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DSP Predistortion for a High-Efficiency Outphasing Transmitter

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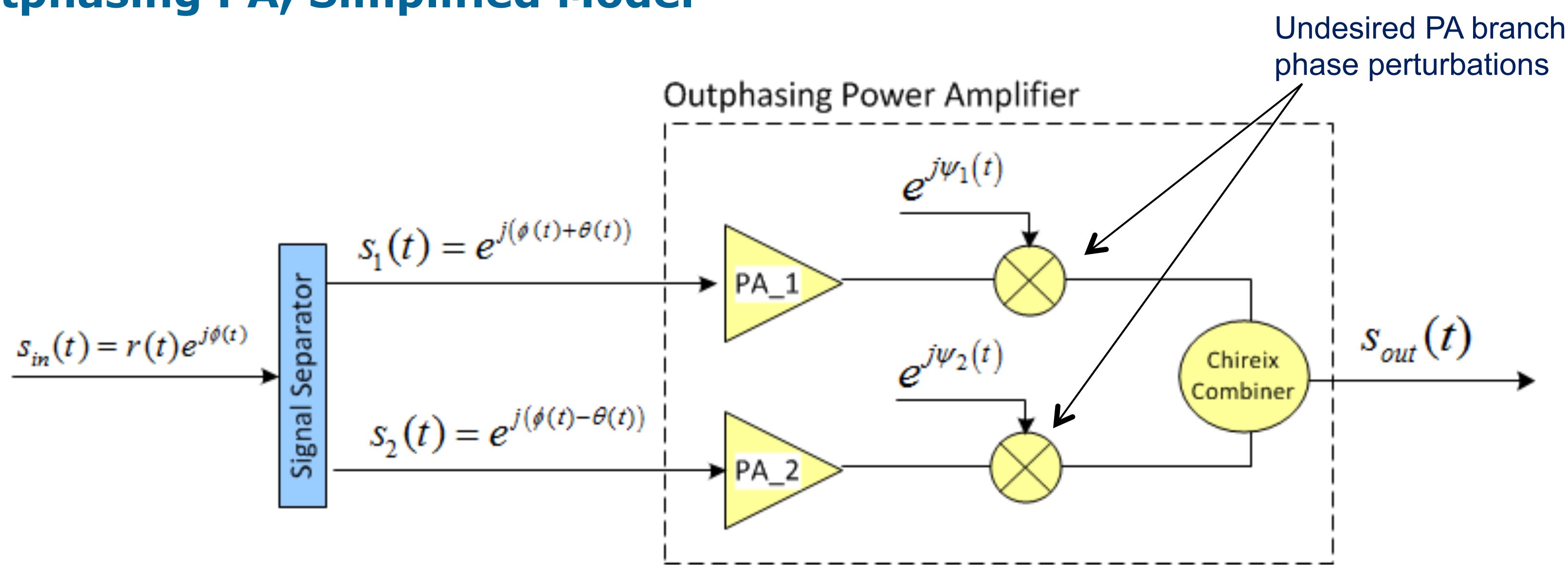
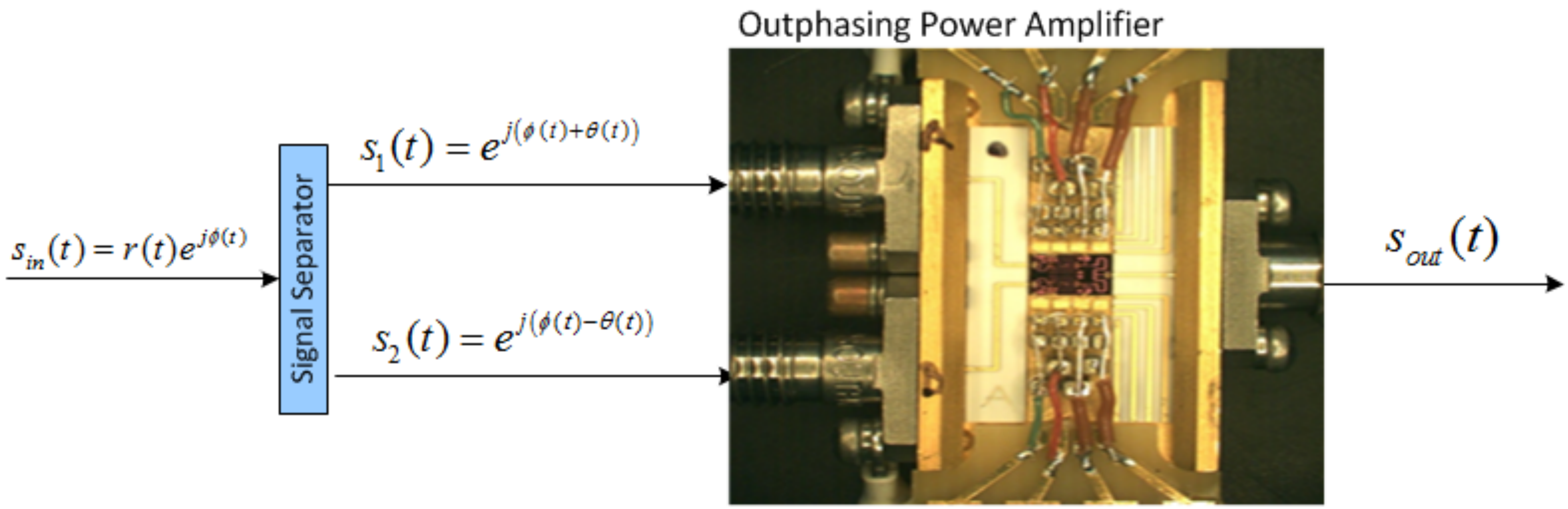
Fundamental Outphasing Operation

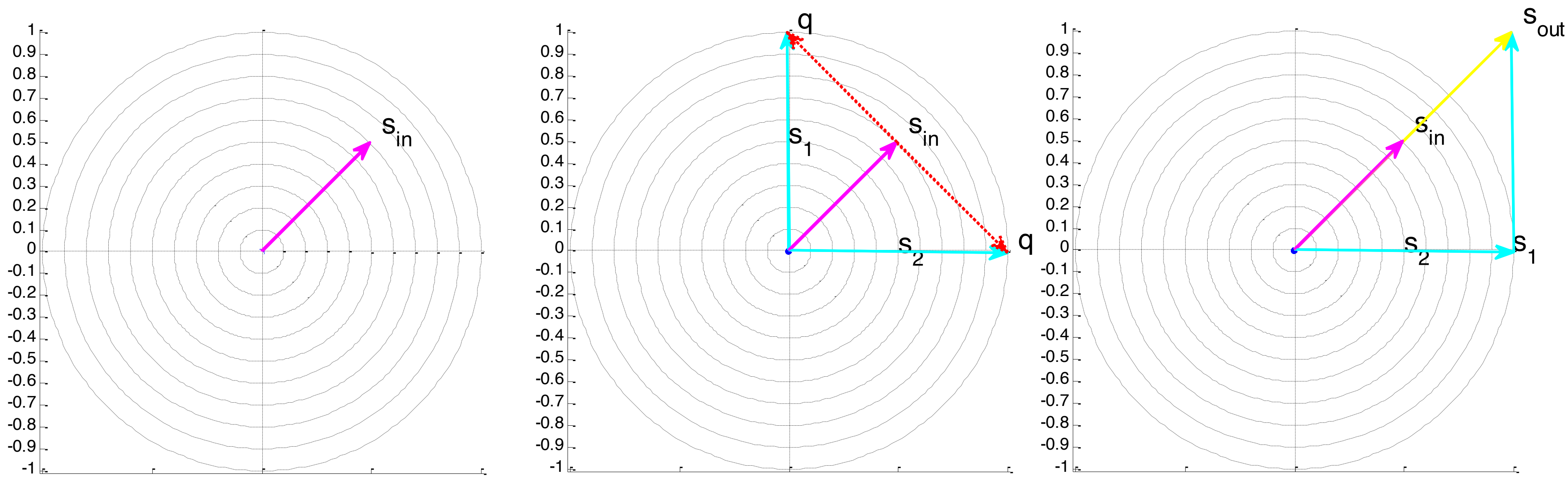
Outphasing PA, Simplified Model





Fundamental Outphasing Operation

$|S_{in}|$=0.7 (assume PA branch phase perturbations = 0):



Input vector, instantanous value

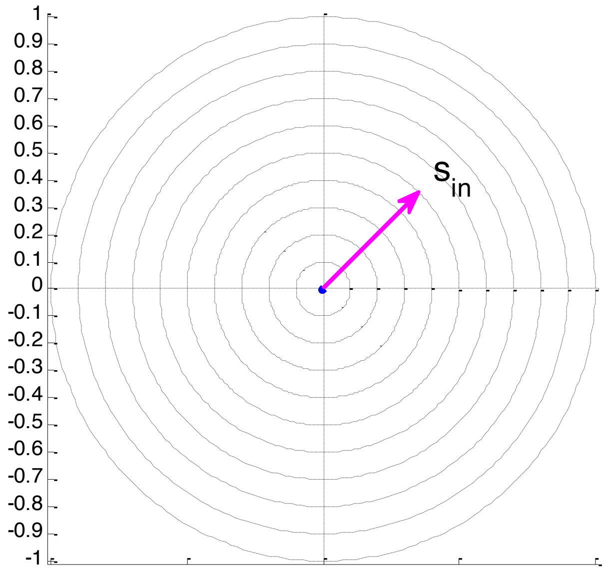
Outphasing vectors s_1, s_2 result from adding and subtracting perpendicular:

$$q = s_{in}\left(\sqrt{\left(\frac{1}{|s_{in}|}\right)^2 - 1}\right)e^{j\left(\frac{\pi}{2}\right)}$$

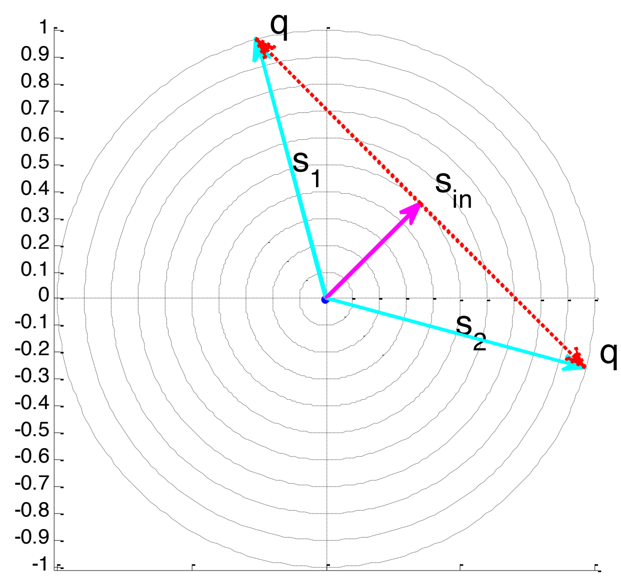
$$s_{out} = s_1 + s_2$$
$$= s_{in} + q + s_{in} - q$$
$$= 2s_{in}$$

Fundamental Outphasing Operation

$|S_{in}|=0.5$ (assume PA branch phase perturbations = 0):

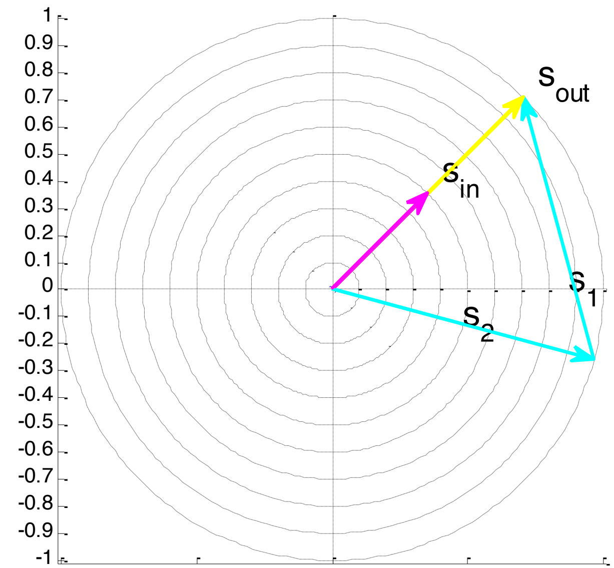


Input vector, instantanous value



Outphasing vectors s_1, s_2 result from adding and subtracting perpendicular:

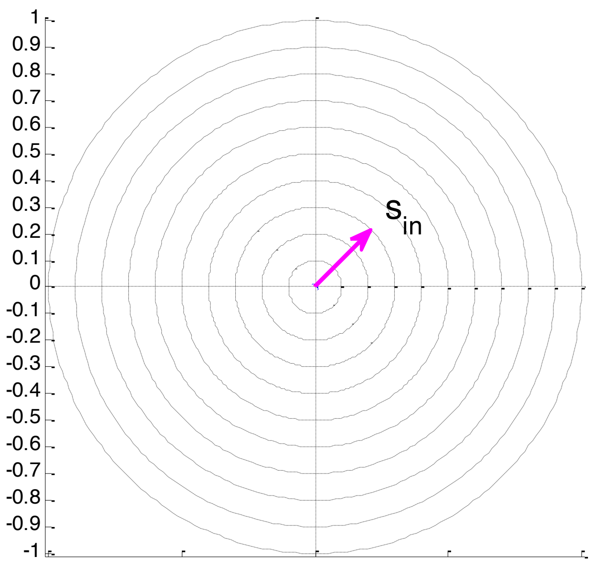
$$q = s_{in}\left(\sqrt{\left(\frac{1}{|s_{in}|}\right)^2 - 1}\right)e^{j\left(\frac{\pi}{2}\right)}$$

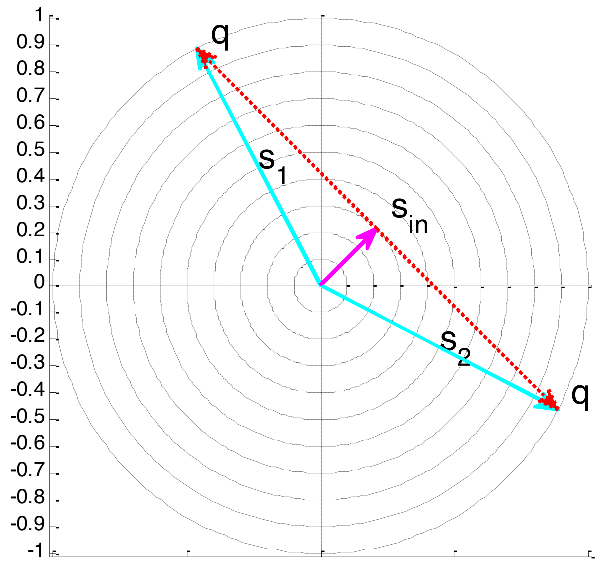


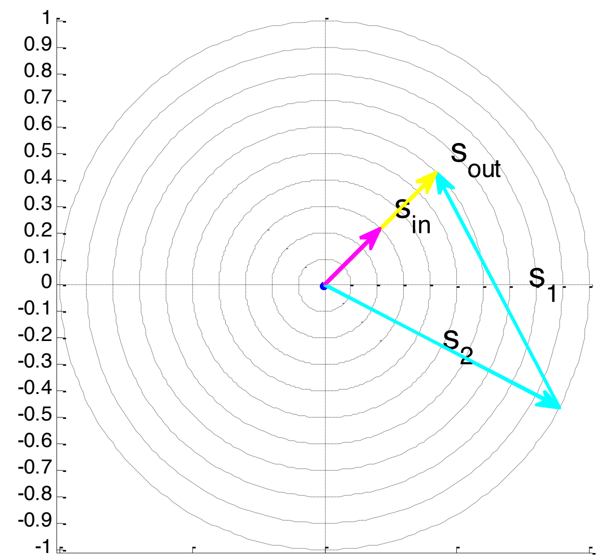
$$s_{out} = s_1 + s_2$$
$$= s_{in} + q + s_{in} - q$$
$$= 2s_{in}$$

Fundamental Outphasing Operation

$|S_{in}|=0.3$ (assume PA branch phase perturbations = 0):







Input vector, instantanous value

Outphasing vectors s_1, s_2 result from adding and subtracting perpendicular:

$$q = s_{in}\left(\sqrt{\left(\frac{1}{|s_{in}|}\right)^2 - 1}\right)e^{j\left(\frac{\pi}{2}\right)}$$

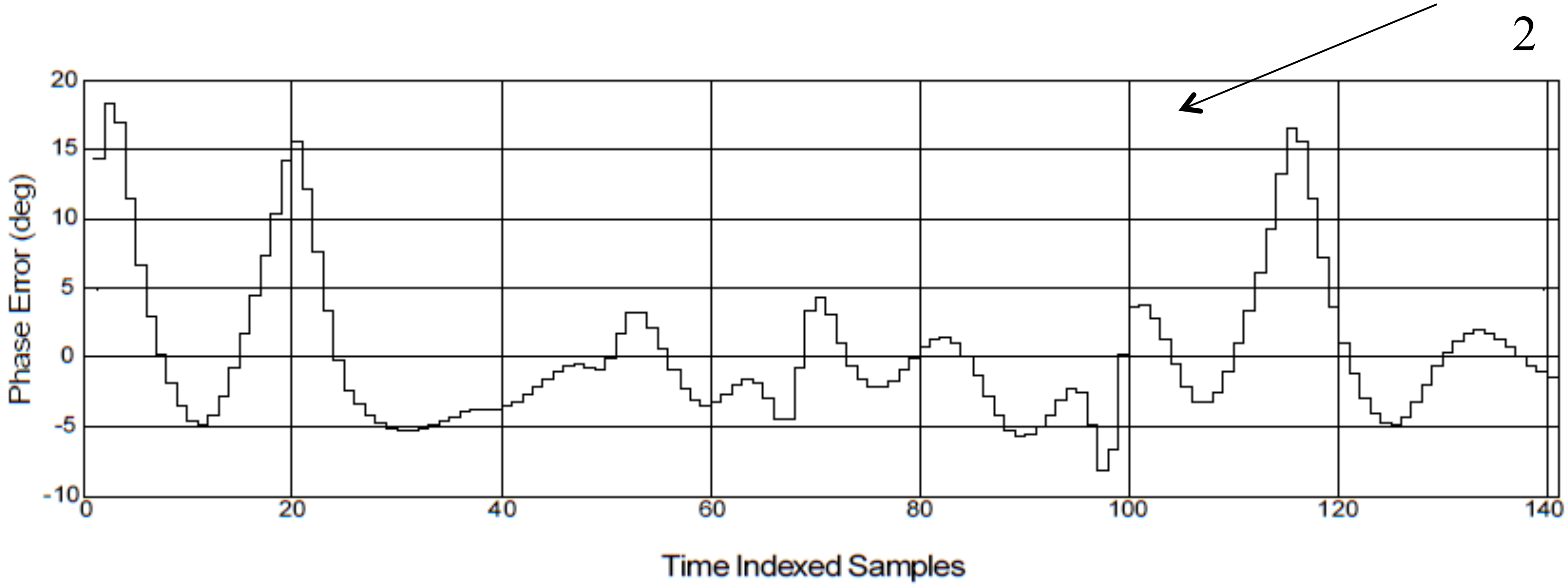
$$s_{out} = s_1 + s_2$$
$$= s_{in} + q + s_{in} - q$$
$$= 2s_{in}$$

Fundamental Outphasing Operation

What do we know about these random PA branch phase perturbations?

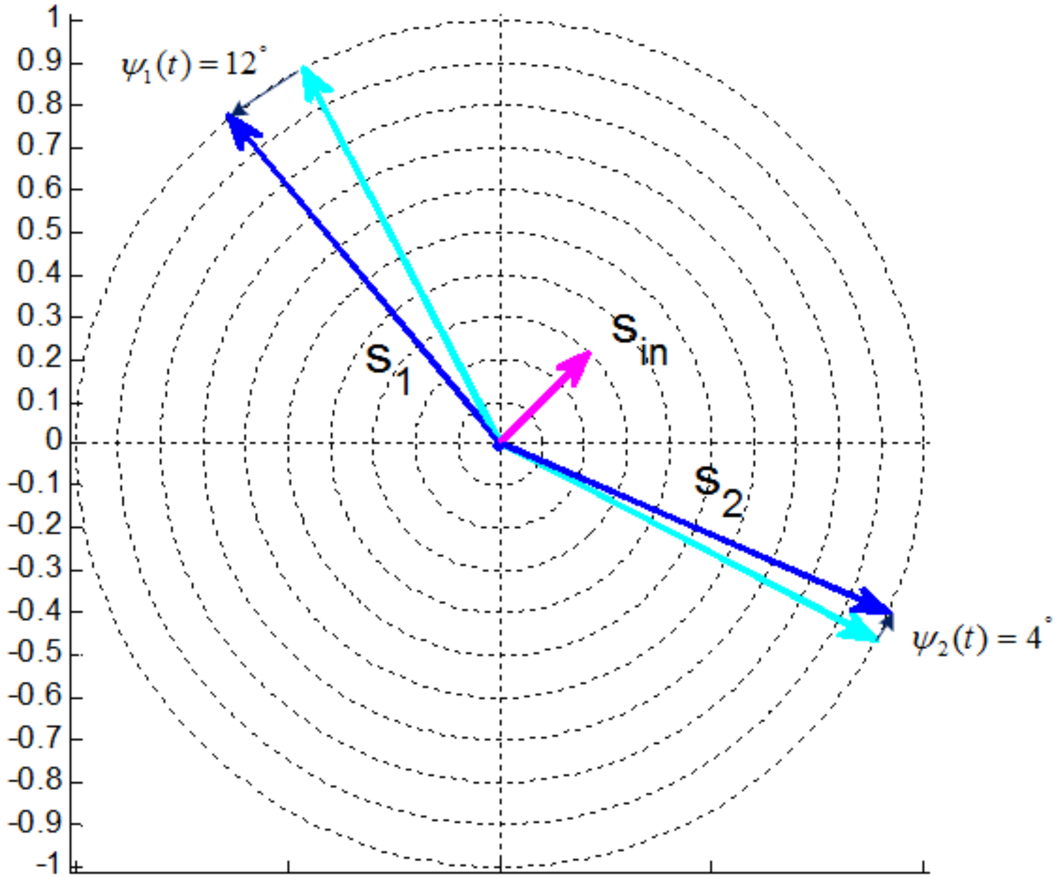
Chireix combiner impedance varies with outphasing angle. Branch PA are not ideal voltage sources and are not strictly identical. These two effects result in PA branch phase perturbations $\psi_1(t)$ and $\psi_2(t)$

Phase perturbations vary dynamically with signal envelope as well as instantaneous frequency. In general they are not equal. They are difficult to measure, however the overall PA phase shift can be measured and is $\frac{\psi_1(t)+\psi_2(t)}{2}$



Fundamental Outphasing Operation

Another look at random instantaneous PA branch phase perturbations

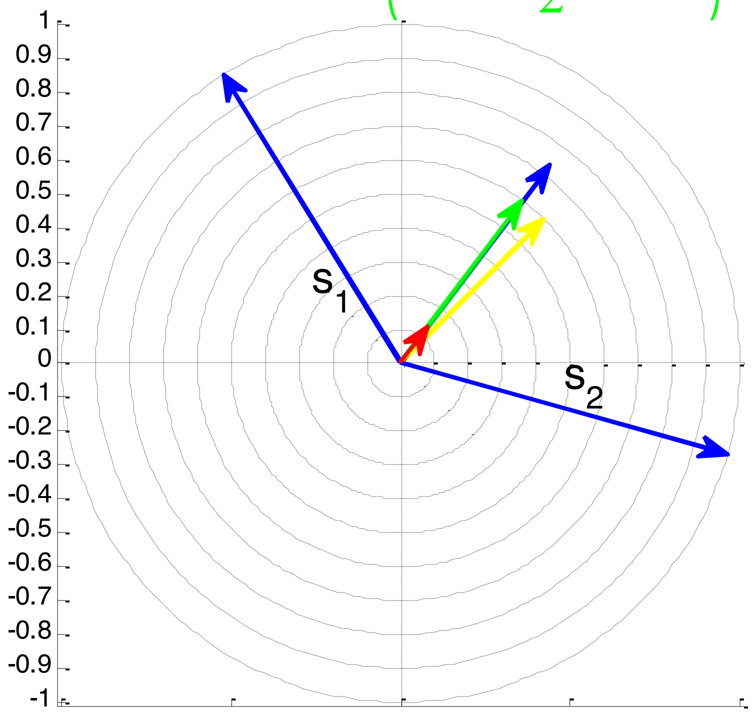


How do these change the outphasing PA output?

Fundamental Outphasing Operation

PA branch phase perturbation effect: Yellow is ideal output, Blue is perturbed output

$$s_{out}^{pert}(t) = 2s_{in}(t)\cos\left(\frac{\psi_1(t)-\psi_2(t)}{2}\right)e^{j\left(\frac{\psi_1(t)+\psi_2(t)}{2}\right)} + 2jq(t)\sin\left(\frac{\psi_1(t)-\psi_2(t)}{2}\right)e^{j\left(\frac{\psi_1(t)+\psi_2(t)}{2}\right)}$$



First term is the desired output $2s_{in}(t)$

attenuated by: $\cos\left(\frac{\psi_1(t)-\psi_2(t)}{2}\right)$

Second term is 'q' rotated 90 degrees and

scaled by: $2\sin\left(\frac{\psi_1(t)-\psi_2(t)}{2}\right)$

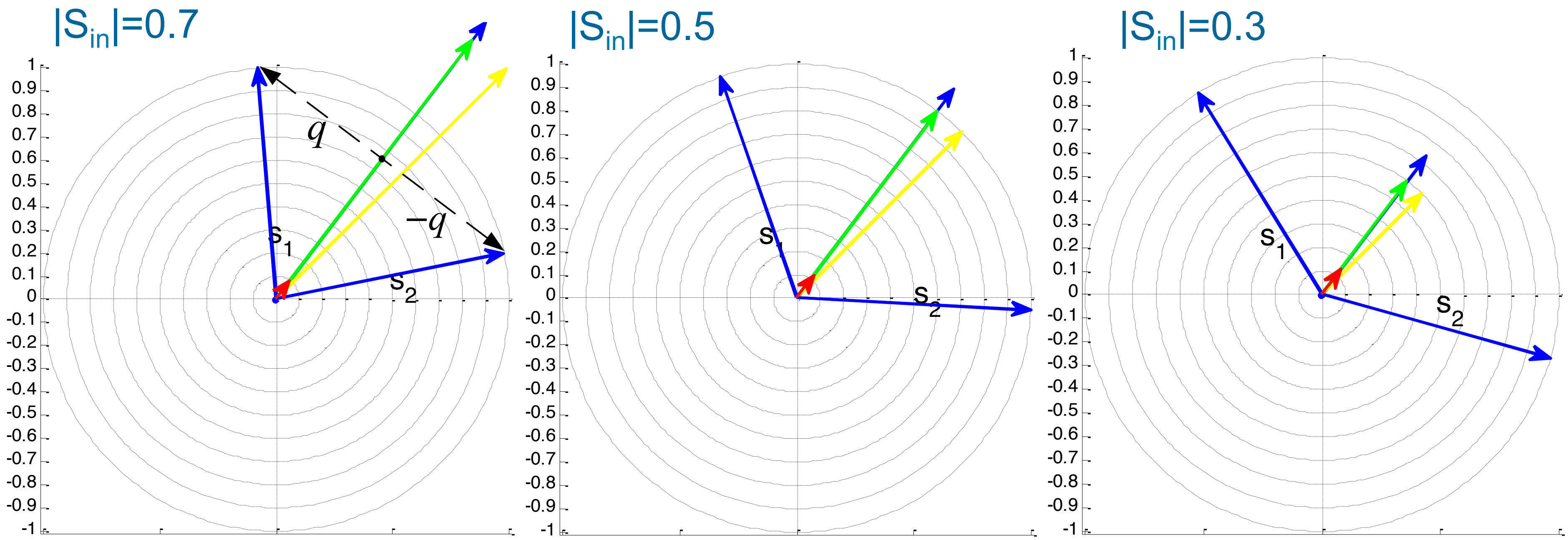
Note that these phase perturbations are a small scale dynamic problem - *not* the same as a static PA phase response mismatch.

Both terms are phase shifted by:

$$e^{j\left(\frac{\psi_1(t)+\psi_2(t)}{2}\right)}$$

ACI Due to Branch Phase Perturbations

For this example, $\psi_1(t) = 12^\circ, \psi_2(t) = 4^\circ$



Key observation: As the output signal (blue) gets smaller the 'q' vector gets larger and, if $\psi_1(t) \neq \psi_2(t)$ then the undesired output (red) gets larger:

$$2jq(t)\sin\left(\frac{\psi_1(t)-\psi_2(t)}{2}\right)$$

Thus for $\psi_1(t) \neq \psi_2(t)$ attempts to null the PA output give rise to this irreducible component of the output. This implies an output dynamic range limitation.

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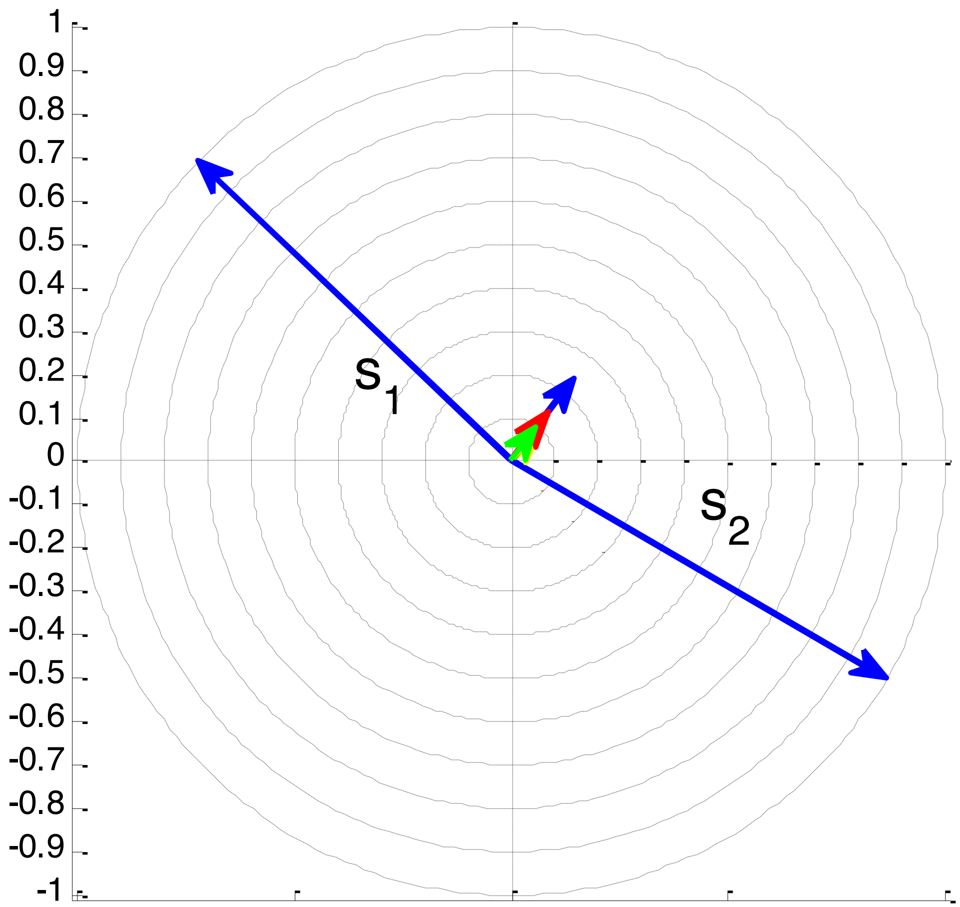
ACI Due to Branch Phase Perturbations

Outphasing PA ACI is due to random phase perturbations.



In the ACI spectral region (outside of +/- symbol rate) we typically need to null the output power.

Difference in random phase perturbations gives rise to the red vector and interferes with nulling

ACI Due to Branch Phase Perturbations

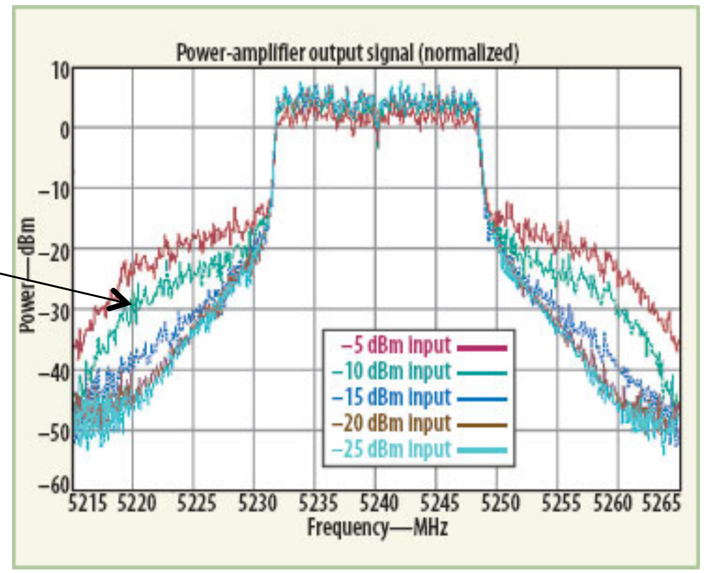
The up-side-down ACI difference between outphasing vs. single branch PA:

Outphasing and single branch PAs both have what looks like spectral regrowth into the adjacent channel region but they are *radically different!*

At high signal levels, the outphasing PA generates far less ACI than single branch. However, at *low* signal levels, outphasing PA ACI *goes up* due to the phase perturbations while single branch ACI *goes down* as it becomes more linear.

Single branch, Class A, B

Single branch *high* level ACI
due to gain compression
Outphasing does this at *low* levels
due to dynamic phase perturbations



ACI due to compression: *generates* odd-order intermodulation distortion

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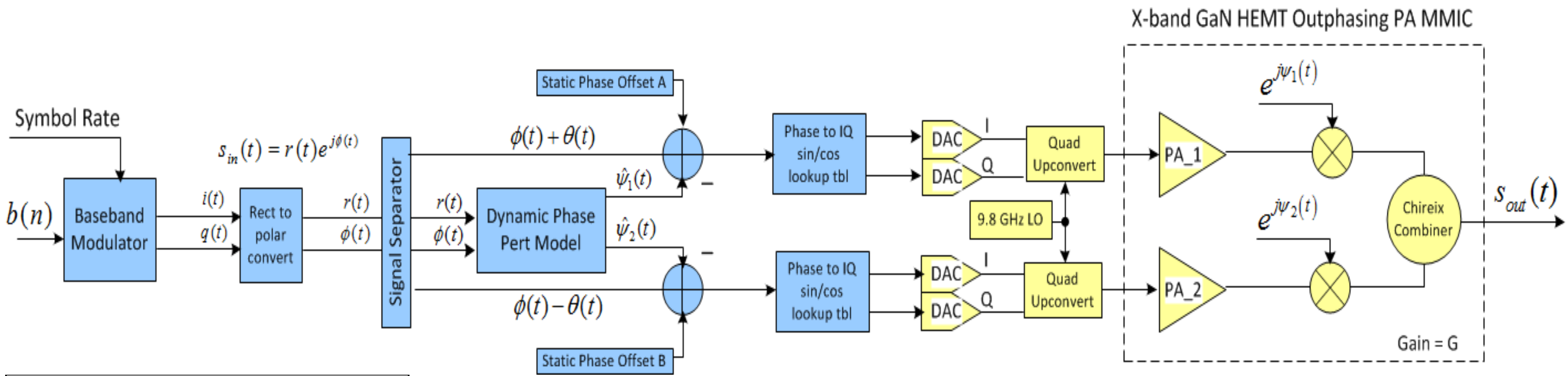
Lowering ACI by Counteracting Phase Perturbations

Challenge: Make outphasing null better for low signal levels

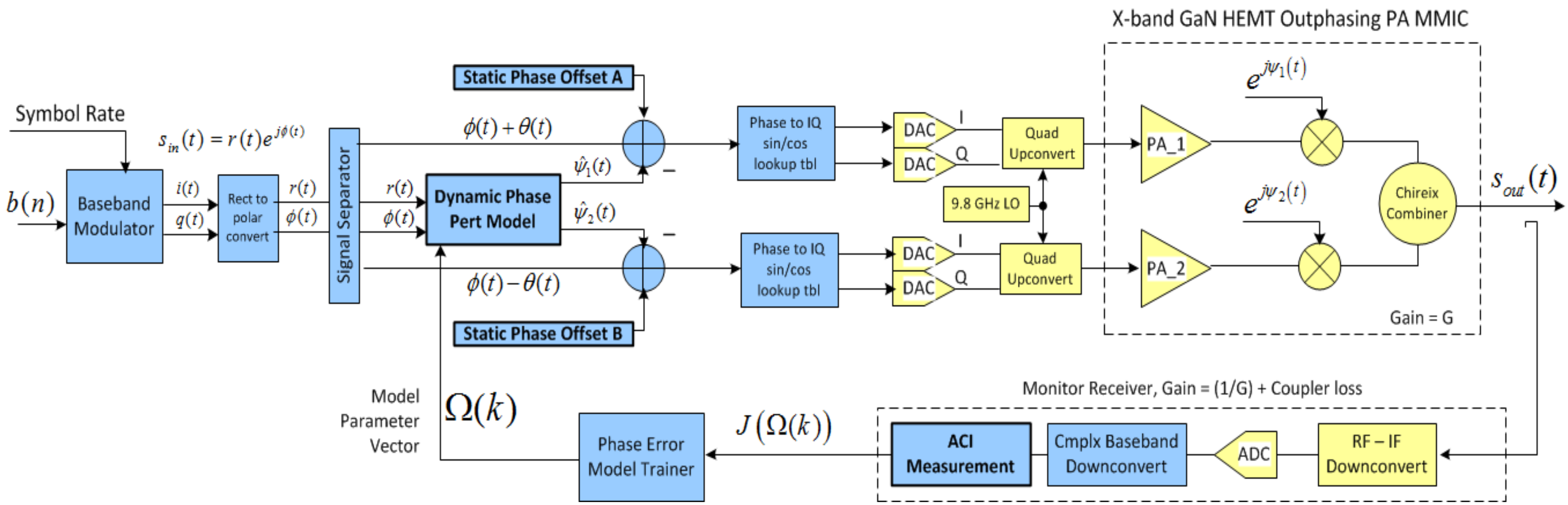


Blue = DSP
Yellow = Analog hardware

Solution: A dynamic phase perturbation parameterized model that predicts and counteracts branch phase perturbations in real time.

Lowering ACI by Counteracting Phase Perturbations

How to determine dynamic phase perturbation model parameters?

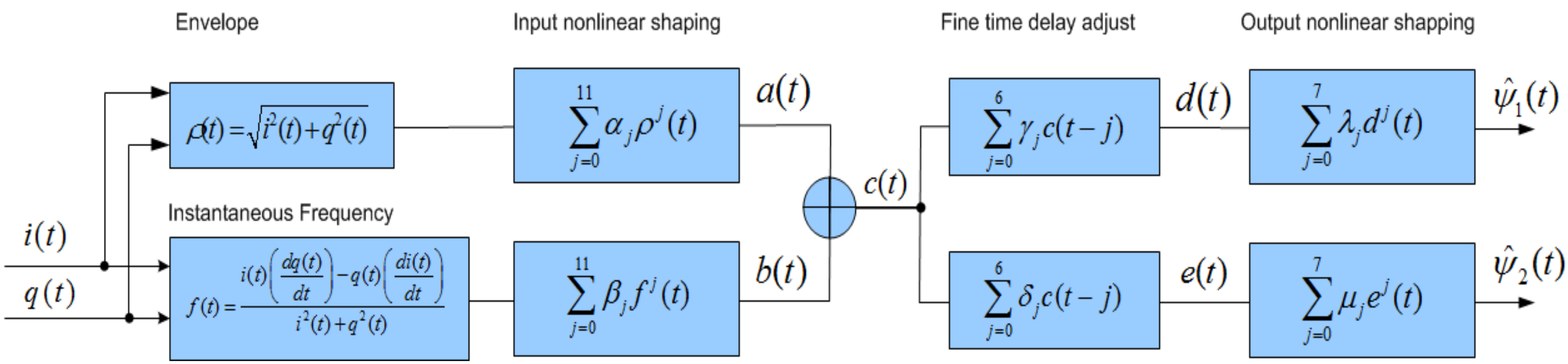


Blue = DSP
Yellow = Analog hardware

Solution: A monitor feedback receiver that uses ACI measurements to guide model adaptation

Lowering ACI by Counteracting Phase Perturbations

Dynamic Phase Perturbation Model

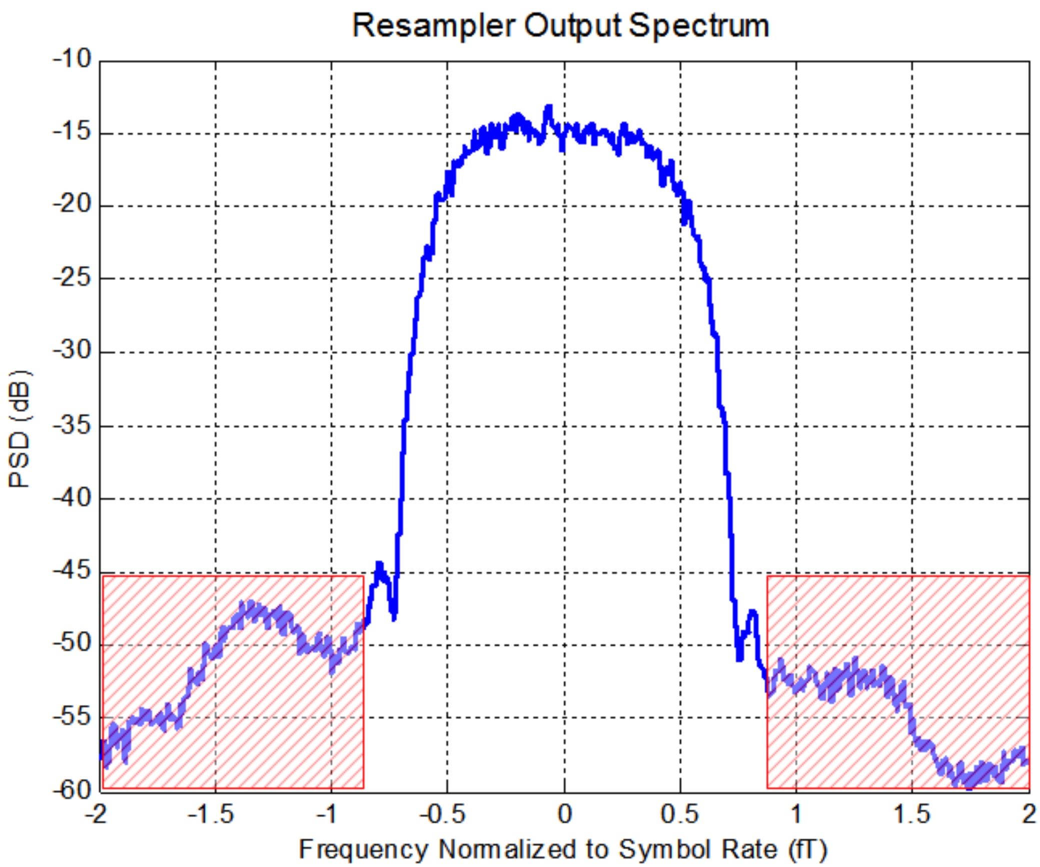


Blue = DSP
Yellow = Analog hardware

<u>Solution</u>: A monitor feedback receiver that uses ACI measurements to guide model adaptation

ACI Measurement

Adjacent Channel Interference Ratio Estimator



Receiver DSP internally generates a spectrum measurement that is very similar to a spectrum analyzer connected to the PA output

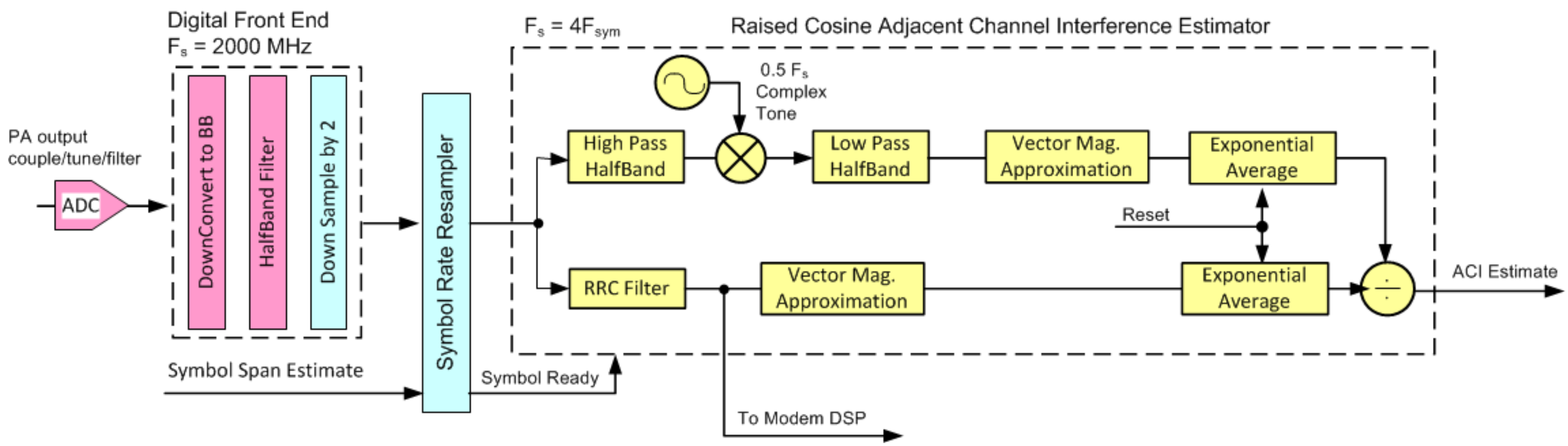
We need lower adjacent channel power to increase PA output dynamic range and meet regulatory requirements.

To lower adjacent channel power we must measure it accurately.

The challenge is to measure close in adjacent channel power without interference from side lobes that are part of the signal.

ACI Measurement

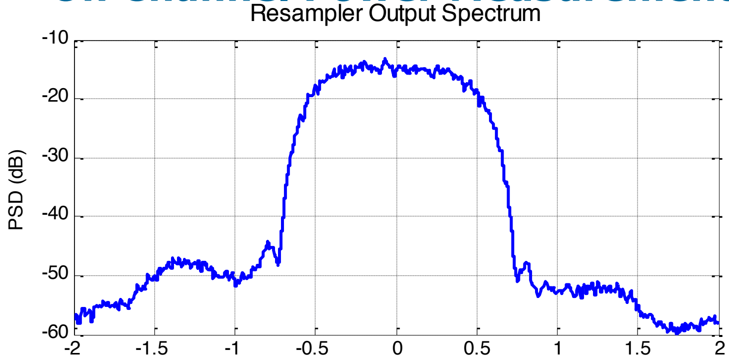
Adjacent Channel Interference Ratio Estimator Receiver DSP

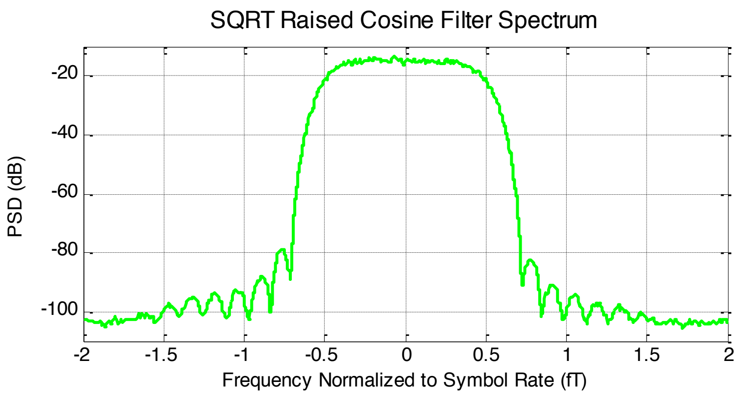


Estimator is run for about 0.2msec after every transmit PD model parameter adjustment.

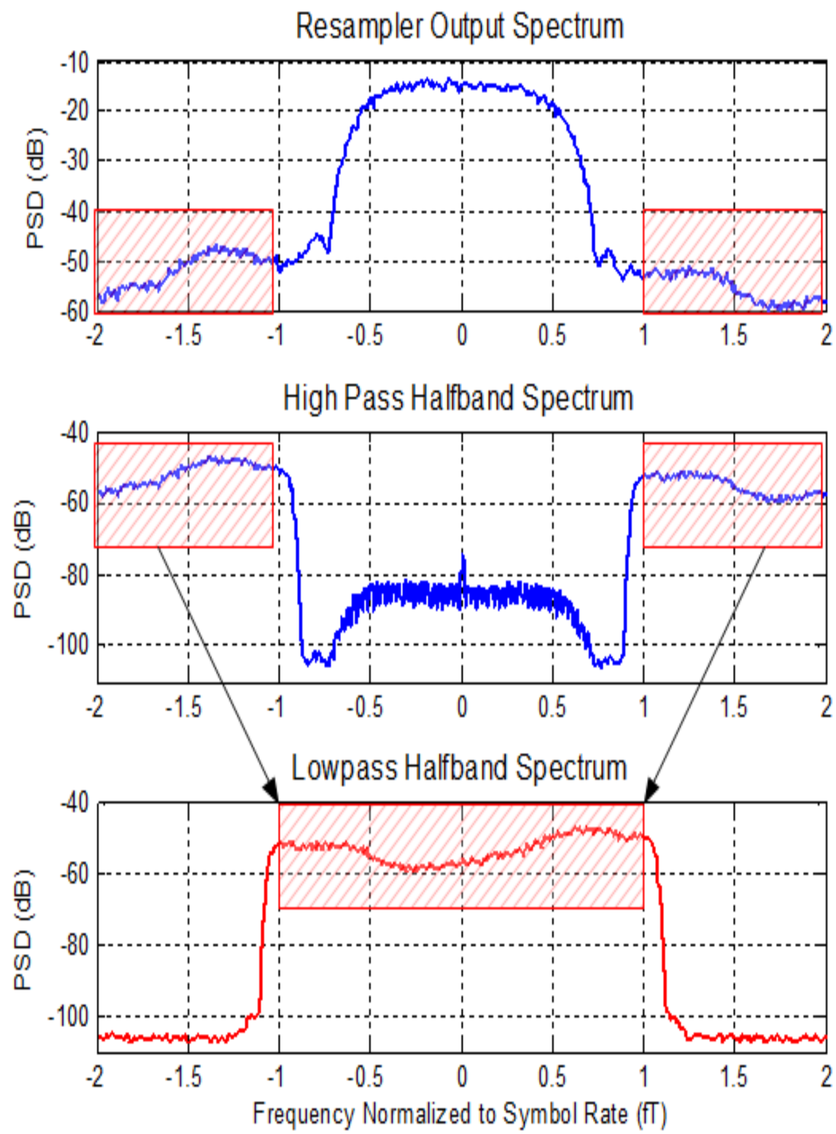
ACI Measurement

On Channel Power Measurement





Adjacent Channel Power Measurement

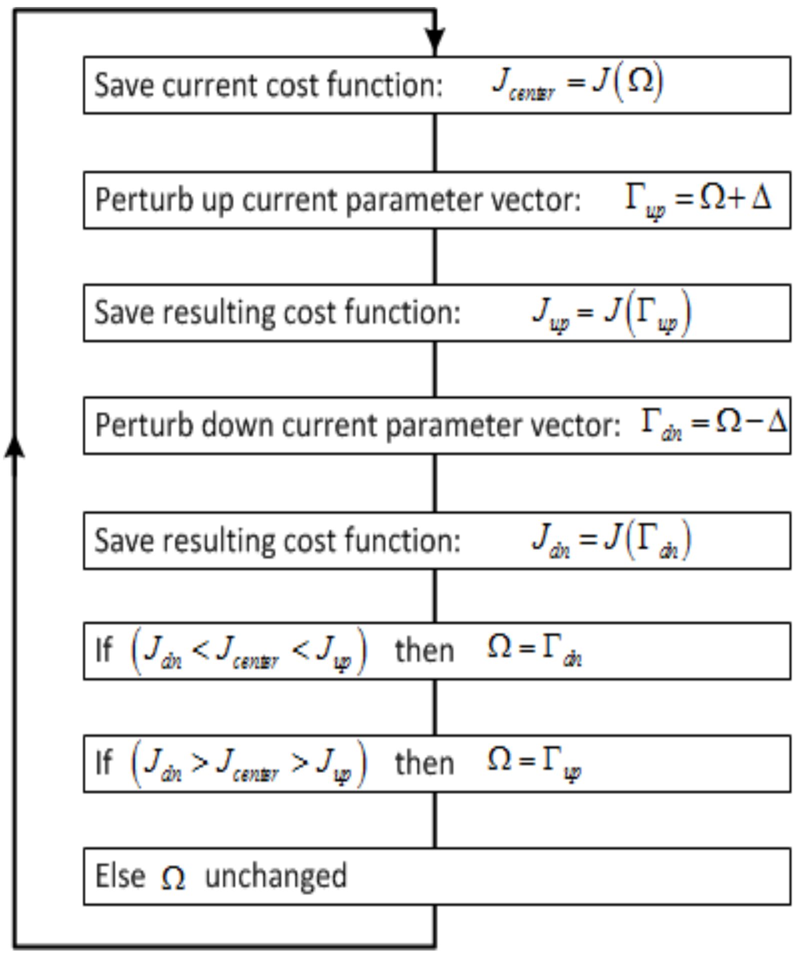


ACI ratio is green divided by red

Note: Sample rate is independent of input symbol rate. This allows consistent ACI ratio measurements and also facilitates follow on modem processing

Lowering ACI by Counteracting Phase Perturbations

Simplified view of zero order search algorithm for driving ACI as low as possible



Phase perturbation model parameter vector: $\Omega(k)$
k = adjustment cycle

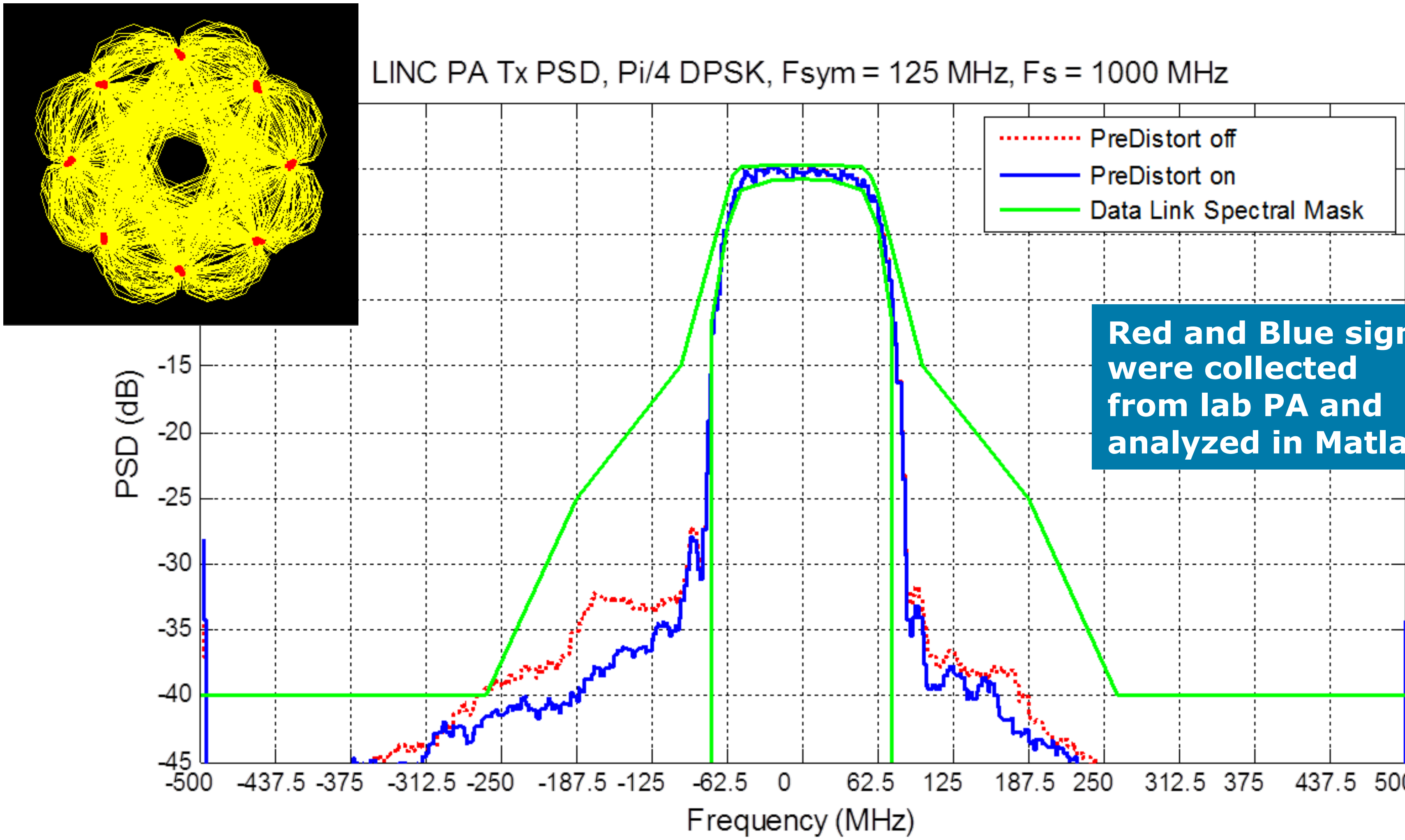
Total integrated adjacent channel power:

$$J\left(\Omega(k)\right)$$

the “cost function”

Lowering ACI by Counteracting Phase Perturbations

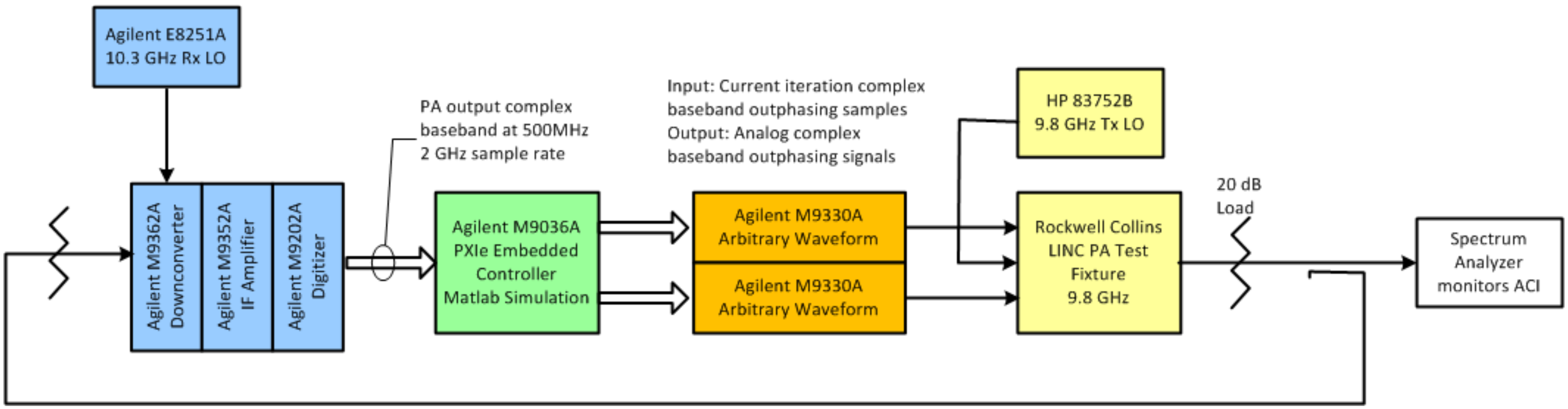
Outphasing PA Output Spectrum Showing Adjacent Channel Power Reduction



Red and Blue signals were collected from lab PA and analyzed in Matlab.

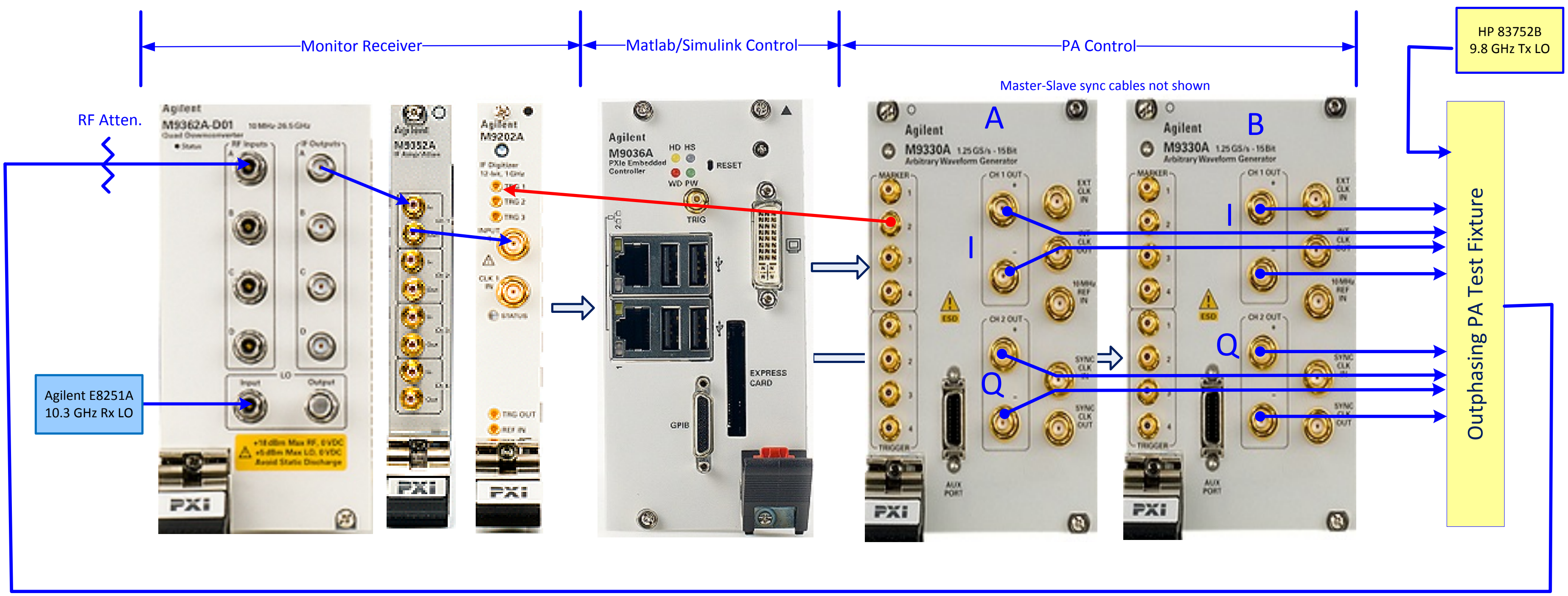
Lowering ACI by Counteracting Phase Perturbations

Outphasing auto-adapting ACI reduction experiment
Lab equipment setup



Lowering ACI by Counteracting Phase Perturbations

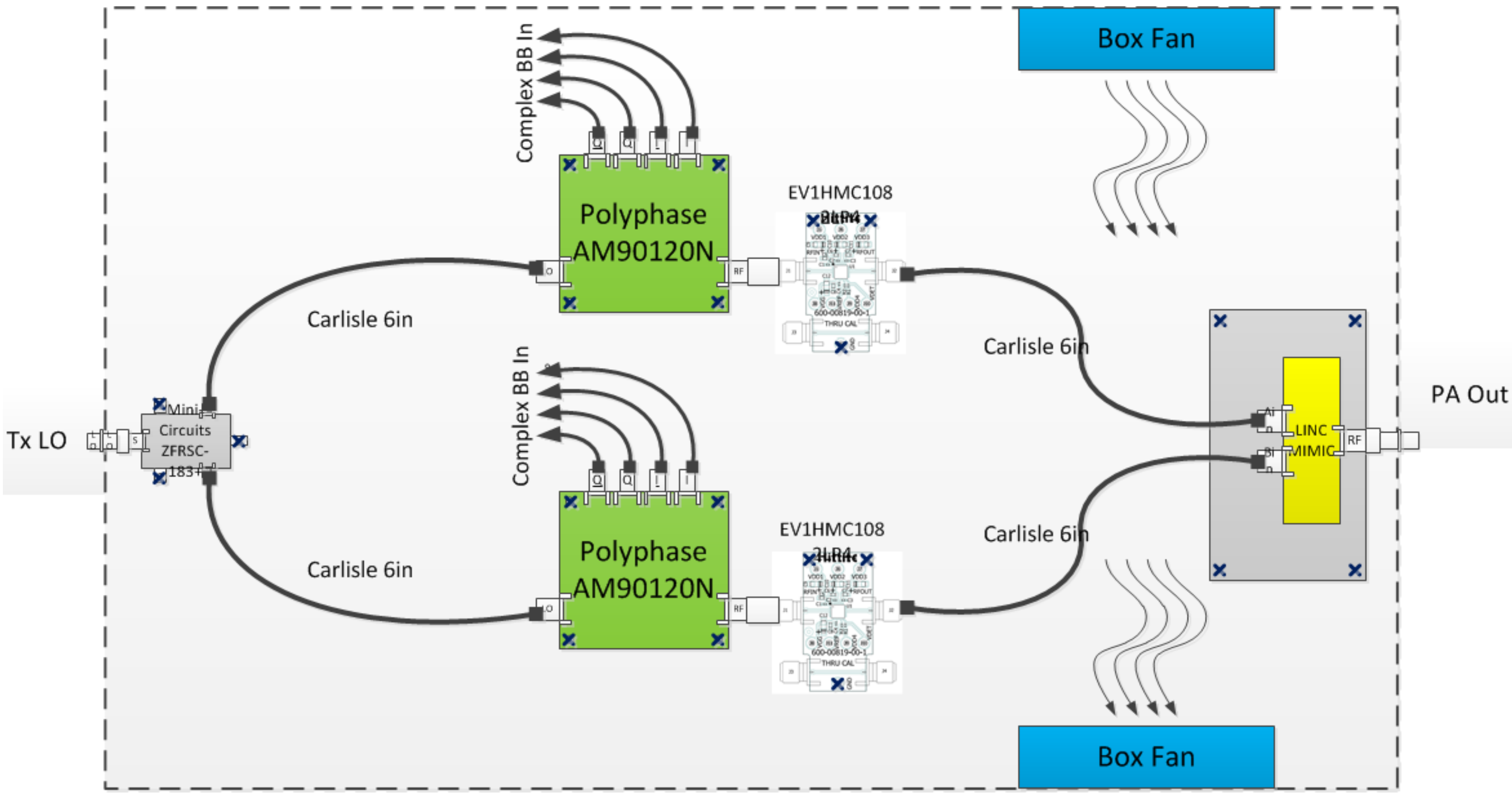
Outphasing auto-adapting ACI reduction experiment
Lab equipment setup, pictorial view



ACI Optimization loop, Feb 28, 2014, J. Reyland

Lowering ACI by Counteracting Phase Perturbations

Outphasing PA Test Fixture:



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Acknowledgements

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