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]

Overview of General Atomics Multiband Impulse Radio (MBIR) 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=½, k=7

Features

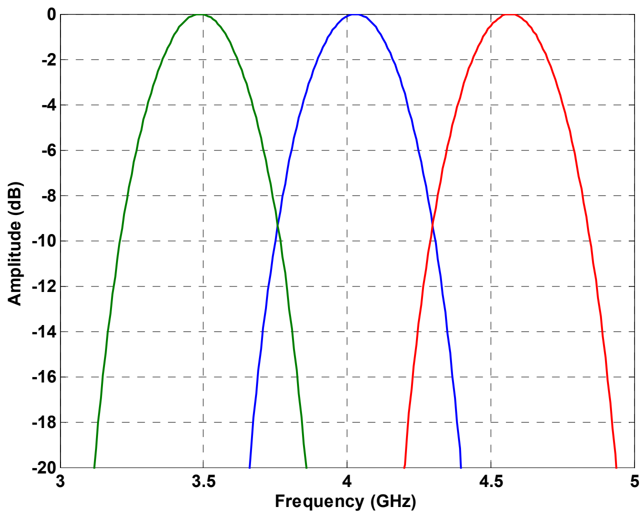
- Spectral flexibility to avoid interference and satisfy different international regulations
- Simple architecture facilitates one chip CMOS or SiGe solution
- Long guard period between pulses enhances multipath immunity
- Ultra low power consumption through simple architecture and low duty cycle
- Scalable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

Major System Parameters

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

Band Plan

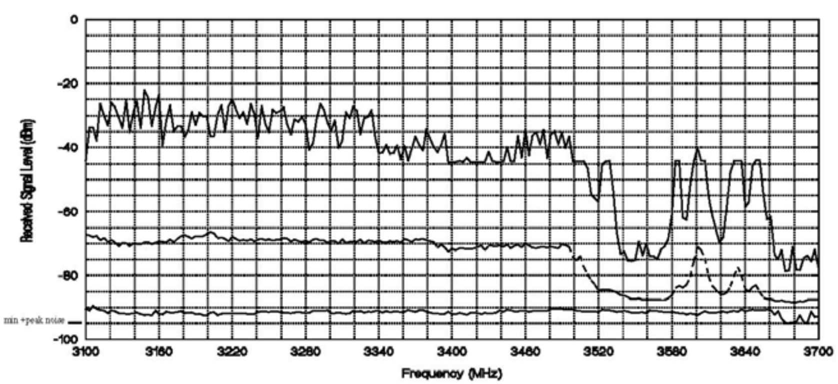
- 3 orthogonal frequency channels in the 3.1-5.0 GHz band
- Provides flexibility for worldwide spectrum regulations
- Channel scan may be used to avoid interference
- Each may have its own orthogonal pn code



Channel	Center Frequency (GHz)	Upper Frequency (GHz)	Lower Frequency (GHz)
1	3.48	3.74	3.22
2	4.02	4.28	3.76
3	4.56	4.82	4.30

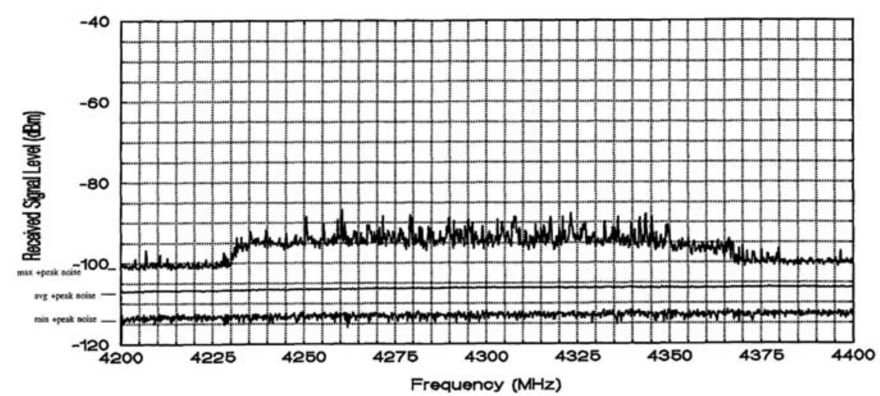
Spectral Flexibility is Essential for Outdoors Operation

- 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



1. AERONAUTICAL RADIONAVIGATION (Ground-based).
2. Radiolocation.
3. Primarily, military airborne, land-based, and shipborne defense radars.

Figure 30. NTIA spectrum survey graph summarizing 70 scans across the 3100-3700 MHz range (System-2, band event 15, stepped algorithm, +peak detector, 3000-kHz bandwidth) at Los Angeles, CA, 1995.

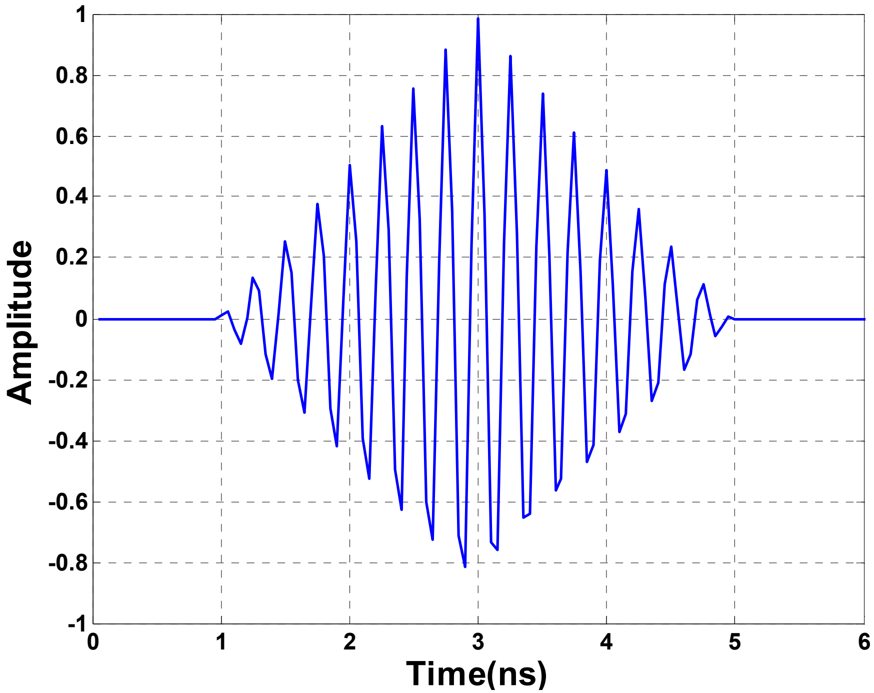


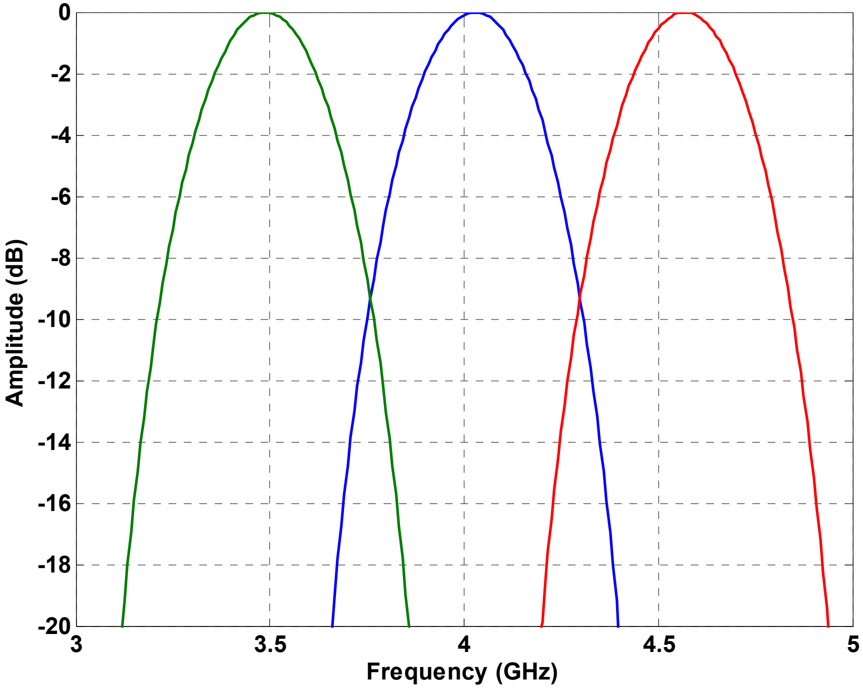
1. 4202 ±12 MHz: Standard frequency and time satellite service (space-to-Earth), permitted.

Figure 32. NTIA spectrum survey graph summarizing 32,500 sweeps across the 4200-4400 MHz range (System-2, band event 17, swept/m3 algorithm, +peak detector, 300-kHz bandwidth) at San Diego, CA, 1995.

Transmit Pulse Shaping

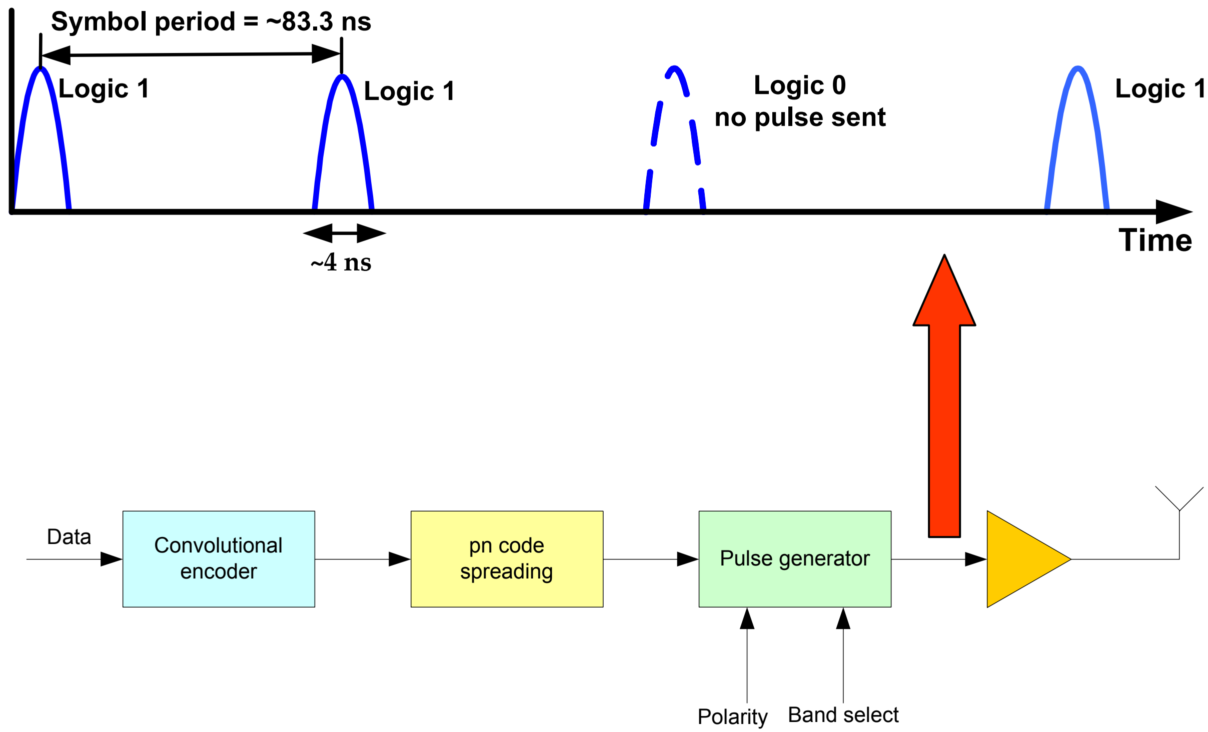
- Triangular or half cosine short pulses ~ 4 ns
  - Polarity of pulses scrambled to flatten spectrum
- Pulses repeated at 12 MHz rate
  - Minimal multipath interference between pulses
- Immune from distortion or ringing from antennas or filters owing to relatively long pulse time





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



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

Seq. 1	001000111101011
Seq. 2	101011001000111
Seq. 3	010110010001111

Simultaneously Operating Piconets

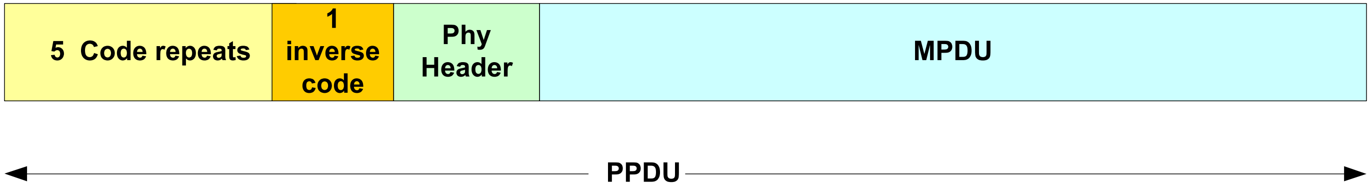
- Three nearly orthogonal frequency channels have been identified
  - orthogonal spreading code will increase isolation between piconets
  - Shaped pulses will reduce spillage from one channel to next
- More channels can be defined with orthogonal spreading codes

Link Budget

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

PHY Preamble

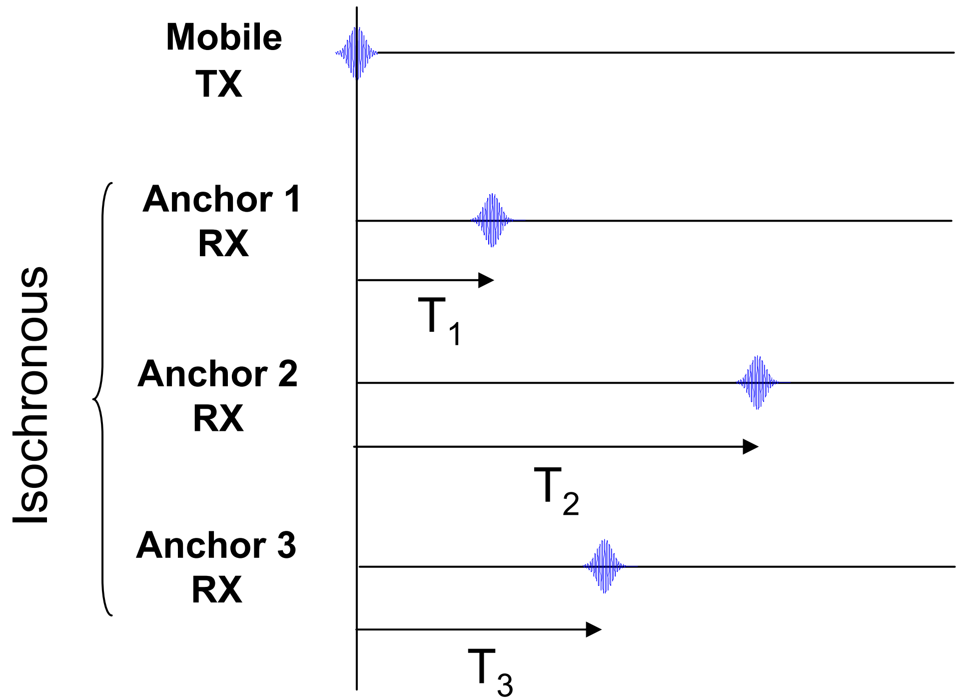
- PHY preamble will consist of 5 repeats of the spreading code followed by one repeat of the inverse of code

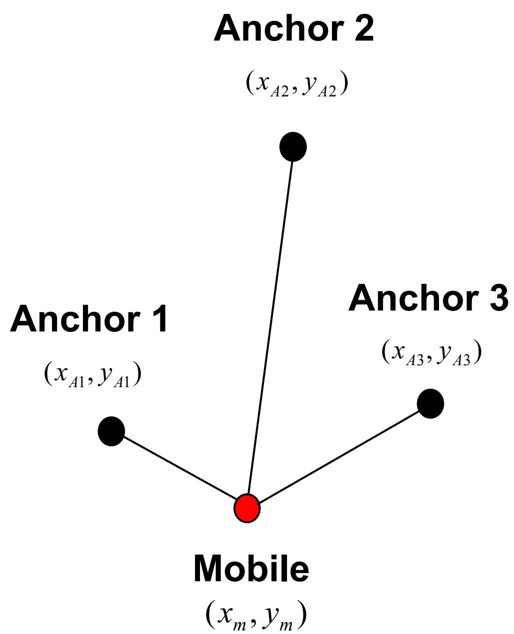


Time-Difference-of-Arrival (TDOA) Location Algorithm using One-Way Ranging (OWR)

- 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
- Immune from distortion or ringing from antennas or filters owing to relatively long subpulse time
- Relaxed antenna characteristics