AN INTERFEROMETER-BASED PHASE CONTROL SYSTEM

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ABSTRACT

An interferometer-based phase control system for focusing and pointing the SPS power beam is discussed. The system is ground based and closed loop. One receiving antenna is required on earth. A conventional uplink data channel transmits an 8-bit phase error correction back to the SPS for sequential calibration of each power module. Beam pointing resolution is better than 140 meters at the Rectenna.

INTRODUCTION

Key to focusing and pointing the SPS power beam is the maintenance of precise phase relationships among the transmitted signals of each Spacetenna subarray. Specifically, the signals transmitted by each power module must arrive at the center of the Rectenna in phase. This results in a power beam having a planar wavefront pointed at the center of the Rectenna. However, structural deformations in the Spacetenna can, if not compensated for, alter the phases of the power module signals at the Rectenna by altering the path lengths of the signals between the power modules and the Rectenna. In addition, variations within the Spacetenna circuitry can also alter the phases of the signals.

Novar Electronics Corporation has developed an interferometer-based phase control system.[1] This approach, which we call Interferometric Phase Control (IPC), has three significant characteristics which differentiate it from the Reference System retrodirective approach.

1. Interferometric Phase Control is a ground based closed loop system.
   Unlike in the retrodirective approach, the phase correction information is obtained on earth by measuring the resultant power transmission of the Spacetenna power modules and comparing them against a reference.
2. The Spacetenna's power modules are calibrated sequentially.
   A signal from a reference transmitter near the center of the Spacetenna is sequentially phase compared with a calibration transmission of each of the power modules.
3. During normal power transmission, the frequency of each power module is shifted slightly during phase calibration.
   Maintenance of a properly focused and pointed power beam can be accomplished concurrently with the normal transmission of power from the SPS by using frequencies for calibration which are different from the power beam frequency.

SYSTEM DESCRIPTION

On or near the Rectenna site, an antenna called the Phase Measurement Antenna (PMA) receives the transmission from the Spacetenna Reference Transmitter (SRT) and the particular power module being phase tuned (calibrated). Analysis of these signals provides sufficient information to generate a phase error correction term which is sent up to the on-board phase control circuitry, shown in Figure 1, of the power module undergoing calibration.

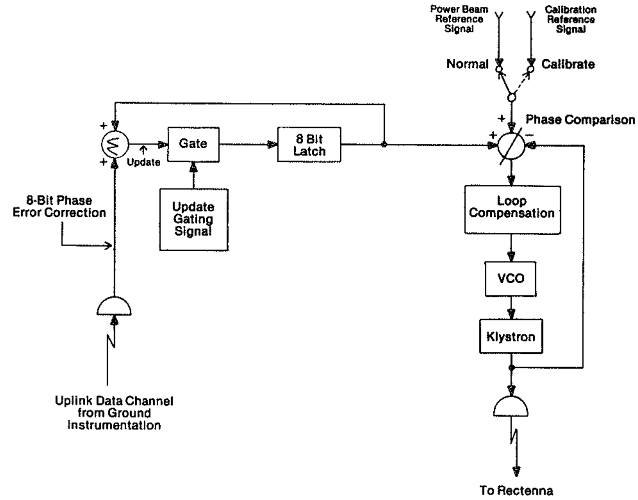

FIGURE 1
POWER MODULE PHASE CONTROL CIRCUITRY

Phase Tuning During Normal Power Transmission

Simultaneous with the transmission of the power beam, coherent signals at three different frequencies are transmitted from the Spacetenna. Two of these signals are transmitted from the SRT, which is located near the center of the Spacetenna, and one is transmitted from the power module being phase tuned, as shown in Figure 2. The two signals transmitted from the SRT are respectively called s_1 and s_{r1}, and the signal transmitted by the power module being phase tuned is called s_2. The frequency of s_1 is midway between that of s_{r1} and s_2 so that the beat frequency of s_1 and s_2 is the same as that of s_1 and s_{r1}.

At the PMA, simple mixing and filtering circuitry detects two difference frequency signals. One signal is due to s_1 and s_2. The other, which is called a phase reference signal, is that due to s_1 and s_{r1}. These two beat frequency signals are then phase compared.

The phase comparison gives the phase difference between the two beat frequency signals which is a function of z-axis deformations* in the power module being phase tuned plus biases in the phase feed network of the SPS. Certain components of the phase difference change with a change in frequency, others do not. Since the power module being phase tuned is transmitting at a frequency different from the power beam frequency, it is necessary to distinguish between these frequency dependent and frequency independent components in order to determine the phase

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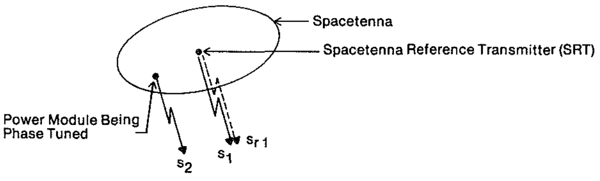
*deformations in a direction toward or away from the Rectenna.

correction that will be correct at the power beam frequency. This is done by shifting s_{r1} and s_2 to a different set of frequencies, according to a phase ambiguity error avoidance criterion, and making a second phase difference measurement. These two phase difference measurements are numerically adjusted by -2π, 0, or $+2\pi$ according to a second phase ambiguity error avoidance criterion. These two numerically adjusted phase differences provide sufficient information to calculate the phase error correction[2] transmitted back to the SPS power module being phase tuned. This phase error correction can be made with an 8-bit binary word sent to the SPS via a data channel. An 8-bit accuracy produces a phase resolution of $360^\circ \div 2^8 \cong 1.4^\circ$. This is sufficient to give a power beam pointing resolution better than 140 meters at the Rectenna.

A tradeoff exists between satellite bandwidth requirements and the power module updating rate which is limited by filter settling times. It is anticipated that the frequency spearation between s_1, s_2, s_{r1} and the power beam will be on the order of 1 MHz. At these frequency separations, the update interval for an entire Spacetenna could be on the order of a few seconds. It is possible that this will be fast enough to correct for any changes that will occur at the Spacetenna due to deformations, thermal effects, etc.



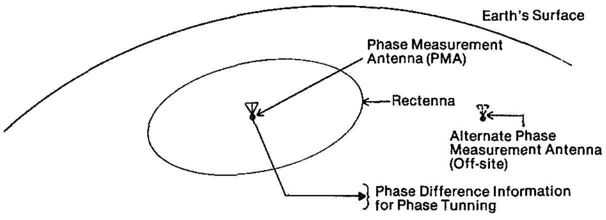


FIGURE 2
INTERFEROMETRIC PHASE CONTROL
-Pictorial representation of relationship between spacetenna signals and ground instrumentation.

Phase Tuning During Startup

It is also possible to use this interferometer technique to phase tune the power modules at the power beam frequency during initial startup or maintenance. This would be necessary to calibrate the phase tuning system used during normal power transmission for any phase vs. frequency nonlinearities. In this case, the measured phase difference is the phase error correction.

IONOSPHERIC EFFECTS

With the ground based closed loop interferometer phase control approach, ionospheric effects are limited to phase errors introduced into the space-to-earth transmission path only.

Although, the PMA is shown to be at the center of the Rectenna, it is not necessary that it be located there or even within the Rectenna site. Off-site measurement has the advantage that the signals being phase tuned do not have to pass through an ionosphere that may be subjected to undetermined heating effects by the power beam.

An important advantage of Interferometric Phase Control is its inherent ability to make use of statistical error reduction techniques to minimize any ionospheric effects. This includes time averaging and/or spatial averaging using several on and off-site phase measurement antennas.

PREDICTION OF DEFORMATION DYNAMICS/MAPPING

It should be pointed out that once the Spacetenna has been initially phase tuned, learning curves or adaptive modeling techniques could be used to predict the dynamics of Spacetenna structural deformations. With such predictions, it is felt that the capability would then exist to phase tune the entire Spacetenna based on frequency measurements of only a "few" key power modules and occasional measurements of the rest. By adding two additional receiving antennas on the earth so that there are three earth antennas spaced a few kilometers apart and not in a straight line, additional phase measurements can be made. These measurements provide information to "map" the face of the Spacetenna, that is, to determine the relative distance, direction and motion of each power module with respect to the SRT. This provides the capability for performing a transverse modal analysis, from the earth, of select samples of power modules on the face of the Spacetenna. In addition, the interferometer phase control technique provides the ability to automatically identify defective power modules.

CONCLUSIONS

Interferometric Phase Control (IPC) was originally developed as a closed loop, ground control approach for focusing and steering the power beam because of Novar's concern over effects that the ionosphere might have on the pilot beam of the retrodirective system. IPC could provide a useful adjunct to the retrodirective system to mitigate phase biasing problems with the retrodirective system and to provide a backup system if there are times when the atmosphere/ionosphere precludes use of a retrodirective system. Until definitive studies have been completed on the atmospheric/ionospheric effects on the retrodirective system, Novar recommends the simultaneous development of power beam control techniques using both the retrodirective approach and IPC.

REFERENCES

1. J. H. Ott and J. S. Rice: "Digital SPS Phase Control Using Traveling Wave Interferometry" Novar Electronics Corporation Technical Report, October, 1978.

2. *Ibid.*, p. 32.