The Front-End Design of a Hydrogen Spectral Line Receiver for Micro Satellite Navigation

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***Abstract*—Regarded as a promising source for future spacecraft navigation, the change in the energy state of neutral hydrogen atoms can provide a super stable electromagnetic radiation in the microwave region. Inspired by this concept, this paper specified the instrumental development of designing the front-end of a Hydrogen Spectral Line(HSL) Receiver receiver to support the micro-satellite navigation in space. The design included a array of 37 copper patches aligned in hexagon. Each patch was fed by microstrip lines to connect a 2-stage low noise amplifier. The a digital phase shifter was yielded to implement the phase control and electrically beam forming. The numerical simulation result showed that this front-end would provide a total 31.7dB gain and beam scanning angle between ±40 degree.**

I. Introduction

Hydrogen line spectral , also named as 21-centimeter line, is a celestial phenomenon in radio astronomy which has strong flux density as spectral line. This natural phenomenon is triggered by the change in the energy state of neutral hydrogen atoms. As the result, the electromagnetic radiation is at the precise frequency of 1420405751.7667±0.0009Hz which is equivalent to the vacuum wavelength of 21.1061140542 cm in free space. Since the prediction of its existence and experimental verification in 1951[1], this phenomenon has shown strong support in the exploration of galaxy formation and development. Meanwhile, according to its super stability in the radiation frequency, it has been regarded as a promising source for future spacecraft navigation[2]. The essence of this idea was to measure the Doppler velocities of the spacecraft with respect to the Hydrogen line source such as masers or pulsars[3]. However, the state-of-art of receiving the radiation on the earth was using large parabolic antenna with mechanic scanning device, the same as the way that many astronomical observatories utilize. The limited dimension of spacecraft cannot accommodate the large parabolic antenna on board. Inspired by this concept, this paper proposed a front-end design of HSL receiver for the micro satellite navigation.

II. Front-end Design Requirement Analysis

There have been two main requirements to design the receiver.

1) Signal amplification and denoising: In the near-Earth space, HSL radiation becomes very weak and almost blended in the noise. For example, we used Perseus Arm as the potential source, which is about 6370 light-years away from the Earth. Its approximate energy flux density is about $6.4 \times 10^{-14} J/m^2s$, equal to $0.6ph/cm^2s$. It is assumed that the noise temperature is 300K. The signal-noise-ratio is about -27dB. If the bandwidth of the hydrogen line radiation is 2.8MHz, the noise power is about -139dBW. So the radiation will be amplified in the narrow frequency band when it is received by the antenna and at least 30dB gain would be provided from the antenna to the Analog-digital converter. Also the digital signal processing will contribute more in denoising.
2) Beam forming: instead of scanning mechanically, digital beam forming technique can be used to carry on the digital weighting to the antenna array and control the antenna beam to fulfill different observation directions. In this case, the HSL receiver can observe more than one radiation source.

III. Receiver configuration

The basic module structure of this receiver was shown in Fig. 1. This module consisted in a micro-patch antenna, a two-stage low noise amplifier and a phase shifter. The electromagnetic radiation from the HSL source can be received and amplified. The phase shifters were used to implement the phase control and further enable the electrically beam scanning when a number of these modules work in array.

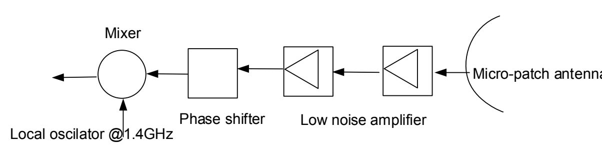

Fig. 1. The basic module structure of hydrogen line spectral receiver.

A. Micro-patch antenna

Fig. 2 showed the geometry of the proposed antenna module. The module consisted in a etched patch on the FR4 substrate, operating at 1.4200GHz with the frequency bandwidth of 30MHz. The relative permittivity was 4.3. The height of the micro patch was 0.035mm and the height of substrate was 1.6mm. The simulated result in CST MICROWAVE STUDIO was shown in Fig. 3. The gain of this single patch module was 7.7dBi.

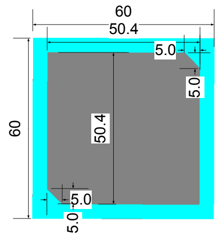

Fig. 2. The micro-patch antenna module.

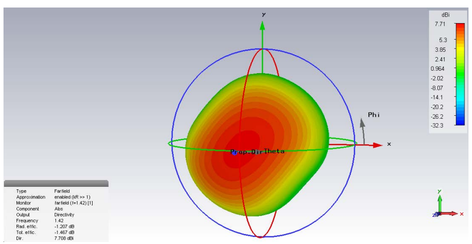

Fig. 3. The radiation of the micro-patch antenna module.

B. Low Noise Amplifier

We selected the GaAs pHEMT MMIC(monolithic microwave integrated circuit) from Analog Devices, HMC618ALP3E, as the low noise amplifier operating between 1.2-2.2GHz. Two chips were connected to provide 38dB gain. Also this chip is featured with 0.75dB noise figure and +36 dBm output IP3 from a single supply of +5V[4].

C. Phase Shifter

We selected the GaAs MMIC, HMC936A, also from Analog Devices as the phase shifter. This circuit is able to provide 360 degrees of phase coverage, with a minimum step of 5.625 degrees from 1.2 to 1.4GHz and low insertion loss variation of ±0dB across all phase states. The phase states can be digitally controlled by six external input voltage pins[5].

D. Mixer

An integrated RF Mixer from Qorvo, RF2051, was used to implement the down conversion from 1.4GHz to the IF. This integrated mixer includes an integrated fractional-N phase locked loop with voltage controlled oscillators and dividers to produce a low-phase noise local oscillator signal with a frequency resolution of 1.5Hz. The conversion gain is -2dB and the mixer input IP3 is +18dBm[6].

IV. System performance analysis

The receiver was formed with 37 basic modules aligned in hexagon, shown as in Fig. 4. The vertical and horizontal distance between each module's geometry center was 70mm. We used the numerical simulation to show the system performance in the hexagon alignment to implement the beam scanning from -45° to 45° using 6 bits. The array formation will increase the antenna gain up to 17dB. The simulated result was shown in Fig. 5.

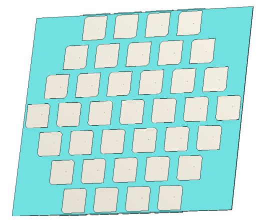

Fig. 4. The antenna array in hexagon.

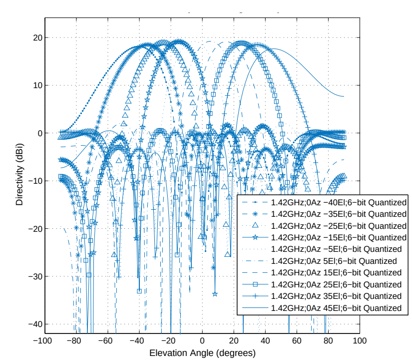

Fig. 5. The simulated phased control performance.

V. Conclusion

The paper introduced a concept of a HSL receiver for the spacecraft navigation and discussed the implementation of its front-end including the electrically beam scanning antenna array, low noise amplifier and down converting mixer. The numerical simulation showed that this receiver can provide a system gain of 31.7dB and fulfill a scanning beam for the observation of different HSL sources. This receiver is under the manufacturing for the future space verification.

References

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