BEng Aerospace Project

Interim Report

Identifying the position of small airborne vehicle by using radio technology

Hao Xu

10th December 2016

Supervisor: Mr Eddie Ball

Introduction, aims and objectives

Introduction

Radio positioning is an old-style method for navigation compared to the state-of-the-art global navigation satellite system (GNSS). However, in the past two hundred years of aviation, radio has proved to be a reliable way for achieving navigation. Meanwhile, radio navigation is continuously evolving to meet contemporary requirements of modern aviation and playing a more important role as one of the alternative methods when GNSS malfunctions. This project focuses on a compatible solution bridging the VOR (Very High Frequency Omnidirectional Range)/TACAN (Tactical Air Navigation)-like system and the GNSS system. In this study, VOR-like signal will be implemented at a GNSS signal frequency, which is generated using MATLAB and Simulink. During the project, two different implementations will be examined in the further stages of study, which involve some lab works.

In the meantime, preliminary theories of the two implementations are developed. First evaluation will investigate the phase modulation of VOR system. And second evaluation will testify an alerted higher frequency VOR-like signal and transmit it in the different time at GPS frequency, i.e. 1.54GHz.

The final test will be carried out with fixed transmitters and a moving receiver installed on a moving vehicle.

Aims

This project aims to achieve a prototype standalone navigation system by using radio.

Objectives

1. The principle of the navigation theory related to combination of time and known position will be proved by using MATLAB

2. The algorithm of solving equation of time and location difference will be explored and examined with MATLAB

3. Ground station signal including time and location source will be determined

4. The system receiver prototype will be implemented into real time system or relevant simulation environment

5. The deliverable / prototype system shall include real hardware where possible, which may include creation of a PCB for both the drone and ground station

6. The produced system will be subject to a field test

7. Target Requirement: to obtain the flying speed of the aircraft

8. Target Requirement: to achieve the accuracy of 100m

9. Target Requirement: coverage range of 1km minimum

Literature review work progress to date

The history of radio navigation dates back to late 19th century before the First World War (Bauss, 1963). Before starting using radio, people had already used compass and stars for thousands years. However, the radio is a game changer which overcame major difficulties of the old navigation method. In the past century, it has been developed from analogue to digital, from ground to space, from inaccurate to accurate, from immobile to portable and from specialized to daily uses.

The first ever radio relative system was radio direction finder, which is tuned to the frequency of a certain station and pointed at its direction using an antenna. This allows pilot to determine the bearing of the station, which enable aircraft or ships to drive towards it. By hearing from two stations, the captains and pilots are able to draw an intersection of two radio station on the map and thus determine its own position. However, it requires a rather long antenna to provide better angle information, which is not practical for small aircraft. In later development, ADF (Automatic Direction Finder) was a great progress, which benefits from modern electronics such as transistors. It works with NDB, i.e. non-directional beacon, and uses phase comparison technic to determine the bearing of the aircraft (Watson & Wright, 1971). However, the accuracy of the system is a critical issue for the usage of modern aviation and not suitable for small scale aircraft due to its huge antenna size.

VOR exhibited a significant improvement from ADF and NDB, featured by better accuracy and a voice channel to identify the station.

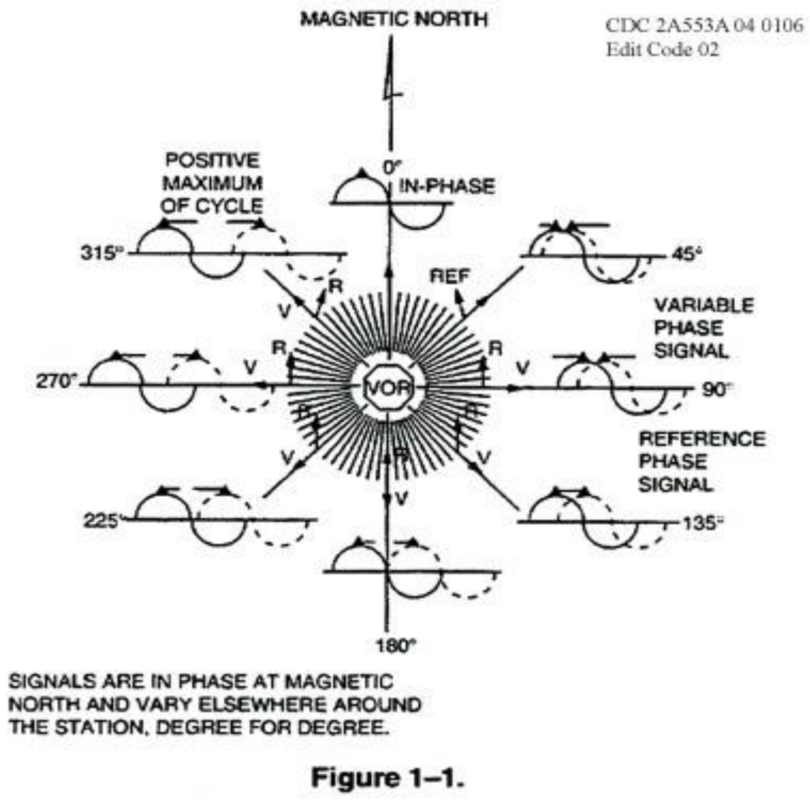


Figure 1 The VOR signal (Beck, 1971)

It consists of three parts: the voice, the reference signal consisting of a continuous signal transmitted from the omnidirectional antenna and a signal rotating at 30Hz causing different phases corresponding to the direction it faced (LAMB, 1948). By comparing the phase difference between the reference and the rotating signals, a bearing can be worked out easily. It has an advanced version named TACAN, which implies higher frequency and more division of phases with distance measuring feature.

Figure 2 A VOR station (photo taken by FARHAN FAROOQ)

Due to the limitation of this project, the study does not include hyperbolic navigation systems due to performance and size issues. Since the most of the hyperbolic systems work at low frequency to achieve wide coverage, their precision is much lower than the required specification of this project and meantime, and meanwhile they require a long antenna to work.

Beam systems, for example the Adcock by Macaroni known as LFR (Low Frequency Range), is also a good idea of navigation (Beck, 1971), however, it requires that the object remains in the coverage of the beam that is used for navigation, and therefore has little value for projects such as detecting the positions of aircrafts. Though it was used as ILS (Instrumental Landing System) equipment in the past sometimes by military and police in their duty, it requires full-manual operation by listening to Morse code. It has same sort of inspiration of using radio, whereas, it can only show directions when the object is in the covered range, or in other words, it is directional. Thus, it has limits of the uses for a general purpose of navigation.

GPS is the best system in term of both precision and feasibility (Staff, 1990). It remains the most popular choice for navigation since it was put into application. Meanwhile, there were many systems, such as those mentioned above, dying or died because of the wide usage of GPS. GPS was the system designed and operated by USAF (United State Air Force), and its huge military potential was well recognized by US military, therefore, the system had two different ranging modes for civil uses and military uses at the beginning. The civil code, however, is less accurate compared to the military code. It works with simple logic using trigonometry. GPS system has multiple satellites on low earth orbits to guarantee that above most of the surface areas of earth there are at least four satellites in the sky. It was so well designed that during most of the time there were actually more than four, which provides a potential opportunity to increase the accuracy. The algorithm relays on three known satellite positions and signal's time of arrival. An extra satellite is needed for time reference in case of wave propagation error. By knowing the time taken during the propagation, the distances can be worked out. Combining three such distances and satellite locations, a matrix can be introduced to provide multiple solutions, whereas only one of them is the correct positon. Furthermore, the result need to be transferred from polar form into panel form and should be projected on the map with the coordinates provided. The problem with GNSS in general is the time to first fix, which takes usually three to four minutes to cold start up and GPS systems are very power hungry.

Pseudolites application implies simulating satellite signal with a ground or aerial station, which can be deployed to blind zones of GPS (Wang, 2002). It has a huge potential in warfare or special circumstance like mining or cave exploring where GPS signal may not viable. Therefore, it is a good object to study for this project. It has a potential to be compatible with current systems and adapt to new environments. This will be significantly involved in this project.

Software Defined Radio is a new way of planting and testing the design, which required individual transmitter or receiver in the past (Seo et al., 2011). SDR (software defined radio) can be operated easily by using MATLAB and Simulink for signal generating and receiving (Lo, Enge, & Narins, 2015). A cheap RTL-SDR kit can be found in the market with a price of £5 and relatively good performance. RTL-SDR is a SDR receiver works from 24 MHz to 1766 MHz, which is great for the usage of this study. This project requires the signal working at GPS frequency, roughly 1.5GHz.

To know the bearing of the vehicle is not enough to determine the specific position of it, thus a distance from station and object is crucial for the navigation (Lo & Enge, 2012). A DME (Distance Measuring Equipment) is capable for this; however, it has a capacity. To explore the improving oppturnity, Pseudolites technic can be adapt to the situation, where the bearing and angle is obtained by radio, and Pseudolites determine distance.

Current status of the work

- Selection of the base system for this project
  Radio navigation evolved from analogue to digital, and GNSS shows its dominance for the navigation industry. Nowadays, previously deployed system such as Loran-C, NDB, Omega, etc. were discontinued and replaced by GNSS navigation. However, VOR/TACAN retained their necessity for modern aviation, though they are not capable with the newly booming trend of aviation, drones.
  The main reasons for developing VOR to further stage to offer navigation to drones were considered as follow:
  The drones are unmanned vehicles whose movements are highly relaying on the navigation system on board. Due to safety concerns, currently most drones have to follow visual flying rules, which means they cannot operate outside drone pilots' view range, even with GPS equipped. Despite the regulation, the reliability of GPS is a potential disadvantage of self-driving drones. Therefore, multiple solutions have been worked out in the past few years, such as computer vision, inertia navigation etc. Thus, alternative navigation should be maintained during the flight and another good solution is to improve VOR.

A potential solution as proposed in this project is to operate VOR at GNSS frequency, and transmit both Pseudolites and VOR-like signal at GNSS frequency to increase system reliability and compatibility. The benefit of operating VOR at higher frequency can be found in several aspects. The size of antenna is smaller due to shorter wavelength, and it makes it more feasible for small drones, and higher frequency can be used to carry more information, which can be used to increase accuracy. In addition, it can minimize the error caused by multipath effect because it works in short range and much more directional.

- Research how RTL-SDR can be used to analyse GPS and VOR signals
  RTL-SDR is a good tool to obtain the GPS signal and also VOR signal. Whereas the VOR is usually only deployed near airport, which made it hard to obtain at this stage. It is important to study this tool to deal with upcoming tasks.

- Understanding VOR

  VOR is a short-range radio navigation for aircraft, which operates from 108 – 118 MHz (Beck, 1971). It has three components in its signal. Voice, Morse code and 30Hz signal with angle shifted. However, in this study, the voice and Morse code are ignored because they are irrelevant. The left components are 30Hz phase-varied signal, which is modulated into the carrier, and the reference 30Hz signal modulated into the 9960Hz subcarrier first then modulated into main carrier. The modulated 30Hz signal will then be transmitted via a mechanically rotated or electronically scanned directional antenna. On the receiver side, it will receive signals at designated frequency, then a 30 Hz filter will pick up directional signal at 30 Hz, and a 9960 Hz filter will pick up reference signal which is modulated inside of 9960 Hz subcarrier. Then a phase-shifted signal can be compared with reference signal, and work out phase difference to solve the bearing of course. The 9960 Hz signal plays the important role to carry reference signal, without it, the reference signal are mixed with the directional phase-varied signal, hence the receiver cannot tell that which is the reference and which is the directional signal. The bearing is worked out from comparing phase difference of two 30Hz signal.

- Prototyping and the Block diagram of proposed system
  - Signal simulation (description goes below)

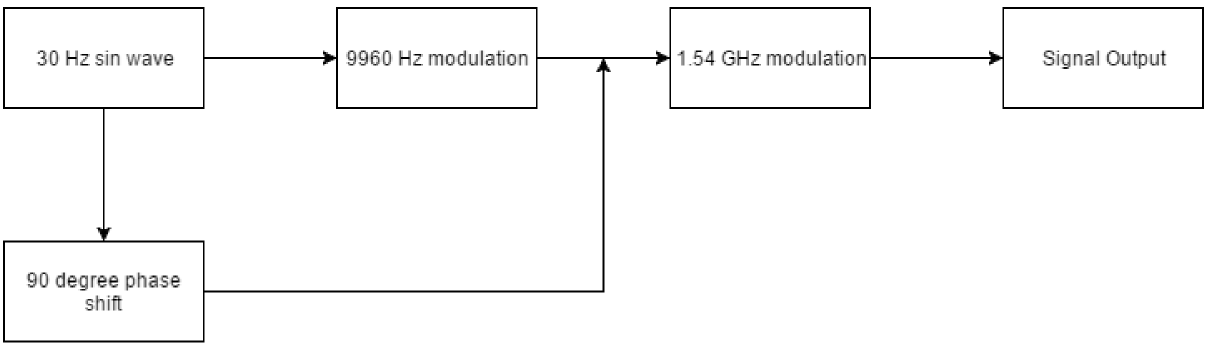


Figure 3 Signal Simulation Block Diagram

  - Receiver design

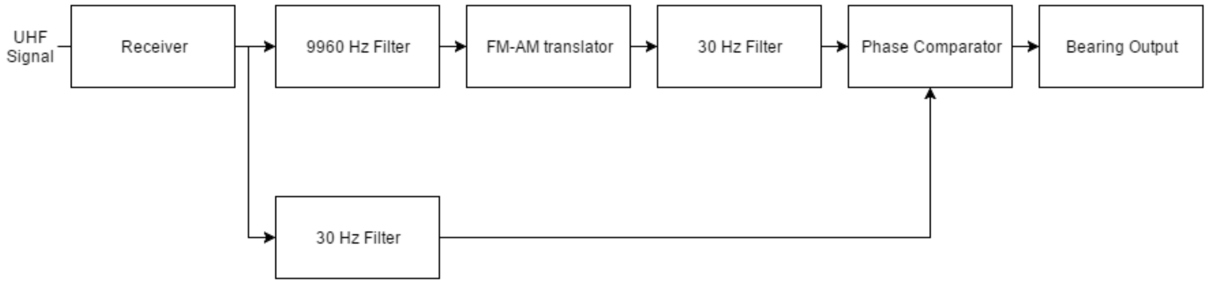


Figure 4 Receiver Design

- Transmitter design

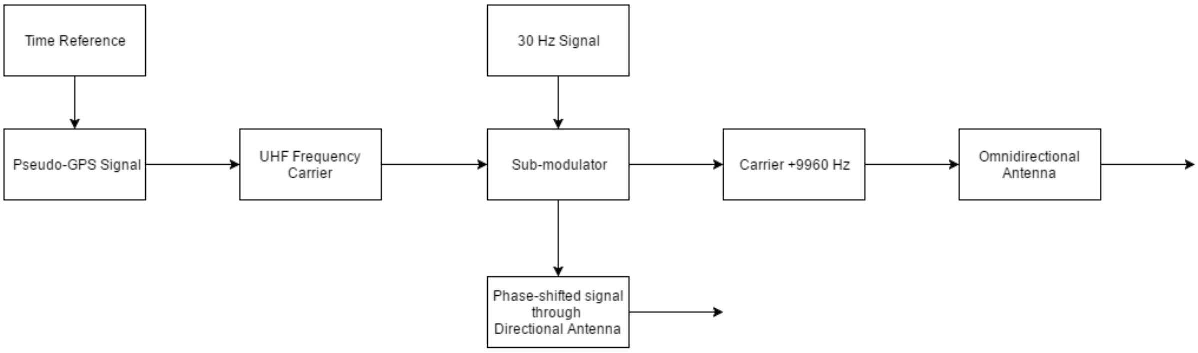


Figure 5 Transmitter design

- System Summary and practical implementation

This system as a prototype focus on replacing carrier frequency with higher one. It will examine the possibility of other subcarrier frequency in next stage too. The signal will be generated using signal generator, and as a direct input to RTL-SDR to simplify the antenna design at this stage. The receiver will be simulated by using MATLAB and Simulink.

- Full scope of the system
  The prototype shown above is a little progress on the original VOR system, however, it can be used for next stage research. The full system, which I proposed, is a standalone Pseudolites based VOR system. It, which combines the feature of GNSS and VOR with higher accuracy and better usability, is fully digitalized system that provides bearing, distance, absolute position, and reliable timing. It has a huge potential as alternative navigation.

- The lab plan of the system
  The system will be simulated by using signal generator, and result signal will be received by RTL-SDR to analyse and obtain the data of phase difference. The lab intends to examine the VOR-like signal working at higher frequency, aka, 1.54GHz GPS frequency. The phase delay will be generated together with the reference signal and modulation will be completed.
- Learning GPS signal and algorithms
  The GPS is the abbreviation of Global Positioning System by using satellites. The system has 32 unit of satellites operating on MEO (Medium Earth orbit) transmit at 2 bands, L1 and L2. The signal is in CDMA format and contains 5 frames of data. However, this information is only useful if there's a background knowledge of Geoscience and Astronomy, which is obvious beyond the scope. Thus a simplified achievable goal is to determine whether the

original signal will be distorted during the secondary modulation. The research of GPS will remain at signal level for this project, however, a higher level study is planned initially.

Self-review

The overall progress is matching up with scheduled, however the practical simulation meets significant difficulty. I spent more time than expected to understand the principle of radio navigation. The major problem for me is the foundation comprehension of radio and electronics. However, after a long period of catching up, I understand how the system modulates signal into different phases and a secondary modulation to mix them together. I spent a large amount of time on the GPS system to find out the mechanism of GNSS. Whereas, the tremendous gap of knowledge stopped my further research on it. It requires higher level of understanding on geoscience and orbit mechanism. From my point of view, it is too beyond my ability to integrate enough GPS knowledge into this project, therefore the target was lower to meet my condition.

Project management

Summary

The plan is divided into two parts according to semesters. In the first semester, most of the work are preparation work for the further study of the project. The project itself is a different field for an aerospace engineering student, therefore a more throughout study on the basis is required before proceeding to the next stage of study and lab work. To the date of the submission of this report, the initialisation is completed and the lab works are planned accordingly.

Current work and planed work for next semester is shown below

• Define project equipment • plan of deliverable content • Plan for lab works • Finishing the interim report • Combing the algorithms with system • Prototyping of models on the hardware platform • Researching Hardware • Developing algorithms • Modelling of the system • Radio fundamental studies • Literature research
Tasks to be completed in semester 2

- Implement system on PCB
- Oral presentation preparation
- Demodulation using the development board
- Prototyping on hardware
- Final Report
- Field Test
- Test running through the Prototyping
- Keep Prototyping of models (MATLAB & Simulink)
- Combing algorithms with systems

References

Bauss, W. (1963). *Radio navigation systems for aviation and maritime use* (1st ed.). Oxford: Pergamon Press; [distributed in the Western Hemisphere by Macmillan, New York].

Beck, G. (1971). *Navigation systems: a survey of modern electronic aids* (1st ed.). London: Van Nostrand Reinhold.

LAMB, J. (1948). Very High-Frequency Techniques. *Nature*, *162*(4107), 83-84. http://dx.doi.org/10.1038/162083a0

Lo, S. & Enge, P. (2012). Capacity Study of Multilateration (MLAT) based Navigation for Alternative Position Navigation and Timing (APNT) Services for Aviation. *Navigation, 59*(4), 263-279. http://dx.doi.org/10.1002/navi.25

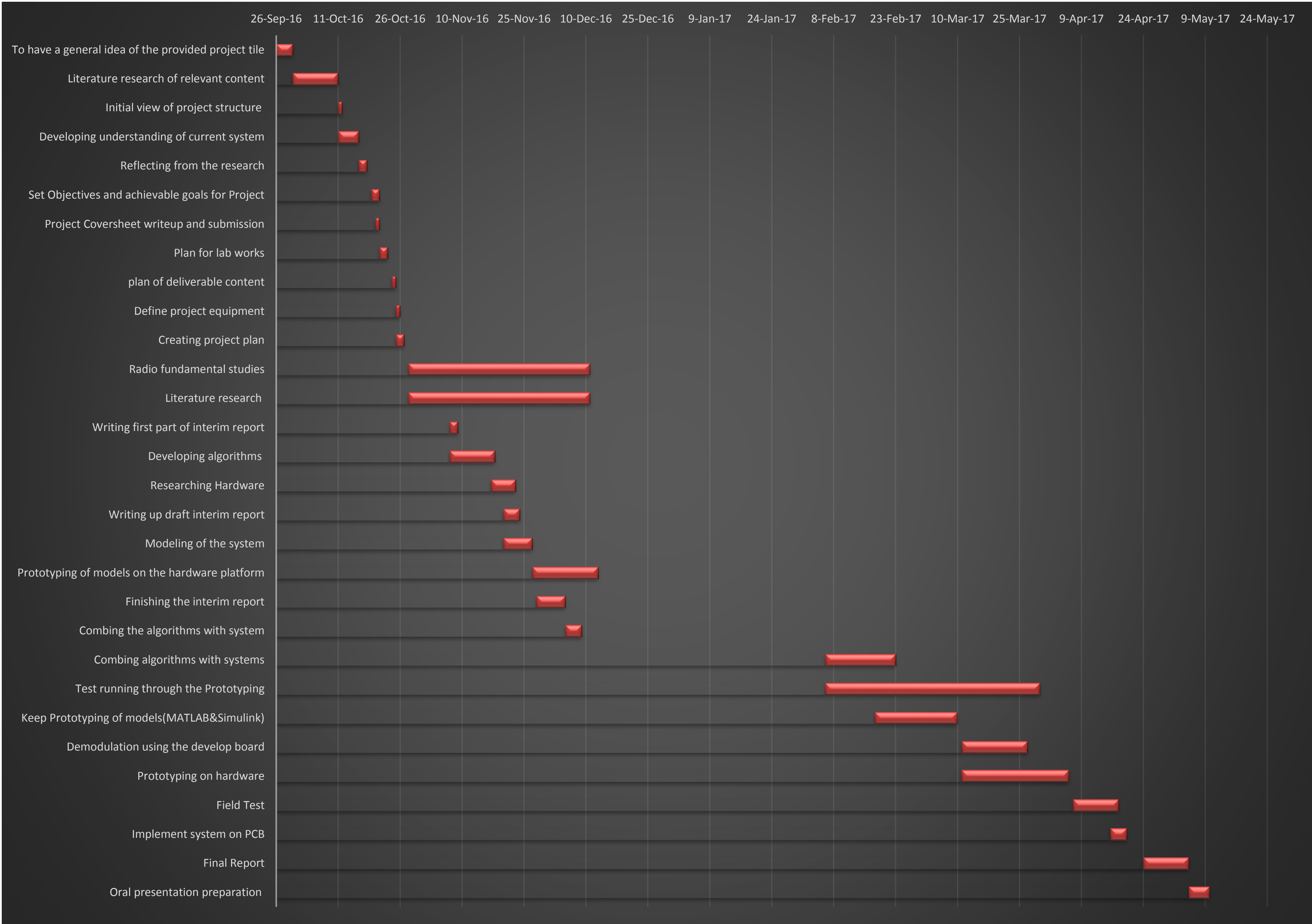
Lo, S., Enge, P., & Narins, M. (2015). Design of a Passive Ranging System Using Existing Distance Measuring Equipment (DME) Signals & Transmitters. *Navigation*, *62*(2), 131-149. http://dx.doi.org/10.1002/navi.83

Seo, J., Chen, Y., De Lorenzo, D., Lo, S., Enge, P., Akos, D., & Lee, J. (2011). A Real-Time Capable Software-Defined Receiver Using GPU for Adaptive Anti-Jam GPS Sensors. *Sensors*, *11*(12), 8966-8991. http://dx.doi.org/10.3390/s110908966

Staff, N. (1990). *Global Positioning System* (1st ed.). Washington: National Academies Press.

Wang, J. (2002). Pseudolite Applications in Positioning and Navigation: Progress and Problems. *Journal Of Global Positioning Systems*, *1*(1), 48-56. http://dx.doi.org/10.5081/jgps.1.1.48

Watson, D. & Wright, H. (1971). *Radio direction finding* (1st ed.). London: Van Nostrand-Reinhold.


26-Sep-16
11-Oct-16
26-Oct-16
10-Nov-16
25-Nov-16
10-Dec-16
25-Dec-16
9-Jan-17
24-Jan-17
8-Feb-17
23-Feb-17
10-Mar-17
25-Mar-17
9-Apr-17
24-Apr-17
9-May-17
24-May-17
To have a general idea of the provided project tile
Literature research of relevant content
Initial view of project structure
Developing understanding of current system
Reflecting from the research
Set Objectives and achievable goals for Project
Project Coversheet writeup and submission
Plan for lab works
plan of deliverable content
Define project equipment
Creating project plan
Radio fundamental studies
Literature research
Writing first part of interim report
Developing algorithms
Researching Hardware
Writing up draft interim report
Modeling of the system
Prototyping of models on the hardware platform
Finishing the interim report
Combing the algorithms with system
Combing algorithms with systems
Test running through the Prototyping
Keep Prototyping of models(MATLAB&Simulink)
Demodulation using the develop board
Prototyping on hardware
Field Test
Implement system on PCB
Final Report
Oral presentation preparation