Sensors & Transducers

A Novel Technology for In-Vitro Electromagnetic Modulation

[1] Bryon Eckert, [1] Bradley Eckert, [1] Huan Truong and [2] Mina Izadjoo

[1] Trideum Biosciences, Frederick, MD, USA
[2] Chiscan LLC, Tempe, AZ, USA
E-mail: mizadjoo@trideumbiosciences.com, bryon@chiscan.com

Abstract: Numerous published papers have noted biological effects based on the modulation frequency of plasma and radio frequency fields, as well as the frequency of electric and magnetic near-field emitters. However, clinical studies in energetic medicine are difficult to justify because the physical mechanism behind the biological interaction is not well understood. Clinical studies are also very expensive and the protocol for selecting an optimum frequency is poorly defined. These problems can be mitigated by studying a bacterial, fungal or viral culture *in vitro* in the laboratory. An array of 96 emitting elements is placed underneath a 96 well culture plate. The array is connected to an FPGA, which generates a set of 96 separate frequencies simultaneously. This speeds the frequency search. The array is also thermally controlled to incubate the culture. Arrays are designed for non-thermal plasma, RF 2.4 GHz, electric, magnetic and optical (LED) stimulation. *Copyright © 2016 IFSA Publishing, S. L.*

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1. Introduction

Previous authors have noted biological effects and cancer therapies based on the modulation frequency of non-thermal plasma [1], modulation frequency of an RF carrier [2], frequency of an electric near-field emitter [3], and pulse frequency of LED light sources [4].

Modern experiments echo the earlier work of Royal Rife, but clinical studies are difficult to justify because the physical mechanism behind the biological interaction is not well understood.

Clinical studies are also very expensive and the protocol for selecting an optimum frequency is poorly defined. These problems can be mitigated by studying a bacterial, fungal or viral culture *in vitro* in

the laboratory, to create a more solid foundation for the science.

The key to reducing the cost of laboratory study in a frequency search is to apply many different frequencies to the culture simultaneously. A good starting point for laboratory use is a standard 96 well culture plate. The instrument should be designed to incubate the culture as well as apply modulated energy to each well.

A picture of the modulation array instrument with 96-well culture plate is shown in Fig. 1.

The modulation array instrument is designed with a common set of electronics for the following:

- Power supply;
- Memory card socket (for managing control and test data in the laboratory);
- Thermal control;

- User interface (2 x 20 character OLED and buttons);
- RS-485 communications for connecting multiple units to a PC via MODBUS;
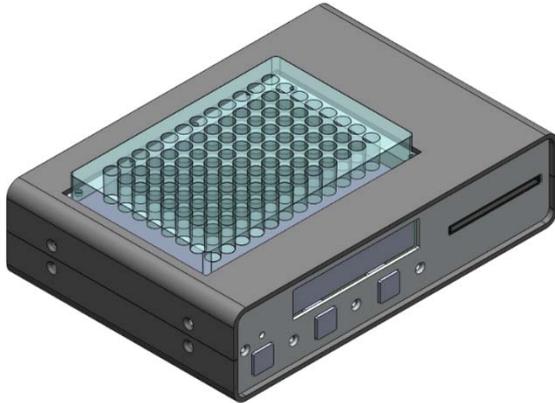- Square wave signal generation on up to 96 signal lines.

Fig. 1. Modulation Array.

A block diagram of the modulation array instrument is shown in Fig. 2. The array and associated electronics are thermally coupled to a heat sink, with thermoelectric device (TEC, for heating or cooling) and fan.

The heat sink and internal electronics are thermally insulated from the case. The fan draws in air from the bottom of the case, past the heat sink and up past the culture tray on top.

Multiple temperature sensors are used for thermal control, including a sensor on the array element module, a sensor on the metal enclosure, and a sensor on the heat sink.
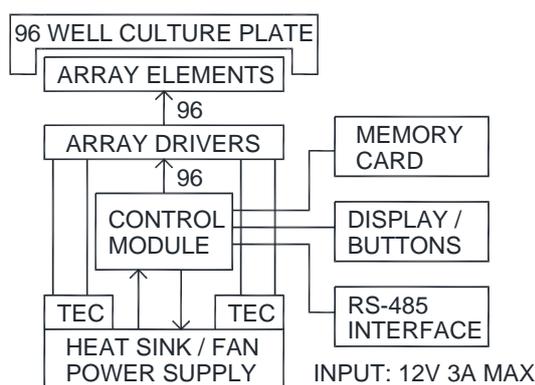

Fig. 2. Modulation Array Block Diagram.

The FPGA is a Xilinx Artix 7. Each signal generator is implemented in VHDL code as a phase accumulator, or numerically controlled oscillator (NCO). The output consists of the most significant bit of the phase accumulator.

Using only a single bit of the output will add deterministic phase jitter, but allows us to easily define 96 units with reasonable FPGA resources. Using a 200 MHz clock and both edges of the clock, the peak timing uncertainty will be ± 2.5 ns.

A typical output frequency will be in the audio range but may go higher. Since the jitter is deterministic, it will manifest as discrete spectra rather than noise and we expect that it will not significantly degrade biological interaction.

2. Array Elements

There are five different array options:
- 2.4 GHz RF;
- Electric field;
- Magnetic field;
- LED;
- Non-thermal plasma.

2.1. RF Array

The RF array element is a resonant structure consisting of a printed spiral inductor and series capacitor, which presents a good impedance match at 2.44 GHz. This is not an efficient antenna since most of the power is dissipated in the spiral structure, but it is meant to couple near field energy into the culture well above it.

The matching is relatively narrowband, and the RF frequency may be adjusted to get an optimum match. A circuit for measuring the forward and reverse power on a single element is included, on the assumption that all the other elements will be very similar.

The antenna array is a separate circuit board, fitting inside the bottom well of the culture tray. The array driver consists of a large number of Wilkinson power splitters, RF switches and load resistors. The digital signals from the FPGA are routed to this module and create a distinct modulation frequency underneath each well.

The RF array driver also contains a TCXO and frequency synthesizer, as well as amplifiers and attenuators for controlling the RF level. The power into the modulation section is -10 dBm to +17 dBm, but the maximum radiated power from the array is expected to be about 1 mW. The RF array antenna structure top view is shown in Fig. 3, and a cross-section view of the array driver is shown in Fig. 4.

2.2. Electric Field Array

The electric field array is a separate circuit board, fitting inside the bottom well of the culture tray. Below this is a thermal pad to transfer heat through the array driver to the tray.
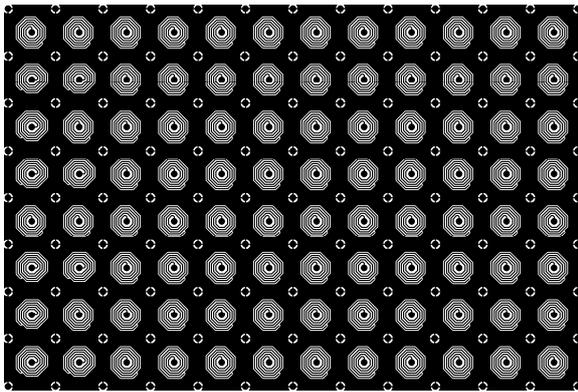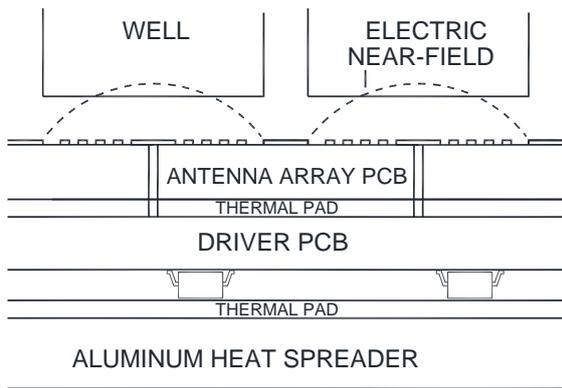
Fig. 3. RF array antenna structure.

Fig. 4. RF array driver cross section.

An illustration of the electric field flux is shown in Fig. 5. For a driving voltage of 5 Vp-p, the peak field strength should be between 1.5 V/cm and 2.5 V/cm. This field strength is similar to a current cancer therapy. A top view of the array is shown in Fig. 6.
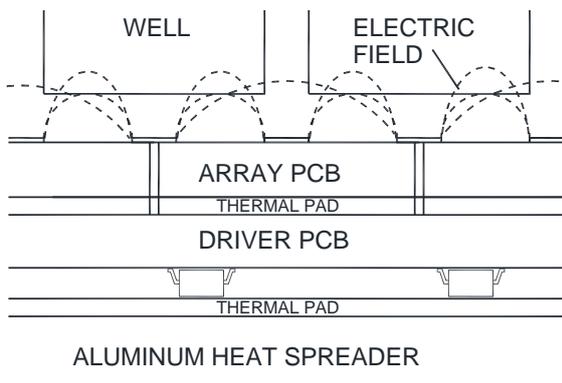

Fig. 5. Electric array element cross section.

If higher electric field strength is desired, the array driver voltage can be increased to 190 Vp-p up to 100 kHz, by using high voltage amplifiers. The peak electric field in the culture well should be between 60 and 100 V/cm. In this case, the electric

field array driver also contains a voltage boost converter to generate the 200 V bias for the amplifiers.
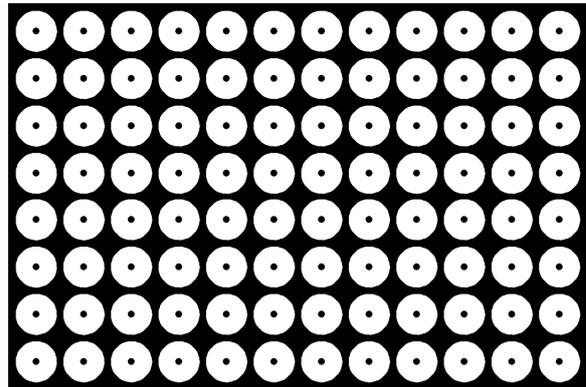
Fig. 6. Electric field array top view.

2.3. Magnetic Field Array

A cross section of the magnetic array and driver is shown in Fig. 7. The magnetic field array is a separate circuit board, fitting inside the bottom well of the culture tray, functioning mainly to hold the tops of the ferrite bars. It also contains a temperature sensor. Below this is a thermal pad to transfer heat through the array driver to the tray.
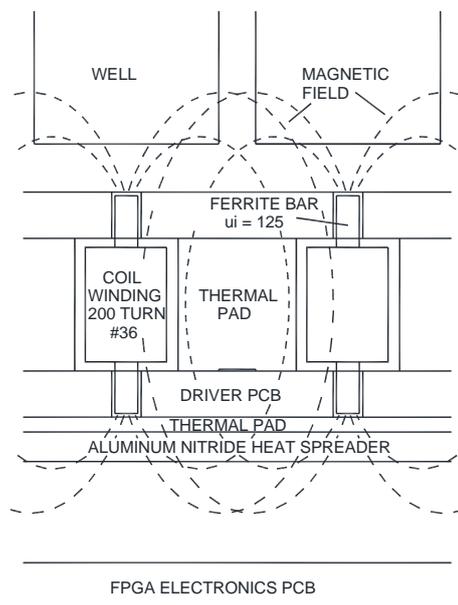

Fig. 7. Magnetic field array cross section.

The magnetic element consists of a ferrite bar, with a length of 7.5 mm and diameter of 0.8 mm. The coil winding around the bar consists of 200 turns of #36 wire, presenting about 100 uH of inductance.

The moderate permeability (ui=125) of the ferrite bar will tend to efficiently couple higher harmonics generated by the driving waveform. The duty cycle

of the driving waveform is adjusted to produce a DC bias of 2 mA at 5 V.

A circuit for monitoring DC bias is connected to a single element, on the assumption that all elements are similar. A calibration routine will determine the required duty cycle for a given frequency.

The heat spreading plate, which is used to conduct heat past the controller board over to aluminum blocks (which conduct heat down to the thermoelectric devices), is constructed of Aluminum Nitride. This keeps metal farther away from the ends of the inductors. The driver PCB maintains an area around the ferrite bar with no metal for a diameter of 0.25 inches.

2.4. LED Array

The LED array is a single module, with the LED lenses inside the well of the culture tray. A thermal pad may be added around the LEDs to improve thermal transfer to the tray.

The LEDs are 1206 package with lens. A wide variety of wavelengths are available, from NIR 850nm to UV 395nm. The LED drivers are designed to run at a fixed current, but the average power can be reduced by adjusting the duty cycle. A cross section of the LED array is shown in Fig. 8. The LEDs are mounted upside down into the driver PCB to create a flush surface for thermal contact with the culture dish.
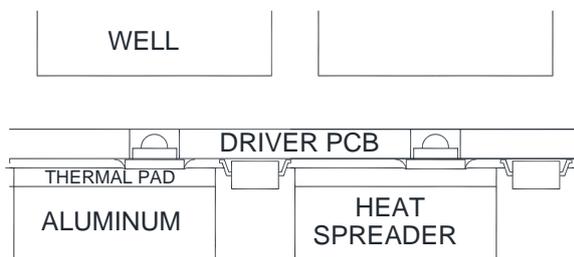

Fig. 8. LED driver cross section.

2.5. Plasma Array

The non-thermal plasma array is a separate circuit board, fitting inside the bottom well of the culture tray. Below this is a thermal pad to transfer heat through the array driver to the tray. This is designed to be replaced by the user at the end of its useful life.

The plasma array driver requires multiple lines from the FPGA to control the plasma driver and high voltage transformer, so there are a total of 24 drivers. Each driver is connected to a set of 4 micro-plasma arrays, which sit underneath the culture wells.

Each set of plasma arrays presents a capacitance of about 20 pF. This capacitance resonates with the plasma drive transformer, and the plasma drive frequency is expected to be about 420 kHz.

The plasma modulation frequency is adjusted inside the FPGA up to 10 kHz. The plasma tends to run at a fixed current, and a duty cycle of 10 % is recommended to reduce average power and extend the array life.

Fig. 9 shows a cross section of the plasma driver with plasma array. The distance between the plasma dielectric and the base of the culture dish is defined by the copper and solder mask thickness at about 2 mils. To maintain constant plasma characteristics, ventilation holes are added outside the plasma areas.
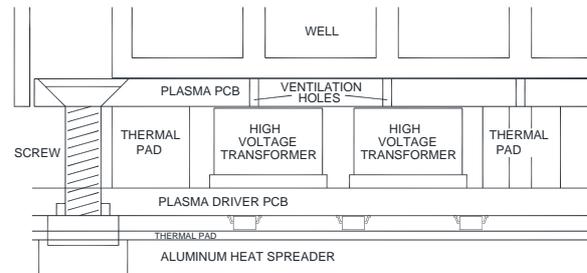

Fig. 9. Plasma driver cross section.

A top view of the plasma array is shown in Fig. 10. A 6mm pitch header plugs into the driver, and a temperature sensor is mounted to the bottom. The top circles with points connect to ground, and a buried layer connects to the 24 high voltage AC lines.
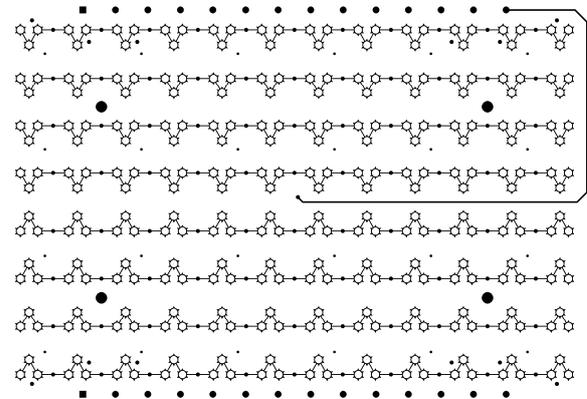

Fig. 10. Plasma array top view.

For any given array module, the associated thermal pads are laser cut to accommodate the different component layouts.

3. Software

Software for the modulation array will generate frequency and temperature control data as part of the research program. At a minimum, this will all be stored in a database, and written to a memory card as well.

Since the lab technician is most likely preparing, staining and monitoring the cultures, handling the

data cards as well is a convenient way to run the program.

The software keeps track of program frequencies used. In the case of an observed effect, the location of the modulation frequencies can be shuffled by the software and repeated to see if the effect in the culture is repeatable. This also compensates for signal overlap between adjacent array elements.

If a large number of arrays need to be managed, connecting up to 128 units in an RS-485 daisy-chain is relatively straightforward. The units set their addresses automatically, and use the MODBUS protocol. The interface is designed so the unit which is first in the cable chain from the PC has the lowest address, and the subsequent units have sequentially higher addresses.

Some sections of this article was included into a poster presentation at the 2016 TechConnect World Innovation Conference held in May 23-25, 2016. National Harbor, Maryland, USA [5].

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