Novel Technique of Measuring Millimeter Wave of Cold Atmospheric Plasma Array

Bryon Eckert[1], Huan Truong[1] and Mina Izadjoo[2]
[*]Trideum Biosciences, Frederick, MD, USA, mizadjoo@trideumbiosciences.com
[**]Chiscan LLC, Tempe, AZ, USA, bryon@chiscan.com

ABSTRACT

Numerous published papers have noted biological effects based on the modulation frequency of non-thermal air plasma. This experiment examines a possible link between the microwave fine resonances of oxygen in the 60 GHz region, and the therapeutic frequencies used in Russian non-thermal EHF therapy. An array of several hundred non-thermal plasma plumes are placed directly in front of a circular horn. A switchable circular polarizer is used to select left hand circular, linear or right hand circular polarization. A programmable frequency converter covers 55.3 to 66.1 GHz at a noise temperature of less than 1150 K. A frequency scan and averaging algorithm is developed to characterize noise temperature versus frequency, comparing noise levels between plasma on and plasma off. Typical equivalent noise bandwidth is 240 kHz with noise averaging of 16384 for a noise temperature resolution of 2 K. Noise levels are observed while switching polarization sense.

Keywords: EHF, biological, plasma, polarization

1 INTRODUCTION

Numerous published papers have noted biological effects based on the modulation frequency of non-thermal air plasma [1]. Another energetic biological effect which has been widely studied in eastern Europe is non-thermal EHF radiation. Some common therapeutic frequencies are 53.6 GHz and 61.2 GHz [2], corresponding to some of the fine resonance frequencies in the oxygen microwave absorption spectrum [3].

Power levels range from 1 pW/cm^2 to 10 mW/cm^2, and biological effects are weakly related to power level. A typical signal source for EHF therapy is a cavity stabilized Gunn or IMPATT oscillator, frequency modulated over a 10 MHz bandwidth to ensure the source frequency sweeps over the precise oxygen fine resonance. Alternatively, the signal source may be an IMPATT device which generates broadband noise between 40 and 80 GHz at the microwatt level.

Since frequency selective EHF therapeutic effects have been observed at extremely low power levels, a search for 60 GHz energy from an array of non-thermal air plasma plumes may provide additional data for examining the therapeutic mechanisms of plasma medicine.

A typical plasma array element is shown in Figure 1. The top element is a metal ring with protruding points to concentrate the electric field, initiating plasma discharge in defined areas. The substrate material is 200um thick FR4, and the plasma is driven at about 100 kHz. Within the area of the horn opening are about 50 plasma elements or 300 plasma plumes.

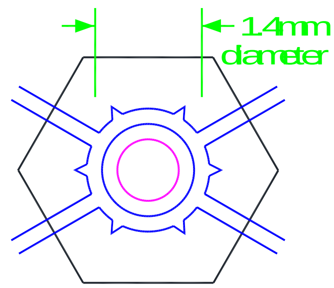

Figure 1: Plasma array element.

The electrical distance between plasma points along the microstrip ring is about $\lambda/4$ at 60 GHz. During each cycle of the driving waveform, the initiation of plasma discharge creates a localized non-homogeneous magnetic field pulse. This separates out atoms with higher energy state, and hence creates localized areas of population inversion.

The resonant mutual coupling between the elements in the plasma array should create a mechanism for stimulated emission at the various fine resonance frequencies of oxygen in the 60 GHz range.

Because the effect would most likely occur in the nanosecond region, it would be seen as broadband noise. Atmospheric studies have shown thermal noise peaks at oxygen fine resonance frequencies in the 60 GHz range [4]

The noise peaks we expect to see should be a combination of thermal noise and the proposed maser mechanism. The radiation of astrophysical masers is typically circularly polarized, so gathering data with both left hand and right hand circular polarization should help detect this. Biological effects have also been linked with circular polarization, with effects observed only with the correct polarization [5].

The atmospheric absorption of oxygen has created commercial interest in 60 GHz short range radio development. A 60 GHz receiver module can be used in a relatively inexpensive apparatus designed to search for low level microwave signals from a plasma array.

2 EQUIPMENT DESCRIPTION

A block diagram of the experiment setup is shown in Figure 2. The circular horn, switchable circular polarizer and associated circular to linear waveguide transition are purchased from Quinstar.

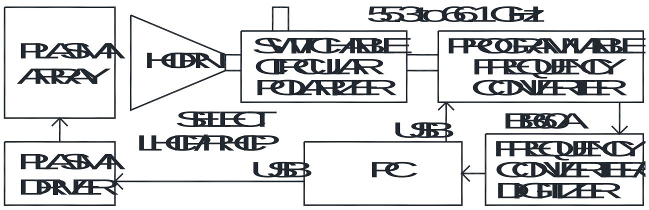

Figure 2: Experiment Block Diagram

The heart of the programmable frequency converter is a 60 GHz SiGe receiver module currently distributed through Pasternack Enterprises. The receiver module has the following features:

- WR-15 waveguide input with standard flange
- Noise Figure: 6.0 dB typical
- Gain: 38 dB minimum at 1.65 GHz IF
- Power dissipation: 600mW typical

A block diagram of the receiver module is shown in Figure 3. The low side image from the sliding IF, which is around 45 GHz at a maximum, is filtered by the LNA design. The synthesizer frequency dividers are determined by the allowable programmable divider output frequency,

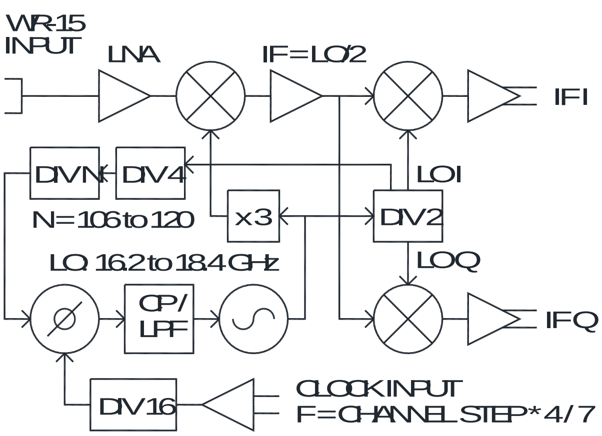

Figure 3: 60 GHz Receiver Module Block Diagram

The programmable frequency converter block diagram is shown in Figure 4. A 2.4 GHz frequency synthesizer and associated frequency divider generate the reference clock for the synthesizer inside the receiver module.

A quadrature coupler and associated switches are used to select between upper and lower IF sideband, extending the usable frequency coverage of the receiver within the bandwidth limits of the LNA.

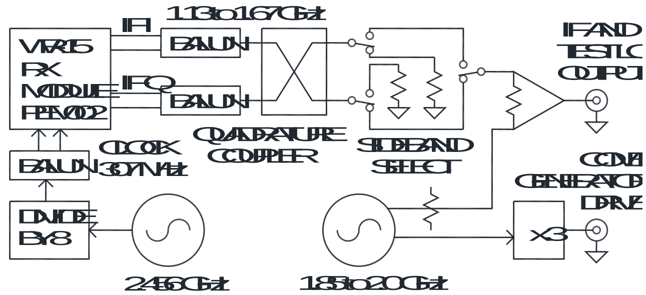

Figure 4: Frequency Converter Block Diagram

A separate frequency synthesizer generates a signal for testing the converter. This can be used to test proper synthesizer programming, opposite sideband rejection, and antenna axial ratio. The basic frequency range is 1.85 to 2.0 GHz. This is routed through a signal combiner to the IF output for verifying the test synthesizer.

The test synthesizer frequency is also multiplied by 3 by a chain of multiplier, filters and amplifiers. Typical output level is +13dBm, suitable for driving an external Schottky diode as a comb generator for generating test signals in the 60 GHz range. A photo of the programmable frequency converter is shown in Figure 5.

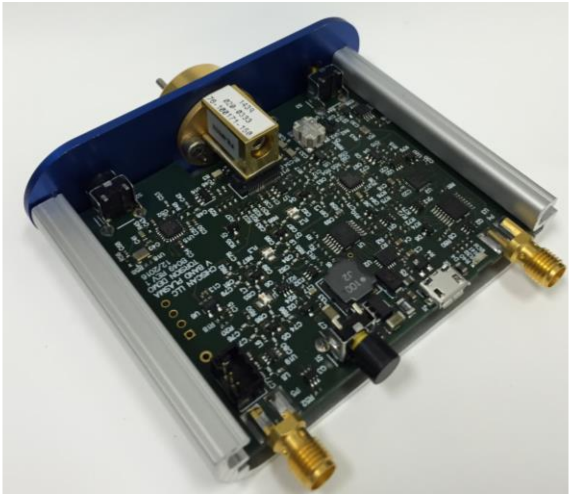

Figure 5: 60 GHz Programmable Frequency Converter

The IF output from the programmable frequency converter connects to a Signal Hound BB60A spectrum analyzer. This is actually a tunable frequency converter and digitizer, since the spectral analysis is performed on an external PC.

The BB60A ADC sample rate is 80MSPS, and the usable analysis bandwidth of 20 MHz is set by the SAW filters before the ADC. A block diagram of the BB60A as used in the specified range of 1.13 to 2.0 GHz is shown in Figure 6.

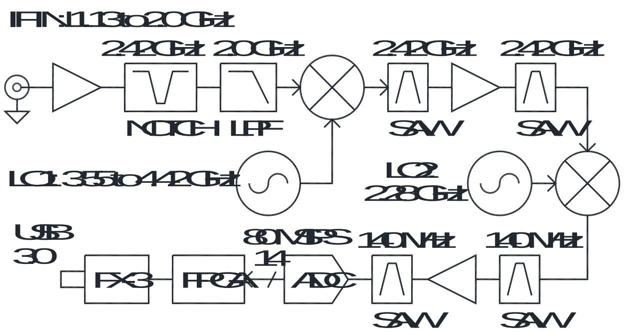

Figure 5: BB60A Block Diagram

The data from the ADC is routed through an FPGA and Cypress FX3 USB3.0 bridge to a PC. Because of the high continuous data rate, the CPU should be at minimum Intel i7 third generation quad core.

3 SOFTWARE ALGORITHM

Spectral analysis is done by FFT to improve analysis speed. The FFT bandwidth must be higher than the plasma drive frequency. For the 80 MSPS sample rate, an FFT size of N=512 creates an equivalent noise bandwidth of 240 kHz.

The FFT results are averaged to smooth the noise floor. Noise temperature resolution of 2 K can be obtained with an averaging size of N=16384, requiring a measurement time of 105 ms. Data is taken with plasma on, and with plasma off. Because the plasma is driven at a duty cycle of about 10%, a frequency scan will require 1 second per channel.

The frequency reference for the synthesizers inside the 60 GHz programmable frequency converter is a 40 MHz TCXO. The synthesizers are Analog Devices ADF4360 series integer N with internal VCO. To minimize the phase noise floor, a high frequency is used on the phase detector.

The step size of the receiver module synthesizer is 7/4 of the clock. A clock frequency of 307 MHz minimizes the clock synthesizer noise floor, and sets the receiver synthesizer step size to 537.25 MHz. The I and Q IF outputs are connected to a quadrature hybrid coupler. The coupler outputs are switched to pass either the high side or low side IF frequency, and reject the opposite sideband.

Although the synthesizer covers 15 channels, some channels are set to low side IF output. Setting the sideband sense along with the LO channel frequency makes a total of 21 receiver channels between 55.28 and 66.14 GHz.

The BB60A spectrum analyzer acts as a programmable frequency converter. Since the first IF frequency is 2420 MHz with 20 MHz bandwidth, the first synthesizer is programmed to tune from 3560 to 4080 MHz in 20 MHz steps.

Each IF scan uses a total of 27 channels, except for the frequency overlap when the IF sideband is switched from low to high. In this case, 21 channels can be skipped. For a full frequency scan, a measurement is performed on a total of 546 IF channels.

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