Detect Phase Shifter Module of Array Antenna Using The Sun

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***Abstract*—The Sun is an emission source which has a wide spectrum and high-energy flow, it can be used as a calibration source; The phase shifter module is the minimum detection unit of the phase array antenna, the paper propose two evaluation parameters, which by receiving the energy of the solar radio, then compare the receiving power of each channel, that can get the two evaluation parameters, those two parameters shows the performance of each phase shifter module; Finally, verify the effectiveness of the method by a simulation experiment.**

Keywords-detection of phase shifter module, solar radio, evaluation parameter

I. INTRODUCTION

The antenna of Phased array radar is generally made up of number of phase shifter models, Currently, detect antenna array phase shifter model, depending on the test signal source and the placement of monitoring systems, can be divided into "External Detecting" and "Internal Detecting". When use the "External Detecting" method, the test signal source placed outside of the antenna array, it can be placed to the far field or near field; when use the" Internal Detecting" method, the test signal placed intside of the antenna array, it can be radar transmitters or a special test signal source. The two detection methods need number of hardware, such as network analyzer, recorder of the lobe and anechoic chamber, generally near-field test equipment and accompanying software not equipped at the range and practical application.

The sun is a continuous spectrum radio stars, with a wide frequency spectrum and high radio flux density, is a natural test signal source. With the development of radio astronomy, the sun more and more being used in the calibration and testing of radar and telemetry equipment. Puhakka, perform an experiment that calibrate the radar using the solar radio[1], Helsinki University use the sun on weather radar calibration[2], A.G.Stov use the solar noise calibrate tactical radar[3]. In this paper, the sun is using as a test signal source to detect the phase shifter module, first introduced the radio characteristics of the sun, then two evaluation parameter propose for the phase shifter module, and then describes the detection method, finally, confirm the availability of the method by a simulation experiment.

II. SOLAR RADIO FEATURES

In 1942, scientists have discovered the solar radio burst, the burst radio frequency covered the whole frequency domain, in the microwave band (wavelength 0.3 to 10cm), the solar radio burst has a strong signal power and a slow change [4]. Astronomically solar radiation flux density usually present as Solar Flux, it is defined as the power received in the normal direction of the ground-rays per unit frequency per unit area, and its unit is W / (m2.Hz) [5]:

$$S(f) = \left[S(f_j)/S(f_k) \right]^{\Gamma(f)} S(f_k) \, , \Gamma(f) = \frac{\log(f/f_k)}{\log(f_j/f_k)}$$

$S(f_j)$ and $S(f_k)$ are the flux density at frequencies of f_j and f_k which are measured by the astronomy station.

Somewhere in a moment the sun elevation and azimuth angles can be calculated by the following formula [6]:

$$\sin\varepsilon = \sin\delta \sin I_{at} + \cos\delta \cos I_{at} \cos S \, ,$$

$$\sin\beta = \sin S / \left(\cos S \sin I_{at} - \tan\delta \cos I_{at} \right) .$$

Where, δ is the declination of the sun, I_{at} is the local geographical latitude, in north the latitude is positive, in south the latitude is negative, S is the sun corner.

When a receiving system receives the solar radiation, the signal noise ratio can be calculated:

$$SNR = W_S / W_N \ ; \ W_S = A_e \cdot S\nu / 2 \ ; \ W_N = 2KT_r \Big/ \sqrt{\Delta f \tau} \ .$$

III. SHIFT THE PHASE DETECTOR MODULE EVALUATION

Phase shifter Module is the minimum unit of antenna array that can detected, by comparing the power of the receiving channel, it can determine the module have fault phase shifter or not, but can not obtain the location information of the fault phase shifter, so that if there is a fault phase shifter its coordinates in the module is randomly distributed, in order to evaluate the performance the module, two evaluation parameters are proposed, which are (α_k, β_k).

Let M be the total number of phase shifters of the sub-array, the total number of modules in the sub-array is K, S_K, k=1~K is the number of phase shifter in the module k that work normally, $S=S_1+S_2+\cdots+S_K$ is the number phase shifter in the sub-array that work normally. Then:

$$\alpha_k = S_k / S,\quad k=1\sim K$$

$$\beta_k = S_k /(M/K) = K\, S_k / M$$

α_k is the relative parameter of the module, it represents the ratio of the number of normal phase shifters in the module and the total number of phase shifters in the sub-array, it calls as the relative parameter; β_k is the absolute parameter of the module, it shows the ratio of the number of normal phase shifters and the total number of phase shifters in the module, called as absolute parameter.

Where S_k and S can not be obtained directly, while α_k can be calculated by comparing the power that received by the channel. The relative parameter can show the module is good or bad. As long as the absolute parameter obtained, it can determine the number of normal phase shifters in the module, when β_k <90%, this module should be replaced.

IV. PHASE SHIFTER MODULE DETECTION METHODS

In order to get (α_k, β_k), there are two stages, first stage, to estimate the relative number of normal phase shifter for each sub-array; the second stage, estimate the evaluation parameters of the module.

The steps of the first stage are following:

First, the antenna toward the sun, zero-phase all the antenna array;

Second, at the output port of each receiver channel, estimate the received power, it can use the following formula to calculate the received power:

$$\sigma_n^2 = \sum_{q=0}^{Q-1} \left| x_{nq} \right|^2, n = 1 \sim N$$

Where: n-Receiver channel number; $|x_{nq}|^2$ - in the span of q second, the square of the modulus of the n-th channel output signal sampling (instantaneous solar noise energy); Q is theNumber of samples.

Third, $a_n=\sigma_n^2/\sigma_{sp}^2$ (σ_{sp}^2- power received by standard channel), v_n=SQRT(a_n), when $a_n \leqslant 1$, v_n=1, when $a_n > 1$. Standard channel is that all phase shifter are normal in the sub-array, it can confirm through numerous experiments or that the channel which received the largest power is the standard channel.

The steps of the second stage are following:

First, the antenna toward the sun, zero-phase all the antenna array;

Second, estimate the power of the sub-array received.

Third, phase the module in the sub-array contrarily one by one, that is, a module phase π, the rest phase zero, then estimate the power of the sub-array received, σ_{nk}^2, $k=1\sim K$.

Ignore the Amplitude and phase errors of the shifter, and the SNR of the solar noise power and receiver noise is much larger than 1, the time span of the power receiving is long enough, so that $X_k=S_k/S=\alpha_k$ can meet the linear equations with the restrictions of $X_1+X_2+\cdots+X_K=1$, $AX=a$, that:

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cdot & \cdot \\ 0 & \cdot & 1 \\ 1 & 1 & 1 \end{pmatrix}_{(K+1)\times K} \begin{pmatrix} X_1 \\ X_2 \\ \cdots \\ X_K \end{pmatrix}_{K\times 1} = \begin{pmatrix} a_1 \\ \cdot \\ a_K \\ a_{K+1} \end{pmatrix}$$

That, $a_k=0.5(1-\sigma_{nk}/\sigma_n)$, $k=1\sim K$, $a_{K+1}=1$。Using the Least squares method to solve the above equation can be obtained:

$$X=(A^{\mathrm{T}}A)^{-1}A^{\mathrm{T}}a$$

By calculating:

$$X = \frac{1}{K}\begin{pmatrix} K & -1 & \cdots & -1 & 1 \\ -1 & K & \cdots & \cdots & 1 \\ \cdots & \cdots & \cdots & -1 & \cdots \\ -1 & \cdots & -1 & K & 1 \end{pmatrix} a$$

Then we can get the absolute parameter of any module in any sub-array:

$$\beta_{nk} = 4 v_n X_k$$

V. NUMERICAL SIMULATION AND ANALYSIS

For the purpose of studying the effectiveness of the detection algorithm, a simulation Experiment Conducted, make the following assumptions: phase shifter 2 bits, $\triangle f$=300kHz, T_r=200K, G=100dB, T_0=290K, τ=0.1s, S_v=37A.U., A_e=0.3m^2, Q=1000~400, SNR_{out}=14dB.

In order to simulate the actual situation, the following mathematical model approach used to calculate the power of the receiver:

$$U_{nq} = \xi_q (1+\lambda_n)\left[\sum_{v} (1+\varepsilon_{nv}) \exp(i\Delta\phi_{nv}) \exp(-i\psi_{nv}) + \sum_{\mu} (1+\varepsilon_{n\mu}) \exp(i\Delta\phi_{n\mu}) \exp(-i\psi_{n\mu}) \right] + \zeta_q$$

Where：

$n=1\sim N$, $q=0\sim(Q-1)$;

ξ_q—single form the sun, $\xi_q = SNR_{out}\cdot(N_{in}\cdot G+\triangle N)$, variance $\sigma_\xi^2 = SNR_{out}/M$ (dB);

ζ_q—receiver noise, $\triangle N = K_{Berzman} \triangle f G$, variance 1dB;

λ_n—normalized relative deviation of the n-th receiver's magnification factor, take ±0.3%;

ε_{nv}, $\triangle\varphi_{nv}$, $\varepsilon_{n\mu}$, $\triangle\varphi_{n\mu}$—modulus value and phase deviations of the Phase shifter transmission coefficient, these deviations are evenly distributed in the range of some value (modulus value approximately ±0.3, phase ±20°).

ψ_{nv}—phase distribution of normal phase shifter, for the detection module, at the first stage $\psi_{nv}=0$, at the second stage $\psi_{nv}=\pi$; The other three modules, the first and second stages are$\psi_{nv}=0$;

$\psi_{n\mu}$—phase random value of Fault phase shifter, take one of four values 0 ,±2/π, π with probability of 0.25.

Simulations are proposed at the assumption of several different Failure rate：Failure rate, simulation, the results are as follows:

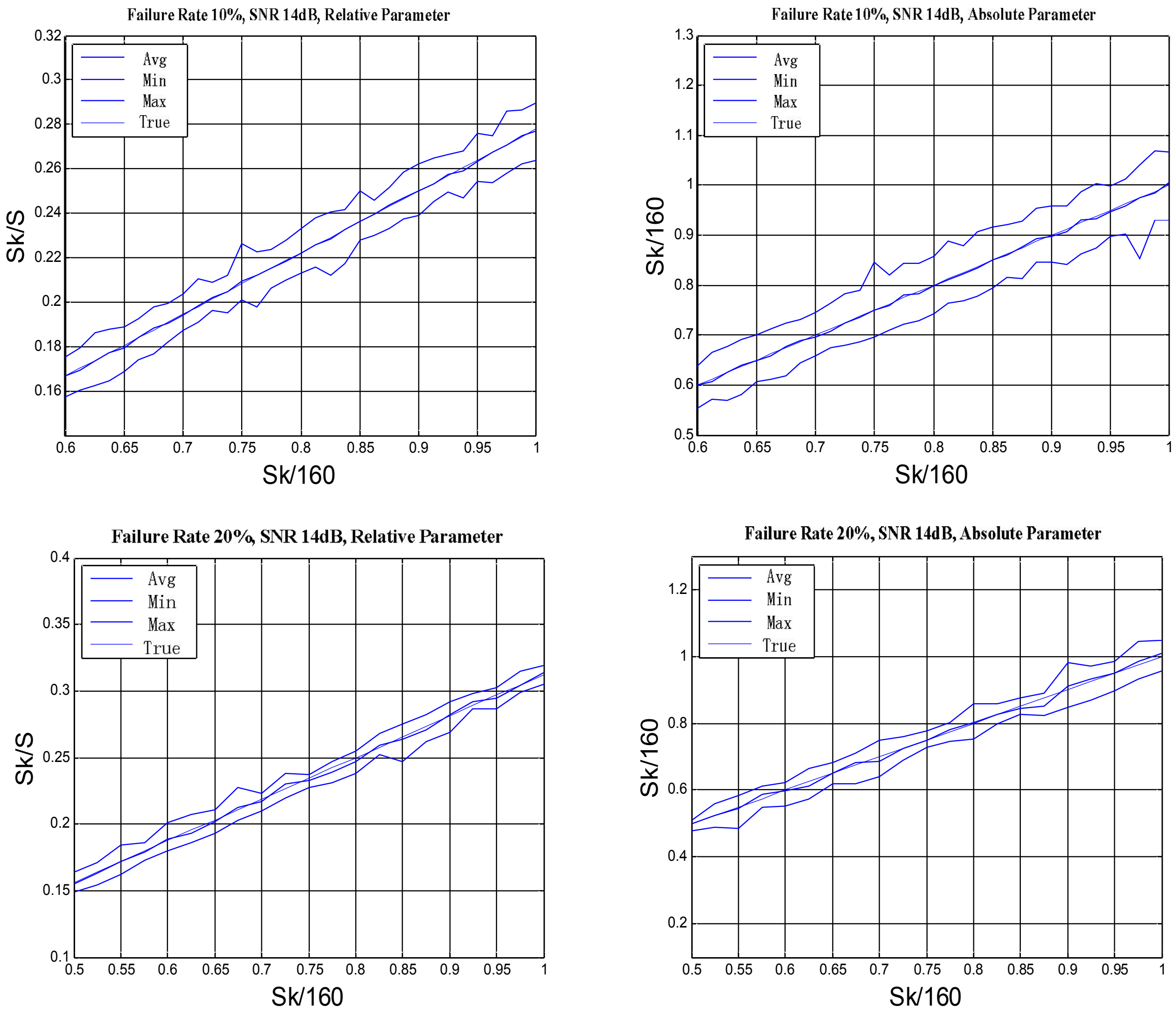

Figure.1 simulation results at failure rate of 10%, 20%

The short dashed line in the figure shows the average of 50 times, the dotted line for the minimum of 50 times, long-dashed line for the maximum of 50 times, solid line is the true value, that the average curve and the true value curve coincide. The variance of the two parameters, as shown in Figure 2.

It can be seen that the root mean square error of the relative parameter is 0.5%, the root mean square error of the absolute parameter is 2.5%, relative parameter has higher accuracy, which is the significance of studying it.

To Improve the accuracy of detection, make more experimental then take the average, for example, take 100 times, ignoring the running time of Program, then the time required is about 1.6~6.4 second.

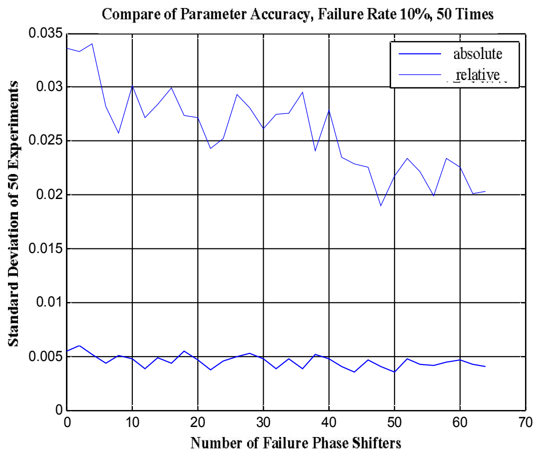

Figure.2 The variance of the two parameters

VI. CONCLUSION

Detect the phase shifter module use the sun is feasible and accurate, relative parameter and absolute parameter has a certain practical significance for the evaluation of the phase shifter module, the simulation results shows that, the relative parameter is more precise, but it is not a true reflection of the module, the error of the absolute parameter is relatively larger, but after several experiments, the average of the absolute parameter reflect the true state of the fault phase shifter module, therefore, the evaluation of comprehensive the two parameters on the module is more accurate and effective, on the other hand, detect the phase shifter module use the solar noise also fast and easily.

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