SYE 3803
Fundamentals of Avionics
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Radio Waves and the Electromagnetic Spectrum

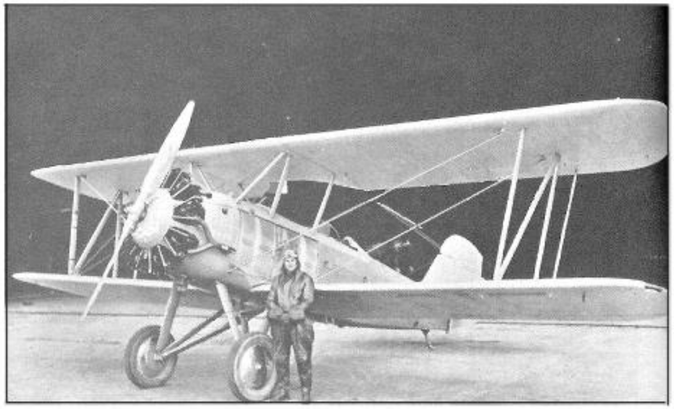
- Electromagnetic waves are fully described by Maxwell's Equations
- Radio waves travel at the speed of light, $c = 2.988 \times 10^8$ m/s
- Information is *carried* on electromagnetic waves using modulation schemes:
    - Amplitude Modulation:
        - $V(t) = V_M(t)\sin(\omega_c t)$, where $V_M(t) = V_o(1 + m\cos(\omega_m t + \phi))$
        - $0 \leq m \leq 1$; m is the depth of modulation
    - Frequency Modulation:
        - $V(t) = V_o\sin(\omega_c t - \frac{\Delta f}{f_m}\cos(\omega_m t))$
        - where $\frac{\Delta f}{f_m}$ is the FM modulation index

RF Communications Spectrum

Acronym	Description	Range
VLF	Very Low Frequency	3 – 30kHz
LF	Low Frequency	30 - 300kHz
MF	Medium Frequency	300 – 3000kHz
HF	High Frequency	3MHz – 30MHz
VHF	Very High Frequency	30MHz – 300MHz
UHF	Ultra High Frequency	300MHz – 3GHz
SHF	Super High Frequency	3GHz – 30GHz
EHF	Extra High Frequency	30GHz – 300GHz

Terrestrial Radio Navigation

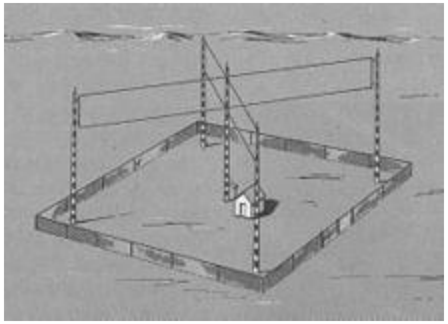
- The “blind flight” made by test pilot Lt. James “Jimmy” Doolittle and check pilot Lt. Benjamin Kelsey on September 24, 1929 required the following minimal equipment:
  - Altimeter more accurate than barometric-pressure based
  - Gyro horizon (artificial horizon or attitude indicator) to prevent spatial disorientation
  - Radio-compass tunable to two NDBs aligned with the runway centerline particularly for landing and take off



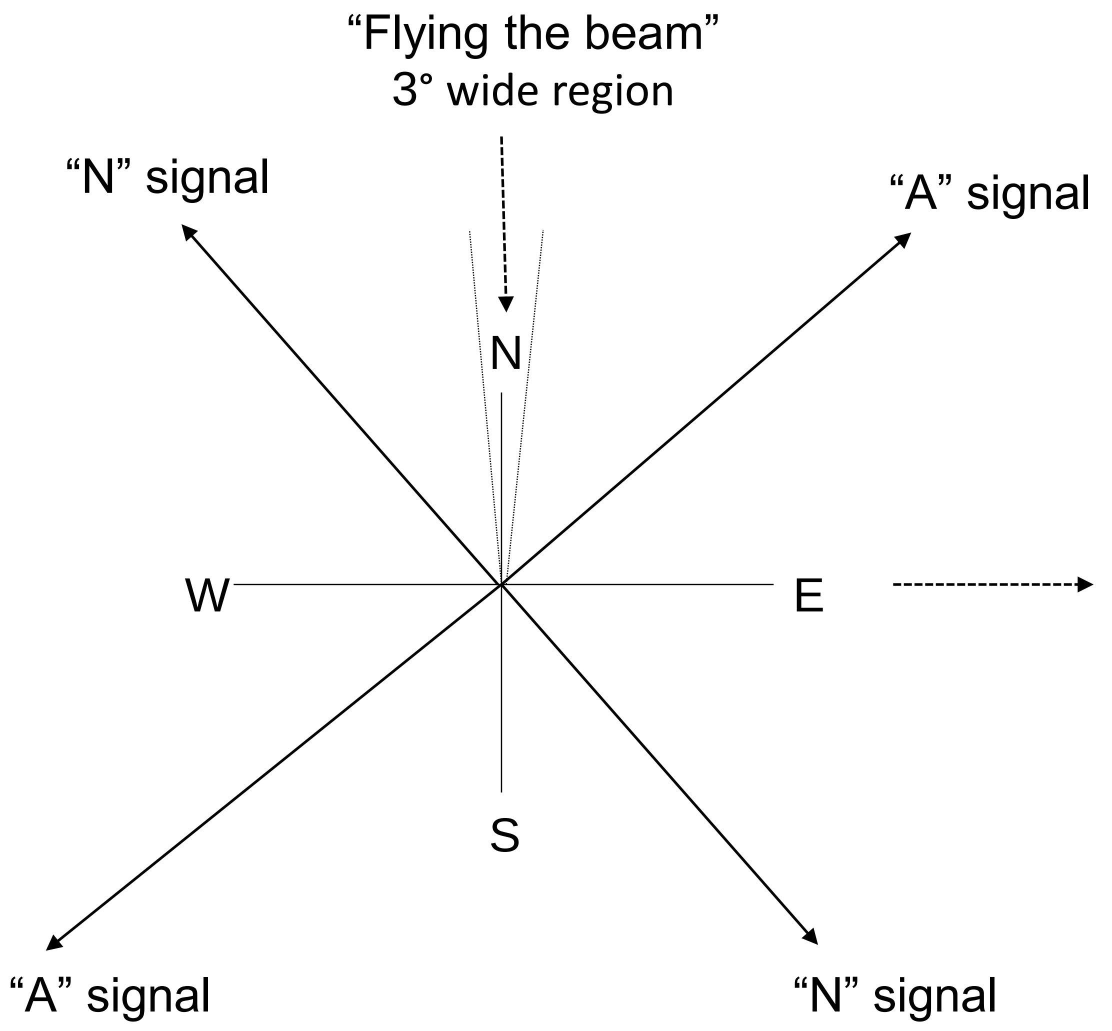
Jimmy Doolittle flew the first blind flight in September, 1929, with instruments that included an artificial horizon, directional gyro and radio receiver with two vibrating reeds that indicated the radio "beam". He used two biplanes as flying laboratories. The airplane shown here, a fast Vought Corsair Navy fighter, was flown in early cross-country instrument flight tests.

Low-Frequency Radio Range (LFR)

- Ground components of an LFR system are referred to by other names including Adcock antenna array and A-N radio range
- “A-N range” became operational in 1932
- A-N range provided a four-quadrant directional AM radio navigation system for early aviators in the 1930s and 40s
- LFR systems transmitted orthogonal *streams* of automated “A” and “N” Morse code:
  - N = -.-.-.-.-.
  - A = .-.-.-.-.-
  - A+N = ____________________
- Aircraft components of an LFR system offered competing visual (vibrating reed ~ “turn left-right” indicator) and aural (audible “A” and “N” codes) cues
- The U.S. government opted to use the aural-based instruments

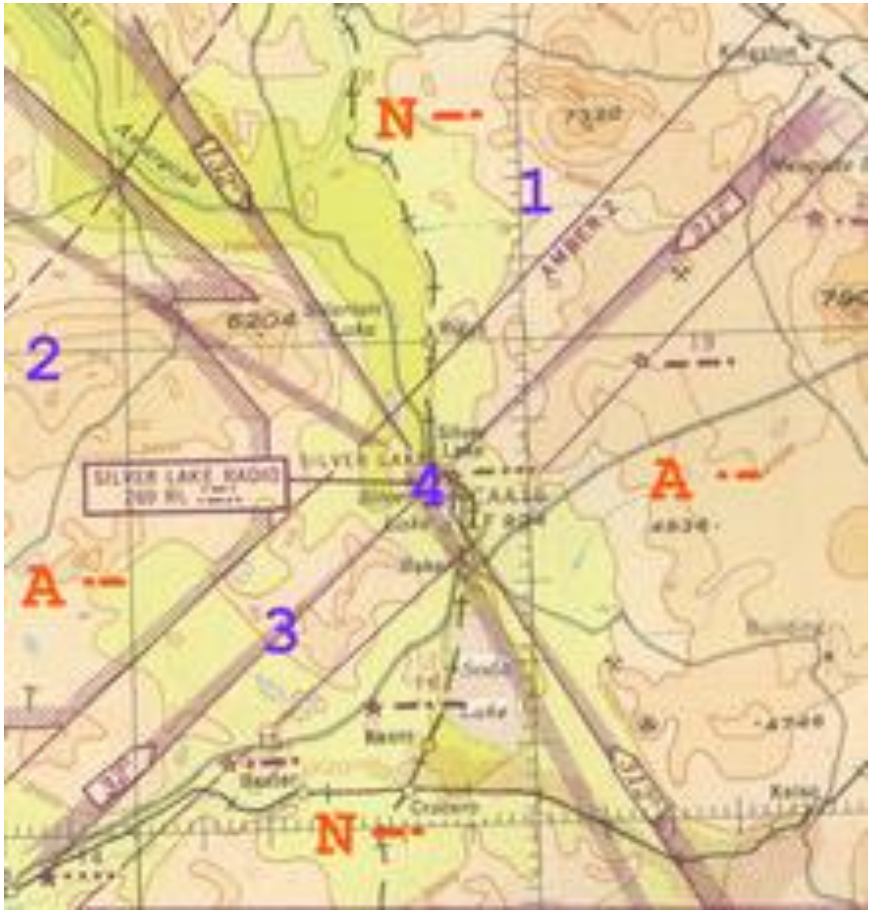


LFR - continued

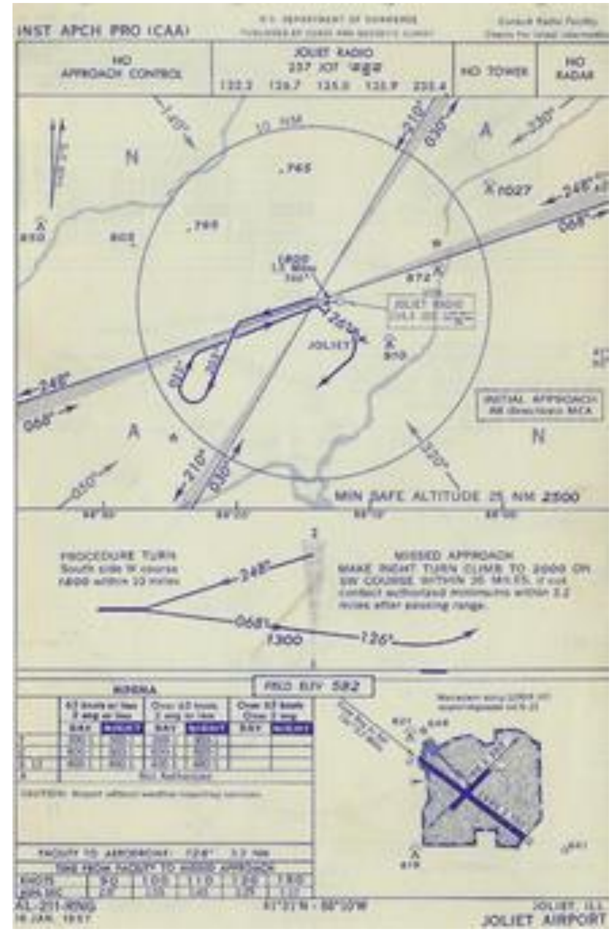


Airways defined by course lines with continuous tone;
Airways could be oriented any direction including the cardinal directions;
Morse Code ID used
To identify the station

LFR - continued



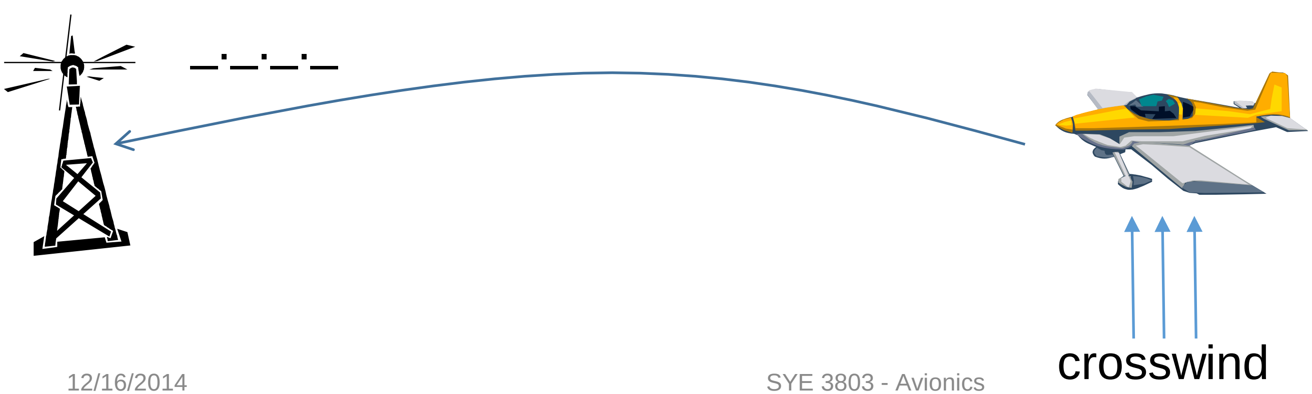
Courtesy: U.S. Coast and Geodetic Survey (NOAA)
Silver Lake LFR: 269 kHz
1 = “N”, 2 = “A”, 3 = steady tone, 4 = nothing

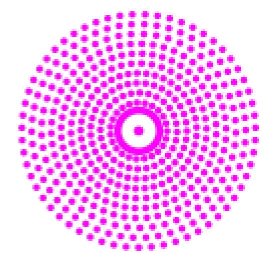


U.S. Dept. of Commerce, Coast and Geodetic Survey LFR instrument and missed approach procedures for Joliet, IL; Final approach would begin over the field since no modulation was heard directly over the tower—it made for a definitive location reference.

Non-directional Beacon (NDB)

- The first radio-based navigational aid was the NDB. They were often deployed at the location of the original light beacons
- NDB signals can be received at greater distances than other radio-based aids (e.g. VOR), since they propagate along the Earth's curvature
- Early aircraft systems included a loop antenna that could be rotated to determine the direction to the NDB
- The NDB standard is specified by the International Civil Aviation Association (ICAO) Annex 10
- Operational frequencies are between 190 kHz and 1750 kHz; North America usually uses the range 190 kHz to 535 kHz
- NBDs are identified by a one-, two-, or three-letter call-sign encoded in Morse code

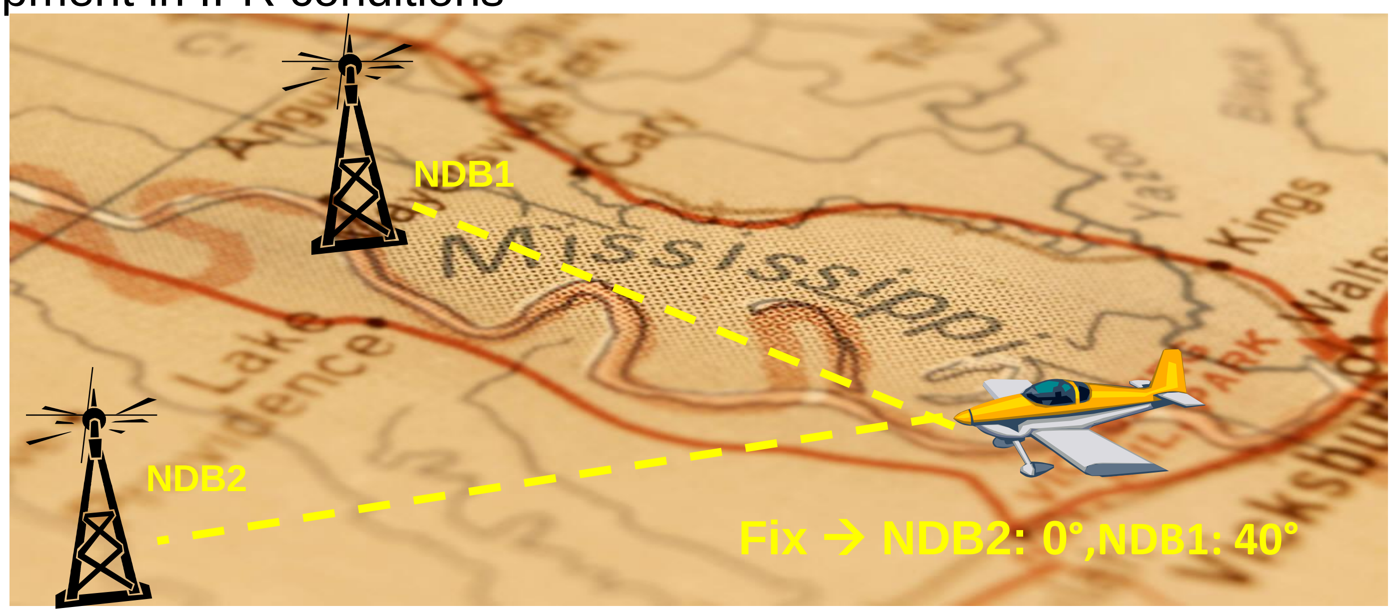




NDB symbol on aeronautical chart

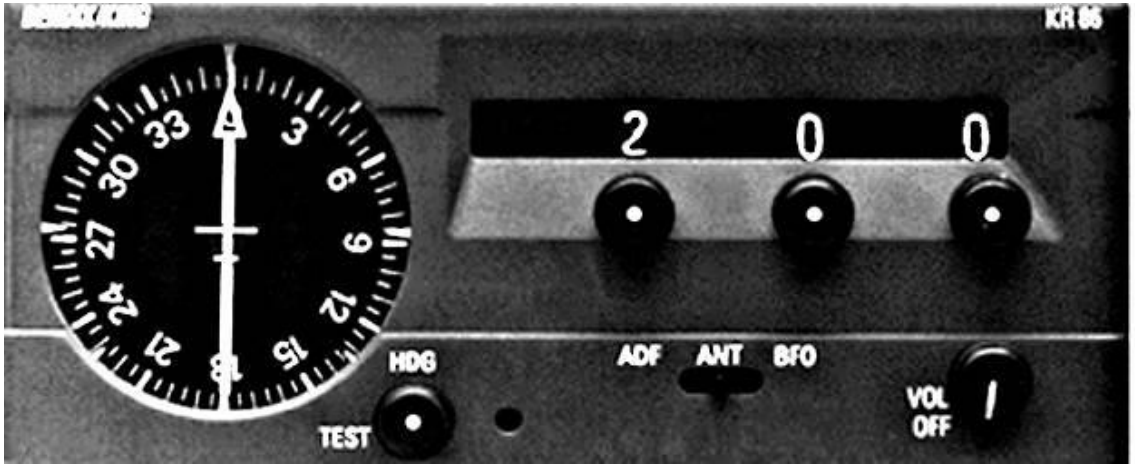
Non-directional Beacon (NDB) - continued

- NDBs can be used to:
  - Home to an NDB in VFR conditions
  - Define airways on aeronautical charts, which can be used for flight planning—VORs are most often used for airway definition
  - Obtain a fix by mapping *bearings* to at least two NDBs
  - Provide non-precision approach to a runway
  - Provide a radio marker, or *locator*, for an instrument landing system ILS
  - Shoot an instrument approach using Automatic Direction Finding ADF equipment in IFR conditions



NDB and ADF (Automatic Direction Finder)

- ADF has the following characteristics:
  - Located on the aircraft
  - Displays the bearing to the tuned NDB on an RBI (relative bearing indicator)
  - 0 degree indicates aircraft heading – Fixed Card Compass only
  - Assuming no crosswinds, tracking toward an NDB requires that the aircraft be flown in the 0 degree heading; Similarly, tracking away from the NDB requires that the aircraft be flow in the 180 degree heading.
  - Crosswinds will require the pilot to flight to the left or to the right of the 0 or 180 degree heading to compensate for drift



Panel-mounted ADF

NDB and ADF (Automatic Direction Finder)

- Aircraft bearing to/from NDB with no crosswinds:

Heading +/- ADF RBI = Bearing to/from NDB

- Magnetic heading to an NDB with no crosswinds:

MB = (RB + MH)%360, if MB > 360°

NDB and ADF (Automatic Direction Finder)

- ADF Indicator Types:
  - Fixed Card Compass
  - Rotatable Card Compass
  - Single-needle Radio Magnetic Indicator (RMI)
  - Dual-needle Radio Magnetic Indicator
- ADF Time and Distance Check Single-needle RMI:
  - Tune to the NDB's Morse Code ID
  - Orient the aircraft so that the needle is orthogonal to the heading
  - Note the time
  - Fly the same heading until the needle changes by 10°
  - Minutes to station = $\frac{elapsed\ time}{bearing\ change\ in\ degrees}$

Dual-needle **Radio Magnetic** Indicator:
Aircraft Heading: 323°
NDB Bearing: 290°

Ref: http://commons.wikimedia.org/wiki/File:Adf_rmi.jpg

NDB and ADF (Automatic Direction Finder)

- ADF Time and Distance Check Single-needle RMI:
  - Tune to the NDB's Morse Code ID
  - Orient the aircraft so that the needle is orthogonal to the heading
  - Note the time
  - Fly the same heading until the needle changes by 10°
  - NM to station = $\frac{TAS(kts)x\ minutes\ flown}{bearing\ change\ in\ degrees}$
- Intercepting a bearing to an NDB using an ADF
  - Turn to the desired bearing
  - Note the numbers of degrees that needle is deflecting to the right
  or the left
  - Double this number
  - Turn toward the needle by the amount determine above
  Note: if turning right, then add the number, if turning left then subtract the number
  - Maintain this new heading until the needle points to the desired bearing
  - Turn to the desired bearing

NDB Video: **http://tinyurl.com/knroe8z**