A Near-Field Modulation Technique Using Antenna Reflector Switching

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Outline

- Introduction
- Signal Modulation using Antenna Reflector Switching (SMARS)
- A 60GHz Proof-of-Concept Transmitter
- Experimental Results
- Conclusion
Conventional Transmitter Architecture

- Signal is modulated at base-band.
- Antenna transmits **the same information** to all directions.
- The only difference between the desired and the undesired directions is the transmitted power level.
- A high-performance receiver at an undesired direction is able to receive and decode the correct modulated signal.
In the conventional architectures, the antenna pattern remains unchanged at each symbol transmission.

For a fixed antenna pattern, any change in the phase and the amplitude of the base-band signal is detectable at the desired direction as well as the undesired direction.
In the proposed transmitter architecture, antenna near-field and far-field change at each symbol transmission but the change in the far-field is not same for all the angles.

Antenna pattern needs to be varied at the same rate as the symbol-rate to be able to modulate the signal.
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Signal Modulation

- Switching changes the antenna reflector’s effective length.
- Reflected signal interferes with the main signal.
- Different effective lengths correspond to different phases and amplitudes of the reflected signal.
Arbitrary Signal Modulation

- We can generate more constellation points by introducing additional reflectors and switches.
- Each additional switch doubles the total number of possible constellation points.
In the SMARS (Signal Modulation using Antenna Reflector Switching) transmitter architecture, high-speed CMOS switches are used to modulate the signal.

As the signal is modulated after the antenna, the PA can operate at its maximum efficiency point while transmitting a non-constant envelope modulated signal.

A narrow-band highly efficient switching PA can be used to amplify the carrier signal.
Secure Communication Link

- Angle dependent modulation provides a secure communication link.
- Correctly modulated signal is only transmitted to the desired direction.
Error-Rate Versus Angle

- By changing the angle, some of the constellation points move to the adjacent cells and introduce error.
A total number of 210 equally-spaced points are selected.
Boresight is set to be the desired direction in this example.
The desired direction can be steered by finding a set of different switching combinations.
High Level of Redundancy

- For a total number of $N$ switches on the reflectors, $2^N$ configurations exist. In our design $N=90 \rightarrow 2^{90} \sim 10^{27}$
- Redundancy can be used to generate a single constellation point with many different switching combinations.
- This will limit the ability of the undesired receiver to properly demodulate the signal.
Redundancy also helps us to transmit independent data to different directions at the same time using a single transmitter at its full rate.
High-Resolution Coverage

- Based on the simulation, we can cover most of the signal constellation space with a high resolution.
Spectral Control

- Pulse shaping and out-of-band emission can be controlled by transition trajectory between two constellation points.
- Almost any arbitrary trajectory can be achieved by rendering the path using multiple points along the trajectory.
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60GHz Transmitter with Antenna

- **Transmitters:** M1+M2+M3
- **Reflectors:** M1+M2+M3
- **Switch:**
- **VCO:**
- **PA:**
- **1500µm**
- **1300µm**
- **375µm**
- **560µm**
- **Transmission Line:** Ground M6, Signal M7
- **Digital Control Unit**
An optional circuitry is designed to provide a coarse control on the phase of the modulated signal.

This unit can be used to select a quadrant on the constellation diagram.
Switch and Reflector

- A circular shielded transmission line resonates out the switch capacitance at its open state.
For a carrier frequency of 60GHz the far-field adopts to the new switch combination in less than 200ps (ideal switch).

Effectively, the transient response is limited by the switch itself.
A 3-stage amplifier drives the on-chip antenna.
Coupled-wire transmission lines and stub tuning are used for matching purposes.
60GHz VCO and Divider

V-band VCO

Injection-locked Divider

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LO Signal Distribution

![Circuit Diagram]

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Up-Converter Mixer (Optional Feature)
The chip includes the on-chip antenna, reflectors, digital control unit, transmitter, receiver, and LO generation blocks.

Chip is implemented in a 130nm SiGe BiCMOS process.
Due to the silicon’s high dielectric constant (11.7), most of the radiated power (95%) is coupled to the silicon instead of air.

A planar substrate behaves as a waveguide and couples the power to the substrate modes.
To minimize the power lost due to the substrate modes, a hemispherical un-doped silicon lens with a diameter of 25-mm is attached to the back-side of the substrate.

This silicon lens converts the substrate modes to useful radiated modes.
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A Lab-View program sends the base-band data to the transmitter through a data acquisition card and at a same time measures the changes in the phase and amplitude of $S_{21}$. 
In this measurement only the reflector switching is used to generate the modulated points.
To cover the four quadrants, the optional coarse control quadrant-selecting unit can be used.
- Measured gain of more than 33dB
- Measured output power of about +7dBm
Circuit Performance

<table>
<thead>
<tr>
<th>Transmitter performance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>130nm SiGe BiCMOS</td>
</tr>
<tr>
<td>Amplifier output power</td>
<td>+7dBm</td>
</tr>
<tr>
<td>Transmitter small-signal gain</td>
<td>33dB</td>
</tr>
<tr>
<td>Transmitter saturated gain</td>
<td>25dB</td>
</tr>
<tr>
<td>VCO tuning range</td>
<td>2.5GHz</td>
</tr>
<tr>
<td>VCO phase noise</td>
<td>-100dBc at 10MHz offset</td>
</tr>
</tbody>
</table>
Conclusions

- **Signal Modulation using Antenna Reflector Switching (SMARS)** is introduced.
- This technique is capable of transmitting information to a desired direction while preventing receivers in undesired directions to properly decode the signal.
- Redundancy can be used to transmit independent information to multiple directions at a same time using a single transmitter.
- The whole switching reflectors including the antenna can be used as a single element in a phased array system. In this case, the switching combinations determine the information beam-width and the desired direction while the phased-array technique can be used to adjust the radiation pattern beam-width and steer the array pattern.
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