International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 9, September - 2013

RSSI Monopulse Azimuth Tracking Demonstration using Wideband Personal Area Network Device

Peerayudh Saratayon, Varavut Pirom, Thanathat Saelim
Control and Communication Laboratory, R&D Department
Defence Technology Institute (Public Organization), DTI
Nonthaburi, Thailand

Abstract

The purpose of this experimental research was to demonstrate the use of current technology of COTS Wireless Personal Area Network (WPAN) devices for RSSI Amplitude Comparison Monopulse Tracking currently conducted for the test of short-range missiles of Thailand's Defence Technology Institute (Public Organization) or DTI. First, system design and architecture was made based on system requirements, Concept of Operation (CONOP) and test configuration, followed by link budget and Fresnel Zone calculations and system sizing. Then simple prototype of each subsystem was designed, developed and tested using tools available in the laboratory and its result was discussed. Monopulse characteristic and system performance was checked and a guideline for simple open-loop short-range dynamic test was suggested.

Keywords-RSSI Monopulse Tracking; Wideband Personal Area Network; CONOP; Printed Yagi Antenna

1. INTRODUCTION

As part of DTI's Control and Communication Laboratory roadmap, Monopulse Tracking has been considered a solution for an improved tracking capability typically relying only on small antenna beamwidth and GPS position. In missile operation, a few challenges arise from high speed and rotation of the airborne platform. Speed over 1.5 Mach introduces a GPS cut-off and hence no position data will be transmitted to the ground. Monopulse tracking will reduce apparent antenna beamwidth to the size small enough so that the missile position can be tracked more efficiently. Two or more of the antenna pointing vectors can, in theory, be triangulated to find absolute missile position (x, y, z). Monopulse technique has obsoleted conical scanning and sequential lobing tracking methods widely used in the past and has been found in abundant of applications nowadays such as UAV, RADAR, Guided Missile, etc.

Amplitude Comparison method was used for the simplicity of electronic circuitry involved. WPAN device was selected for its increasing use in long-range point-to-point network-ready applications. Not only being modular and small in size, the provision of spread spectrum, AES encryption, RSSI (Received Signal Strength Indicator) output, and very good sensitivity made it a good candidate, even for tactical applications, although the use of wide bandwidth put some constraints on front-end subsystem design. Printed Yagi antenna was used for receiving signal as it was easy to design and develop. Even though its beamwidth and sidelobe level are not small enough for practical use, it is perfect for demonstration purposes. 2.4 GHz was selected due not only as a compromise between the 900 MHz and the 5.8 GHz ISM bands, but also for the availability of supporting equipment and tools. Simple FR-4 substrate can be used both on ground and on the wrap-around antenna onboard the missile.

2. SYSTEM REQUIREMENT AND SYSTEM DESIGN

2.1. CONOP and Test Configuration

During missile development and test phases, telemetry data which consists of onboard sensor and monitoring data need to be collected and sent to the ground in the quickest possible manner. It is also assumed that the missile will be fired from the shore and be completely unrecoverable after hitting the sea. Even though the missile's rotation improves its stability, it has adverse effect on tracking capability. System design and architecture depends directly on missile parameters as shown in TABLE 1.

TABLE 1. Main Missile Parameters

Missile Parameters	Data	Remarks
Range	up to 20 km	Flight time of about 1 minute
Max. Speed	1.5 Mach	Normally a few seconds after firing
Max. Height	up to 3 km	At firing angle of 45° - 50°
Max. Spinning Rate	~ 10 round/s	Spinning rate varies along the flight.

Test configuration in Fig.1 shows a firing range of 20km which is relatively small for LOS RF transmission and therefore is manageable by only 1 tracking station locating mid-way, a few kilometers aside of trajectory path.

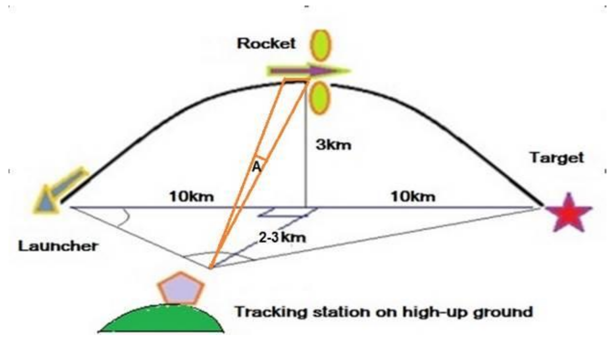

Figure 1: Test configuration showing small angle A of about 10° and slant range of about 3.5 km, therefore yielding a maximum tracking agility at boresight of about 5°/s (assuming missile speed of 1 Mach at boresight, slant range x sin 10° ~600m)

Conformal antenna onboard the missile produces Horizontal Polarization (HP) when the missile is parallel to the ground. Naturally, the spinning of the missile will transform it into Circular Polarization (CP) but only when looking directly from behind or in front of the flight path. The use of CP for the ground tracking antenna will result in seeing LHCP when the missile is approaching the ground station and RHCP when it is departing or vice versa. It is therefore decided that a simple HP will be used on the ground tracking antenna. The 3dB circular-to-linear polarization loss will be allocated in the Link Budget and the linear polarization misalignment loss will be counteracted by adjusting the antenna to the predicted flight profile by means of roll control of the antenna pointing axis.

2.2. System Architecture

From the CONOP and missile parameter, initial system architecture is designed as shown in Fig.2. As a communication backup, it is planned that an optional UAV in-the-air logging station might be needed.

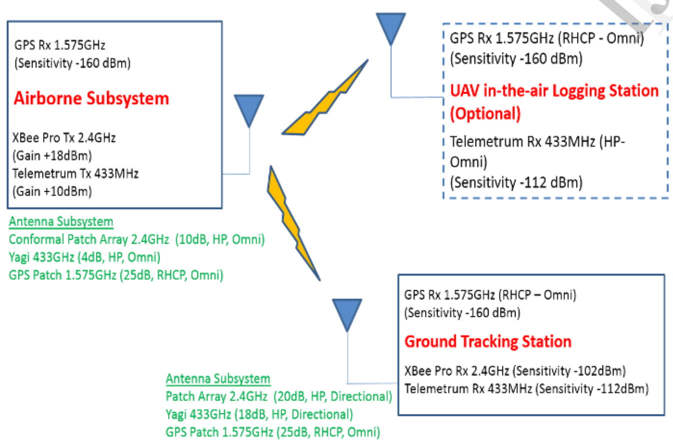

Figure 2. Communication System Architecture

2.3. Link Budget Calculation

Only the 2.4 GHz telemetry data will be tracked and its link budget calculation, using Free-Space path loss model is shown below:

Pr = Pt + Gt + Gr - Path Loss - Other Losses (1)

= 18 dBm + 10 + 20 - 126.2 - 7

= -85.2 dBm

Note: Other Losses = (3dB Polarization Loss) + (4dB Tx-Rx Connector Loss)

As the communication is very tactical in its nature and the missile is going to be tested over the sea where unwanted reflection may be prominent, a worst case link margin of 30 dB will be used [1]. This means that the received power, Pr, can be as low as -115.2 dBm. Such figure is lower than the receiver's sensitivity of -102 dBm (at 9600 bps) and therefore it is decided that a 5W power amplifier is used onboard just before the antenna which will boost the transmitting power from 18 dBm to 37 dBm.

2.4. Fresnel Zone Calculation

The communication between the missile and the ground tracking station starts from even when the missile is on the launcher, when status checking and GPS initialization are to be carried out (through umbilical plug), followed by LOS communication in the air, right until when the missile almost hits the target. It is required that the ground station should stay in contact with the missile for most of the flight, the critical points therefore are at the vicinity of the launch site and the impact point where earth obstructions can be prominent.

Assuming the ground tracking antenna is locating mid-way aside of flight path and using K-factor of 4/3 for Earth radius, 100% of 1st Fresnel Zone radius is calculated as 8.657 $\sqrt{(D/f)}$ or 17.5m, where D is the total distance between the transmitting missile and the receiving ground tracking station of about 10km and f is frequency in GHz. Equal antenna height is calculated as 18.9 m. However in most cases, the launcher is often locating on flat terrain or at sea level, while the ground tracking station is on the hill or elevated terrain. The critical moment is when the missile is just about to leave the launcher and when it is approaching the impact point where Fresnel Zone clearance might not be sufficient. Such a problem can be alleviated by raising the ground tracking site onto very high ground up. In case the missile (and its antenna) is 5m above sea level, the result from the calculator [2] shows that the tracking station needs to be as high as 70m. If this is not a viable option, another antenna situating at the vicinity of the launch site would be needed.

3. Literature Review

3.1. Monopulse Tracking

Monopulse Azimuth Tracking is achieved by having 2 feeders of an antenna or 2 antennae sitting next to each other to receive left and right signals (or 4 feeders for AZ-EL tracking) as shown in Fig.3.

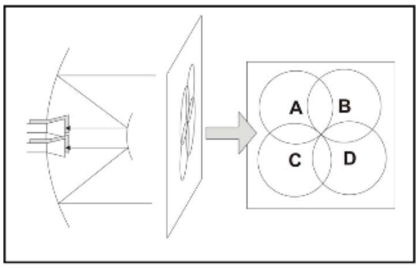

Figure 3. AZ-EL Monopulse Concept

The offset of individual beam from boresight, or squint angle, is generally set to ½ of -3dB beamwidth in order to maximize the response. These signals will be passed into a 'Monopulse Comparator', where the sum (∑) and difference (Δ) signals are produced as shown in TABLE 2. ∑ signal, when demodulated, is the required telemetry data with added gain, while the antenna pointing error (Δ/|∑|) can be found after some post-processing.

TABLE 2. Comparison of AZ and AZ-EL Tracking

	AZ-Tracking Monopulse	AZ-EL Tracking Monopulse
∑ = o/p	(A+B)/2	(A+B+C+D)/2
Δ_{AZ}	(A-B)/2	[(C+D) – (A+B)]/2
Δ_{EL}		[(A+C) – (B+D)]/2

Either amplitude or phase of the incoming signal or both can be used for tracking. Amplitude tracking is the simplest but is vulnerable to reflection and multipath which easily causes constructive and destructive effects to signal amplitude and therefore an antenna with relatively high gain and low 1st sidelobe level would be required. However, printed Yagi antenna with approximately 60° beamwidth will be used here for demonstration purposes.

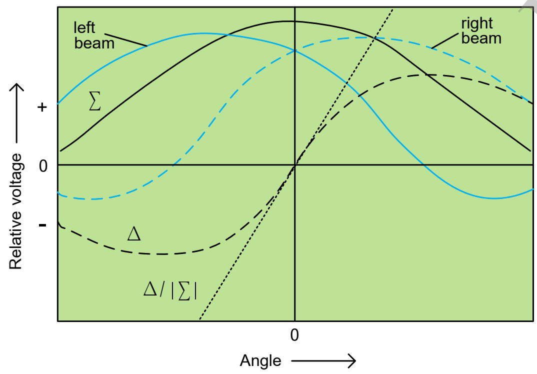

Figure 4. Theoretical responses of Δ, ∑, and Δ/|∑| signals

From Fig.4, the error signal (Δ/|∑|) is not totally linear and would normally need to be linearized in the central region which is the tracking angle of interest. It is also noted that apparent beamwidth of ∑ signal is smaller than that of the left or the right beam alone. In general the ∑ beamwidth would be symmetrical about Y-axis, i.e. when the antenna is bore-sighted. Any error from feeder misalignment will create a shift of the axis of symmetry from Y-Axis and hence needs to be offset or compensated accordingly.

Monopulse Comparator is the key component for producing Δ and ∑ signals. It can be realized in many forms depending on power ratings. Here, a low-power 180° Hybrid Ring or Rat-Race coupler is used for its design simplicity and easy fabrication onto FR-4 substrate.

3.2. Wideband Transceiver

Many wideband transceiver modules of different frequencies are currently available. ISM 2.4GHz is chosen as 900 MHz antenna will be too big for the missile onboard antenna. Similar to their predecessor, XStream 2.4GHz which provides Frequency Hopping Spread Spectrum (FHSS), XBee from Digi.com, popular for in-door/multi-path application, comes with Direct-Sequence Spread Spectrum (DSSS) and has for some times introduced its long-range versions which look very promising for this experimentation. Suitability of use between FHSS and DSSS can be arguable. In general DSSS can provide greater capacity than FHSS but is more sensitive to multipath and jamming environment. As our test configuration is over the sea, multipath effect will be of less problematic, and as long as the tracking beamwidth is kept small enough, there should be little effect from sea reflection and therefore the cheaper and more simple-to-use DSSS XBee Pro (Series 1) is selected. XBee Pro, with its 18 dBm power, is a more powerful version of XBee, which has only 0 dBm. Advantages of using such COTS module are system flexibility, simplicity, and size. The transceiver module, together with a power amplifier are to be used for sending telemetry signal from the missile to the ground and therefore two of such module, one for LH antenna and the other for RH antenna, will be needed on the ground station to give azimuth tracking.

While spread spectrum helps combat multipath to some extent, it may cause some difficulties in subsystem matching. Even though the ISM band (2.4000-2.4835 GHz) is used, careful frequency channel selection helps reduce unwanted interference. As seen in yellow in Fig.5, channels 25 and 26 are least disturbed by adjacent frequency channels. However, it is recommended that WLAN channel power scanning program, such as Windows' inSIDDer [3] or X-CTU [4] AT command line – "ATED", is used for checking frequency channels in the vicinity before assigning the working channel. Carefully narrowing down the working frequency this way also eases the matching and developing of various front-end components.

Wide system bandwidth can be susceptible to Doppler Shift. In this case, maximum speed of the missile will introduce a Doppler Shift of $f_d = 2(V_r)/\lambda = 8$ kHz which will not cause significant shift of the incoming modulated signal when compared with 802.15.4 DSSS channel of 2 MHz, while maximum data payload of 102 bytes can be achieved [5].

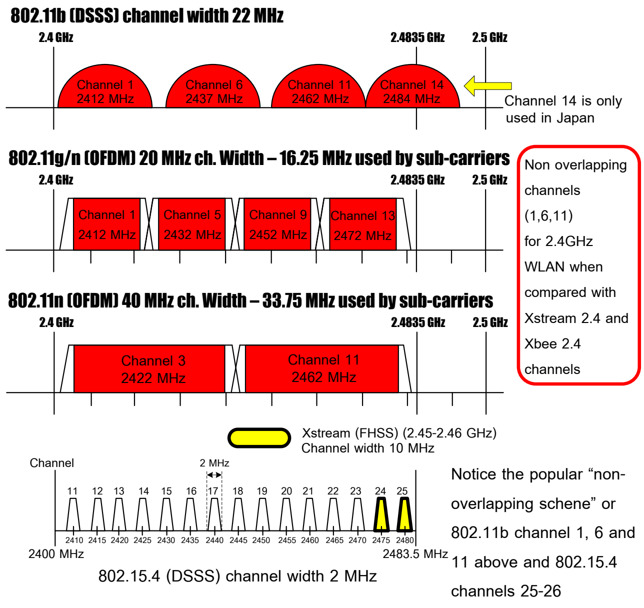

Figure 5. Comparison of 802.11b non-overlapping channels with that of XStream 2.4 and XBee 2.4 (in yellow)

The validity of using RSSI as an indication of received power can be arguable as it only represents power of the last received packet. However, as the test configuration is Point-to-Point, this should not pose much of a problem. Communication discontinuity which is the nature of this type of half-duplex transceiver will result in intermittent halting of RSSI level. Such halt only occurs in series-2 XBee, with more sophisticated routing algorithm, but is of no problem with series-1 XBee, where only simple 802.15.4 protocol is used and therefore is most suited to Point-to-Point communication. Two RSSI PWM signals can be captured into a computer to be compared directly. TABLE 3 shows some performance-related parameter among COTS candidates. XBee wireless module from Digi.com is popular for its ease-of-use, with minimal connections needed to run the module as shown in Fig.6 below.

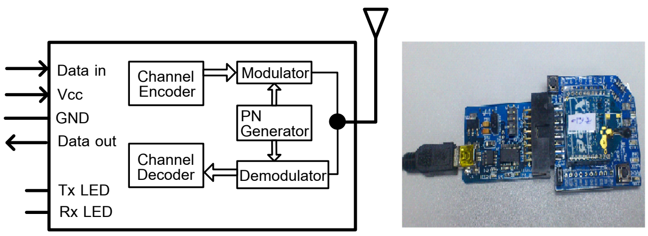

Figure 6. XBee's serial interface and simplified functional block diagram

TABLE 3. Comparison of various methods for amplitude tracking using 2.4GHz COTS equipment

COTS Equipment	Sensitivity	Dynamic Range	Data Rate	Remarks
Logarithmic Amplifier, e.g. LT5534 (50-3000MHz) ADL5513 (1-4000MHz)	-58 dBm -70 dBm	60 dB 80 dB	N/A N/A	- low sensitivity - wideband - low sensitivity - only video o/p available, not suitable for digital data reception
2.4GHz XStream RF Module	-105 dBm	PWM RSSI -35 to -105dBm	9,600 bps	- 802.15.4 protocol - FHSS - 50 mW - 10MHz bandwidth
2.4GHz XBee Pro Module [6]	-102 dBm	PWM RSSI -53 to -102dBm	9,600 bps	- 802.15.4 protocol - DSSS (8 chips/bit) - 63 mW - 2MHz bandwidth

In order to prove that the RSSI PWM signals from XBee can be acquired and that their duty cycles vary significantly with varying distance, ten sets of experiments have been made by sending, 1000 data packets, each of which is 2 Bytes in size, with non-LOS separation between the transmitter and the receiver of 1, 5, and 10m respectively.

It is found that the received RSSI PWM has a frequency, f, of 15.625 kHz (or a period, T, of 64 μs) for XBee Series 1, while the value for XBee Series 2 is 5 kHz (or a period of 200μs) respectively. The varying duty cycles for different non-LOS separations for XBee Sereies 1 is shown in Fig.7.

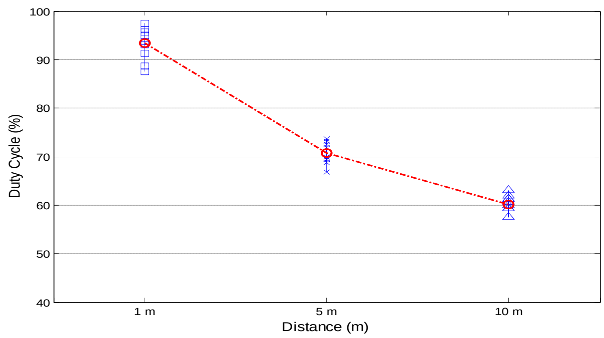

Figure 7. Average duty cycles from XBee's RSSI output pin for different non-LOS distances

3.3. Antenna Subsystem

Even though, telemetry signal is usually transmitted from an airborne wraparound antenna to a ground tracking station equipped with dual-feeder parabolic dish antenna, however in this project, a standard-gain horn antenna is transmitting signal to a pair of homemade printed-Yagi antennae.

Rectangular patch array is easy to realize on paper or FR-4 substrate and therefore is suitable for demonstration with short development time. Even though the frequency response of XBee Pro covers relatively wide impedance bandwidth

(85MHz for the 2.4GHz ISM band), printed Yagi antennae with built-in Balun and VSWR < 1.5 dB have been developed.

4. Subsystem Design and Development

Among many others, "Altium Designer" is used for PCB design, "Antenna Magus" is used for conceptual antenna design, "Tx-Line" is used for microstrip line calculation, while "ZVH-8" cable and antenna analyzer, with spectrum analyzer and vector analyzer options from R&S have been used extensively for our measurements.

4.1. Monopulse Comparator

FR-4 has been used as a substrate, the design, implementation, together with S21 responses are shown in Fig.8-9 respectively.

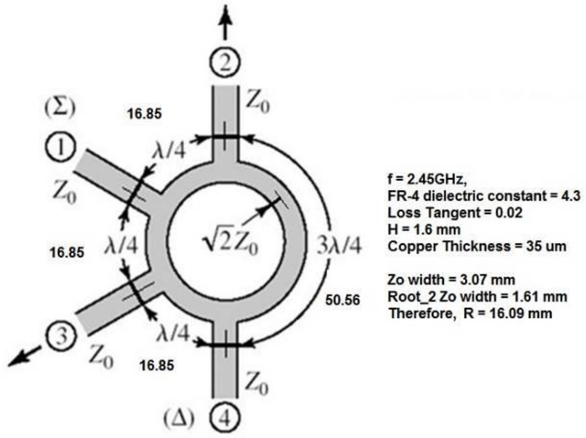

Figure 8. Calculation for the 180° Hybrid Ring

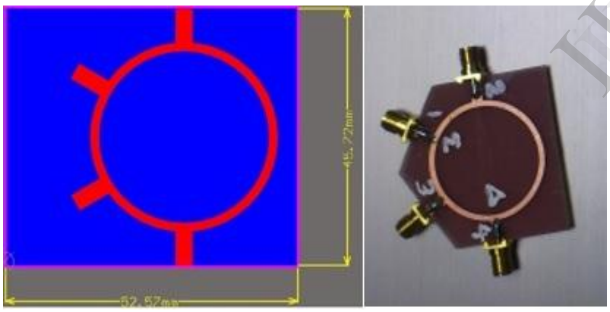

Figure 9. The 180° Hybrid Ring designed with Altium Designer

After setting the ZVH-8 in Vector Analyzer mode, a 2-way 2.4 GHz splitter/combiner connected to output port of ZVH-8 is used for testing the Hybrid Ring. When signals with equal amplitude are fed into ports 2 and 3 in Fig.8, the S21 of Δ and ∑ signals from ports 4 and 1 are noted as -29.05 dB and -5.68 dB respectively, i.e. the difference between Δ and ∑ signal at boresight of about 23.37 dB is achieved. The S21 responses are shown in Fig.10.

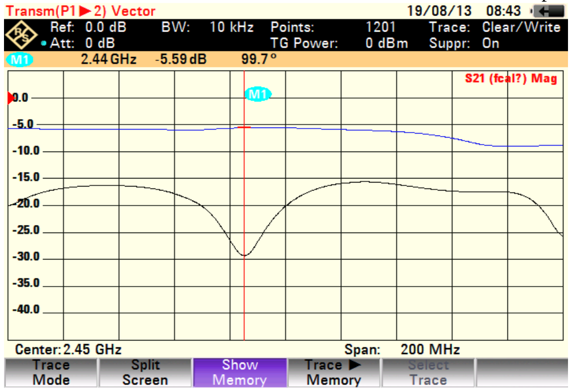

Fig. 10. Δ and ∑ S21 responses of the Hybrid Ring measured with approximately equal-gain inputs

4.2. Wideband Transceiver Module

Δ and ∑ signals in their RF forms from the Hybrid Ring are passed into the RF inputs of the two XBees. RSSI outputs from pin no.6 of each XBee are in the forms of PWM signals of varying duty cycles. Before they can be used, these RSSIs must be transformed into DC voltages by regulators and low-pass filters (designed for the incoming PWM frequency).

After setting the right baud rate for all XBees, one has to make sure both transmitting and receiving XBees are communicating in the same network by assigning them with a unique PAN ID in order to reduce possible interferences from other users nearby. In order to ensure of equal traveling time of signal from the missile to the receiving XBee modules, "Broadcasting Mode" must be used. This mode requires that the transmitting module is set as "Coordinator" and the two receiving modules are set as "End Device". "Number of Retries" also needs to be set to zero or smallest number as long as system reliability is till maintained.

4.3. Printed Yagi Antenna

Printed Yagi dipole, with built-in Balun, is made on 0.8mm FR-4 substrate with ε_r about 4.3 at 2.45 GHz. Even though, there is a shift in frequency from the designed value of 2.45 GHz to about 2.415 GHz and the lowest VSWR values are 1.89 and 2.01 respectively as shown in Fig.11, overall responses are similar and therefore would be acceptable for use as receiving antenna pair.

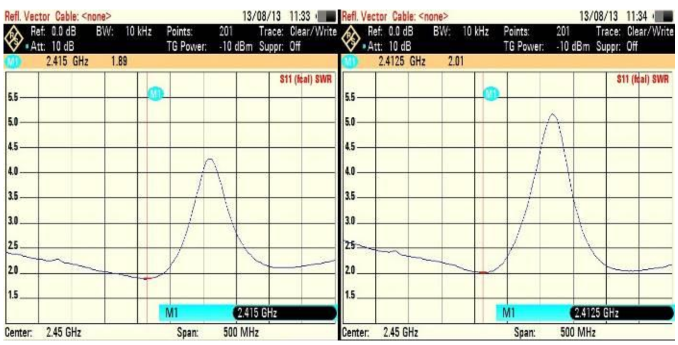

Figure 11. VSWR responses of left and right printed Yagi dipole antennae

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 9, September - 2013

Actual antennae and their response are shown in Fig.12-13. The measured gain drops from the designed value of about 8dB to about 7 dB.

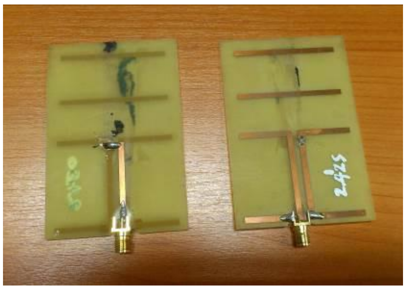

Figure 12. Actual left and right printed Yagi dipole antennae

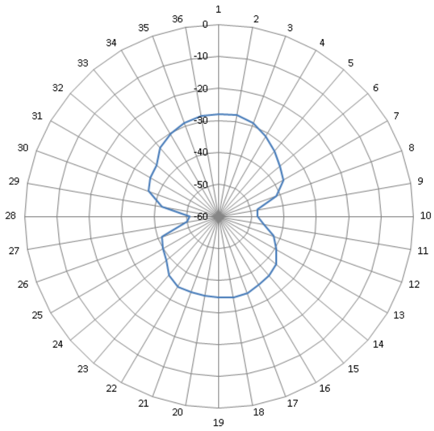

Figure 13. Radiation pattern of the printed Yagi dipole perpendicular to the plane of the antenna with about 60° -3dB beamwidth.

4.4. Error Signal Production and Stepper Motor Control

The tracking is realized using a 1.8° 6A stepping motors available in the laboratory. Such resolution is considered very good when considering that only a 60° -3dB beamwidth antenna is used. In the design, many factors have to be considered namely missile maximum speed, tracking agility and tracking frequency. As shown previously, with speed of about 1 Mach at boresight, the agility is calculated as about 5°/s. As the 1.8° stepper motor resolution is used, a number of 5.4°/s will be used instead. This implies that motor Step Rate Control of 3 steps/s is needed and this needs to be reflected in the Look-Up Table (LUT) within the microcontroller or control computer, i.e. the Monopulse error curve, especially the central region where slope of the graph are relatively linear, should be resampled every 1.8° from boresight to the left and the right. The control frequency or motor bandwidth calculated this way is not necessarily the case for a Monopulse system which tends to have large size and inertia, and as the result, the control frequency can be as low as a few Hz per second.

Different from stepper motor, deadband of a servo motor will be the factor limiting Monopulse resolution. For example, a deadband of 12μs will result in having a resolution of 12/1000x90 = 1.08° for a digital servo and 12/1000x180 = 2.16° for an analogue servo respectively.

After the Δ and ∑ RSSIs, in their DC voltage forms, are obtained from the Low-Pass filter circuit, they will be ready to be read into the computer and the rest can be done in Engineering Assisted Software. MATLAB is well recommended as it not only provides many mathematical and engineering tools for simple signal manipulation and LUT-related work, it can also perform real-time target simulation. This means that MATLAB can receive the RSSI signals, manipulate them, compare them with the values saved in the LUT, and send command signals to control the motor accordingly. The process can be depicted in Fig.14.

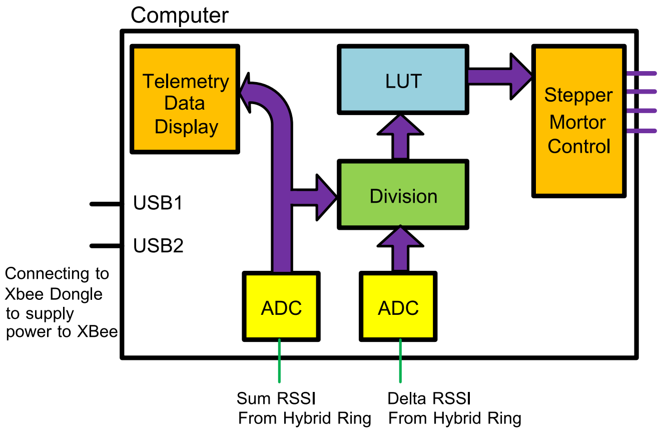

Figure 14. Monopulse signal processing performed in the computer

During performance test, a reference set of Monopulse error signals will be recorded into the LUT for later comparison with any incoming signal in order to find Direction of Arrival (DOA) of that signal and steer the antenna to that direction accordingly. As the response needs to be used as a reference, the test should be performed in an Anechoic Chamber. The target will be moved left and right from boresight while S21 of Δ and ∑ signals for different angles are recorded into the computer. These S21 values will be put into arrays after they are interpolated every 1.8°. After that, the Monopulse error signal (Δ/|∑|) will be calculated simply by dividing Δ S21 array by ∑ S21 array. The result will be put into the LUT and used as a reference during actual operation.

During tracking operation, a loss of signal may occur and needs to be considered. Such a case can be cured by ordering the motor to move to home position, or better by moving back to the last known position plus time-predictive displacement. The scheme can be shown as follows:

During normal operation;

$$\text{Position } (n+1) = \text{Position (LUT)} \qquad (2)$$

During loss of signal;

$$\text{Position } (n+1) = \text{Position } (n) + S \qquad (3)$$

The Predictive Displacement, S, can be found simply by multiplying missile velocity with the time difference as long as it is short enough or by other more sophisticated scheme.

5. SYSTEM TEST AND EVALUATION

After the spacing between LH and RH antennae is set in order to achieve ½ of -3dB squint angle, S21 magnitude and phase for both Δ and ∑ signals are measured with the test configuration as shown in Fig.15-16. Even though the far-field distance is achieved, the wall and ceiling as well as some piping are main sources of unwanted reflection which causes the non-symmetrical responses.

Figure 15. Performance test set-up

5.1. Performance Test

The performance test is carried out using Vector Analyzer function of ZVH-8. During the test, S21 of Δ and ∑ signals are recorded separately and used for Monopulse error signal (Δ/|∑|) calculation.

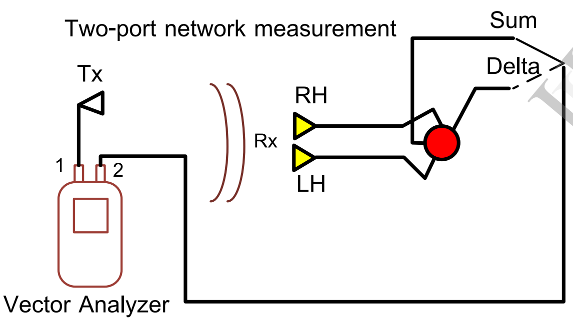

Figure 16: S21 measurement of the system using Vector Analyzer

As shown in MS Excel plots in Fig.17, both Δ and ∑ S21 must first be offset so that the Δ response is passing zero at boresight. The non-symmetrical response between the left and the right response around Y-axis is due mainly to unwanted reflections in the room. It is noted also that the whole response is not at its optimized value as the difference of gains at boresight is decreased from 20dB previously measured on the Hybrid Ring with equal-gain inputs to only 12dB due to the not-so-resemble characteristics of the antennae used.

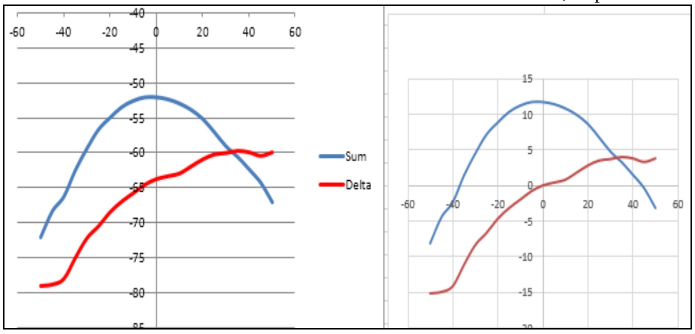

Figure 17. Original Δ and ∑ S21 (left) and offset Δ and ∑ S21 (right)

It can be observed in the Δ/|∑| plot in Fig.18 that the response is more or less linear in the central region between -30° to +30°. This reflects the -3dB beamwidth of the printed Yagi dipole. The region around the -3dB beamwidth is the most important area as most of the time the tracking antenna would be pointed to. Ultimately, the antenna will be controlled such that it follows the peak of the ∑ response all the time. In case of missile tracking, a miss of 1 second would mean a pointing error of over 300m. It can be noticed also that the slope in such area is not as steep as it should be when compared to a profession Monopulse tracking system due mainly to the low-gain broad-beamwidth characteristic of the antenna used. Therefore, for a better amplitude discrimination, a high-gain low-sidelobe antenna is recommended.

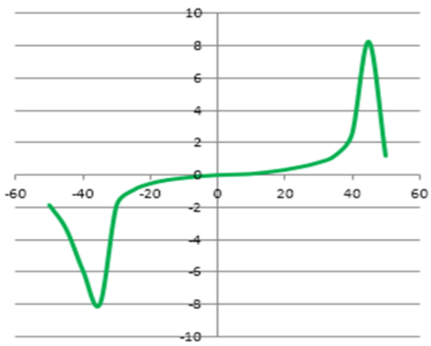

Figure 18. Monopulse error response (Δ/|∑|)

It can be seen also in Fig.18 that the error signal values are positive on the right of boresight and negative on the left. Ideally, these should be odd-symmetrical and therefore may need some boresight-offset. The central region will be resampled every 1.8m, which is the resolution of the stepper motor used in this project, and put into an LUT for comparison. The main reason why the error response has to be in the form of 'division' or 'normalized value' is that no matter how far or near the target is from the tracking antenna, the ratio should remain the same as long as the target stays at the same Angle of Arrival (AOA).

5.2. Dynamic Test

To look at the whole system during actual operation, both the transmitter and receivers will be replaced by XBee Pro modules. Although both microcontroller device and computer can well perform the processing of the signals, it is recommended that a computer running MATLAB would be an easy alternative. Most conventional Monopulse tracking system requires relatively high and fast processing power because the tracking process starts extensively right from the IF stage. By using RSSI, most processes are shorten for a great deal and therefore can well be supported by a personal computer.

A dynamic test can be performed using any moving target with the speed and antenna radiation pattern similar to actual missile operation as shown in Fig.19. For simulation of long distance, software or hardware attenuator can be used.

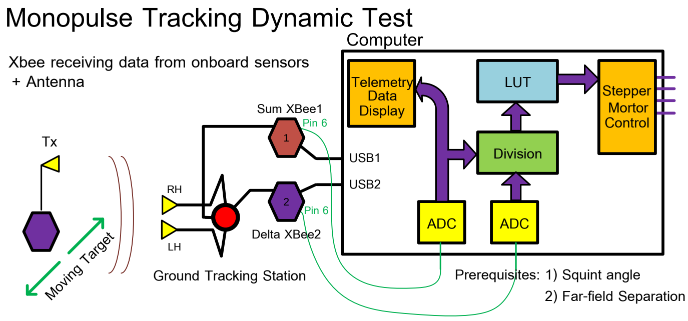

Figure 19. Monopulse dynamic test set-up

6. CONCLUSION

In this project, an overall picture of Monopulse system design process is presented, starting from the studying of CONOP, system parameter and test configuration, followed by the link budget calculation and system sizing as well as LOS and Fresnel Zone issues before any subsystem design and implementation can take place.

The use of RSSI from WPAN device such as XBee Pro is introduced, with recommendations for efficient configuration and usage. Printed Yagi dipoles, together with a Hybrid Ring coupler, are used for system demonstration. A performance test is carried out while detailed procedures for obtaining Monopulse error response is laid out. At the end, a dynamic test configuration is proposed with guidelines for interfacing the system with the antenna motor control system.

7. ACKNOWLEDGEMENT

The authors wish to thank all members of the Control and Communication Laboratory, Defence Technology Institute (Public Organization), Thailand, for their helps on this project, physically and mentally, for the whole 2013.

8. REFERENCES

[1] R.E Collin, "Hertzian dipole radiating over a lossy earth or sea: some early and late 20th- century controversies," IEEE Antennas and Propagation magazine, vol. 46, no. 2, pp. 64-79, April 2004.

[2] http://www.afar.net, "Fresnel zone clearance and antenna height calculator", Aug. 10, 2013.

[3] http://www.metageek.com, WLAN frequency scanning program – "nSSIDer" from Metageek.

[4] http://www.digi.com, Range test and XBee setup program – "X-CTU" from Digi International, Inc.

[5] Jin-Shyan Lee, Yu-Wei Su, and Chung-Chou Shen, "A comparative study of wireless protocols: Bluetooth, UWB, ZigBee, and Wi-Fi", The 33rd Annual Conference of the IEEE Industrial Electronics Society (IECON), Nov. 5-8, 2007.

[6] "XBee/XBee Pro ZB user manual", Digi International, Inc, 2012.

[7] Lorenzo Lo Monte, Russell Vela, "Rediscovering Monopulse radar with digital sum-difference beam forming", University of Dayton Research Institute, Wright-Patterson Air Force Base, OH, USA, IEE, 2012.

[8] Sridhar Kanamaluru, "Ka-band Monopulse comparator", Microwave Systems Communications Systems & Networking Sarnoff Corporation, Princeton, 2005.

[9] Henry Berger, M.I.T. Lincoln Laboratory, "On the optimum squint angles of amplitude Monopulse radar and beacon Ttacking systems", IEEE Transactions on Aerospace and Electronic Systems, 1972.

[10] David K. Barton, Sergey A. Leonov, "Radar technology encyclopedia", Artech House, Boston, London, 1997.

[11] Joseph Albert Bruder, "Method and aparatus for off-boresight angle correction for Monopulse Radars with slow AGC normalization", United States Patent, Dec. 16, 1975.

[12] Skolnik M. I., Dean D. Howard, "RADAR Handbook – Chapter 18: Tracking RADAR", McGraw-Hill, 3rd Ed, New York, 2001.