Development of Signal Interface for Band-Switchable Transceiver IC

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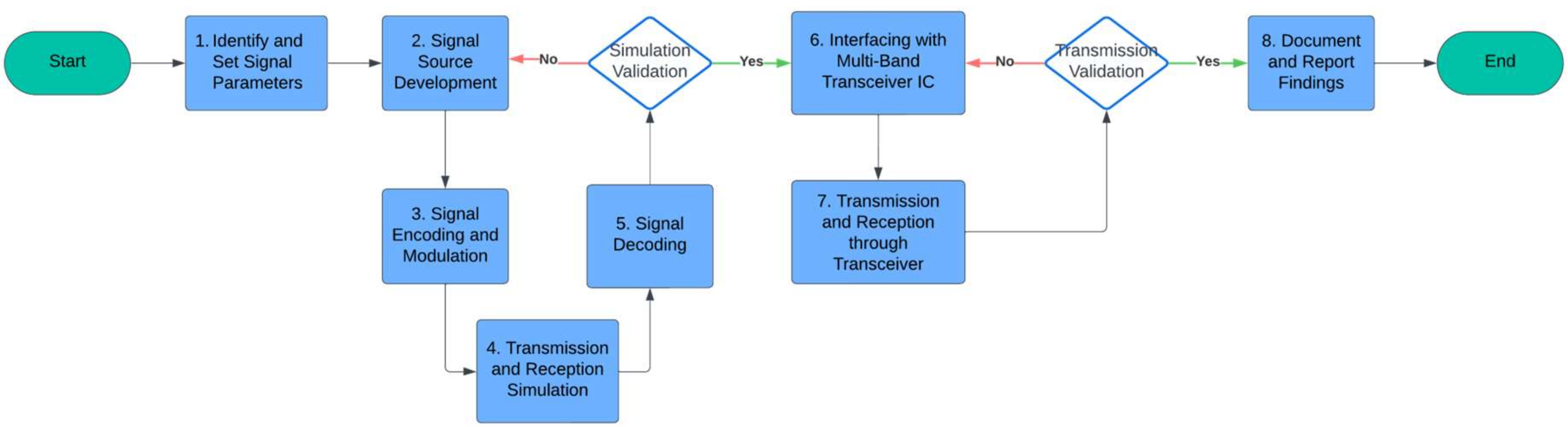
Project Overview

Key Accomplishments

1. **ADS-B Message Composition**: Gained comprehensive understanding of ADS-B message structure and transmission protocols
2. **Signal Generation:** Created MATLAB function to generate 112-bit ADS-B bitstreams from user-defined data
3. **Encoding and Modulation:** Implemented PPM (Pulse Position Modulation) encoding of ADS-B bitstreams, adhering to ICAO standards
4. **Simulation:** Conducted transmission and reception simulations, transferring generated waveforms from MATLAB to Cadence
5. **Signal Recovery:** Tested successful recovery of original ADS-B bitstream from received signals in simulation



Project Overview

Future Work – Thesis under Dr. Dawn

Key Objectives

1. **Transceiver Integration:** Interface with the multi-band transceiver being developed by Babak
2. **ADS-B Signal Testing:** Conduct thorough transmission and reception tests of ADS-B signals through the transceiver
3. **Validation and Refinement:** Compare findings with simulated results to validate and further refine the process
4. **Signal Expansion:** Research and implement RemoteID and 900MHz ISM signal generation and processing. Conduct transmission and reception tests, similar to current efforts.

Reason to choose ADS-B as a starting point

1. **Remote ID Signals:**
   - Evolving standards and limited academic resources.
   - Chosen ADS-B as initial focus due to established protocols and abundant documentation.
2. **900 MHz ISM Signals:**
   - Diverse applications and complex FCC regulations.

Aircraft Surveillance Technologies

Primary Surveillance Radar

- Radar shoots revolving fan-shaped beams that periodically bounces off aircraft's surface and listens for echoes.
- Determines aircraft position using:
  - Range: Time between pulse emission and reflection reception
  - Bearing: Antenna azimuth at reflection reception
- Provides 2D representation of aircraft positions

- Limitations:
  - Coverage gaps, especially above antenna
  - No aircraft identity or accurate altitude information
  - Cannot distinguish multiple aircraft at same slant range
  - Affected by ground clutter and weather
  - Expensive to install and maintain

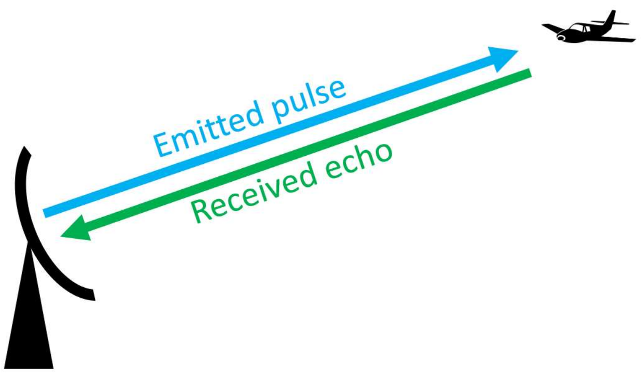


Fig 1. Basic Operation Principle of PSR

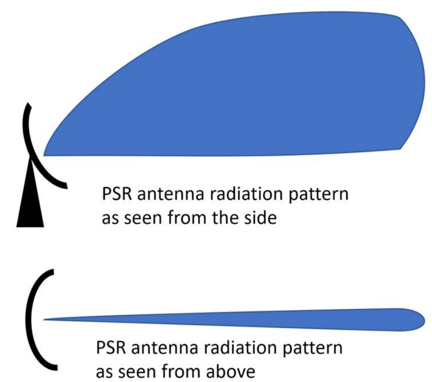


Fig 2. PSR antenna radiation pattern

Image Source: skybrary.aero/articles/primary-surveillance-radar-psr

Aircraft Surveillance Technologies

Primary Surveillance Radar

- Frequency bands:
  - L-band: 1215-1400 MHz (en-route surveillance)
  - S-band: 2700-3100 MHz (terminal area surveillance)
- Key characteristics:
  - Transmitter peak power: Up to 100 kW
  - Pulse duration: Typically, 1μs
  - Antenna rotation speed: 5-12 rpm
  - Detection range: 0.5 to 200 NM (depending on band)
  - Azimuth accuracy: ≤ ±0.18°
  - Range accuracy: ≤ ±60 m

Fig 3. An ASR-9 airport surveillance radar antenna. The curving lower reflector is the primary radar, while the flat antenna on top is the secondary radar.

Source: ICAO Doc 4444 PANS-ATM

Image Source: en.wikipedia.org/wiki/Airport_surveillance_radar

Aircraft Surveillance Technologies

Secondary Surveillance Radar

- Cooperative surveillance system using ground-based interrogators and airborne transponders.
- Operating Frequencies:
  - Interrogation – 1030 MHz
  - Reply – 1090 MHz
- Initial implementations of SSR worked on Mode A and Mode C.
- Mode S, modern implementation of SSR, mitigated the problem of garbling in Mode A/C by enabling selective interrogations.
- Automatic Dependent Surveillance-Broadcast (ADS-B) operates on 1090 MHz (same as SSR Mode S).
- ADS-B allows the aircraft to broadcast their flight state periodically without the need for interrogation.
- ADS-B supports both air-to-ground and air-to-air surveillance

Source: ICAO, "ADS-B Implementation and Operations Guidance Document," Edition 7.0, September 2014.

Understanding ADS-B Messages

ADS-B Message Structure

- ADS-B Data Frame is 112 bits long

```
+----------+---------+-------------+-----------------------+----------+
| DF (5)   | CA (3)  | ICAO (24)   |        ME (56)        | PI (24)  |
+----------+---------+-------------+-----------------------+----------+
```

Bit	No. bits	Abbreviation	Information
1–5	5	DF	Downlink Format
6–8	3	CA	Transponder capability
9–32	24	ICAO	ICAO aircraft address
33–88	56	ME	Message, extended squitter
(33–37)	(5)	(TC)	(Type code)
89–112	24	PI	Parity/Interrogator ID

- DF is set to 1001 (17) for ADS-B messages
- A unique ICAO address is assigned to each Mode S transponder of an aircraft and serves as the unique identifier for each aircraft

- CA provides information about the transponder's capabilities.

CA	Definition
0	Level 1 transponder
1–3	Reserved
4	Level 2+ transponder, with ability to set CA to 7 when on-ground
5	Level 2+ transponder, with ability to set CA to 7 when airborne
6	Level 2+ transponder, with ability to set CA to 7 when either on-ground or airborne
7	Indicates that the Downlink Request value is 0, or that the Flight Status is 2, 3, 4, or 5, either airborne or on the ground

Understanding ADS-B Messages

ADS-B Message Structure

- ME (Message Elements) contain various types of data, including position, velocity, and other operational parameters.
- Specific message content depends on the Type-Code defined in this field.

Type Code	Data frame content
1–4	Aircraft identification
5–8	Surface position
9–18	Airborne position (w/Baro Altitude)
19	Airborne velocities
20–22	Airborne position (w/GNSS Height)
23–27	Reserved
28	Aircraft status
29	Target state and status information
31	Aircraft operation status

- PI (Parity/Interrogator ID) are the last 24 bits are used for error checking and is CRC remainder.
- During the summer, sample ADS-B messages of Type Code 1-22 have been created and simulated.

Understanding ADS-B Messages

ADS-B Availability and Transmission Rate

- ADS-B messages are available to any receiver equipped with ADS-B IN capabilities.
- ADS-B transmission rate depends on the message type, aircraft status and change in uncertainty (change in quality of data).

<table>
<tr><th>Messages</th><th>TC</th><th>Ground (still)</th><th>Ground (moving)</th><th>Airborne</th></tr>
<tr><td>Aircraft identification</td><td>1–4</td><td>0.1 Hz</td><td>0.2 Hz</td><td>0.2 Hz</td></tr>
<tr><td>Surface position</td><td>5–8</td><td>0.2 Hz</td><td>2 Hz</td><td>-</td></tr>
<tr><td>Airborne position</td><td>9–18, 20–22</td><td>-</td><td>-</td><td>2 Hz</td></tr>
<tr><td>Airborne velocity</td><td>19</td><td>-</td><td>-</td><td>2 Hz</td></tr>
<tr><td rowspan="2">Aircraft status</td><td rowspan="2">28</td><td colspan="3">0.2 Hz (no TCAS RA and Squawk Code change)</td></tr>
<tr><td colspan="3">1.25 Hz (change in TCAS RA or Squawk Code)</td></tr>
<tr><td>Target states and status</td><td>29</td><td>-</td><td>-</td><td>0.8 Hz</td></tr>
<tr><td rowspan="2">Operational status</td><td rowspan="2">31</td><td rowspan="2">0.2 Hz</td><td colspan="2">0.4 Hz (no NIC/NAC/SIL change)</td></tr>
<tr><td colspan="2">1.25 Hz (change in NIC/NAC/SIL)</td></tr>
</table>

Understanding ADS-B Messages
ADS-B Versions and Uncertainties

1. Version 0: DO-260/ED-102

- Introduced the concept of broadcasting aircraft position, velocity, and identification based on GPS data.
- Only uncertainties are defined:
  - Navigation uncertainty category - position (**NUCp**): In general, a higher NUCp number (lower TC number) represents higher confidence in the position measurement.
  - Navigation uncertainty category - rate (**NUCr**): Used to indicate the uncertainty of the horizontal and vertical speeds.

2. Version 1: DO-260A

- Uncertainty category is removed, replaced by the accuracy category and the integrity category.
  - Navigation integrity category (**NIC**): Designed to replace NUCp, but with more levels included.
  - Navigation accuracy category – position (**NACp**): Complementary indicator of NIC
  - Navigation accuracy category – velocity (**NACv**): Replaces NUCv from version 0.
  - Surveillance integrity level (**SIL**): Indicates the probability of measurements exceeding the containment radius.

Understanding ADS-B Messages

ADS-B Versions and Uncertainties

3. Version 2: DO-260B/ED-102A

- Incremental update based on operational experience gained.
- Enhanced Integrity Reporting.
- Additional NIC Levels: NICa, NICb & NICc
- Incorporated the ability to broadcast Mode A code in emergency/priority messages.
- Additional SIL supplement bit (SILs)
- NACp and NACv: Same as version 1

4. Version 3: DO-260C

- Focusses on optimizing data transmission and enhancing functionality for modern air traffic management needs.
- Optional Weather Data Broadcasting
- **Autonomous Distress Tracking (ADT):** Automatically transmit an aircraft's position at least once per minute when in distress.
- Support for new applications such as wake turbulence avoidance and hazardous weather detection.

Receiving ADS-B Messages

Hardware and Software Setup

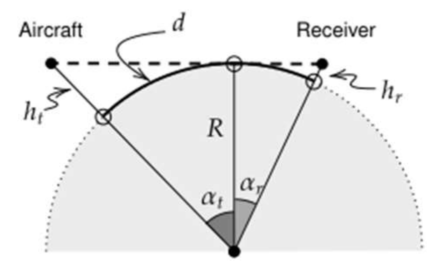
- Hardware:
  1. Raspberry Pi 3B+ running a basic copy of the Raspbian Operating System
  2. RTL-SDR USB Receiver
     1. Operating Range: 24 to 1766 MHz
     2. Max Sampling Rate: 2.8 MSPS
     3. Only capable of listening in the frequency ranges
  3. 1090MHz dipole antenna
- Software:
  1. dump1090 for ADS-B decoding
  2. pyModeS for message parsing

Receiving ADS-B Messages
Receiver Range Calculations

- Mode S uses L band signals that follow the line-of-sight propagation.
- The maximum distance (d) of a Mode S receiver can be obtained by knowing the altitude of the receiver antenna:

$$d = (\alpha_r + \alpha_t)R$$

$$d = \left(\arccos\frac{R}{R + h_r} + \arccos\frac{R}{R + h_t}\right) R$$



- R is the radius of the earth, while h_t and h_r are the height of the aircraft and receiver above the sea level
- In real-life applications, Mode S signal follows the Friis transmission model. Thus, maximum distance also depends on the power of the transmitter, as well as the directivities of the transmission and receiving antennas.
- The actual radio range for the receiver is typically lower than the theoretical values calculated from the equations mentioned.

Receiving ADS-B Messages

Antenna Setup

- Any antenna designed for the radio frequency around 1 GHz can be used for receiving Mode S signals.
- The carrier frequency of Mode S is 1090 MHz, which corresponds to the wavelength (λ) of $27.5\ cm$.
- $\lambda = \frac{c}{f}$ where $c = 3 \times 10^{8}\ m/s \quad and \quad f = 1090\ MHz$
- A simple metal wire (conductor) and a coaxial feeder cable was used to design a dipole antenna.
- Half-wave antenna implemented with a total conductor length of $13.75\ cm$

Receiving ADS-B Messages

Receiver Setup – dump1090

- dump1090 is an open-source Mode S decoder offering embedded HTTP server that displays the currently detected aircrafts on Google Map, along with TCP server streaming and receiving raw data to/from connected clients.
- Provides an interactive command-line-interface mode where aircrafts currently detected are shown as a list refreshing as more data arrives
- Installation and compiling directory:

```
$ git clone https://github.com/antirez/dump1090.git
sudo apt-get install build-essential debhelper librtlsdr-dev pkg-config dh-systemd
libncurses5-dev libbladerf-dev
$ cd dump1090
$ make
```

- Start receiving and decoding signals with the live view of all aircrafts captured using the –interactive option:

```
Hex     Flight   Altitude  Speed   Lat       Lon        Track  Messages Seen .
--------------------------------------------------------------------------------
a30f85           0         415     0.000     0.000      277    2         4 sec
ad99f9  ASA1139  14975     357     46.908    -122.596   37     24        1 sec
a1d105  ENY3859  6850      225     47.651    -122.161   3      401       5 sec
a183d3  SKW3428  4200      259     47.315    -122.305   164    554       0 sec
a51968  ASA353   17875     350     47.849    -121.118   276    14        43 sec
aaf831  ASA958   6575      294     47.231    -122.309   181    1281      0 sec
a2dac7  SKW3688  4875      231     47.741    -122.208   273    670       40 sec
ae055c           32000     0       0.000     0.000      0      243       0 sec
a97251  ASA1327  6275      261     47.423    -122.455   0      806       0 sec
a7888c  ASA1022  19000     381     47.127    -120.906   108    2915      1 sec
a99d87  ASA705   14425     302     47.283    -121.972   304    2894      0 sec
a4ce21  ASA305   9850      283     47.384    -122.181   328    3544      28 sec
```

Receiving ADS-B Messages

Receiver Setup – pyModeS

- Open-source Python library for decoding Mode-S and ADS-B signals.
- Functionalities of this project was broken down to use the low-level decoding functionalities to decode and verify the generated ADS-B messages (in MATLAB).
- Core functions to decode Downlink Format, ICAO address, ADS-B Type Code, as well as to perform parity check.

```
import pyModeS as pms

pms.df(msg)          # Downlink Format
pms.icao(msg)        # Infer the ICAO address from the message
pms.crc(msg)         # Perform parity check
pms.typecode(msg)    # Obtain ADS-B message Type Code
```

- ADS-B related functions allow information such as identity, position, and velocities to be decoded.

```
import pyModeS as pms

# position messages
pms.adsb.position(msg_even, msg_odd, t_even, t_odd)
pms.adsb.altitude(msg)

# velocity messages
pms.adsb.velocity(msg)
```

Generating Sample ADS-B Messages

Aircraft Identification and Category - Description

- Type Code = 1 to 4
- 56-bit ME filed consists of 10 parts, as follows:

```
+------+------+------+------+------+------+------+------+------+------+
| TC,5 | CA,3 | C1,6 | C2,6 | C3,6 | C4,6 | C5,6 | C6,6 | C7,6 | C8,6 |
+------+------+------+------+------+------+------+------+------+------+

TC: Type code
CA: Aircraft category
C*: A character
```

- C1 to C8 represent the callsign characters.
- Characters are mapped based on a lookup table which maps the corresponding decimal number (represented in binary code) to each character.

```
A - Z :   1 - 26
0 - 9 :  48 - 57
    ␣ :  32
```

- The ␣ symbol refers to a space character.

- The CA value in combination with TC value defines the wake vortex category of the aircraft.

TC	CA	Category
1	ANY	Reserved
ANY	0	No category information
2	1	Surface emergency vehicle
2	3	Surface service vehicle
2	4-7	Ground obstruction
3	1	Glider, sailplane
3	2	Lighter-than-air
3	3	Parachutist, skydiver
3	4	Ultralight, hang-glider, paraglider
3	5	Reserved
3	6	Unmanned aerial vehicle
3	7	Space or trans-atmospheric vehicle
4	1	Light (less than 7000 kg)
4	2	Medium 1 (between 7000 kg and 34000 kg)
4	3	Medium 2 (between 34000 kg to 136000 kg)
4	4	High vortex aircraft
4	5	Heavy (larger than 136000 kg)
4	6	High performance and high speed
4	7	Rotorcraft

Generating Sample ADS-B Messages

Aircraft Identification and Category Function – Input and Data Flow

- MATLAB function has been defined that generates ADS-B message for aircraft identification and category.
- ADSB_aircraftID_category.m - Function to generate Aircraft ID messages
- **Input Collection**:
  - DF: Downlink Format
  - CA: Capability
  - ICAO_hex: ICAO address in hex
  - type_code: Message type code
  - category: Aircraft category
  - aircraft_id: Aircraft identification/callsign

```
>> DF = 17;
CA = 5;
ICAO_hex = '4840D6';
type_code = 4;
category = 0;
aircraft_id = 'KLM1023';
```

- **Data Flow and Processing**:
  1. **Message Construction:** Convert DF and CA to 5-bit and 3-bit binary, ICAO address to 24-bit binary, type_code (5 bits) and category (3 bits) to binary, aircraft_id to 6-bit binary for each character.
  2. **Message Assembly:** Concatenate all binary components: [DF + CA + ICAO + type_code + category + aircraft_id]. Result will be an 88-bit ADS-B message without parity.
  3. **CRC Calculation:** Use polynomial division with generator: 1111111111111010000001001, append 24 zero bits to the message, perform XOR operations, last 24 bits form the CRC remainder.
  4. **Final Message Formation:** Append 24-bit CRC to the 88-bit message. Result will be a 112-bit complete ADS-B message.
  5. **PPM Encoding:** Parameters: Use 1 Mbps bit rate and 0.5 μs pulse width. 0 bit will be a pulse at start of bit period. 1 bit will be pulse at end of bit period

Generating Sample ADS-B Messages

Aircraft Identification and Category Function - Output

- **Outputs:**
  1. **ADS-B Message without Parity**

     Hexadecimal: 8D4840D6202CC371C32CE0

     Breakdown:

     1. 8D: DF (17) and CA (5)
     2. 4840D6: ICAO address
     3. 20: Type Code (4) and Category (1)
     4. 2CC371C32CE0: Encoded Aircraft ID
  2. **Parity Bits**

     Hexadecimal: F1B562
  3. **Final ADS-B Message with Parity**

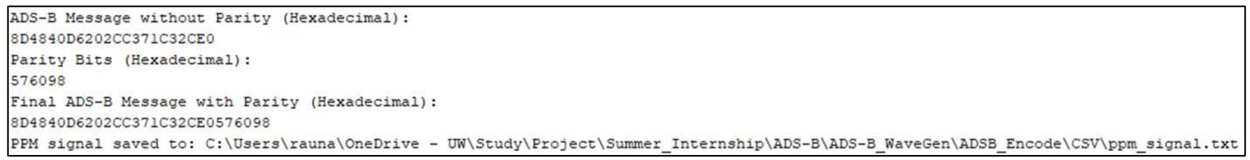
     Hexadecimal: 8D4840D6202CC371C32CE0576098

     First 88 bits (22 hex characters): Original message

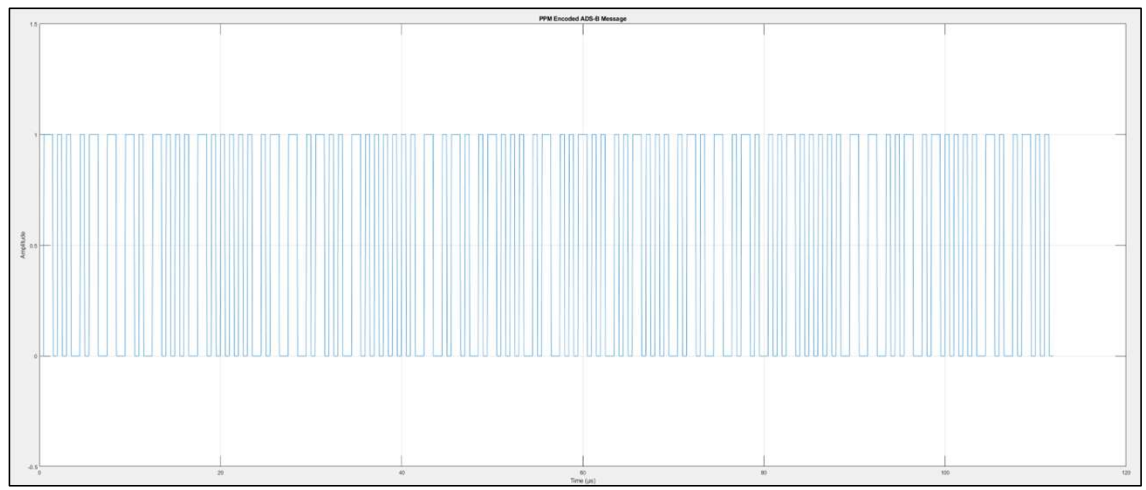
     Last 24 bits (6 hex characters): Appended parity
  4. **PPM Signal**

     Saved as CSV file. Contains time and amplitude data.

     Represents the 112-bit message in Pulse Position Modulation format.



```
ADS-B Message without Parity (Hexadecimal):
8D4840D6202CC371C32CE0
Parity Bits (Hexadecimal):
576098
Final ADS-B Message with Parity (Hexadecimal):
8D4840D6202CC371C32CE0576098
PPM signal saved to: C:\Users\rauna\OneDrive - UW\Study\Project\Summer_Internship\ADS-B\ADS-B_WaveGen\ADSB_Encode\CSV\ppm_signal.txt
```



Generating Sample ADS-B Messages

Aircraft Airborne Position - Description

- Type Code = 9 to 18 (Barometric Altitude) or 20 to 22 (GNSS Altitude).
- ME field structure:

```
+-------+-------+--------+---------+------+------+-------------+-------------+
| TC, 5 | SS, 2 | SAF, 1 | ALT, 12 | T, 1 | F, 1 | LAT-CPR, 17 | LON-CPR, 17 |
+-------+-------+--------+---------+------+------+-------------+-------------+
```

FIELD		MSG	ME	BITS
Type Code	**TC**	33-37	1-5	5
Surveillance status	**SS**	38–39	6–7	2
Single antenna flag	**SAF**	40	8	1
Encoded altitude	**ALT**	41-52	9-20	12
Time	**T**	53	21	1
CPR Format	**F**	54	22	1
Encoded latitude	**LAT-CPR**	55-71	23-39	17
Encoded longitude	**LON-CPR**	72-88	40-56	17

- Position information is encoded in Compact Position Reporting (CPR) Format.

- Decoding methods for airborne position messages:
  1. **Globally unambiguous position decoding:** Without a known position to start with, using odd and even frame bit to decode the position.
  2. **Locally unambiguous position decoding:** Knowing a reference position from previous sets of messages, using only one message (even/odd data frame) for the decoding.

- Parameters
  1. N_z - Represents the number of latitude zones between the equator and a pole. $N_z = 15$ in Mode S communication.
  2. $NL(lat)$ - Longitude zone number

$$NL(lat) = floor\left\{\frac{2\pi}{arccos\left[1 - \frac{1-\cos(\frac{\pi}{2N_z})}{cos^2\left(\frac{\pi}{180}.lat\right)}\right]}\right\}$$

  3. For latitudes that are close to the equator or the poles

```
lat = 0      ->    NL = 59
lat = +87    ->    NL = 2
lat = -87    ->    NL = 2
lat > +87    ->    NL = 1
lat < -87    ->    NL = 1
```

Generating Sample ADS-B Messages

Aircraft Airborne Position – Encoding Calculations

- **Latitude Calculation**
  - Bit 54 determines whether it is an odd or even frame.

    0 – Even Message; 1 – Odd Message
  - Bits 55–71 and 72-88: Represents the fractions of latitude and longitude within the latitude and longitude grid.

    $$lat_{cpr} = \frac{N_{cpr,lat}}{2^{17}} \qquad \mathrm{lon}_{cpr} = \frac{N_{cpr,\mathrm{lon}}}{2^{17}}$$
  - For even and odd messages, the latitude zone sizes are defined as follows:

    $$\mathrm{dL}at_{\mathrm{even}} = \frac{360°}{4N_z} \qquad \mathrm{dL}at_{\mathrm{odd}} = \frac{360°}{4N_z - 1}$$
  - Calculate Latitude Zone Index:

    $$j = floor\left(59.\,lat_{cpr,even} - 60.\,lat_{cpr,\mathrm{odd}} + \frac{1}{2}\right)$$
  - Based even and odd frames, two latitudes are computed as follows

    $$lat_{even} = \mathrm{dL}at_{\mathrm{even}}\big(mod(j,60) + lat_{cpr,even}\big)$$
    $$lat_{odd} = \mathrm{dL}at_{\mathrm{odd}}\big(mod(j,59) + lat_{cpr,odd}\big)$$
  - For the southern hemisphere

    $$lat_{even} = lat_{even} - 360, \qquad if\ lat_{even} \geq 270$$
    $$lat_{odd} = lat_{odd} - 360, \qquad if\, lat_{odd} \geq 270$$

- **Longitude Calculation**
  - Longitude index, m

    $$= floor\left(\mathrm{lon}_{cpr,even}.\,[NL(lat) - 1] - lon_{cpr,odd}.\,NL(lat) + \frac{1}{2}\right)$$
  - Longitude zone size, n

    $$n_{even} = \max[NL(lat), 1] \qquad n_{odd} = \max[NL(lat - 1), 1]$$
  - Longitude zone sizes are defined as follows:

    $$\mathrm{dL}on_{\mathrm{even}} = \frac{360°}{n_{even}} \qquad \mathrm{dL}on_{\mathrm{odd}} = \frac{360°}{n_{even}}$$
  - Longitude is calculated as:

    $$lon_{even} = \mathrm{dLon}_{\mathrm{even}}\big(mod(m, n_{even}) + \mathrm{lon}_{cpr,even}\big)$$
    $$lon_{odd} = \mathrm{dLon}_{\mathrm{odd}}\big(mod(m, n_{odd}) + \mathrm{lon}_{cpr,odd}\big)$$
  - Position messages are often converted from 0 ° to 360° to -180° and +180°.

    $$lon = lon - 360, \qquad if\ lon \geq 180$$

Generating Sample ADS-B Messages

Aircraft Airborne Position Function – Input and Data Flow

- MATLAB function has been defined that generates ADS-B message for encoding airborne position of an aircraft.
- ADSB_encode_airbornePosition.m - Function to generate airborne position messages
- **Input Collection**:
  - Latitude, Longitude, Altitude
  - Timestamps (t0, t1)
  - Type Code, Surveillance Status, Single Antenna Flag
  - Downlink Format (DF), Capability (CA), ICAO address

```
>> latitude = 52.2572;
longitude = 3.91937;
altitude = 38000;
t0 = 1457996402;
t1 = 1457996400;
typeCode = 19;
surveillanceStatus = 0;
singleAntennaFlag = 1;
DF = 17;
CA = 5;
ICAO = '40621D';
```

- **Data Flow and Processing:**
  1. **CPR Encoding:** Calculate dLat values for even/odd frames. Compute CPR latitudes and longitudes. Determine number of longitude zones (NL).
  2. **Altitude Encoding:** Convert altitude to 12-bit representation. Range should be -1000 to 50175 feet.
  3. **Message Construction:** Create 56-bit ME field. Include type code, surveillance status, antenna flag. Append encoded altitude, CPR latitude, CPR longitude.
  4. **Full Message Assembly:** Combine DF, CA, ICAO address with ME field. Convert to hexadecimal format.
  5. **CRC Calculation:** Apply CRC algorithm to ensure data integrity. Append 24-bit CRC to each message.
  6. **Timestamp Comparison:** Determine most recent message (ME0 or ME1)

Generating Sample ADS-B Messages

Aircraft Airborne Position Function – Output

- **Outputs:**
  1. **Message0: 8D40621D265862D690C8ACF9EA27**
     DF (Downlink Format): 17 (10001)
     CA (Capability): 5 (101)
     ICAO: '40621D’
     ME (Message, Extended squitter): '265862D690C8AC’
     - Altitude: '862' (encoded 38000 ft)
     - CPR Latitude (Even): 'D690C’
     - CPR Longitude (Even): '8AC’

     CRC: 'F9EA27'
  2. **message1: 8D40621D26586241ECC8ACDF67B5**
     DF+CA: '8D' (same as message0)
     ICAO: '40621D' (same as message0)
     ME: '26586241ECC8AC’
     - Altitude: '862' (same as message0)
     - CPR Latitude (Odd): '41ECC’
     - CPR Longitude (Odd): '8AC’

     CRC: 'DF67B5'
  3. **mostRecent: 'ME0 is the most recent message’**
     This is determined by comparing timestamps t0 and t1

```
message0 =

    '8D40621D265862D690C8ACF9EA27'


message1 =

    '8D40621D26586241ECC8ACDF67B5'


mostRecent =

    'ME0 is the most recent message'
```

Generating Sample ADS-B Messages

Aircraft Surface Position - Description

- Type Code = 5 to 8
- ME field structure:

```
+-------+--------+------+--------+------+------+------------+------------+
| TC, 5 | MOV, 7 | S, 1 | TRK, 7 | T, 1 | F, 1 | LAT-CPR, 17 | LON-CPR, 17 |
+-------+--------+------+--------+------+------+------------+------------+
```

FIELD		MSG	ME	BITS
Type Code	TC	33-37	1-5	5
Movement	MOV	38–44	6–12	7
Status for Ground Track	S	45	13	1
Ground Track	TRK	46-52	14-20	7
Time	T	53	21	1
CPR Format	F	54	22	1
Encoded latitude	LAT-CPR	55-71	23-39	17
Encoded longitude	LON-CPR	72-88	40-56	17

- Position information is encoded in Compact Position Reporting (CPR) Format.

- **Parameters**

1. **Movement**: Encodes the aircraft ground speed non-linearly and with different quantizations.

Encoded Speed	Ground Speed	Quantization
0	Speed not available	
1	Stopped ($v < 0.125$ kt)	
2-8	$0.125 \le v < 1$ kt	0.125 kt steps
9-12	1 kt $\le v <$ 2 kt	0.25 kt steps
12-38	2 kt $\le v <$ 15 kt	0.5 kt steps
39-93	15 kt $\le v <$ 70 kt	1 kt steps
94-108	70 kt $\le v <$ 100 kt	2 kt steps
109-123	100 kt $\le v <$ 175 kt	5 kt steps
124	$v \ge 175$ kt	
125-127	Reserved	

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Aircraft Surface Position – Encoding Calculations

- **Parameters**

2. **Ground Track:** If Ground Track is set to 1, ground track is encoded with a precision of (and rounded to) 360/128 degrees. If Ground Track is set to 0, information contained in the ground track fields should be considered as invalid.

$$X = \frac{360\, n}{128}\ (degrees)$$

3. **Position:** CPR format bit indicates whether the message is an even or odd message. Latitude zone size is defined as:

$$\mathrm{dL}at_{\mathrm{even}} = \frac{90°}{4N_z} \qquad \mathrm{dL}at_{\mathrm{odd}} = \frac{90°}{4N_z - 1}$$

The longitude zone size is smaller too:

$$\mathrm{dL}on_{\mathrm{even}} = \frac{90°}{n_{even}} \qquad \mathrm{dL}on_{\mathrm{odd}} = \frac{90°}{n_{even}}$$

Generating Sample ADS-B Messages

Aircraft Surface Position Function – Input and Data Flow

- MATLAB function has been defined that generates ADS-B message for encoding surface position of an aircraft.
- ADSB_encode_surfacePosition.m - Function to generate surface position messages
- **Input Collection**:
  - Type Code, Ground Track Status, Movement Speed, Track Angle
  - Latitude, Longitude
  - Reference Latitude, Reference Longitude
  - Timestamps (t0, t1)
  - Downlink Format (DF), Capability (CA), ICAO address
  - Time Flag (optional)

```
>> typeCode = 7;          % Type code for surface position
groundTrackStatus = 1;   % Ground track status (1 for valid, 0 for invalid)
movementSpeed = 17;      % Speed in knots
trackAngle = 92.8125;    % Track angle in degrees
latitude = 52.32061;     % Latitude in degrees
longitude = 4.73473;     % Longitude in degrees
refLat = 51.990;         % Reference latitude)
refLon = 4.375;          % Reference longitude
t0 = 1457996410;         % Unix timestamp for even frame
t1 = 1457996412;         % Unix timestamp for odd frame
DF = 17;                 % Downlink Format
CA = 4;                  % Capability
ICAO = '484175';         % ICAO address (hexadecimal)
```

- **Data Flow and Processing:**
  1. **CPR Encoding:** Calculate dLat values for even/odd frames. Compute CPR latitudes and longitudes. Use reference coordinates for longitude calculation.
  2. **Movement Speed Encoding:** Convert speed to 7-bit encoded value. Different ranges have different encoding rules.
  3. **Track Angle Encoding:** Convert angle to 7-bit representation.
  4. **Message Construction:** Create 56-bit ME fields. Include type code, movement, ground track status, track angle, time flag. Append CPR latitude and longitude
  5. **Full Message Assembly:** Combine DF, CA, ICAO address with ME field. Convert to hexadecimal format.
  6. **CRC Calculation:** Apply CRC algorithm to ensure data integrity. Append 24-bit CRC to each message.
  7. **Timestamp Comparison:** Determine most recent message (ME0 or ME1)

Generating Sample ADS-B Messages

Aircraft Surface Position Function – Outputs

- **Outputs:**
  1. **msg0: 8C48417538DA13858A126CABE85A**
     DF (Downlink Format): 17 (10001)
     CA (Capability): 4 (100)
     ICAO: 484175
     ME (Message, Extended squitter): 38DA13858A126C
     - Movement: DA
     - CPR Latitude (Even): '58A12’
     - CPR Longitude (Even): '6C'

     CRC: ABE85A
  2. **msg1: 8C48417538DA15323E11E81C4BB2**
     DF+CA: ‘8C' (same as message0)
     ICAO: 484175 (same as message0)
     ME: 38DA15323E11E8
     - Movement: DA (same as message0)
     - CPR Latitude (Odd): 23E11
     - CPR Longitude (Odd): E8

     CRC: 1C4BB2
  3. **mostRecent: 'msg1 is the most recent message’**
     This is determined by comparing timestamps t0 and t1

```
msg0 =

    '8C48417538DA13858A126CABE85A'


msg1 =

    '8C48417538DA15323E11E81C4BB2'


mostRecent =

    'msg1 is the most recent message'
```

ADS-B Signal Integration with Cadence Virtuoso

MATLAB to Transceiver Chain in Cadence

1. PPM Signal Generation
   - A generatePPM function creates the PPM signal and time axis.
     - ppm_signal: An array of 0s and 1s representing the PPM-encoded ADS-B message
     - time_axis: Corresponding time values for each sample
   - writematrix function is used to save data to a text file.
   - outputpath: Specifies the location of the txt file.
   - The column is set to a tab character.
   - Saved with a precision of double
   - Signal Duration: 112 μs (112 bits at 1 Mbps)
   - No header row is included

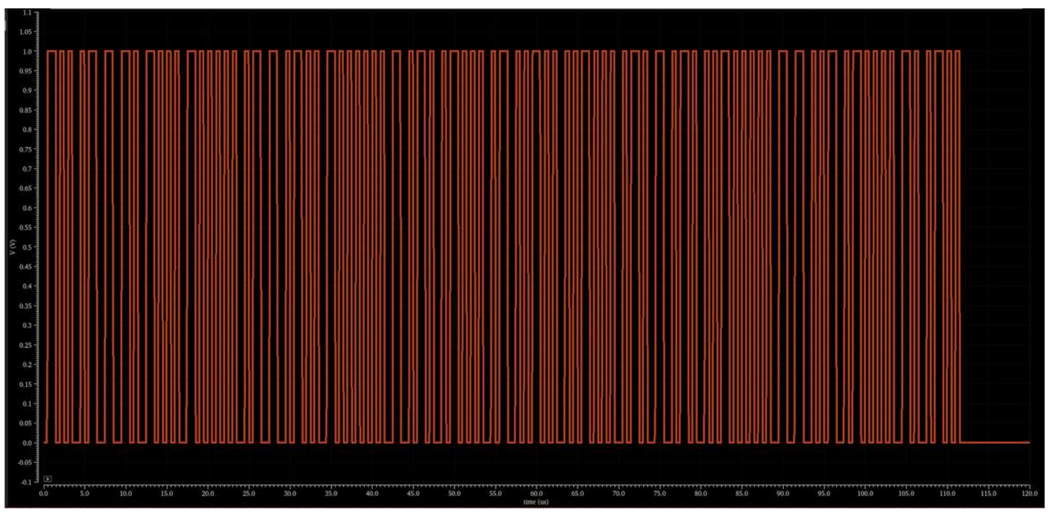
```matlab
function [ppm_signal, time_axis] = generatePPM(binary_message)
    % ADS-B PPM encoding parameters
    bit_rate = 1000000; % 1 Mbps
    samples_per_second = 20000000; % 20 MHz sampling rate for smooth representation
    samples_per_bit = samples_per_second / bit_rate;
    pulse_width_samples = round(0.5 * samples_per_bit); % 0.5 μs pulse width

    % Initialize PPM signal
    ppm_signal = zeros(1, length(binary_message) * samples_per_bit);

    % Generate PPM signal
    for i = 1:length(binary_message)
        if binary_message(i) == '0'
            start_index = round((i-1) * samples_per_bit) + 1;
        else
            start_index = round((i-1) * samples_per_bit + samples_per_bit/2) + 1;
        end
        end_index = min(start_index + pulse_width_samples - 1, length(ppm_signal));
        ppm_signal(start_index:end_index) = 1;
    end

    % Generate time axis
    time_axis = (0:length(ppm_signal)-1) / samples_per_second;
end
```

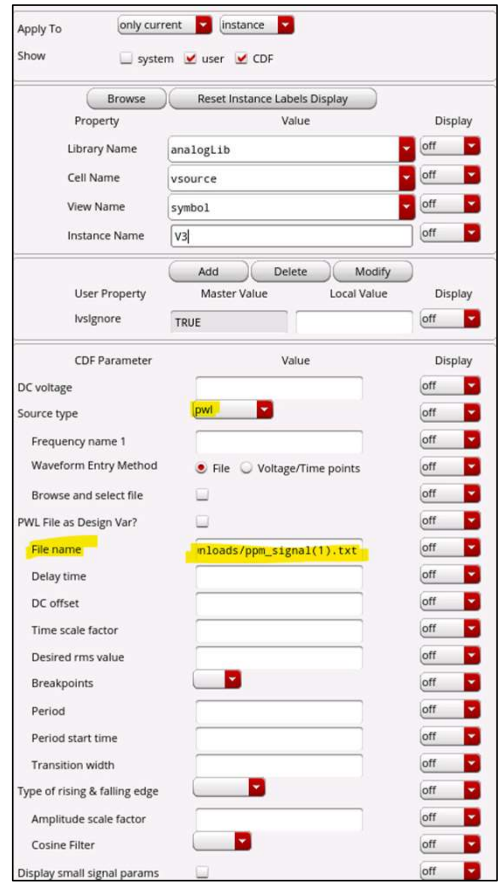
```matlab
% Save PPM signal to text file
    outputPath = 'C:\Users\rauna\OneDrive - UW\Study\Project\Summer_Internship\ADS-
B\ADS-B_WaveGen\ADSB_Encode\CSV\ppm_signal.txt';
    writematrix([time_axis', ppm_signal'], outputPath, 'Delimiter', 'tab');
    disp(['PPM signal saved to: ', outputPath]);
```

ADS-B Signal Integration with Cadence Virtuoso

MATLAB to Transceiver Chain in Cadence

2. A voltage source (**vsource**) from the analogLib library was used to import the PPM waveform.
   - “Source Type” to “PWL” (Piece-Wise Linear)
   - “File Name” contains the path to the MATLAB-generated text file.
3. This enables any waveform created in MATLAB to be imported in Cadence as a txt file.





ADS-B Signal Integration with Cadence Virtuoso

I+ and I- components of ADS-B

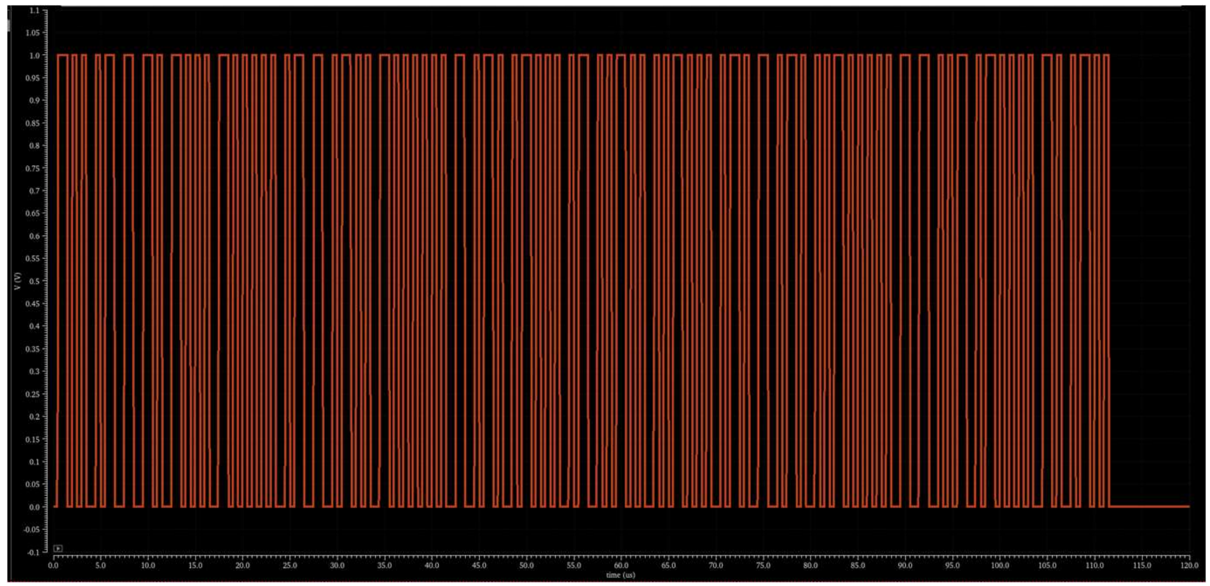
- Explored the creation of I+ and I- components for ADS-B signals.
- Current Approach: Using a flipped version of the original ADS-B signal for simulation as the I- component. Using the original ADS-B PPM signal as I+, representing the primary information signal.
- Further Steps: Investigate Time-Shifted Signals. Explore time-shifting to create I- and Q components that maintain orthogonality.
- generateflippedPPM.m - Converts a hexadecimal ADS-B message to binary. Generates both original and flipped PPM signals. Plots both signals for comparison and saves the flipped signal to a text file.

```
function generateFlippedPPM(hex_value)
    % Convert the hex message to binary
    hex_message = hexToBinaryVector(hex_value);

    % Generate PPM encoded signal for the original message
    [ppm_signal, time_axis] = generatePPM(hex_message);

    % Plot PPM encoded signal for the original message
    figure;
    plot(time_axis * 1e6, ppm_signal); % Convert to microseconds for display
    ylim([-0.5, 1.5]);
    grid on;
    title('Original PPM Encoded Message');
    xlabel('Time (μs)');
    ylabel('Amplitude');

    % Display the original PPM message
    disp('Original PPM Encoded Message (Hex):');
    disp(hex_value);
    disp('Original PPM Encoded Message (Binary):');
    disp(hex_message);

    % Flip the bits in the binary message
    flipped_message = char(bitxor(hex_message - '0', 1) + '0');

    % Generate PPM signal for the flipped message
    [flipped_ppm_signal, flipped_time_axis] = generatePPM(flipped_message);

    % Display the flipped binary message
    disp('Flipped PPM Encoded Message (Binary):');
    disp(flipped_message);

    % Plot flipped PPM encoded signal
    figure;
    plot(flipped_time_axis * 1e6, flipped_ppm_signal); % Convert to microseconds for display
    ylim([-0.5, 1.5]);
    grid on;
    title('Flipped PPM Encoded Message');
    xlabel('Time (μs)');
    ylabel('Amplitude');

    % Save flipped PPM signal to text file
    outputPath = 'C:\Users\rauna\OneDrive - UW\Study\Project\Summer_Internship\ADS-B\ADS-B_WaveGen\PPM\CSV\flipped_ppm_signal.txt';
    writematrix([flipped_time_axis', flipped_ppm_signal'], outputPath, 'Delimiter', 'tab');
    disp(['Flipped PPM signal saved to: ', outputPath]);
end
```

ADS-B Signal Simulation

ADS-B Signal Simulation Setup Overview

- ADS-B Signal Generation
  - The ADS-B signal is generated in MATLAB with PPM encoding.
  - A flipped version of the ADS-B signal is created to represent the I- component.
- Signal Export and Preparation
  - The generated PPM signal is exported as time-voltage pairs in a text file for further processing. This will be the I+ component of the baseband signal.
  - The flipped version of the signal will be the I- component of the ADS-B signal.
- Signal Import:
  - Both I+ (original PPM) and I- (flipped PPM) signals are imported into Cadence Virtuoso.
  - Utilized '**vsource**' as Piece-Wise Linear (PWL) input to accurately represent the signals.



ADS-B Signal Simulation

Transceiver Chain Operation

- Input Baseband Signal
  - The I+ and I- components act as the input baseband signals for the transceiver.
- Frequency Upconversion
  - The baseband signals are upconverted to the ADS-B transmission frequency of 1090 MHz.
- Amplification and Transmission
  - The upconverted signal is amplified using a Power Amplifier to ensure adequate transmission power.
  - The simulation is conducted under ideal conditions to assess performance without external interference.
- Signal Reception
  - The transmitted signal is received by a receiver input.
  - The received signal is downconverted back to baseband for analysis.
- Simulation Duration Constraints
  - The entire ADS-B message lasts 112μs, but due to simulation constraints, only the first 3μs could be processed.

ADS-B Signal Simulation

Results and Simulation Constraints

- The successful simulation of the first 3µs demonstrates the validity of the implementation approach.
- Close resemblance between transmitted and received signals in this initial segment suggests that full signal processing would likely yield positive results.
- Simulation Constraints
    1. ADS-B signal duration: The complete ADS-B signal spans 112µs.
    2. Simulation Time Challenge:
        - Processing 1µs of the ADS-B signal requires approximately 1-1.5 hours of simulation time.
        - Current simulation capacity: Only the first 3µs of the ADS-B signal could be transmitted and received.
- Promising results from the initial 3µs provide a strong foundation for extending the simulation to the complete ADS-B message.