A 4-Way 0.11THz Power Synthesizer Based on IMPATT Source

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***Abstract*—The lack of high frequency source with a simple structure and enough power output at THz band limit the development of terahertz technology. As a result achieving high-power THz radiation has attracted many efforts. In this paper, we investigate the possibility of power synthesis at 0.11THz based on discrete sources. The simulation and test results show that with a precision digital phase control, a power synthesizer at 0.11THz band can be achieved. For demonstration, we implement a 0.11THz prototype system employing solid-state impact avalanche and transit time (IMPATT) diodes. The method mentioned in this paper may be have a wide foreground in THz at higher frequency by increasing the digital bit width and give a more precise phase control.**

I. INTRODUCTION

So far, the solution of terahertz signal generation can be roughly sorted by the mechanism into two kinds. At the low band of the terahertz about 0.1-0.5THz, the solid-state electronic transit time devices are still used to generate terahertz signal, such as impact avalanche and transit time diodes (IMPATTs), Gunn diodes, resonance tunnel diodes (RTDs) [1] and Schottky multipliers , give a higher power than photonic method. Recently, CMOS and Sige based terahertz source have been reported[2-3], too. Contrast to low terahertz band, the photo and photonic method is often adopted to generate the terahertz signal at high terahertz band, among which quantum cascade lasers (QCLs) and III-V family semiconductor lasers are typically employed. However, at the 0.1-10THz band, both of the two kind of solutions give an output power sharply decrease as the frequency rise, which is called "terahertz gap".

The output power yield by the two kind of solutions sharply decrease as the frequency rise. Trying to provide an alternative approach, the possibility of power synthesize in "terahertz gap" based on the solid-state electronic devices is investigated here.

II. DESIGN AND COMPONENT TEST

A. System Design

The traditional power synthesis system is shown in fig. 1. May be all of the researcher in this field know that there are two important factor to impact the system combining efficiency, which are the discrete source signal phase and amplitude. However all of the signals from the discrete sources at the combining spot are the same phase is the main factor and give a big influence to the combining efficiency. So many efforts are being done to control the discrete sources output phase to make the combing efficiency as high as possible.

At high frequency band, the technological level is not high enough make the synthesis circuit as accurate as simulation. We have to add a phase shifter to tune the signal phase, which can make all the discrete sources a same phase at the combining spot. Meanwhile，as the frequency is too high, the digital phase shifter is difficult to be realized at D band in our system nowadays, no device and techniques, so the low frequency end phase shift method was adopted, which means shift the signal phase before the multiplier. The theory based on is the phase of multiplied signal has a linear relationship with the base signal.

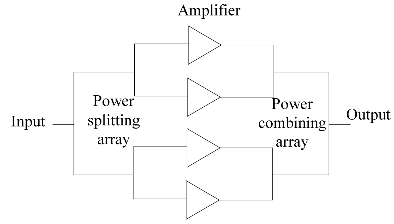

Fig. 1. Block diagram of the traditional power synthesis system

Based on the method mentioned above, we designed the system as shown in fig. 2. Where CCS is constant current source, which drive the IMPATT diode as DC bias. TCXO is the temperature Compensated Crystal Oscillator, which supplies the base signal for PLLs and amplifiers sequentially connected behind the base source. DA is the Digital to analog convertor, which serves as the bridge for MCU (microcontroller unit) to control the amplifier working at a desire gain value. Fig. 3 shows the assembly of the whole 4-way power synthesis system.

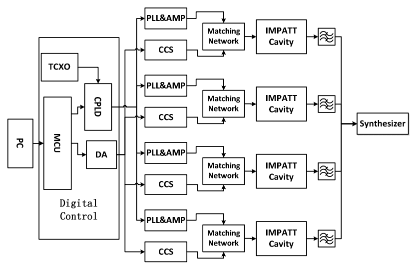

Fig. 2. Block diagram of our power synthesis system

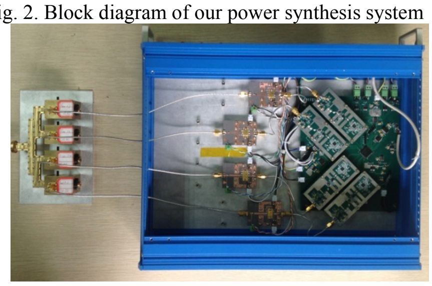

Fig. 3. Assembly of the whole 4-way power synthesis system

B. The design of multiplier

The key problem lying in the design of the IMPATT diode multiplier is to achieve impedance matching at the frequencies of both the RF bias and the sub-THz output. As a strongly nonlinear and large signal device, both the SPICE model and the S parameters of the IMPATT diode at the operation state can't be got easily. The main reason is that the circuit parameters of the IMPATT diode dynamically change with the DC and RF biases. Different from the computer analysis method proposed in [5], we used an approach that combines the full wave simulation and the dynamic measurement to solve the problem in our prototype.

Fig. 4(a) shows the cavity model for our frequency multiplier, which is used for full wave simulation on a commercial Maxwell solver. The diode with a co-axial package is installed in the center of a rectangular waveguide cavity supporting a TE_{101}-mode resonance. The cross section of the cavity has the same dimensions of a standard WR10 rectangular waveguide. A 0.6mm diameter cylindrical copper wire connecting the anode of the IMPATT diode is used to feed the 7.333GHz excitation power through a co-axial structure penetrating the upper wall of the cavity. A micro-strip low pass filter (LPF) with cutoff frequency around 8 GHz is used to feed this co-axial structure and implement impedance matching. With this LPF, the RF excitation power is allowed to enter the cavity with little loss, while the sub-THz signal is reflected back to the cavity. A sliding short circuit on the right side is used to adjust the resonance frequency of the cavity. Compared with [5], this cavity is a simplified version that only supports one IMPATT diode. One important difference is that, in [5], an absorbing material is used to adjust the impedance matching and block the sub-THz frequency. In our design, however, the LPF is used to accomplish both functions.

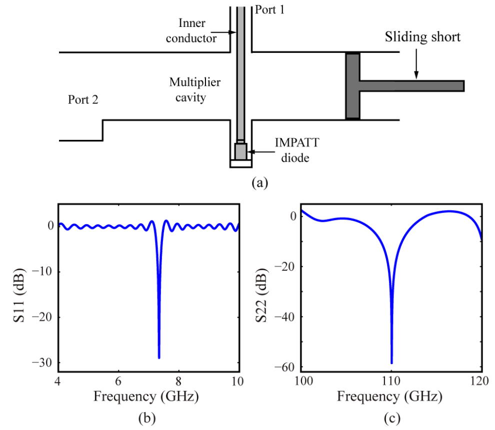

Fig. 4. The cavity model and full wave simulation results.

C. 4-way waveguide power combiner

Fig. 5 shows the assembly of the combiner connected with the four multipliers. The inputs of this assembly are 4 DC and RF biases through the SMA connectors. After 15th order frequency multiplication, the synthesized power is generated at the output port of the power combiner.

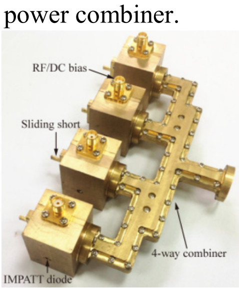

Fig. 5. The 4-way power combiner connected with the multiplier sources.

III. Results

At high frequency band, the technological level is not high enough to make the synthesis circuit as accurate as simulation. We have to add a phase shifter to tune the signal phase, which can make all the discrete sources a same phase at the combining spot. Meanwhile, as the frequency is too high, the digital phase shifter is difficult to be realized at D band in our system nowadays, no device and techniques, so the method that shift the signal phase before the multiplier was adopted. The theory supporting our method is that the phase of multiplied signal has a linear relationship with the base signal.

The measurement is setup for the 0.11THz signals output from the multipliers. The signal is attenuated and sent to a sub-THz harmonic mixer (Farran's FTL7885). The down-converted signal is then sent to a spectrum analyzer through a Duplexer (Farran's FTL2639B) or a power meter. Then, the power and the spectrum of the multiplied 0.11THz signal can be obtained.

Fig. 6 (left) shows the signal-to-noise ratio of the synthesized 0.11THz signal, measured using 50-MHz VBW and 10-kHz RBW. It is seen that a 48-dB SNR is obtained. The output power measured by the spectrum analyzer is around -60.5 dBm, corresponding to an actual power of 2.82mW. Compared with the averaged 1mW input powers, the power synthesis efficient is around 70.4 %. Fig. 6 (right) shows the wideband phase noise spectrum measured with a 200 kHz VBW and a 100 Hz RBW. The measured phase noise is -52.3 dBc/Hz at 10 kHz, and -61.8 dBc/Hz at 100 kHz, respectively. The measured phase noise remains the same as the input signals before the power synthesis because the randomized jitter will not be increased during the power synthesis.

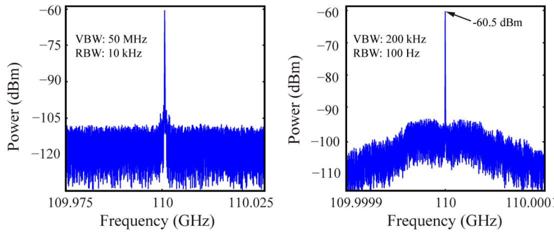

Fig. 6. Measurement of the synthesized power

IV. Summary

The possibility of power synthesis at 0.11THz based on discrete sources has been investigated. The test results show that with a precision digital phase control, such a power synthesizer can be achieved. For demonstration, we implement a 0.11-THz prototype system employing solid-state IMPATT diodes. And the method in this paper may be have a wide foreground in THz at higher frequency by increasing the digital bit width and give a more precise phase control.

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