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

Submission Title: [General Atomics Call For Proposals Presentation]

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Re: [802.15.4a Call For Proposal]

Abstract: [This presentation outlines General Atomics’ PHY proposal to the IEEE 802.15.4a Task Group]

Purpose: [To communicate a proposal for consideration by the standards committee]

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Overview of General Atomics
PHY Proposal to IEEE 802.15.4a

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Outline of Presentation

• Summary of proposal
• Parameters and band plan
• Proposal details
• Ranging approach
• Evaluation based on selection criteria
Summary of Proposal

- Compliant with FCC 02-48, UWB Report & Order
- Shaped UWB pulses ~4 ns long and ~500 MHz BW
- Scalable data rates from 100-400 kbps
- ON/OFF Keying (OOK) modulation
- Pulse (chip) rate is 12 MHz
- Inner maximal length pn code sequence for improved range and channelization
- Multiple frequency channels for interference avoidance and channelization
- Error correction with a convolutional code of rate=$\frac{1}{2}$, k=7
Features

• Spectral flexibility to avoid interference and satisfy different international regulations
• Simple architecture facilitates one chip CMOS or SiGe solution
• Long guard period between pulses enhances multipath immunity
• Ultra low power consumption through simple architecture and low duty cycle
• Scalable receiver architectures that can provide tradeoff between complexity and performance
## Major System Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilized Spectrum</td>
<td>3.30 – 4.82 GHz</td>
</tr>
<tr>
<td>No of Frequency Channels</td>
<td>3</td>
</tr>
<tr>
<td>Pulse rate</td>
<td>12 MHz</td>
</tr>
<tr>
<td>Symbols per pulse</td>
<td>1</td>
</tr>
<tr>
<td>Modulation</td>
<td>On-Off keying</td>
</tr>
<tr>
<td>Spreading code</td>
<td>M-sequence length 15</td>
</tr>
<tr>
<td>Bit rate after coding</td>
<td>800 kbps</td>
</tr>
<tr>
<td>Convolutional code</td>
<td>R=1/2, k=7</td>
</tr>
<tr>
<td>Data rate before coding</td>
<td>400 kbps</td>
</tr>
<tr>
<td>Data rates supported with repeat codes</td>
<td>100, 200 kbps</td>
</tr>
</tbody>
</table>
Band Plan

- 3 orthogonal frequency channels in the 3.1-5.0 GHz band
- Provides flexibility for worldwide spectrum regulations
- Channel scan may be used to avoid interference
- Each may have its own orthogonal pn code

<table>
<thead>
<tr>
<th>Channel</th>
<th>Center Frequency (GHz)</th>
<th>Upper Frequency (GHz)</th>
<th>Lower Frequency (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.48</td>
<td>3.74</td>
<td>3.22</td>
</tr>
<tr>
<td>2</td>
<td>4.02</td>
<td>4.28</td>
<td>3.76</td>
</tr>
<tr>
<td>3</td>
<td>4.56</td>
<td>4.82</td>
<td>4.30</td>
</tr>
</tbody>
</table>
Spectral Flexibility is Essential for Outdoors Operation

- Outdoor spectrum surveys in USA for the 3.1-5 GHz band show high levels of interference
  - It is expected that worldwide surveys will show similar results
- Outdoors UWB system will need to be able to select usable band based on spectral surveys
Transmit Pulse Shaping

- Triangular or half cosine short pulses ~ 4 ns
  - Polarity of pulses scrambled to flatten spectrum
- Pulses repeated at 12 MHz rate
  - Minimal multipath interference between pulses
- Immune from distortion or ringing from antennas or filters owing to relatively long pulse time
OOK Modulation Enables Simple Transmitter Architecture

- OOK requires a very simple transmitter architecture
- Pulses with different center frequencies may be generated without a local oscillator
- Separation of pulses by ~83 ns provides enough time for multipath decay

Symbol period = \(~83.3\) ns

Time

Logic 0

no pulse sent

Logic 1

Pulse generator

Convolutional encoder

pn code spreading

Data

Polarity Band select

\(~4\) ns
Spreading Code Description

- Spreading code increases SNR per bit and provides isolation for multiple uncoordinated piconets
- Maximal length (m-sequence) with m=4, n=15 will be utilized
  - Logic 1 uses the sequence Logic 0 is the inverse
- Each channel will have its own orthogonal sequence
- Additional repeat code can tradeoff range for lower data rates

<table>
<thead>
<tr>
<th>Seq.</th>
<th>Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>001000111101011</td>
</tr>
<tr>
<td>2</td>
<td>101011001000111</td>
</tr>
<tr>
<td>3</td>
<td>010110010001111</td>
</tr>
</tbody>
</table>
Simultaneously Operating Piconets

- Three nearly orthogonal frequency channels have been identified
  - orthogonal spreading code will increase isolation between piconets
  - Shaped pulses will reduce spillage from one channel to next
- More channels can be defined with orthogonal spreading codes
# Link Budget

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Xi</th>
<th>Xo</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak payload bit rate (Rb)</td>
<td>400.0</td>
<td>100 kbps</td>
<td></td>
</tr>
<tr>
<td>Proposed range</td>
<td>30.0</td>
<td>60 m</td>
<td></td>
</tr>
<tr>
<td>Average Tx power (Pt)</td>
<td>-17.0</td>
<td>-17.0 dBm</td>
<td></td>
</tr>
<tr>
<td>Tx antenna gain (Gt)</td>
<td>0.0</td>
<td>0.0 dB</td>
<td></td>
</tr>
<tr>
<td>Center frequency (Fc)</td>
<td>4.0</td>
<td>4.0 GHz</td>
<td></td>
</tr>
<tr>
<td>Path loss at 1 meter (L1=20Log(4PI*Fc/c) )</td>
<td>44.6</td>
<td>44.6 dB</td>
<td></td>
</tr>
<tr>
<td>Path loss at 30/60 meters (L2=20log(d))</td>
<td>29.5</td>
<td>35.6 dB</td>
<td></td>
</tr>
<tr>
<td>Rx antenna gain (Gr)</td>
<td>0.0</td>
<td>0.0 dBi</td>
<td></td>
</tr>
<tr>
<td>Rx power (Pr =Pt+Gt+Gr-L1-L2)</td>
<td>-91.1</td>
<td>-97.1 dBm</td>
<td></td>
</tr>
<tr>
<td>Average noise power per bit (N=-174 +10*log(Rb))</td>
<td>-118.0</td>
<td>-124.0 dBm</td>
<td></td>
</tr>
<tr>
<td>Rx Noise Figure Referred to the Antenna Terminal (Nf)</td>
<td>7.0</td>
<td>7.0 dB</td>
<td></td>
</tr>
<tr>
<td>Average noise power per bit (Pn=N+Nf)</td>
<td>-111.0</td>
<td>-117.0 dBm</td>
<td></td>
</tr>
<tr>
<td>Minimum Eb/No (S)</td>
<td>8.0</td>
<td>8.0 dB</td>
<td></td>
</tr>
<tr>
<td>Implementation Loss(I)</td>
<td>5.0</td>
<td>5.0 dB</td>
<td></td>
</tr>
<tr>
<td>Transmit p-p voltage at PA</td>
<td>0.7</td>
<td>0.7 Volt</td>
<td></td>
</tr>
<tr>
<td>Link Margin (M=Pr-Pn-S-I)</td>
<td>6.9</td>
<td>6.9 dB</td>
<td></td>
</tr>
<tr>
<td>Min. Rx Sensitivity Level (Pr-M)</td>
<td>-98.0</td>
<td>-104.0 dBm</td>
<td></td>
</tr>
<tr>
<td>Achievable Range in AWGN</td>
<td>66.2</td>
<td>132.4 m</td>
<td></td>
</tr>
</tbody>
</table>
PHY Preamble

- PHY preamble will consist of 12 symbols, each is a repeat of the spreading code making a ‘1’, followed by one repeat of the inverse of code.
- PHY header will be 1 byte long

12 Code repeats | 1 inverse code | Phy Header | MPDU

16.25 usec.
Time-Difference-of-Arrival (TDOA) Location Algorithm using One-Way Ranging (OWR)

- TDOA determines relative position of the mobile transmitter with respect to the anchor receiver
  - No clock accuracy requirement for mobile
  - Need synchronization between anchor receivers
- Ranging function may be carried out in multiple frequency channels
  - Increases resolution accuracy
- Three TDOA measurements are needed for target location estimation
TDOA Measurements & Location Estimation

\[ c(T_2 - T_1) = \sqrt{(x_{A2} - x_m)^2 + (y_{A2} - y_m)^2} - \sqrt{(x_{A1} - x_m)^2 + (y_{A1} - y_m)^2} \]

\[ c(T_2 - T_3) = \sqrt{(x_{A2} - x_m)^2 + (y_{A2} - y_m)^2} - \sqrt{(x_{A3} - x_m)^2 + (y_{A3} - y_m)^2} \]
Manufacturability & Technical Feasibility

- One chip solution in CMOS or SiGe
  - Chips based on this technology are available
- The relatively long subpulse time makes it immune from distortion or ringing from antennas or filters owing to Relaxed antenna characteristics
- A simple analog based solution or a digital high performance receiver are both feasible
Scalable Receiver Architectures

- Receiver architecture scalable from a simple analog solution to a Rake based digital solution
Conclusions

• UWB pulsed multiband system
• Multiple frequency channels provide spectral flexibility and robustness against interference.
• Low signal repetition frequency to reduce inter chip interference and reduce power consumption
• Scalable architecture for lower cost and power and higher performance
• Remaining material will be presented at the next opportunity
• General Atomics will actively pursue opportunities for merging with other proposals