Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [An MSK system for Mobile Multi-Gb/s at 60GHz, concept, application and implementation]

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Source: [Troy Beukema, Brian Gaucher, Yasunao Katayama, Scott Reynolds, Alberto Valdes-Garcia]
Company [IBM Research]
Address [1101 Kitchawan Rd. Rte. 134, MS:30-116]
Voice:[+914-945-2596], E-Mail:[bgaucher@us.ibm.com]

Re: [Request of contributions for the 802.15.3c subgroup]

Abstract: [Design considerations and preliminary results of an MSK-based system for Multi-GB/s communications at 60GHz over a band limited directional channel, suitable for ‘MAC-less’ systems, MP3 player/HD synchronization applications…]

Purpose: [For discussion only]

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Outline

- Applications for a 60GHz directional channel.
- Principles of MSK modulation.
- Performance and effects of band limitation.
- Integrated MSK modulator and measurement results.
- Summary.
Tiered standard needed:

- ‘Simple’ multi-Gbps portable applications require low complexity, low power, low cost solutions: e.g. Directional, single carrier link
  - Kiosk applications
  - Synchronization (MP3 Players, HDs, iPODs…)
  - Point-point links (Campus, HDMI…)

- ‘More complex’ multi-Gbps less portable applications can afford higher complexity, power and cost solutions: e.g. Omni-directional, multi-carrier network
  - WPAN
  - High definition video system network
Ex. Applications for 60GHz Systems

No-MAC Wireless Point-to-Point Cable: e.g. One-way uncompressed video, Kiosk, MP3 Player or HD sync...

- **E.g. Half-Duplex Ethernet Mac for Wireless Point-to-Point 2Gb/s “Point and Shoot” Ethernet**
  - Laptop/Desktop
    - Ethernet (half duplex)
    - HD-SDI, HDMI serial data
    - 60GHz Directional Channel
    - Portable Device
    - Ethernet (half duplex)

- **E.g. Full-Duplex Ethernet Mac for 1Gb/s Wireless Point-to-Point Ethernet Bridges**
  - Ethernet Bridge
    - Ethernet (full duplex)
    - 60GHz Directional Channel
    - Ethernet Bridge
    - Ethernet (full duplex)
MSK can be described as phase-continuous 2-level FM with deviation = R/4 where R = data rate.

The frequency is allowed to change polarity on quadrant boundaries only.

MSK data encoding:

1 bit: freq = +R/4
0 bit: freq = -R/4

Frequency changes at phase = 0, pi/2, pi, and 3pi/2 radians only
Example MSK Generation

MSK can be generated by modulating the signs of half-sine pulses separated by 90 degrees on I and Q axes.

A sine pulse sign is encoded with a data bit corresponding to the first half of the pulse in time duration.

To encode + Frequency (1) data bit value:
- on Q pulse: \(Q\) pulse sign = \(I\) pulse sign over bit interval
- on \(I\) pulse: \(I\) pulse sign = opposite of \(Q\) pulse sign over bit interval

To encode - Frequency (0) data bit value:
- on \(Q\) pulse: \(Q\) pulse sign = opposite of \(I\) pulse sign
- on \(I\) pulse: \(I\) pulse sign = \(Q\) pulse sign

\[
\begin{array}{cccccccccccccccc}
\text{Data} & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 \\
\end{array}
\]
MSK Demodulation

MSK can be demodulated using a FM limiter/discriminator + CDR for low power/low complexity, or with conventional A/D + DSP for higher power/higher complexity and better sensitivity.

**FM Discriminator/CDR approach:**

- MSK IF signal
- Bandwidth Limit
- Envelope Limit
- FM Discriminator Detector
- CDR
  - Data Slicer (20mW)
  - Clock
  - FPGA/ASIC

**A/D + DSP approach (~3dB better sensitivity; can also add channel equalization):**

- MSK Baseband IQ signal
- Bandwidth Limit
- AGC
- Lowpass Filter
- A/D (200mW+)
  - 2Gs/s+
- A/D
- LPF
- DSP
- FPGA/ASIC
MSK AWGN Sensitivity

FM limiter/Discriminator $P_b$ is shown below: 15dB SNR is needed for low error rate ($1e^{-5}$) operation. The addition of a RS(255,239) code improves sensitivity to ~11dB SNR for length 1912 bit payload.

MSK FM Discriminator AWGN BER Sensitivity

Frame Error Rate
RS(255,239) : 1912 bits

$P_b$
60GHz Bandwidth Limited MSK Modulation System (Simulation)

Data Rate | 3dB IF BW | 1st Sidelobe | 99.5% BW
---|---|---|---
1Gb/s | infinity | -23dB | 1.6 GHz
1Gb/s | 1GHz | -30dB | 1.1 GHz
2Gb/s | infinity | -23dB | 3.3 GHz
2Gb/s | 2GHz | -30dB | 2.2 GHz

FM Discriminator
Low Power CDR/Data Slicer

2Gb/s Detected Eye Diagram
Tx IF BW = 2GHz

NRZ Signal

99.5% Power Bandwidth = 2.22GHz
4-pole Bessel IF Filter BW = 2GHz

99.5% Power Bandwidth = 3.3GHz
No IF Filter

No Band Limit
2GHz BW
IF Filter

3dB IF BW

FM
Discriminator
Detector

-2.5GHz to 2.5GHz
-2GHz to 0Hz
0Hz to 2GHz
-500ps to 500ps
-400ps to 0ps
0ps to 400ps
-300ps to 300ps
Integrated MSK Modulator

- The prototype IC incorporates:
  - MSK modulator
  - IF up-conversion mixer
  - Active IF filter.

- Designed to support multi-Gbps data rates

- Compact implementation for 60GHz transmitter
MSK system transistor-level simulation

- Setup includes cascaded TX/RX transistor-level IF bandpass filters

- 1.6Gb/s eye diagram
- Data rate suitable for HDMI
MSK modulator measurement results

- First test results at moderate speeds confirm proof of concept.
- 250MB/s IF (7GHz) MSK spectrum in good agreement with theory.
- IF filter BW ~2GHz, side-lobe suppression is due to modulation only.
Summary

- An MSK-based system for multi-Gb/s comm. at 60GHz presents significant advantages (i.e. lower complexity and power consumption) in a directional channel.
- An FSK detector has been characterized in 60GHz RX.
- An integrated MSK modulator has been demonstrated.
- A full TX and RX with MSK mod/demod have been fabricated, characterization for a high data rate link will follow.
- This work supports the lower power, lower complexity, lower cost directional link systems.

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