PROCEEDINGS OF ISAP '92, SAPPORO, JAPAN

Study on the Two-element Superconducting Superdirectional Antenna Array

Yu ligang[*], Shi changsheng[*], Wang richu[#], Zhou meiling[#]
* Department of Electronic Engineering, Tsinghua University, Beijing, china
# Department of Material and Engineering Central- South University of Technology, Changsha, China

Abstract- In this paper, the two- element high- Tc superconducting superdirectional antenna array will be analysed and studied theoretically and experimentally, Especially on the links which now exit in the studying process of the superdirectional antenna array. we'll do a further detailed research. In the end, we will obtain the criterion which the fed sensitivity of the two-element superdirectional antenna array requires. And the analysis of the experimental result indicates, compared with the corresponding copper array, the radiation efficiency of the high- Tc superdirectional antenna array will have a increase of 4--6.9 dB.

I. INTRODUCTION

The superdirectional antenna array(the SAA.)has been studied and designed for nearly half a century. By now, it is only feasible in theory. From its devolopment process, we can easily find that it has three difficulties.

In 1943, S.A.Schelkunoff[1] demonstrated the possibility of the SAA..

In 1948, R.M.Wilmotte[2] pointed that the SAA. had low efficiency. And it was one main difficulty. Then, L.J.Chu[3] demonstrated that the SAA had a narrow-band. And this is also a difficulty. After that, T.T.Taylor[4] found that the fed sensiticity of SAA is poor. And this is another main difficulty.

In 1951, N.Yara[5] calculated the directivity, radiation efficiency and fed sensitivity of the SAA.. For the nine-element SAA.(array length: $\lambda/4$) . the calculated result shows: directivity: 8.5; radiation efficiency: $1X10^{-4}$; fed sensitivity: $1X10^{-11}$.

In 1978, S.Adachi, Y.Mohri, S.Ohnuki, K.Achida[6] made a experimental study on the SAA.. For the requirement of the fed precision, they chose few elements array(two-element) and they adopted low-Tc superconductor(pb) to made antenna elements and matching network, so the radiation efficiency of the array was raised. Their antenna elements were dipole antennas and small current loops.

In 1990, we designed to use high-Tc superconductor to make the two-element SAA., and worked out the SAA. 's low efficiency problem successfully. In experimental method, because the high-Tc conductor is the fragile china(not Pb), so, we managed to fix two half-wave elements on a medium lining side by side, the lining is firm and low in loss. We conbined the matching unit and radiation array together, and adoped a Half-Wale Length Balan to equilibrate feeding. The structure of our experimental antenna is shown in Fig. 1. The experiment shows that we have achieved satisfactory and experimental results.

II. STRUCTURE OF THE SAA. AND DIRECTIVITY

Fig.1 shows that the distance between two elements: $d/\lambda \ll 1$. If the fed point is chosen appropriately, it can be proved that the antenna array will match to every transmission line.

The directional graph of the SAA. is shown in Fig.2, The calculation of the max directivity of the SAA. is following: Suppose $F(\theta \, . \, \phi)$ indicates unitized electronic field intensity's directivity of the SAA..

$$F(\theta,\phi)=\cos((\pi/2)\cos\theta)\sin((kd/2)\sin\theta\sin\phi)/(\sin\theta\sin(kd/2))\ldots\ldots(1)$$

$$D=4\pi/\int_0^{2\pi}\int_0^{\pi}F^2(\theta,\phi)\sin\theta\,d\theta\,d\phi\ldots\ldots\ldots\ldots(2)$$

For half-wave element, $D_o=1.64$, so, the improved directivity is shown in Fig.3. From Fig.3, we can see that the improvement of directivity is not sensitive to the unit distance in a large range.

III. EFFICIENCY OF THE TWO-ELEMENT SAA. AND IMPROVED RATIO OF THE SUPERCONDUCTING SAA.'SEFFICIENCY

Ror a single copper half-wave element, its radiation efficiency is very high. But for the SAA., the radiation eletroic field of these two elements fold over and counteract in the space, its radiation power is less relatively. Therefore, the affection of the loss power in the total power of antenna is very large. The total power of the SAA. is following:

$$P = P_r + P_{cu} \ldots\ldots (3)$$

Here, P_r----radiation power. P_{cu}---the loss power of the copper antenna. The efficiency of the SAA.:

$$\eta = P_r/(P_r+P_{cu}) \ldots\ldots (4)$$

$$P_r = \int_0^{2\pi}\int_0^{\pi} 0.5|E(\theta,\phi)|^2 r^2 \sin\theta / W d\theta d\phi \ldots (5)$$

$$P_{cu} = \int_{-1}^{1} (I_M \cos(kz))^2 (Rs/(2\pi a)) dz \ldots\ldots (6)$$

Here, Rs expresses surface resistance of the conductor. To general metal, $Rs=(\omega\mu/2\sigma)^{1/2}$, Rs inscreases with $(\omega)^{1/2}$. To superconductor, $Rs=\omega^2\mu_0^2\lambda^3\eta_n\sigma_n/2n$; here, λ, η_n, σ_n, n are reference quantities related with superconducting material, and, Rs will inscrease with ω^2.

According to the difference of their internal composition, superconductors can be divided into polycrystal and singlecrystal. There is only one kind of composition existing in singlecrystal, and there are mang kinds of composition existing in polycrystal. Our antennas are made of polycrystal.

See Fig.4, in the frequency band of 500～700 MHz, the Rs of polycrystal supercoductor is less than that of metal(Cu), and the Rs of singcrystal superconductor is less than that of polycrystal superconductor.

From Formular 4, we can see, to increase the radiation efficiency, superconductor can be chosen to made the element. In Fig.4, Rs curve shows that, $Rs_{sup} < Rs_{cu}$ in corresponding frequency band. So that, radiation efficiency of the SAA. will be improved.

Figure.5 shows the $\eta \sim d$ curve of copper array and superconducting one.

The improved efficiency ratio T:

$$T = 10\log(\eta_{sup}/\eta_{cu})$$

here, η_{sup}--the superconductor anttenna's radiation efficiency.
η_{cu}--Copper anttenna's radiation efficiency.

IV.FED SENSITIVITY OF THE SAA.

Fed Sensitivity of the SAA. is a reference quantity expressing the sensitive degree of antenna's radiation field to fed error. By analyse, we find that the main cause of error to our array is that Half Wavelength Balan's equal length is not strictly equal to halh-wave(see Fig.6)

If the Half Wavelength Balan's length is strictly equal to $\lambda_{1e}/2$(λ_{1e} express cable's conductive wave length).

Then, the potentail of the fed point A and B can be expressed as:

$U_1=U_0e^{j(\pi/2)}$.....(7); $U_2=U_0e^{-j(\pi/2)}$....(8);

here, U_0--voltage amplitude of the Half Wavelength Balan's fed point.

But, when length error (Al') exists in transformer, potentail of fed point A and B will be expressed as:

$U_1=U_0e^{j(\pi/2+A)}$..(9): $U_2=U_0e^{-j(\pi/2-A)}$..(10): ($A=(1/2)k_e Al'$)

Its vector graph is shown in Fig.7.

here, U_1'and U_2' respectively expresses the reverse phase voltage which is fed at the first and the second unit, these are the voltages which are required for producing superdirection, we call them differential model voltages. U_1" and U_2" express the common phase voltages, we call them common model voltages, and they can't produce superdirective radiation. Differential model and common model exciting are shown in Fig.8 and Fig.9 respectively.

The existance of common model current makes the SAA's real efficiency dropping correspondingly. So, we'll introduce differential model's efficiency quantity η_d to describe this effection.

The main results is shown as follow:

a). $I_0=2\cos(A)U_0/(\sin(2\pi Al'/l')Z_0) \ldots\ldots (11)$

here, I_0--current amplitude of differential model. U_0-- voltage amplitude of the Half Wavelength Balan's fed point. Al'- - error length of the Half Wavelength Balan. l'--length of the Half Wavelength Balan

b). $AI_{o1}=\sin(A)U_0/(2Z_{in}\sin(K_e(\lambda_e/4+Al)))$..(12)

$AI_{o2}=\sin(A)U_0/(2Z_{in}\sin(K_e(\lambda_e/4-Al)))$.(13)

here, AI_{o1}--amplitude of common model current which is on the longer part from the antenna's matching point. AI_{o2}--amplitude of common model current which is on the shorter part from the antenna's matching point. λ_e-- wave length of the antenna unit. Z_{in}--common model input impedamce(it can be obtained by calculation). Al--centre distance of fed point.

c). $\eta_d = p_d/(P_d+P_c)$

$$P_c = 0.5 I_c^2 R_{\Sigma c} \ldots\ldots (15)$$

$$P_d = 0.5 I_d^2 R_{\Sigma d} \ldots\ldots (16)$$

here, $I_d = I_o$, amplitude of differential model current.

$I_d = I_{o1} + I_{o2}$, amplitude of common model current.

$R_{\Sigma d}$--differential model's radiation resistance. $R_{\Sigma c}$-- common model's radiation resistance. $R_{\Sigma d}$, $R_{\Sigma c}$ can be obtained by calculation.

For typical reference quantity: length of element l= 200 mm; radius of element a=0.4 mm; interval distance d= 4; 12 mm. The graph of $\eta_d \sim Al'$ calculated curve is shown in Fig.10.

After comparing the radiation pattern of differential model current and common one's, it can be easily found that in the direction (Φ = 90) , the differential model current's radiation field is zero, but the common one's is not. So, we introduce a quantity: E(90°)/E(0°), it will be used to describe the influence which is added to the SAA's radiation pattern, this influence is caused by common model current which is produced by the Half Wavalength Balan's length error. According to these analysis, it can be inferred:

$$E(90^\circ)/E(0^\circ) = (K d I_o / AI + 1)^{-1} \ldots\ldots (17)$$

here, AI--equal amplitude of common model current, it submit to the relationship:

$$\int_0^{\lambda/2} AI\sin(k_e z)dz = \int_0^{(\lambda/4+AI)} I_{o1}\sin(k_e z)dz - \int_{(\lambda/4+AI)}^{\lambda/2} I_{o2}\sin(k_e(\lambda_e/2-z))dz \ldots\ldots (18)$$

As the same, for typical quantity: l=200 mm, a=0.4 mm, d=4; 12 mm. E(90°)/E(0°)$\sim$Al' calculated curve is shown in Fig.11.

V.EXPERIMENT MEASUREMENT

1.The experiment of improving the efficiency of the SAA.:

In the experiment, the element length l=200 mm, its radius a=0.4 mm.

Superconducting material is YBCO, contrastive antenna is made of red copper. Experimental results are shown in table 1. The ratio of improved efficiency is shown in Fig.12.

In table 1, when we calculate the efficiency of the SAA. theoritically, we have considered the medium effection of matching lining and liquid nitrogen.

2.Experiment of the SAA.'s fed sensitity:

The receiving antenna is moved around SAA., encircle and measure it. Experimental results are shown in table 2.

VI.CONCLUSION

The application of the high-Tc superconducting material has solved the low efficiency problem of the SAA. successfully. The experiment and theory show, for two-element array: d=4mm, Φ=0.8mm, the efficiency can be raised more than 6.5 dB. The using of the Half Wavelength Balan also finely solve the fed sensitivity problem. And the effect on direction by fed error is controled in a certain range.

Reference:

[1] S.A.Schelknoff,'A mathematical theory of linear arrays, 'Bell Sys. Tech .Jour., vol.22, pp.80-107; Jannuary, 1943.

[2] R.M.Wilmotte.'A Note on practical limitations in the directivity of antennas,'Proc.I.R.E., vol.36, p.878; July, 1948.

[3] L.J.Chu, 'The physical limitations of directive radiating system,', Jour .Appl.Phys., p1163; December, 1948.

[4] T.Taylor 'A Dicussion of the Maximum Directivity of an Antenna'Proc.I.R.E. p1135, 1948.

[5] N.Yara 'A Note on Super-Gain Antenna Array'Proc.I.R.E.p1081-1085, 1951.

[6] Saburo Adachi, Yoshihiro, Shigeo Ohnuki'Experiments on superconducting electric dipole and array', A-7-2, p109-113, 1978.

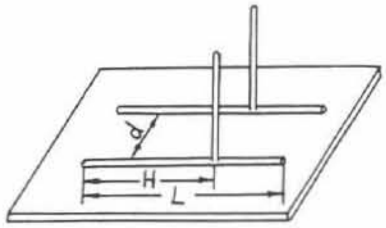

Fig.1-Arrary struture.

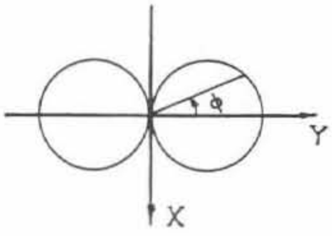

Fig.2- Directional graph

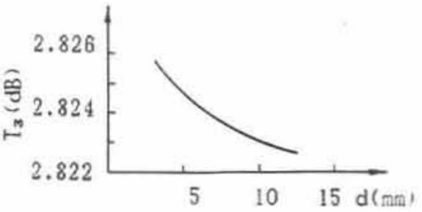

Fig.3-Improved directivity

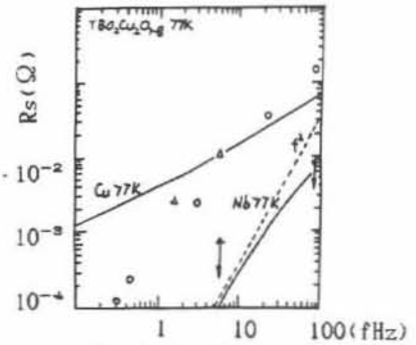

Fig.4-Rs～frequency

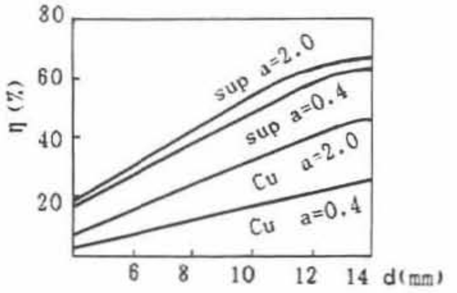

Fig.5-η～d relationship

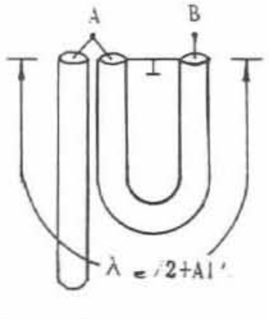

Fig.6-Fed error

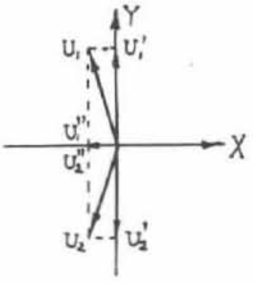

Fig.7-Vector graph

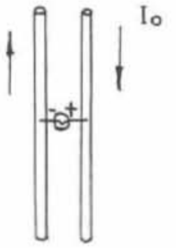

Fig.8-D--Model exacting

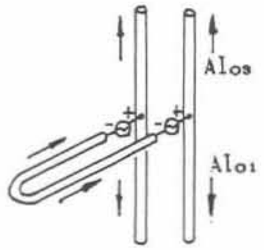

Fig.9-C--Model exacting

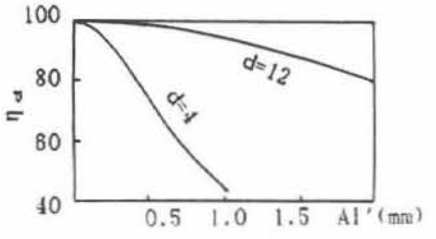

Fig.10-η_d～Al'curve

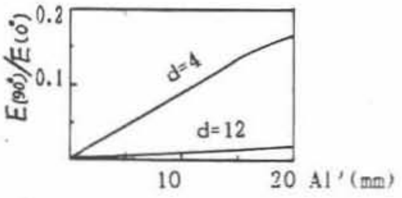

Fig.11-Fed sensitivity

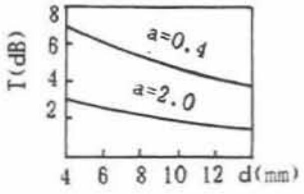

Fig.12-Improved efficiency

Table.1: Array reference and result

No.	d mm	Improved efficiency	
		experiment value(dB)	calculated value(dB)
No.1	4	6.40	6.93
NO.2	8	4.80	5.39
No.3	12	3.60	4.20

Table.2: Fed sensitivity experiment

Al' (mm)	5.5	16.6
Experiment value	0.034	0.18
calculated value	0.051	0.14