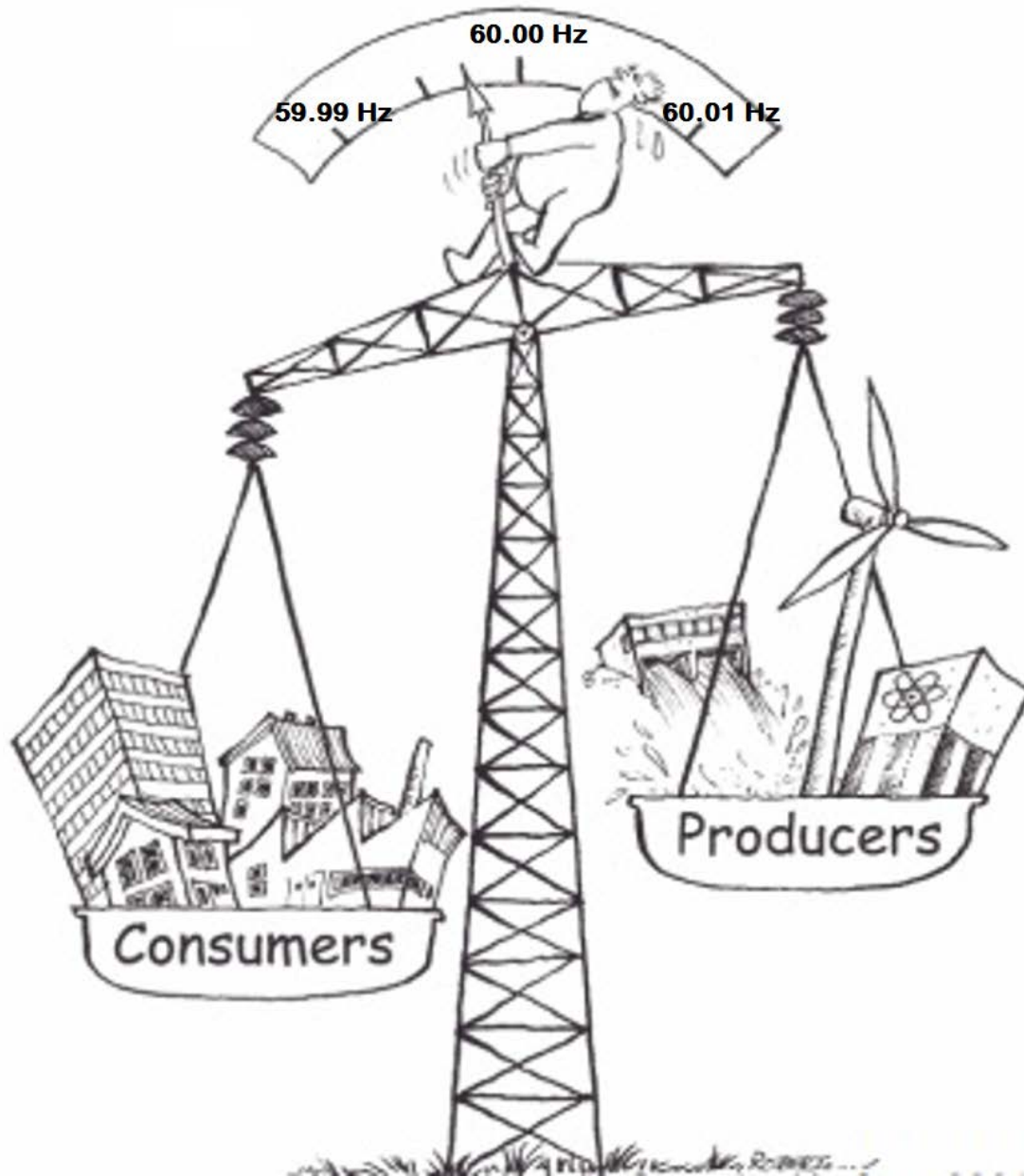


# GPS Time Backup for Power Industry



John Lowe  
Radio Station Manager  
NIST Time & Frequency  
Division

# WWV Ft. Collins, CO.



# WWVH Kauai, HA.



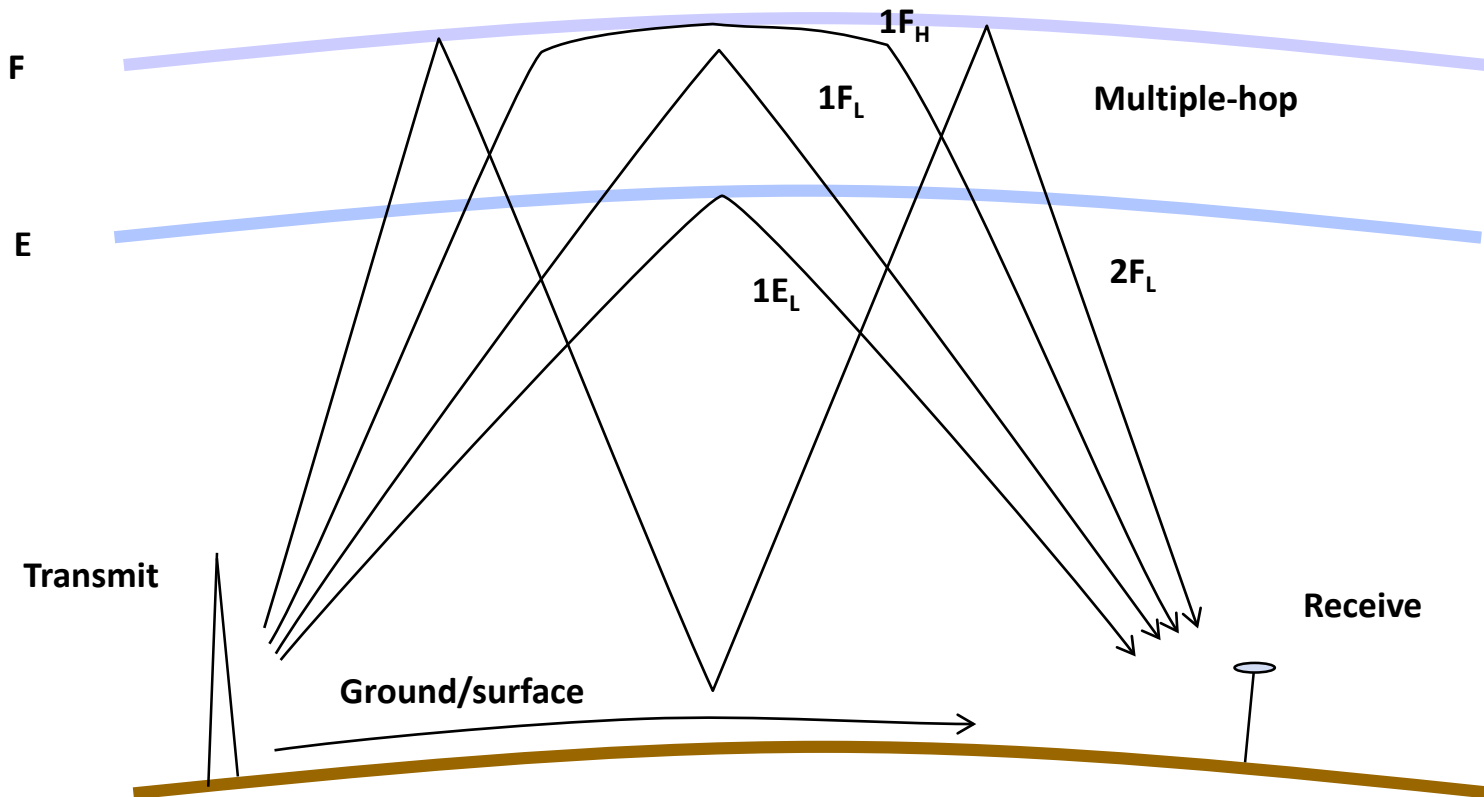
# WWV/WWVH

## Provided Syntonization

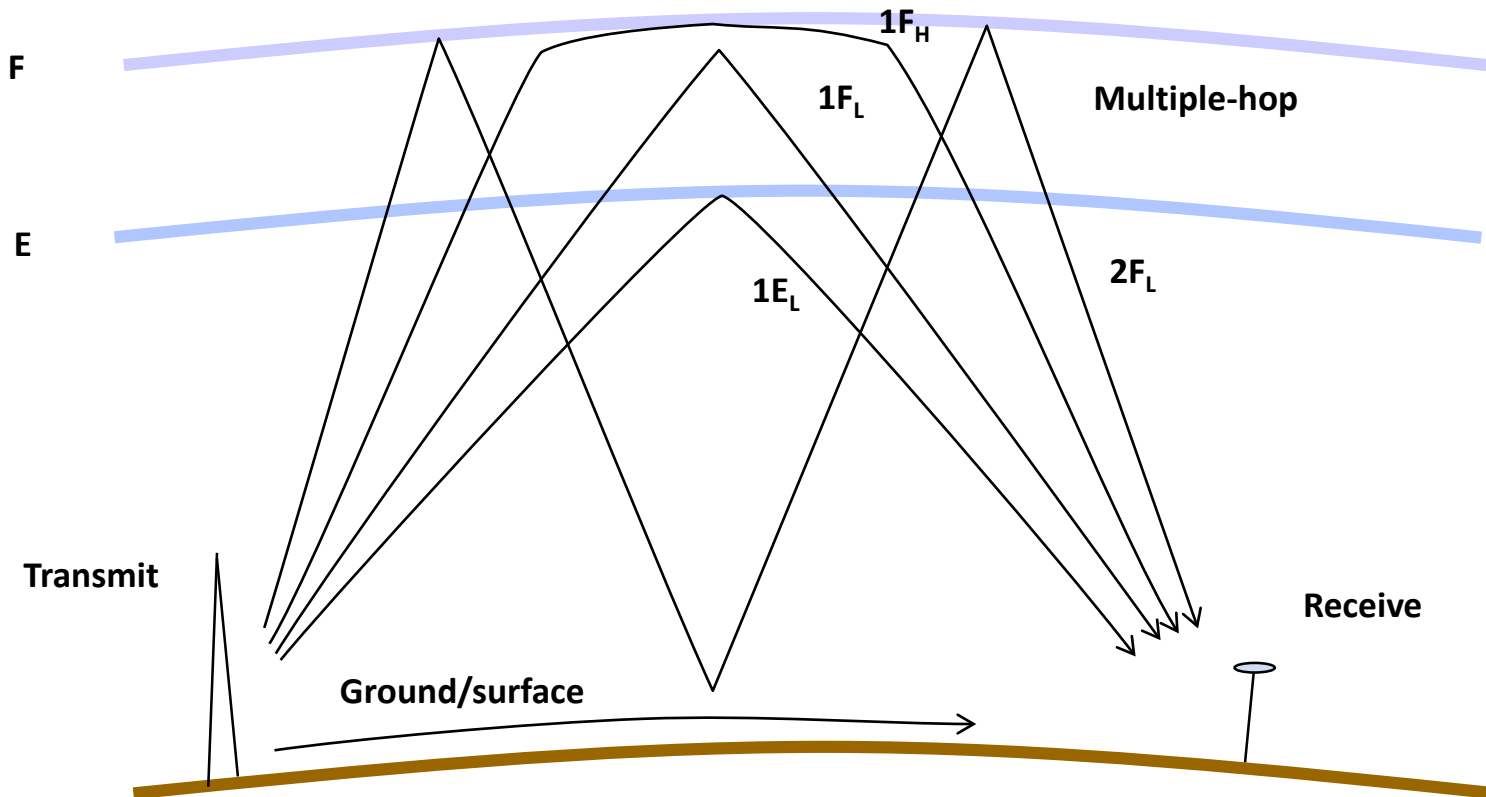
### Frequency Calibration

- Standard Carrier Frequencies
- 2.5, 5, 10, 15, 20 & 25 MHz
- @10 kW radiated power on 5, 10, and 15 MHz
- @2.5 kW radiated on 2.5, 20 and 25 MHz

# WWV/WWVH Reception



# WWV/WWVH Reception



Frequency stability  $1 \times 10^{-9}$

Time Synchronization 1mS

# WWVB

## Provided Syntonization

### Frequency Calibration

- Standard Carrier Frequency
- 60 KHz
- @70 kW radiated power (upgraded in 99')

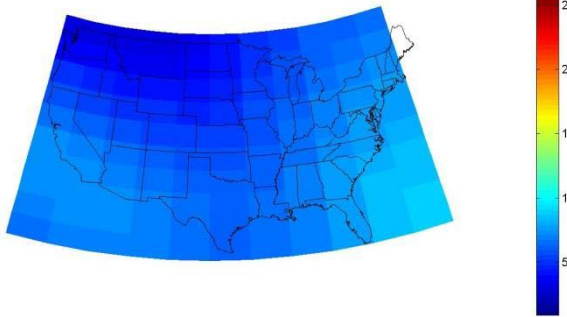
# WWVB



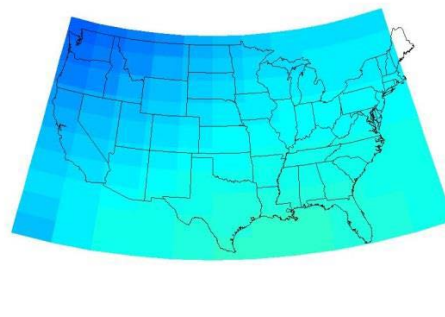


# Electron Content Diurnal Maps

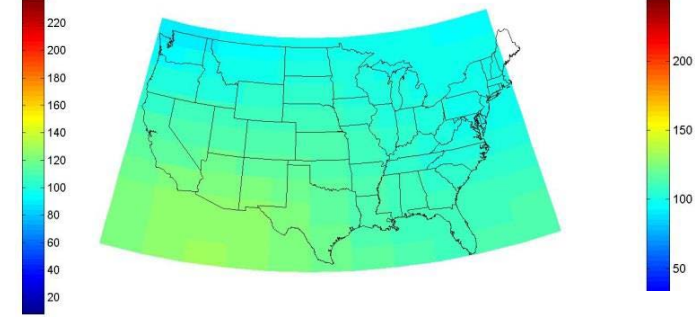
Ionospheric Total Electron Content (TEC) map of the world on 14-Aug-2007 12:00:00 UTC



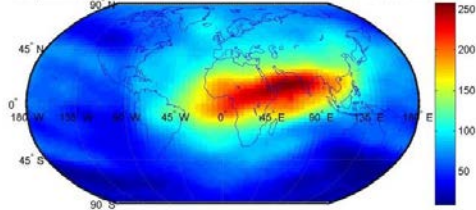
Ionospheric Total Electron Content (TEC) map of the world on 14-Aug-2007 14:00:00 UTC



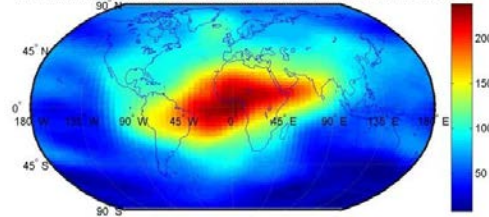
Ionospheric Total Electron Content (TEC) map of the world on 14-Aug-2007 16:00:00 UTC



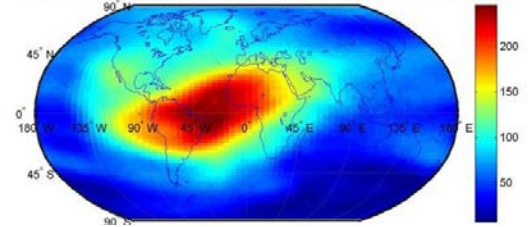
Ionospheric Total Electron Content (TEC) map of the world on 14-Aug-2007 12:00:00 UTC

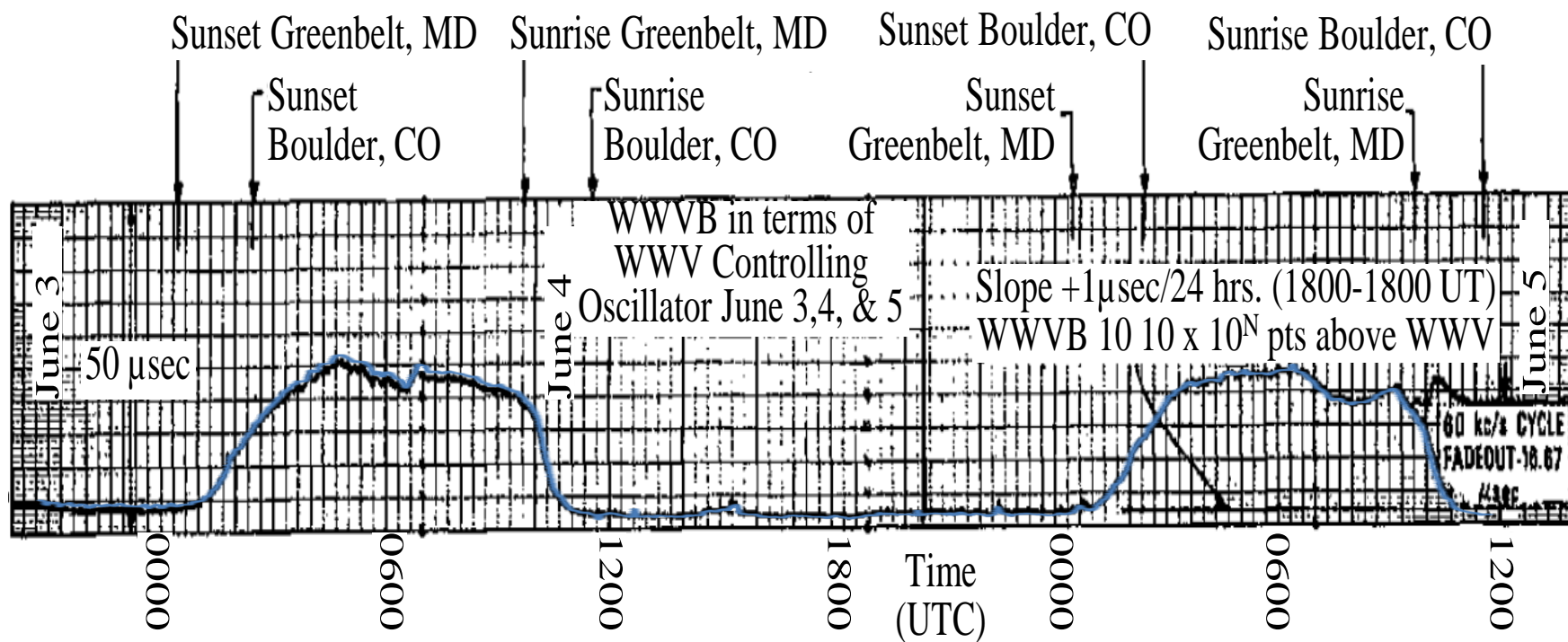


Ionospheric Total Electron Content (TEC) map of the world on 14-Aug-2007 14:00:00 UTC



Ionospheric Total Electron Content (TEC) map of the world on 14-Aug-2007 16:00:00 UTC







Frequency stability  $1 \times 10^{-11}$

$1 \times 10^{-12}$  With averaging

Time Synchronization 100  $\mu$ S (?)

# Power Grid Application Timing Needs

Application	Need
General Purpose	$< \pm 100 \text{ ms}$
Time-Stamping SCADA and Operational Data Logs	$< \pm 1 \text{ ms}$
Substation Monitoring e.g. phasor measurement units (PMUs) (IRIG-B Replacement Applications with a local PTP grandmaster )	$< \pm 1 \text{ } \mu\text{s}$
Extended distance applications (fault detection, transient suppression)	$< \pm 1 \text{ } \mu\text{s}$

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What GPS gives you!



# *Proposed Solution*

To Backup GPS

# *Proposed Solution*

To Backup GPS

Internet Connected

“Radio Common View”

Radio KNIT

Knowledgeable Networked

Integrated Time

# *Proposed Solution*

To Backup GPS

Internet Connected

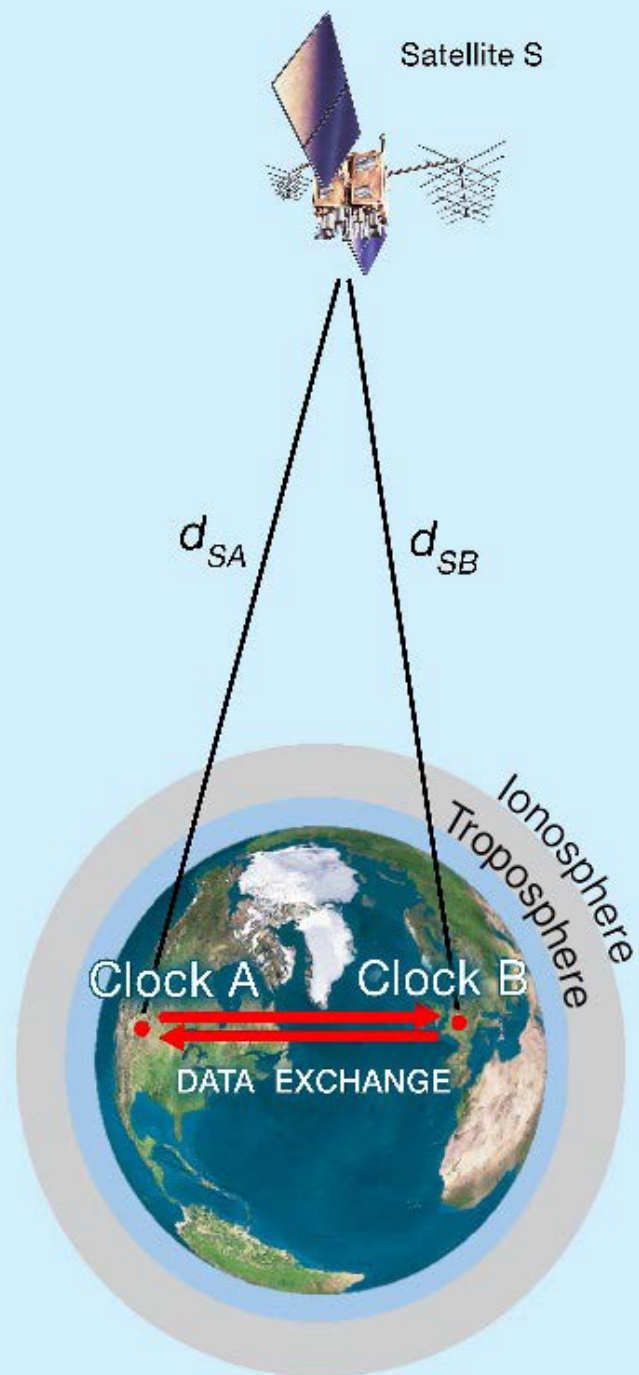
“Radio Common View”

Radio KNIT

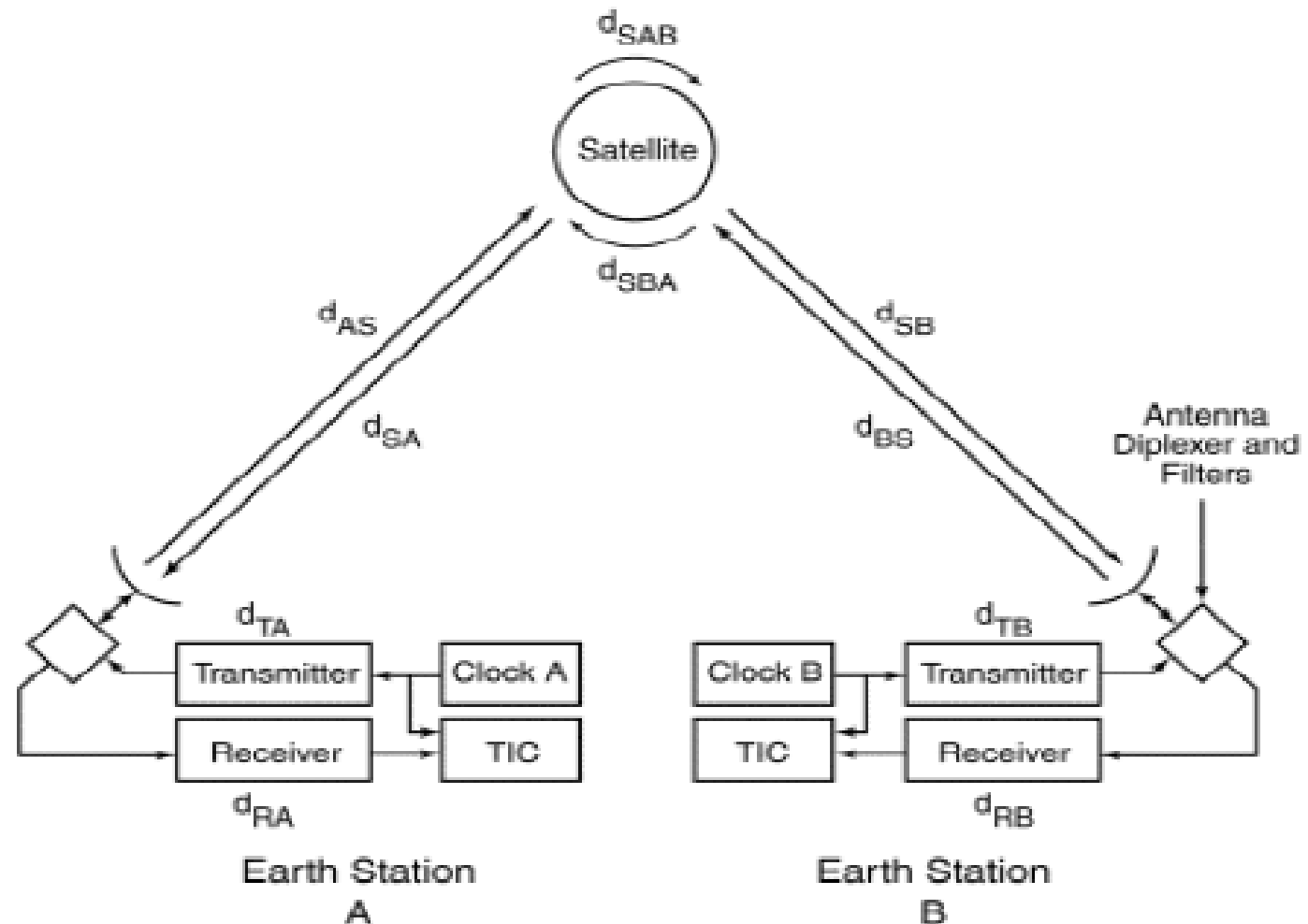
Knowledgeable Networked

Integrated Time





# Two-Way Satellite Time and Frequency Transfer TWSTFT



# *Proposed Solution*

# Pinch Hitting for GPS

## ***Radio KNIT***

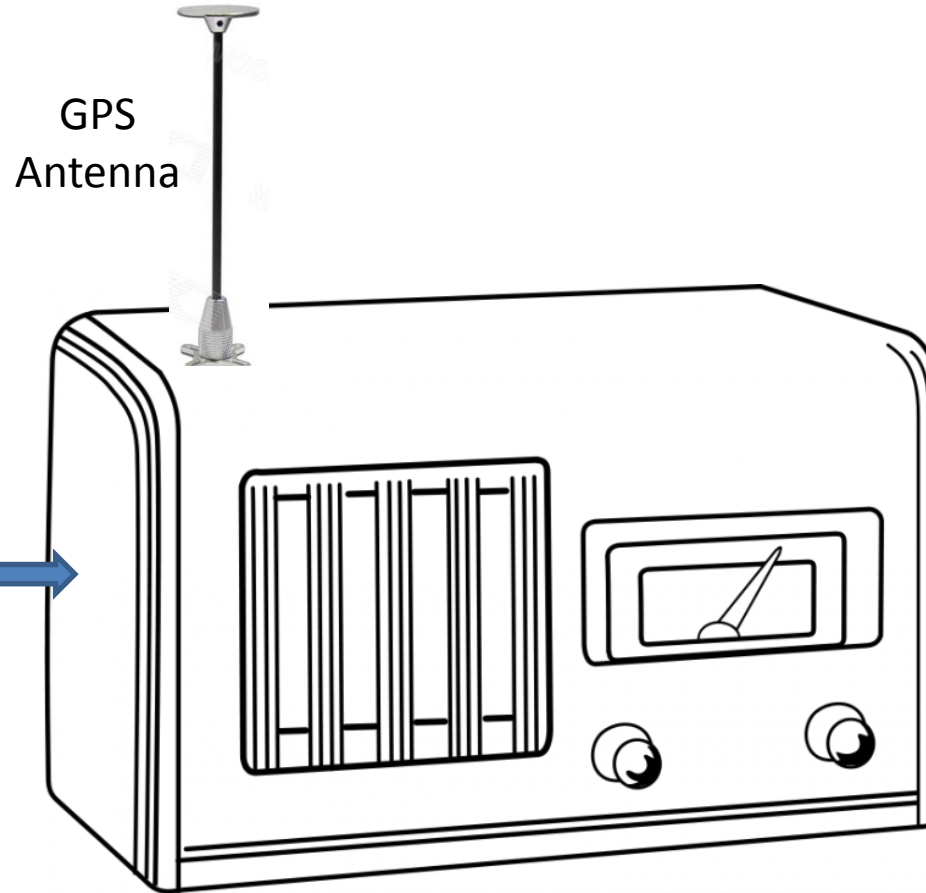
*Knowledgeable Networked Integrated Time*



Backing up GPS “time” by knitting together:

- NIST radio station signals
- Common View algorithms
- Smart Internet connectivity

# Field Receiver



Local clock

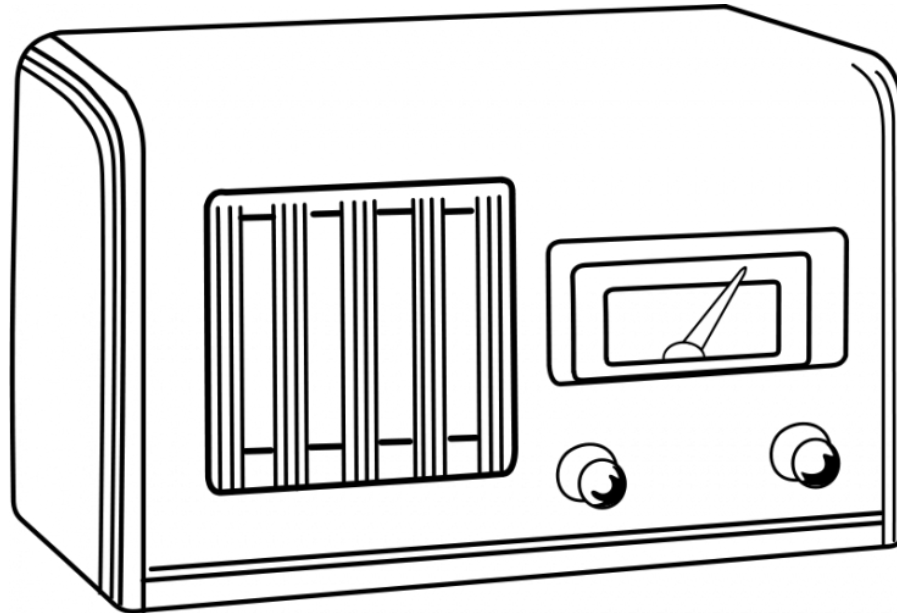
# Field Receiver



GPS  
Antenna



NIST  
Radio Station  
Antenna



Internet  
Connection



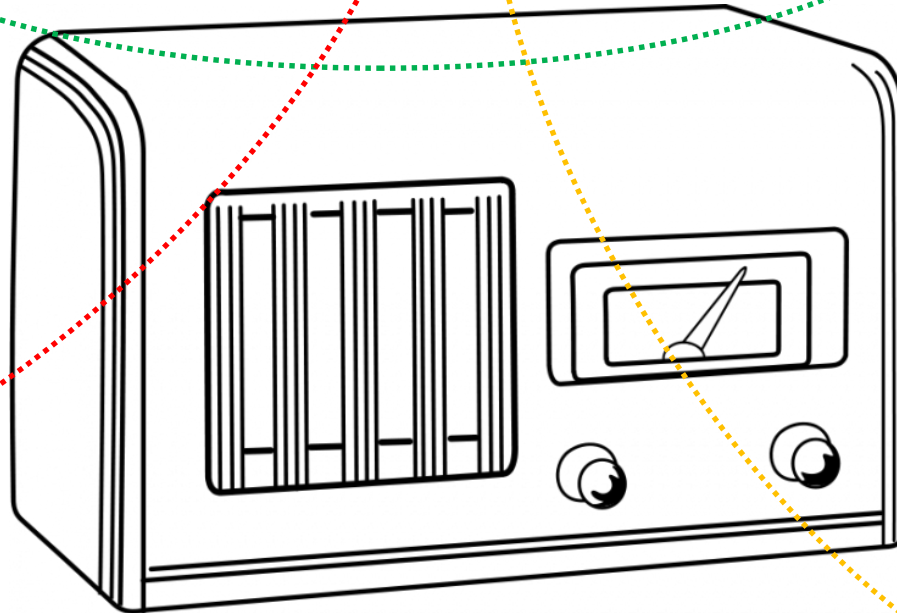
Local clock

# Field Receiver

GPS  
Antenna



NIST  
Radio Station  
Antenna



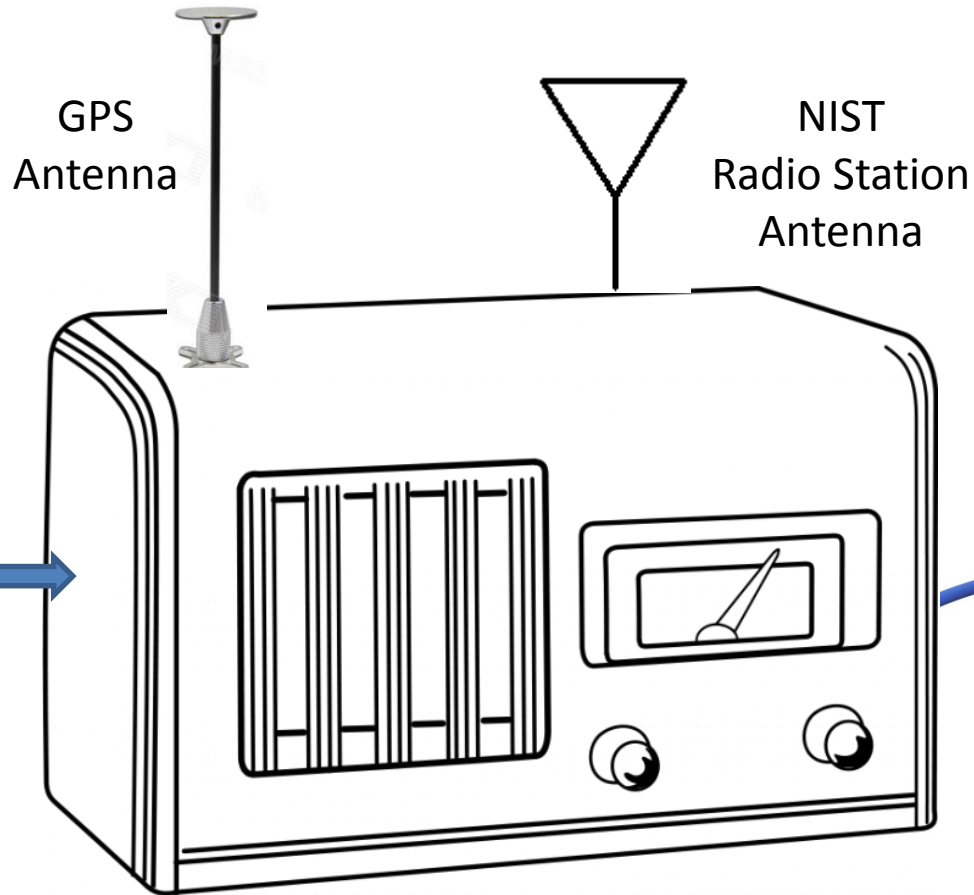
Local clock



Internet  
Connection

# KNITting

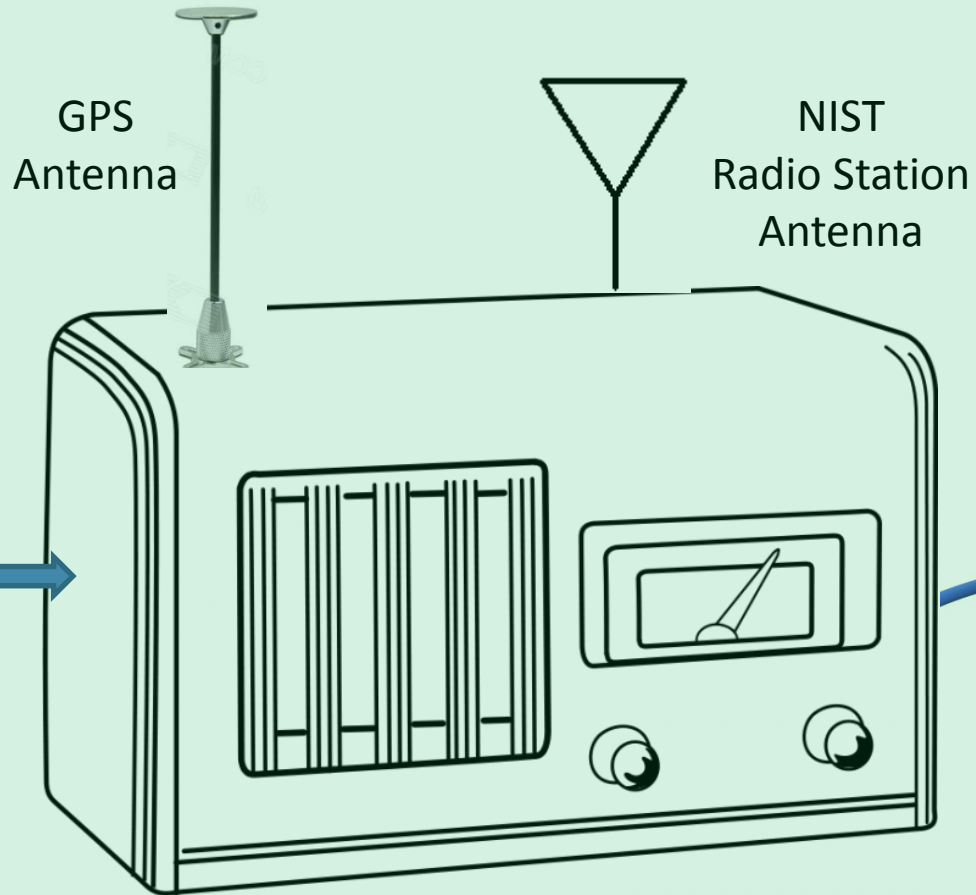
# Field Receiver

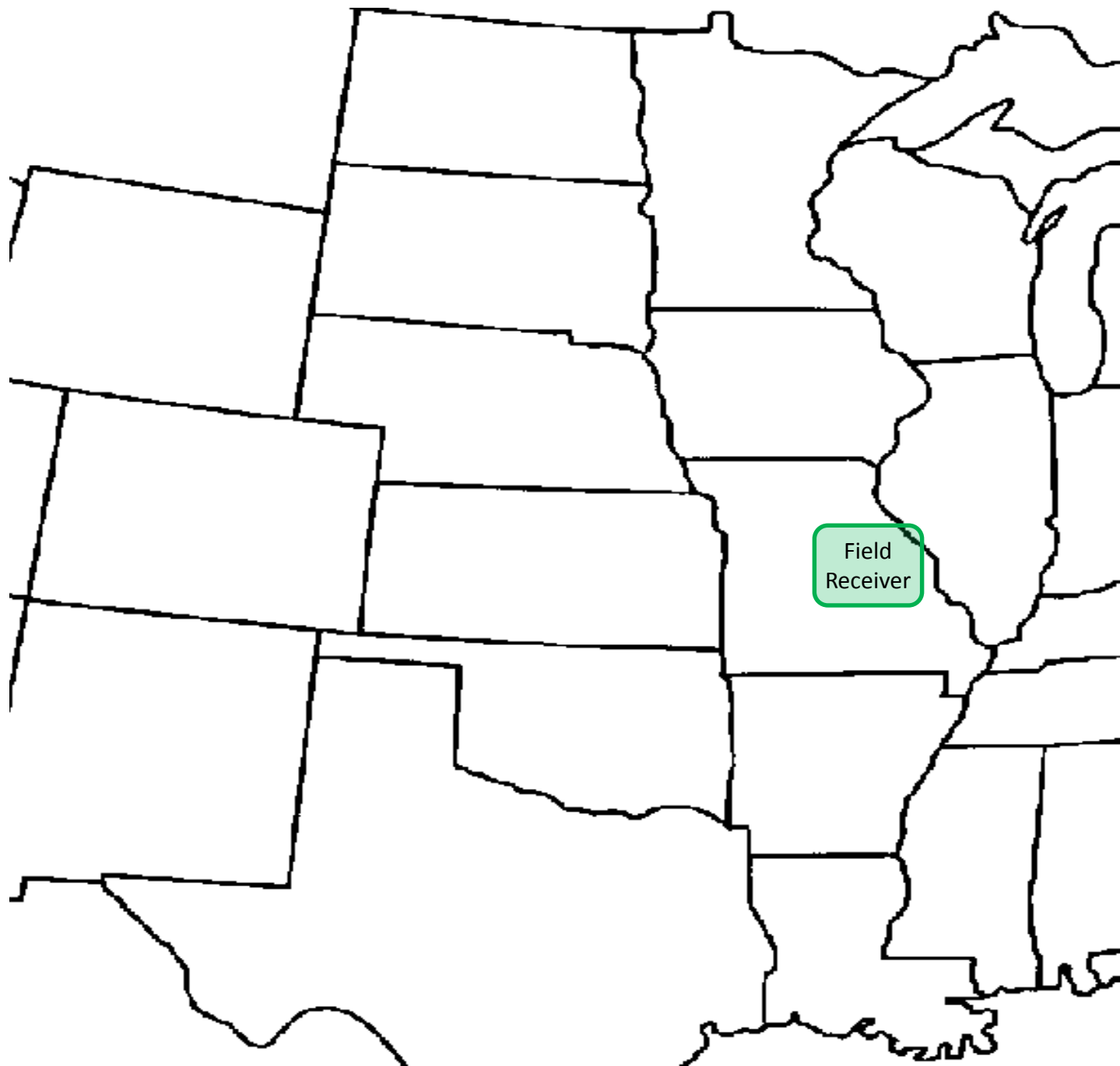


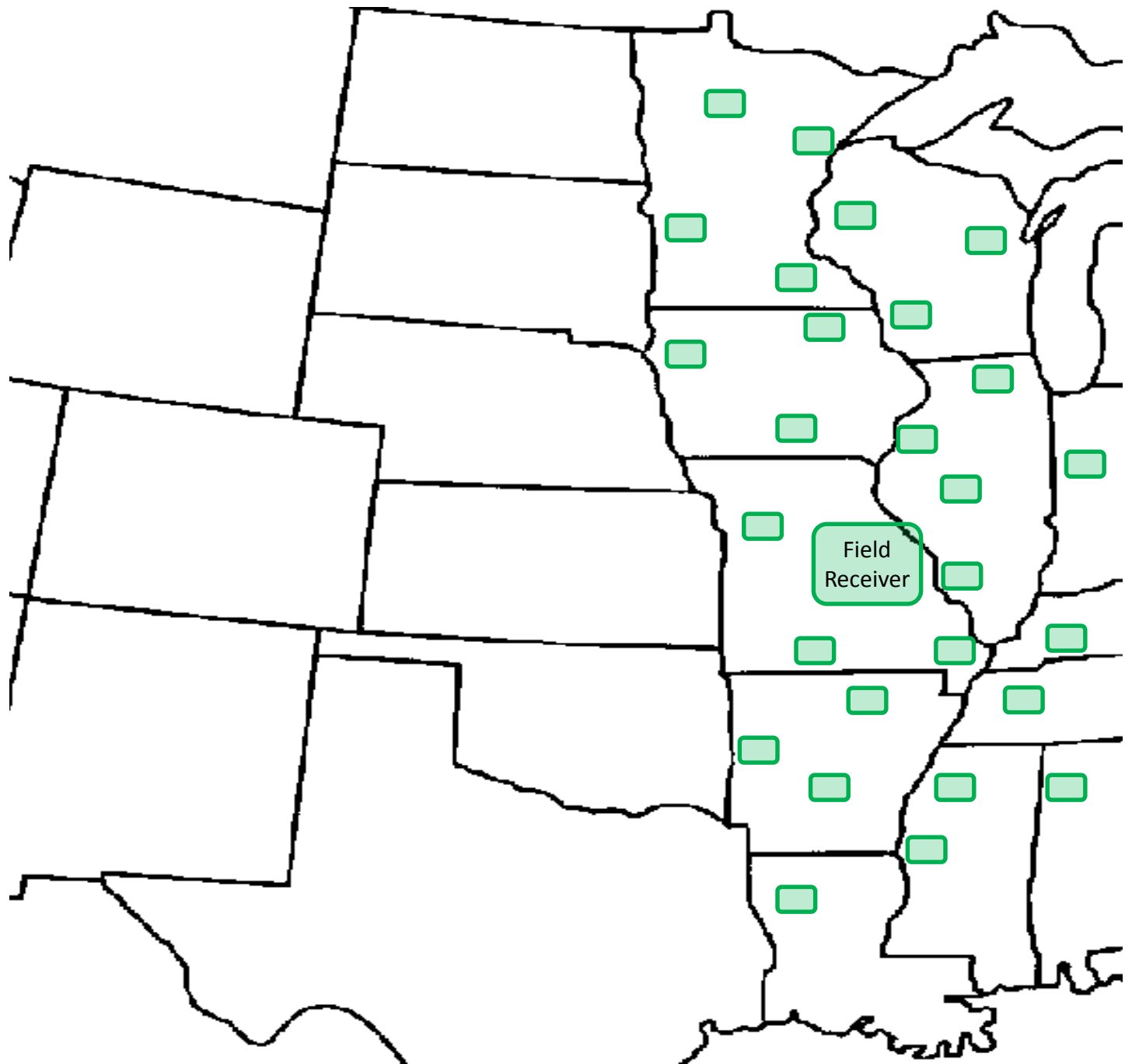
## KNITting



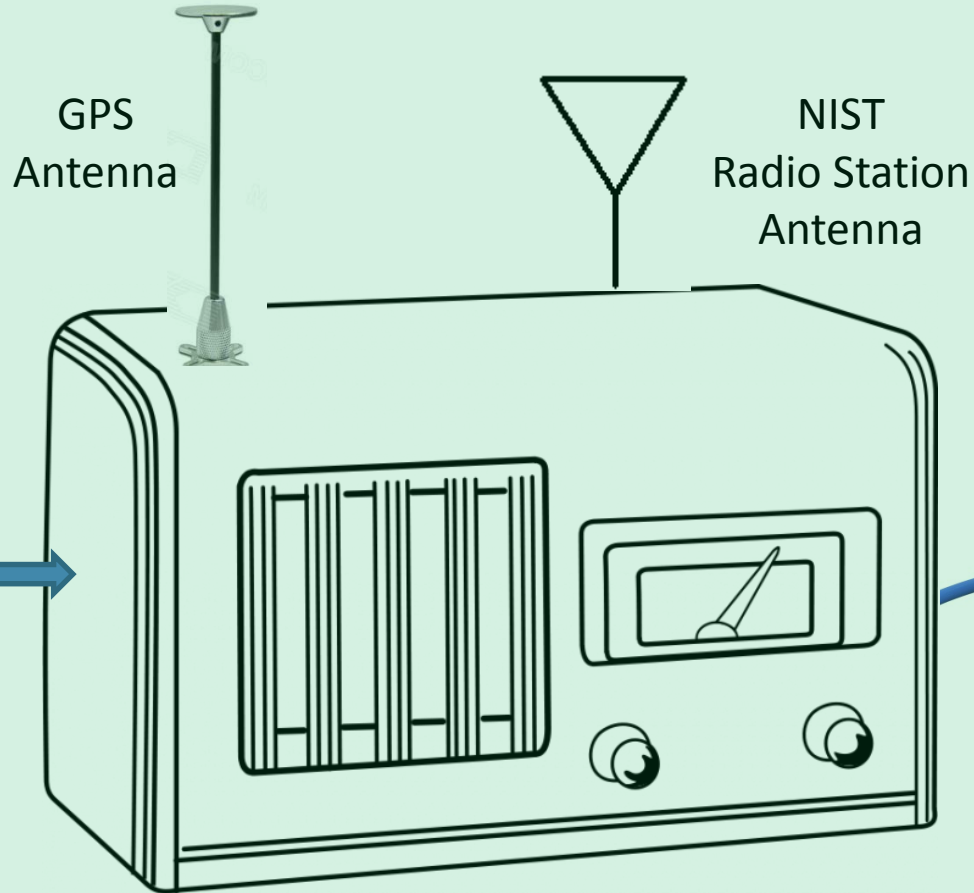
# Field Receiver



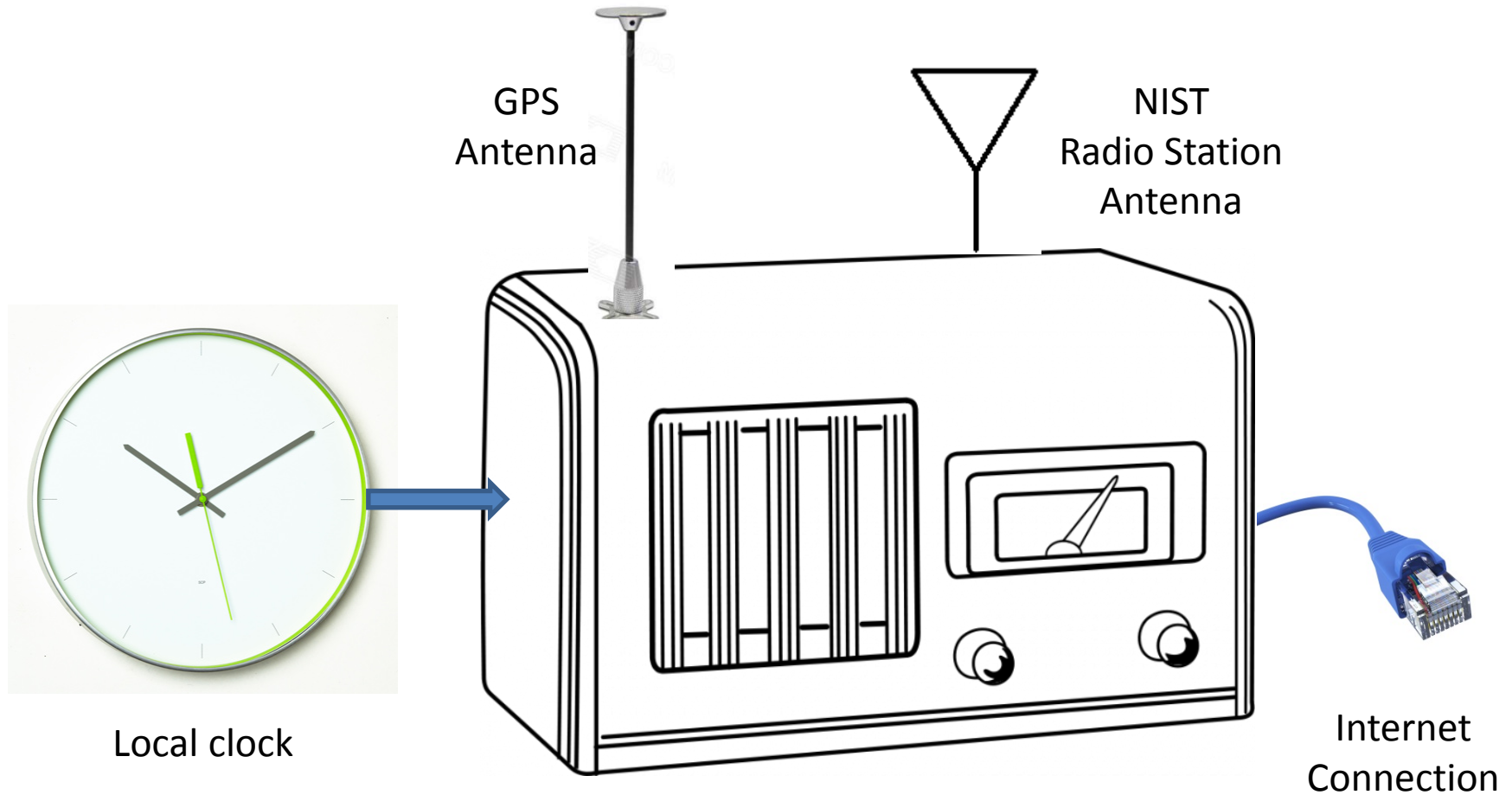




# Field Receiver

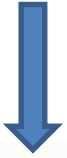


# New Type Receiver

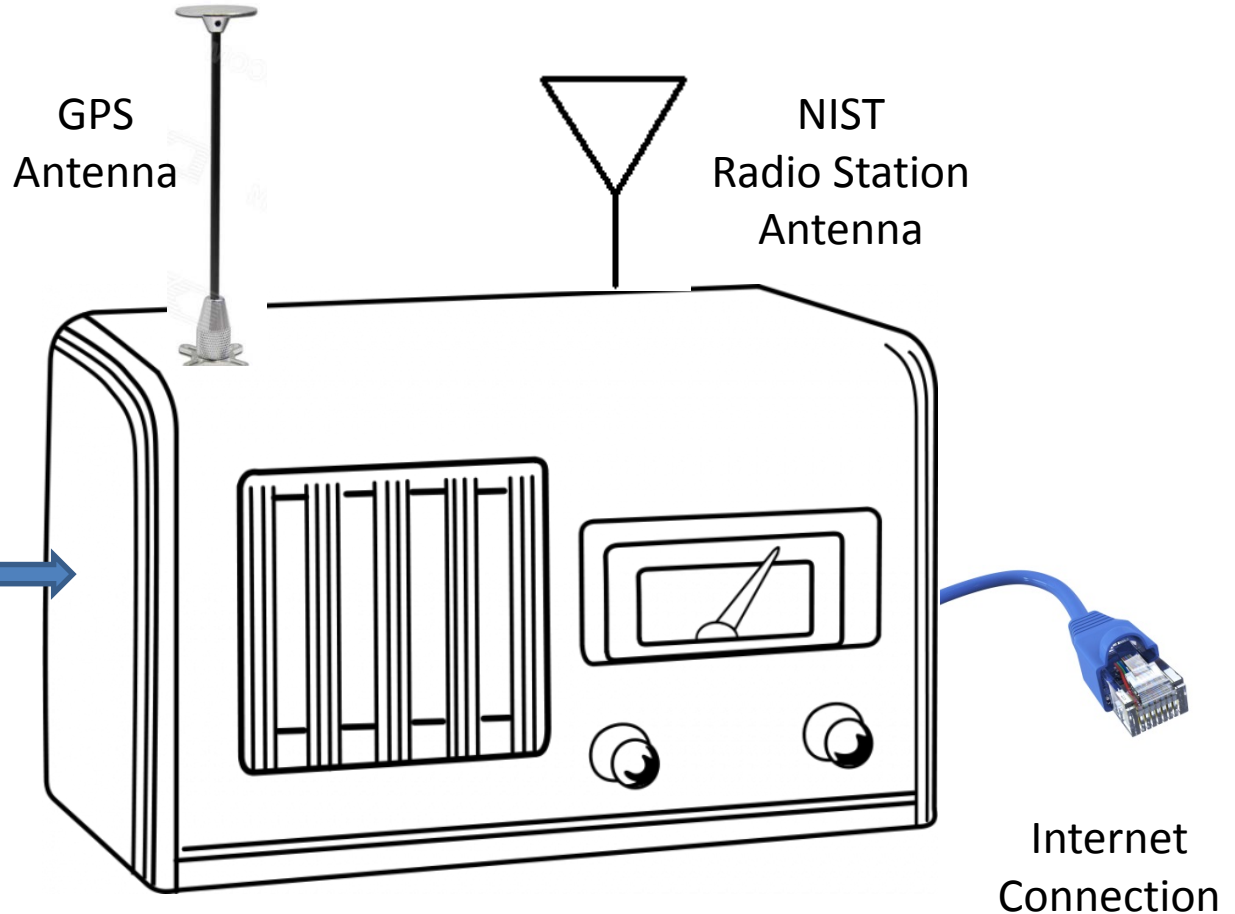


# New Type Receiver

Add  
Better  
Clock

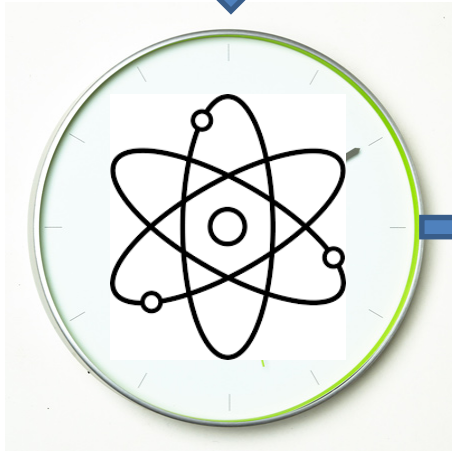
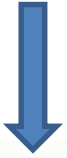


Local clock

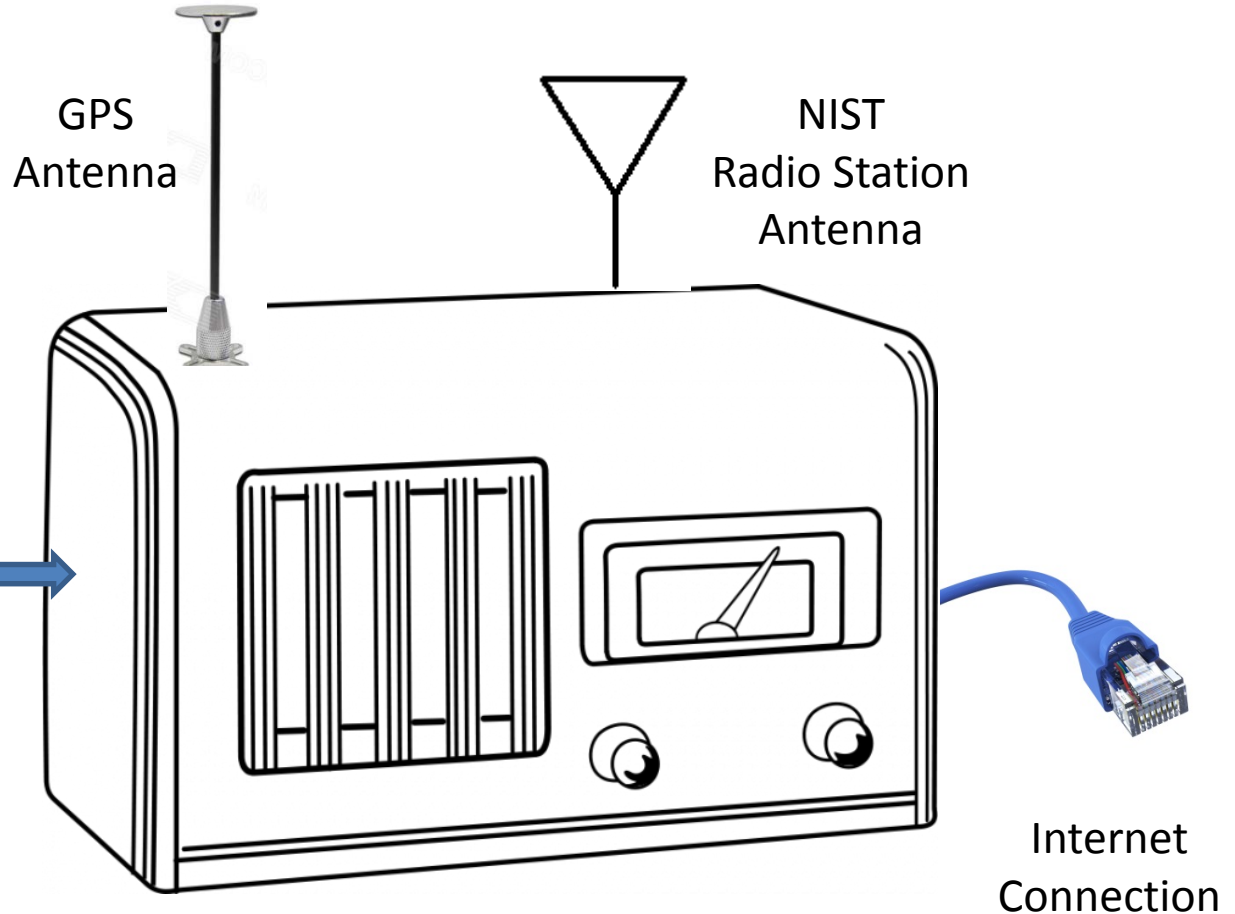


# An New Type Receiver

Atomic  
Clock

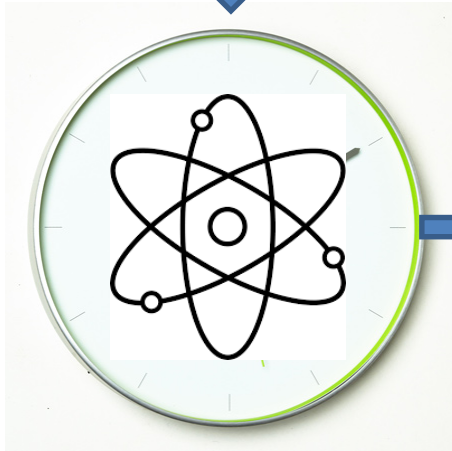
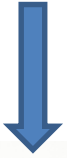


Atomic clock



# An Monitoring Station

Atomic  
Clock



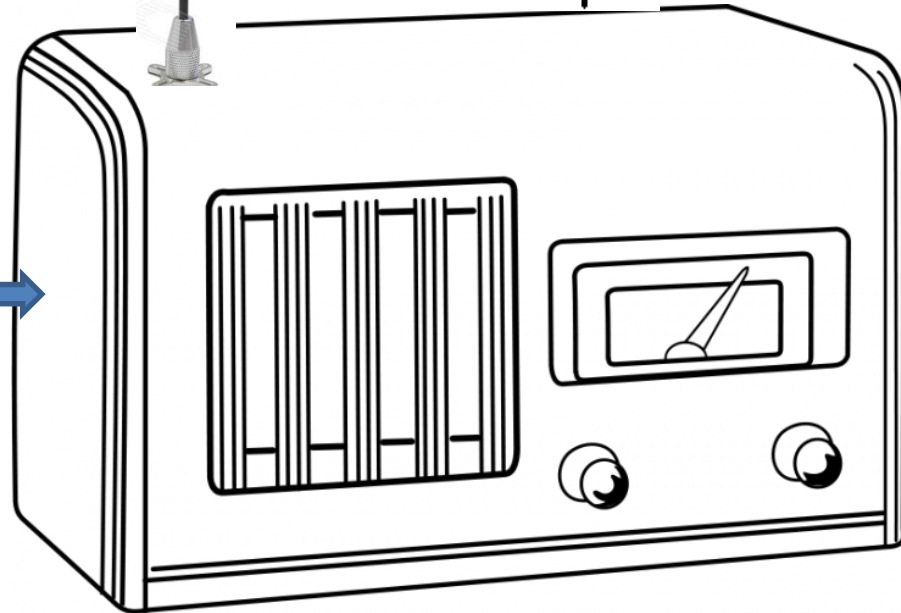
Atomic clock



GPS  
Antenna



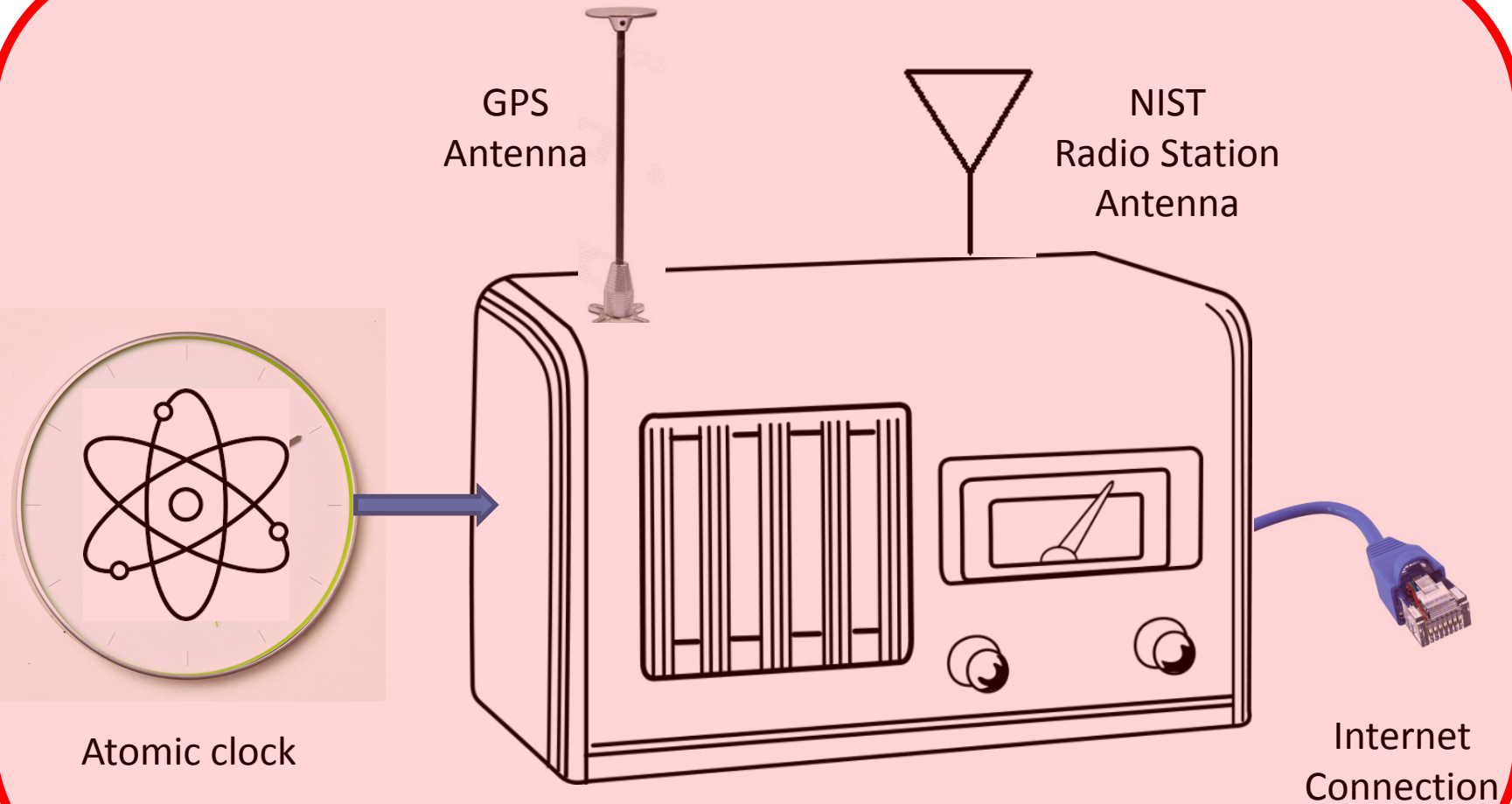
NIST  
Radio Station  
Antenna

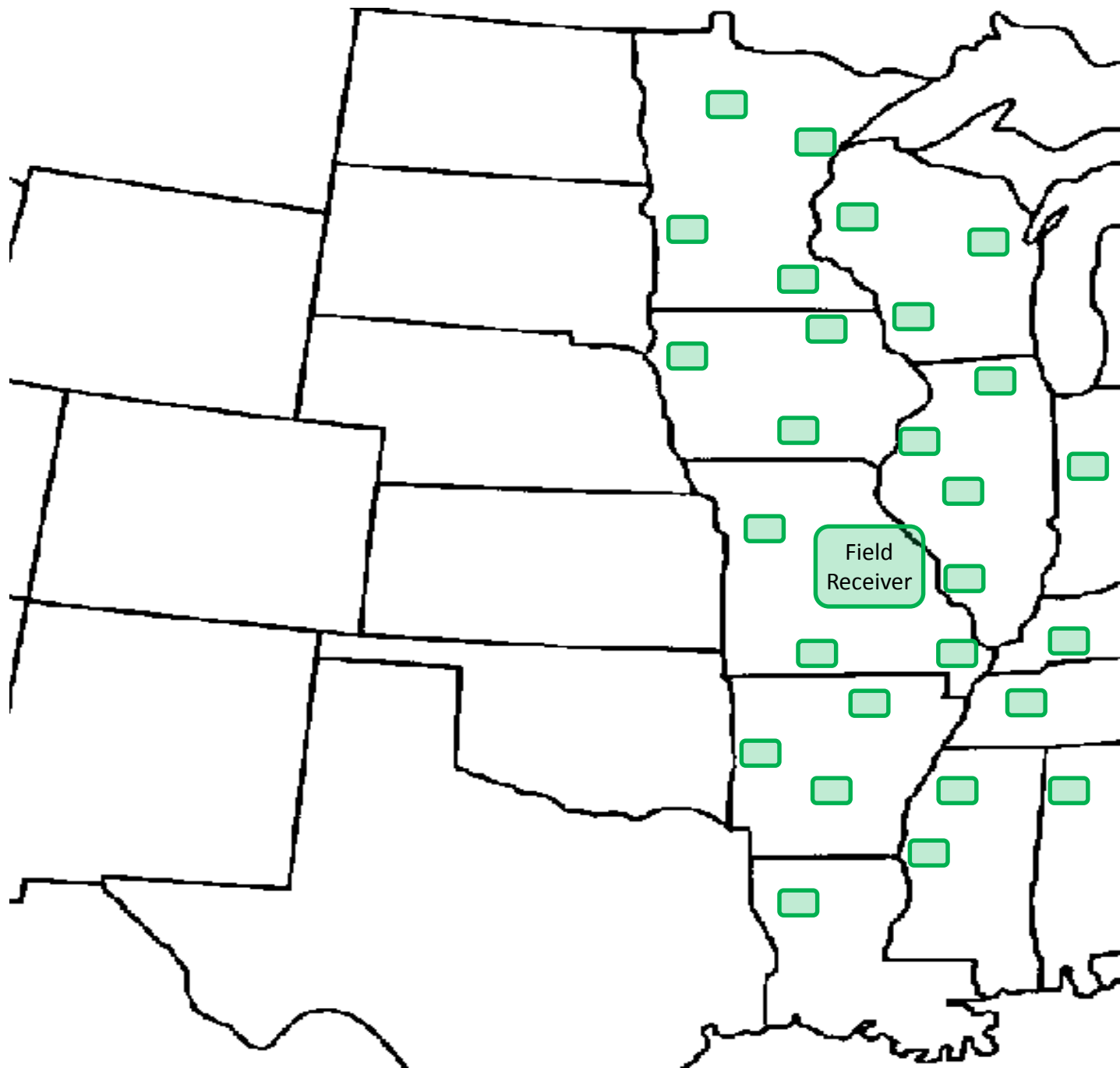


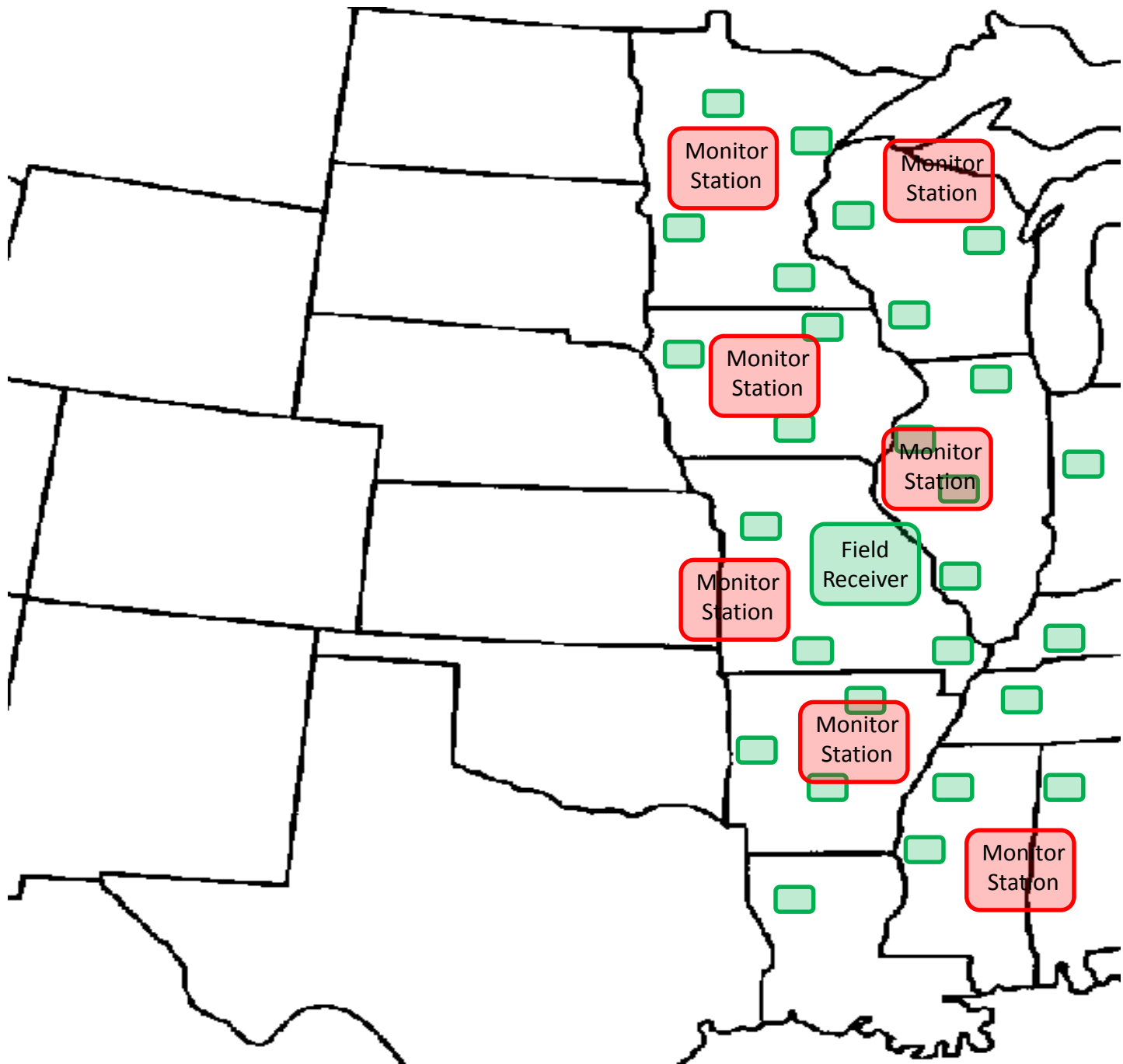
Internet  
Connection

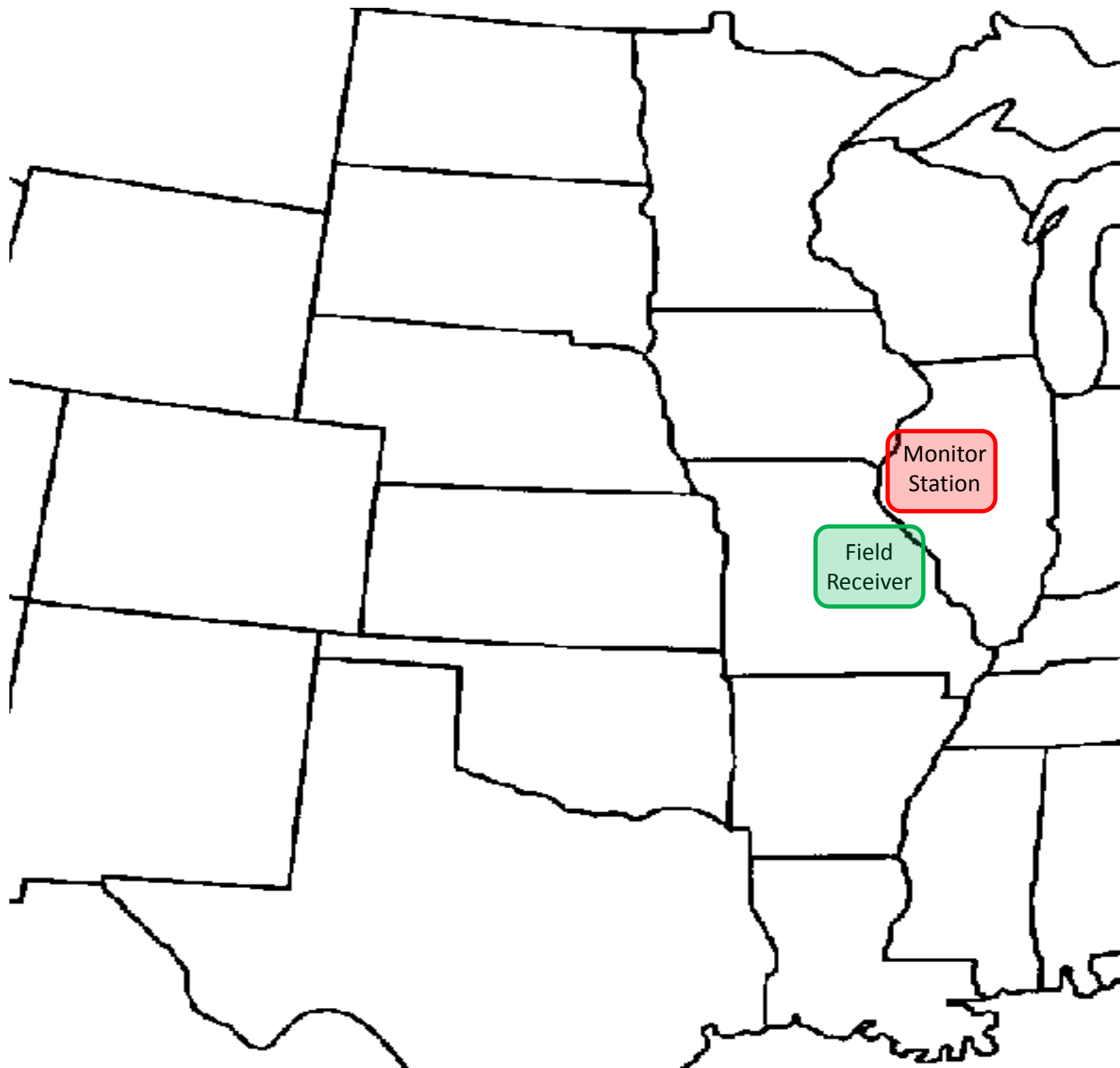


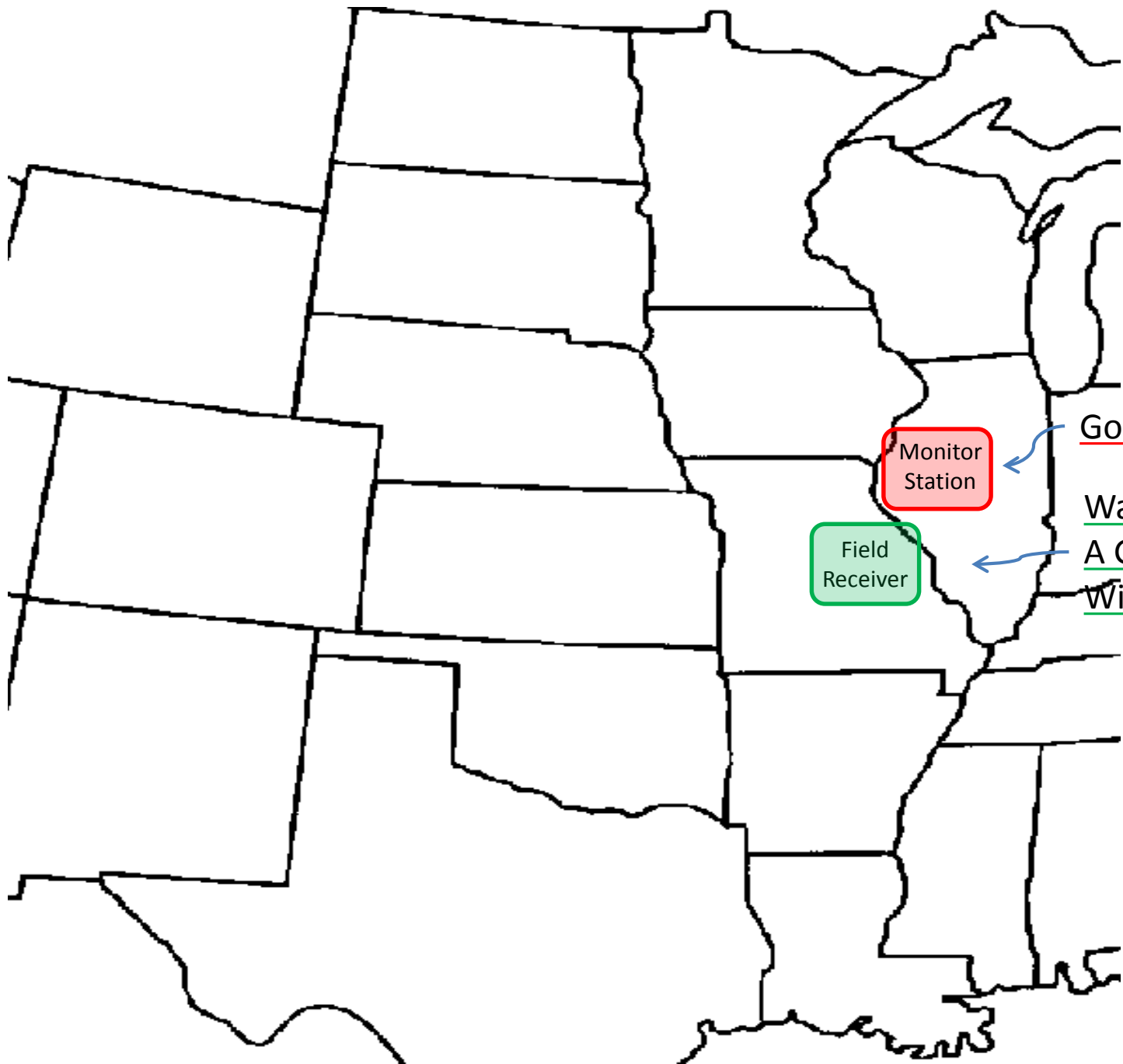
# Monitoring Station





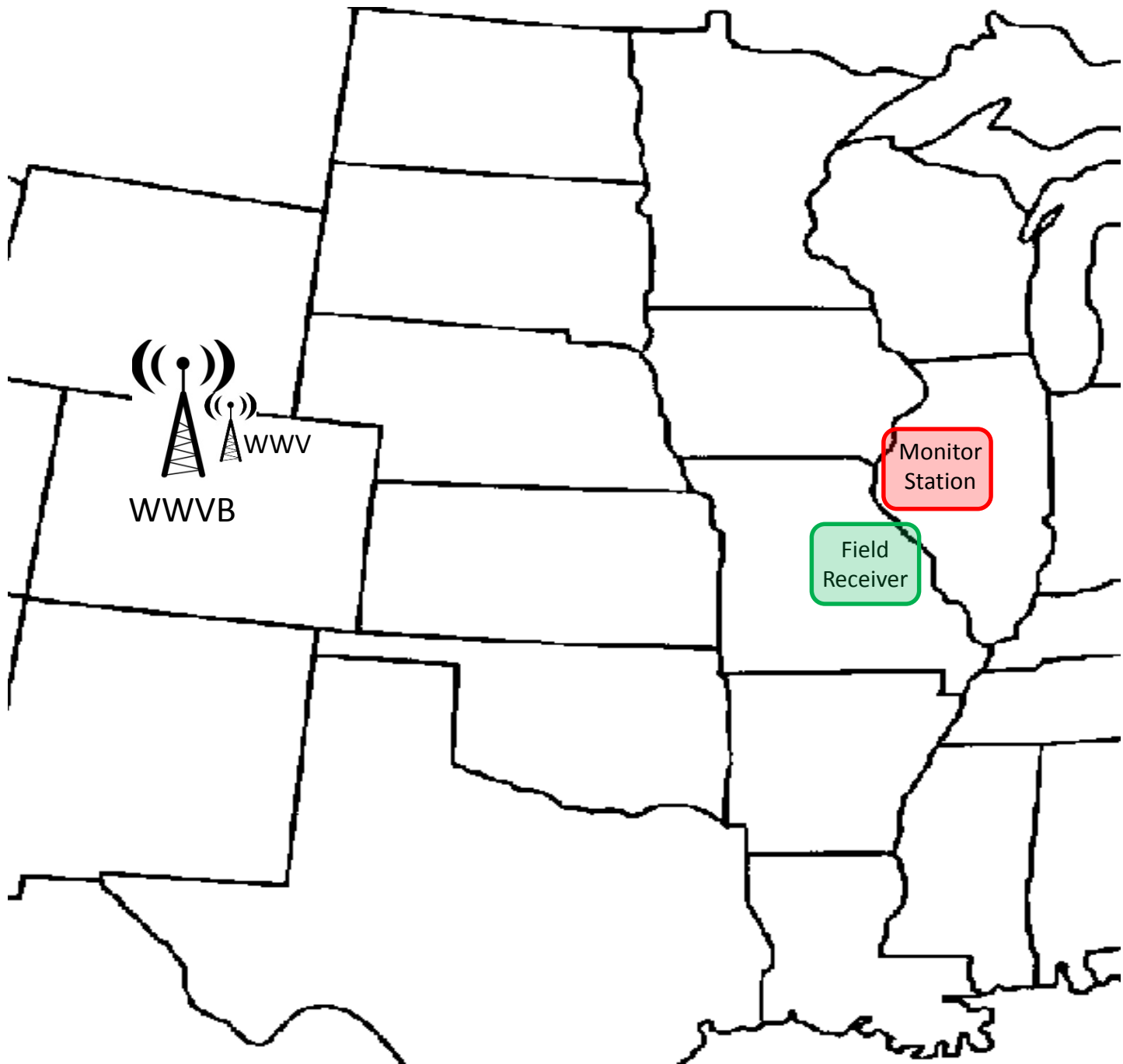




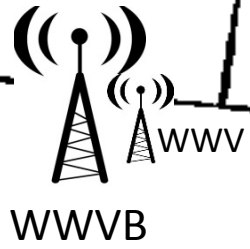


Good Clock

Wants to be  
A Good Clock  
Without GPS



CHU

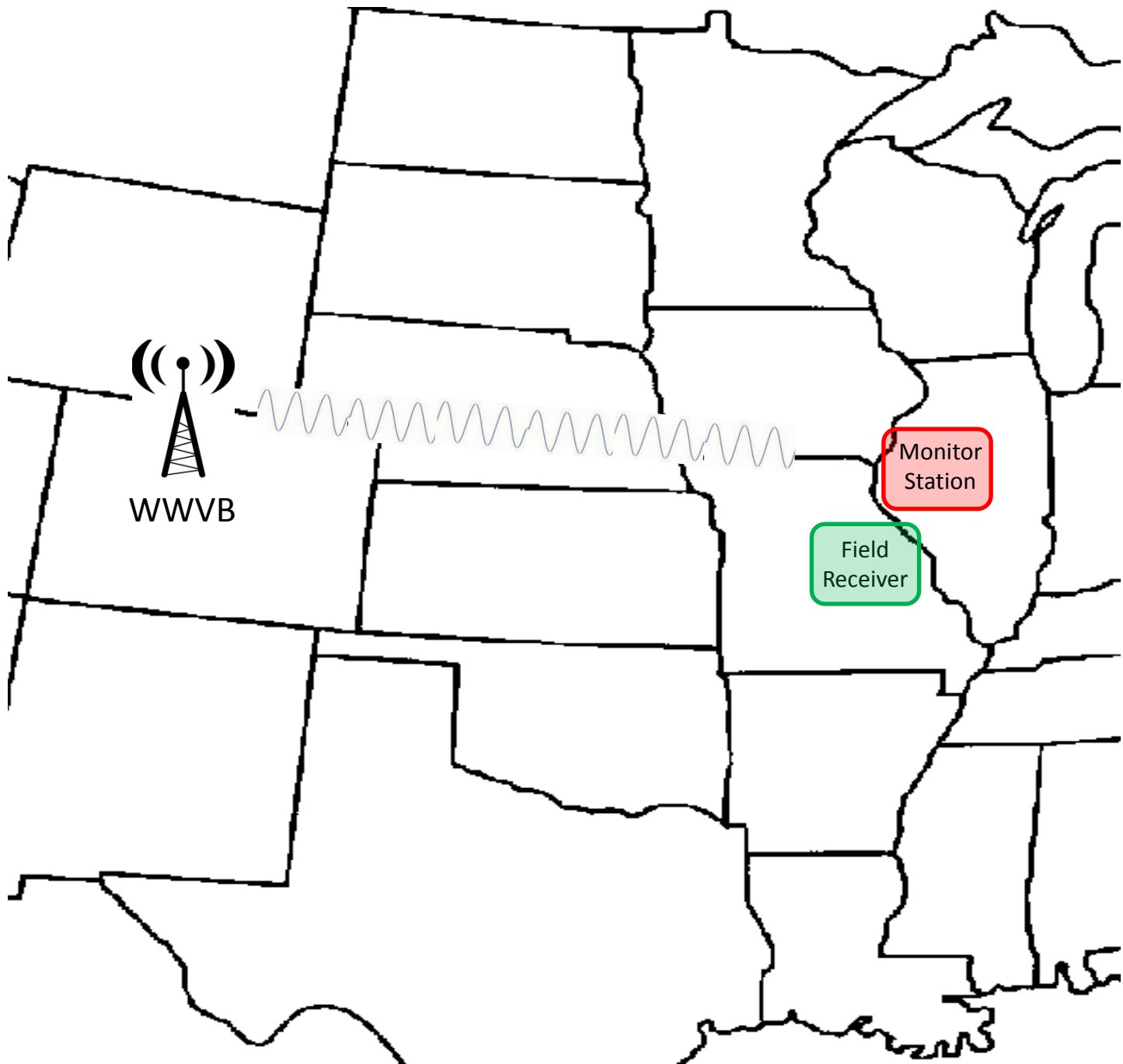


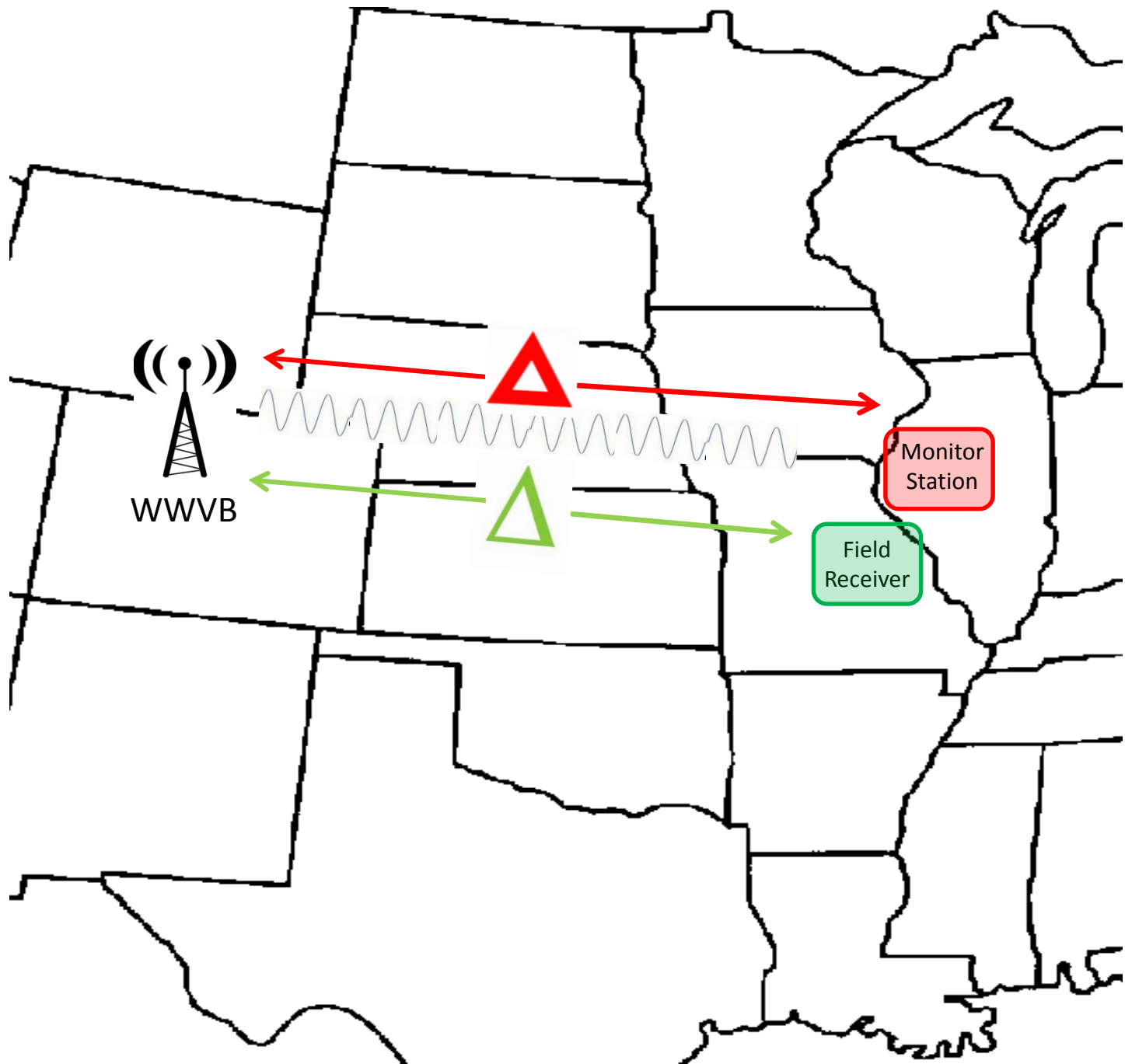
Monitor  
Station

Field  
Receiver

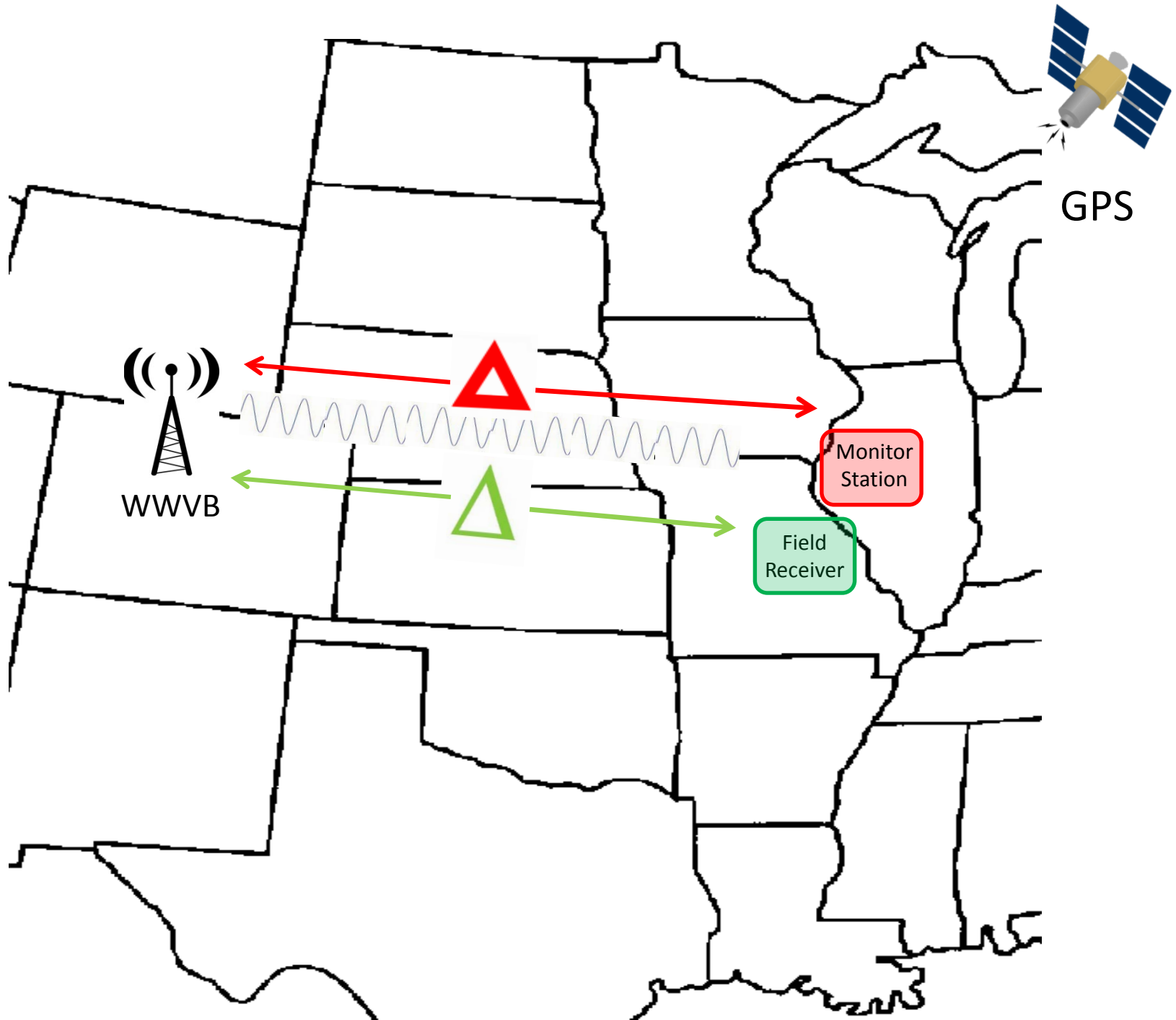


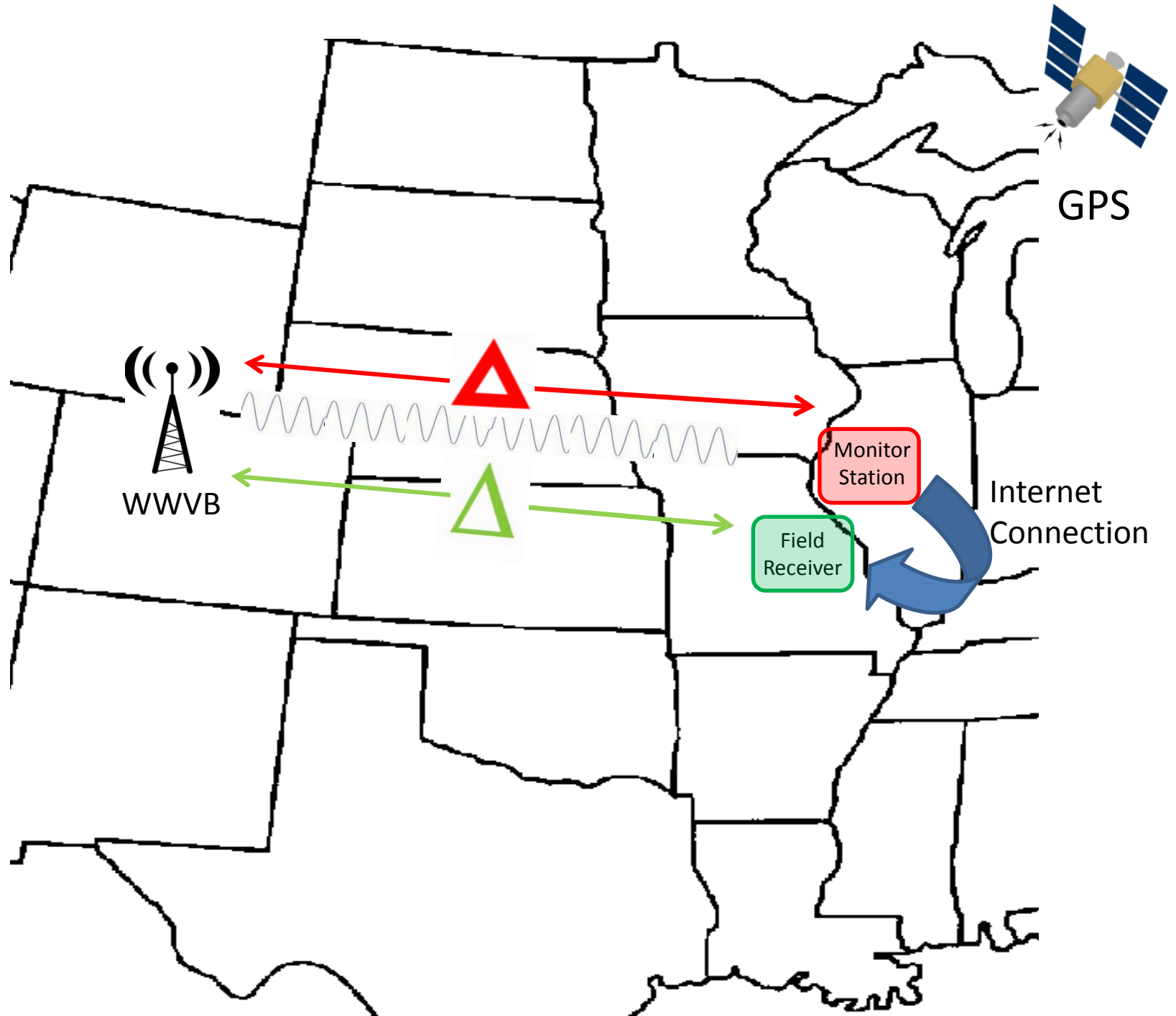
WWVH



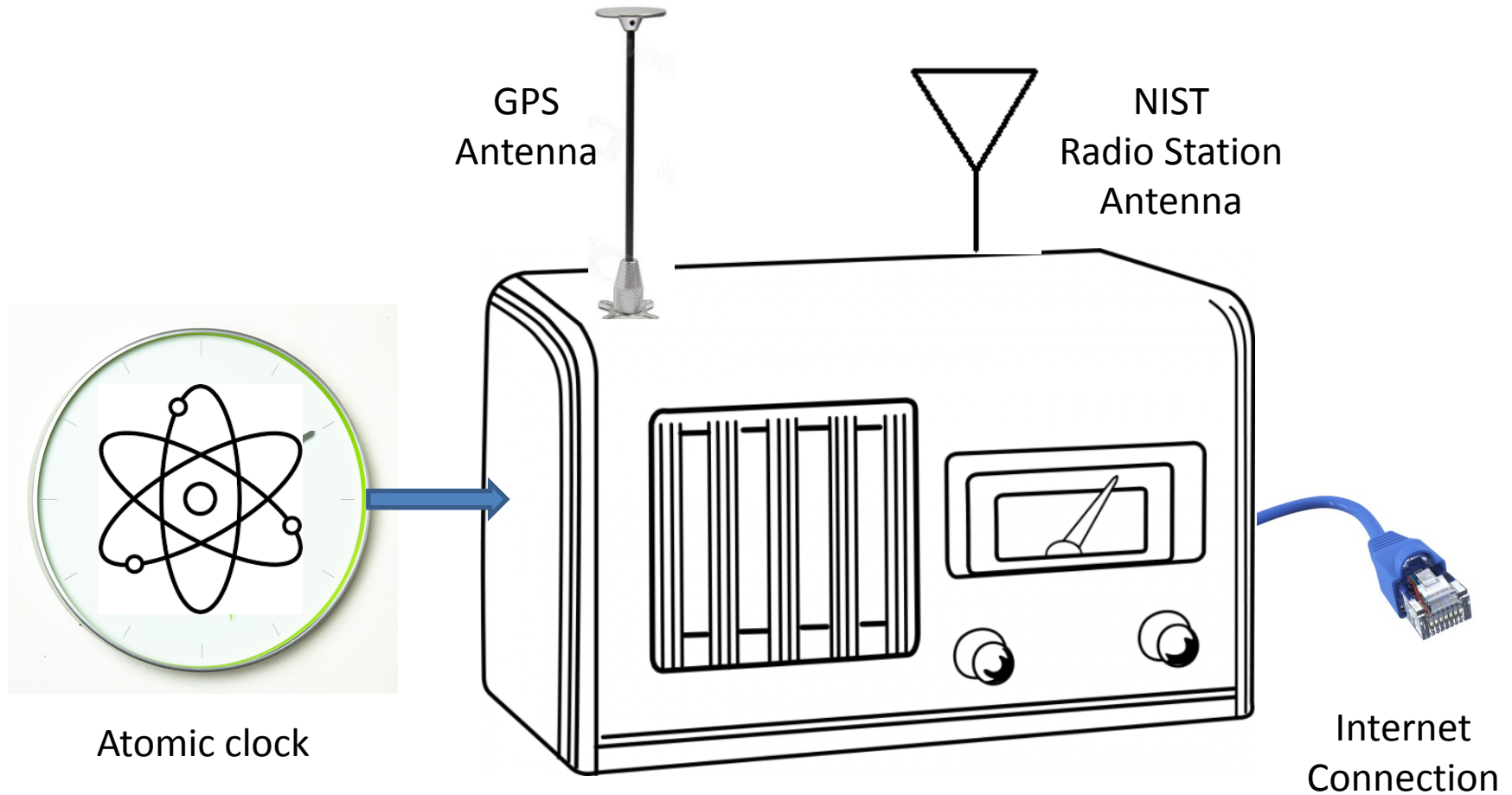




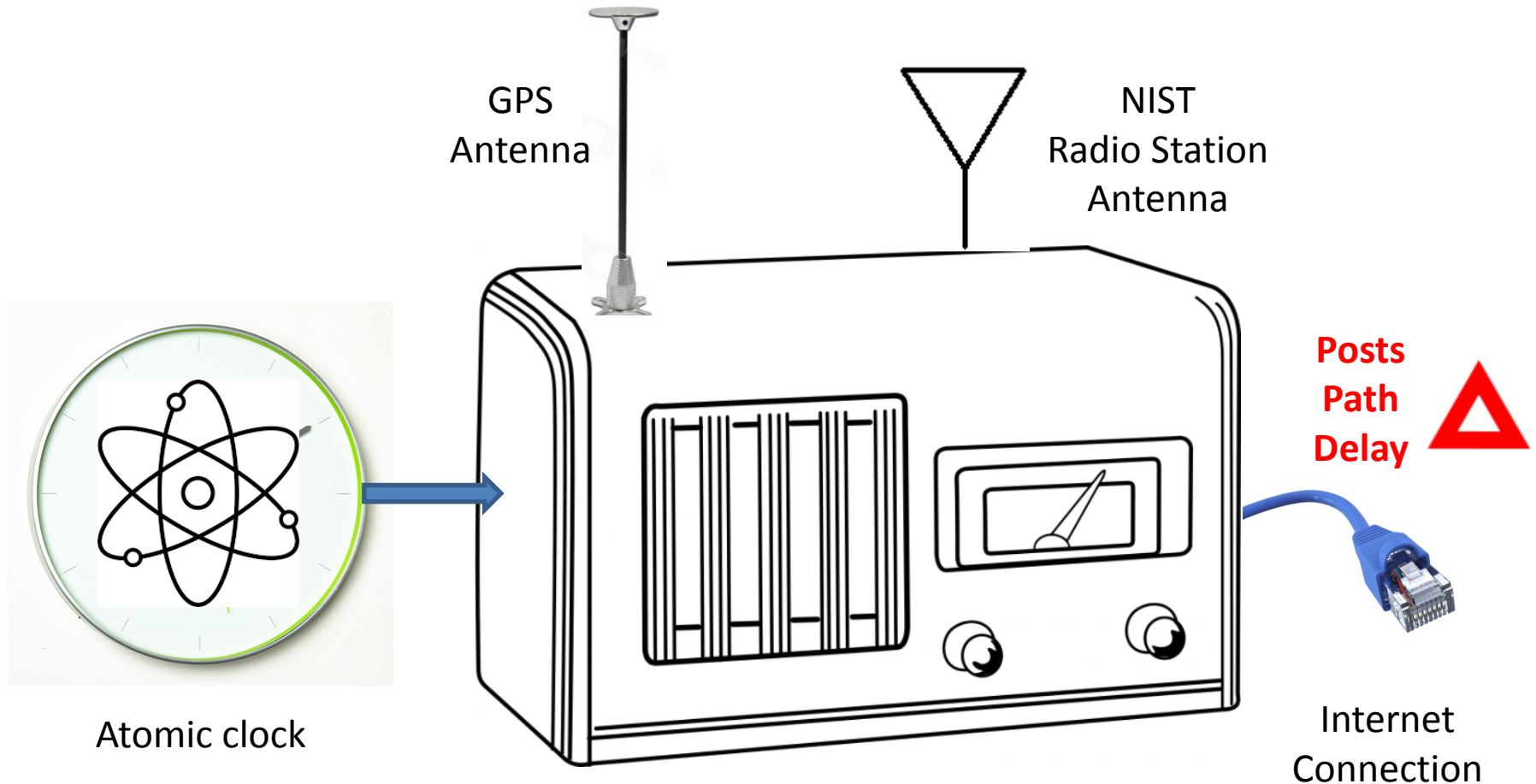




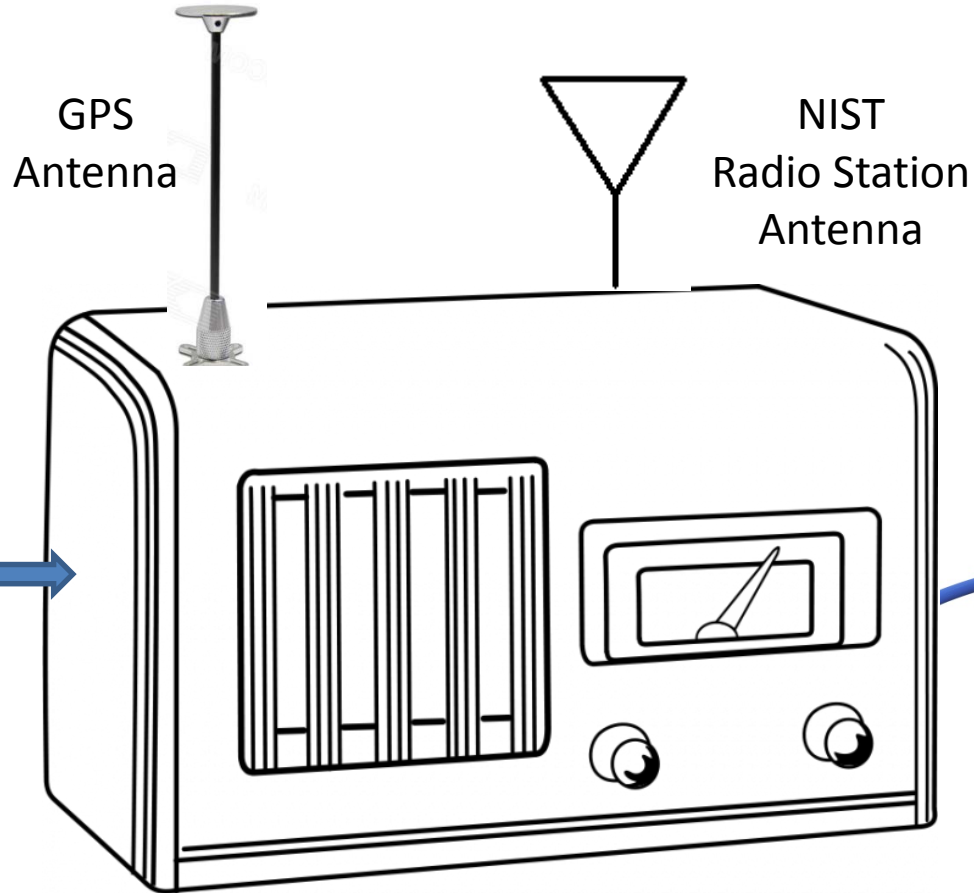
# Monitoring Station



# Monitoring Station

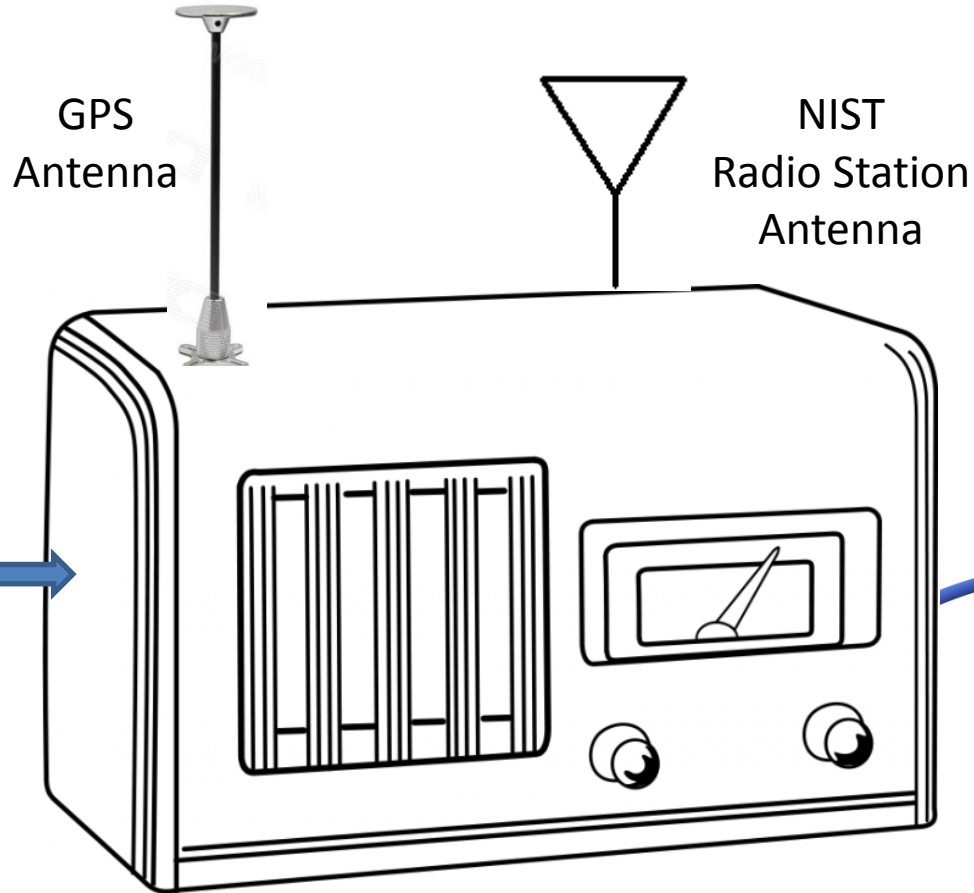


# Field Receiver



Local clock

# Field Receiver



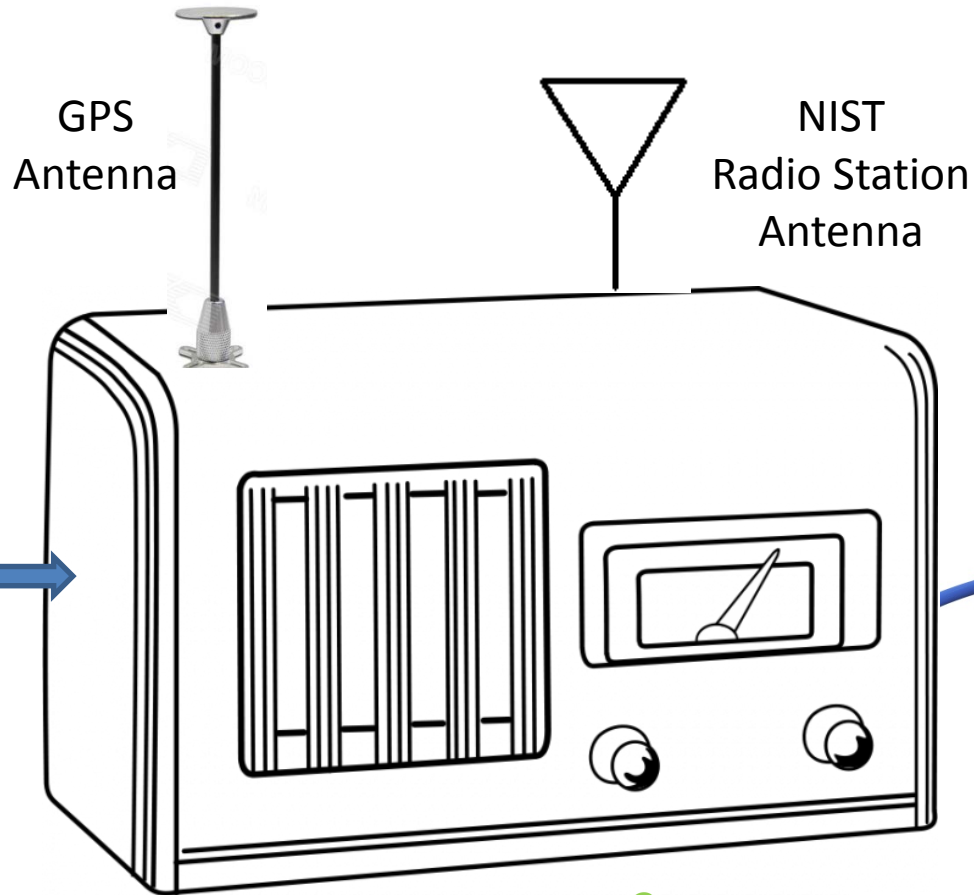
Local clock

**Reads  
Monitor's  
Path  
Delay**

Internet  
Connection



# Field Receiver



Local clock

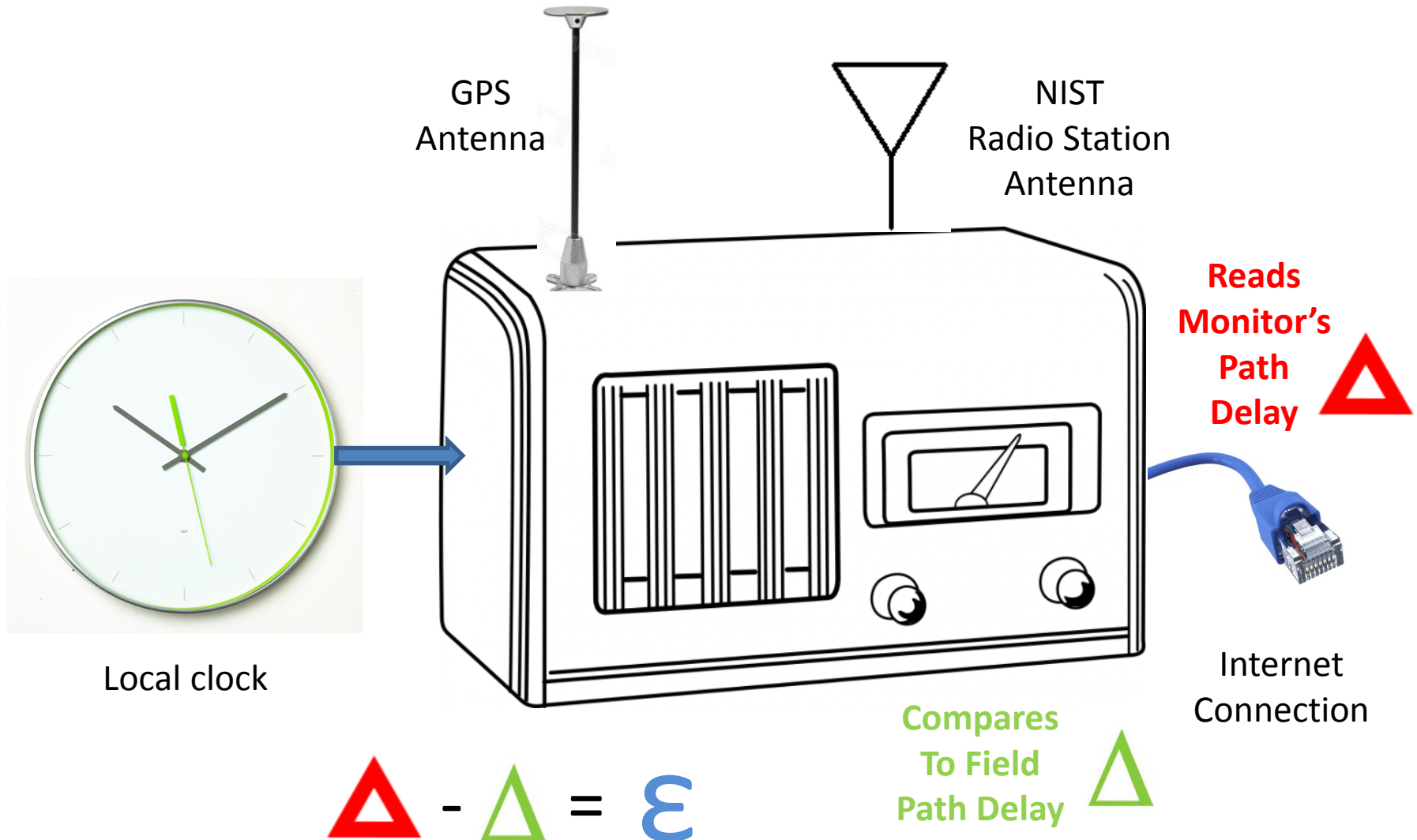
**Reads  
Monitor's  
Path  
Delay** 

**Compares  
To Field  
Path Delay** 

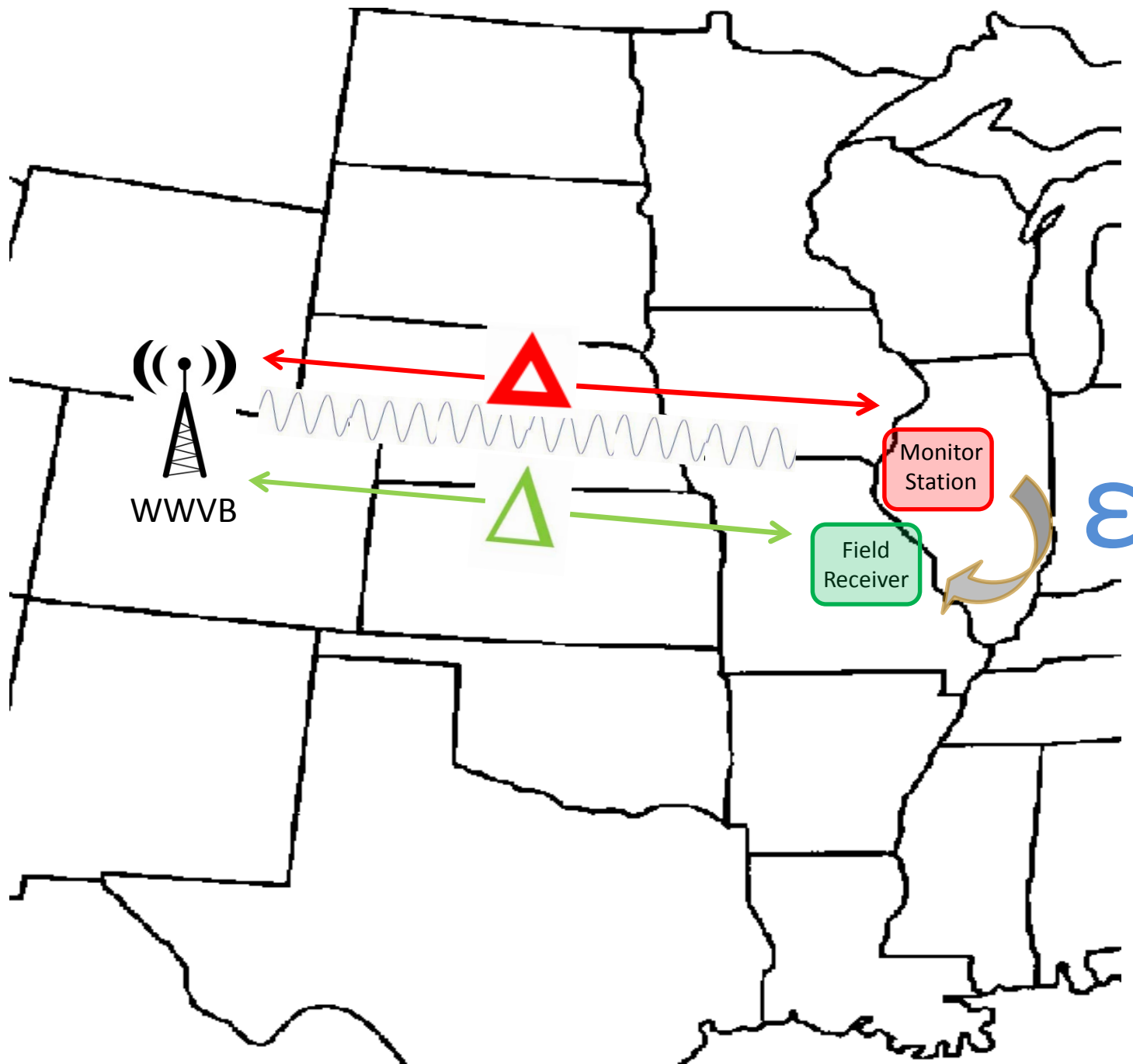
Internet  
Connection



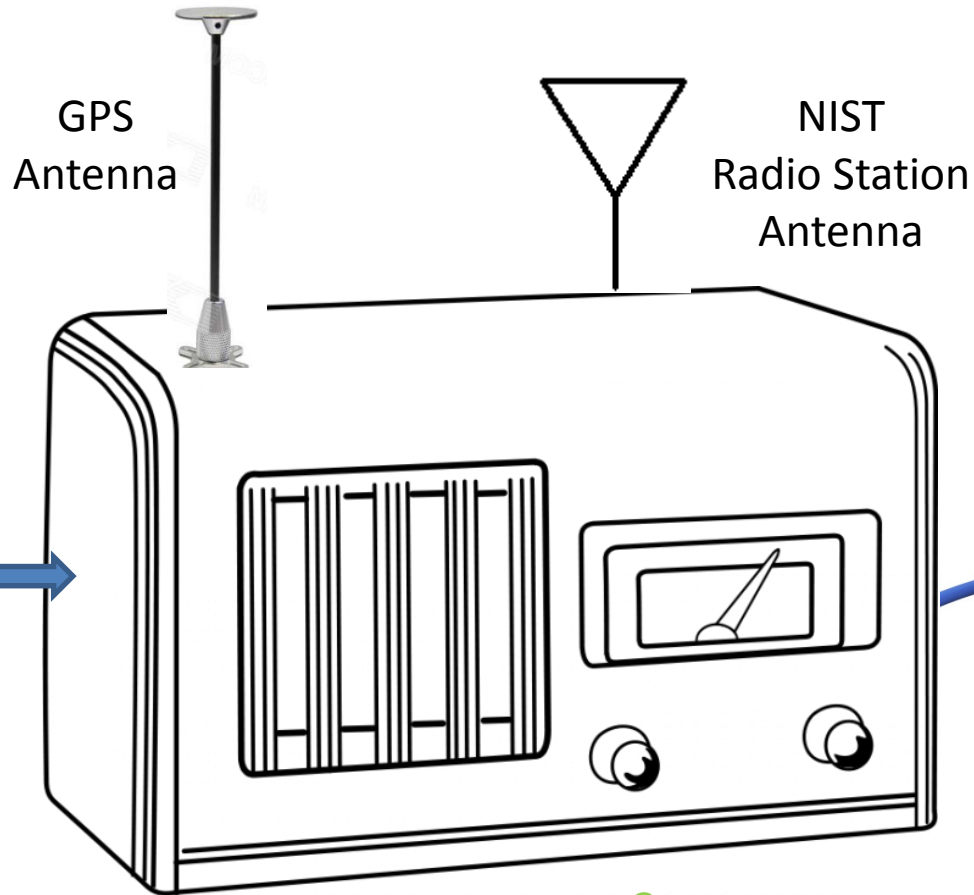
# Field Receiver







# Field Receiver



Local clock

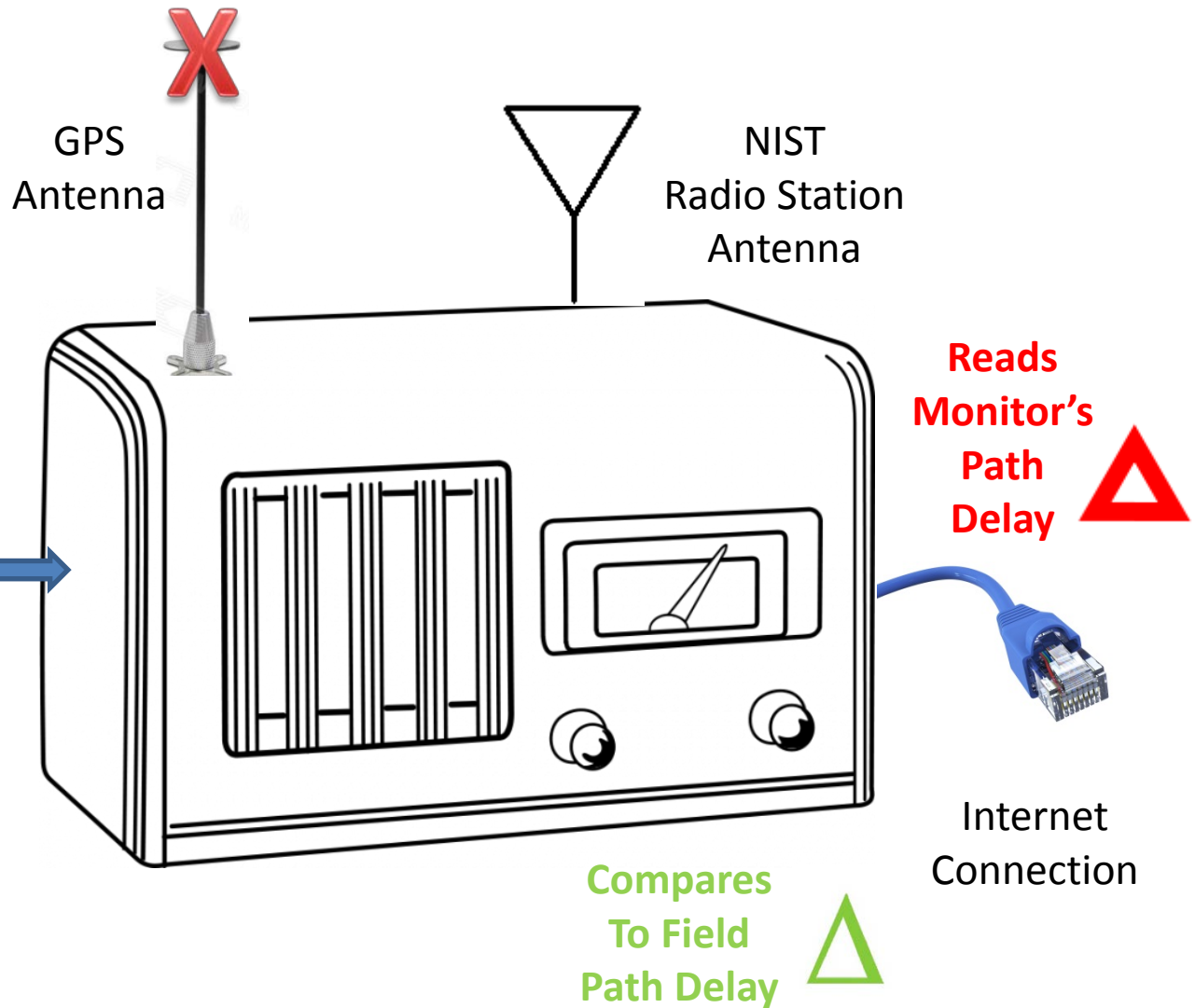
**Reads  
Monitor's  
Path  
Delay** 

**Compares  
To Field  
Path Delay** 

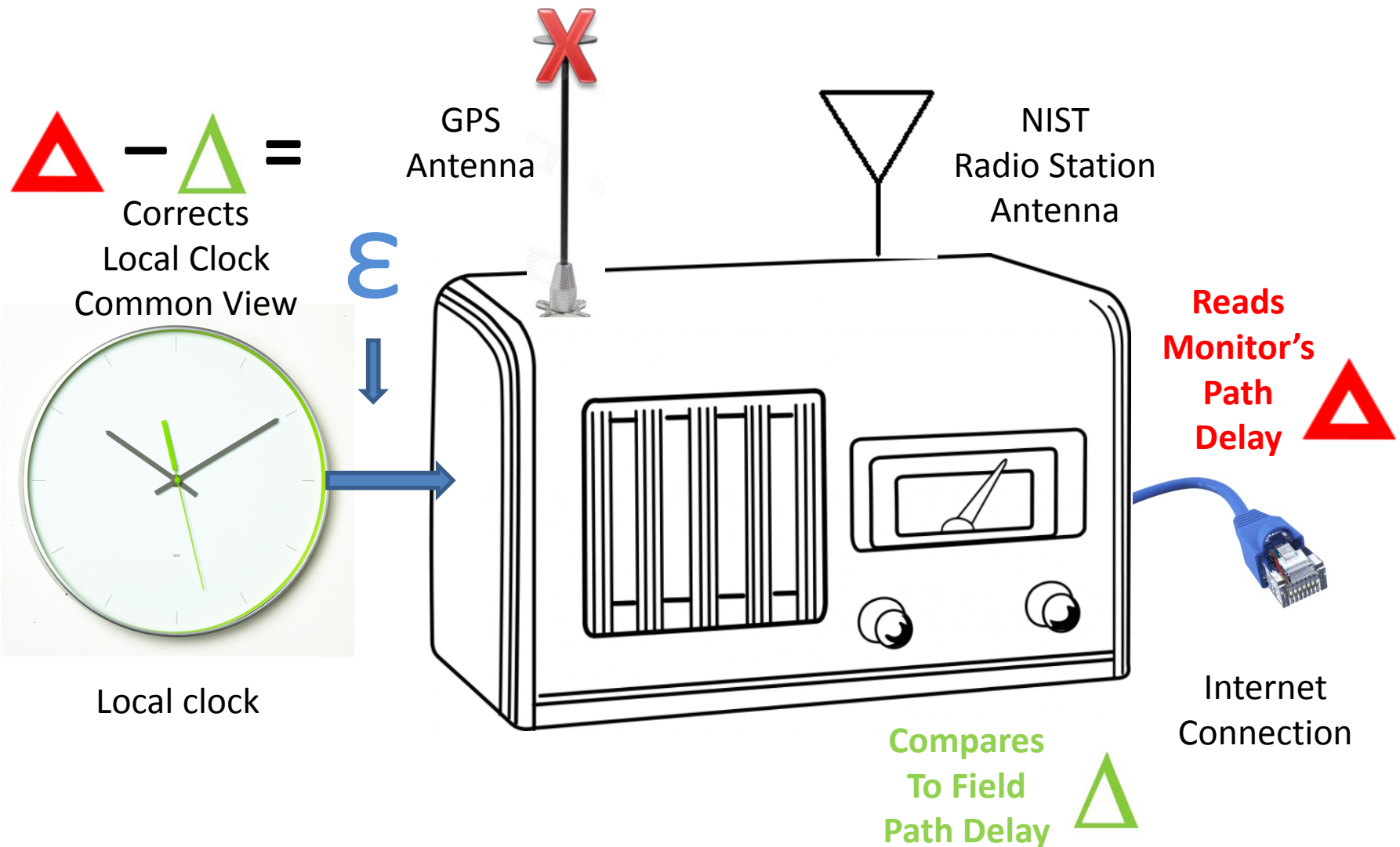
Internet  
Connection



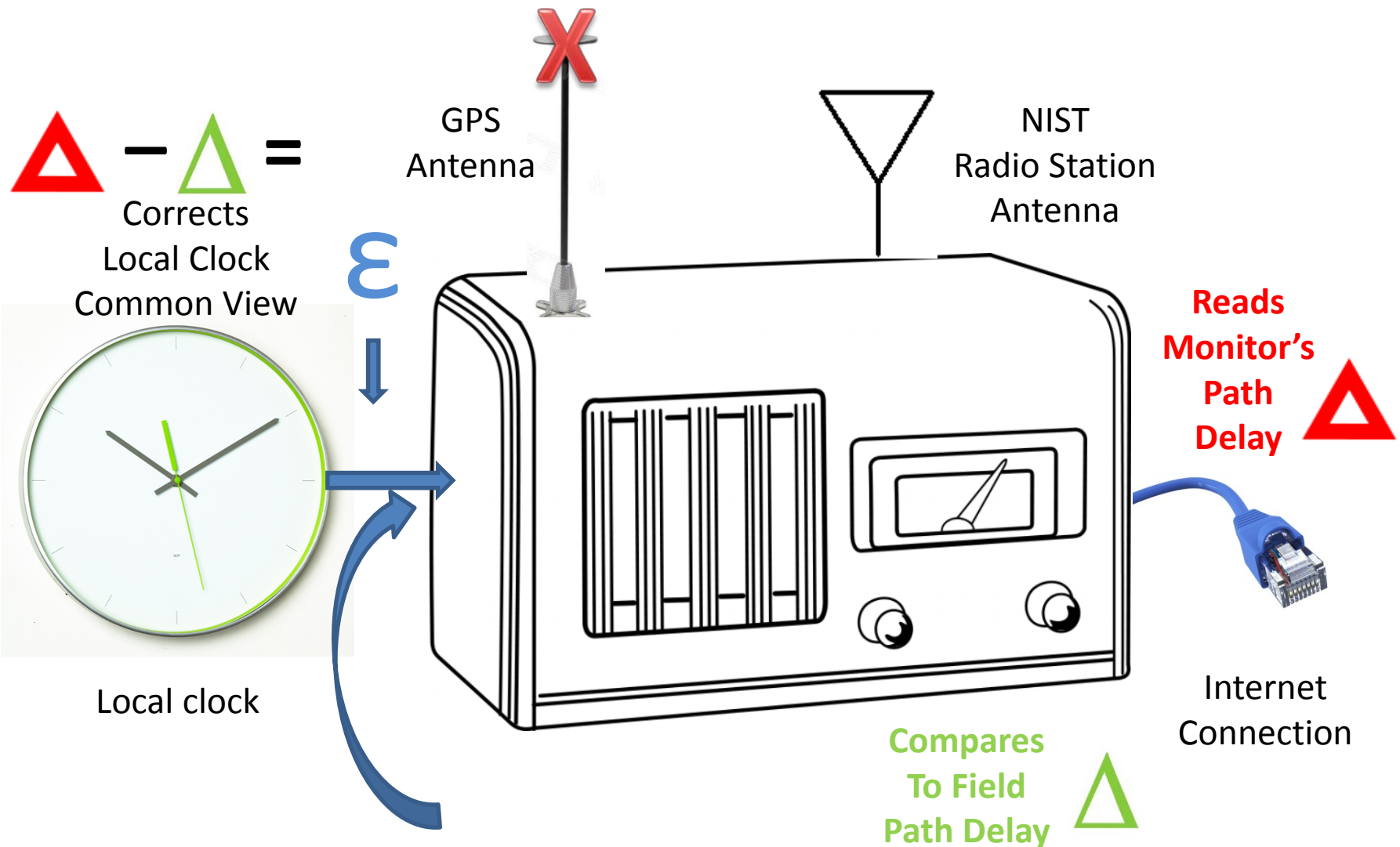
# Field Receiver



# Field Receiver



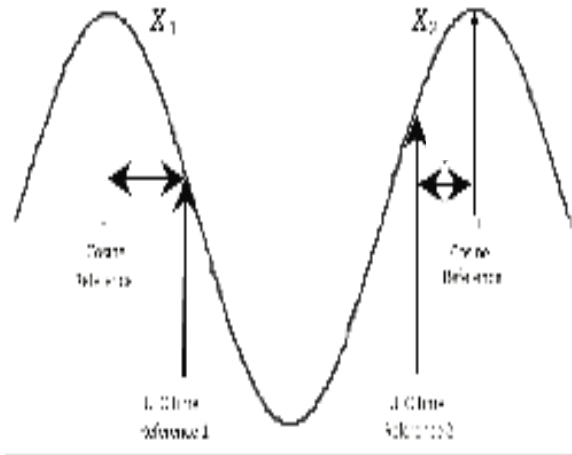
# Field Receiver



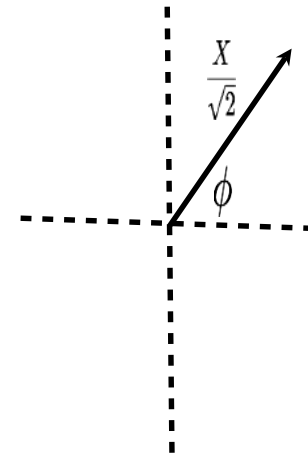
Maintains Synch

# Monitoring Station Clock

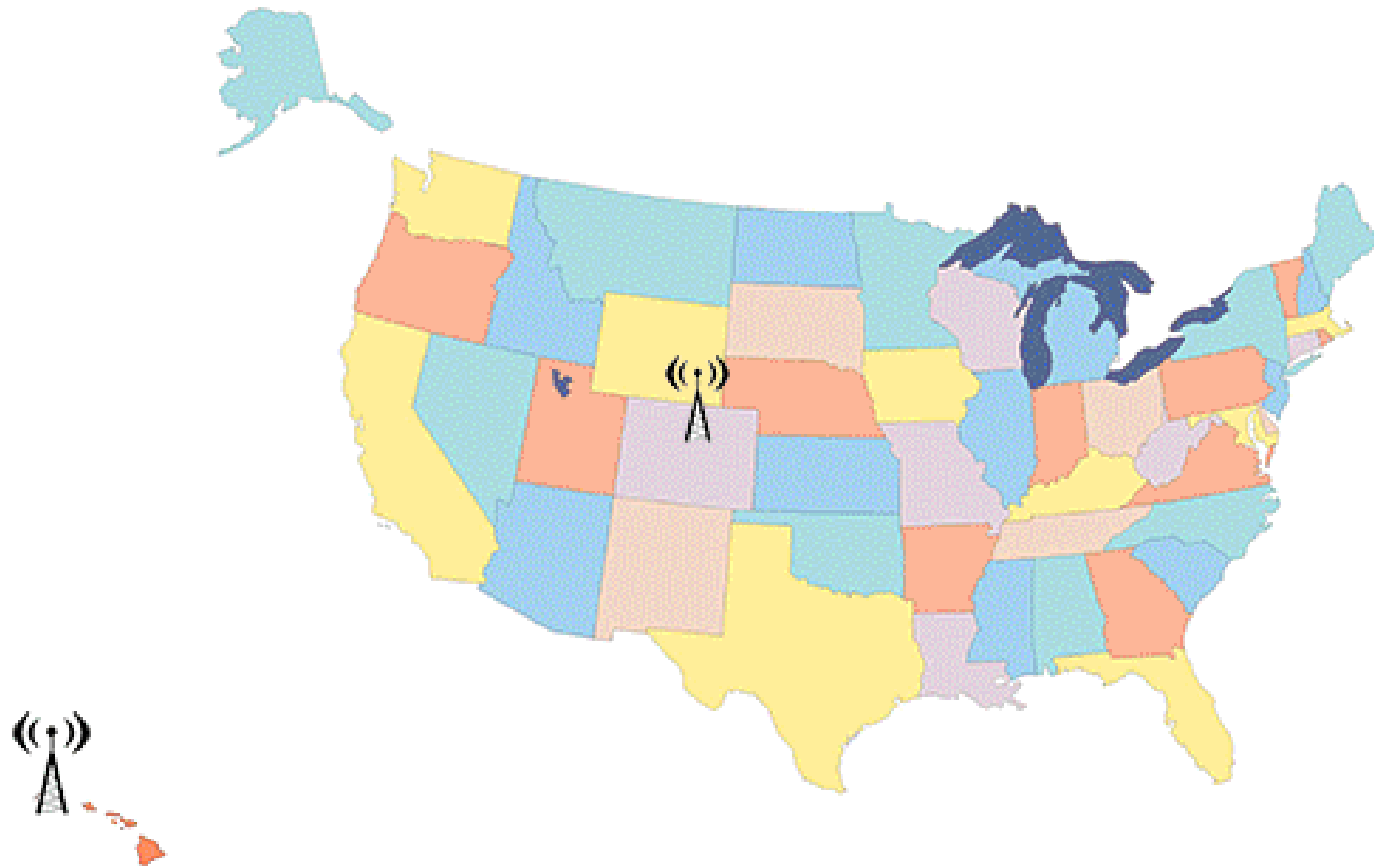
We want a clock that can hold  $<1 \mu\text{s}$  timing accuracy for  $>7$  days...



A synchrophasor is defined as the magnitude and angle of a cosine signal as referenced to an **absolute point in time**.

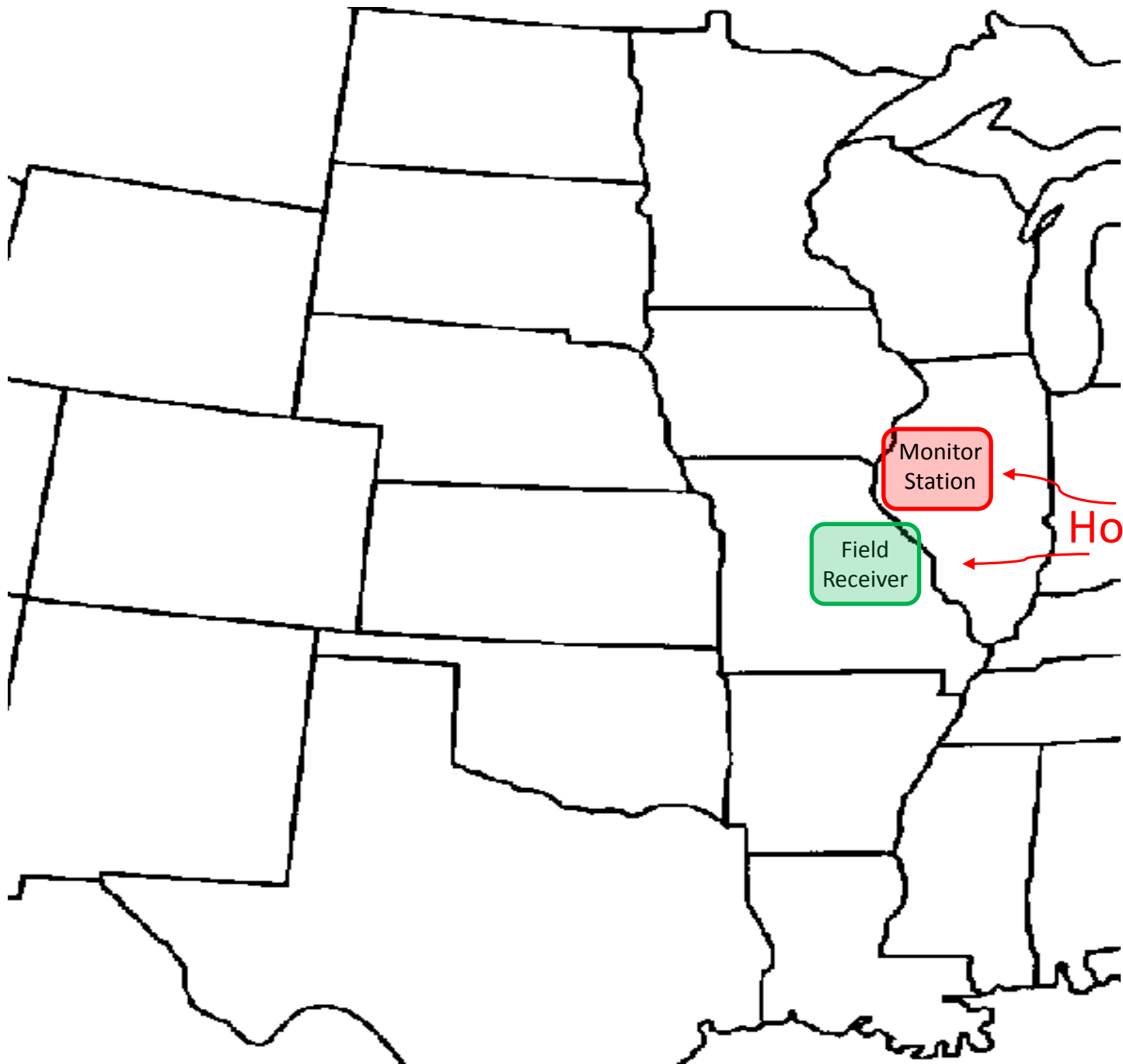


## ***Pinch Hitting for GPS***



***CLICK TO ANIMATE***

***Using NIST clocks and broadcast signals for GPS backup***



Monitor  
Station

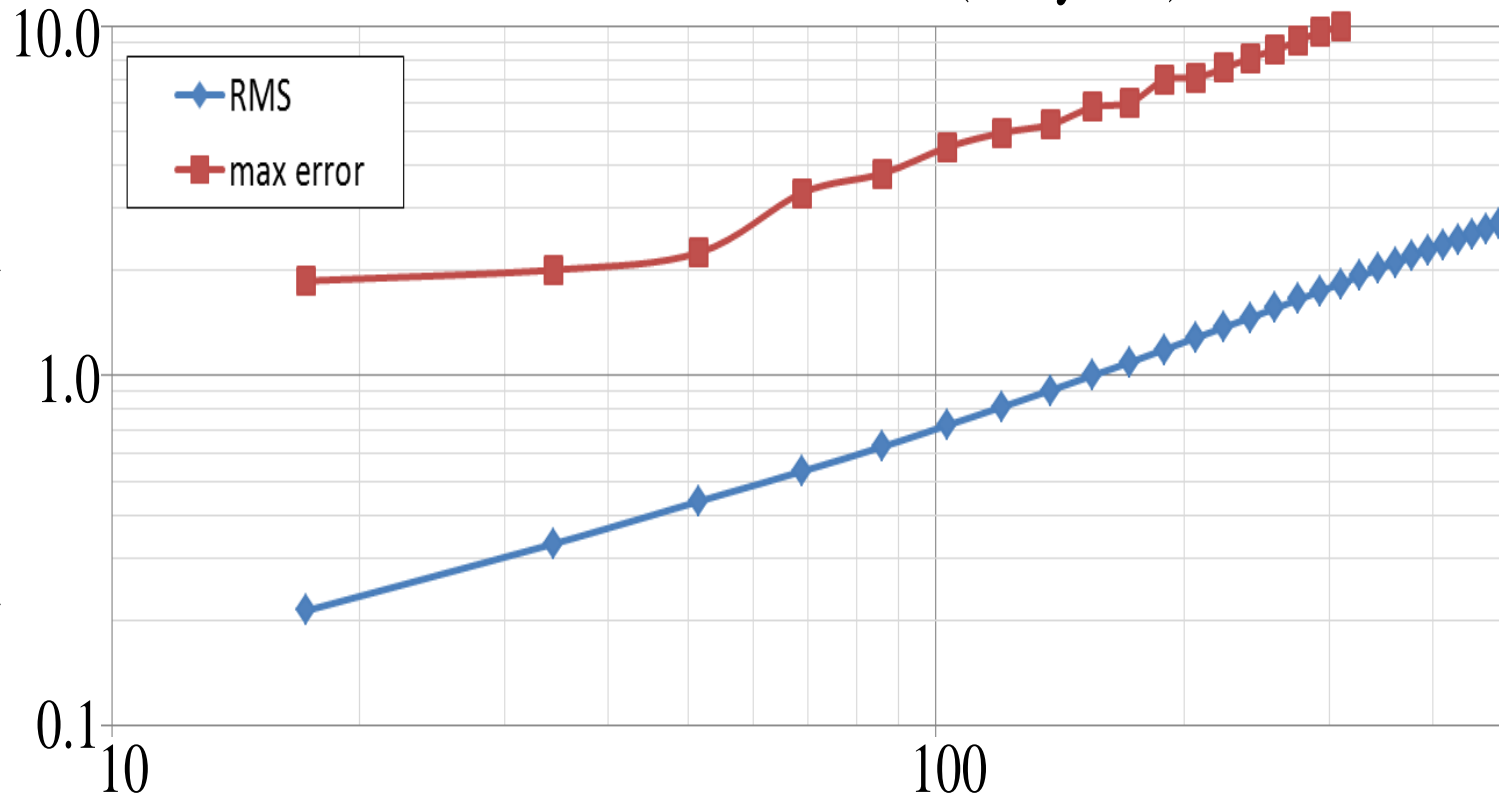
Field  
Receiver

How Far?



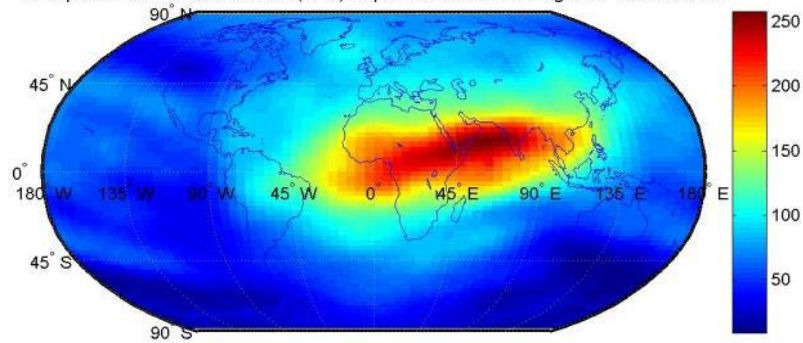
Differential WWVB Error (over 24 hrs) as a function of Distance  
from Reference Receiver (Maryland)

RMS Differential Timing Error  
(Unmodeled) [us]

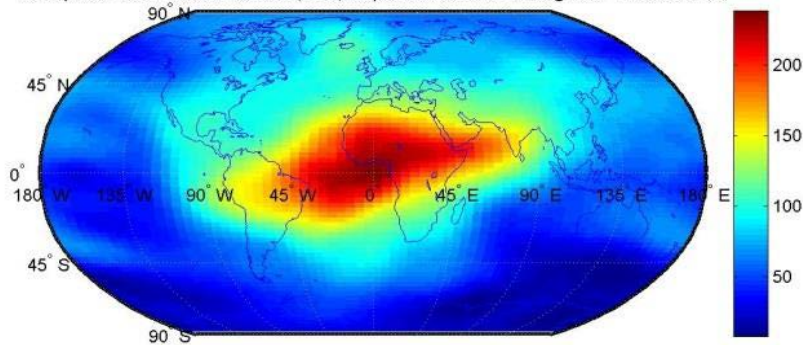


Distance of WWVB Receiver relative to Reference [Miles]

Ionospheric Total Electron Content (TEC) map of the world on 14-Aug-2007 12:00:00 UTC

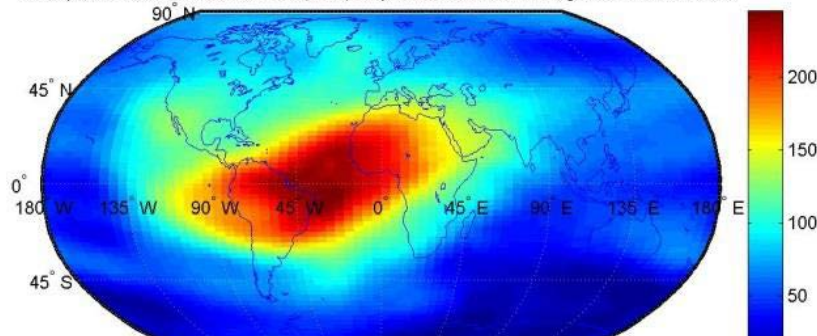


Ionospheric Total Electron Content (TEC) map of the world on 14-Aug-2007 14:00:00 UTC



How Far?  
North/South  
East/West

Ionospheric Total Electron Content (TEC) map of the world on 14-Aug-2007 16:00:00 UTC



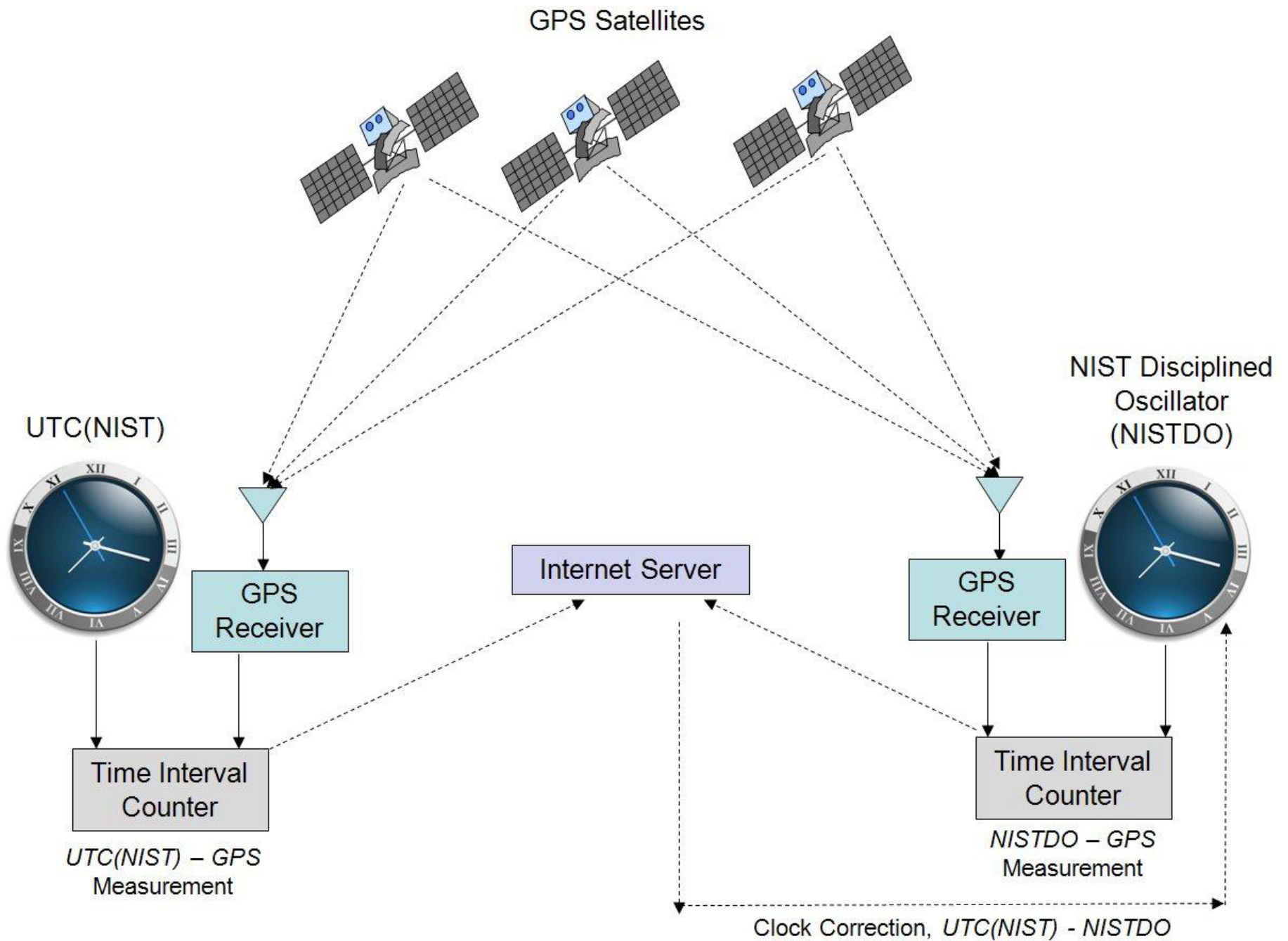
# Joint Proposal

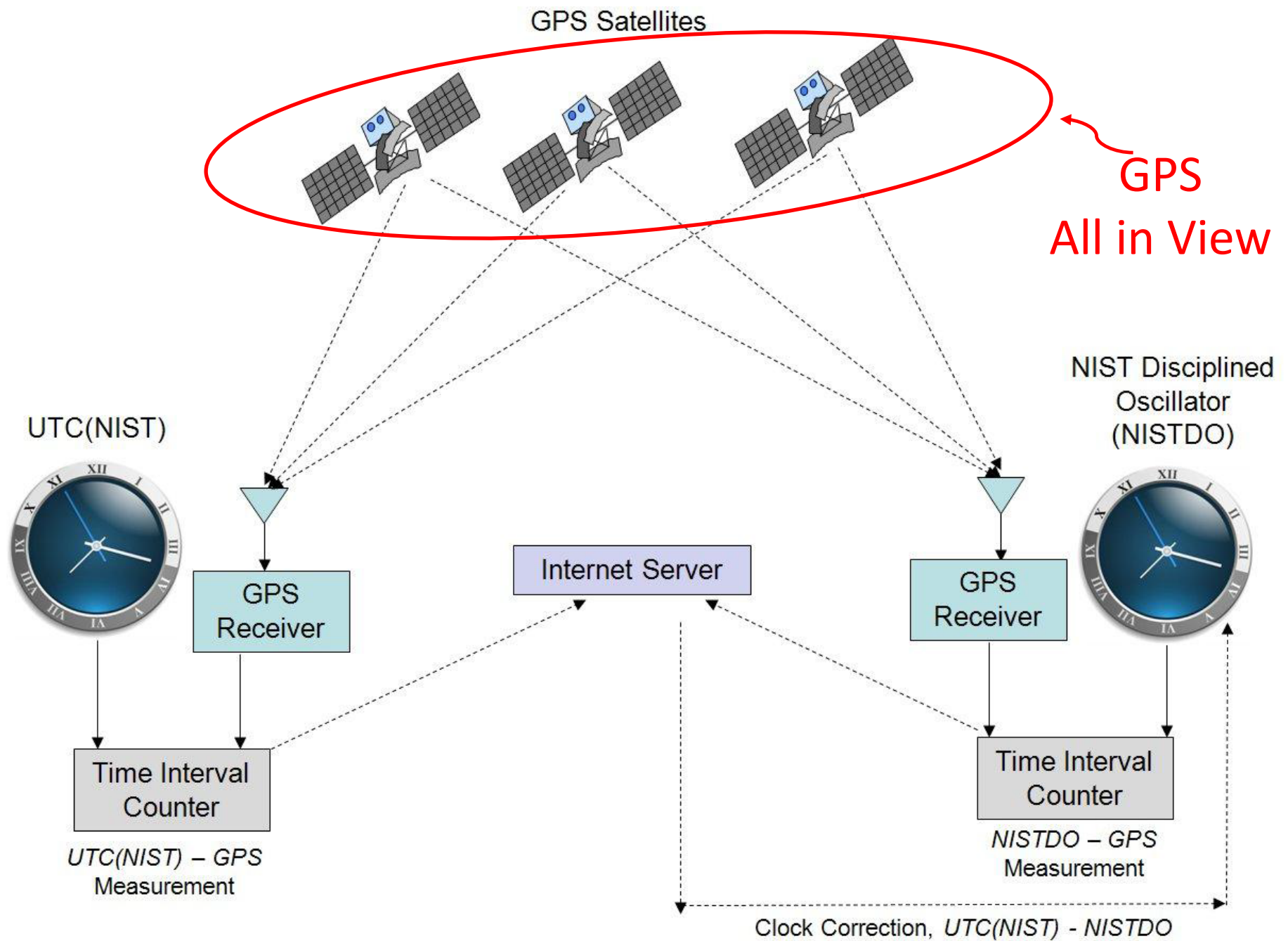




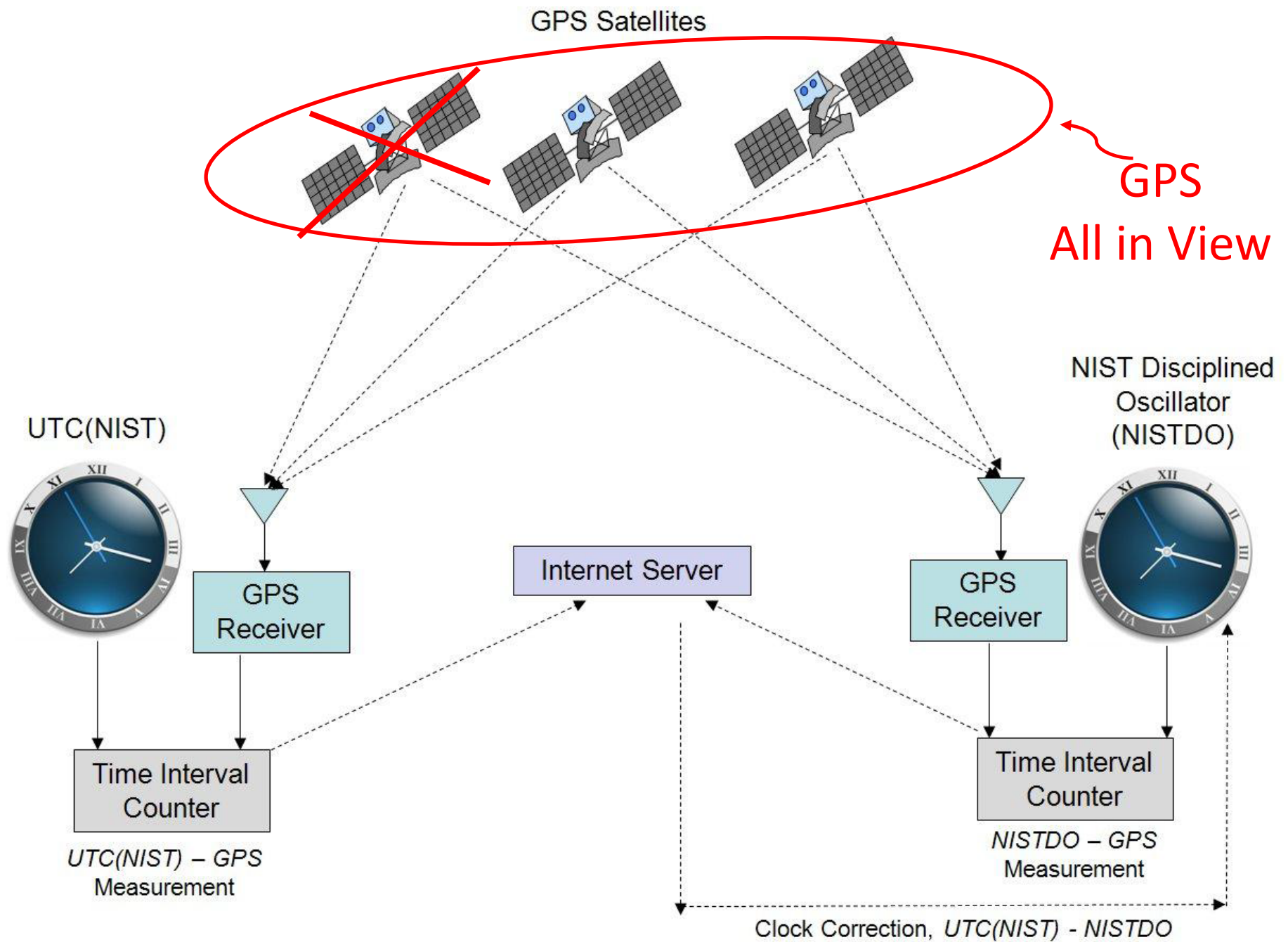
# Assured Timing for Critical Infrastructure Request for Proposal

Other things  
NIST is working on...



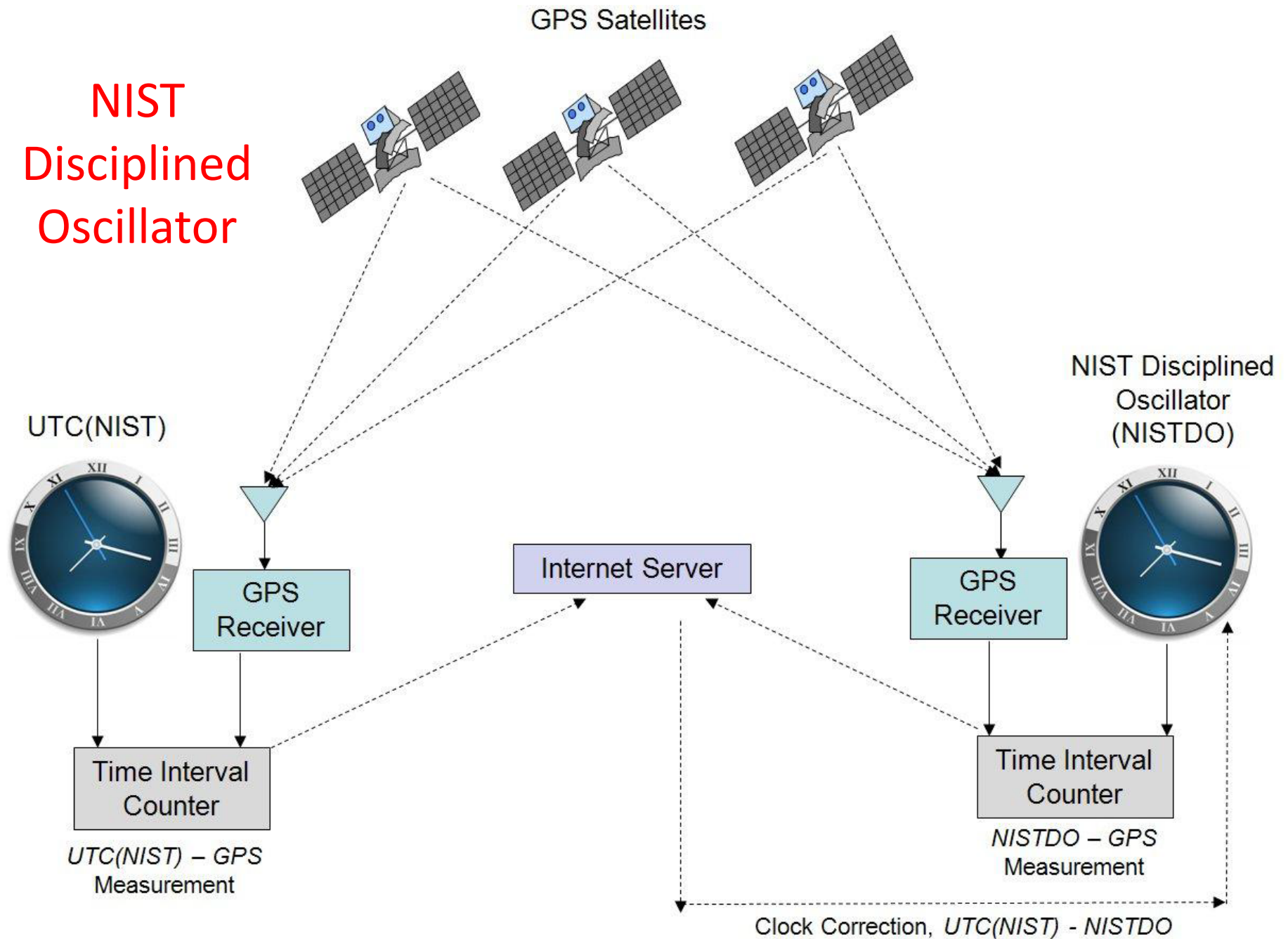








# NIST Disciplined Oscillator



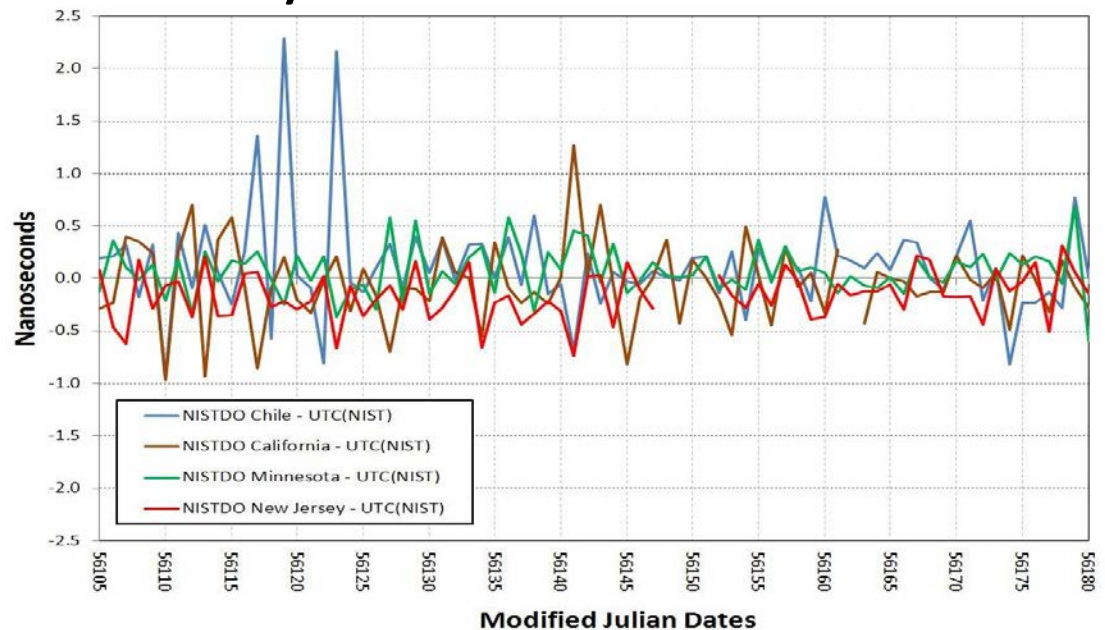
# NIST Disciplined Oscillator



# NIST Disciplined Oscillator



Frequency stability  $5 \times 10^{-14}$   
Time Synchronization 10 nS



# NIST Disciplined Oscillator

## FMAS

Frequency Measure  
& Analysis Service

## TMAS

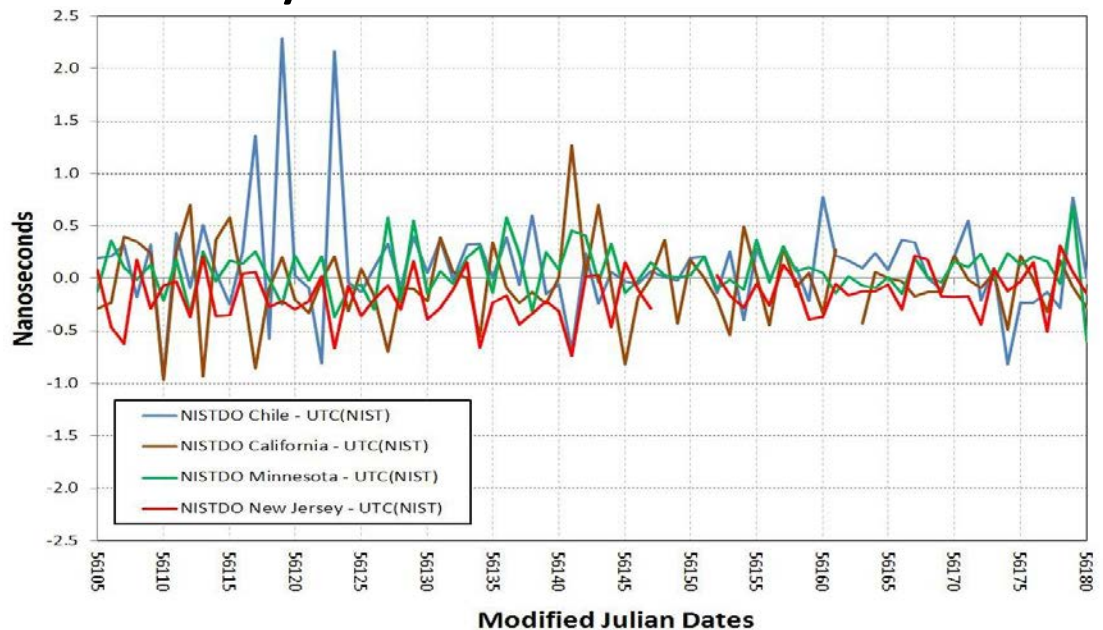
Time Measure  
& Analysis Service

## SIM

Sistema Interamericano de Metrologia (SIM). This time scale, known as the SIM time scale, or SIMT, was developed to complement the official world time scale, Coordinated Universal Time



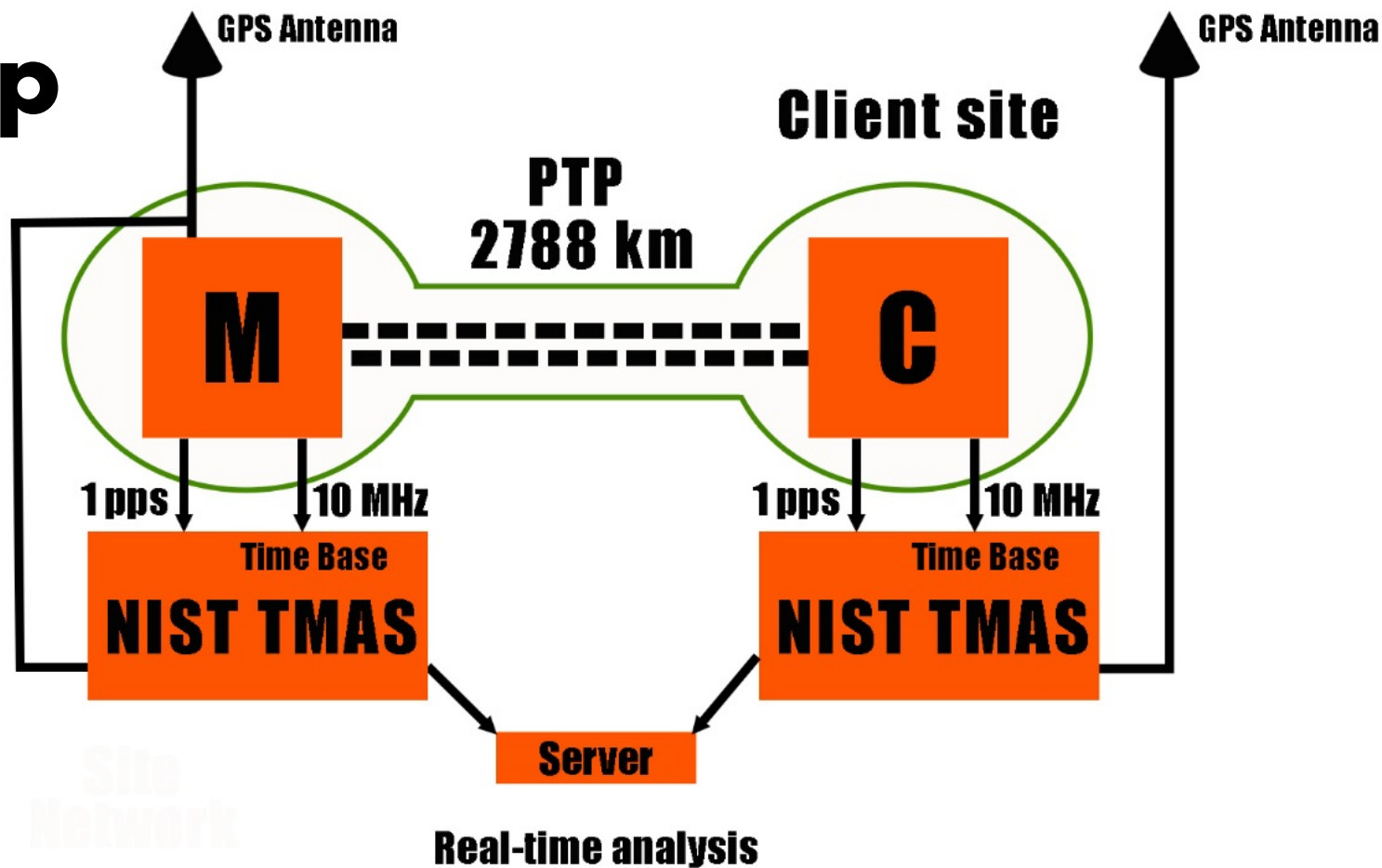
Frequency stability  $5 \times 10^{-14}$   
Time Synchronization 10 nS



Also  
Precision Time Protocol

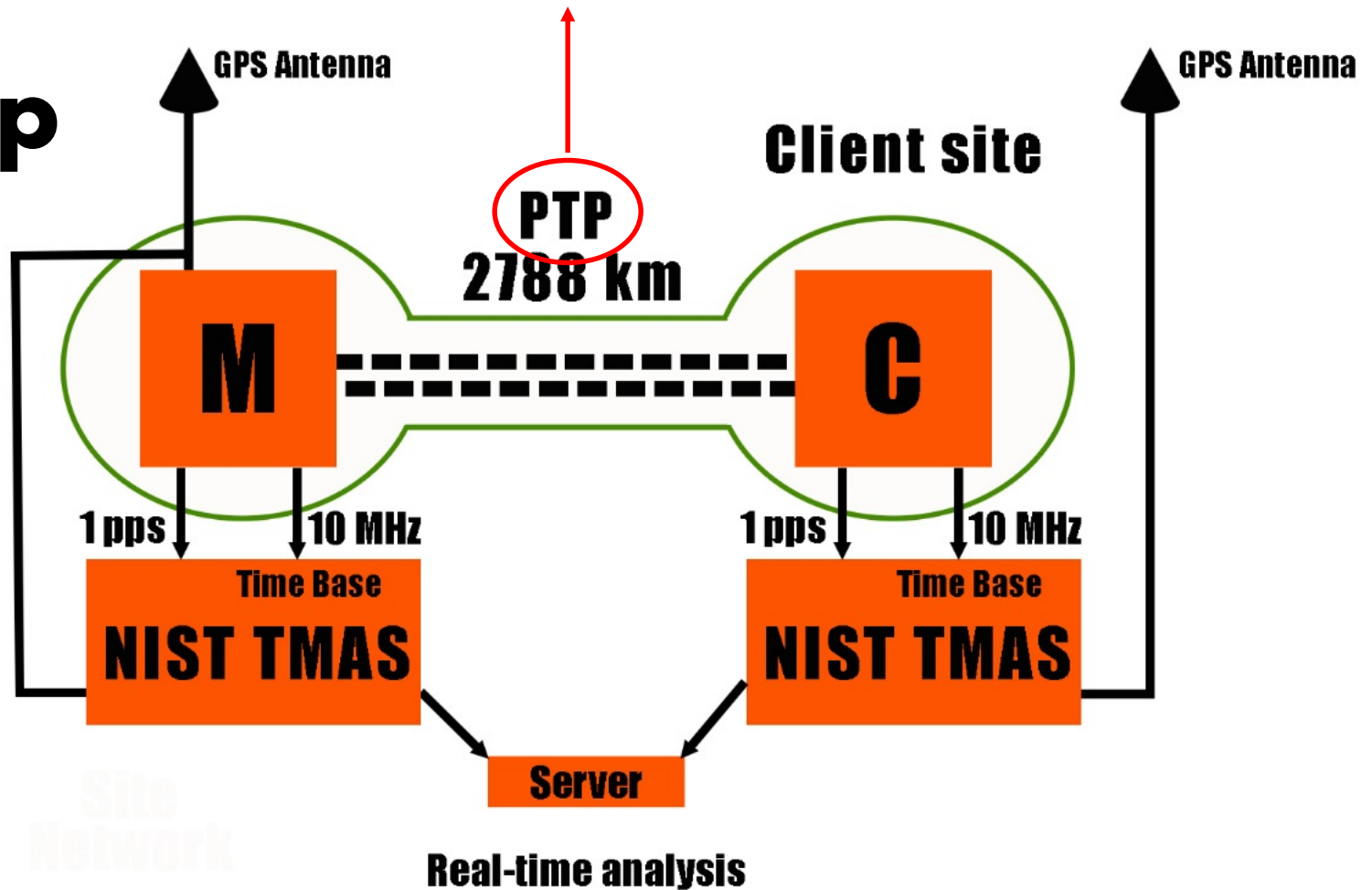


# Setup



# Precision Time Protocol

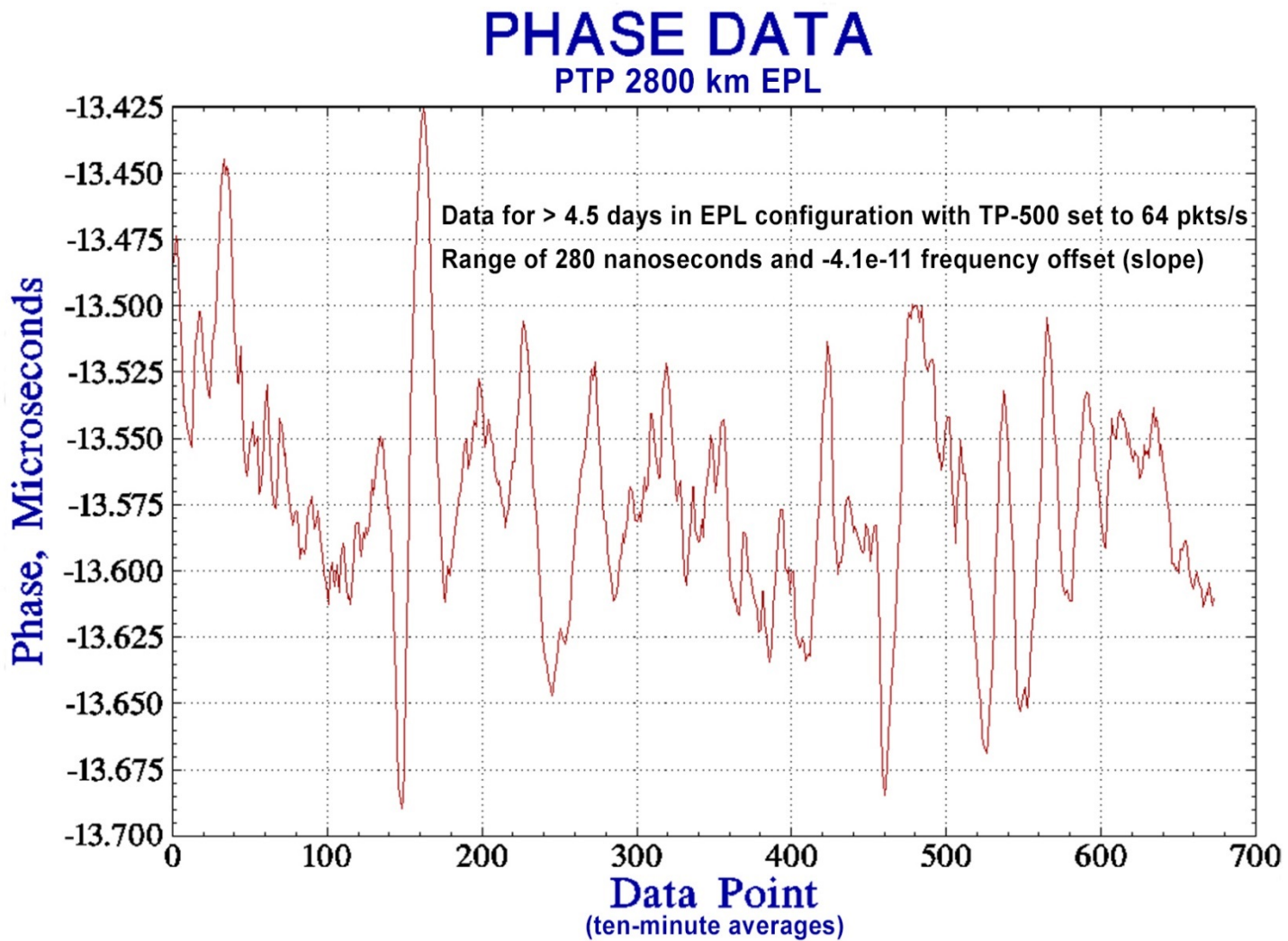
## Setup



Average Time Offset  
13.6 us

Calibrate  
the Client

Specification for  
LTE 1.5 us  
Ideally: < 1 us

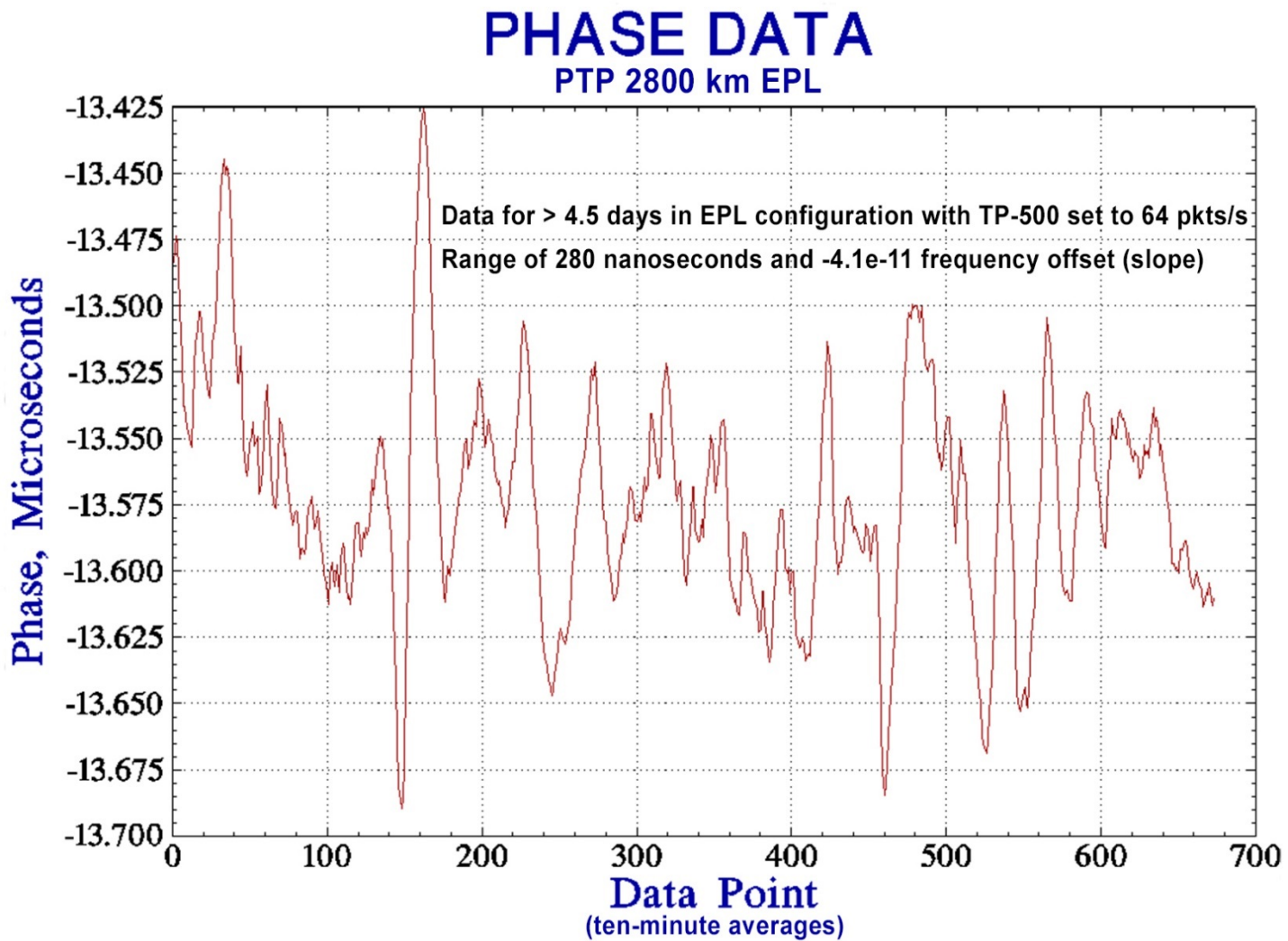




Average Time  
Offset  
13.6  $\mu\text{s}$

Calibrate  
the Client

Specification for  
LTE 1.5  $\mu\text{s}$   
Ideally: < 1  $\mu\text{s}$

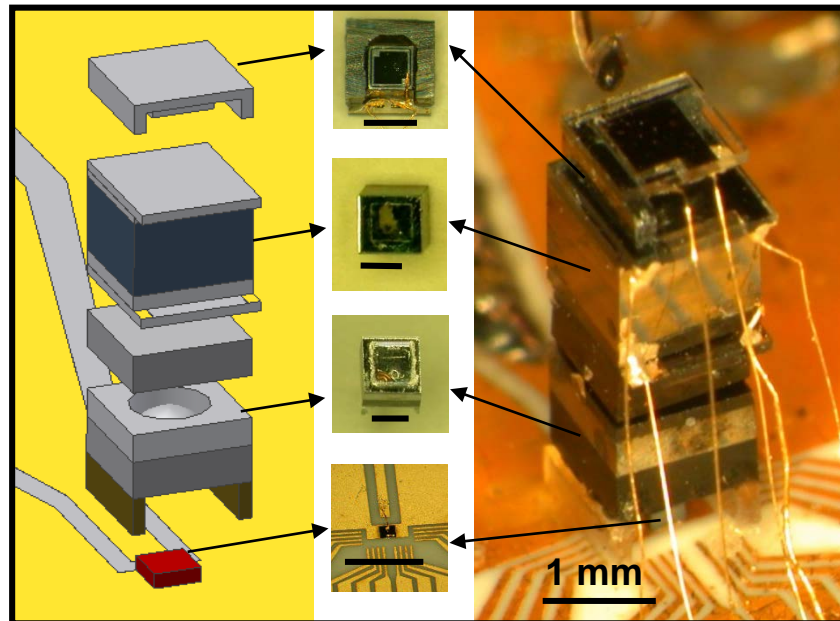
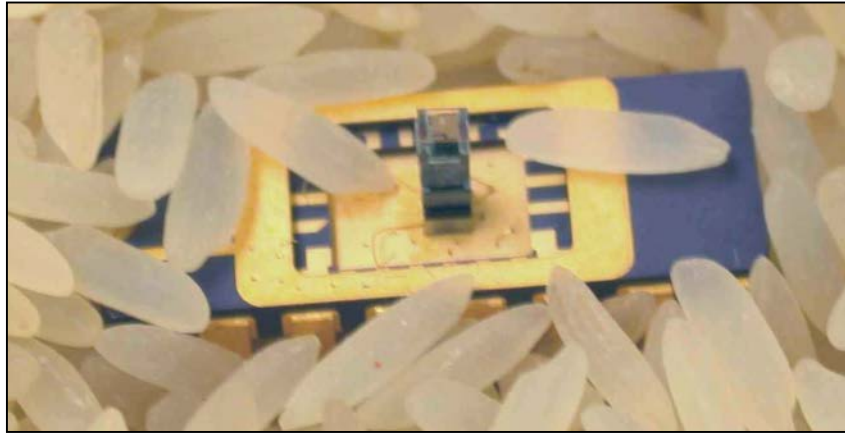


300 nS RMS

# Chip-scale Atomic Clocks

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# Chip-scale Atomic Clocks

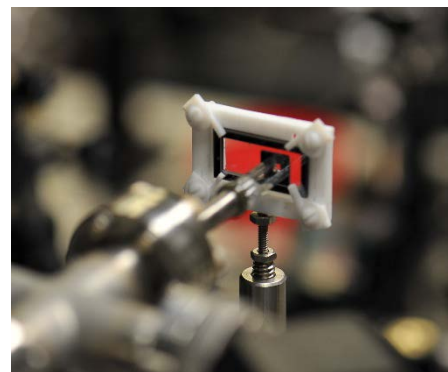
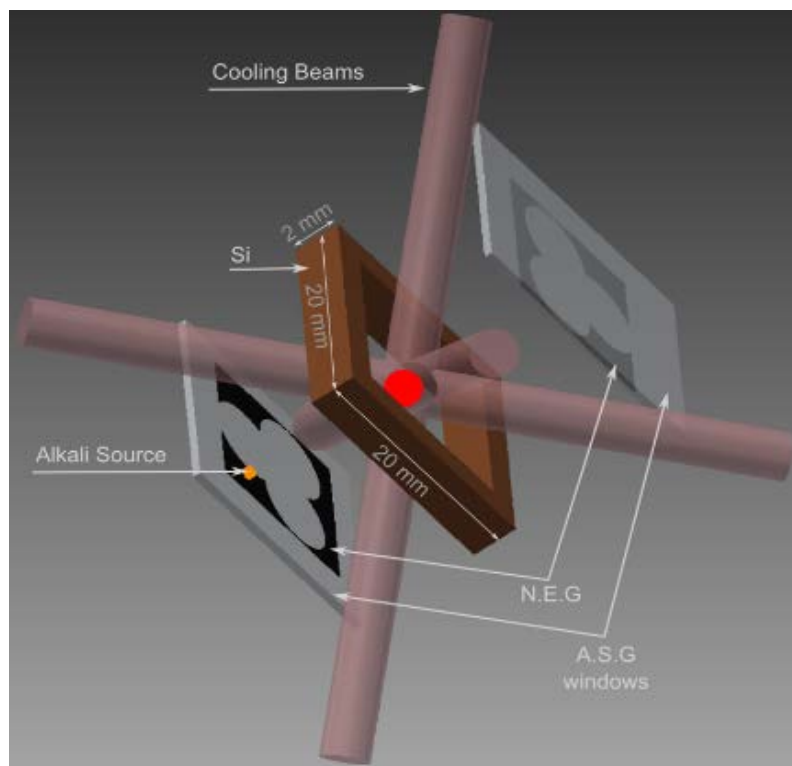


# Monitoring Station Clock

<1  $\mu$ s timing error over a week and  $1 \times 10^{-12}$  fundamental accuracy

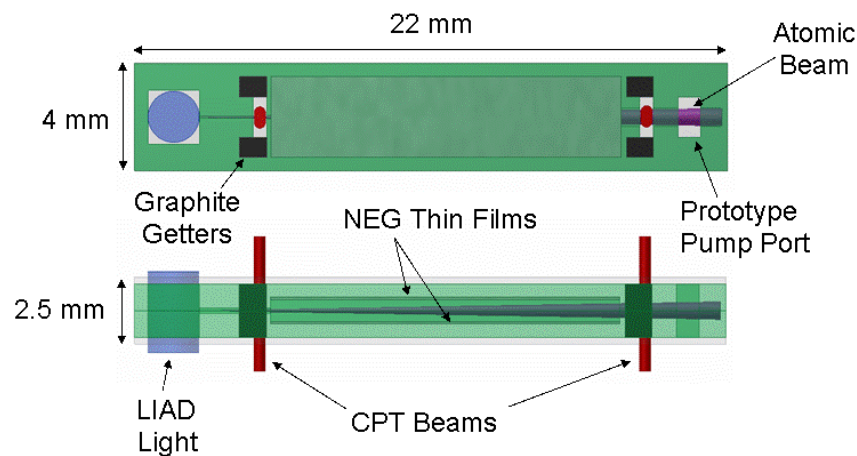
## NIST-on-a-Chip

### Passively Pumped Design:



Actively Pumped Prototype:

### MEMS Beam-Clock Design:



The End