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Submission Title: [Feasibility of Spectral Shaping]

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Abstract: [Feasibility of Spectral Shaping]

This document has been prepared for explaining feasibility of implementation of spectral shaping of transmitted UWB signals in order to show some examples for avoiding interference to coexisting systems. Three approaches for spectral shaping are discussed. One is based on an analog notch filtering with a analog delay line and 180 degree hybrid. Second is based on spreading codes to make periodical notches. Third is based on multiple frequency antenna.

Purpose: [Provide technical information to the TG3a voters regarding DS-UWB (Merger #2) Proposal]

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Feasible Implementation of Soft Spectral Shaping

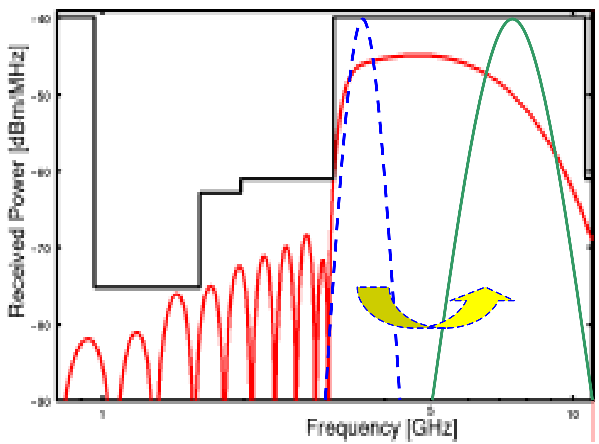
1. **Notch generation by using a simple analog delay line:** Analog type of SSA

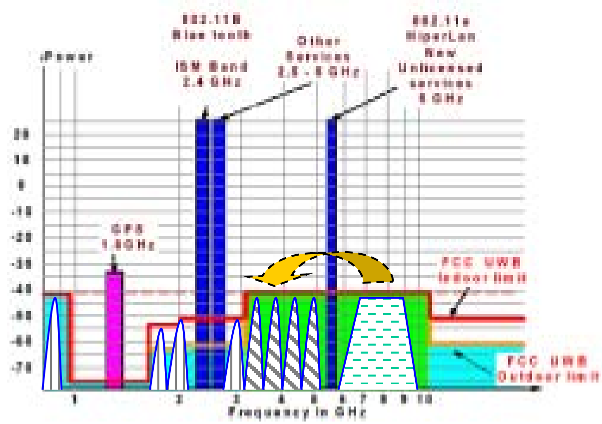
2. **Notch generation by using a spreading code**

3. **Notch generation by using a multiple frequency antenna**

1. Basic philosophy of Soft-Spectrum Adaptation

- Design a proper pulse waveform with higher ***frequency efficiency*** corresponding to any spectral mask
- Adjust transmitted signal's spectrum with ***flexibility***, so as to minimize interference to/from coexisting systems
- Employ ***optimized*** pulse wavelets to achieve higher system performance





Basic Formulation

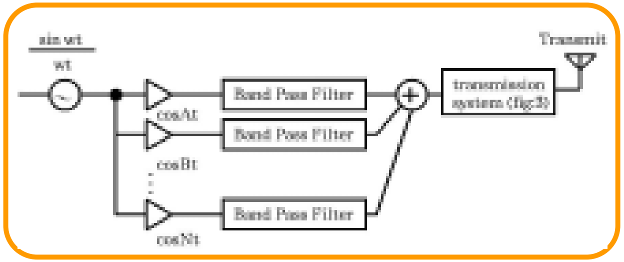
$$f(t) = \sum_{k=1}^{N} f_k(t)$$ ← **Synthesize pulse waveform**

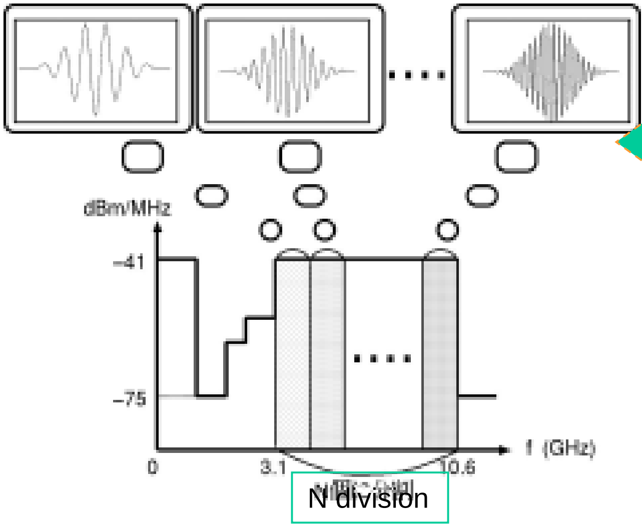
In case of multiband: Kernel function is Sinusoidal

$$f_k(t) = \cos[2\pi(f_L + \frac{(1+2k)B}{2N})t] \times \frac{\sin(B\pi t)}{N\pi t}$$

B:bandwidth [f_H ∼ f_L]

Example of Pulse Generator



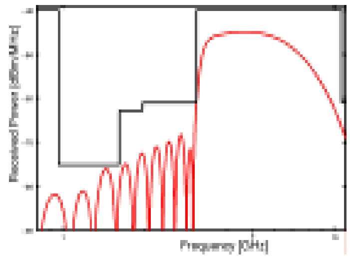


Feasible Solution: Pulse design satisfying Spectrum Mask

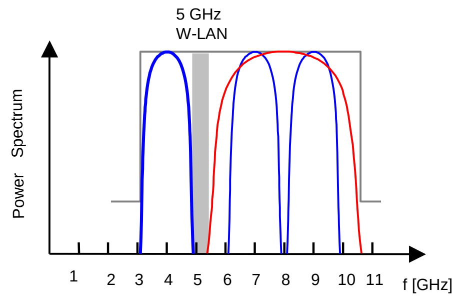
- Divide (spread-and-shrink) thewhole bandwidth into several sub-bands → *Soft Spectrum* (spectrum matching)
- Pulse synthesized by several pulses which have different spectra→ *Soft Spectrum,* *M*-ary signaling

SSA-UWB with flexible band plan

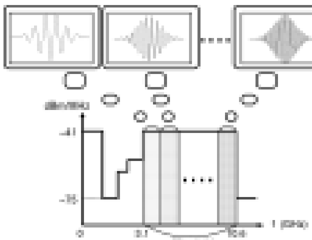
Single-band



Dual- or Triple-band

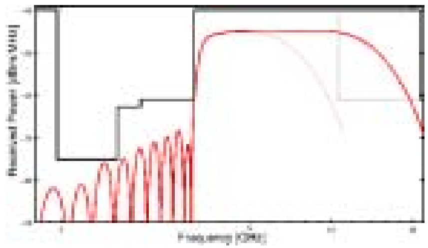


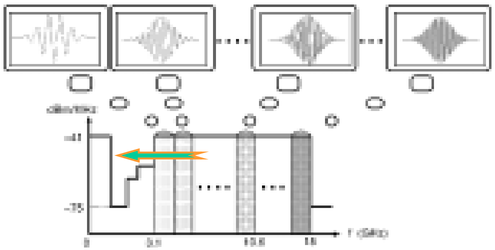
Multi-band



N division

In the future, if the restricting ruggedness of regional spectral mask (e.g. FCC mask) is eased, band allocation can be extended <u>below</u> 3.1 GHz or <u>above</u> 10.6 GHz.





N+α division

Soft-Spectrum Adaptation (SSA) can correspond freely

Soft-Spectrum Adaptation(SSA) Classification

(1) Free-Verse Type of SSA

→ A kernel function is non-sinusoidal, e.g. Gaussian, Hermitian pulse etc.

→ Single band, Impulse radio

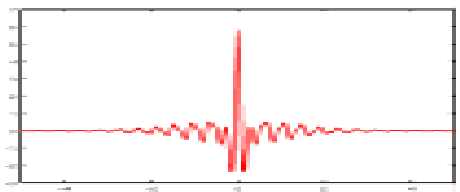
(2) Geometrical Type of SSA

→ A kernel function is sinusoidal with different frequency.

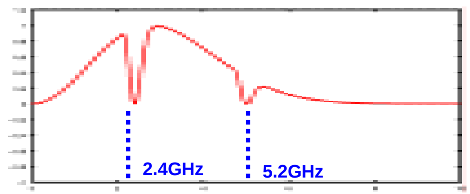
→ Multiband with carriers and Multi-carrier

(1) Free-verse Type Soft-Spectrum Adaptation

→ Freely design pulse waveforms by synthesizing pulses, e.g. overlapping and shifting

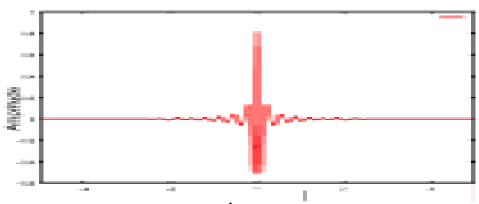


time

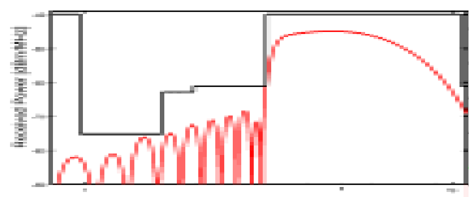


frequency

K-3 Free-verse *Soft-Spectrum* Adaptation pulse
(Note: band notches *clearly* happen at 2.4 and 5.2 GHz as well)



time

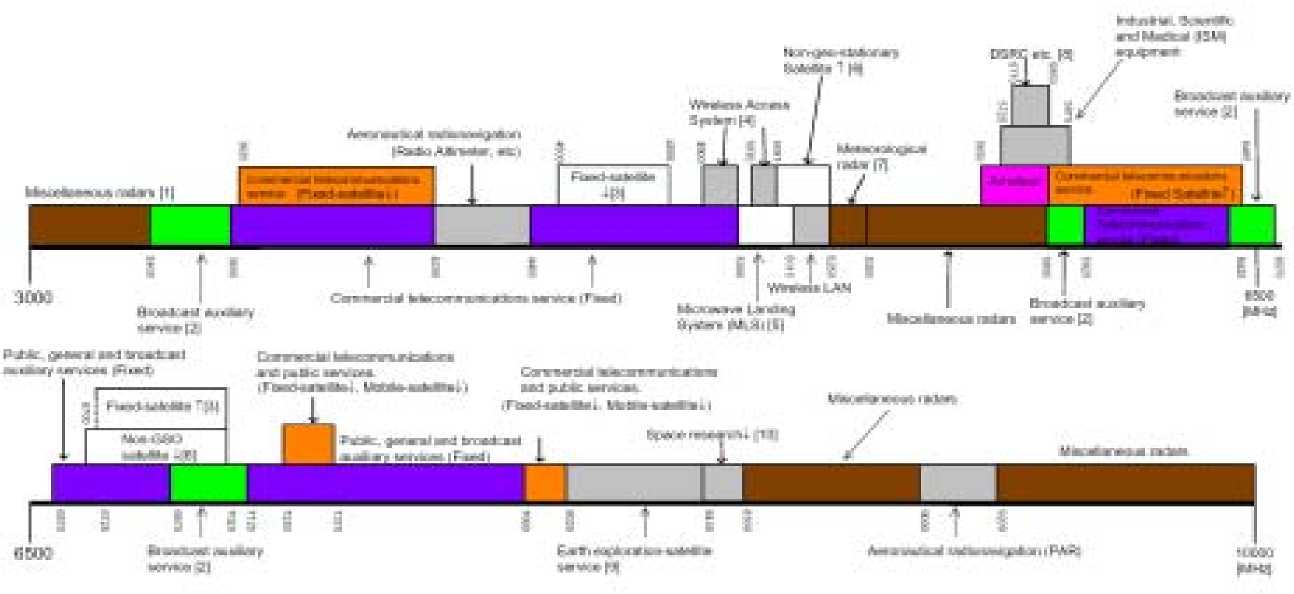


frequency

K-4 Free-verse *Soft-Spectrum* Adaptation pulse
(Note: pulse waveform has more freedom)

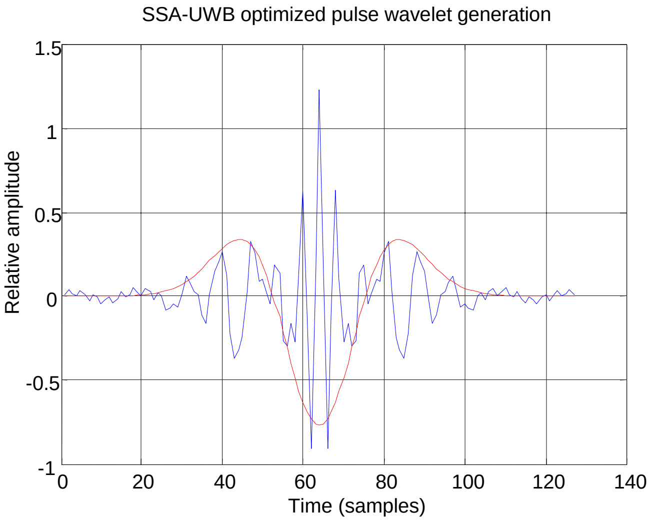
Japanese Spectral Allocation of Coexisting Systems in 3.1～10.6GHz (no blank spectrum slot)

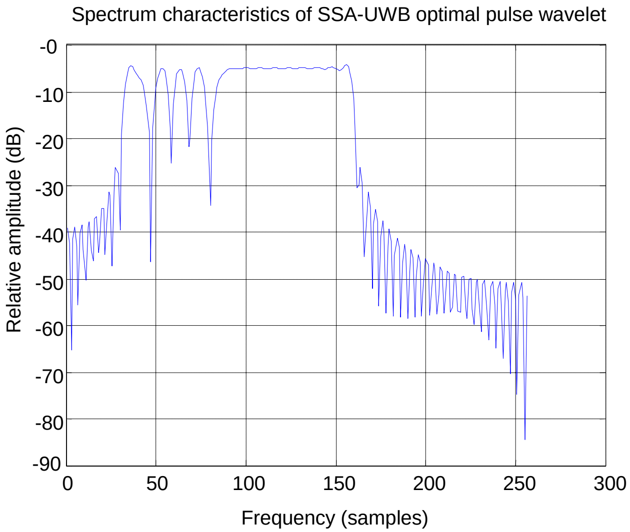
3000 MHz – 10000 MHz

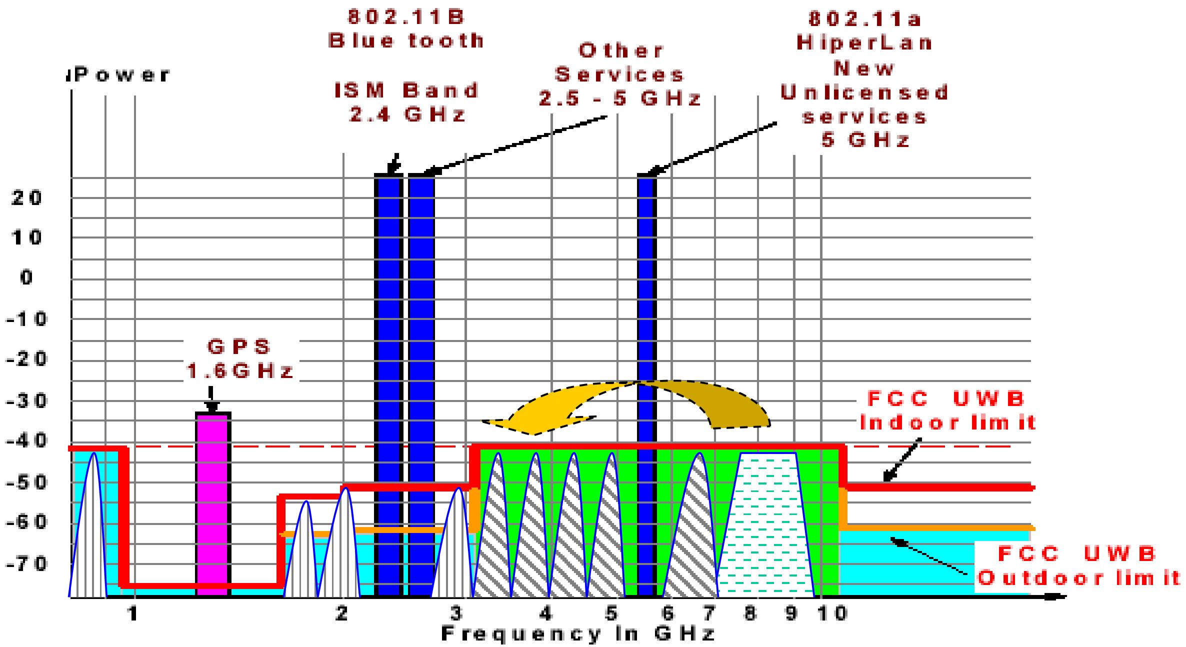


* Supplementary information on the next page.

Modified SSA-UWB pulse wavelet with adaptive spectral notches achieving coexistence, flexibility and efficient power transmission

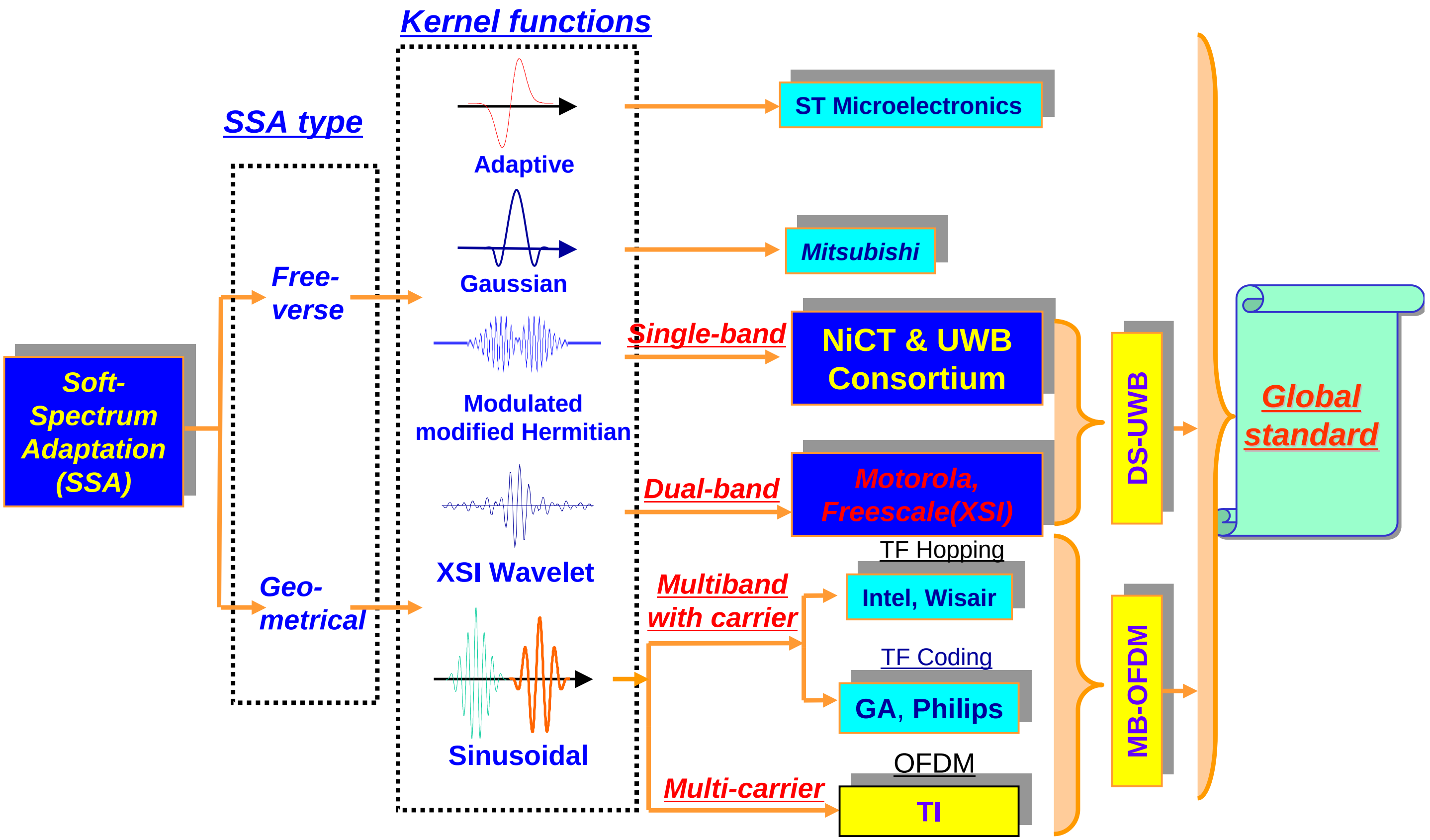






Geometric Soft-Spectrum Adaptation (*Spread-and-Shrink*) and pulse waveform shaping provide new dimension, frontier, and challenge (seeing FCC UWB Emission Limit: FCC 02-48, UWB Report & Order)

Global harmonization and compromise based on SSA-UWB



Summary of Soft-Spectrum Adaptation

- ***Global Regulatory Satisfaction: Soft-Spectrum adaptation(SSA)*** can satisfy the FCC Spectrum Mask and any Mask adaptively.

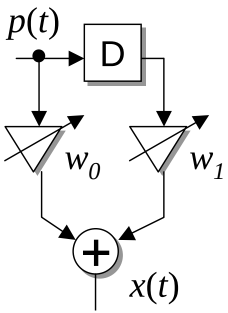
- ***Interference Avoidance: SSA*** can be applied to avoid possible interferences with other existing narrowband wireless systems.

- ***Global Hamonization: SSA*** is good for harmonization among different UWB systems because ***SSA*** includes various proposed UWB systems as its special cases.

- ***Future Version-up: SSA*** is so scalable as to accept future UWB systems with better performance like ***Software Defined Radio(SDR)***.

1. Notch generation by using a simple analog delay line: Analog type of SSA

- Example： **Just Two taps delay line**



The output signal x(t) is given by

$$x(t) = w_0 p(t) + w_1 p(t - \delta)$$

where $p(t)$ is a pulse signal , and δ is delayed time by a delay line D.
By assuming that coefficients w_0 and w_1 is time- invariant,
then its signal in frequency domain is given by

$$X(f) = \left(w_0 + w_1 e^{j2\pi f\delta}\right) P(f)$$

Now, we set w_0=1 and w_1=a (a *is in real value*), we obtain

$$X(f) = \left(1 + a e^{j2\pi f\delta}\right) P(f) = \left(1 + a\cos 2\pi\delta f + j \cdot a \sin 2\pi\delta f\right) P(f)$$

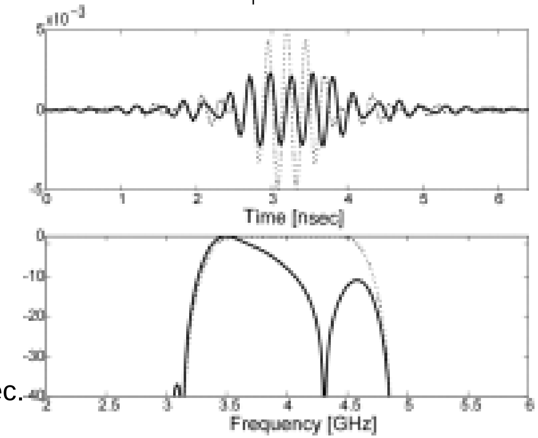
A notch is generated at a frequency f_n where $|X(f_n)|^2=0$, then

$$a^2 + 2a\cos 2\pi\delta f_n + 1 = 0$$

The solutions are given by $a = -\cos 2\pi\delta f_n \pm \sqrt{-\sin^2 2\pi\delta f_n}$,
however, the coefficient a can take only real value. Therefore,

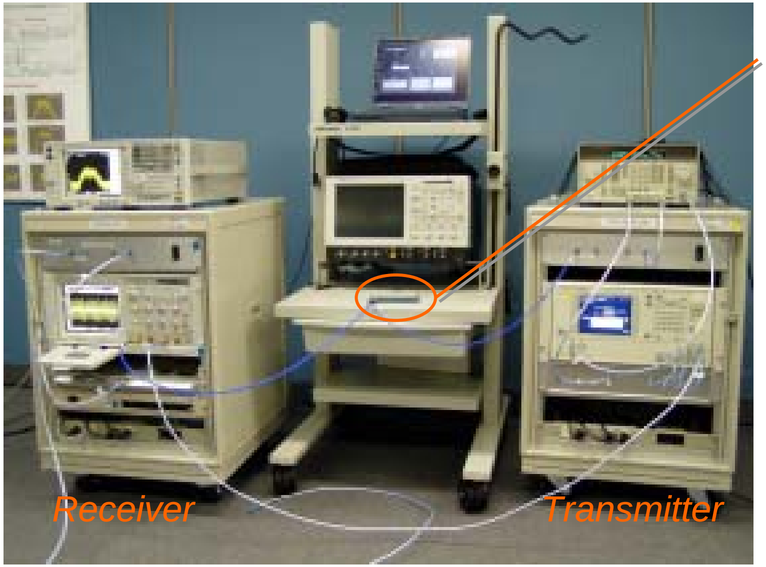
$$f_n\delta = m/2 \quad (m=1,2,3,\ldots) \qquad a = -\cos m\pi$$

As you can see, the coefficient a takes +1 or -1.
It leads simple implementation.

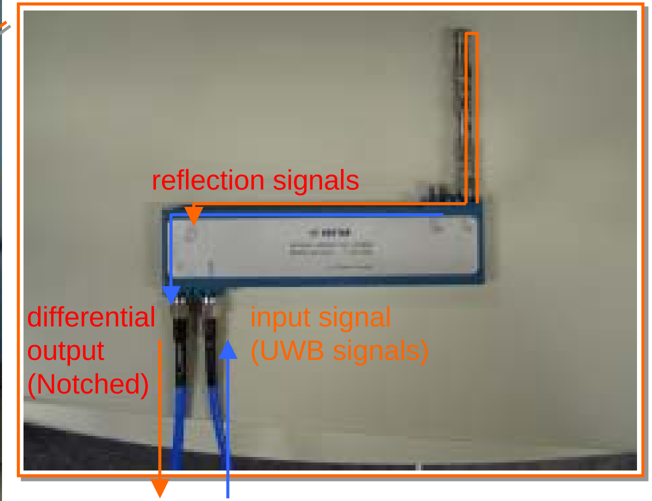


The right figure is an example; a is set to 1 and δ is set at 0.116nsec.

Notching (Experiments)



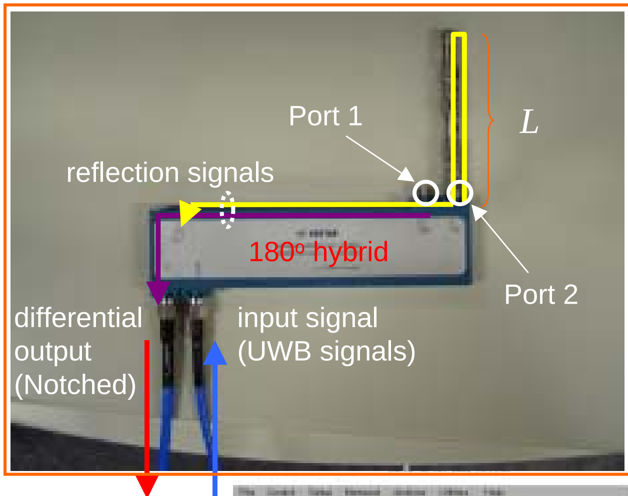
UWB Testbed by *NICT*

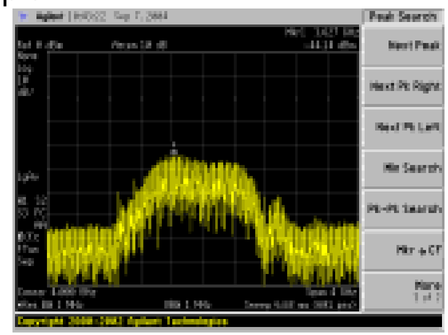


Notch generator
(by using 180º Hybrid)

Experiments

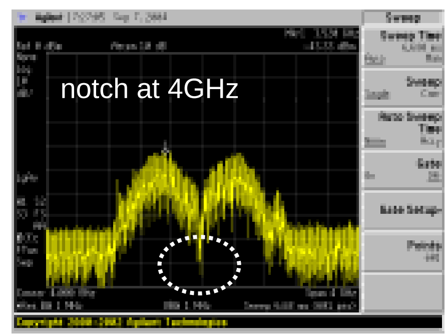
By setting the electric length L $(=c\delta=c/f_n;\ m=2)$, a notch at arbitrary frequency f_n is obtainable, in principle.





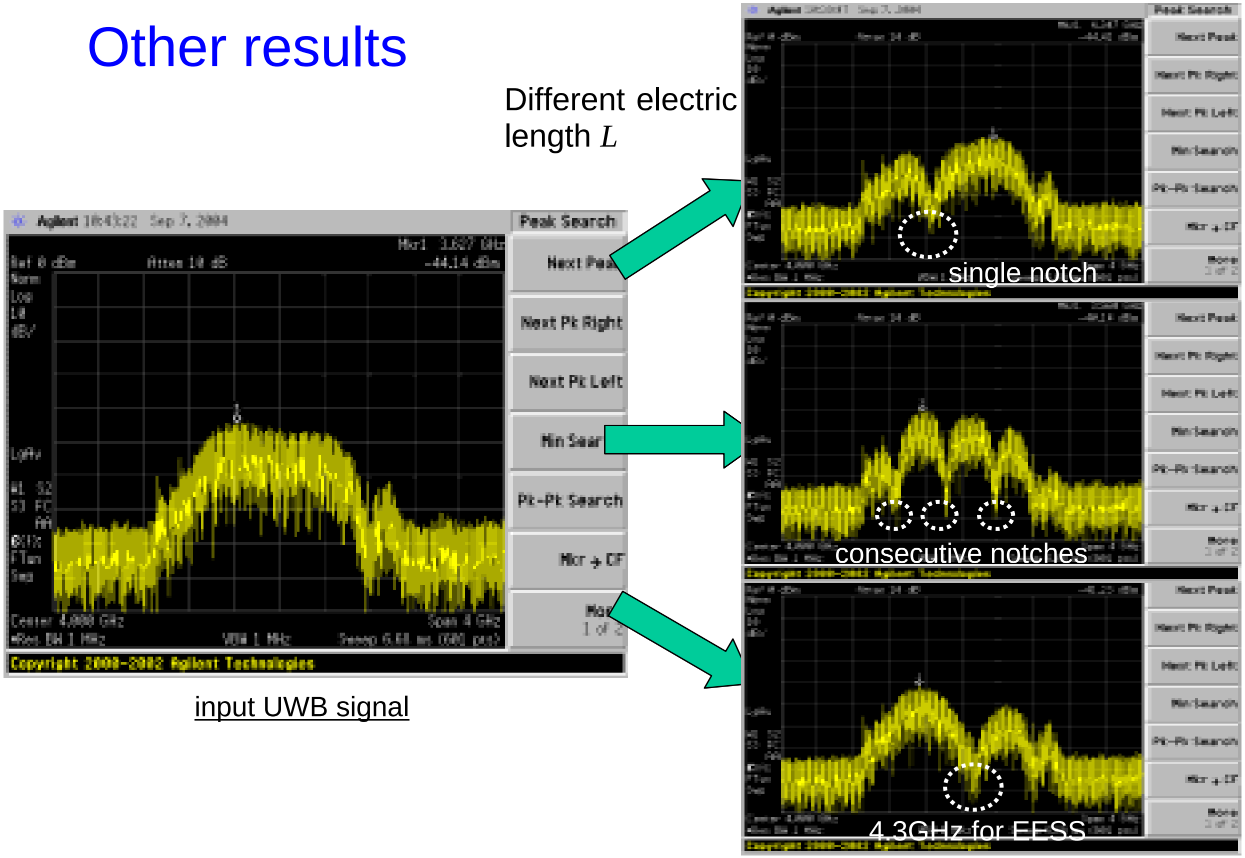
input signal (UWB signals)

reflection signals from Port 1 and 2



output signal (L=3. 5cm)

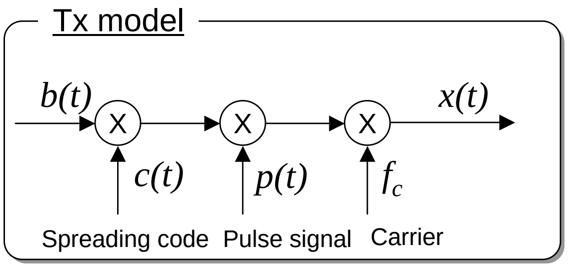
Other results



input UWB signal

2. Notch generation by using a spreading code

- DS-UWB systems



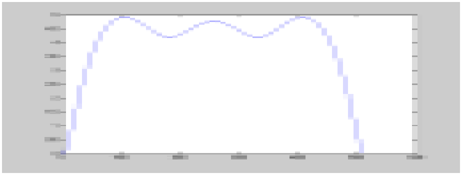
Frequency domain

$$X(f+f_c)=\underline{B(f)\otimes C(f)\otimes P(f)}$$

Output spectrum is given by convolution

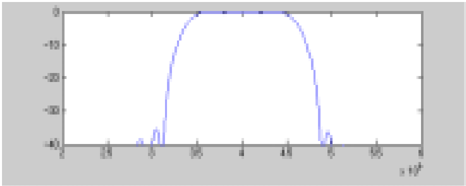
By choosing appropriate spreading code, we can design notch matched with a coexisting system.
Example: $c(t)$=[-1 -1 -1 1 1 -1 1 1]

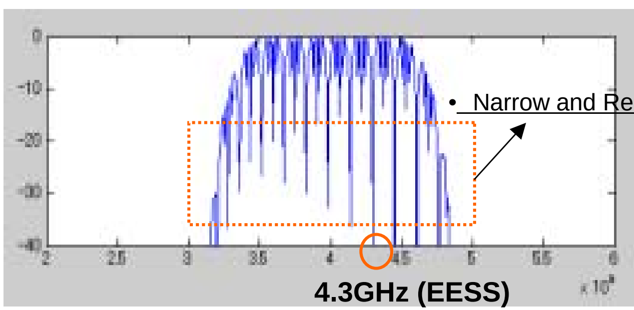
Spectrum of a spreading code



Convolution $\otimes$

Spectrum of a pulse signal



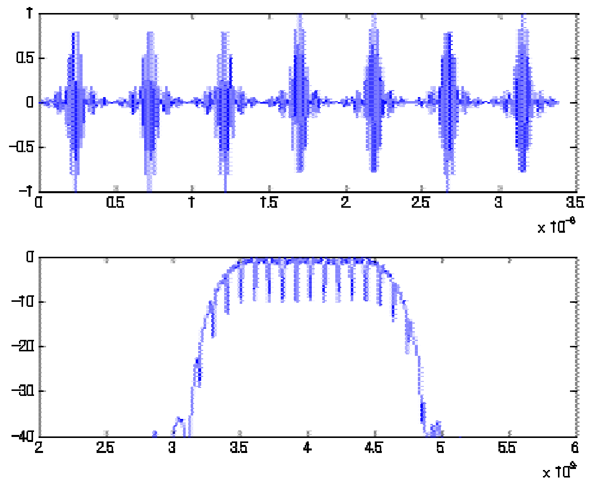


- Narrow and Repetitive

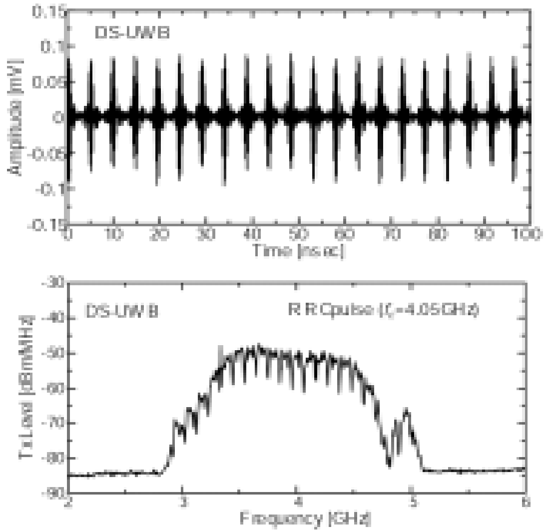
4.3GHz (EESS)

Notch generation by using a spreading code

- Experimental result by UWB Test bed

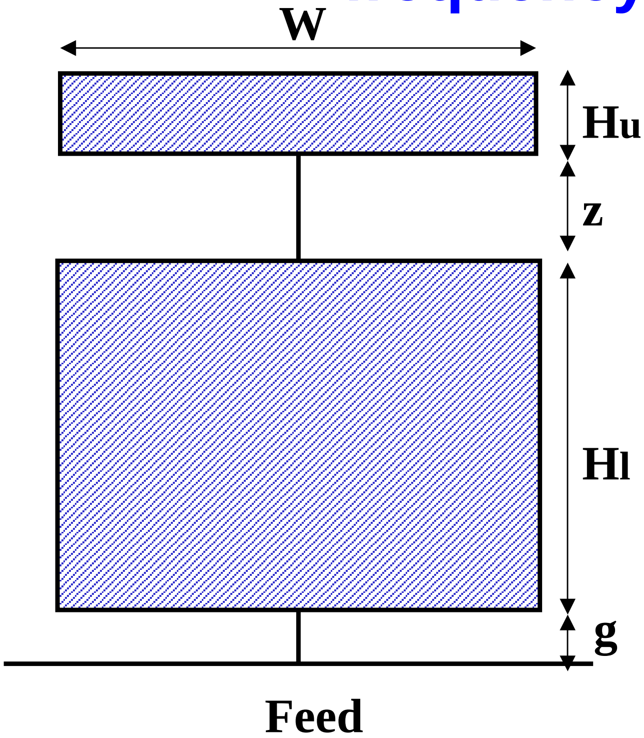


MATLAB results



UWB testbed outputs

3. Notch generation by using a multiple frequency antenna



Upper : Rectangle element
(connected with lower)
Lower : Rectangle element
(Planar monopole antenna)

FDTD parameter

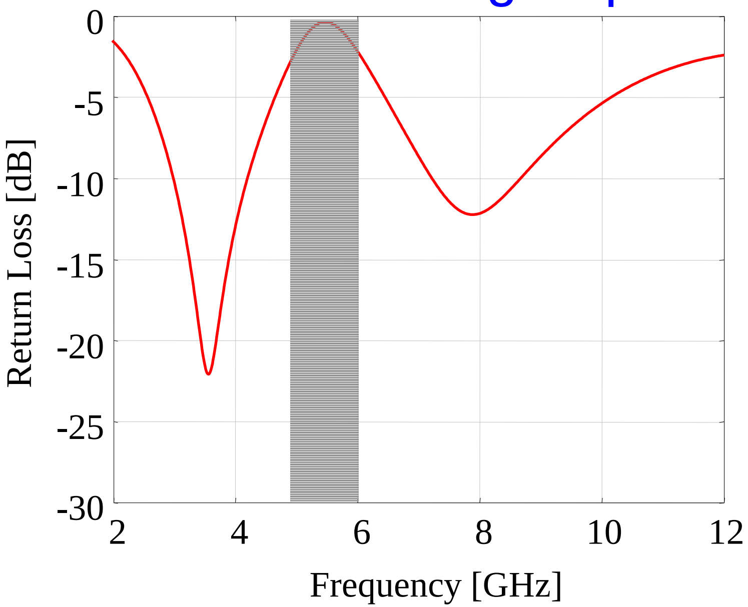
Cell size: Dx,y=1mm
Dz=0.5mm

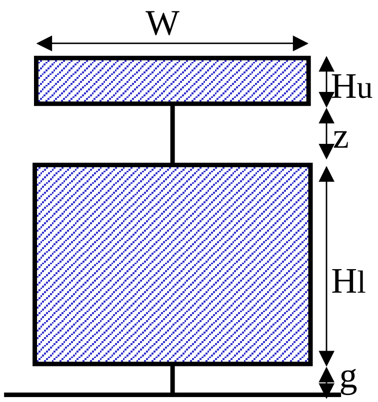
Iteration steps : 5000

ABC : PML 8 layer

Input：Gaussian Pulse

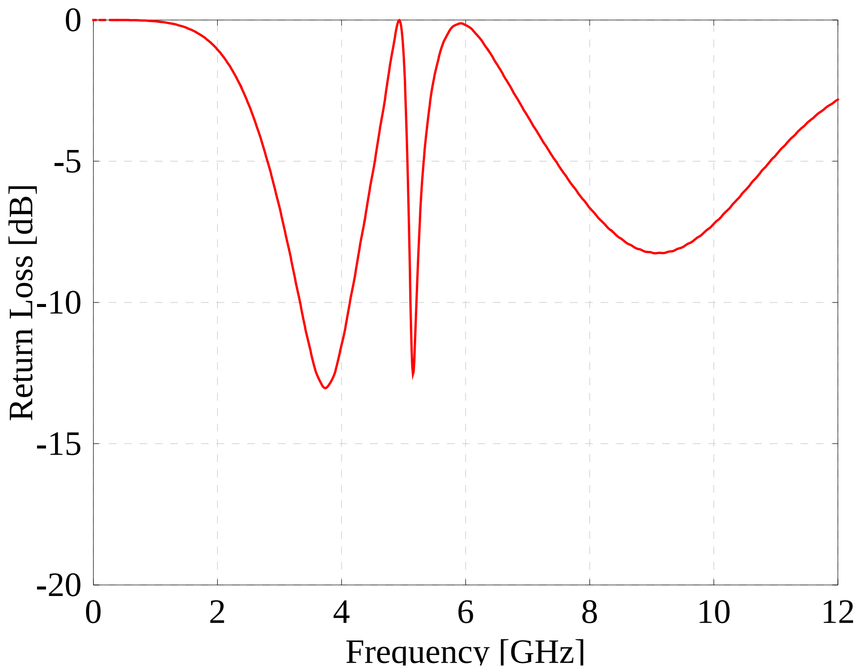
Return Loss Characteristics of Example Antenna With Notch Filtering Capability to Avoid Interference

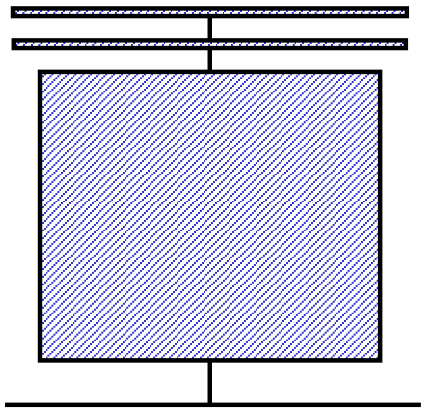




Wide bandwidth with dual frequency can be achieved.
Return Loss level is almost 0dB at around 5~6GHz.

Example Antenna
With Notch Filtering Capability for More Interferences





Conclusion on Implementation of Soft Spectral Shaping

1. To satisfy world wide regulation, a method to avoid interference to coexisting systems is necessary. Since a regulation may be different in each region, a method to avoid interference should be flexible.
2. NICT has presented a Soft Spectrum Adaptation (SSA) and appropriate UWB antennas to satisfy this requirement.
3. SSA is a theoretical optimal solution based on software reconfigurable radio(SDR) concept for this purpose.
4. There are many ways to carry out SSA by digital and analog implementation. This document shows some feasible examples of a way to implement.

(Approach 1): Notch generation by using a simple analog delay line:
(Approach 2): Notch generation by using a spreading code
(Approach 3): Notch generation by using a multiple frequency antenna