SSB-AM-based detection of phase error in active phased array antenna for space application

Sang-Burm Ryu, Eun-Su Kang, Hyeon-Cheol Lee, Sang-Soon Yong, Sang-Kon Lee and Sang-Gyu Lee✉

A phase variation detection scheme based on a SSB-AM detector for the active phased array antenna is introduced. Since the phases of arrayed elements for the active phased array antenna vary unavoidably with increase in the surrounding temperature, such shifts should be detected and compensated accordingly, for maintaining the accuracy of beam direction radiated from the phased array antenna. Simulation results show that the proposed scheme is quite feasible.

Introduction: As the resolution and swath of earth observation satellite image are enhanced, the steerable high-gain antenna is widely used for achieving good EIRP in the limited allocated X-band. However, the directional antenna based on a two-axis gimbal causes jitters directly in the image taken while moving the antenna. In addition, the degradation becomes more significant with increase in resolution. Thus, recently, the active phased array antenna (APAA) has been developed to electrically control the beam direction from the low earth orbit (LEO) satellite [1]. However, since the accuracy of the resultant beam shapes depends very much on the phases of the array elements [2], whose phases vary in general with their temperature variations due to activation power supplies, surrounding conditions and etc., the detection and compensation of phase distortion for the phased array antenna has been an important subject [3]. For example, phase difference is known to be measured using a power detector [4]. When rapid compensation is an important requirement as in many LEO satellite systems with limited communication duration, however, such a scheme would not be sufficient. Thus, in this Letter, we introduce an SSB-AM-based detector for effectively measuring the distortion of the phase in an APAA for LEO satellites.

Proposed scheme: Fig. 1 depicts usual APAA, including the functions necessary for the compensation of phase distortion. The antenna is in general composed of a phase shifter (Φ), an attenuator, a power amplifier (PA), a power and phase detector (PPD) and so on. As can be seen from the Figure, the main idea is that for detecting the phase variations occurring in an APAA on orbit, a PPD with an AM demodulator has been considered; the PPD detects the phase of the transmitted SSB-AM signal denoted by $M_{SSB}(t)$ at the output stages of the PAs.

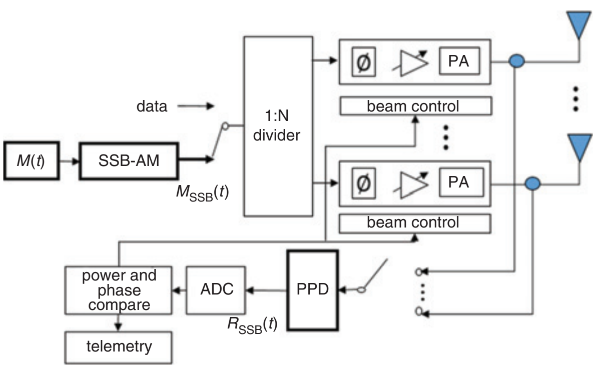

Fig. 1 *APAA with SSB-AM-based phase detector function*

In detail, the calibration signal of angular frequency ω_s (rad/s) denoted by $M(t) = \sin(\omega_s t)$ is modulated by the SSB-AM module in Fig. 1 as

$$M_{SSB}(t) = A_c\{M(t)\cos(\omega_c t) \mp \hat{M}(t)\sin(\omega_c t)\} \tag{1}$$

where ω_c (rad/s) is the angular carrier frequency and, if we assume some phase distortion of θ_d on $M(t)$, then the output of the AM demodulator denoted by $R_{SSB}(t)$ is expressed by

$$R_{SSB} = M(t)\cos\theta_d \pm \hat{M}(t)\sin\theta_d \tag{2}$$

where $\hat{M}(t)$ denotes the conjugate of $M(t)$ and, by substituting $M(t) = \sin(\omega_s t)$ in (1), we could achieve only the term of $\sin(\omega_s t + \theta_d)$ induced by phase shift θ_d in the calibration signal of $M(t)$. Of course, other harmonic waves are able to be eliminated easily by adding a LPF in general.

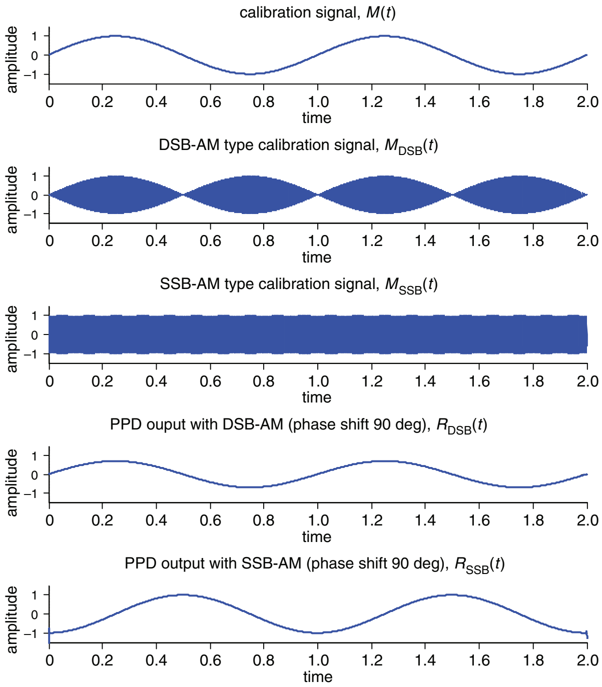

Fig. 2 *PPD outputs resulting from different calibration signals*

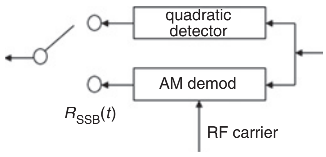

Fig. 3 *Functional architecture of modified PPD for simulation*

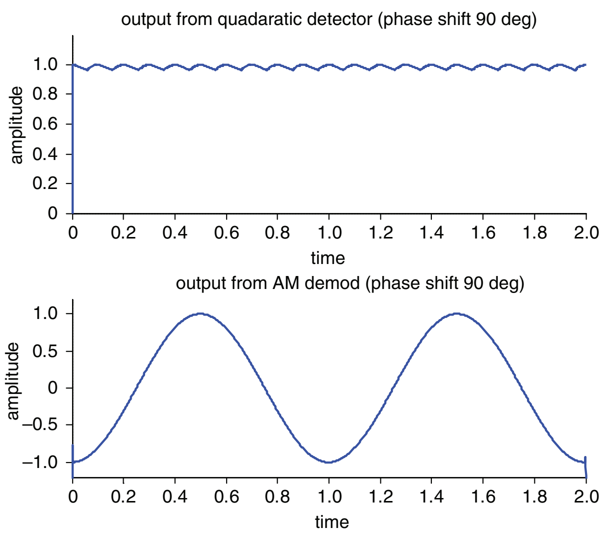

Fig. 4 *Comparison of output from AM detector with one from quadratic power detector*

It is noted that phase detection using the quadratic power detector is well known [4], but since it detects the calibration signal converted into a form of data stream from the DC power signal, boring iteration would be necessary in general to achieve an accurate phase difference. Thus, in this work, we focus mainly on the possible real-time detection of the phase using the above-explained SSB-AM-based calibration signal of $M(t)$.

Simulation and results: To check the feasibility of the idea, assuming that the PPD is an AM receiver applicable to the demodulation of both the DSB-AM and the SSB-AM, we compared the PPD outputs with changing the type of calibration signal from SSB-AM to DSB-AM while holding the frequency of the calibration signal $f_s = 1$ Hz. We note that the frequency of the calibration signal may be nothing to do with the details of the data to be transmitted, in principle. In addition, as can be seen from Fig. 2, that while the use of the DSB-AM signal leads to an imperceptible phase shift, the proposed SSB-AM-based detector well detects the phase shifts of the carrier signal.

Meanwhile, for the purpose of further investigations, we added the quadratic power detector function into the PPD as can be seen from Fig. 3.

In addition, we compared the output from the proposed SSB-AM-based detector with the one from the power detector in Fig. 4, which clearly shows that the SSB-AM-based phase shift detection shall be quite viable.

Conclusion: This Letter has introduced an SSB-AM-based detection of the phase and power shift for an APAA, which suffers in general from the phase deviations due to abnormal heat variation while functioning at the satellite. Simulation results show that the proposed scheme could distinctly detect the probable phase shift in an APAA. Although this Letter takes a rather theoretical approach with a noise free condition, we anticipate that the idea will be quite feasible and useful for detecting variation of the phase in APAAs for various space applications, in principle.

22 October 2014
doi: 10.1049/el.2014.3766
One or more of the Figures in this Letter are available in colour online.

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