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Adaptive Side lobe Jamming Cancellation for Low altitude radar

Habib Rezaei, Mohsen Mivehchy, Saied Ali Hashemi

Abstract*— Side lobe jamming technique is a safe method that prevents detection of interference source. Side lobe cancellation can be efficiently employed to reduce the effects of jammers on radar systems through antenna side lobes. The feedback control method doesn't require any components with a high dynamic range for reduction of side lobes, which is suitable for analogous processing. The feedback control enables us to reducing the side lobes interference up to 40dB. In this method, by comparing the main receiver signal with the side receiver signal, Phase and power difference between the signals can be determined. Side receiver signal is collected by a weighting factor whit main receiver signal, to cancel the side lobes interference.

***Index Terms*—Radar, Side lobes cancellation, Jamming, ECCM.**

I. INTRODUCTION

Today's radar systems are powerful in battlefield, therefore during the war, disrupting the radar systems is an important goal. Side lobe jamming technique is a safe method that prevents detection of interference source, and can be influence the radar performance in wide angle. The radar antenna pattern has side lobes in addition to the main lobe, which have lower gain and different propagation direction than the main lobe. In designing antenna, whenever it is possible, the side lobes number and pattern power have to be reduced. Side lobe canceller system, reduces radar side lobe effect by auxiliary antennas in addition to the main antenna. The radars usually have one or more auxiliary antenna, which are aligned with the main antenna. The width of the main lobe of the auxiliary antenna is bigger than the whole radiation area of each of main radar antenna side lobes. This antenna main lobe gain is more than any main antenna side lobes. Every signal which is received by the side lobes of main antenna is received with the further gain by the auxiliary antenna. Side lobe canceller system can be efficiently employed to reduce the effects of jammers on a radar system through antenna side lobes. When comparing the main receiver power with the side receiver's power, if the side receiver's power is more than the main receiver's, then signal has been received by the side lobes.

II. FEEDBAK CONTROL METHOD FOR SIDE LOBE CANCELLATION

The purpose of SLC is reducing the interfering signal from radar's main receiver, and the real target signal remains intact. In this method the power difference between the side and main receiver is determined and with multiplying the main receiver signals at I and Q signals (Quadrature) of side receiver, the phase difference between the main signal and side I and Q signals are extracted. With a weight ratio the two side receiver signals, I and Q are gathered and produce a signal which has the same power and phase as the main interfering signal. By subtracting generated signal from the main receiver, the interference signal is removed from main signal, and only the target signal remains in the main receiver. The block diagram of this method is shown in Figure.1.

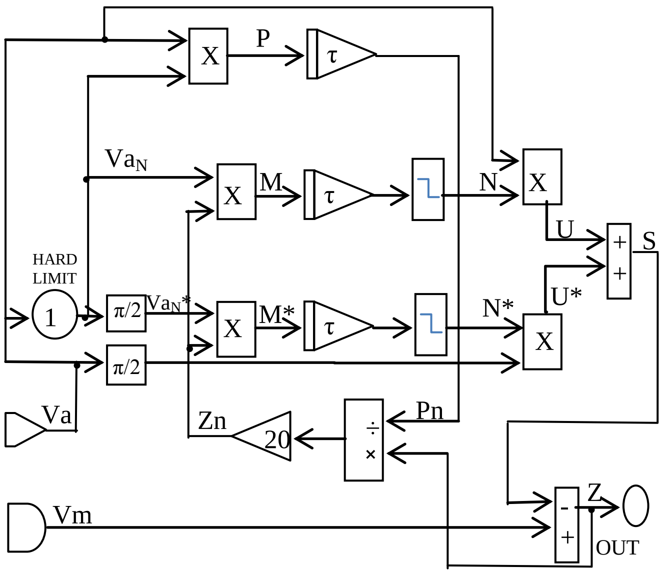

Fig 1. SLC block diagram

If side receiver signal is given by *Va*, then *Va* can be represented by(1):

$$Va = BCos(\omega_J t + \varphi) \quad (1)$$

B=Jamming signal amplitude coefficient at side receiver
ω_J =Jamming frequency

Side receiver signal is hard limited for attenuation amplitude variations in the side receiver signal. By placing a LPF after this system, the high frequency component is removed and amplitude of the output signal is fixed. The remained signal is Va_N ,The amount is by (2) equal to:

$$Va_N = Cos(\omega_J t + \varphi) \quad (2)$$

P obtained from multiplying the side receiver signal and side limited signal.[2] (Side receiver signal power can be extracted by Log Amp chips.)

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$$P = Va_N \times Va$$
$$= BCos(\omega_J t + \varphi)^2 \Rightarrow \quad (3)$$
$$P = B\frac{[1 + Cos2(\omega_J t + \varphi)]}{2}$$

If a low-pass filter is placed at the output *P*, the high frequency component is filtered and the remaining amount is the side receiver voltage amplitude. According to (4) the amount of *Pn* is:

$$Pn \cong \frac{B}{2} \quad (4)$$

If the target signal is accompanying the interfering signal in the main receiver and coefficient of the target signal amplitude is equal *H*; then the main receiver signal can be shown by (5):

$$Vm = A\cos(\omega_J t) + HCos(\omega_J + \omega_S)t \quad (5)$$

A=Jamming signal amplitude
ω_S=frequency difference between jamming and target signal in figure.1. *Z* is the output of SLC system, which the interfering signal is canceled.

$$Z = \frac{A}{D}\cos(\omega_J t) + \frac{H}{K}Cos(\omega_J + \omega_S)t \quad (6)$$

D= interference signal attenuation
K=target signal attenuation

Zn is the normalized output Z which is amplified by factor 20and normalized by Pn. Z_N value according to (7) is:

$$Z_N = \frac{Z \times 20}{Pn}$$
$$= \frac{40A}{B \times D}\cos(\omega_J t) + \frac{40H}{B \times K}Cos(\omega_J + \omega_S)t \quad (7)$$

If Z_N and Va_N have equal frequency and φ phase difference, multiplied to each other, the output value is a function of the phase difference between two signals and Z_N signal power. *M* is the phase difference between Z_N and Va_N. M value according to (8) is:

$$M = Z_N \times Va_N =$$
$$= \frac{40A}{B \times D}\cos(\omega_J t + \varphi) \times \cos(\omega_J t) +$$
$$\frac{40H}{B \times K}\cos(\omega_J t + \varphi)Cos(\omega_J + \omega_S)t = \quad (8)$$
$$\frac{20A}{BD}\left(\cos\varphi + \cos(2\omega_J t + \varphi)\right) +$$
$$\frac{20H}{BK}\left(\cos(\omega_S - \varphi) + \cos((2\omega_J + \omega_S)t + \varphi)\right)$$

If *M* filtered by a LPF, High frequency components are removed, and low frequency signal is remained. That shown by N.

$$N \cong \frac{20A}{BD}\cos\varphi \quad (9)$$

*M** is the value of Z_N signal multiplied by $\frac{\pi}{2}$ shifted Va_N. The value of M * is given by (10):

$$M^* = Z_N \times Va^* =$$
$$= \frac{40A}{B \times D}Sin(\omega_J t + \varphi) \times \cos(\omega_J t) +$$
$$\frac{40H}{B \times K}Sin(\omega_J t + \varphi)Cos(\omega_J + \omega_S)t = \quad (10)$$
$$\frac{20A}{BD}\left(Sin\varphi + Sin(2\omega_J t + \varphi)\right) +$$
$$\frac{20H}{BK}\left(Sin(\omega_S t - \varphi) + Sin((2\omega_J + \omega_S)t + \varphi)\right)$$

If *M** filtered by a LPF, high frequency components are removed, and low frequency signal is remained. That shown by N*.

$$N^* \cong \frac{20A}{BD}Sin\varphi \quad (11)$$

A limiter, limits the output of the *N* and ***N**** between [-1.1]. This limiter will prevent the reduction of the target signal in the absence of interference. *U* is the product of multiplying phase difference signals (*N*) by side receiver signal (*Va*). The value of *U* is given by (12):

$$U = Va \times N = \frac{20A}{D}\cos(\omega_J t + \varphi) \times Cos\varphi \quad (12)$$

*U** is the product of phase signal difference (*N**) by $\frac{\pi}{2}$ shifted side signal (*Va**). The value of U* is given by (13):

$$U^* = Va^* \times N^* = \frac{20A}{D}Sin(\omega_J t + \varphi) \times Sin\varphi \quad (13)$$

The sum of *U* and *U** signals are shown in figure.1 by S, and it is generated by SLC system in order to cancell the interference from main receiver's signal. In Figure 2 it is shown how to sum I and Q signals. The value of *S* is given by equation 14:[7]

$$S = U + U^* =$$
$$\frac{10A}{D}\begin{bmatrix}\left(\cos(\omega_J t + \varphi - \varphi) + Cos(\omega_J t + \varphi + \varphi)\right) + \\ \left(\cos(\omega_J t + \varphi - \varphi) - Cos(\omega_J t + \varphi + \varphi)\right)\end{bmatrix} \quad (14)$$
$$\frac{20A}{D}Cos\omega_J t \Rightarrow S = \frac{20A}{D}Cos\omega_J t$$

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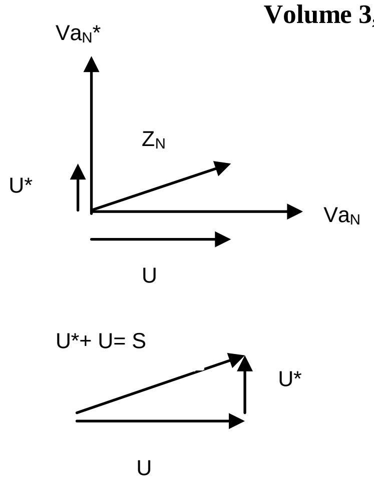

Fig 2. How to sum I and Q signals

If S signal subtracted from the main receiver signal (Va), then SLC output(Z) is generated.

$$Z = Vm - S \Rightarrow Z =$$

$$= \frac{AD - 20A}{D} Cos\omega_J t + HCos(\omega_J + \omega_S)t$$

$$Z = \frac{A}{D}\cos(\omega_J t) + \frac{H}{K}Cos(\omega_J + \omega_S)t$$

$$\frac{A}{D}\cos(\omega_J t) + \frac{H}{K}Cos(\omega_J + \omega_S)t = \frac{AD - 20A}{D} Cos\omega_J t + HCos(\omega_J + \omega_S)t \quad (15)$$

$$\frac{21A - AD}{D} = 0 \Rightarrow$$

$$D = 21 \quad \& \quad \frac{H}{K} - H = 0 \Rightarrow K = 1$$

$$\rightarrow Z = \frac{A}{21}\cos(\omega_J t) + HCos(\omega_J + \omega_S)t$$

According to equation 15, the interference signal is attenuated by factor 21 and target signal remains unchanged. This SLC system is designed for ICWAR (HAWK) radar in order to reduce side lobe interface. ICWAR radar is a low altitude radar system with heavy reflective clutter cause the SLC system which does not detect interference signal, so using a crystal notch filter to remove reflective clutter.

III. SIMULATED SIGNALS

Side antenna has wide beam, so the interference signal at the side receiver will be received long time. By using MATLAB Simulink, interference signal at the side receiver is shown in Figure 3. In the main receiver, the target signal is only presents in the main lobe of the antenna, however, the interference signal in addition to antenna main lobe is present in the antenna side lobes. The signals of radar's main receiver in MATLAB Simulink are shown in Figure4, and the implementation system in laboratory is shown in Figure5. (frequency difference of interference signal and target signal is 5KHz)

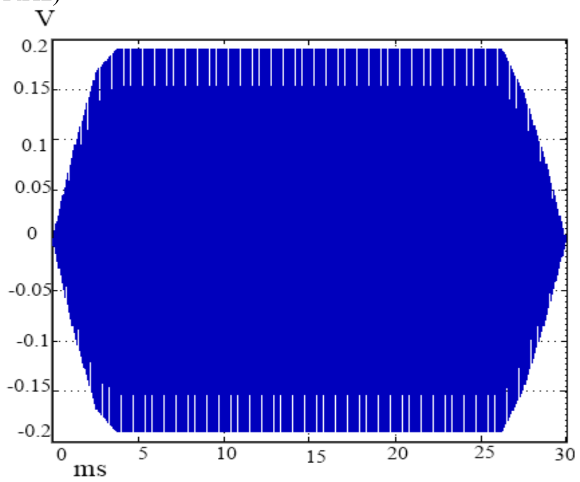

Fig 3. The interference signal at the side receiver in MATLAB Simulink

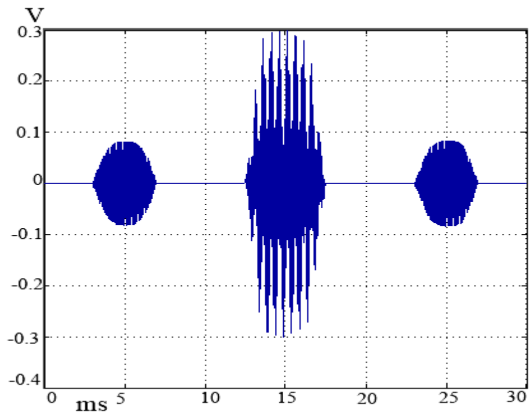

Fig 4. The signals of radar's main receiver in MATLAB Simulink Software

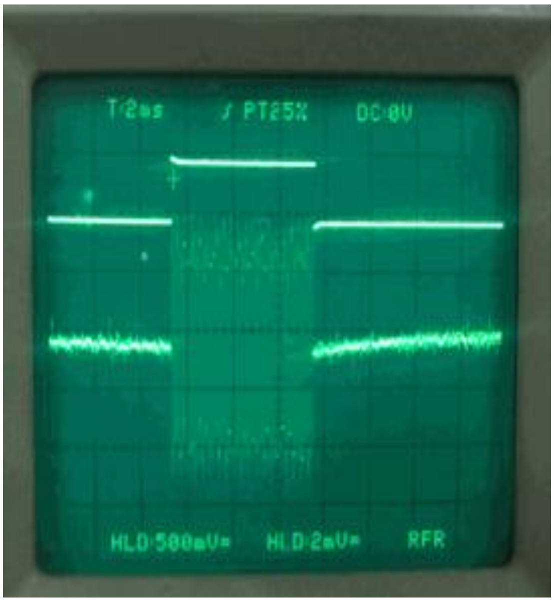

Fig 5. Generated signals for radar's main receiver in laboratory

In figure6, the generated signals for radar's main receiver in laboratory are displayed on a spectrum analyzer. (Interference signal power is -32dBm and target signal power is -72dBm)

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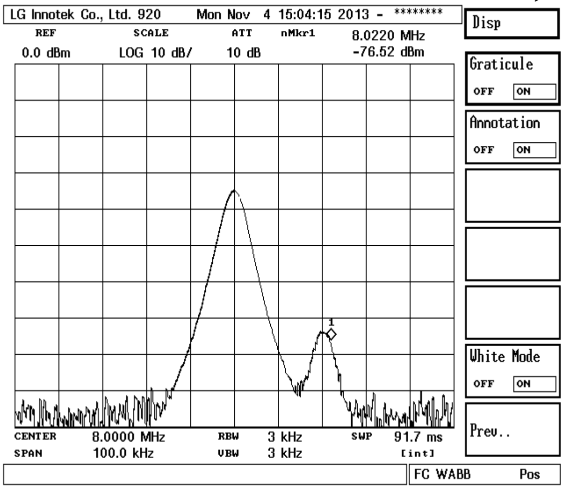

Fig 6. Generated signals for radar's main receiver in laboratory on a spectrum analyzer

The final output signal of the SLC system in MATLAB Simulink is shown in Figure7 and implementation system in laboratory is shown in Figure8.

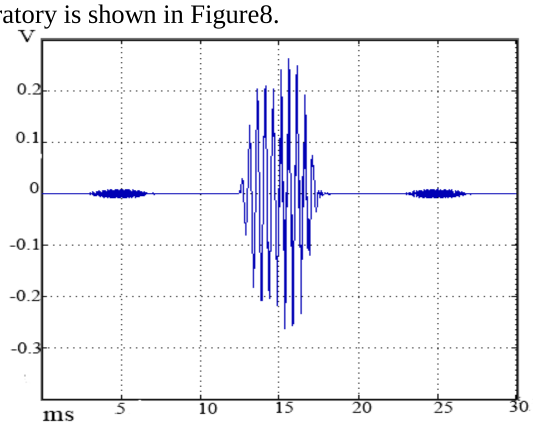

Fig 7. Final output of the SLC system in MATLAB Simulink

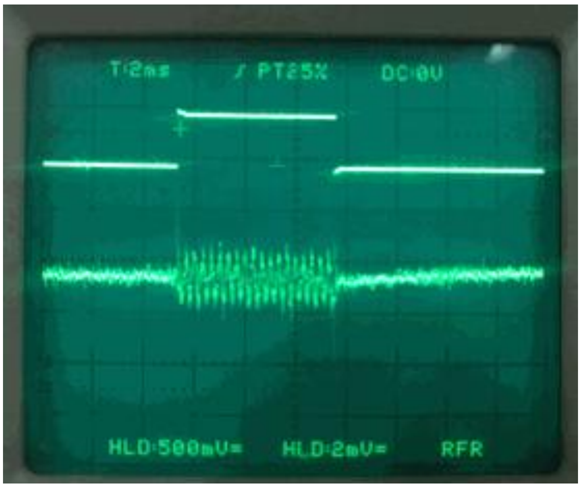

Fig 8. Final output of the SLC system in laboratory

In Figure 9, the final output of the SLC system is displayed on a spectrum analyzer. The target power is unchanged, but the Interference signal is around 40dB attenuated.

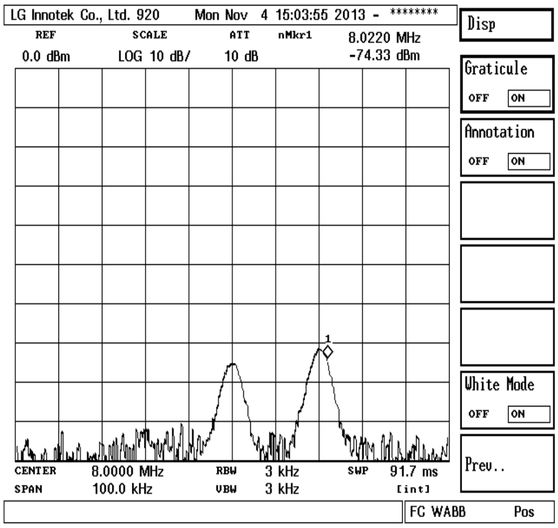

Fig 9. Final output of the SLC system on a spectrum analyzer

IV. THE MEASURED RESULTS

The radar's main and auxiliary antenna gains are 37dB and 20dB respectively. In table.1 (main power) is the power of interfering signal with a frequency of 8/000MHz in the input of the main receiver, In this test, a target with power of -80dBm and frequency of 8/005MHz was made, which remains unchanged in the output.

Mnia receiver power[dBm]	SLC_{out} Side power =main power[dBm]	SLC_{out} Side power+6dB = Mnia power[dBm]	SLC_{out} Sidepower+ 20dB= Mnia power[dBm]
-15	-34	-36	-16
-18	-39	-42	-18
-21	-45	-47	-22
-24	-51	-53	-24
-27	-57	-57	-27
-30	-64	-63	-31
-33	-69	-67	-33.5
-36	-73	-67	-36.5
-39	-76	-68	-40
-42	-76	-69	-44
-45	-76	-69	-47
-48	-76	-70	-50
-51	-76	-70	-53
-54	-76	-71	-56
-57	-76	-72	-59
-60	-76	-72	-62
-63	-76	-73	-64.5
-66	-77	-74	-67
-69	-78	-75	-69
-71	-79	-76	-71
-74	-80	-78	-74
-77	-81	-80	-77
-80	-83	-82	-80

TABLE I SLC OUTPUT POWERS FOR DIFFERENT INPUT JAMMING (JAMMER)

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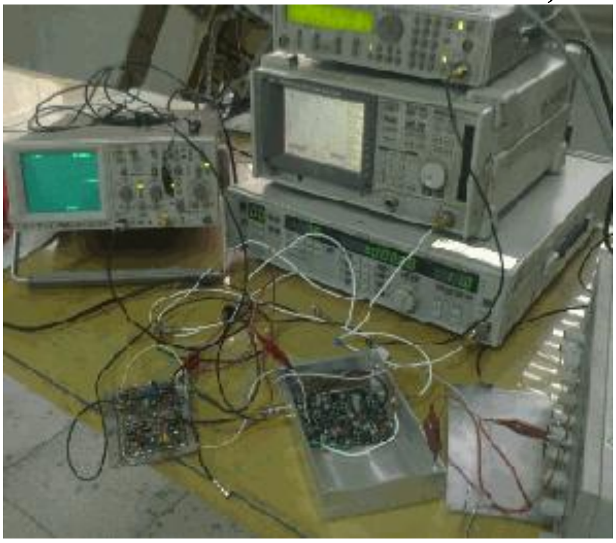

Fig 9. Test equipment

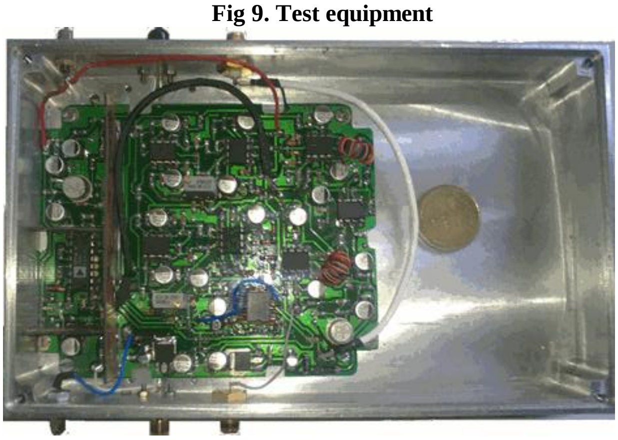

Fig 10. Implementation SLC system

V. CONCLUSION

Since the closed-loop method does not require any components with high dynamic range, therefore, it is more suitable to cancel side lobes by analog processing. Using closed loop method enables removing jamming signal to IF or RF stage and preventing jamming signals impact on receiver circuits. SLC system reduces unrealistic targets and the real target signal remains intact. For removing more number of interferences, requires more number of axillary antennas and side lobe canceller loops.

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AUTHOR'S PROFILE

HabibRezaei was born in Khoy, Iran, on April 17, 1985. He received the B.S. degree in telecommunications engineering from Iran Air Force University in 2006 and received Master degree in telecommunications engineering from majlesi Azad University in 2014. He Start up working in 2006 in radar center of Esfahan University. He worked in HAWK radars (ICWAR, HPI). He was involved with the design of RF and IF circuit for radar receiver system.

Mohsen Mivehchy was born in Iran in the year 1960. He received the B.Sc. in electronic engineering from Isfahan University of Technology (IUT) in 1986.The M.Sc. in communication engineering from IUT in 1990 and the P.H.D from Isfahan University in 2010. In September 1990 he joined the faculty of Isfahan University of Technology (IUT). Since 2010 he has been an assistant professor of electrical engineering department in Isfahan University. His field of interest includes high frequency circuits and radar systems.

Saied Ali Hashemi was born in Iran in the year 1968. He received the B.Sc. in communication engineering from Sharif University of Technology in 1990.The M.Sc. in communication engineering from Sharif University of Technology in 1994 and the P.H.D from Azad University in 2007. Since 2007 he has been an assistant professor of communication engineering department in Azad University.