ECE 4880

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Chapter 7

Architecture to Improve Linearity

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Goals

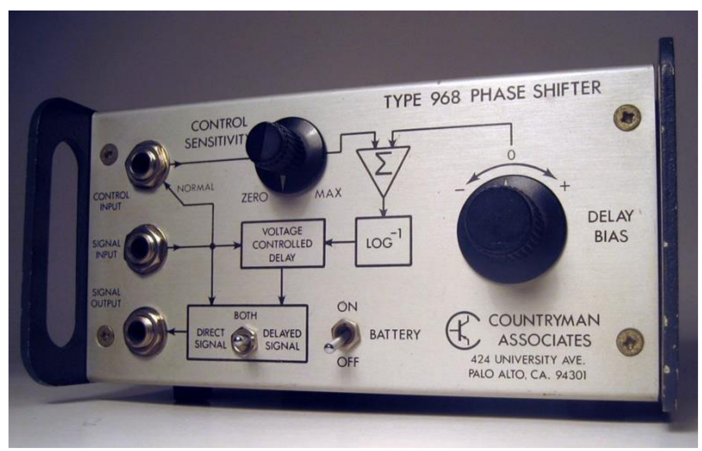
- Passive modules of
  - phase shifter
  - directional coupler
  - power divider
  - quadrature coupler
  - power/signal combiner
- Parallel combining
- Feedforward distortion cancellation
- Other feedback structures

Phase Shifters

Passive: limited bandwidth

Tuning tines

Active: nonlinearity

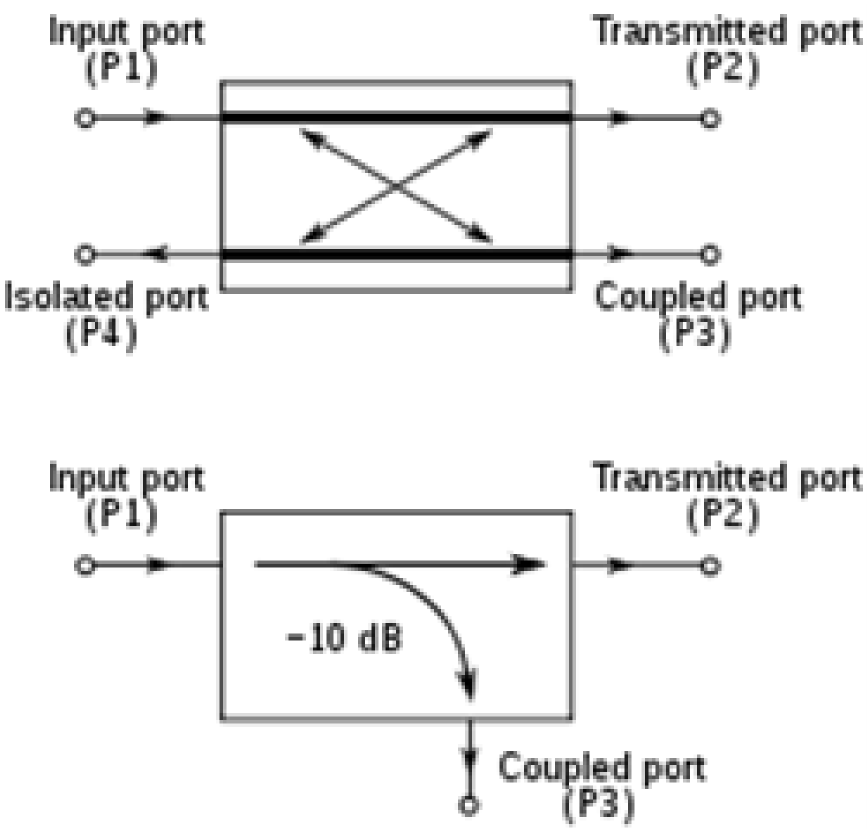


Signal/Power Splitters

Passive: broad bandwidth

- Half power to Out1 and Out2 (3dB), or $\frac{1}{\sqrt{2}}$ in voltage magnitude.
- Many splitters are bi-directional and can be used for combiner.

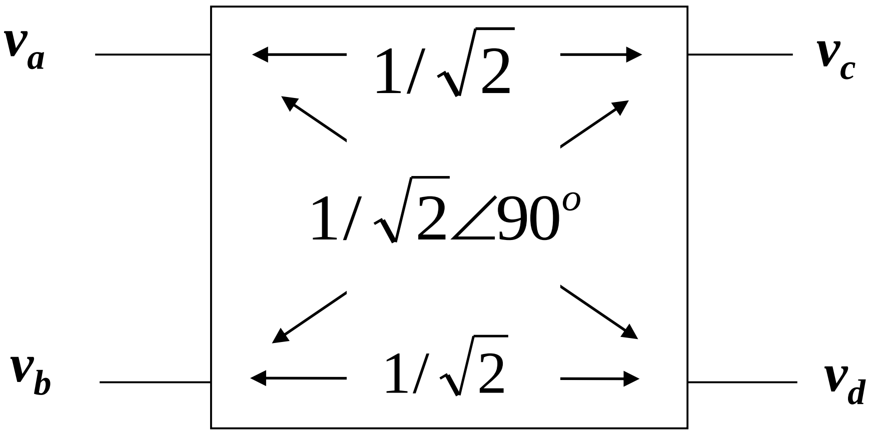
Directional Couplers

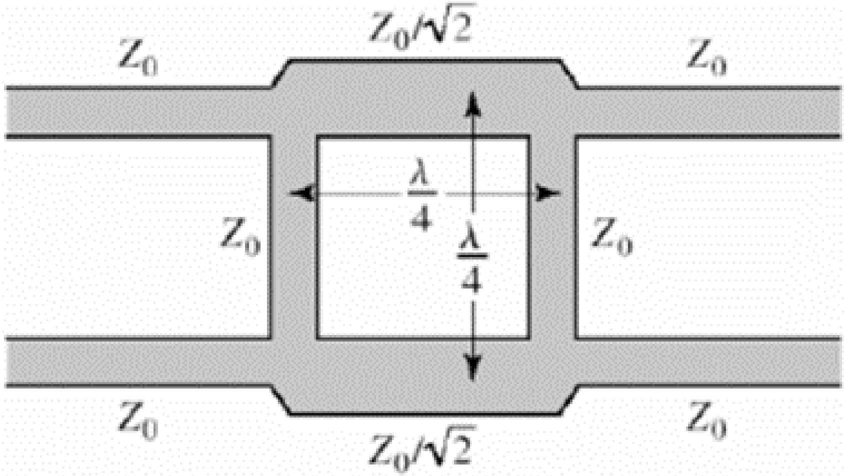


- P1 ↔ P2 about –0.5dB
- P1 → P3 about –10dB
- P2 → P3 about –50dB

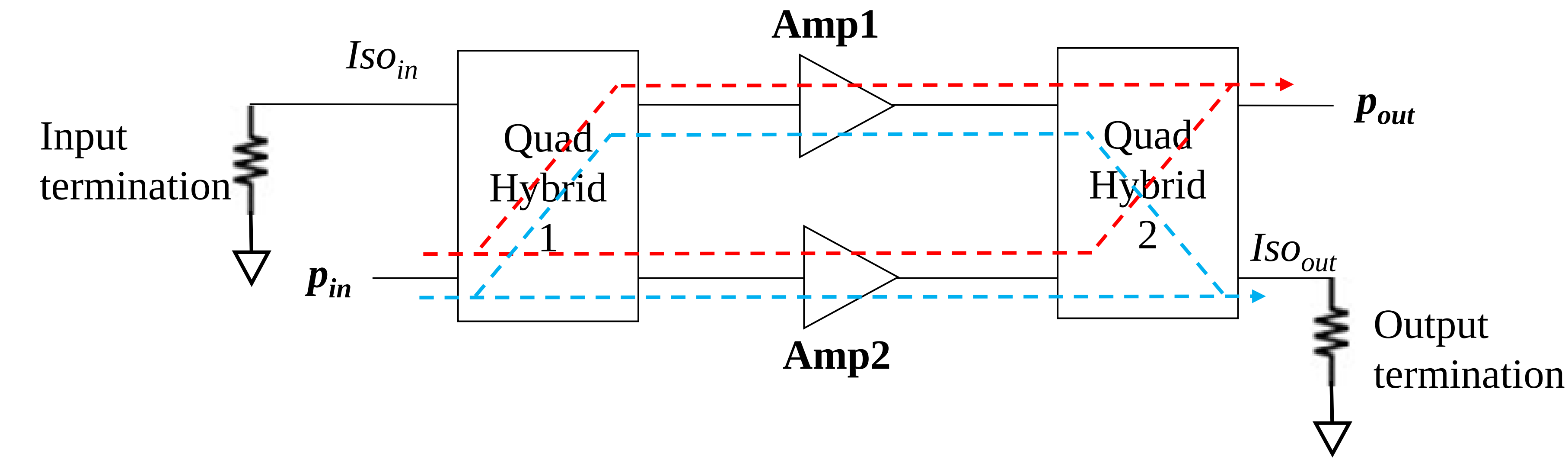
Passive: broad bandwidth

Quadrature Hybrid Couplers (90°)



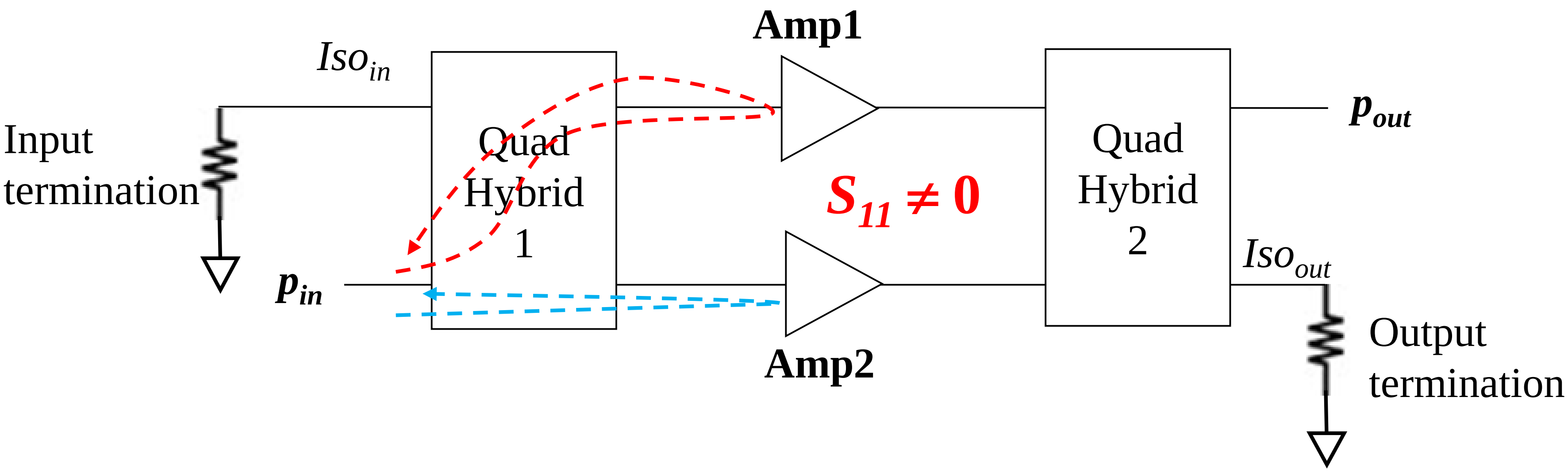


Parallel Combining by Quad Hybrid



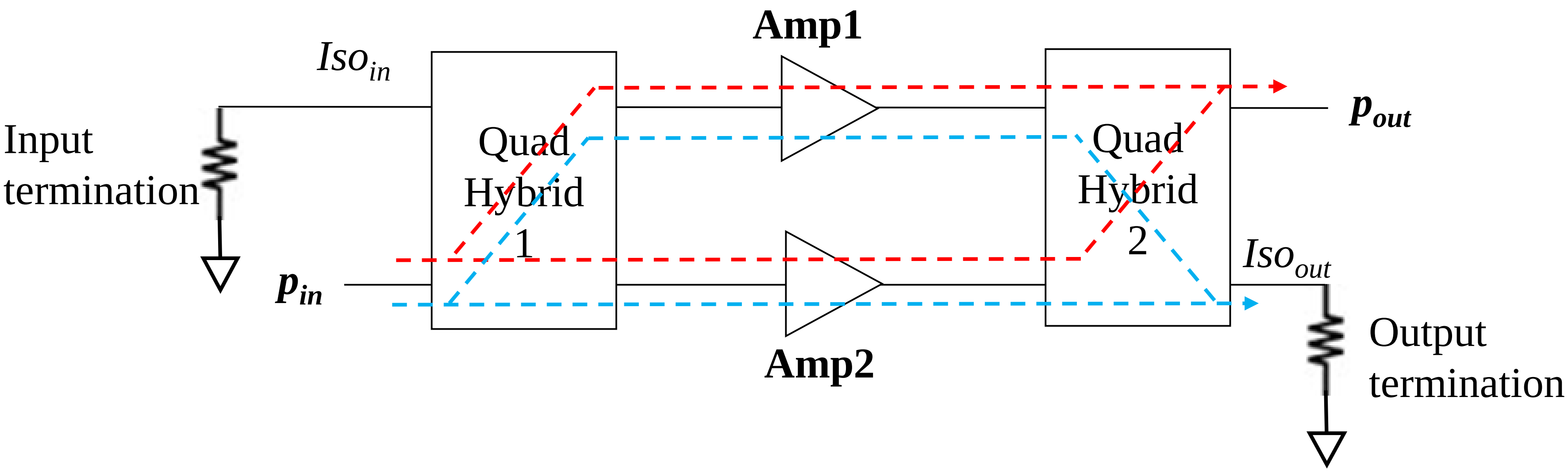
- $p_{in} \rightarrow p_{out}$; both paths 90° shift: in phase.
- $p_{in} \rightarrow Iso_{out}$; one path 0° shift and the other 180° : out of phase.
- Amp1 and Amp2 shares the power amplification to generate the same p_{out}, but have 3dB lower input ⇒ 3dB lower in p_{outIM2} and 6dB lower p_{outIM3}

Impedance Matching in Quad Hybrid



- $p_{in} \rightarrow Amp1 \rightarrow p_{in}$; 180° shift
- $p_{in} \rightarrow Amp2 \rightarrow p_{in}$; 0° shift: out of phase.
- If Amp1 and Amp2 have mismatched impedance to Z_0, as $Z_{in1} = Z_{in2}$, the reflection to p_{in} will be cancelled, and NO jitter to p_{in}! (Where does the reflective power go?)
- How about the output impedance for Amp1 and Amp2?
- Iso_{in} and Iso_{out} can dissipate non-match energy and for debugging

H2 and H3 in Quad Hybrid



- $p_{in} \rightarrow Amp2 \rightarrow p_{out}$:

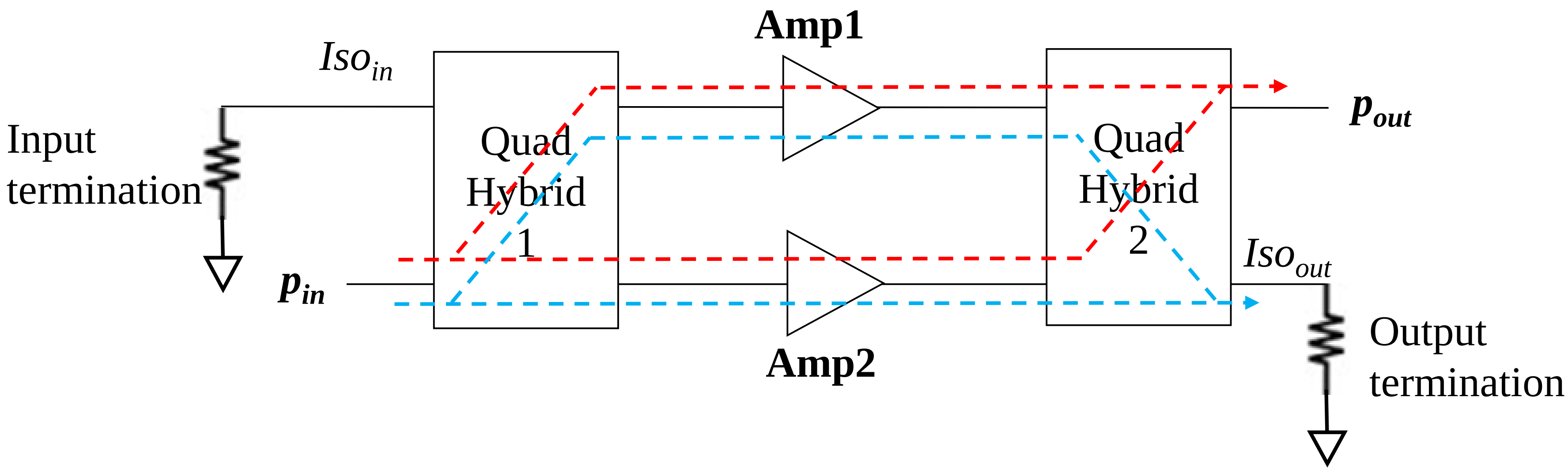
  $v_{out2} = a_1\cos(\varphi - 90^o) + a_2\cos(2\varphi - 90^o) + a_3\cos(3\varphi - 90^o)$

- $p_{in} \rightarrow Amp1 \rightarrow p_{in}$:

  $v_{out1} = a_1\cos(\varphi - 90^o) + a_2\cos(2\varphi - 180^o) + a_3\cos(3\varphi - 270^o)$

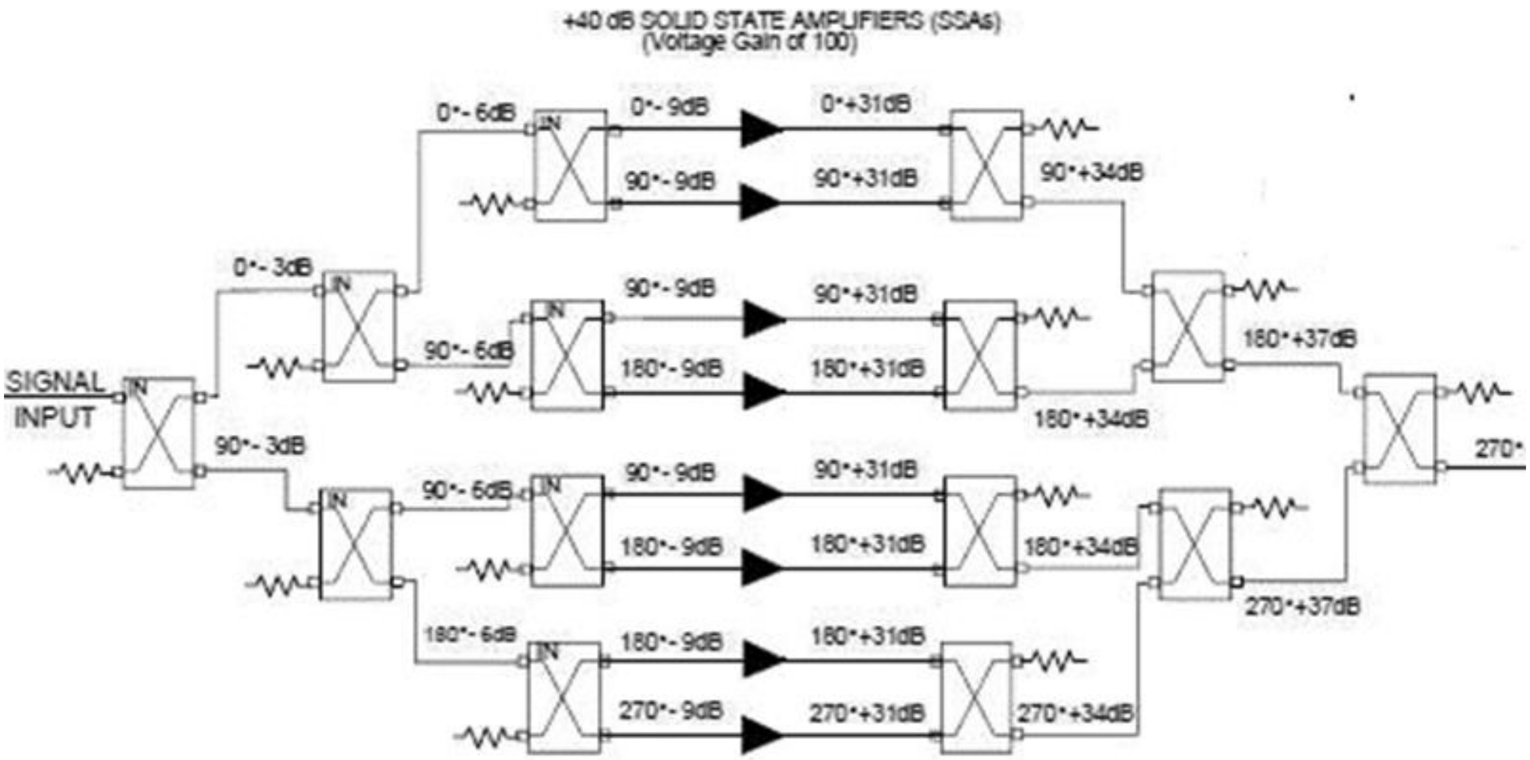
- Fundamental: in phase; H2: 90^o out of phase; H3: out of phase

Intermodulation in Quad Hybrid



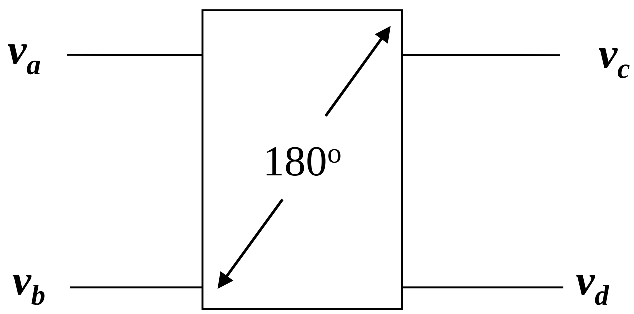
- IM2 (i.e., pin has two tones of f_a and f_b) is 3dB lower in power
- IM3 of $2f_a + f_b$ and $f_a + 2f_b$ are cancelled.
- IM3 of $2f_a – f_b$ and $2f_b – f_a$ will add up in phase unfortunately, although we still have the original –6dB reduction from the lower output power in each amplifier.

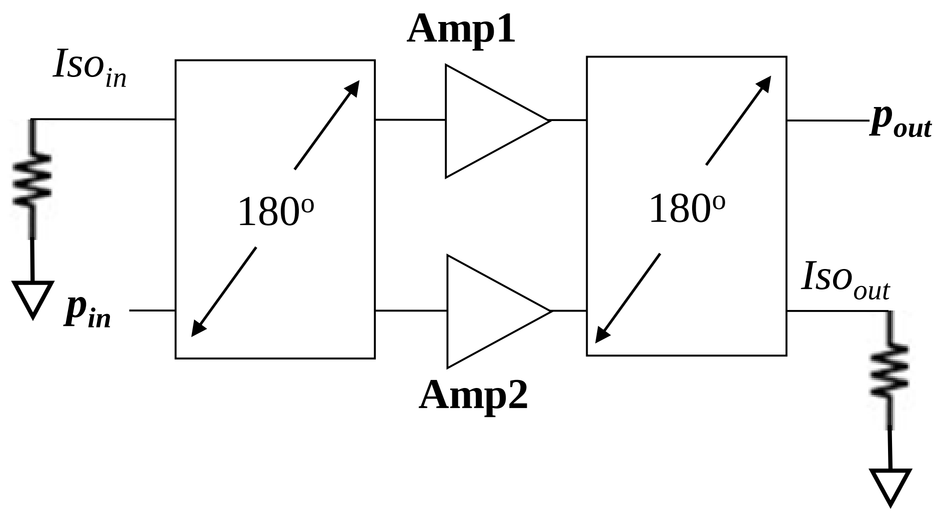
Hierarchical Quad Hybrid



- We can repeat this module to achieve even better linearity.
- Combining 8 amplifiers to achieve 9dB reduction of v_{in} and v_{out} of each amplifier, while combined for the same p_{out}
- This will have an effective reduction in IM3 by 18dB!!

180° Hybrid

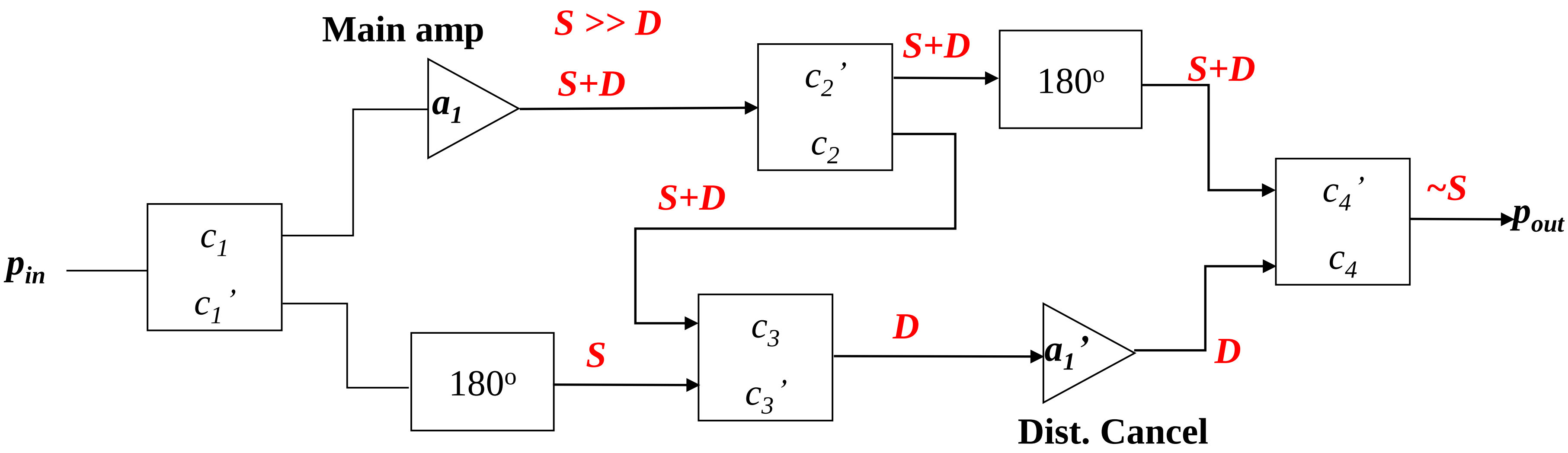




- v_a is split to v_c and v_d both in phase with 3dB attenuation
- v_b is split to v_d in phase with 3dB attenuation
- v_b is split to v_c with 180° phase shift as indicated by the only arrow in the block

- For the fundamental frequency, the two paths to p_{out} will add up in phase, and will cancel at Iso_{out} with 180° out of phase.
- Any impedance mismatch will cause some power subtracted from p_{out} to Iso_{out}.
- H2, H3, IM2 and IM3?

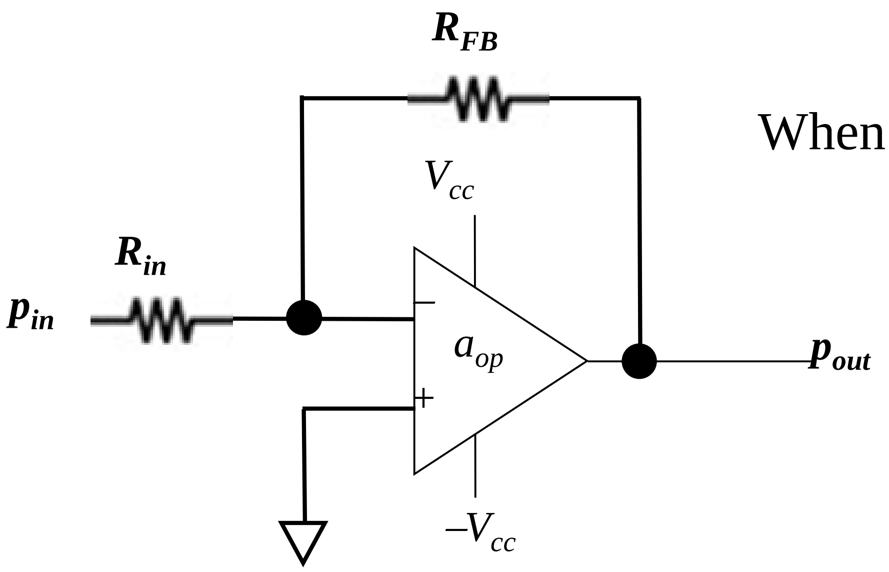
Feedforward Distortion Cancellation



- Main path: $c_1 a_1 c_2' c_4'$ = Distortion eval path: $c_1 a_1 c_2 c_3 a_1' c_4$
- Distortion sample path: $c_1 a_1 c_2 c_3$ = Signal eval path: $c_1' c_3'$
- Distortion cancellation: $c_2' c_4' = c_2 c_3 a_1' c_4$

  $c_1 a_1 c_2 c_3 = c_1' c_3'$
- $c_i + c_i' = 1$, for $i = 1 – 4$.
- The main path gain to be maintained: $c_1 \simeq c_2' \simeq c_4' \cong 1$.
- Therefore, the real choices are just c_3 and a_1'.

Feedback Architecture



When $a_{op} \rightarrow \infty$ and $R_{out} \rightarrow \infty$, gain $\cong \dfrac{R_{FB}}{R_{in}}$

- Although LC resonators can be integrated into the OP AMP, the loop delay caused by the large Miller capacitance (as the OP AMP has huge gain) will limit the frequency range severely.

Feedback Architecture Concerns

- **Huge distortion** (aka nonlinearity) when output voltage is close to V_{cc} or $-V_{cc}$ of the OP AMP! Even many OP AMPs have V_{cc} from 10 – 24V, this is still just 30 dBm to 38 dBm of p_{out} on a 50Ω output resistance.
- The linear gain depends on the output load has much larger resistance than R_{FB} so that the gain is not heavily dragged down. However, R_{out} is mostly around 50Ω, which makes **R_{FB} and R_{in} to be very small and hence leaky**.
- We will either need a **matching network** or other circuit blocks to stabilize the linear gain.
- The power consumption at V_{cc} and $-V_{cc}$, and the leakage through R_{FB} and R_{in} can be serious, and the **power efficiency** is often very low without other resonance network.
- Not good for RF amplifiers, but probably good baseband amps.

What Have You Learned?

- Components for RF signals splitting and combining
- Advantages of quad hybrids
- “Differential path architecture” can help linearity and impedance match
- Architecture to evaluate nonlinearity and apply cancellation