SOME PROPOSALS FOR THE SSPS ACTUALIZATION FROM INNOVATIVE COMPONENT TECHNOLOGY STANDPOINT

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Abstract: The SSPS RF transmission method, beam control method and receive method are studied briefly to make sure that the final scale of the SSPS can be actualized using innovative component technology currently available with practical enhancement.

I. Introduction

In order to contribute to the SSPS actualization, many researches have been made from system level feasibility[1] to the component level feasibility[2]. Some of them created breadboard or prototype models, and evaluated whether or not their approaches can attain the proposed performance. Such models were configured with, by nature, extremely smaller or much-smaller number of components compared with the actual scale of the final SSPS. Due to such a limited fidelity of those models, a careful approach is naturally required from the standpoint that performances verified at the models can be succeeded to the final SSPS with no big theoretical and technological modification. Bearing this in mind, the authors made a study to configure each subsystem of RF transmission, the beam control and the rectenna, utilizing innovative component technology available at the present satellite communications with practical enhancement, so that the study results may be directly applicable to the final system. The major points of the study are as follows:

1) The RF transmission modules proposed so far require RF wave source signal distribution which has the same frequency as the transmitted RF wave, say, a few GHz, and therefore require many intermediate drivers between the source and each module when in-between distance is long at the final SSPS. Furthermore, the RF module itself comprising multistage SSPA reduces the DC to RF conversion efficiency. In order to resolve this problem, DDS-PLL technology is applied to RF transmission modules.

2) The conventional retro-directive configuration uses slightly different receive (Rx) and transmit (Tx) frequencies to minimize bilateral interference and maintain the phase conjugate characteristics. The isolation performance would be insufficient due to big difference of RF power between Rx and Tx, and would become sensitive to the used component characteristics. To overcome this difficulty, PLL-Heterodyne technology is applied to the beam control subsystem and enables the retro-directive configuration equivalently.

3) The most popular rectenna configuration would be the micro-strip antenna. If a large-scale, space and mobile application are assumed, how to make light weight the rectenna is a natural question. As a course of this study, rectenna configured with thin film and reduced grounded plane is evaluated analytically.

II. Ultra-low Loss RF Transmitter by DDS-PLL Technology

A simplified block diagram of the conventional RF module is shown in Fig.1(a). The RF module mainly consists of a phase shifter and multistage SSPA. Given the huge scale of the SSPS, a large number of power drivers would be needed between the source and each module to compensate the loss of the source signal. This would complicate the transmission assembly as well as the power consumption and weight. Configuration of DDS-PLL type RF module is shown in Fig.1(b). Output wave of high power VCO is synchronized exactly to the DDS output wave by PLL function. Multi-bit phase resolution of DDS can control the output phase of the VCO so that the phase array antenna can be constituted. By this application, one-order-smaller number of intermediate drivers, thanks to reduced need of the RF source distribution from GHz source to a few MHz clock, and more than two-times efficiency of DC to RF conversion, thanks to the FET use at the saturated region with no harmful phase degradation, should be achieved. Configuration of the developed power transmission system as a prototype is shown in Fig. 2[3], which employs 3 reflector array with 9 DDS-PLL modules. Output power of each VCO, comprising standard FET (35% as power efficiency) and diodes and DC to RF conversion efficiency are measured to be more than 8W and 21 %, respectively. When the same FET is used for the final stage of conventional SSPA, the efficiency is estimated to be less than 10 % due to driver stage power consumption and a few dB back-off for beam control. Since the FET power efficiency is improving drastically at C-band toward 80% range, DC to RF conversion efficiency of
future DDS-PLL module is estimated as 50% range. The authors also verified the reasonable beam scanning characteristics and radiation pattern of the prototype system as shown in Fig.3.

**III. Precise Retro-directive Beam Control by PLL-Heterodyne Technology**

Conventional approaches to the retro-directive system introduces slightly different frequency for Rx and Tx, say, 5.99 GHz and 6.01 GHz. The background of the approaches would be; a) obtain isolation between Rx and Tx as much as possible, b) obtain phase conjugate as simply as possible, and c) use the same antenna elements for Rx and Tx. Considering the big difference of the RF power between Rx and Tx, the isolation between those naturally becomes a big problem. In order to resolve this problem, the authors studied if more different Rx/Tx frequency (3.85 GHz for Rx and 5.77 GHz) is applicable, similar to satellite communication system. A block diagram of our proposed PLL-Heterodyne retro-directive antenna is shown in Fig. 4. The relationship among transmit frequency \( f_{tx} \), receive frequency \( f_{rx} \), and local frequency \( f_{lo} \) are;

\[
 f_{tx} = N f_{rx}
 \]

\[
 f_{tx} - f_{lo} = N (f_{rx} - f_{lo})
 \]

Figure 5 shows the principle of equivalent phase conjugate at a difference path of two adjacent antennae under the retro-directive control. By employing a frequency multiplier shown in Fig.4, phase difference between two adjacent antenna elements is multiplied according to the ratio of Rx and Tx frequency, and the transmit beam direction could, therefore, be controlled to the pilot signal direction. Furthermore, interference between Rx and Tx, could be easily suppressed by narrow bandwidth filter placed in front of the LNA. By this application, selection of the frequencies of Rx and Tx becomes flexible, maintaining the equivalent phase conjugate. For information, the authors plan the Rx and Tx antenna elements to be co-located.

**IV. Thin Film Rectenna by Micro-strip Antenna Technology with Reduced Ground Plane Configuration**

Conventional rectenna configuration employing the micro-strip antenna (MSA) is shown in Fig.6. In order to make light weight the rectenna, thin-film micro-strip antenna with reduced grounded plane would be one of the solutions. The authors quantified the characteristics of the MSA parametrically with thinness of substrate and reduction rate of grounded plane using analysis model shown in Fig.7 with 3D electromagnetic simulation. The result shows that film substrate thicker than 700 micron is necessary to obtain reasonably good radiation efficiency, say >50%, due to the effect of Q factor. Fig.8 shows the concept of grounded plane reduction method. The feeder line impedance is first selected so as to match \( Z_{in} \) obtained by analysis, and then the analysis to see \( Z_{in} \) dependence with respect to the grounded plane reduction \( a_0 - a \) is conducted.
under constant feeder line impedance. The result shows that the impedance matching is maintained within the range of \( a_\text{r} - a > \lambda/10 \) from Fig.9, and therefore grounded plane reduction to this ratio is acceptable. Through the chain of this study, it turns out that light-weighting approach using MSA thin film construction is so constrained and therefore further study with a different antenna type, say, a balanced strip-line type, is required.

V. Conclusion
Some study to apply the innovative component technology to actualize the SSPS is described. The advantage of DDS-PLL implementation is clearly proven through the prototype test. The PLL-Heterodyne implementation is theoretically advantageous to actualize retro-directive system, and the prototype test evaluation will follow shortly. The light-weight rectenna configuration still needs further study, but the authors believe solutions will exist along the extension of this study. The major point that the authors intended in this paper is “We should always make a step-by-step approach based on the existing innovative component technology with reasonable and practical enhancement, even targeting an extremely challenging object, such as the SSPS.” The authors would appreciate if wide support is given to this approach.

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REFERENCES