Bluetiful: All-Digital Bluetooth Low Energy (BLE) Transmitter ASIC using Standard I/O Backscatter

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Backscattered Bluetooth

- **Bluetooth Low Energy (BLE)** allows **extremely low power wireless** advertising transmissions, perfect for small wireless devices
- **Problem:** This requires an **external RF Bluetooth peripheral** to operate in the 2.4 GHz band
- In contrast, **backscatter modulation** reflects an external carrier wave without needing an internal signal generator
- Previous work has used FPGA I/O pins as modulators

Standard I/O Cells

- **Our Solution**: We implemented BLE transmission using backscatter modulation digitally on an entirely **Standard Cell Library-synthesized ASIC**

- This ASIC is synthesized entirely from Verilog RTL, no RF cell design or external switches
- The tri-state I/O cell driver (right) toggles between **Ground** and **High-Z** and create a BLE signal
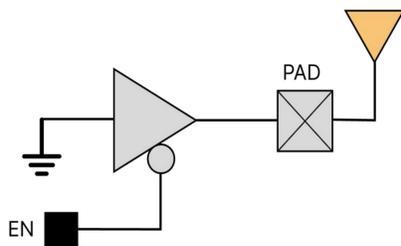
System Design

- We created a lightweight, flexible core that can broadcast at **1Mbps**, supporting **custom data packets, switching BLE channels,** and can run on **variable clock** inputs
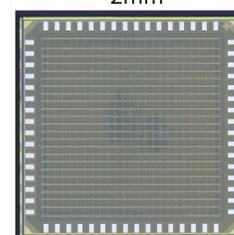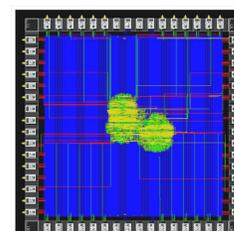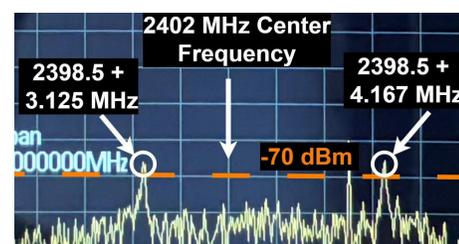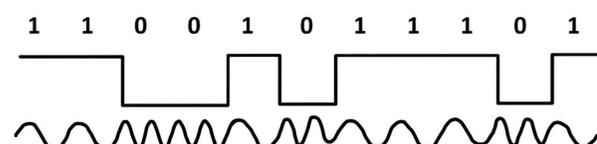

IC Block Diagram
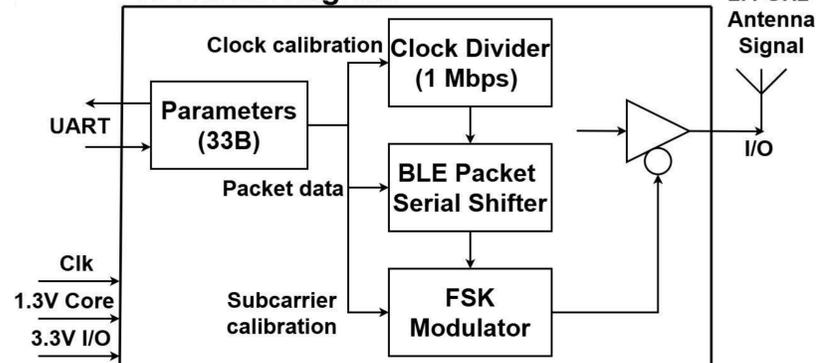
Frequency Shift Keying

- As the I/O pad toggles at between **GND** and **Z** at the subcarrier frequencies, it **modulates the carrier wave, adding and subtracting**
- E.G. A 2.3985 GHz Carrier wave, with 3 and 4 MHz subcarriers, creates a signal at 2.4015 and 2.4025 GHz, centered on BLE channel 37

Frequency Shift Keying (FSK)

1 1 0 0 1 0 1 1 1 0 1

2402 MHz Center Frequency
2398.5 + 3.125 MHz
2398.5 + 4.167 MHz
-70 dBm

-----------2mm-----------

ASIC Design

- **UART-accessible registers** allow changing of **primary clock-divider** and subcarrier frequency values. UART also allows changing advertising packet
- Core has an area of **0.085 mm²** and consumes **601 uW** of power when operating on a **1.3 V** power and **12 MHz** core clock

Validation

- The ASIC is fed a clock input (12 MHz typ) and power supply (1.3 V logic, 3.3 V I/O)
- A Carrier Wave can be generated by at 2.3985 GHz, and the advertising packet in Channel 37 is picked up by a nearby receiver
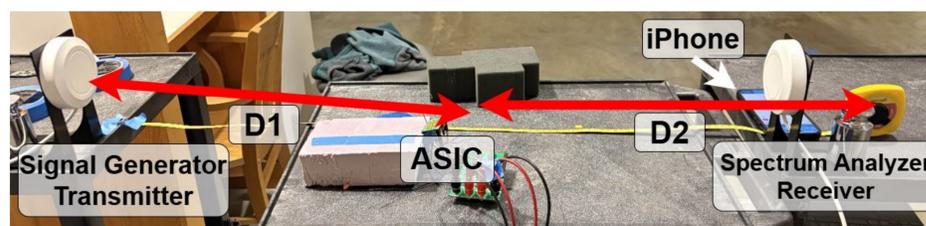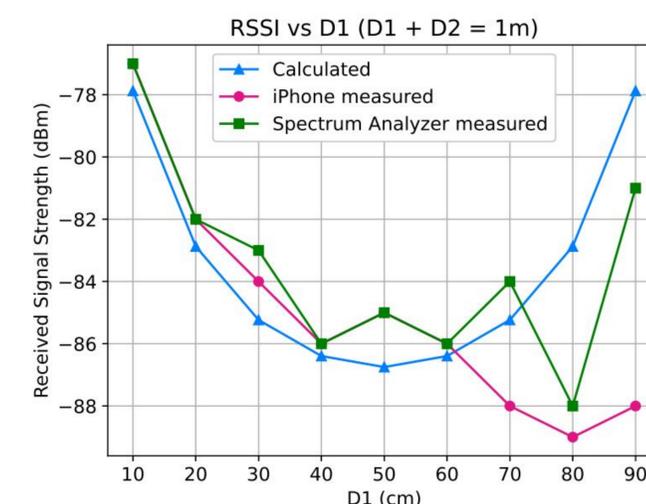

Transmission Setup with Signal Generator and Signal Receiver 1m apart

Validation

Our transmitter was detected on an **iPhone** BLE Scanner app 1 foot away with a Signal Strength of **-77 dBm**

RF Performance

RSSI vs D1 (D1 + D2 = 1m)

Predicted vs Measured Signal Strength performances at varying distances. Calculated values are based on our **Link Budget**

Evaluation

- Achieved modulator gain of -24.17 dB
- Achieved successful transmission beyond 1m
- Minimal Area and High Flexibility vs comparable Backscatter ASICs