Analog Optical Signal Processing using Hyperfine Technology

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Essex Background

ESSEX

- Located in Columbia MD
- Core team from NSA Advanced Processing Technologies Division
- Building AOSPs since 1984
- Primary business areas
  - Hybrid processors based on AOSP
  - Fiber optic telecom based on hyperfine technology
  - Synthetic Aperture Radar processing
    - AOSP
    - Digital

AOSP Background

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- Cabochon - a frequency domain triple product processor (TPP) for spread spectrum code recovery and transmitter location
- Labyrinth - a hardened version of Cabochon for field deployment
- TTD - a true time delay beam former
- AOP - a 250 MHz to 1 GHz bandwidth radar range-Doppler imager
- Raptor - current program funded at $2.4M for a field demo of an AOP type processor at 1 GHz bandwidth ($5M for next year)
- ImSyn-i and ImSyn-k - Fourier transforms of non-rectilinear gridded data for SAR processing, medical imaging, and holographic GPen and FoPen.

Processing Hardware

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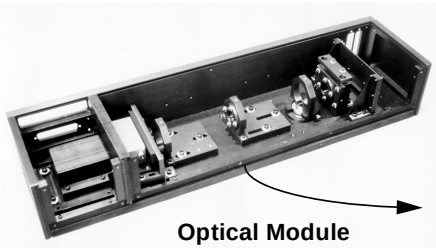
ImSyn

AOP



Optical Module

RF Module
- channelizer
- amplifier

Camera Module (4 6U-VME boards)
- detector A/D
- timing
- buffer memory

Pentium-II PC
- control
- post processing
- display

Hyperfine AOSP program

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- Phase I
  - Requirements study
  - Architecture and device study
  - Breadboard demo (one dimensional with in-house components)
- Phase II
  - Large BT architecture and device study
  - Brassboard design and fabrication
  - Testing
- Phase III
  - Field test and evaluation

Essex AOSP Phase I

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- EW Requirements analysis
- AOSP device and architecture study
- Architecture selection and design
- Demonstration based on in-house components

EW Signal Intercept System

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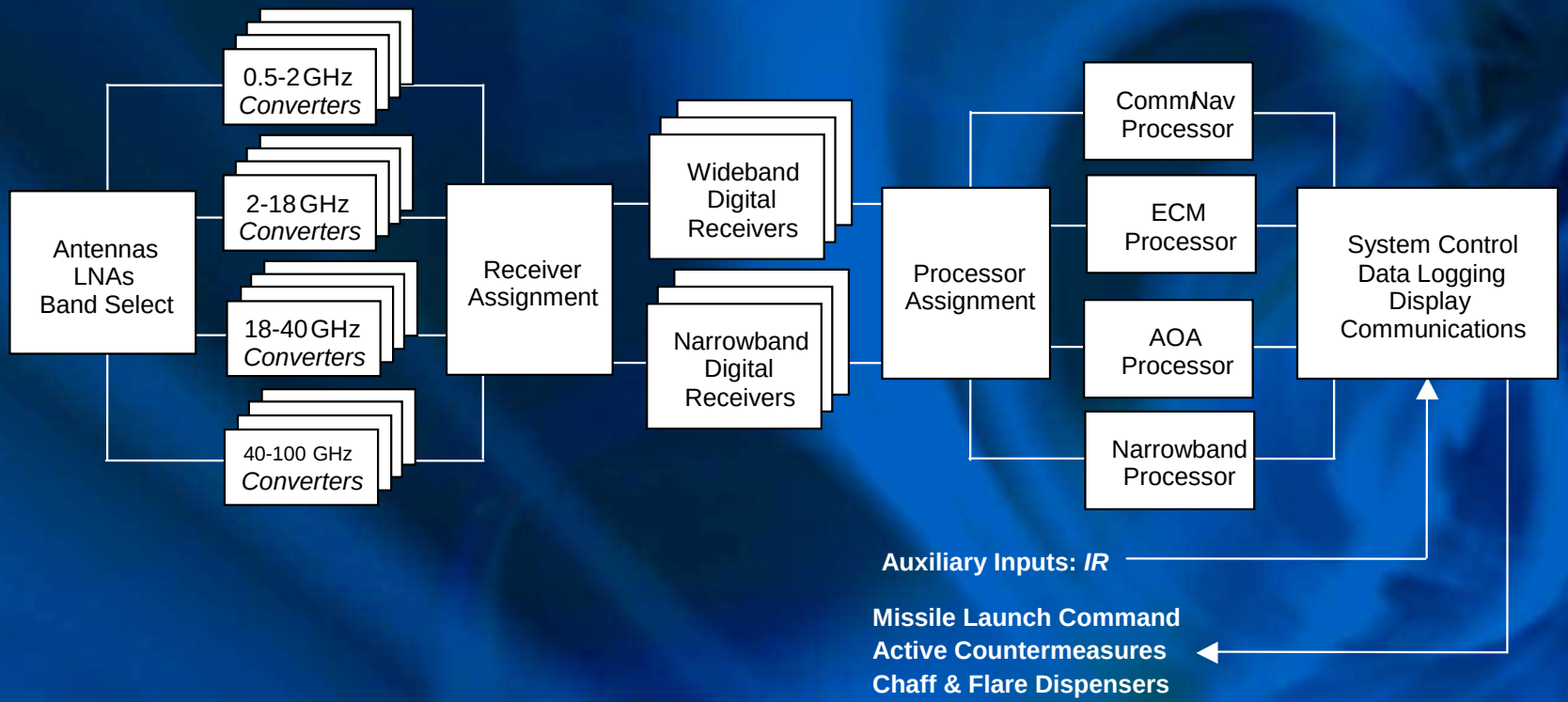

Hyperfine Based EW System

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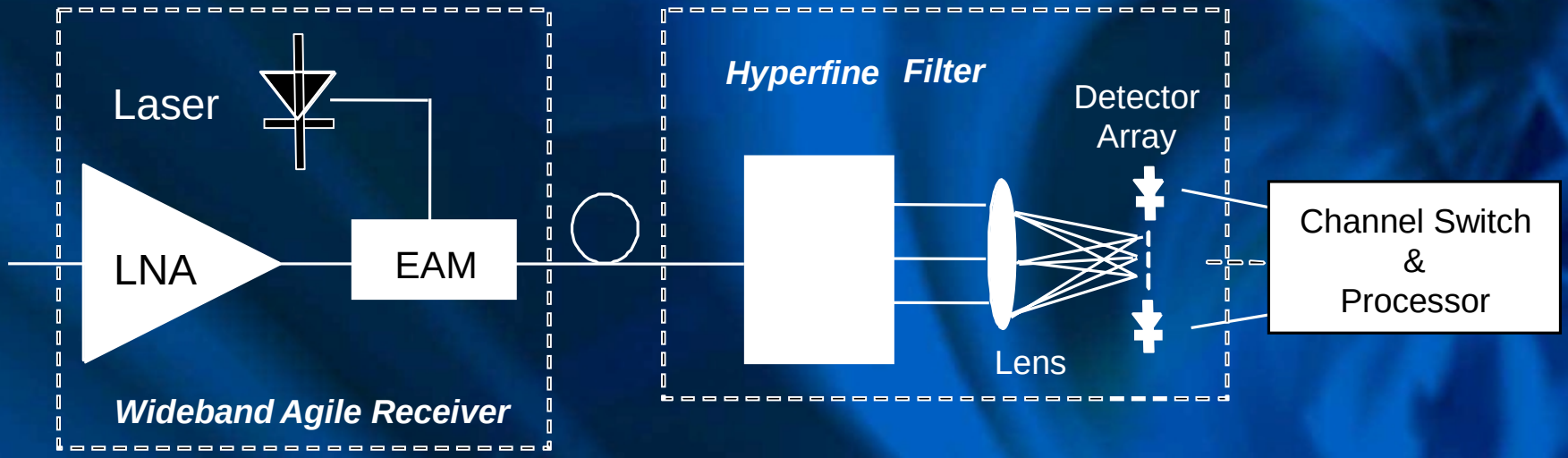

Architecture for Phase I

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- Demonstrate a breadboard hyperfine EW device
- Implement a coherent optical receiver
- Such a receiver enables wideband instantaneous coverage with narrowband sensitivity for
  - Detection
  - Characterization
  - AOA
  - LPI detection
  - Frequency measurement
- Use existing hyperfine devices and modulators

Hyperfine Technology

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- Originally designed as a Bragg cell replacement in optical processors
- Represents a breakthrough in wideband spatial light modulator technology
- Applicable to telecommunications and to wideband signal processing
- Essex has an effort to commercialize a fiber optic multiplexer and demultiplexer based on this technology

Wide-band Technology

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- Bandwidths from a Gigahertz to a Terahertz
- Spectral resolution from 50 MHz to 50 GHz
- Totally passive technology
- Can replace a Bragg cell in most signal processing architectures
- Can approach 100% diffraction efficiency in many applications
- The technology is free space optics, similar to a diffraction grating but with much higher resolution for a given aperture (a 250 MHz resolution spectrum analyzer is less than 1 cm aperture)
- Totally linear

Hyperfine WDM

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Passive Optical Multiplexing Technology

- **High density – 50 MHz to 50 GHz spacing**
- **Excellent filter shape control**
- **High channel isolation**
- **Low insertion loss**
- **Can be produced for all optical bands**
- **Small packaging**
- **Cost effective**
- **Standard manufacturing processes**

Field Trial Units

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Specifications

Technology	Passive Demux
Channels	16
Spacing	6.25 GHz
Free Spectral Range	100 GHz
Size	1.5 x 3.75 x 11”
Insertion Loss	5 dB (8 dB edge)
PMD	<1ps
PDL	<0.5dB
Channel Isolation	>25 dB
Data Rate	2.5 Gbps
Optical Window	C Band

Flat-Top Close-up 12.5 GHz

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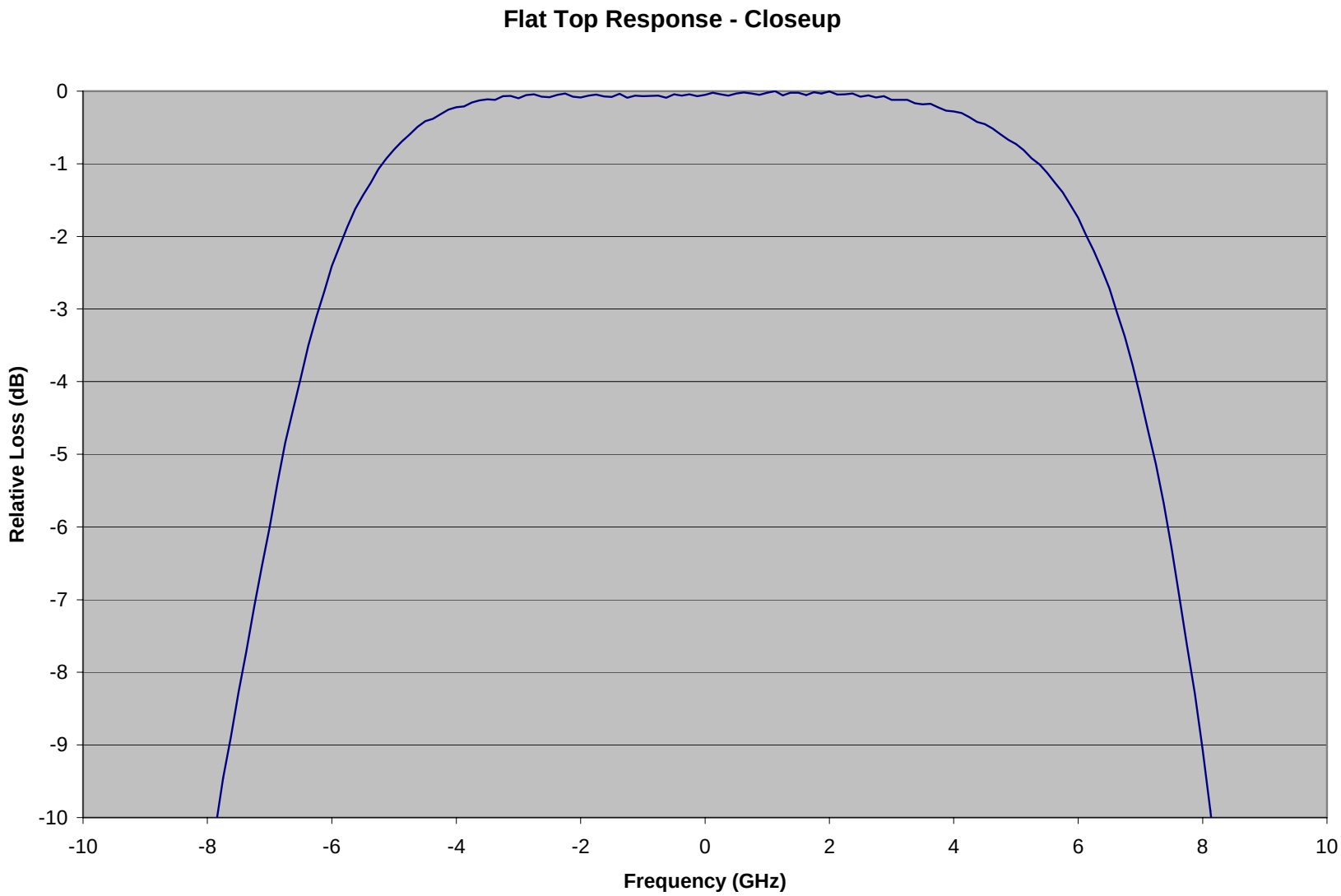
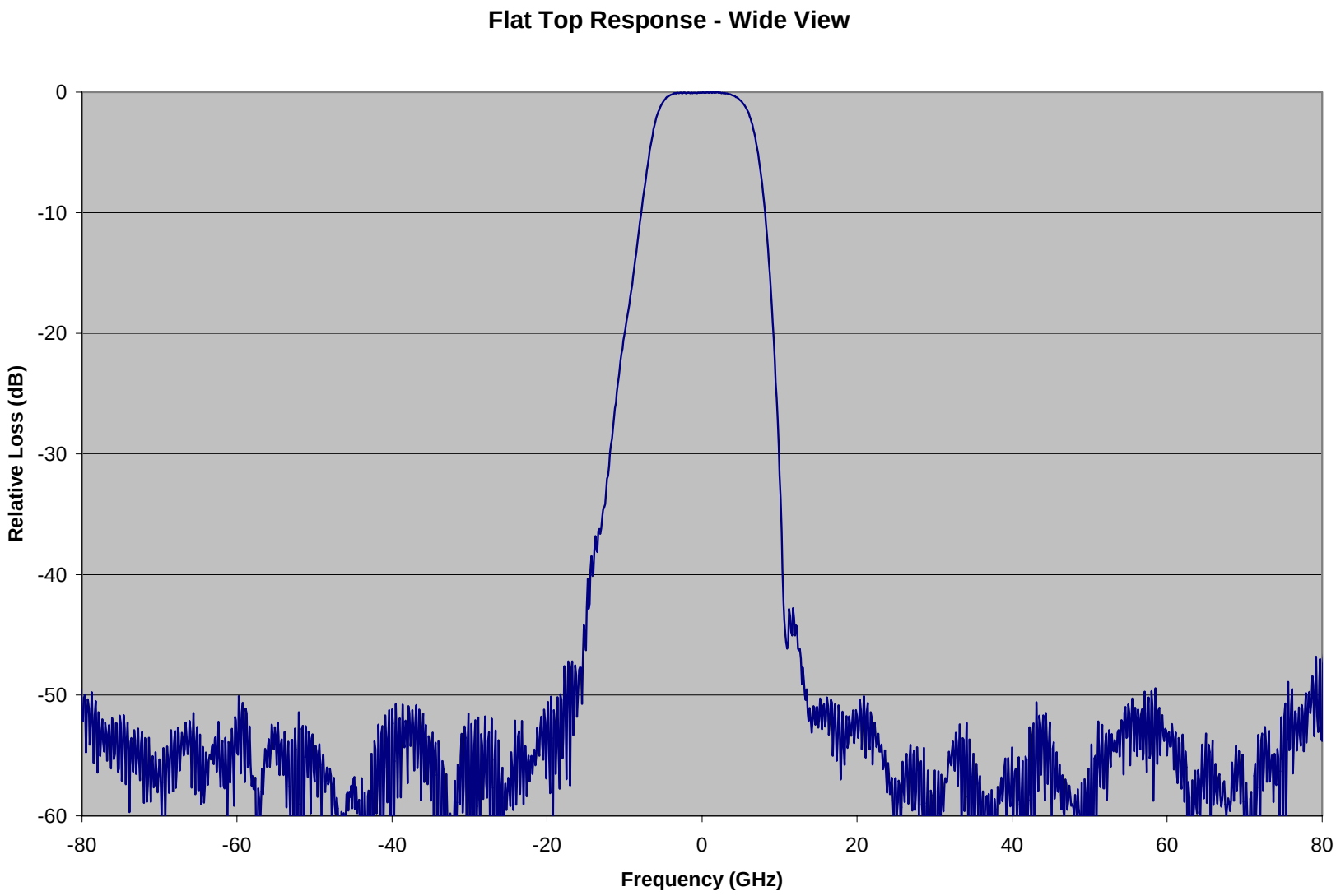


Flat-Top Filter Shape



Alpha Package

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6” x 3” x 0.5”

HfWDM – Demultiplexer Channelizer

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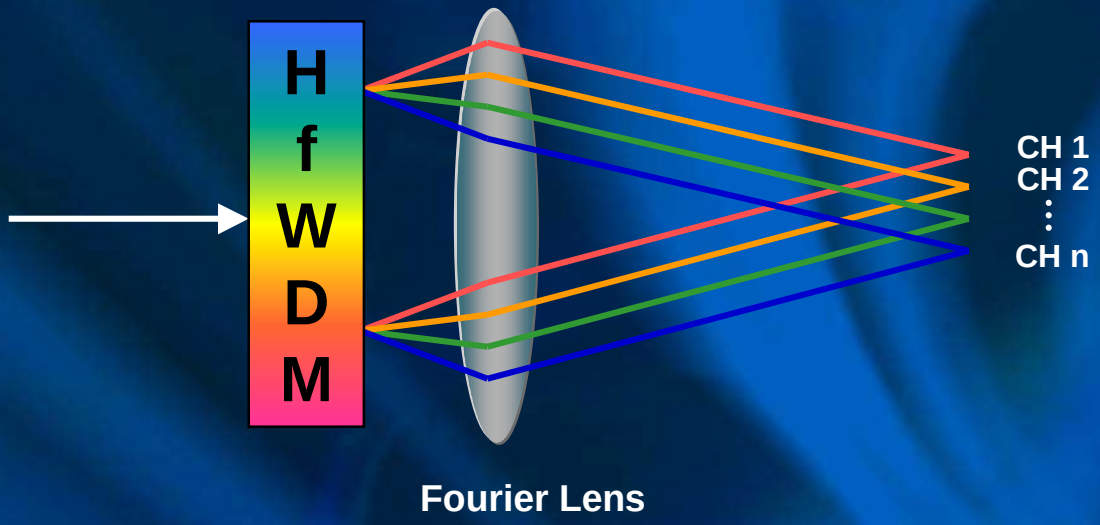

DeMux

Coherent Optical Receiver

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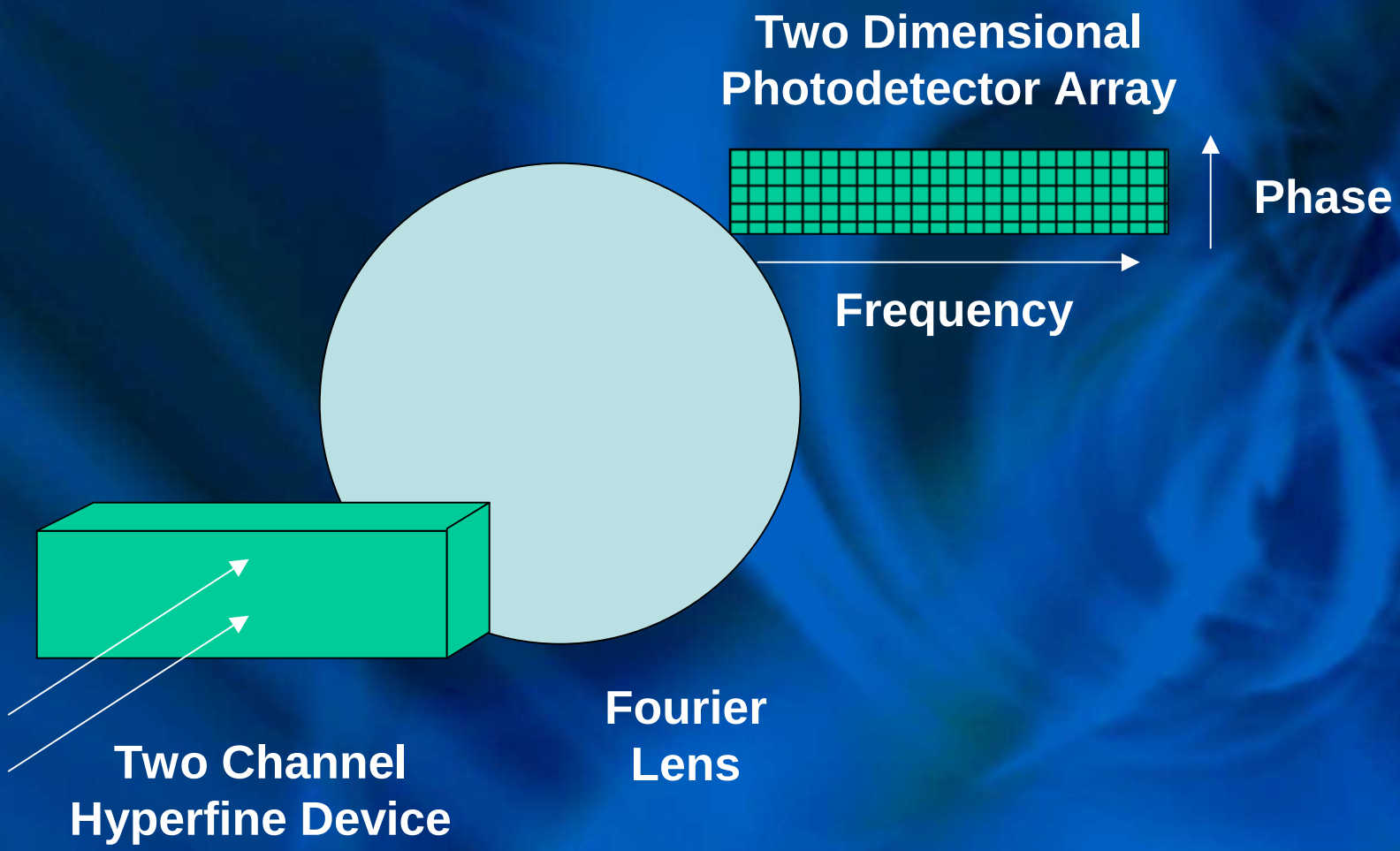

Output

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- All spectra have a vertical spatial carrier
- The phase of this carrier is the phase difference between to two optical channels
- Result can be integrated in time on the detector for additional sensitivity

Applications

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- Frequency vs. angle of arrival
- Channelized discriminator for precise frequency measurements
- Coherent spectrum analyzer
- Cross power processors (correlator for detection of weak signals in noise)
- Front end to range-Doppler imager

Frequency vs. Angle of Arrival

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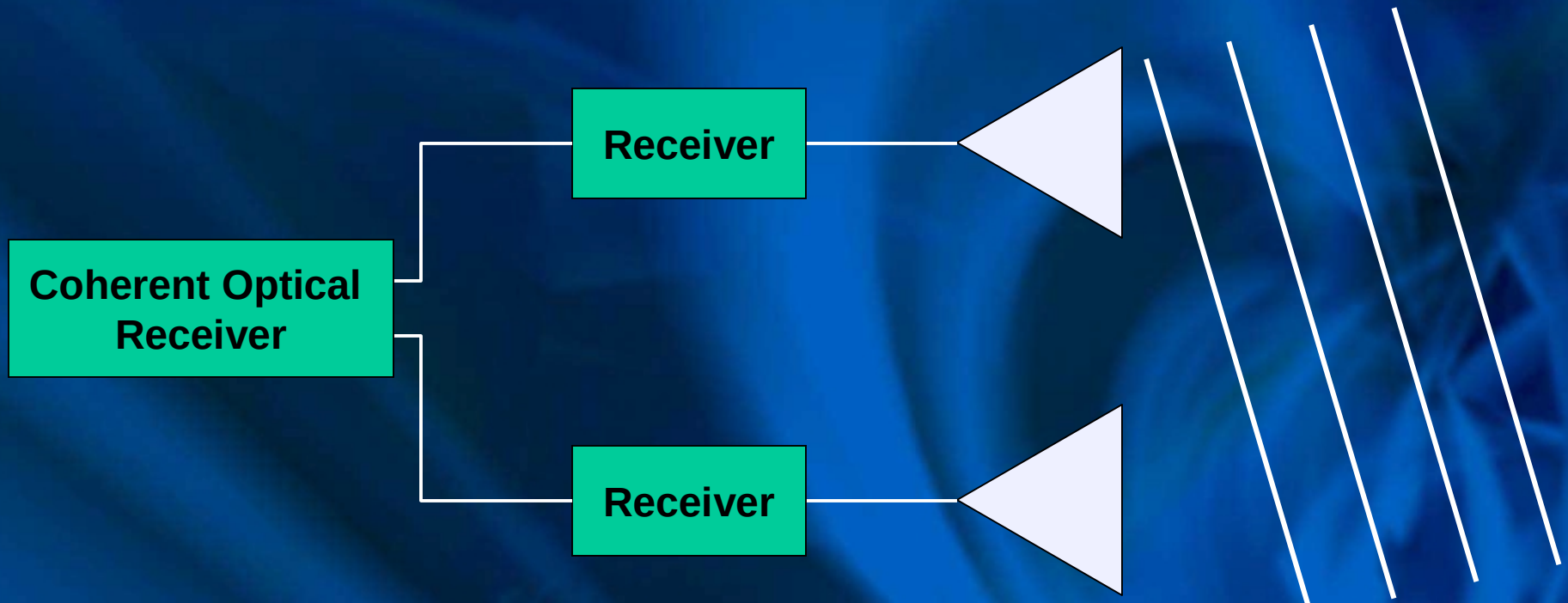

- The phase in each channel represents angle of arrival
- Long integration time improves sensitivity for weak CW signals

Channelized Discriminator

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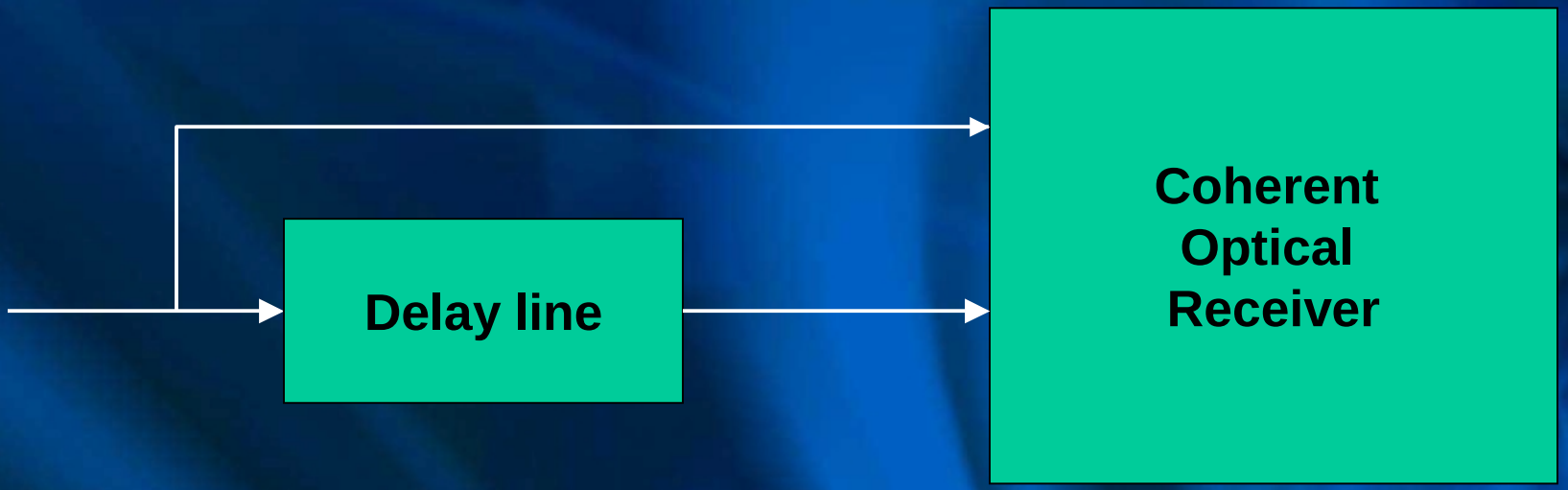
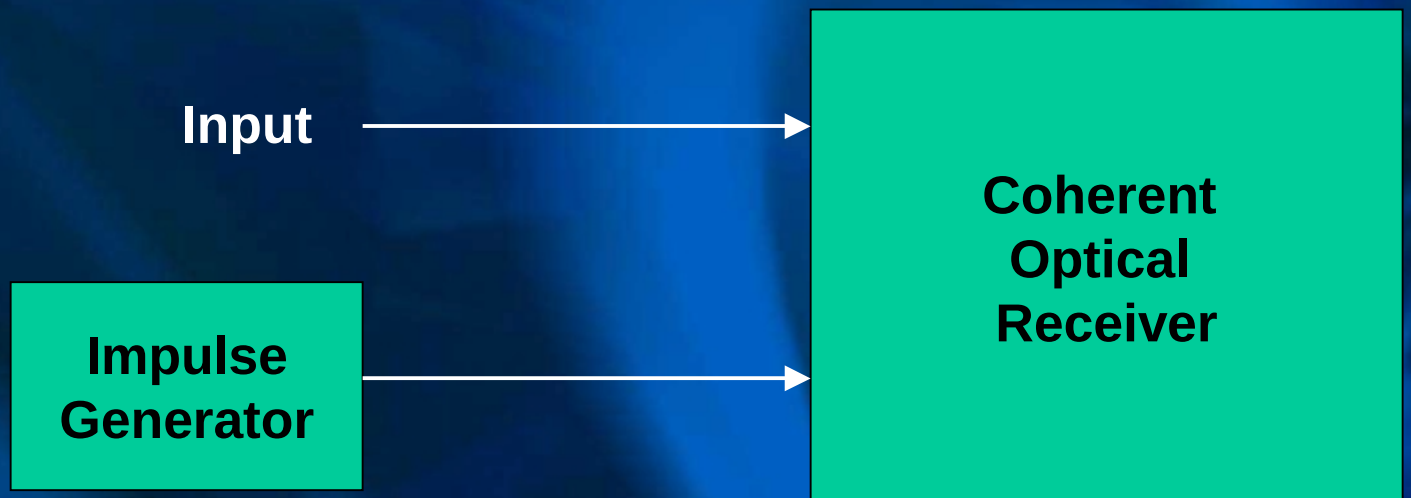


- The delay line has a delay of 1/resolution of the receiver
- The phase will shift 360 degrees from one side of a passband of a frequency cell to the other providing a more accurate measure of instantaneous frequency

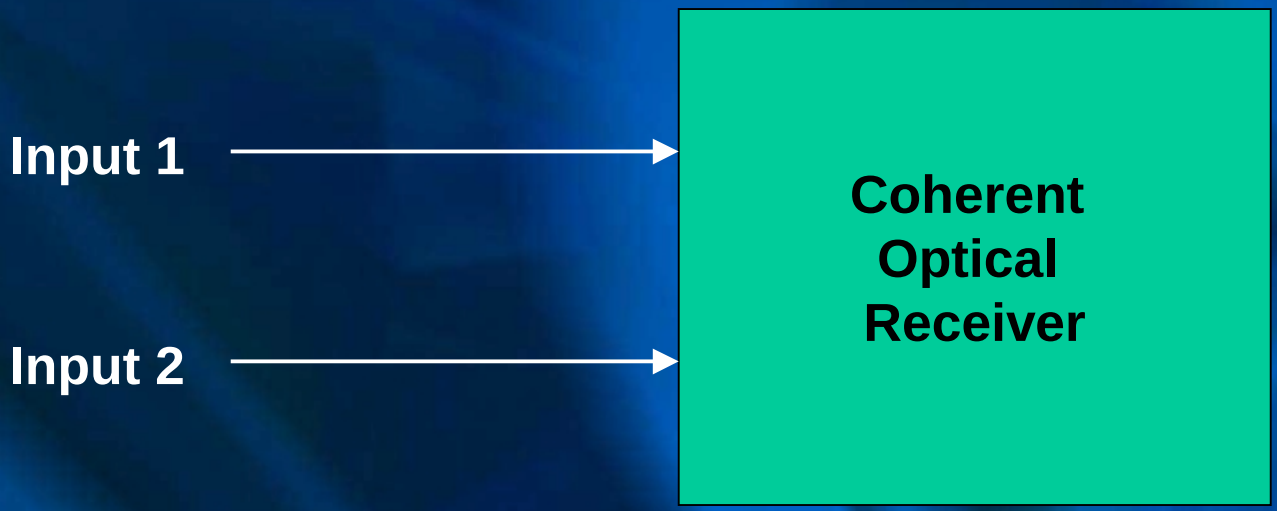
Coherent Optical Spectrum Analyzer

ESSEX



- The impulse generator provides all of the frequencies in the passband to act as phase references for all of the signals input into the analyzer

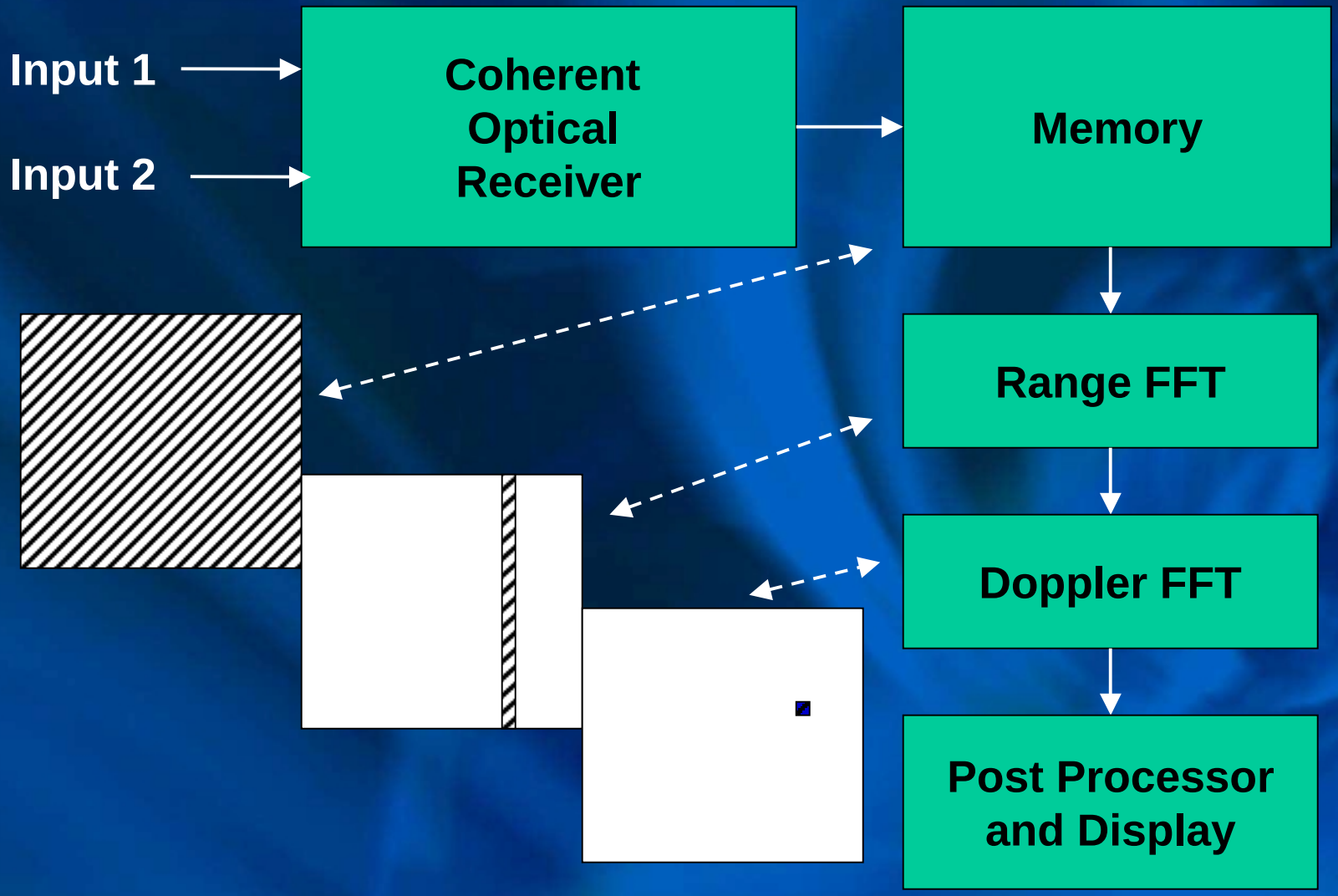
Cross power spectrum analyzer (Correlator)



- The output is the complex cross power spectrum of the two signals integrated in time on the photodetector
- The inverse transform will produce the cross correlation of the two signals over the integration time of the photodetector.

Range-Doppler Imager

ESSEX



Hyperfine Coherent Optical Receiver

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- Simple
- Flexible
  - Many functions
  - Wide choice of operating parameters
- Output data rate can be low compared to input data rate
- High processing gain potential

Other Potential Users

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- Essex has a current analog optical signal processor contract with Missile Defense Agency ($2.4M to be expanded to $7M) for a 1 GHz bandwidth range-Doppler imager.
- Application is target discrimination.
- Hyperfine coherent optical receiver would expand the resolution of this processor to the centimeter range and below for ultra wideband radars.

Phase II

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- **High resolution devices 50 MHz and better**
- **Examine two dimensional systems.**
  - **Folded spectral analysis**
    - For example cross two 500 BT devices to achieve 250,000 BT.
  - **Triple product processors**
    - Ambiguity functions
    - Tri-spectrum
    - Cyclic spectrum
  - **Select and build brassboard**
- **Examine hybrid systems using hyperfine plus AO and/or other spatial light modulators**

Some Candidate Architectures (2D)

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- Folded spectrum analyzer (50 MHz resolution or better with 100 GHz bandwidth or more)
- Folded cross power spectrum analyzer (extend both the range and resolution of the previous coherent receiver)
- Correlators for specific signal detection
- Time integrating correlator for detection of very weak wideband signals (ultra broadband)
- Ambiguity function processors for target location
- Back-projection processors for SAR processing and geolocation
- Quadratic processors (CAF, CS, etc.)

Folded Spectrum Analyzer

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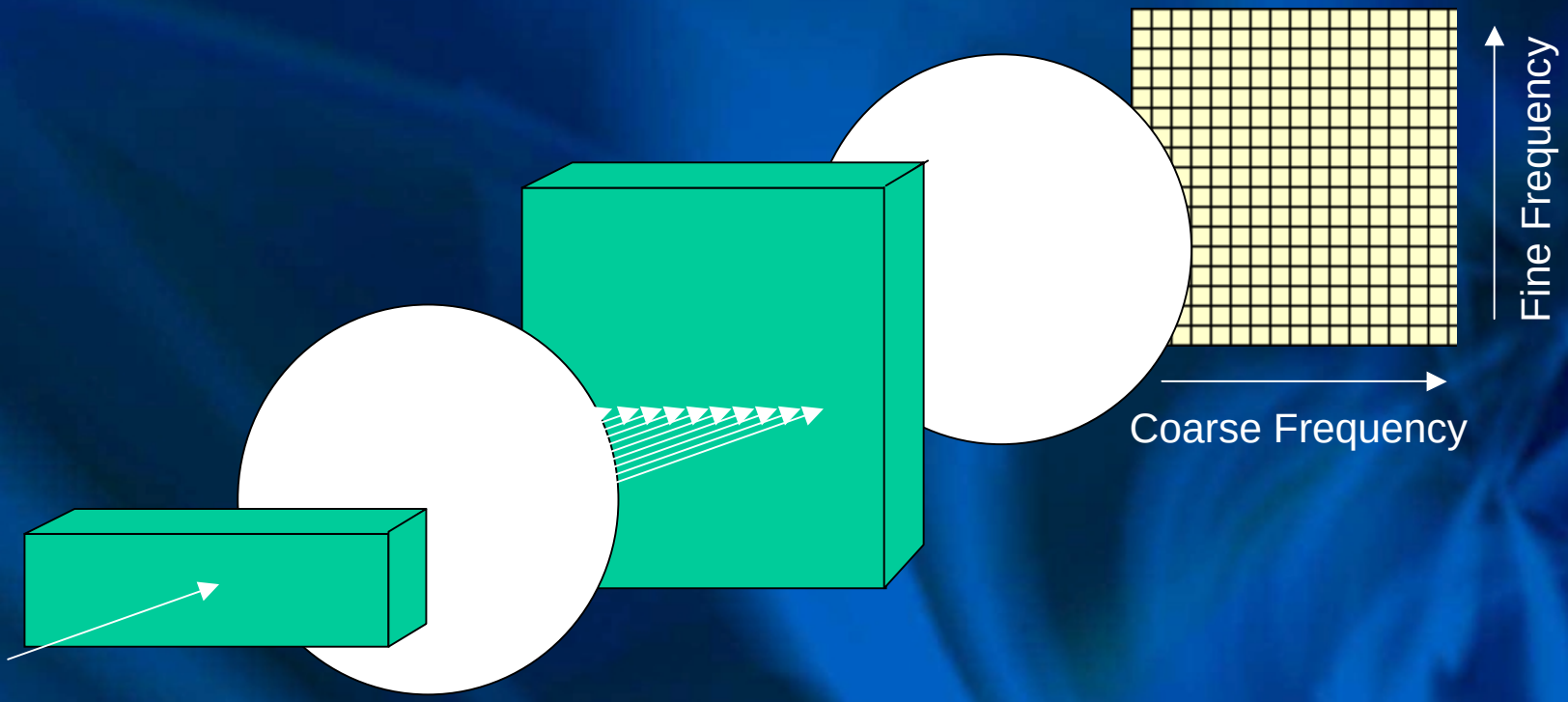
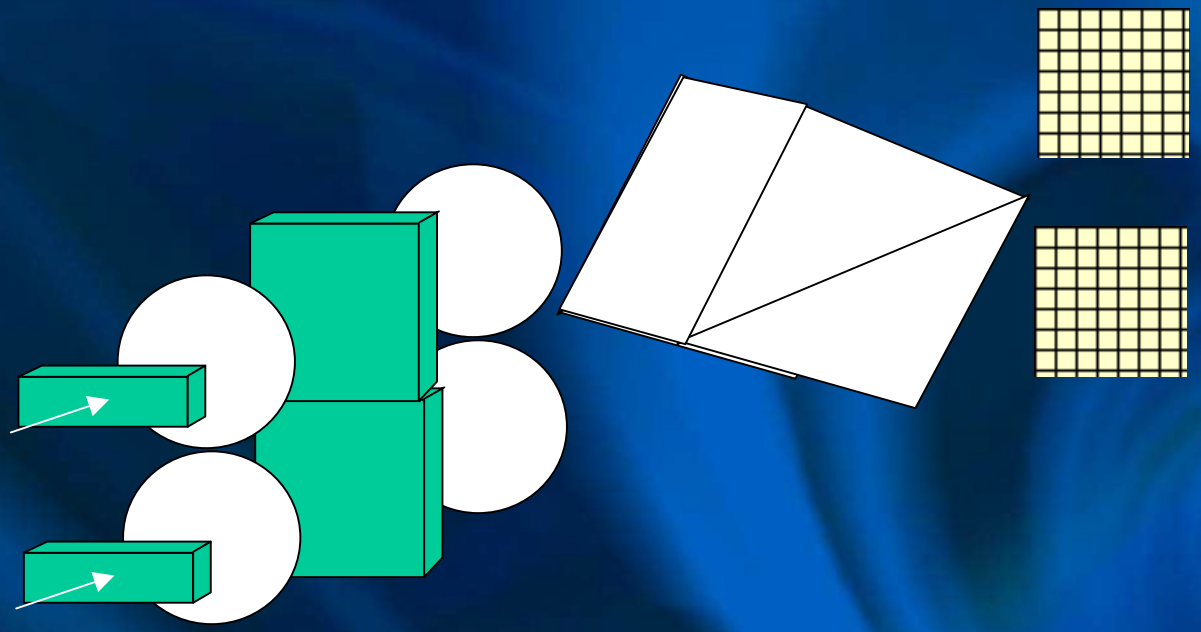


- **The first hyperfine device resolves the channels to 50 MHz or better but is ambiguous on 2 GHz centers**
- **The second hyperfine device has 1 GHz or better resolution with 100 GHz or more bandwidth and resolves the ambiguities producing a fine-frequency by coarse-frequency display**

Folded Coherent Spectrum Analyzer

ESSEX



A Costas prism combines the inputs coherently to produce a folded coherent spectrum analyzer

Observations

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Hyperfine technology:

- Permits EW receivers to achieve narrowband sensitivity and wideband instantaneous coverage in a compact low power package
- Compatible with the myriad of component technologies developed for fiber such an multi-line lasers/generators, modulators and ultra-stable lasers
- Integrates well with acousto-optic and other opto-electronic spatial light modulators
- Applicable to wideband waveform synthesis
- Can be used to produce very fast bit level processors for identification of optical signals
- Can be used to improve the performance of free space optical communications links and Lidar