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Shaking Mechanism Dynamics for Micro-strip Array Antenna Used in Surveillance Coastal Radars

Edwar Yazid and Estiko Rijanto

Pusat Penelitian Tenaga Listrik dan Mekatronik (Puslit Telimek),
LEMBAGA ILMU PENGETAHUAN INDONESIA (LIPI),
Research Center for Electrical Power and Mechatronics,
INDONESIAN INSTITUTE OF SCIENCES,
Jl. Cisitu No.21/154D, Bandung 40135, Indonesia; email: estiko@hotmail.com.

Abstrak

Di dalam makalah ini diusulkan sebuah mekanisme baru yang disebut mekanisme penggeleng yang digunakan untuk menggerakkan antenna radar jenis micro-strip array yang dipakai pada radar pantai. Salah satu keunggulan jenis antena micro-strip array adalah memiliki masa yang ringan. Jika prinsip frekuensi-modulated continuous wave (FMCW) yang digunakan sebagai radar maka tidak mememerlukan catu daya tinggi seperti pada radar pulsa. Kombinasi penggunaan radar jenis micro-strip array dan prinsip FMCW berkontribusi pada penghematan energi. Mekanisme menggelengkan antena ke kanan dan ke kiri arah sudut horisontal yang diusulkan pada makalah ini bertujuan untuk lebih meningkatkan mutu hasil pengolahan sinyal radar. Di dalam makalah ini telah dilakukan perbandingan antara mekanisme rotasi konvensional dengan mekanisme baru yang diusulkan. Hasil analisa numerik menunjukkan bahwa mekanisme yang diusulkan dapat meningkatkan jumlah hit per siklus rotasi dan dapat meningkatkan nilai rasio S/N, tetapi dengan biaya berupa kebutuhan energi tambahan karena adanya pengaruh inersia mekanisme.

Kata kunci:Mekanisme penggeleng, antena, radar pantai, micro-strip array,FMCW, rotasi, rasio S/N.

Abstract

This paper proposes a new mechanism named shaking mechanism used for moving micro-strip array radar antenna which is used in coastal radars. One advantage of micro-strip array antenna is that it is light weight. On the other hand, by using frequency modulated continuous wave (FMCW) radar it requires lower output power than pulse radars hence avoids hardware complications which arise as a result of high power requirements. Combination between micro-strip array antenna and FMCW radar contributes to energy saving. The shaking mechanism which moves the coastal radar beam point in azimuth direction is proposed in this paper to further enhance the quality of radar signal processing. Comparison study has been conducted between the proposed mechanism and the conventional rotation mechanism. From numerical analysis results obtained in this study, it is concluded that the proposed shaking mechanism enhances number of hit per cycle and enlarges S/N ratio value at the cost of additional energy consumption due to inertia of the mechanism.

Key words: shaking mechanism, antenna, coastal radar, micro-trip array, FMCM, rotation, S/N ratio.

1.Introduction

To extract radar target information from an echo signal, the signal must first be conditioned to have sufficient magnitude to overcome the effects of interference. Radar equation is used to predict echo power and interfering power to help in making the determination of whether or not the condition is satisfied. A surveillance radar presents a special case of radar equation for two reasons, both related to its search pattern. It has a limited time-on-target (T_{OT} -the time for each scan that a particular target is within the beam of the antenna), and it does not point the peak gain of the antenna at targets for all hits in a look.

A surveillance radar must scan rapidly to cover their assigned scan area in as short a time as possible. Also, short scan time reduces the radar target maneuvering possible between scans and help maintain more accurate target position report. However, it must scan slowly enough so that the required number of hits is received from within the antenna's beam width.

Radar equation for a surveillance radar is unique primarily because of the need to use antenna scan rate, beam width, and PRF to account for the antenna scan loss and the required integration number. In a system where the signal processor determines integration number (all digital signal processors), the scan rate can be set so that the number of pulses transmitted as the antenna beam scans past a given point matches the integration number in the signal processor.

The time-on-target T_{OT} is the time the antenna beam requires to scan one antenna beam width. Another parameter is data gathering time (T_d), also known as dwell time (T_d), integration time T_I , and look time T_L . If the beam width, scan rate, PRF, and signal processing match one another, T_{OT} and T_d are equal. If the scan and integration parameters match the following holds [1]

$$T_d = T_{OT} = \frac{\theta_{3(Az)}}{\omega} \quad (1)$$

where $\theta_{3(Az)}$ is the 3 dB azimuth beam width of the antenna [degree], and ω is the antenna scan rate [degree/second]. More over, the signal-to-noise ratio (S/N) for the surveillance radar is proportional to the 3 dB azimuth beam width as well as PRF and proportional to the inverse of the scan rate [2].

$$S/N \approx \frac{\theta_{3(Az)} \cdot PRF}{\omega} \quad (2)$$

Continuous Wave (CW) and Frequency Modulated Continuous Wave (FMCW) radars presents an entirely different problem regarding the prediction of signal-to-interference and maximum detection/tracking ranges than do pulsed radars. The primary difference is that, while in pulse radars, receiver noise is the ultimate limiting interference, in CW and FMCW radars, the ultimate limiting interference is usually contamination of the receiver input by the transmitter which is called spillover.

If a CW or FMCW radar has sufficient isolation between transmitter and receiver and sufficient transmit stability, noise again becomes limiting, and the system can be treated much the same as if it was a pulsed radar. The signal-to-noise (S/N) ratio for a CW or FMCW radar limited by receiver noise is proportional to the look (dwell) time T_L [1].

$$T_L = \frac{N_L}{f_S} \quad (3)$$

where N_L is the number of samples in a dwell, and f_S is the sample frequency [Hz].

Applications like coastal management and ship guidance required increased data density compared to single point measurements with current meters and wave bouys. Remote sensing techniques also have the advantage of no need to install a mooring in the open sea, which can be damaged by bad weather conditions or ships passing too near. High frequency radars at 25 MHz to 30 MHz have been used as coastal radars with ground-wave propagation [3].

Mechanical technology plays important role in radar technology development. One example which demonstrates the significance of mechanical technology development can be found in the paper entitled Mechanical Technology Development on a 35-m Deployable Radar Antenna for Monitoring Hurricanes [4].

In order to solve the trade off between the S/N ratio specification and maneuvering target position detection accuracy specification, in this paper a new antenna rotating mechanism named shaking mechanism is proposed. The shaking mechanism is considered to be feasible since it is used to move a micro-strip array antenna which is usually light in weight. This new mechanism provides an advantage where it is applied to a surveillance coastal radar since the radar needs only to scan the area in the sea direction.

2. Antenna Shaking Mechanism

Figure 1 shows an illustration of the micro-strip array antenna used in a surveillance coastal radar. Radar antenna has several functions including: 1) act as a transducer and impedance match between the transmitter and the propagation medium, and between the medium and the receiver, 2) provide gain to concentrate the transmitted signal in a preferred direction, 3) steer the transmitted power to the desired angular position, and 4) provide for effective reception over a small angular direction only and to move the response to the desired direction (steer the received beam).

In a conventional surveillance coastal radar, the antenna is rotated in a certain angular velocity. An example of antenna used for a coastal radar has horizontal beam width of 1.2^o , and rotational speed for 20 to 40 rpm [5].

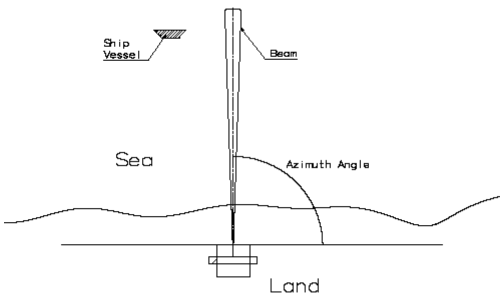

Figure 1. Surveillance Coastal Radar Using Micro-strip Array Antenna.

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Figure 2 shows an illustration of the structure of the antenna. In a conventional rotation antenna, external forces affecting on the mechanical structure of the antenna may come from wind force, rain fall and storm. When a shaking mechanism is used, additional force which arises from the actuator force also affects on the mechanical structure. To maintain a stable radar beam under external and internal forces, strength and rigidity of the mechanical construction should be taken into consideration.

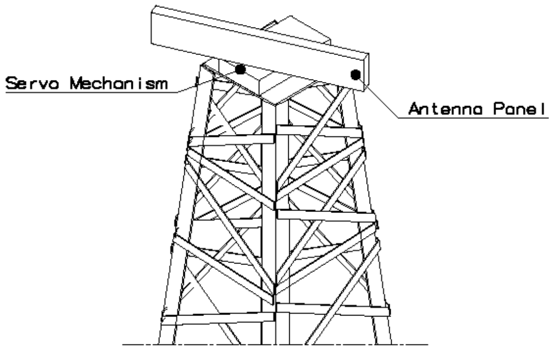

Figure 2. Illustration of the Antenna Structure.

Figure 3 shows the illustration of the shaking mechanism proposed in this study. It is basically constructed of two subsystems those are: four-bar mechanism and reduction gear. Its function is to convert rotational movement generated by electrical motor into shaking movement of the antenna between 0 [Degree] to 180 [Degree].

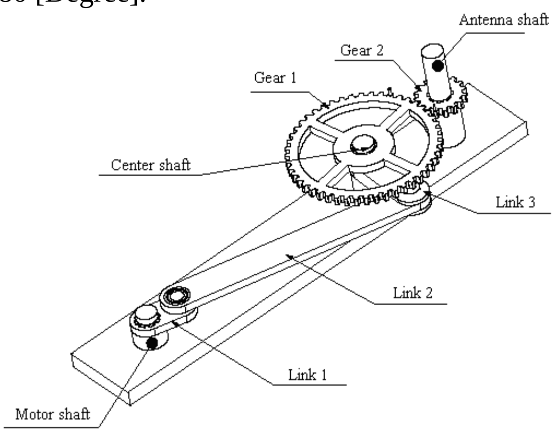

Figure 3. Shaking Mechanism for Micro-strip Array Antenna Used in a Surveillance Coastal Radar.

Loop-closure equations of the shaking mechanism have been derived as shown in the following equations.

$$\left.\begin{aligned}\theta_4 &= \tan^{-1}(y_3, x_3) \pm \cos^{-1}((x_3^2 + y_3^2 \\ &\quad + r_2^2 - r_1^2)/2 \cdot r_2 \cdot \sqrt{(x_3^2 + y_3^2)}) \\ \theta_3 &= \tan^{-1}((y_3 - r_2 \cdot \sin(\theta_4))/r_1, \\ &\quad (x_3 - r_2 \cdot \cos(\theta_4))/r_1)\end{aligned}\right\} \quad (4)$$

$$\left.\begin{aligned}\omega_3 &= -\omega_2 \cdot r_2 \cdot \sin(\theta_4 - \theta_2)/(r_3 \cdot \sin(\theta_4 - \theta_3)) \\ \omega_4 &= \omega_2 \cdot r_2 \cdot \sin(\theta_3 - \theta_2)/(r_4 \cdot \sin(\theta_3 - \theta_4))\end{aligned}\right\} \quad (5)$$

$$\left.\begin{aligned}\alpha_3 &= (-r_2 \cdot \alpha_2 \cdot \sin(\theta_4 - \theta_2) + r_2 \cdot \omega_2^2 \cdot \\ &\quad \cos(\theta_4 - \theta_2) + r_3 \cdot \omega_3^2 \cdot \cos(\theta_4 - \theta_3) - r_4 \cdot \\ &\quad \omega_4^2)/r_3 \cdot \sin(\theta_4 - \theta_3) \\ \alpha_4 &= (r_2 \cdot \alpha_2 \cdot \sin(\theta_3 - \theta_2) - r_2 \cdot \omega_2^2 \cdot \cos(\theta_3 - \theta_2) + \\ &\quad r_4 \cdot \omega_4^2 \cdot \cos(\theta_3 - \theta_4) - r_3 \cdot \omega_3^2)/r_4 \cdot \sin(\theta_3 - \theta_4)\end{aligned}\right\} \quad (6)$$

where: $\theta_{2,3,4}$ represents angular position of link 2 ,3 and 4, respectively. $\omega_{2,3,4}$ represents angular velocity of link 2 ,3 and 4. $\alpha_{2,3,4}$ denotes angular acceleration of link 2 ,3 and 4, and $r_{1,2,3,4}$ is the length of each link.

Rotational angle, angular velocity and angular acceleration have been calculated by solving the loop-closure equations of the shaking mechanism [6]. Figure 4, figure 5, and figure 6 show these results.

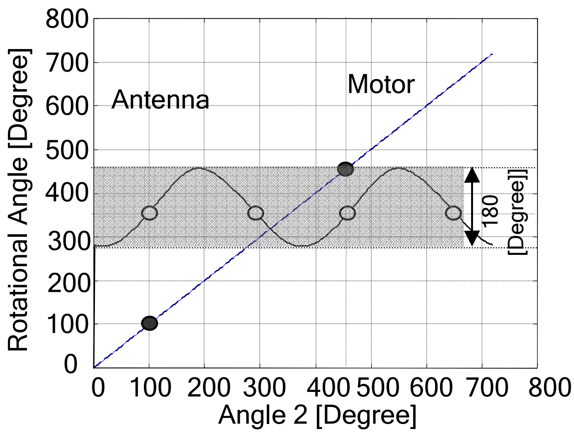

Figure 4. Rotational Angle.

Figure 4 shows rotational angle of the electrical motor and the antenna. Horizontal axis is rotational angle of the electrical motor (Angle 2) and vertical axis expresses rotational angle of the electrical motor and of the antenna. In this figure, the electrical motor rotates at a constant angular velocity of 40 rpm in 2 cycles which equivalent to 0 [Degree] to 720 [Degree].

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The pattern of the rotational angle of the electrical motor represents the rotation pattern of conventional rotating antenna. It is obvious that in the conventional rotating antenna mechanism, the antenna only scans once every cycle of rotation which in the figure is labeled with dotted cycle. On the other hand, the proposed shaking mechanism moves the antenna in sinusoidal-like pattern along the span of 0 to 180 [Degree]. It can be seen that except the azimuth angle of 0 [Degree] and 180 [Degree], the position in this span is scanned twice in every cycle of rotation which is labeled with hollow cycle in the figure. In other words, the proposed mechanism increases number of hits per rotation cycle. This enables the signal processing unit of the antenna to increase accuracy of the maneuvering target position detection.

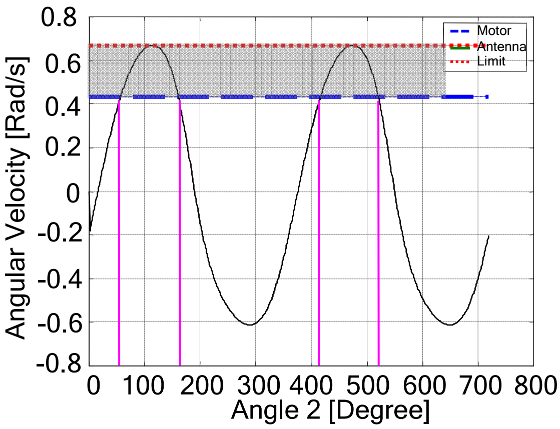

Figure 5. Angular Velocity.

In figure 5, the horizontal axis expresses the rotational angle of the electrical motor (angle 2), and the vertical axis expresses the angular velocity of the electrical motor and the antenna. The electrical motor is moved at constant angular velocity, and as a result the antenna angular velocity pattern resembles sinusoidal. The antenna starts moving from stationary at azimuth angle of 0 [Degree], experiences acceleration to the maximum angular velocity at azimuth angle of 90 [Degree], then decelerates and stops moving at azimuth angle of 180 [Degree], and then followed by the same pattern of movement in the opposite direction. In order to make the maximum angular velocity of the antenna equals to 40 rpm the electrical motor is rotated at 26 rpm.

Since the S/N ratio is proportional to the inverse of the angular velocity of the antenna, it is clear from figure 5 that the proposed shaking mechanism provides 2 zones of S/N ratio performance. The proposed shaking mechanism provides better S/N ratio than the conventional rotating antenna in the zone where the angular velocity of the antenna is less than 26 rpm. Conversely, the proposed shaking mechanism provides worse S/N ratio value than the conventional rotating antenna in the zone where the angular velocity of the antenna is larger than 26 rpm.

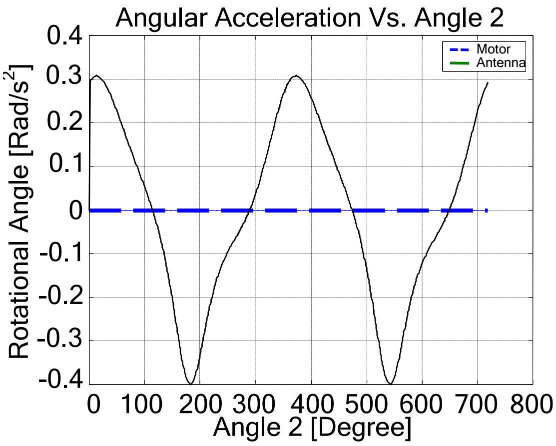

Figure 6. Angular Acceleration.

Figure 6 shows the angular acceleration. The horizontal axis expresses the rotational angel of the electrical motor (angle 2) and the vertical axis expresses the angular acceleration of the electrical motor and the antenna. Since the electrical motor is controlled to move at constant velocity its angular acceleration equals to zero. The angular velocity of the antenna in the proposed shaking mechanism is not always zero. This implies that in the conventional rotating antenna only electrical energy is needed to maintain constant angular velocity, while in the proposed shaking mechanism additional electrical energy is required to compensate inertia energy of the antenna.

3. Analysis of Energy Consumption.

In order to analyze energy consumption of the proposed mechanism, equations of motion have been derived using Recursive Newton Euler approach based on the following general expression.

$$\tau = M(\theta)\,\ddot{\theta} + C(\theta, \dot{\theta})\ddot{\theta} + F(\ddot{\theta}) + G(\theta) \qquad (7)$$

where

θ : the vector of generalized joint coordinates describing the pose of the manipulator,

$\dot{\theta}$: the vector of joint velocities,

$\ddot{\theta}$: the vector of joint accelerations,

M : the symmetric joint-space inertia matrix, or inertia tensor,

C : describes Coriolis and centripetal effect,

F : describes viscous and Coulomb friction,

G : the gravity loading is the vector of generalized forces associated with the generalized coordinates θ.

Mechanical power consumed during operation of the shaking mechanism of the radar antenna was calculated and the results are plotted in figure 7.

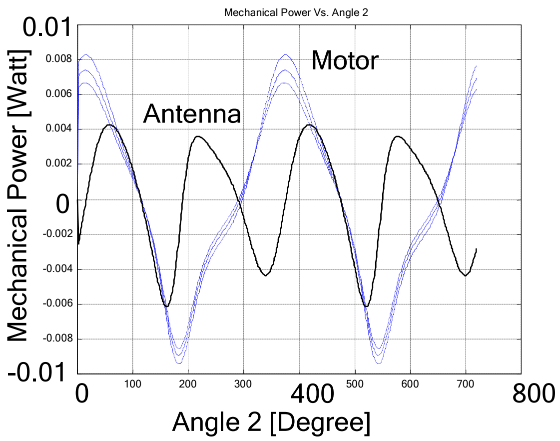

Figure 7. Mechanical Power.

Horizontal axis expresses the rotational angle of the electrical motor (angle 2) and the vertical axis is the mechanical power consumed. The solid line is the mechanical power consumed by the antenna and the broken lines are the mechanical power consumed by the electrical motor. In this figure, mass of each element of the control mechanism between the electrical motor and the antenna has been changed in 3 variations. As the consequence, in order to realize the same movement of the antenna three different amount of energy is required by the electrical motor. The variation of the mass of each element of the control mechanism is 100%, 50%, and 10%. In this paper the following energy efficiency η_E is defined.

$$\eta_E = \frac{Antenna\ energy}{Motor\ energy} x100\% \qquad (8)$$

From these results it has been obtained that the energy efficiency is 61% for mass of 100%, the energy efficiency is 67% for mass of 50%, and the energy efficiency is 72% for mass of 10%. Thus, the lighter the weight of the component the higher the energy efficiency.

4. Conclusions and Discussions

From the results obtained in this study, the following conclusions can be drawn:

1) The proposed shaking mechanism increases number of hit per cycle, thus increases the maneuvering target position detection accuracy.
2) The shaking mechanism provides better S/N ratio than the conventional rotating antenna where the angular velocity is less than 26 rpm and it provides worse S/N ratio than the conventional rotating antenna where the angular velocity is higher than 26 rpm.
3) The shaking mechanism requires additional energy supply to realize the antenna movement due to inertia energy consumption.
4) The energy efficiency of the proposed mechanism can be enlarged by using light weight component of the shaking mechanism compared to the mass of the antenna.

Acknowledgment

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References

[1] Byron Edde, ”RADAR: Principles, Technology, Applications”, Prentice Hall Inc., New Jersey, 1993.

[2] IEEE Standard Radar Definition, Institute of Electrical and Electronics Engineers Standard 686-1982, New York, 1982.

[3] K.W.Gurgel, H.H.Essen, and T.Schlick, ”Application of Coastal Radars for Monitoring the Coastal Zone”, Euromar Workshop’99, 1999.

ISBN.9-793-68869-6

[4] Houfei Fang and Eastwood Im, "Mechanical Technology Development on a 35-m Deployable Radar Antenna for Monitoring Hurricanes", Earth Science Technology Conference 2006, June 28th, 2006.

[5] Masbah RT.Siregar, et.al., "Development of Coastal Surveillance Radar in a Radar Network", Proposal for a Cooperative Research Project, Indonesian Institute of Sciences and Delf University of Technology, 2006.

[6] A.R.Holowenko and Cendy Prapto, "Dinamika Permesinan", Penerbit Erlangga, 1992.