A Beam Tracking System – System Analysis Incorporating Electromagnetic Field Simulation

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***Abstract* – In this summary, the system analysis of a modified mono-pulse tracking system based on the beam-forming technique was carried out. Significantly, the full wave electromagnetic field simulation was incorporated into the calculation for considering the mutual coupling between antennas. The parameters affecting the tracking performance such as signal-to-noise ratio and amplitude/phase imbalance between the two receiver channels were included in this research.**

***Index Terms* — Mono-pulse system, tracking system, beam-forming.**

1. Introduction

The mono-pulse principle has been a continuous research topic for several decades [1]. A time-division multiplexing based mono-pulse architecture was successfully developed [2] for DVB-SH application. The commonly used mono-pulse tracking system is fixed to a gimbal; the mechanical steering enables the alignment between the mono-pulse antennas and the direction of the incoming wave. Contrarily, in this research, the mono-pulse system incorporating the electronic beam steering is proposed, together with the system analysis including the electromagnetic field simulation of the plane-wave incidence on the antennas.

The system analysis of a mono-pulse system usually was carried out based on the ideal conditions, such as the ideal isotropic antennas and perfect amplitude and phase balance between the two radio frequency (RF) channels (receivers), and noise free. Under those constrains, one can hardly evaluate the performance of a realistic system. Nevertheless, in this research, the system analysis takes into account the RF impairment such as the amplitude- and phase-imbalance, and the antenna radiation characteristics including the radiation pattern and mutual coupling. Additionally, the effect of signal-to-noise ratio of the receiver on the tracking performance will also be considered.

2. Mono-pulse Principle

Figure 1 shows the system block of a mono-pulse system consisting of two receivers, each of which contains one end-fire antenna (forward radiation toward the *z*-axis) and one I/Q demodulator. The two antennas were placed along the *x*-axis at $x=-d/2$ and $x=d/2$, respectively. Notice that the low-noise amplifier (LNA) and bandpass filter were neglected here for brevity; however, their non-ideal characteristics will be included in the system analysis. A plane electromagnetic wave is assumed to be obliquely incident on the antennas; the incident angle is denoted as θ, which is counted from the *z*-axis. The RF signal received by each of the antennas is down-converted into baseband in-phase and quadrature components of the signal, denoted as I and Q, respectively. The two receivers share the same stable local oscillator. If the baseband signals at the output ports of the two receivers are $x_1(t)$ and $x_2(t)$, one may obtain the sum, $x_1(t)+x_2(t)$, and difference, $x_1(t)-x_2(t)$, respectively.

The ratio of difference to sum is defined as a new variable S, which can be used to evaluate the angle of arrival. For example, if a plane wave is normally incident on the two antennas shown in Fig. 1, the difference will vanish because they receive the identical signals. Consequently, the null of S occurs at the perfect alignment between antennas and the incoming wave. The traditionally used mono-pulse system mechanically steers the antennas to search the minimum value (or null) of S.

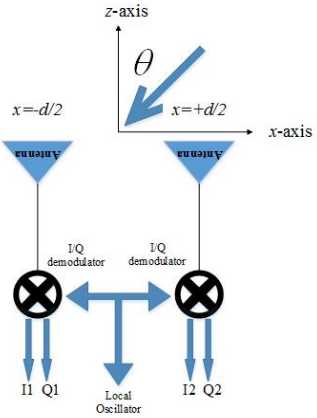

Fig. 1. System block of a mono-pulse tracking system

3. Mono-pulse Incorporating Electronic Beam Steering

Returning to Fig. 1, due to the oblique incidence the phase difference between the waves arriving at the two antennas is $k_o d\sin\theta$, where k_o is the free-space wavenumber equal to $2\pi/\lambda$ Parameters λ is the operation wavelength and d is the separation distance, which is less than half wavelength for not introducing the grating lobes. Therefore, we may obtain the coherent signals at the two antennas by compensating the phase difference at oblique incidence. This is the basic principle of a phased-array antenna. The phase shifting can be performed after the antennas (analog beamforming) or after the I/Q demodulator directly at the baseband signal (baseband beamforming). Here, the two baseband signals can be explicitly written below:

$$x_1[n]=G_1(\theta)\cdot\exp(-jk_o d\sin\theta/2)s[n]+N_1[n] \qquad (1)$$

$$x_2[n]=G_2(\theta)\cdot\exp(+jk_o d\sin\theta/2)s[n]+N_2[n] \qquad (2)$$

Where $G_i(\theta)=G_{ant,i}(\theta)T_i$, with i = 1, or 2. Parameters $G_{ant,i}(\theta)$ represents the antenna gain pattern. Notice that even the two receivers, operated under the same condition, share the same circuit layout and component part number, the baseband signals may differ considerably when they are fed with the same RF signals. The effect of RF-to-baseband receiver path is lumped into a complex coefficient T_i with amplitude, $|T_i|$, and phase, ϕ_i. Besides, variable $N_i[n]$ denotes the additive white Gaussian noise (AWGN) signal caused by the receiver. The AWGN has zero mean; its variance represents the noise power. Here, the amplitude imbalance between the two receivers is defined as $||T_2|/|T_1|-1|$; while the phase imbalance is ϕ_2-ϕ_1. Parameter $s[n]$ is the incoming signal. The bracket after the signal in (3) and (4) means the time-series data after sampling by the analog-to-digital converter (ADC). By introducing a phase shift (φ) at the second antenna to align the arriving time, the difference over sum can be obtained as follows.

$$S(\varphi)=\{\exp(+j\varphi)\cdot x_2[n]-x_1[n]\}/\{\exp(+j\varphi)\cdot x_2[n]+x_1[n]\} \quad (3)$$

Moreover, by dynamically scanning the phase shift angle (φ), we may plot |S| with respect to the variable φ. The position of null allows us to know the incident angle. The relationship between the phase shift angle and incident angle is $k_o d\sin\theta+\varphi=0$.

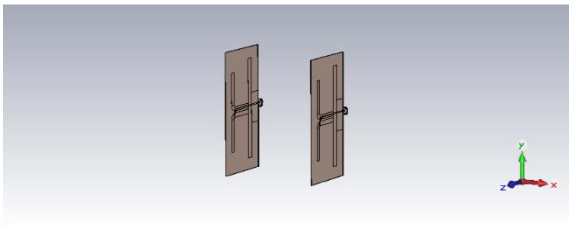

Fig. 2. The two printed Yagi-Uda antennas employed in the mono-pulse tracking system.

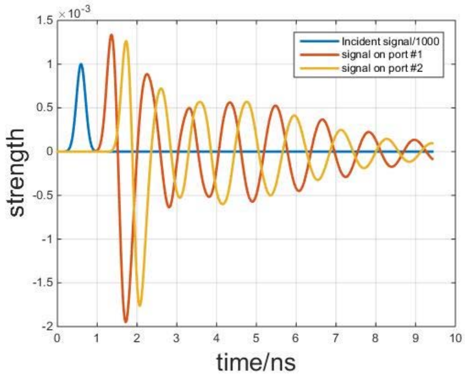

Fig. 3. The time-series data received at the individual antenna port together with incident waveform.

4. Numerical Results and Discussion

Here, we consider an incoming plane wave with incident angle, θ = 45 degree. The two Yagi-Uda antennas shown in Fig. 2 were placed along the x-axis with separation distance equal to half wavelength. The full-wave simulation using CST microwave Studio was carried and the time-domain waveform at the individual ports together with the incident one were plotted and depicted in Fig. 3. It is apparently to see that a time shift between the two receiving signals is present due to the path difference between them.

By adding up the AWGN on the time-series sampling data given in Fig. 3, we can simulate the receiving data corrupted by noise. The SNR is assumed to be 20 dB in this example. Figure 4 shows the strength of difference over sum, S, against the observation angle (in degree). Here, we scan the phase shift angle (φ) from -180 to 180 degrees in the increment of 1 degree. Apparently to see that the minimum takes place at 45.26 degree, which almost coincides with that of the incident angle. Although not shown here, the deep of the null is obvious for the case with a considerable SNR. Extensive numerical results will be presented in the conference.

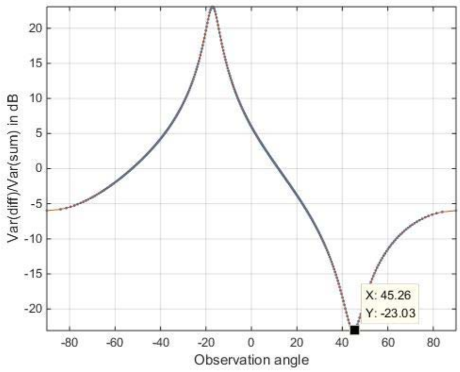

Fig. 4. The variation of difference/sum against the observation angle (in degree)

5. Conclusion

In this summary, the tracking performance of a mono-pulse system based on the electronic beamforming technique was evaluated together with the full-wave electromagnetic field simulation for the two printed antennas. The factors affecting the tracking performance such as SNR and amplitude/phase imbalance will be presented in the conference.

Acknowledgment

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References

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