A SUPERRESOLUTION TECHNIQUE
FOR ANTENNA PATTERN MEASUREMENTS

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1. INTRODUCTION

In measurements of gain and radiation pattern for a large aperture antenna, a measurement system must be constructed outdoors to achieve a far–field range. In this case, reflected signals from the ground and other objects often impinge on the antenna, and the measured data are disturbed by them. A recently developed vector network analyzer provides time–domain processing based on the fast Fourier transform (FFT). We can mathematically remove the unwanted responses that appear as ripples in the frequency domain by gating them in the time–domain presentation [1]. However, desired (direct path) and unwanted (*e.g.* ground path) responses must be clearly separated in the time–domain presentation. Thus, the difficulty often arises in measuring narrow pass–bandwidth antennas. Furthermore, outdoor wideband antenna measurements are not preferable because the wideband radiation may interfere with another radio system, and because the measurement system may be interfered with by another radio system. The authors have proposed antenna gain measurements [2] [3] using a MUSIC algorithm[4], and have shown that we can measure the antenna gain using much narrower frequency bandwidth data in comparison with the conventional FFT based time–domain processing. However, the MUSIC algorithm usually needs many sets of frequency–domain data (snapshots) to estimate a correlation matrix. We used 50 snapshots to obtain the antenna gain[3]. However, it is not preferable to need many snapshots for the antenna pattern measurements because it takes a very long measurement time. It should be noted that we must obtain the response of antenna at each angle of rotation for the antenna pattern measurements. In this paper, we propose a new superresolution method which employs the MUSIC algorithm accompanied with the FFT and gating techniques. The new method needs only a few snapshots. In this paper, we show examples of the method using a single snapshot.

2. FORMULATION OF THE NEW METHOD

We assume that we only have a direct path and a single reflected path. The formulation stated below can be straightforwardly expanded into more complicated multipath environment. We denote propagation delays of the direct and reflected responses as t_1 and t_2, respectively. The measured value at the frequency of f is given by

$$r(f) = s_1 e^{-j2\pi f t_1} + s_2 e^{-j2\pi f t_2} + n(f) \tag{1}$$

where s_1 and s_2 denote the signal parameters (amplitude and phase) of the direct path and reflected path, respectively. Also, $n(f)$ denotes a noise component. We assume that

s_1 and s_2 are independent of frequency in a narrow frequency band. If s_1 is estimated at each angle of rotation, we can obtain the antenna pattern.

In Eq.(1), $n(f)$ is an only stochastic quantity. It should be noted that $s_1 e^{-j2\pi f t_1}$ and $s_2 e^{-j2\pi f t_2}$ are transmission coefficients (S_{21}), and then they are deterministic quantities. If it were not for the noise, we would be able to apply the MUSIC algorithm with a single snapshot. This is because we can obtain the correlation matrix using a single snapshot. Thus, if we reduce the noise component drastically, we can apply the MUSIC algorithm with only a few snapshots. Our goal is to apply the MUSIC algorithm using a single snapshot.

Now, we describe the method to reduce the noise drastically in the following. At first, we measure the frequency–domain data using measurement equipment such as a network analyzer. We denote the sampling frequency separation as ΔF. We obtain the time–domain response using the inverse FFT (IFFT). The signal responses concentrate on the time around $t=t_1$ and $t=t_2$. However, the noise component distributes over a whole visible region ($1/\Delta F$). ΔF is determined in such a way that we have $1/\Delta F \gg t_2 - t_1$. If we extract the time–domain response around $t=t_1$, t_2 by the gating technique, the signals are not damaged but the noise component outside the gating filter is suppressed in the time domain. Since $1/\Delta F \gg t_2 - t_1$, we can reduce the noise drastically. Also, we transform the time–domain response into the frequency domain by the FFT. We again have the same formula as Eq. (1). However, the noise component is reduced compared with the raw data by the above time–domain processing.

3. SIMULATION RESULTS

In order to show the performance of the new superresolution technique, we made computer simulations. We employed a monopole antenna of the length 3cm and diameter 1mm for the antenna under test (AUT). We obtained the necessary electric characteristics of the monopole antenna using the moment method. We assumed that two signals (the direct path and reflected path) are incident on the antenna as stated in the previous section, and that we have $t_1=0$nsec and $t_2=5$nsec. Also, we assumed that the direct and reflected path outputs (s_1, s_2) from the AUT at the frequency of 2.205GHz are given by $0.05\angle 0°$ and $0.02\angle 0°$, respectively. $n(f)$ was generated by a Gaussian random number with mean 0 and variance 10^{-6}.

Fig.1 shows the time–domain responses given by the IFFT. The frequency band is from 2.20GHz to 2.28GHz, and the number of sampling points is 801. Because the bandwidth of the frequency–domain data is narrow (80MHz), the two responses are not resolved. However, they concentrate on the time around 0nsec. Since $\Delta F=100$kHz, the noise distributes from -5μsec to 5μsec ($1/\Delta F=10\mu$sec). The noise level ranges from about -80dB to about -60dB (raw data). We suppressed the noise outside the signal response by the gating technique. The gated response is also shown in Fig.1. We can see that the noise is strongly suppressed outside the signal response.

Fig.2 shows the time–domain responses using the MUSIC algorithm with only one snapshot. The signal coherence was destroyed by spatial smoothing preprocessing (SSP)[2]. Refer to the literature[2] for the parameters shown in the figure caption. The curve marked by "raw data" was calculated by applying the MUSIC algorithm to the original frequency–domain data. The curve marked by "gated data" was obtained using the frequency–domain data whose noise component is reduced by the gating technique stated above. We see that the new superresolution technique can estimate the delay time t_1 and t_2, and that the conventional MUSIC algorithm fails to estimate them. We

needed 80MHz bandwidth data (2.20~2.28GHz) to reduce the noise component by the gating technique. The curves shown in Fig.2 were obtained by the MUSIC algorithm using 70MHz bandwidth data (2.205~2.275GHz). Moreover, we can calculate the direct path response (s_1) by means of the estimated delay time (t_1, t_2)[2]. Note that when we use the FFT and gating techniques, we need 3GHz bandwidth data to estimate the direct path response even at a single frequency point.

4. ANTENNA PATTERN MEASUREMENTS

We carried out antenna pattern measurements. We employed the double ridged guide antenna (EMCO Model 3115) for the AUT. We placed the AUT and metal plate in a radio anechoic chamber. Then, we had an intentional reflected path other than the direct path. The delay difference between the direct and reflected path signals is about 1.4nsec. The frequency–domain data were obtained by the network analyzer system (8510B) every 6 degrees of rotation. Fig.3 shows the antenna patterns at the frequency of 5.2GHz. We can see that the measured pattern (raw data with a metal plate) is distorted due to the reflected signal by the metal plate. The distortion is recognized from 0° to 60°. In Fig.3, we also show the following results.

(1) Antenna pattern which was obtained by suppressing the reflected signal using the conventional FFT and gating techniques (FFT–GATE). The required frequency bandwidth was 6GHz (5~11GHz).

(2) Antenna pattern which was obtained by suppressing the reflected signal using the MUSIC algorithm accompanied with the gating technique. We used a single snapshot of 800MHz bandwidth data (5.04~5.84GHz : ΔF=2MHz, 401points) to reduce the noise component by gating. We employed the SSP to destroy the signal coherence. f_1=5.2GHz, N=46, M=23, Δf=6MHz.

(3) Antenna pattern without the metal plate. This is the actual antenna pattern.

From Fig.3, we see that these three patterns ((1)~(3)) coincide with each other very well. Namely, if we employ the proposed superresolution technique, we can obtain the antenna pattern using a single snapshot of 800MHz bandwidth data. Compared with 6GHz bandwidth data required by the FFT and gating techniques, the superresolution technique can obtain the antenna pattern using much narrower frequency bandwidth data. Furthermore, we need only a single snapshot, and then the superresolution technique proposed in this paper saves the measurement time.

5. CONCLUSIONS

We have proposed the new superresolution method employing the MUSIC algorithm accompanied with the FFT and gating techniques. The method can be used for the antenna pattern measurement because it saves the measurement time.

References

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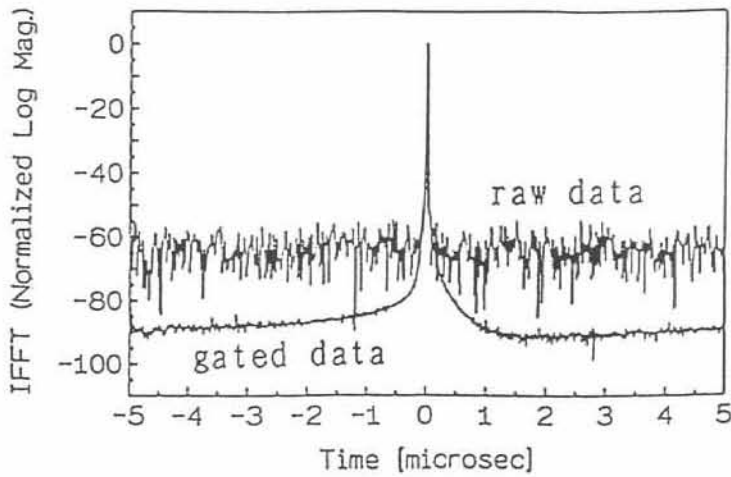
Fig.1. Time–domain responses of raw data and gated data. Gate center : 0 nsec, Gate span : 100 nsec.
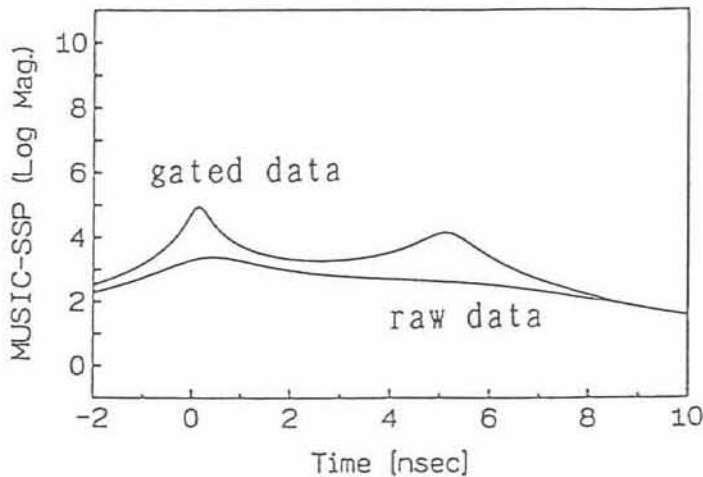

Fig.2. Time–domain responses given by the MUSIC algorithm. f_1=2.205 GHz, N=20, M=10, Δf=2.5 MHz, Required bandwidth : 70 MHz, Snapshot : 1.
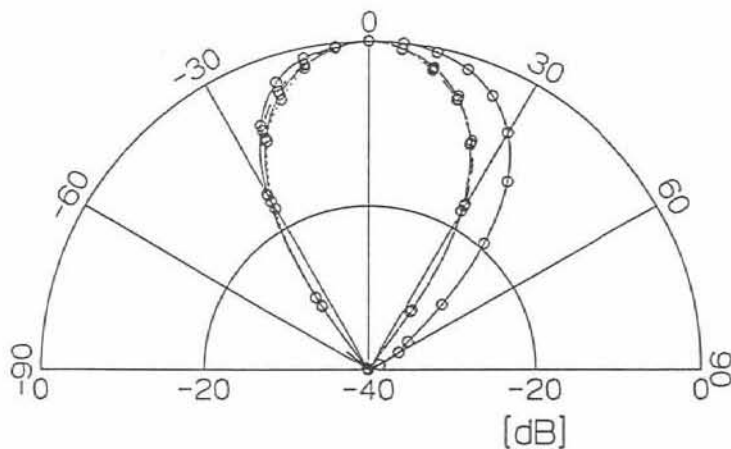

Fig.3. Antenna patterns.
——— Raw data with a metal plate
- - - - - FFT–GATE
·········· MUSIC algorithm accompanied with the gating technique
—·—·— Raw data without a metal plate