RFIT 2022

2022 IEEE International Symposium on Radio-Frequency Integration Technology

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Program Booklet

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W3B: Emerging Technologies, Circuits, Systems, and Applications

13:30 – 15:10, Wednesday, 31-Aug, Room: Vernazza

Chairs: Tae Wook Kim, Yonsei University
Jaeduk Han, Hanyang University

W3B.1 *Invited*
13:30 – 13:50
A Wearable Oscillator Tag for Heart Health Monitoring
Tzyy-Sheng Jason Horng (National Sun Yat-sen University, Taiwan); Rezki El Arif (Universitas Brawijaya, Malang & National Sun Yat-Sen University, Kaohsiung, Taiwan); Wei-Chih Su (National Sun Yat-sen University, Taiwan)

W3B.2 *Invited*
13:50 – 14:10
Planar Microwave Sensors for Measuring Materials Composition and Mechanical Parameters
Kamran Ghorbani and Amir Ebrahimi (RMIT University, Australia)

W3B.3 *Invited*
14:10 – 14:30
Emerging Computing Systems Utilizing Electro-Magnetic Near-Field Connectivity
Noriyuki Miura (Osaka University, Japan)

W3B.4 *Invited*
14:30 – 14:50
140 GHz Silicon I/O Interconnect Exploiting Metadevices for Short-Range OOK Communications
Hao Yu (SUSTech, China); Yuan Liang (Nanyang Technological University, Singapore); Hao Chi Zhang and Tie Jun Cui (Southeast University, China)

W3B.5 *Invited*
14:50 – 15:10
RF Front-End Transmitting System for Agricultural Applications
Phanam Pech, Samdy Saron, Girdhari Chaudhary, Yu Kyeong Shin and Jun Gu Lee (Jeonbuk National University, Korea (South)); Yongchae Jeong (Chonbuk National University, Korea (South))

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RF Front-End Transmitting System for Agricultural Applications

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***Abstract*—In this paper, a design of an RF front-end transmitter for actuating greenhouse plant leaves with electromagnetic wave is proposed. The proposed RF front-end transmitter consists of a phase-locked loop (PLL), variable attenuator, power amplifier (PA), protector and detector circuits, and antenna. The overall circuit is designed for ISM band application with a center frequency of 2.45 GHz. The attenuation range of the variable attenuator is 20 dB. This variable attenuator is connected between PLL and driver PA to control the radiated electromagnetic wave power level for the optimum plant growing condition. The RF power higher than 20 W can be obtained at the output port of PA. The protector and detector circuits consist of the isolator, dual directional coupler, and RF detecting circuits. The isolator is used to protect the PA from the reflected power when the antenna is disconnected from the system. The RF detecting circuits are connected to the couple ports of the dual directional coupler to check long time operation. The designed PAs have been operated very well on humid operating conditions for 14 days.**

Keywords—Actuating greenhouse plants, microwave energy, RF front-end, transmitting system.

I. Introduction

As stated, a greenhouse often needs heating all year round, typically by the burning of fossils such as oil and natural gas. Specific power requirements vary depending on the time and season [1]. Oil prices have risen to record levels nowadays and most sources indicate peak oil supply has been reached [2]-[4]. As such, governments worldwide have been seeking another solution to solve this problem. The use of microwaves in growing plants is reported in the literature. The heating of mature tomato and pepper crops, in a cavity within a greenhouse and using microwave radiation, with a specific emphasis on reducing the occurrence of grey mould are investigated in [5]. In [5], the authors claimed that it was possible to heat the plants without visible damage and with no increase in susceptibility to grey mould. The greenhouse air did not warm up and remained at a nearly constant temperature. They also claimed that the energy required for microwave heating was 55% of that required by hot-air heating. Plants were deliberately infected with grey mould

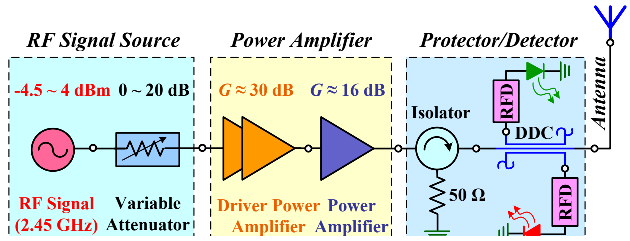


Fig. 1. Structure of proposed RF front-end transmitter system for agricultural applications.

after or before microwave heating and placed in warm and humid conditions to encourage the onset of mould growth. The authors found that the susceptibility to grey mould was lower in greenhouse plants radiated with electromagnetic waves and these leaves were warmer than the air at all times. The fruit was found to be cooler and nearly constant in temperature, compared to the leaves, which were the warmest components. This was attributed by the authors, to the fruit having a much larger mass of water than the leaves.It was claimed that exposure to electromagnetic wave radiation resulted in no visible injury to leaves, flowers, and fruits.

A further application of electromagnetic waves on living plants has been for the destruction of weeds in agricultural fields, as an alternative to low efficiency thermal methods [6]. It has been shown that small herbaceous species in fields can be destroyed by a tractor-towed array of high power electromagnetic wave source radiate the ground. A novel kind of greenhouse is currently being developed and is reported in the literature [7]. The greenhouse design used a specially shaped roof and reflective lining to divert near infra-red radiation towards an array of water-cooled photovoltaic cells. In summer, this allowed the collection of low grade heat, as well as the generation of electricity. The photo-synthetically active radiation is allowed to pass through the covering, enabling the plants inside the greenhouse to grow, whilst reducing overheating. In winter, stored heat can be recovered using an electrically powered heat pump to supplement greenhouse heating. However, these electromagnetic heating systems are difficult to design and install.

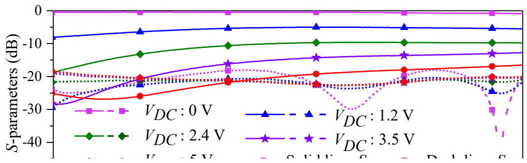


Fig. 2. Measured *S*-parameters of variable attenuator.

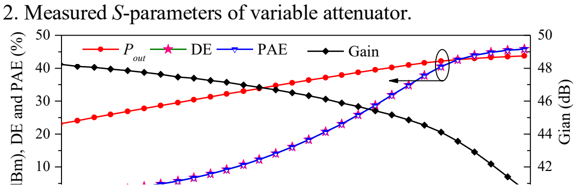


Fig. 3. Measurement results of 3-stage PA.

In this paper, we proposed a design of an RF front-end transmitter system for agricultural applications. The proposed heating system consists of a phase-locked loop (PLL), variable attenuator, power amplifiers (PAs), protector and detector circuits, and antenna. The PLL is used to generate the RF signal while the variable attenuator is used to control the radiated electromagnetic wave power for the optimum plant growing condition. This small signal is amplified by PA. The protector and detector consist from the isolator, dual directional coupler, and RF detecting (RFD) circuit. The isolator is used to protect PA from the reflected power when the antenna is disconnected from the system. The RFD circuits are connected to the couple ports of dual directional coupler. A patch antenna was designed and used to radiate electromagnetic wave in this work.

II. RF Front-End Transmitter Design

Fig. 1 shows the structure of the proposed RF front-end transmitter for agricultural applications. The proposed RF front-end transmitter consists of PLL, variable attenuator, PAs, protector and detector circuit, and antenna. The selection and designation of each block in the structure are described as the following.

A. Phase-Locked Loop

A phase-locked loop (PLL) is a control system that generates an output signal whose phase is related to the phase of an input signal. There are several types; the simplest is an electronic circuit consisting of a variable frequency oscillator and a phase detector in a feedback loop. The oscillator generates a periodic signal and the phase detector compares the phase of that signal with the phase of the input periodic signal, adjusting the oscillator to keep the phases matched. Keeping the input and output phase in lock step also implies keeping the input and output frequencies the same [8]. In this work, ADF4351 PLL/signal generator was used to generate a sine wave. This PLL/signal generator was able to generate the signal with a frequency range from 35 MHz to 4.4 GHz.

B. Variable Attenuator

Variable attenuators, which primary function is to provide amplitude control for various applications, are key components in wireless communication and measurement systems. The variable attenuators are also used in RF systems for gain control [9]. In this work, a variable attenuator is connected between PLL and driver PA to control the input power level of PA. Generally, the output power level of PA is related to the input power level.

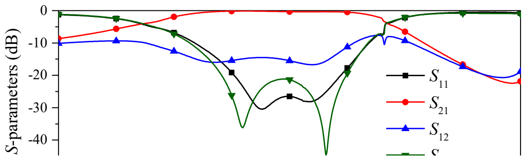


Fig. 4. Measured *S*-parameters of protector and detector circuit.

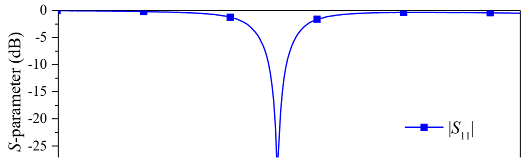


Fig. 5. Measured *S*-parameters of patch antenna.

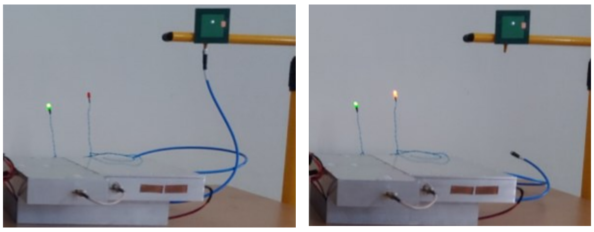
A reflection type variable attenuator with high attenuation range, and simultaneous minimized flat amplitude error and insertion phase variation was designed with the center frequency (f_0) of 2.45 GHz. The attenuation is controlled with bias voltage. This variable attenuator consists of a 3-dB hybrid, where the couple and through ports are terminated with reflection load. The reflection load consists of the transmission line (TL) with the shunt capacitor and PIN diode. Fig. 2 shows the measured *S*-parameters of the fabricated variable attenuator. In Fig. 2, the attenuation is increased as the bias voltage increases. The attenuation range is varied from 0. 2 dB to 20 dB. The minimum input return loss better than 19.6 dB can be obtained at f_0.

C. Power Amplifiers

The 3-stage PA is designed to amplify the small input signal from PLL. The 1st- and 2nd-stage are represented as the driver PAs. The 1st-stage PA was designed by using the AH102A-G medium power gain transistor. The supply drain-to-source voltage (V_{DS}) of AH102A-G is 9 V. The 2nd-stage PA was designed by using CGH4006P GaN HEMT from CREE. The supply V_{DS} of CGH4006P is 28 V. The 3rd-stage was the balanced PA which was realized by using CGH40010F GaN HEMT from CREE with V_{DS} of 28 V from the class-F PAs [10]. Fig. 3 shows the measured performances of 3-stage PA. The measured small-signal gain of the overall stage PA was around 48 dB. The measured output power ($P_{3\text{-dB}}$) of around 44.5 dBm can be obtained at f_0. On the other hand, the measured drain efficiency (DE) and power added efficiency (PAE) of the overall stages were better than 45%.

D. Protector and Detector

The protector consists of a 3-port circulator terminated with a 50 Ω high power term of 50 W at port 3. The circulator with the part number ADC250CE was used. The detector was instructed from a dual directional coupler, RFD circuits, and LEDs. The RFD circuits were connected to the coupled ports of the dual directional coupler to convert the coupled RF power to DC power [11]. The green and red LEDs are connected to the outputs of RFD circuits. Fig. 4 shows the measured *S*-parameters of the overall circuits in the protector and detector block. The overall insertion loss of these circuits is 0.2 dB while the return losses are better than 20 dB.



(a) (b)

Fig. 6. Measurement of RF front-end transmitter system: (a) the antenna is connected well and (b) the antenna is disconnected.

E. Patch Antenna

A patch antenna is a type of antenna with a low profile, which can be mounted on a metal surface over a ground plane [12]. In this work, the rectangular patch antenna is designed on Taconic substrate with a dielectric constant (ε_r) of 3.5 and thickness (h) of 1.52 mm. Fig. 5 shows the measured reflection characteristic of the rectangular patch antenna. The input reflection of better than 27 dB can be obtained at f_0.

III. Setup And Experiment

After the measurement of each circuit is finished, the overall circuits are cascaded as shown in Fig. 6. Each circuit, except the patch antenna, was designed and fabricated on the Taconic substrate with ε_r of 2.2 and h of 0.787 mm. As shown in Fig. 6(a), the green LED is brightened while the red LED is in an off state, which means that the power is well transmitted from PA to the antenna. In Fig. 6(b), both LEDs are brightened, which means that the power is transmitted from PA but it is reflected back due to the antenna being disconnected from the system. The fabricated transmitter is humid sealed for agricultural greenhouse application.

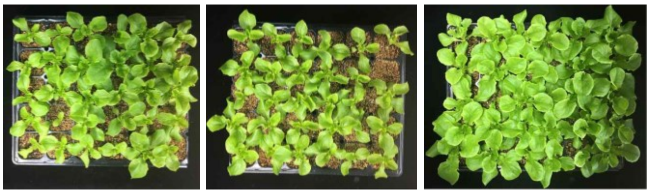
The experiment is performed and investigated on lettuces. Fig. 7(a) shows the sample of lettuces for the experiment in a greenhouse. There are three different conditions in the experiment process for the comparison of growth. The lettuces were located in three different rooms of the greenhouse. The temperatures in the 1st– and 2nd-room were set to 12 °C and 8 °C for day and night, respectively, and assumed as the low-temperature conditions. The proposed transmitter is installed in the 1st-room as shown in Fig. 7(b) and RF power of 13 W was applied to each antenna. The temperature in the 3rd-room was controlled to 24 °C and 20 °C for day and night, respectively, and assumed as the controlling condition. The experiment was performed in the greenhouse for 14 days. The comparison of growth is shown in Fig. 8. The lettuces from the 1st-, 2nd- and 3rd-room are shown in Fig. 8(a), 8(b), and 8(c), respectively. The lettuces were growing well with the controlling condition in the 3rd-room. On the other hand, the growth of the lettuces at low-temperature condition is poor. However, the growth of the lettuces in the 1st-room is much better than the growth of the lettuces in the 2nd-room.

IV. Conclusion

This paper demonstrated the overall design of the RF front-end transmitter. The overall circuits for the transmitter system such as RF signal source, variable attenuator, PA, protector and detector circuits, and antenna are introduced and designed. The front stage of the system is protected well from the reflected power. The presents of transmitted and reflected RF power can be noticed by green and red LEDs in the detector block, respectively. The RF power is transmitted to the antenna and radiated as microwave energy or microwave

(a) (b)

Fig. 7. Experimental setup: (a) samples of lettuces and (b) microwave heating system installed in the 1st-room.



(a) (b) (c)

Fig. 8. Comparison of growth: (a) low-temperature with microwave, (b) low-temperature, and (c) controlling conditions.

heat. The proposed RF front-end transmitter can be applied in agricultural applications.

Acknowledgment

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