A Low Power 60 GHz 6 V CMOS Peak Detector

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Outline

• Peak detector: definitions, applications and requirements
• Applied new ideas
• Design details
• Experimental results
• Comparison
• Conclusion
Peak Detector

Also known as:
• envelope detector
• power detector
Peak Detector

After PA in TX path
- Linearization
- Output power control
- Overvoltage protection

in RX path
- Amplitude demodulator
- Gain
- High Linearity

• High $V_{in}$
• Back-off
Detection architectures

Peak
Rectifying & max holding

Average
Rectifying & filtering

RMS
Squaring & filtering

Thermal
Crystal detector

- First crystal detector patent in 1901 (Bose)
  - Spark-gap era
- Silicon crystal detector 1906 (Pickard)
New ideas

An unfashionable architecture improved with:

- Use of I/O devices
- Clamping
- High input impedance*
- Transmission line integration
Challenges of HV detector design

- Withstand high input signals (self-protection)
- Avoid unnecessary division (SNR)
- Increase input voltage range $\rightarrow$ Clamping
- Low input power $\rightarrow$ High $Z_{\text{in}}$
- Design integration / low area $\rightarrow$ T-line integ.

I/O device

T-line integ.
Linearity & Protection: I/O Devices

• No gain required $\Rightarrow f > f_T$
  – Pulsed large signal operation
  – Higher input voltage swing (breakdown voltage)
    • Lower voltage division at the input $\Rightarrow$ better SNR
    • Higher linear operation range ($V_{DD}-V_{th}$ $\Rightarrow$)
Clamping

- $V_{pp}$ swing $<$ breakdown voltage
- Information in upper half wave

Reduce swing to upper half wave

$Z_{in}$ dominated by $C_b$ & $C_u$
Design Integration

- Transmission line
  - capacitive voltage divider for coupling
- Below GND plane
  - area efficient
  - ground shield helps in low-pass filtering
- Only RF node:
  - gate of $M_{\text{det}}$
Block diagram

- Rectifier: $M_{det}$
- Attenuator: $C_u$ & $C_b$
- Integrator: $C_L$
- Pull-down: $I_b$
- Clamping: $M_{clamp}$
- Integrated into a t-line
Schematic

One input cascode biasing
Sets clamping threshold

RF path
RF → Bias isolation

<table>
<thead>
<tr>
<th>nf</th>
<th>Wf</th>
<th>L</th>
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<td>M_{det}</td>
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<td>M_{clamp}</td>
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<td>450</td>
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<tr>
<td>M_{bias}</td>
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<td>450</td>
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<tr>
<td>M_{1-4}</td>
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<tr>
<td>M_{5-8}</td>
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<tr>
<td>M_{11-13}</td>
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<tr>
<td>M_{14-16}</td>
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Measurement: “DC” characteristic

• Average output as a function of input power
Measurement: demodulation bandwidth

- 10 MHz bandwidth
## Comparison

<table>
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<th>node</th>
<th>f&lt;sub&gt;c&lt;/sub&gt; [GHz]</th>
<th>V&lt;sub&gt;in_max&lt;/sub&gt; [V]</th>
<th>BW [MHz]</th>
<th>P&lt;sub&gt;DC&lt;/sub&gt; [mW]</th>
<th>DR [dB]</th>
<th>area [µm&lt;sup&gt;2&lt;/sup&gt;]</th>
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<td>—</td>
<td>5.8</td>
<td>12&lt;sup&gt;†&lt;/sup&gt;</td>
<td>150000</td>
<td>CS</td>
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<td>35.2</td>
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<td>750000$^&lt;$</td>
<td>CS</td>
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<tr>
<td>[4]</td>
<td>130</td>
<td>2</td>
<td>190</td>
<td>25</td>
<td>25.3</td>
<td>540000$^&lt;$</td>
<td>CB</td>
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<tr>
<td>[1]</td>
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<td>0.32</td>
<td>10</td>
<td>—</td>
<td>30</td>
<td>—</td>
<td>CB</td>
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<tr>
<td>[18]</td>
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<td>0.32</td>
<td>—</td>
<td>20</td>
<td>10&lt;sup&gt;†&lt;/sup&gt;</td>
<td>13000</td>
<td>CS</td>
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<tr>
<td>This</td>
<td>22&lt;sup&gt;‡&lt;/sup&gt;</td>
<td>65&lt;sup&gt;*&lt;/sup&gt;</td>
<td>6</td>
<td>10</td>
<td>0.006</td>
<td>25.2</td>
<td>0 (234)</td>
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</table>

<sup>†</sup> for one detector cell of the cascade;  
<sup>‡</sup>L<sub>min</sub>=150 nm IO transistors were used;  
<sup>*</sup>limited by instrumentation;  
<sup>$</sup>including test pads;  
DR: dynamic range; CS, CG, CD: common source, gate and drain  
P<sub>DC</sub>: DC power consumption; f<sub>c</sub>: maximum measured carrier frequency
Conclusion

• High voltage, low-power mm-wave detector was presented
• Diode-based peak detection revisited
• Input voltage range was extended with
  – High voltage I/O devices, working above their $f_T$: $\sim 3x$
  – Clamping: $\sim 2x$
• Zero area by direct transmission line integration
  – Input divider adjustable for the voltage swing
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Appendice
References

Measurement Setup
BW Measurement Principle

• Similar to travelling and standing wave composition
• Waves in opposite direction with slightly different frequency
  → Travelling wave + a slowly changing “standing” wave
• Measuring at one point the “standing” component is a sinusoid as well with the difference frequency
• The peak detectors have been integrated into a transmission line where wave can travel
S-parameters

![Diagram of a circuit](image)

Graphs showing S-parameters $S_{11}$ and $S_{21}$ vs. Frequency.
Dynamic range extension by cascading

- By using attenuation or gain blocks
Sim: waveforms during clamping

- 6V input amplitude