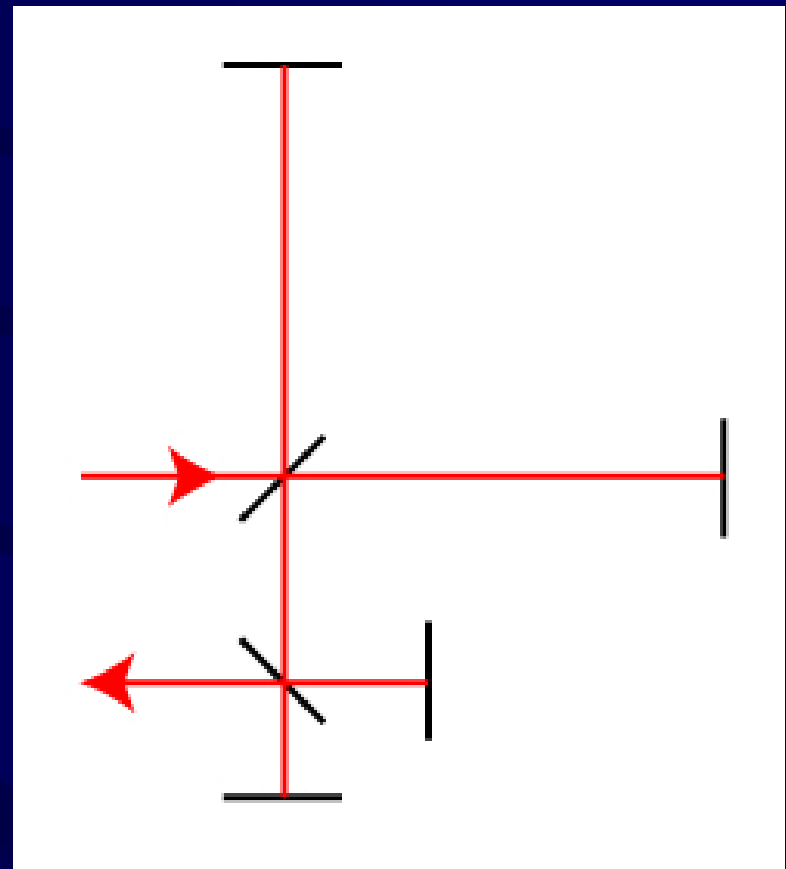


What is the UTM for?

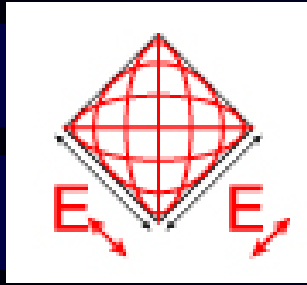
- GW rf control systems are based on injecting PM
 - GW inteferometer optical freq response can convert PM to AM according to its state
 - AM is detectable \rightarrow readout/error signals
- UTM innovation: inject AM along with PM such that actuators overcompensate
 - Result: tunable lock points

Tuning GW detector responses

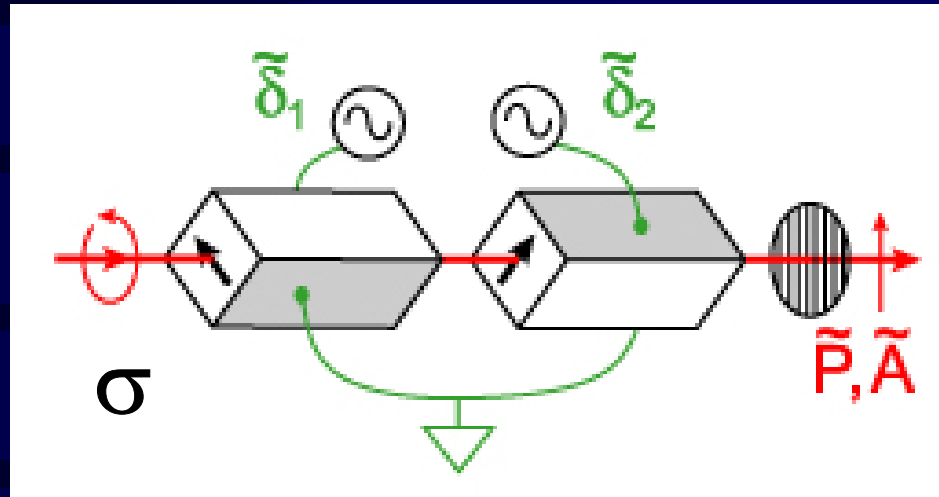
- Consider simplified GW detector \rightarrow
- Signal cavity and 2nd Michelson phase conditions determine detector response
 - Cavity and Michelson require AM of orthogonal phases \rightarrow UTM can do this
 - Potential to tune-lock **both** dof with a single UTM



How the UTM works

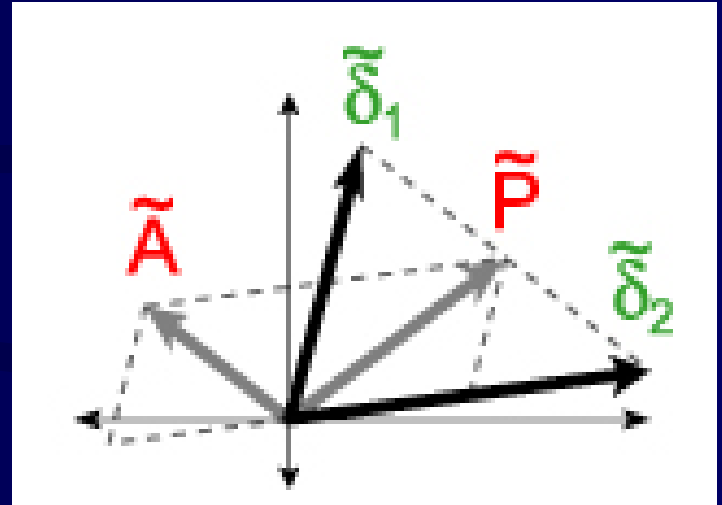
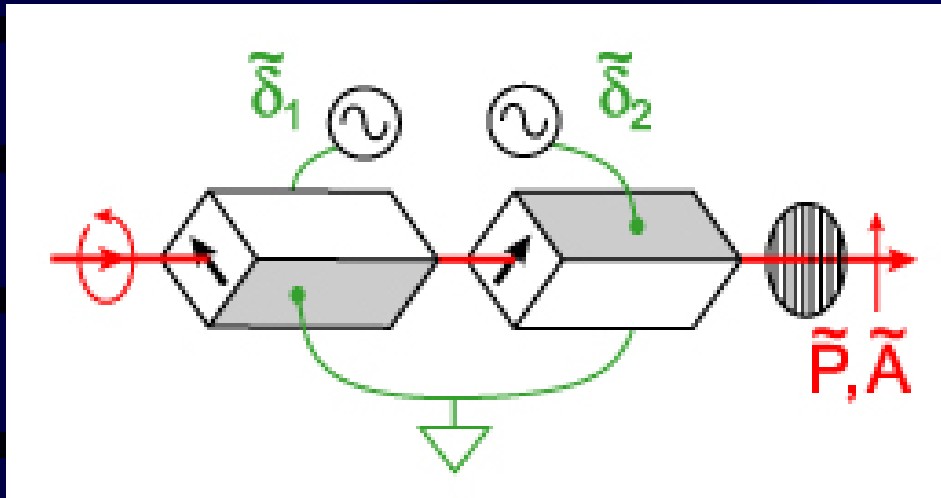


$\sigma = 0 \rightarrow$ vertical
 $\sigma = 90 \rightarrow$ circular
 $\sigma = 180 \rightarrow$ horiz'l



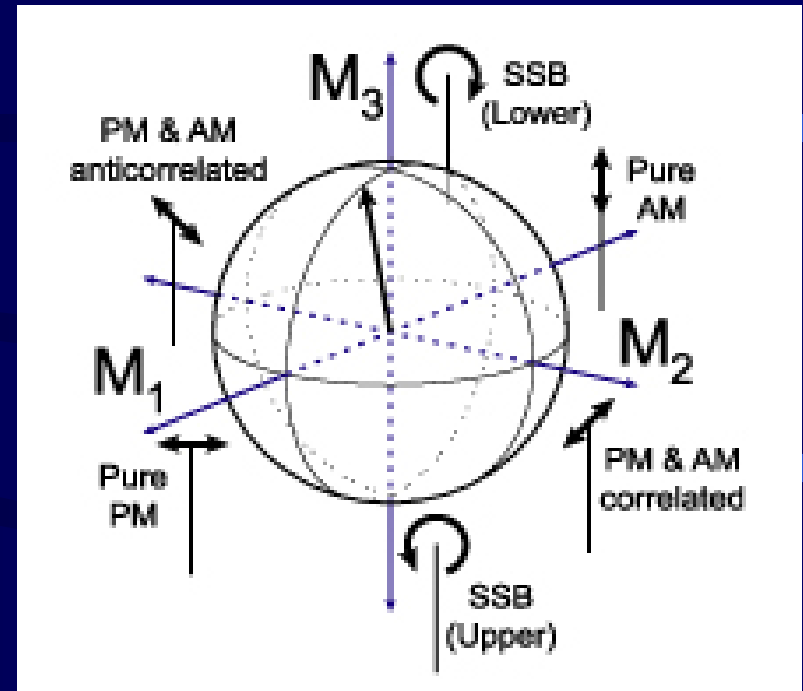
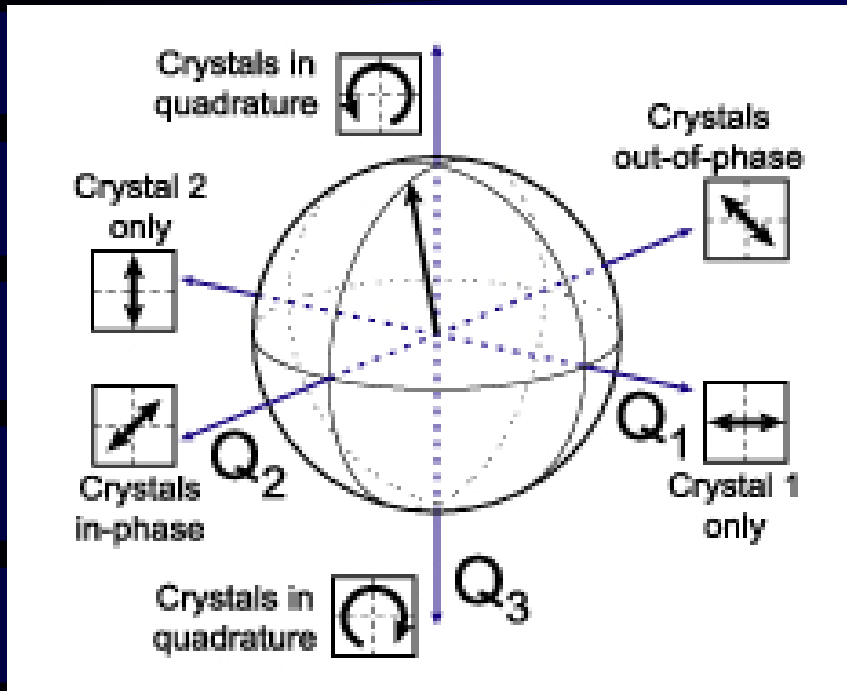
- 2 PM crystals, 2 V-sources, linear polariser
- Circular (elliptical) polarisation input: σ
 - **Choose small σ to avoid dumping too much power**
- Equivalent to Mach-Zehnder modulator
 - polarisation interferometry, spatially degenerate

UTM Transfer Function



$$\tilde{P} = \frac{1}{2} \cos\left(\frac{\sigma}{2}\right) (\tilde{\delta}_1 + \tilde{\delta}_2)$$
$$\tilde{A} = \frac{1}{2} \sin\left(\frac{\sigma}{2}\right) (\tilde{\delta}_1 - \tilde{\delta}_2).$$

The Modulation Sphere



If $\sigma = 90$
(circular)

$$M_0 = \frac{1}{4} Q_0$$

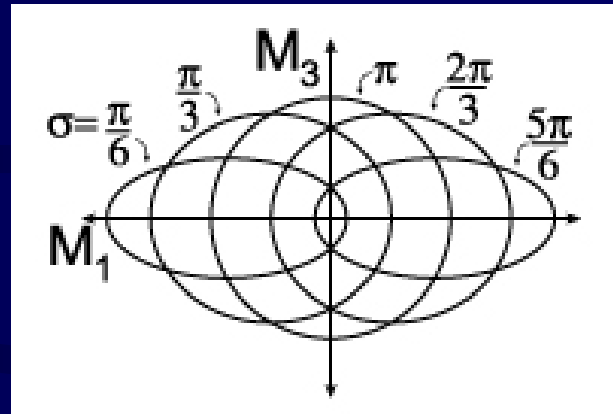
$$M_1 = \frac{1}{4} Q_2$$

$$M_2 = \frac{1}{4} Q_1$$

$$M_3 = -\frac{1}{4} Q_3$$

Modulation Ellipse

- If $\sigma \neq 90$, a sphere in “Q-space” maps to an **ellipse** in “M-space”
- M-space ellipse is:
 - off-centre
 - prolate (along M_1)
 - one focus at origin
 - orthogonality of axes preserved (important!)

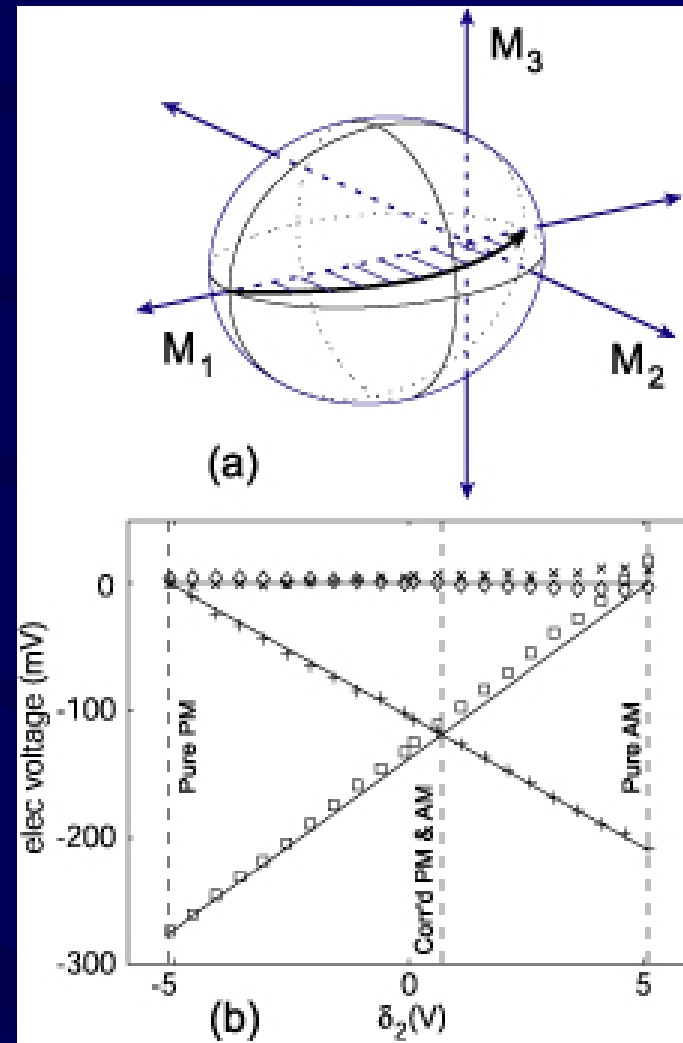
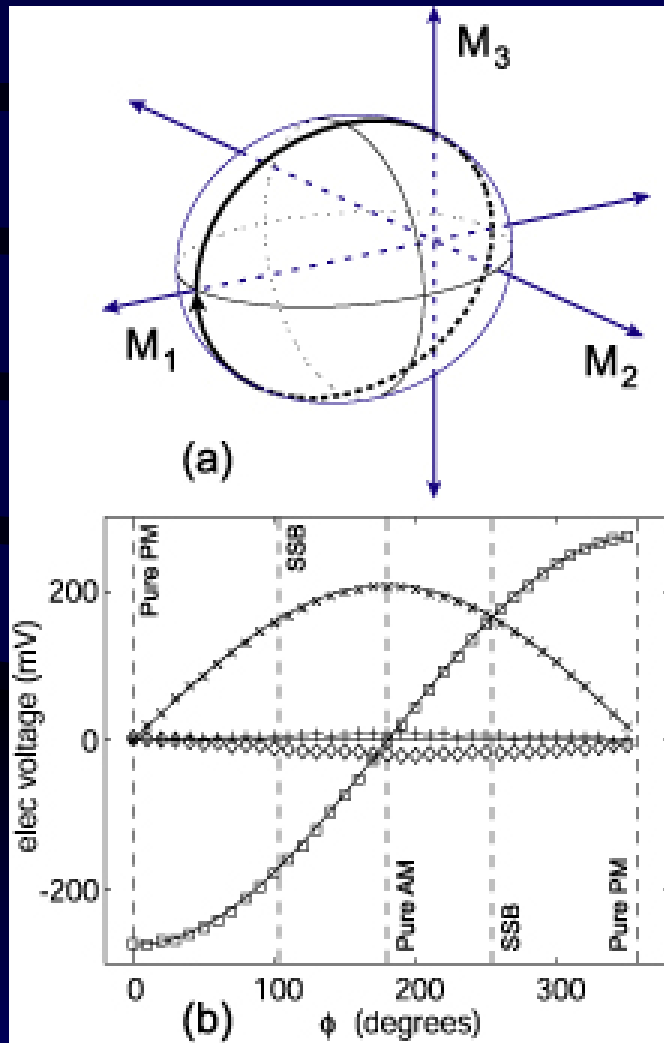


$$M_0 = \frac{1}{4} (Q_0 + Q_2 \cos(\sigma))$$
$$M_1 = \frac{1}{4} (Q_0 \cos(\sigma) + Q_2)$$
$$M_2 = \frac{1}{4} \sin(\sigma) Q_1$$
$$M_3 = -\frac{1}{4} \sin(\sigma) Q_3$$

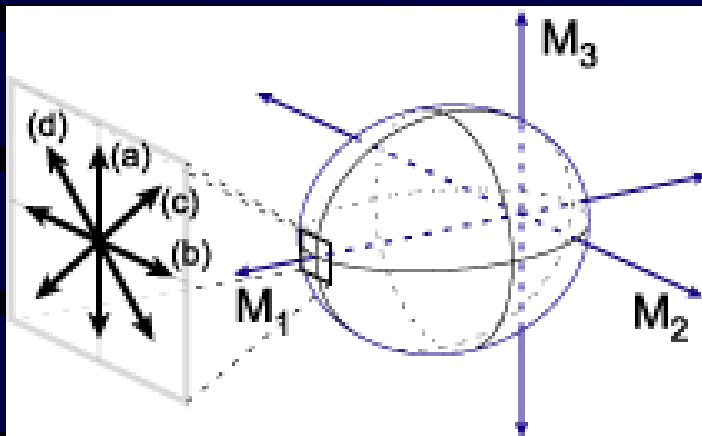
Prototype Characterisation

- Chose two properties of merit to evaluate:
- *Variability*:
 - device continuously tunes around M-space in a predictable, repeatable manner
 - should be able to “dial-up” modulation once calib’d
- *Purity*:
 - specific modulation states attainable with high precision and time-stability

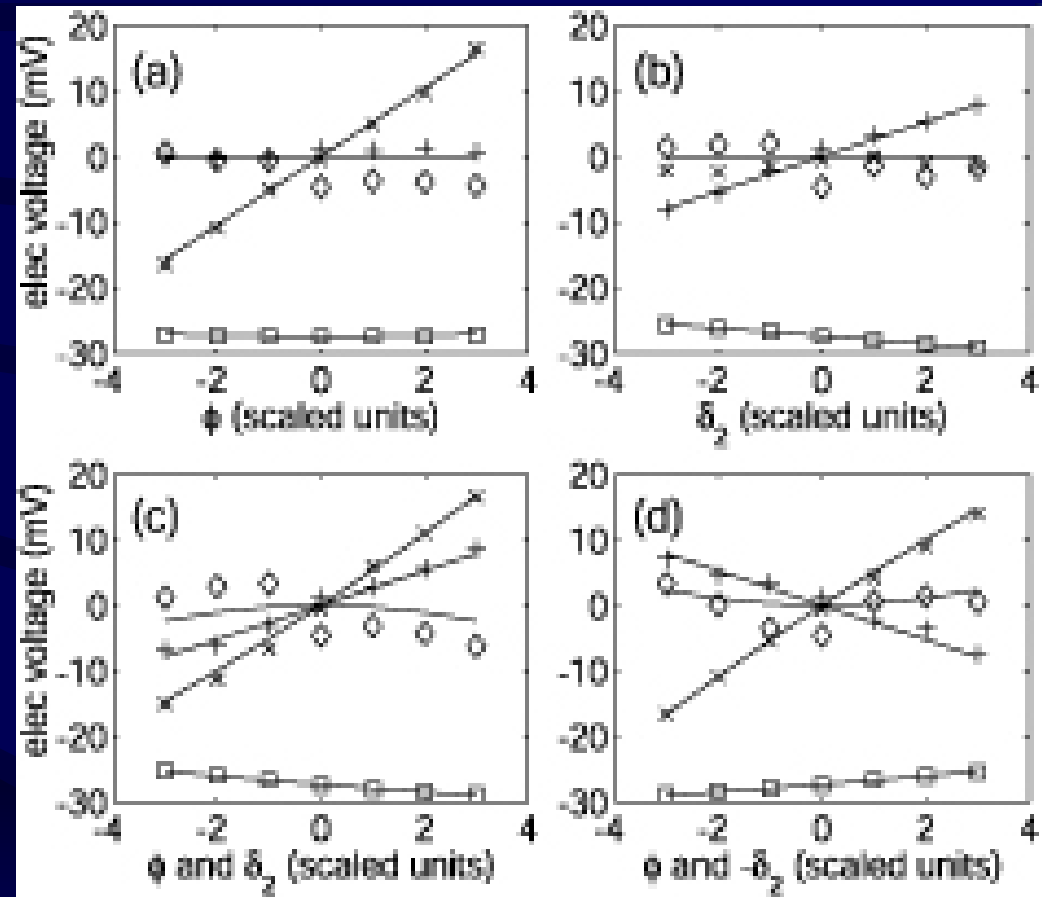
Variability: sweep around sphere



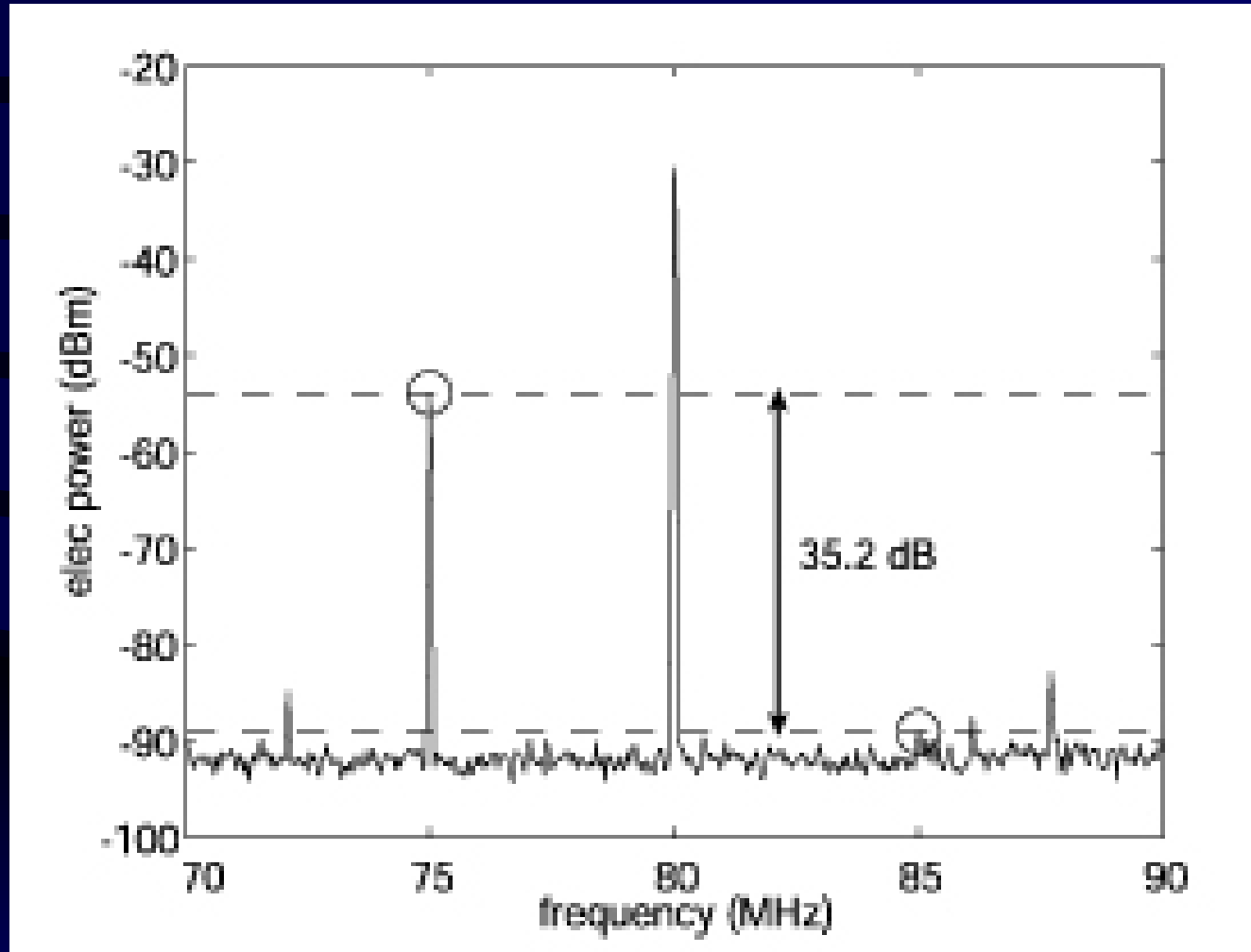
Variability: PM locality



- PM area important for offset locking
- Main PM (squares) scaled down by factor of 10 to fit



Purity: single-sideband state



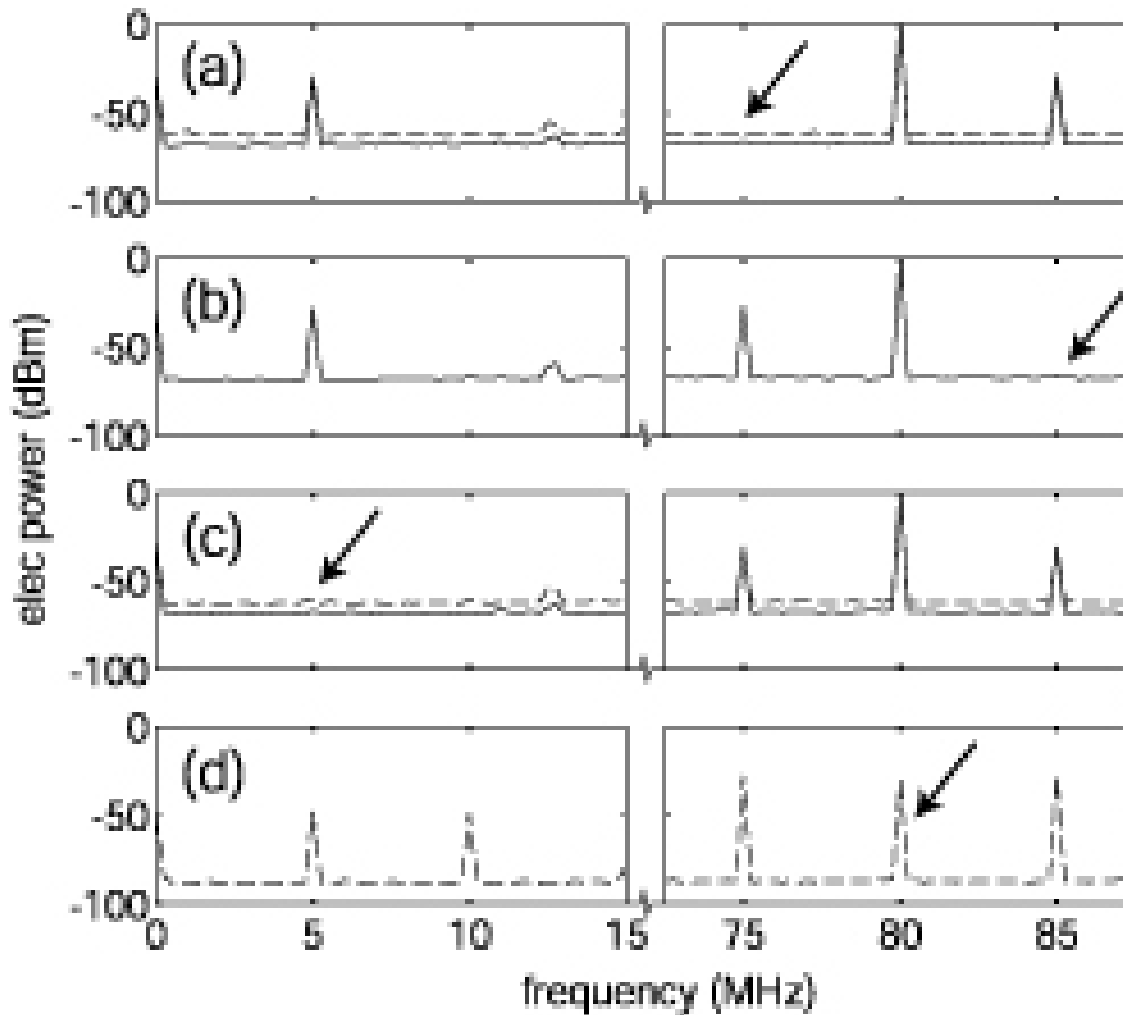
Purity: other operating points

SSB
(upper)

SSB
(lower)

Pure
PM

Suppressed
Carrier
($\sigma = 180$)



34.9
dBm

39.5
dBm

~38
dBm

~30
dBm

A few difficulties ...

- UTM birefringence limits purity
 - spatial modes produced at tap off: $\sim 1\%$ power
- Optical path length drift due to crystal temp
 - dual crystal design helps; long τ locking loop?
- Electrical impedances not well matched
- Nor modulation impedances (xtal spatial fx)
 - needs careful alignment and electrical filters where very high performance required

Summary

- Universally Tunable Modulator tested
- Heterodyne / double demodulation scheme
- Prototype *variability & purity* demonstrated
- Phasor description and geometric phase description (modulation sphere) developed
- Potential for GW detector control scheme
 - tune frequency response with rf locking