Extensions to the Positive Feedback Pilot System for Second Loop Control of a Feedforward Compensated Amplifier

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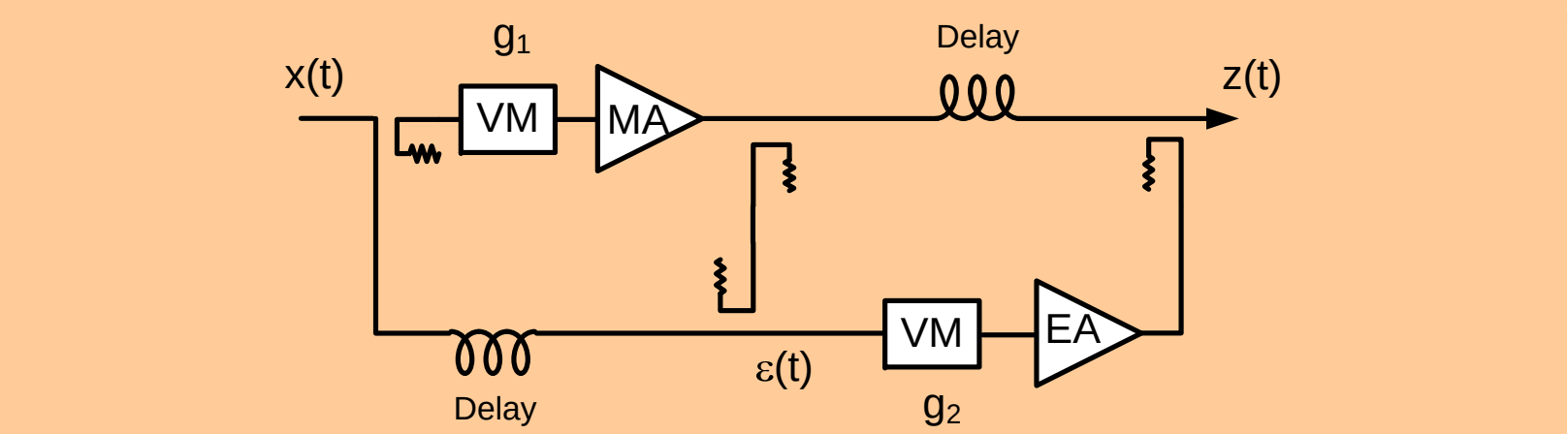
Goal

- Linear amplification of an RF signal.
  - Large instantaneous bandwidths.
- Compensate for amplifier degradations.
  - Distortion, noise.
  - Linear impairments.
- Adaptive.
  - Optimize distortion cancellation.

Outline

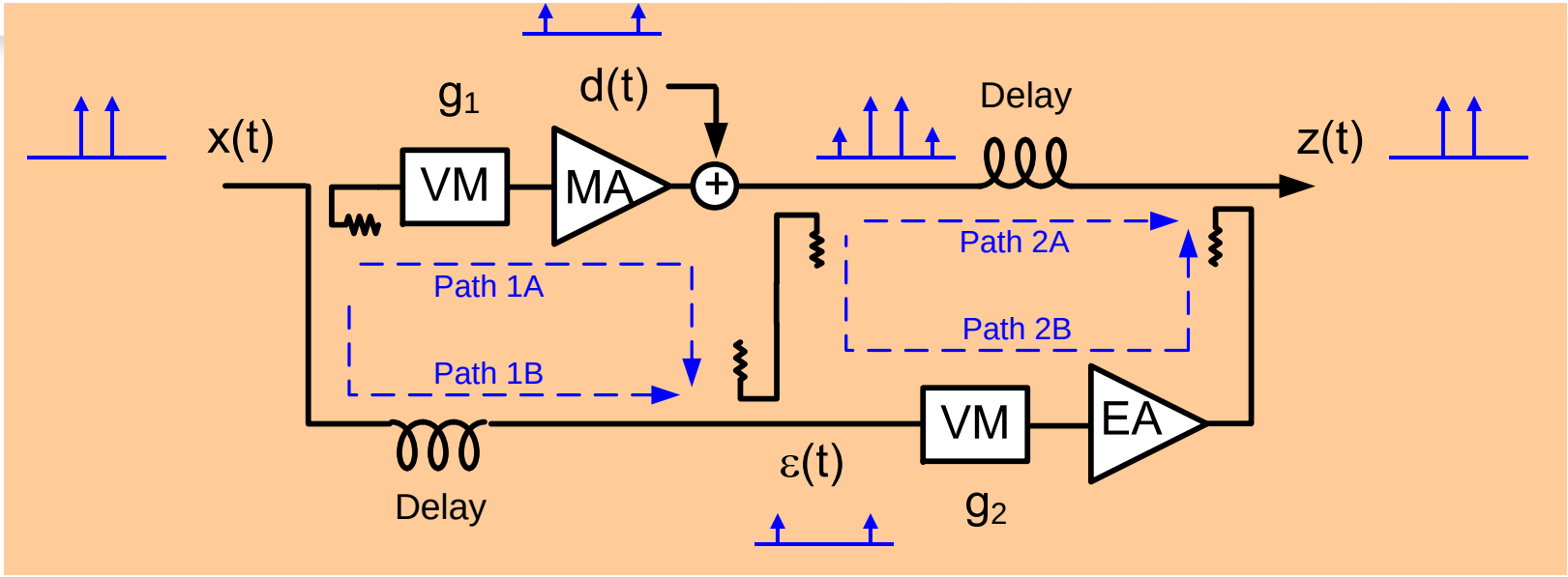
- Background
  - Feedforward structure.
  - Loop alignment.
- Pilot-based alignment of 2nd loop.
  - Standard pilot systems.
  - Original positive feedback pilot system.
  - Extensions.
- Summary

Feedforward Structure



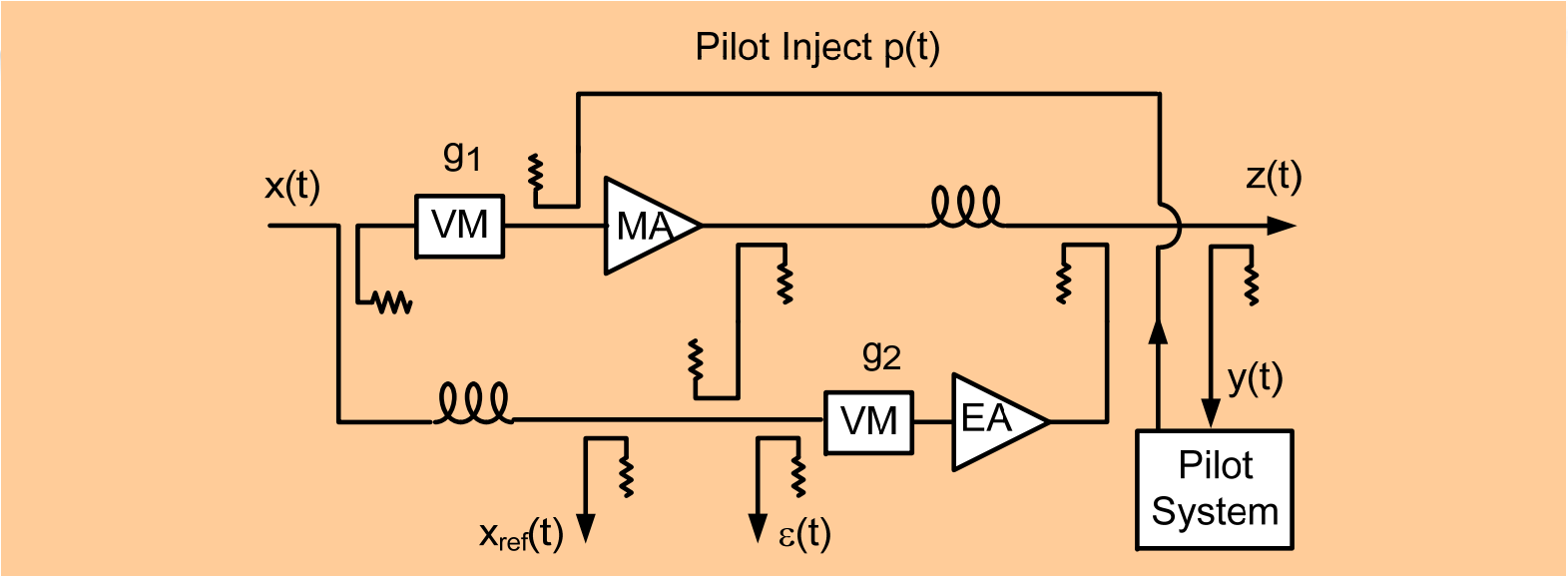
- Two amplifiers
  - Main amplifier (MA) determines the power capability.
  - Error amplifier (EA) determines linearity of system.
- Optimization
  - Adjust gains g_1 and g_2 to minimize the distortion power in the output signal z(t).

Feedforward Linearization



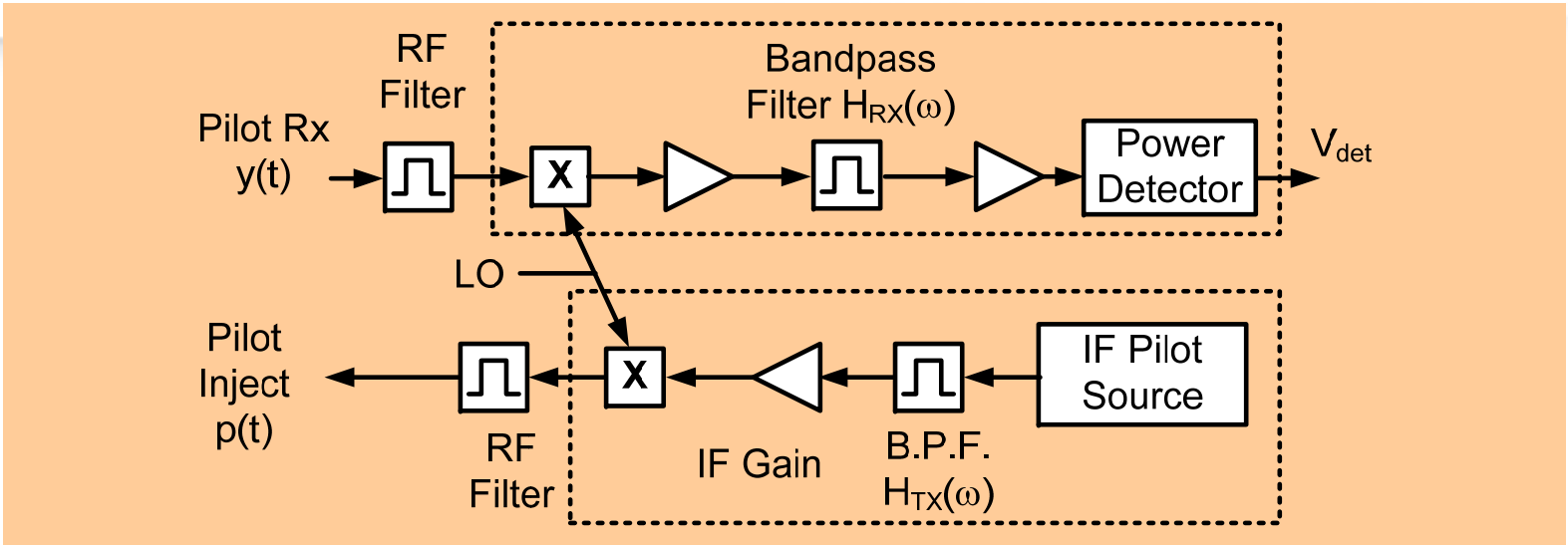
- First cancellation loop (Path 1A-1B).
  - Estimates of distortion d(t) generated within the MA path.
  - Select gain g_1 to cancel linear signal within $\varepsilon(t)$.
- Second cancellation loop (Path 2A-2B).
  - Select gain g_2 to cancel distortion within z(t).

Pilot Assisted Second Loop Control



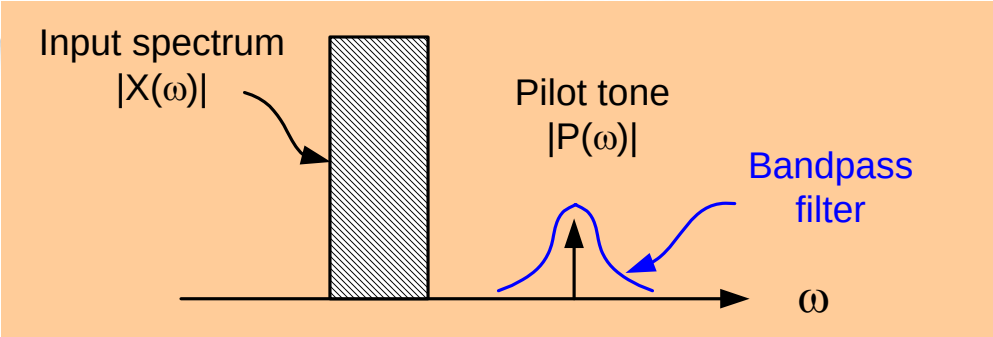
- Inject pilot into MA path.
- Adjust g_2 to minimize residual pilot in z(t).
  - Optimum value is denoted $g_{2,opt}$.
- 2nd loop cancellation transfer function
  - $G_2 = 1 - g_{EA}\, g_2 = (g_{2,opt} - g_2) / g_{2,opt}$
  - Optimal value is $G_2 = 0$.

Standard Pilot System



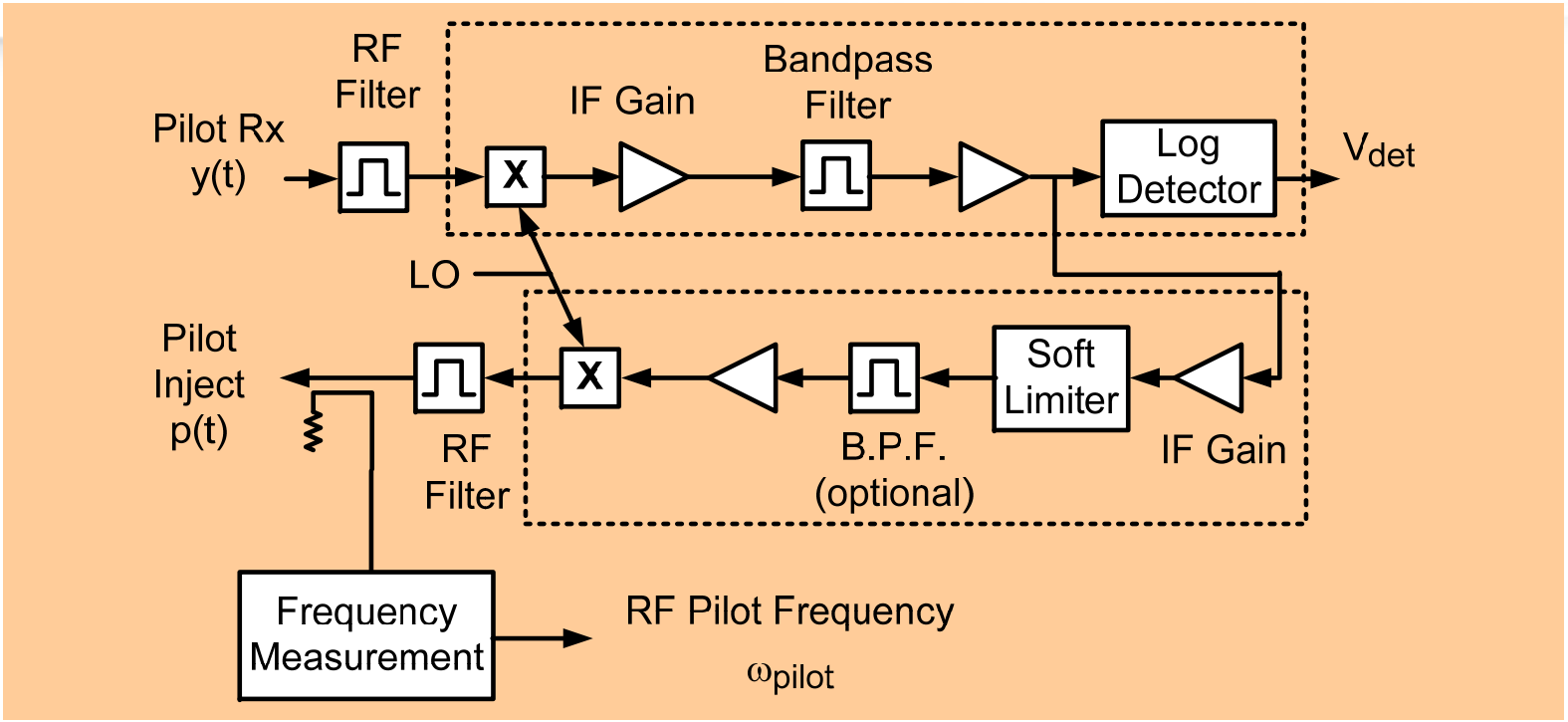
- Pilot generation (bottom section)
  - LO selects pilot frequency to be outside of carrier BW.
- Pilot detection (top section)
  - Band pass filter at IF blocks carrier.
  - Measures residual pilot power, V_{det}.

Pilot



- Pilot is located outside of input signal spectrum.
  - Detected reliably by band pass filtering z(t).
  - Injected pilot is independent of x(t).
    - Able to adapt 2nd loop when there is no input signal x(t).
- Drawbacks
  - Residual pilot is considered a spurious emission.
  - 2nd loop adaptation based on power minimization is slower than a gradient-based search.

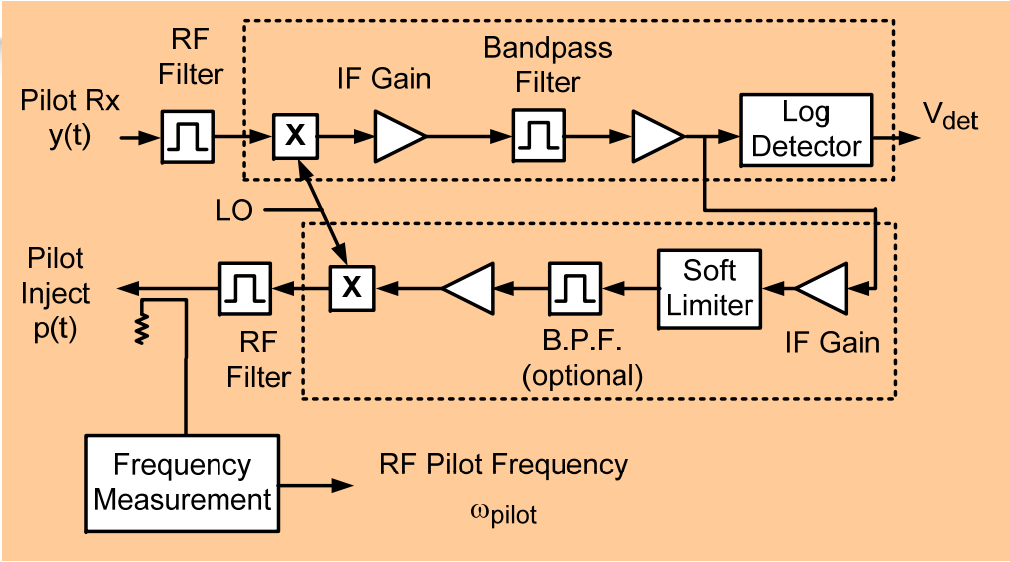
Positive Feedback Pilot System



- Self oscillating pilot signal.
  - Generated from noise within a nonlinear feedback loop.
  - Oscillation occurs if loop gain is large enough that the soft limiter is clipping the fed back signal.

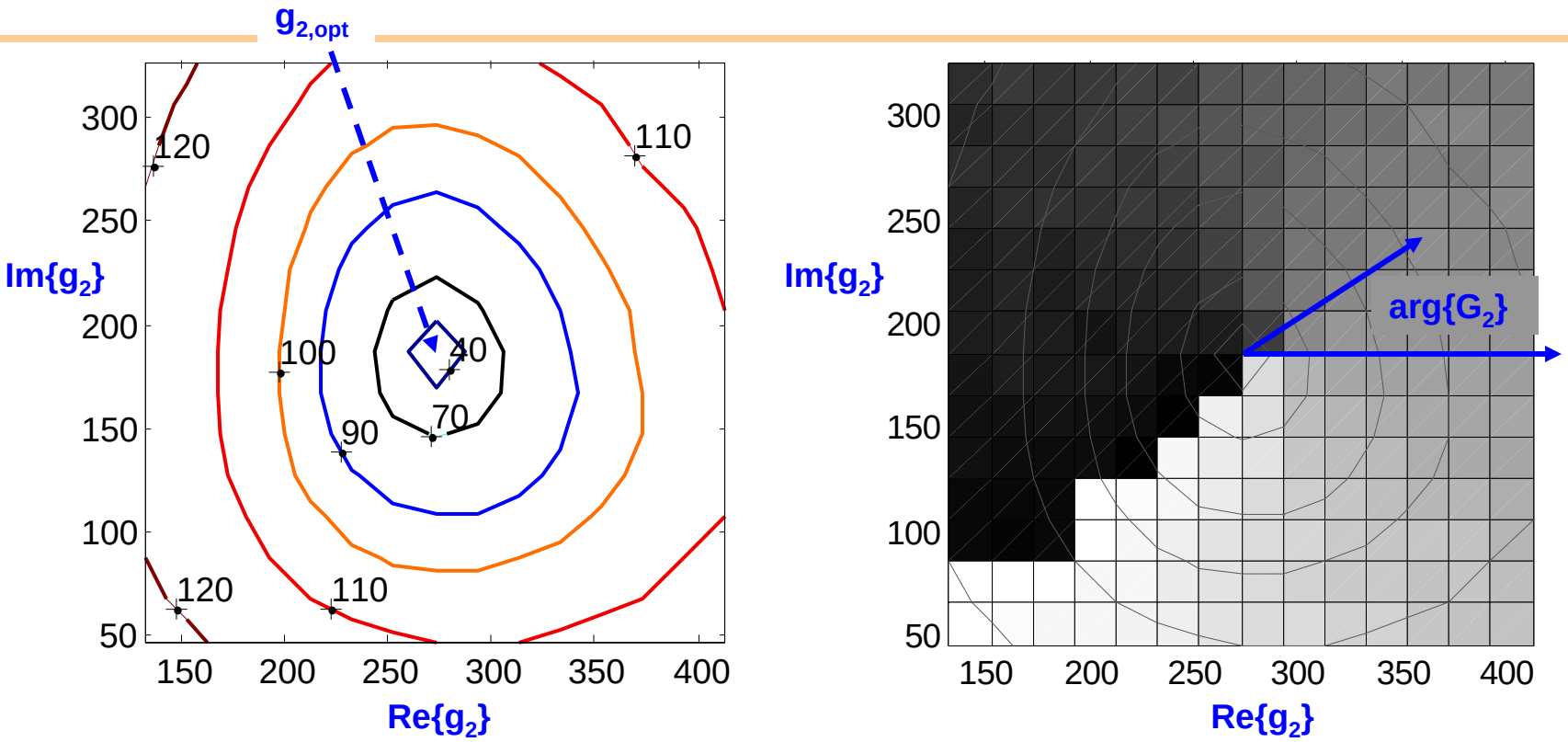
Positive Feedback Pilot System

- Key equations
  - $V_{det} = k_a \log(|G_2|) + k_b$.
  - $\omega_{pilot} = \omega_o + \arg(G_2) / T_{loop}$.
  - T_{loop} is the loop delay.



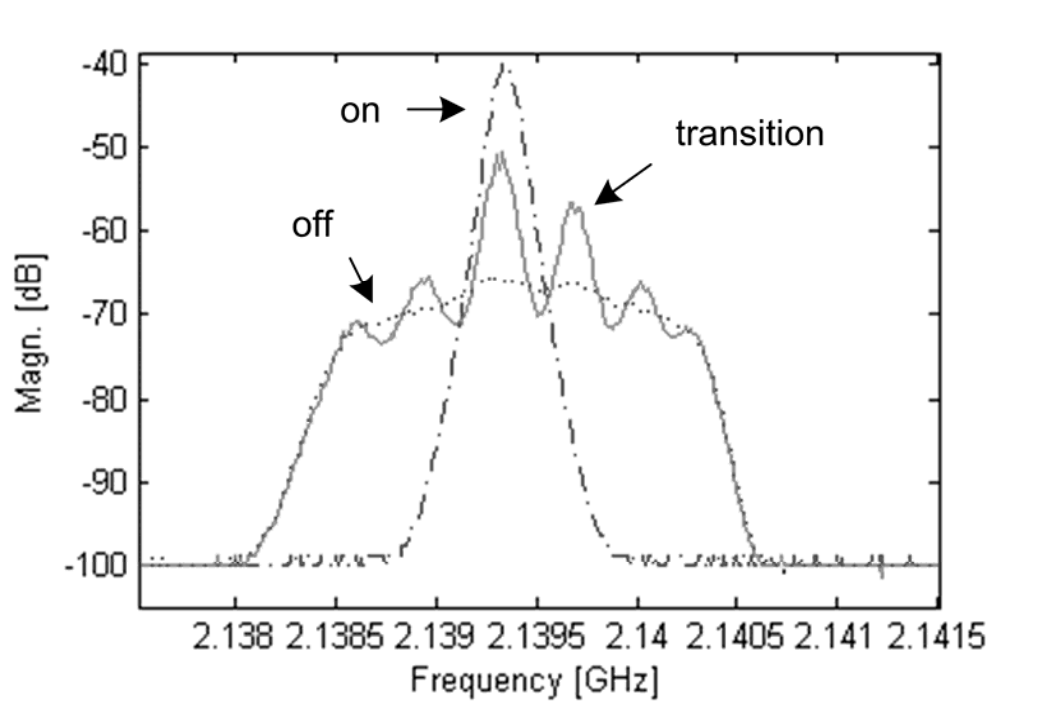
- Advantages
  - Independent measurements of $|G_2|$ and $\arg(G_2)$.
  - Synchronous detection improves convergence.
  - Pilot shuts off automatically when $|G_2|$ is small.
    - Residual pilot no longer discernible (24 dB reduction).
    - See Braithwaite, TCAS-I, vol. 55, no. 10, Nov. 2008.

Magnitude and Frequency vs. Alignment g_2



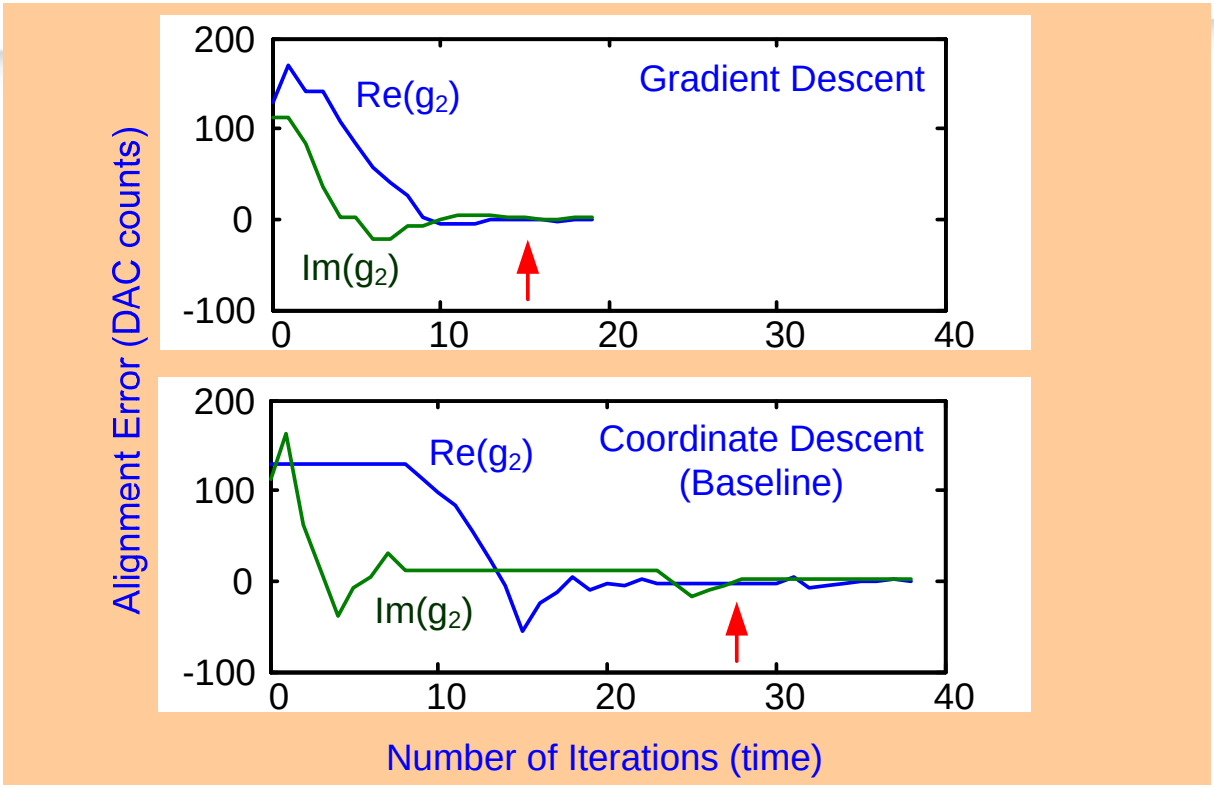
- Magnitude contours: $V_{det}(g_2) = k_a \log\{|G_2|\} + k_b$
  - Convex, one minimum region.
- Frequency contours: $\omega_{pilot}(g_2) = \omega_0 + \arg\{G_2\} / T$
  - Freq is proportional to arg{G_2}, except at discontinuity.

Pilot Spectrum



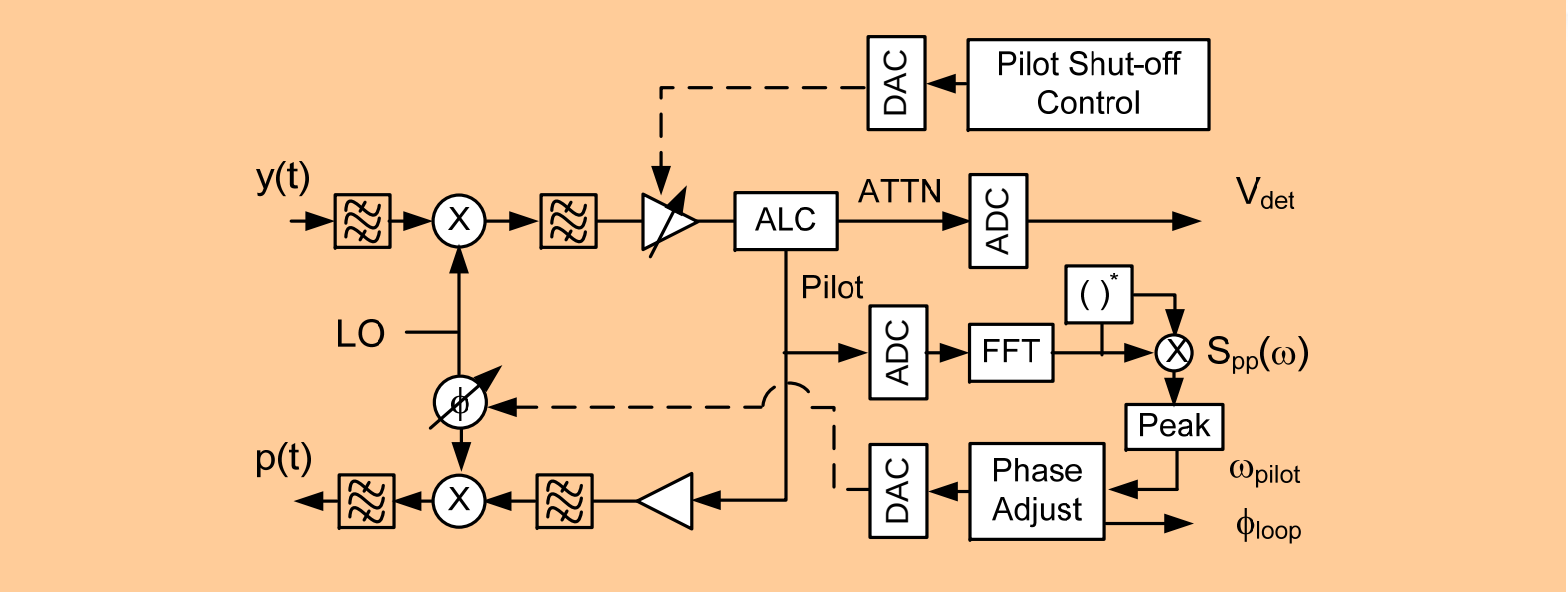
- Pilot on state (oscillating)
  - Single frequency tone, high amplitude.
- Pilot off state
  - Wide bandwidth, low amplitude.

Rate of Convergence



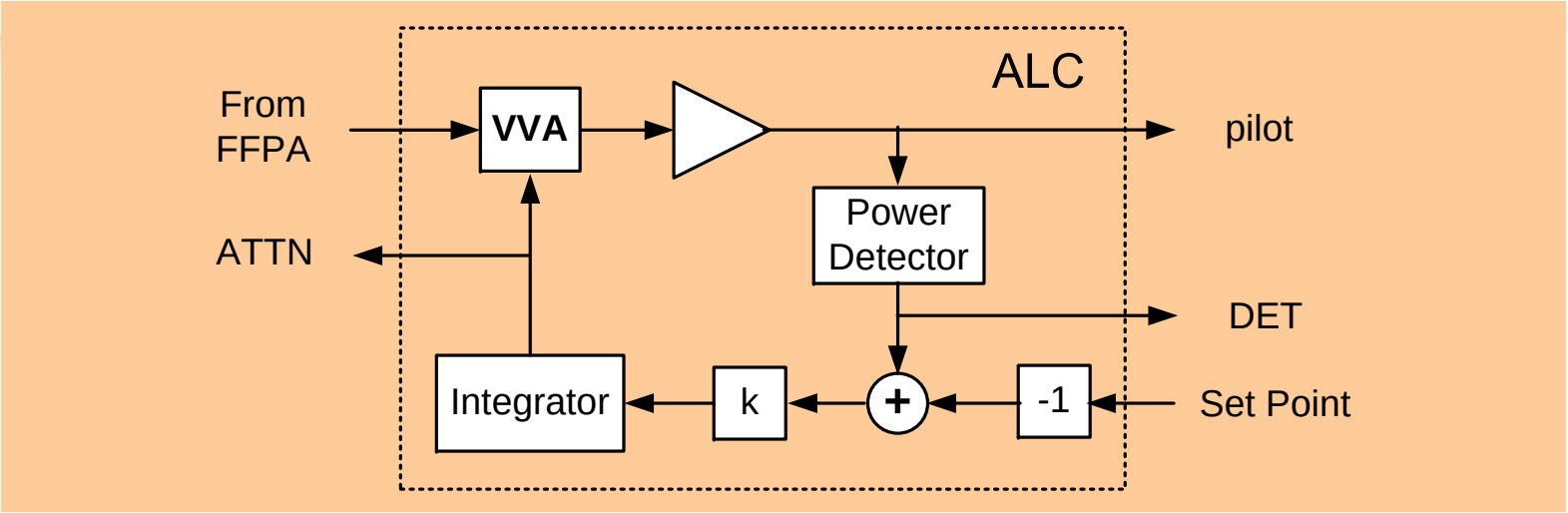
- Synchronous detection.
  - Gradient-based search, faster convergence.
- Magnitude only.
  - Coordinate descent, slower convergence.

Improved Positive Feedback Pilot System



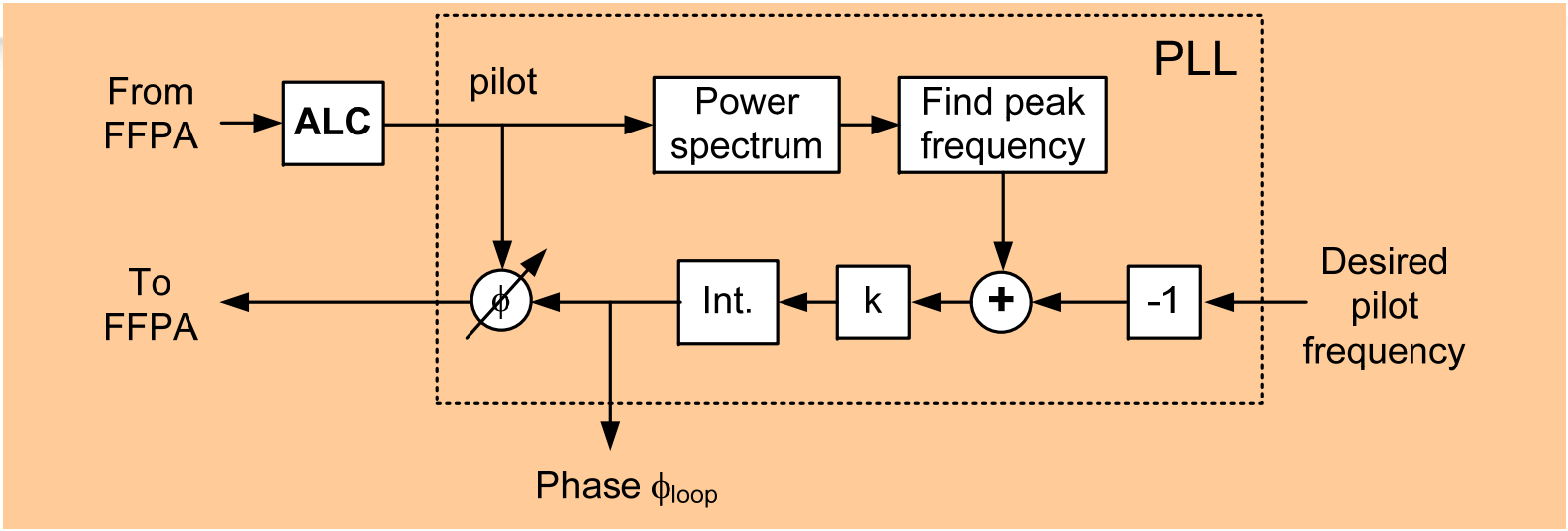
- New features
  - Automatic level controller (ALC).
  - Digital phase lock loop (PLL).
  - Power spectrum measurement of pilot.
  - Adjustable pilot shut-off level.

ALC



- Replaces limiter and detector.
  - Variable attenuation based on a feedback loop.
    - Keeps pilot amplitude constant while VVA is in range.
  - VVA control measures residual pilot power (ATTN).
  - Pilot shut off begins when VVA reaches lower limit.
- Less harmonic content in pilot signal.

Digital PPL

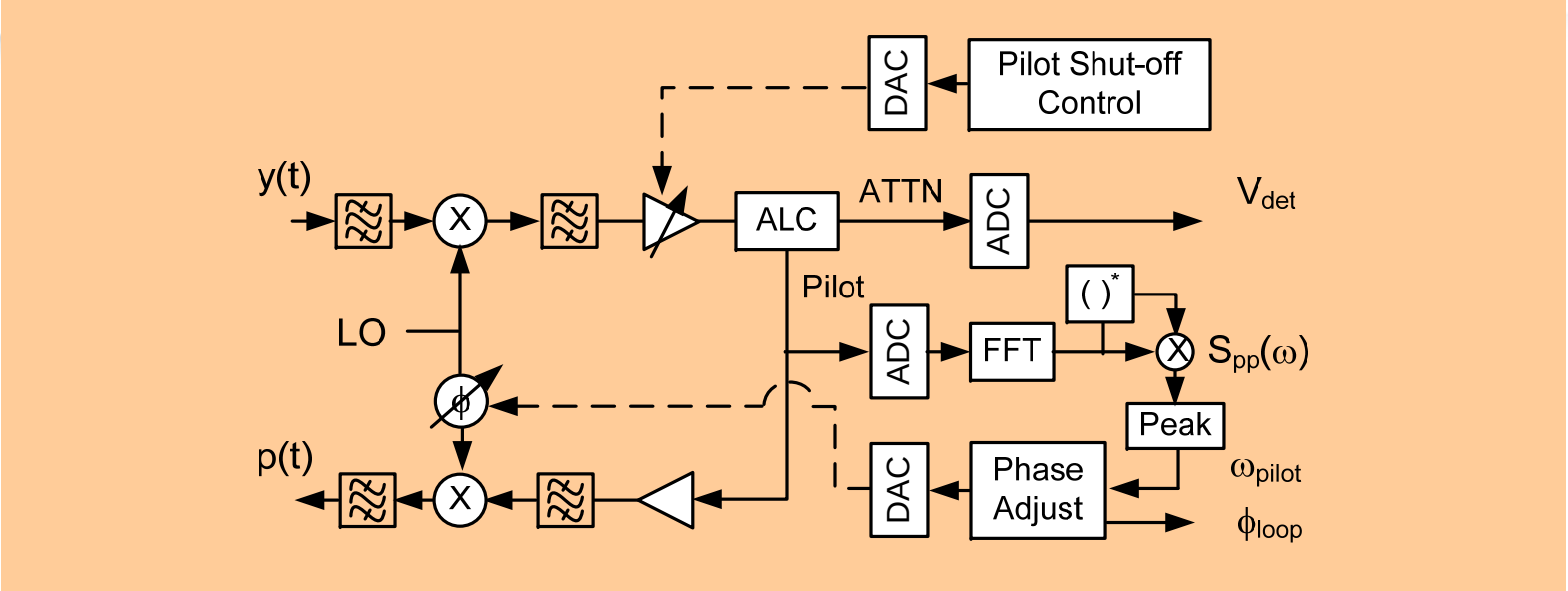


- Frequency lock loop.
  - Variable phase shifter controls pilot frequency.
  - Loop keeps pilot frequency constant.
    - Compensates for frequency shifts associated with changes in g_2.
  - Phase control ϕ_{loop} measures arg{G_2} directly.
- Phase shifter may be placed at LO port.

Power Spectrum of Pilot

- Part of the digital phase lock loop.
- Used to extend the residual pilot measurement.
  - Needed when the ALC-VVA reaches lower limit.
  - Allows control of g_2 within the pilot shut off region.
- Used to reduce the detection bandwidth.
  - Useful when the ambient noise level of the input signal to the feedforward PA is high.
  - Example: optically fed radio head amplifiers.

Adjustable Pilot Shut-off



- Adjustable gain stage placed before ALC.
  - Allows selection of the second loop cancellation level, $|G_2|$, when pilot shut off begins.
  - Increasing pilot shut off gain reduces $|G_2|$ shut off level.

Conclusion

- Positive feedback pilot system.
  - Direct measurements of a feedforward PA's second loop cancellation transfer function.
  - Both amplitude and phase.
  - Improves second loop convergence.
- Extensions
  - Constant pilot frequency using PLL.
  - Variable detection bandwidth using power spectrum measurements.
  - Adjustable pilot shut-off threshold.

Thank You

- Questions?