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Single Phase Transformerless Photovoltaic Inverters

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ABSTRACT

Transormerless inverters are attractive solution for the grid connected photovoltaic (PV) systems.Unfortunately, it has issues on galvanic isolation between PV systems to the grid. When the galvanicisolation disappears from the PV inverter, leakage currents will flow in a resonant circuit formed by theground capacitance, the converter, the ac filter and the grid. In order to avoid the leakage currents, varioustransformerless inverters have been proposed using different topologies to generate constant commonmode voltage. In this paper, various recently-proposed transformerless PV inverters are investigated. Theirperformances are compared and analyzed.

Keywords—PVSystem, Transformerless Inverter, SPWM, Virtual DC bus concept,Operation Modes of the circuit, Hardware Theory

I. INTRODUCTION

Renewable energy sources are key issues in the attempt to address energy problems. Among theall energy sources, solar energy is one of the most up to date techniques. However, theapplications are limited by relatively high cost in comparison with traditional sources. Today'sworld needs more energy due to skyrocketing population and industries. Hence, renewable energyplays an important role to ensure a better future. Solar energy has greatest role in present trend because it is free from pollution and green. PV(Photovoltaic) systems with grid connected aretypically categorized into two types i.e. with transformer and without transformer. For the lowpower applications, a single phase converter is usually used, embedded with low- or highfrequencytransformer. Nevertheless, the transformer requires few numbers of power stages andthus, the design of highly-efficient, low-cost and small-size inverters become a difficult task [1].On the other hand, it is possible to remove the transformer from the inverter in order to reducelosses, size and cost of those systems, namely transformerless PV systems. However, the resultinggalvanic connection between the grid and PV array introduces ground leakage current path due tothe effect of solar panel parasitic capacitance [2] e.g. 10-100nF/kwp. As a result, higher leakagecurrents give rise to EMC problems and increase the harmonics injected into the grid. Certainstandards such as the DIN VDE 0126-1-1[3], impose the disconnection of the PV array from theconverter if the ground leakage current exceeds its prefixed limits. Moreover the harmoniccontent and its amplitude depend upon the converter topology and parameters of the resonantcircuit.Recently, many solutions have been proposed based on the converter topology and PWMmethods [16]-[17]. Most of the efforts are to limit the leakage currents under 300 mA to meet the standard requirement. Based on the topology and controlling methods, the following observationsare obtained [8-14]:• Disconnect the PV array from the grid: dc bypass method (H5) and ac bypass (HBZVR,HERIC).

• Connect the negative terminal of PV panels with the neutral line of utility grid Clamping techniques (H6, HBZVR-D).All the transformerless PV inverters are designed based on the condition when CMV is constantthroughout the different switching states. In transformerless PV inverters [5]-[6], a main designcriterion is to reduce the leakage current flowing through the parasitic capacitance to the ground.In this paper, a comparison based on simulation results of the different methods is evaluated.2. Common-mode voltage and leakage current analysis intransformerless PV Inverter.When transformer is removed from the grid connected inverter, galvanic is created in a resonantcircuit through parasitic capacitance, filters inductance, grid and includes leakage current flowingto the ground as shown in Figure 1.In order to analyze the system CMV, differential mode voltage behavior, the following steps haveto be considered:In case of single-phase system, the common mode and differential mode behavior are derivedbetween two phases with respective to the neutral as shown in Figure1. (a)-(c) [4].In any transformerless PV inverter CMV is defined as the average of the sum of voltages betweenthe outputs and common reference i.e. phase A, B and common reference N

$$V_{cm\text{-}AB} = \frac{V_{AN}+V_{BN}}{2}$$

The differential mode voltage is defined as the difference between the two voltages withcommon reference N

Vdm= VAN-VBN=VAB

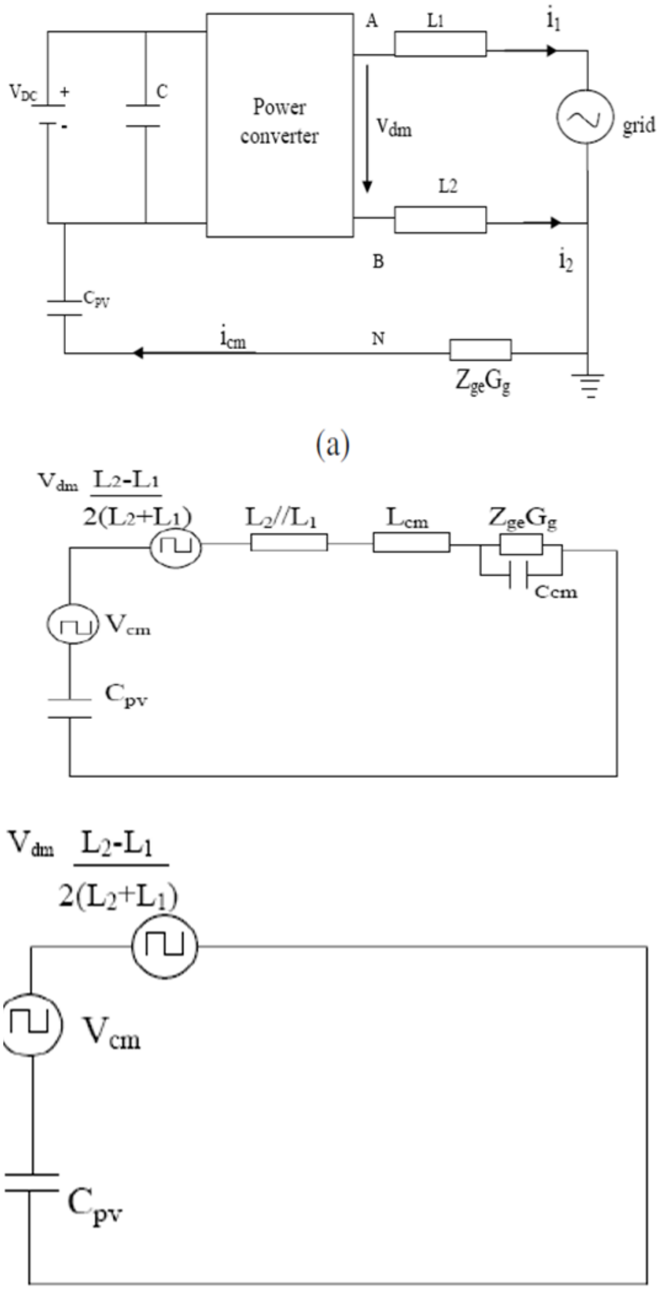


Figure 1. (a) System full model, (b) detailed common model, (c) simplified common mode model

The voltages between the converter output points and the reference point N can be expressed as:

$$V_{AN} = V_{dm\text{-}AB} + \frac{V_{cm\text{-}AB}}{2}$$

$$V_{BN} = -V_{dm\text{-}AB} + \frac{V_{cm\text{-}AB}}{2}$$

Common mode current is defined asicm= i1+i2

Different transformerless PV inverters:

The full bridge (FB) inverter is shown in Figure. 2 [7]. The FB inverter can be modulated witheither unipolar or bipolar modulation techniques.In unipolar modulation, both leg A (S1, S2) and leg B (S3, S4) switched with high frequency withmirrored sinusoidal reference. And two zero output voltage states are possible: S1, S3=ON andS2, S4=ON. With this modulation technique, the implementation is more feasible and popular.However, high CMV appears and leads to high leakage currents. In the bipolar modulation, bothlegs A and B are switched simultaneously in the diagonal pairs, i.e., positive half cycle S1=S3and negative half cycle S2=S4. The advantage of

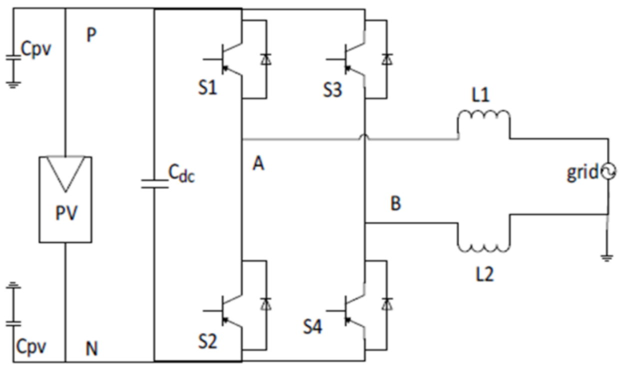


Figure 2.single phase FB inverter

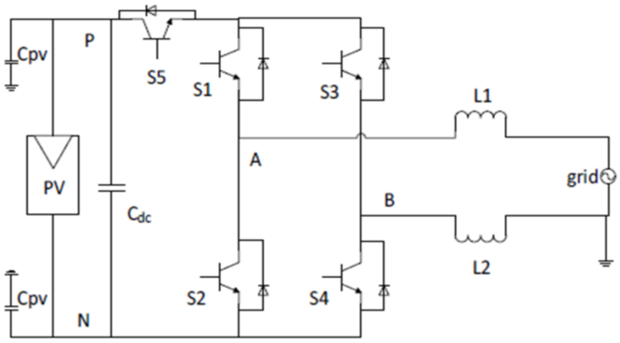


Figure 3.H5 topology.

Bipolar modulation technique is the constant CMV which eliminates the leakage currents.However, bipolar modulation technique causes large ripple currents which deteriorated the powerquality and the efficiency. Recent topologies are combining the constant CMV of the bipolar modulation with those of theunipolar modulation (the three level voltage output, absence of the ripple current and high efficiency).

3.2. DC bypasses method:

In dc bypass method, the inverter gets disconnected from the grid in the dc side. The galvanicisolation can be realized in freewheeling state with proper modulation. The basic FB inverter addsswitches on the dc side as dc-decoupling switch such as H5 topology as shown in Figure. 3. H5topology was developed by SMA technologies.Zero voltage vectors can be realized when S5 OFF. The freewheeling path is created via switchS1 and the anti-parallel diode of switch S3 during the positive active state. Similarly, duringnegative active state, freewheeling path is created via switch S3 and the anti-parallel diode ofswitch S1.Unfortunately, dc bypass method such as H5 topology is not able to maintain the CMV exactly atVDC/2 [8]. The leakage currents are still flowing with respect to the parasitic parameters of theresonant circuit. Beside floating CMV, another disadvantage is higher conduction loss due tomore switches in the conduction path.

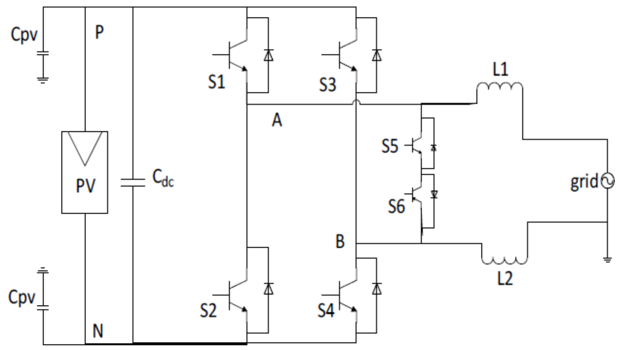
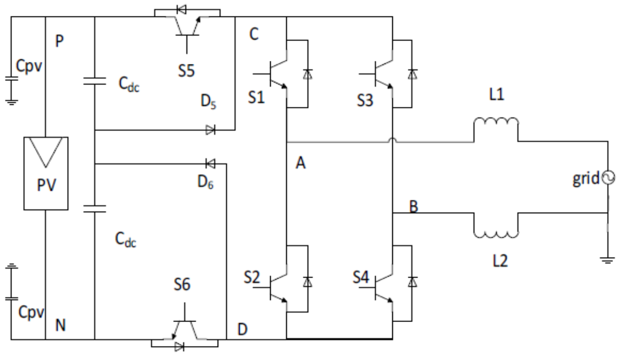


Figure 4. HERIC topology



AC bypass method:

In ac bypass method, switches or diodes are added on the ac side of the inverter to create thefreewheeling path. HERIC (High efficient and reliable inverter concept) [9] topology isimplementing this method as shown in Figure.4. HERIC topology combines the advantages of theboth unipolar and bipolar modulation techniques.In ac-decoupling method, the significant difference from dc-decoupling method is the utilizationof less switches in conduction mode (only 2 switches). This helps to reduce the losses ascompared to dc-decoupling method. During the freewheeling states, it is necessary to generate theCMV at exactly VDC/2 to eliminate the leakage current. Similar to dc bypass method, ac bypassmethod fails to generate the constant CMV.

Clamping method:

This method improves the common mode behavior of the decoupling method, with one clampingbranch connected to the midpoint of the dc link to realize constant CMV. Figure.5 shows one ofthe topology employing clamping method; FB-DCBP (full bridge dc bypass diode clamp) [10].Positive active vector can be realized via switches pair S1, S4. During this period, S5 and S6commutate at the switching frequency. The negative active vector can be realized via S2 and S3.S5, S6 commutate at the switching frequency. Zero voltage vectors are realized when switch S5and S6 are OFF. In this realization the voltage across the VAB, VCD tends to zero. In order toovercome these issues, two additional diodes such as D5 and D6 are used to fix freewheeling pathvoltages exactly half of the dc input voltage i.e. VAN=VBN=VDC/2.

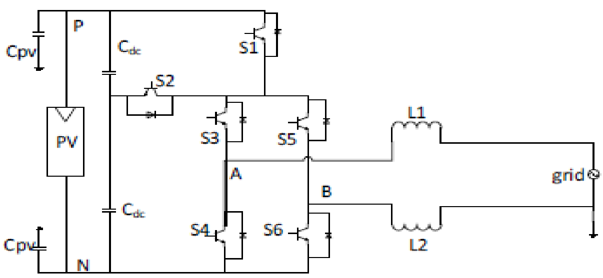
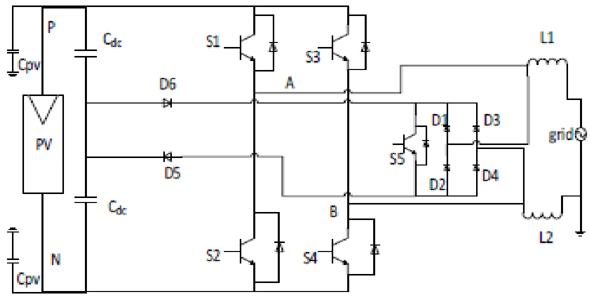


Figure 6.oH5 topology



AC Figure 7.HBZVR-D topology

Furthermore, the CMV is clamped at constant with the help of clamping diodes in CMV clampingmethod. In other words, the leakage currents are reduced significantly, approximately zero. FBDCBPtopology generates unipolar (three level) output voltage. Therefore, it has very highefficiency and becomes an attractive solution for the transformerless PV inverter.Another recently proposed topology which employs clamping method is HBZVR-D (H-bridgezero voltage state rectifier diode) [14] as shown in Figure.7. The operating principle is similar toabove discussed topology, except in freewheeling periods, with the help of protection circuitformed by one active switch and diode. In this topology the main drawback is the bipolar outputvoltage due to the dead time period between the conduction and freewheeling mode. This effectcan be minimized with proper setting of the dead time period. It is high in efficiency and lowleakage current compare to FBDCBP because of ac-decoupling family.And another clamping topology such as oH5 proposed in [11] as shown in Figure.6. It is similarto above clamping methods instead of clamping branch components such as clamping takes place

using switches such as S1, S2. However, it has high conduction losses due to more switchesutilized in conduction path as compared to HBZVR-D topology. The other drawback of oH5 topology is voltage balancing on the capacitors due to dispersion of the component and parasiticparameters. This effect can be minimized by using one simple resistor across the switch orcapacitor. In conclusion clamping method topologies such as FBDCBP, HBZVR-D & oH5 hasvery attractive solutions for the transformerless PV inverters compare to the dc, ac decouplingmethods due to improved common mode voltages and approximately zero leakage current.Moreover, HBZVR-D has high efficiency among the other clamping topologies.

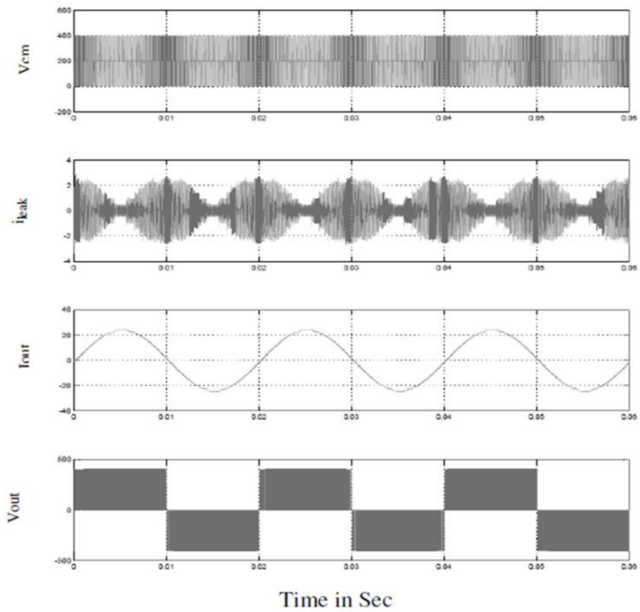
II. SIMULATION AND DISCUSSIONS

The simulation of different transformerless PV inverters was performed using the MATLABSOFTWARE with parameters based on Table 1. In this section, comparison of differentparameters such as output voltage, common mode voltage (CMV), leakage current and currenttotal harmonic distortion (THD) of the various transformerless inverter are discussed. [15]

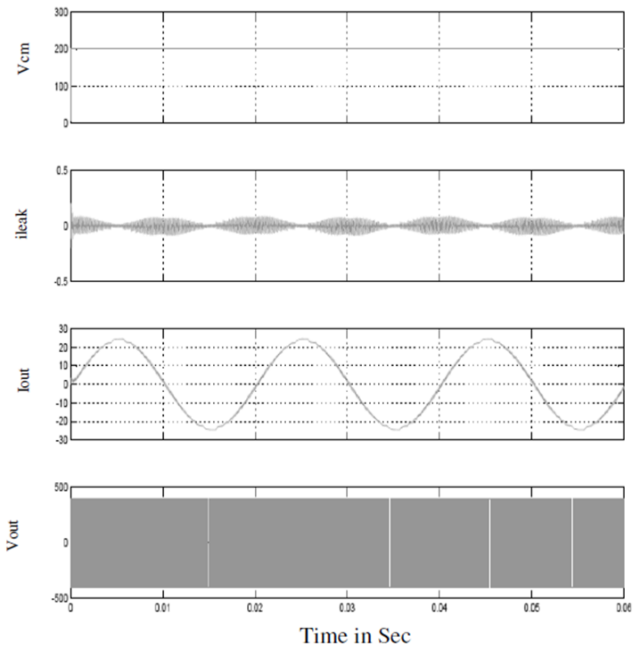
Table1: Selected parameters in simulation

Filter inductance L1, L2	1.8mH
Filter capacitance C_f	2 μF
Load resistance	15 Ω
Input dc voltage VDC	400 V
Dc-link capacitor C_{dc}	250 μF
Parasitic capacitance of the PV array Cpv	100 nF
Switching frequency F_{sw}	10 kHz

The full bridge with unipolar modulation has three level output voltage as well as good efficiency.However, this topology generates varying common mode voltages; it causes high leakage currentsas shown in Figure.8 (a). This topology is not suitable for the transformerless PV inverter due tosafety issue from high leakage current.In case of bipolar modulation, it has two level output voltage. The full bridge inverter withbipolar modulation does not generate the varying CMV thus significantly reduce the leakagecurrent as per standards as shown in Figure.8 (b). This topology helps to avoid the injection of dccurrent into the grid [10]. However, full bridge bipolar modulation generates high current % THD(3.84%) such as current ripples and switching losses.



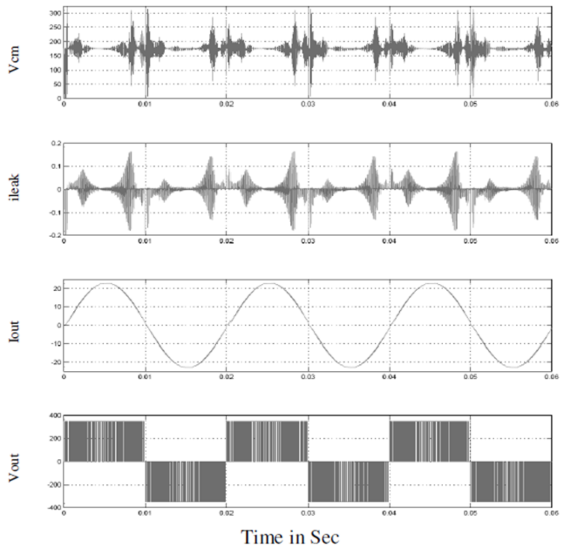
(a)



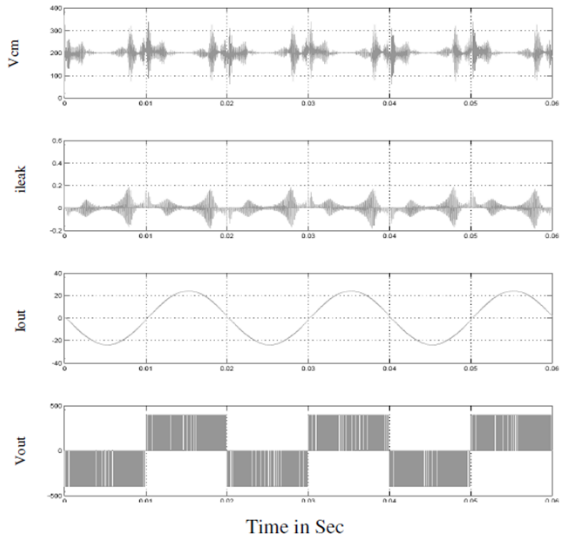
(b)

Figure.8 (a), (b). Common mode voltage (CMV), leakage current (ileak), output current (Iout) and output voltage (Vout) for full bridge unipolar and bipolar PWM

HBZVR The performance analysis of CMV clamping family (FBDCBP, HBZVR-D, oH5) and the dcbypass family (H5), ac bypass family (HERIC) are shown in Figures 9(a)-(e). Dc- and ac-bypassfamilies fail to generate constant CMV as shown in Figure. 9 (a) and Figure.9 (b) respectively.This injects the ripple to the grid current which increases the % current THD as shown inFigure.10 (a)-(b). On the other hand, FBDCBP, HBZVR-D and oH5 topologies improve the common-mode behavior by introducing the CMV clamping branch. The CMV is constant whicheliminate the leakage current as shown in Figure.9(c)-(e). The current THD is almost similarwhich is much better than the bipolar modulation technique due to very low leakage current.Among the recently proposed topologies, CMV clamping techniques are very attractive solutionfor the transformer less PV inverters due to high efficiency and very low leakage current.



(a)



(b)

III.CONCLUSION

A line transformer is omitted in a PV system, galvanic isolation problems occur between the PVto the grid. Besides this issue high leakage current flowing through the parasitic elements of theresonant circuit, for the safety issue it can be minimized as per standards VDE 0126-1-1.Toovercome these issues various transformerless PV inverters are proposed with different operatingprinciples, which has to minimize the critical issues on common mode voltage and leakagecurrent. Such way that number of topologies can be designed by the basic full bridge inverter,which has to disconnect the switches from dc, ac side in freewheeling states such as H5, HERICtopologies belongs to this category and clamp the voltage to the constant level using differentclamping branches, which belong to this category such as FBDCBP, HBZVR-D and oH5.Insimulation results the full bridge inverter with unipolar and bipolar PWM are not suitable to thetransformerless PV inverters due to high leakage current and losses. And compare to the dcbypass method ac bypass methods have high efficient, besides this, still leakage current flowingin both topologies due to fluctuating potentials occurs at PV array. In clamping topologies suchas FBDCBP, HBZVR-D and oH5 are minimizing the leakage current approximately zero withimproved constant common mode voltages.Furthermore in simulation results show that oH5, HBZVR-D is very attractive solutions for thetransformerless systems. Besides this, harmonic issues are analyzed using fast Fourier transform(FFT) analysis %THD is very low in H5 among the other topologies such as FB-unipolar, bipolar,HERIC, FBDCBP, HBZVR-D and oH5.However, HERIC manage to achieve the maximumefficiency but poor performance in terms of the common mode behavior. But unfortunately H5also fails in constant common mode behavior moreover it has low efficiency with high leakagecurrent flowing in a circuit. On the other hand HERIC supplies the active power to the grid whenin ideal case and also this process can lead to extra losses because some power would not be fedto the grid. To overcome these all shortcomings further investigations will be done.Hence, this paper analyzes and compares the performance of the various evaluation methods ofsingle phase transformerless PV inverters for the selected topologies do not eliminate the leakagecurrent completely. It includes working principles and their control strategies were explained aswell. And all topologies are validated by simulation and now they are being assemble to verifythe experimental results.

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