**Motivation**

- Single-channel full-duplex wireless:
  - Adaptive cancellation of strong TX leakage at the RX
  - Time delay requirements of the order of several RF carrier cycles
  - Cancellation highly sensitive to amplitude and delay mismatch

**Proposed Technique: Better time delay approximation**

- For narrowband signal, time delay can be seen as Envelope delay + carrier phase shift (0 – 2π)
- Mathematical representation:
  \[ x(t - \tau) = a(t) \cos(\omega_c(t - \tau) - \phi(t)) \]
  \[ = a(t) \cos(\omega_c \tau - \phi(t)) \]
  Where \( \Theta = \omega_c \tau \) (mod 2π)
- LPF with \( f_1 \gg BW \) acts as a linear phase filter
  Use LPF as a time delay
- Most modern modulation schemes have asymmetric baseband spectra -> Quadrature down-conversion
- Another implementation of the same topology is obtained by expanding the shifted carrier term:

**Phase Range**

- Gain of +1, -1 and 0 implemented by MOS switches.
- 45° phase step
- Due to mixer switching, output also contains signal around odd LO harmonics.
- Can be suppressed by filtering

**Performance Comparison**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>This Work</th>
<th>[2]</th>
<th>[3]</th>
<th>[4]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topology</td>
<td>Frequency Translation</td>
<td>Active RTPS</td>
<td>Vector Modulator</td>
<td>Switched TLPS</td>
</tr>
<tr>
<td>Frequency (GHz)</td>
<td>Multi-band</td>
<td>2.4-2.5</td>
<td>1.2-1</td>
<td>2.5-3.2</td>
</tr>
<tr>
<td>Phase tuning range (°)</td>
<td>360</td>
<td>120</td>
<td>90</td>
<td>360</td>
</tr>
<tr>
<td>Gain (dB)</td>
<td>-3.4-13</td>
<td>-5 to 0</td>
<td>4.8</td>
<td>-2.5</td>
</tr>
<tr>
<td>Input noise current ((\mu A/\sqrt{Hz}))</td>
<td>28</td>
<td>280</td>
<td>101</td>
<td>37</td>
</tr>
<tr>
<td>Power (mW)</td>
<td>9.84</td>
<td>111</td>
<td>4.2</td>
<td>60</td>
</tr>
<tr>
<td>Area (mm²)</td>
<td>0.10</td>
<td>0.36</td>
<td>0.08</td>
<td>4.16</td>
</tr>
<tr>
<td>Technology</td>
<td>130 nm CMOS</td>
<td>180 nm CMOS</td>
<td>180 nm CMOS</td>
<td>180 nm CMOS</td>
</tr>
</tbody>
</table>

**CMOS Implementation**

- Fully differential current mode implementation with 25% duty-cycle LO driven passive mixer
- Direct summation of output RF current
- Excellent Linearity, negligible flicker noise
- \( R_k \) and \( R_C \) depend on circuit impedance levels
- LPF configured to provide envelope delay of 2.5 ns (= 6 LO cycles at 2.5 GHz)
- Can be tuned using capacitor C.
- Carrier phase tuned by changing \( \cos \theta \) and \( \sin \theta \)
- Always between \(-1\) and \(+1\), irrespective of carrier Multi-band operation possible

**Conclusion**

- A better approximation to true time delay is demonstrated based on frequency translation.
- The proposed architecture is capable of operating across multiple frequency bands.
- Implementation with passive mixers is likely to benefit immensely with downscaling of CMOS technology in terms of area and power consumption.

**References**


