Optimal design of S band with graphene frequency multiplier

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Abstract:A graphene frequency multiplier is proposed in this paper.The nonlinear characteristics of Graphene are similar to the reverse parallel diode.In order to improve the efficiency of GFM,we use the method of recovering the fundamental and fifth harmonic wave which utilizes the way of branch recovery.According to this mechanism,a S band graphene frequency multiplier is designed.During the working frequency between 500MHz and 3GHz,the minimum conversion loss of -20.81 dBm can be obtained at 830 MHz and the input power is 18 dBm.

Keywords:Graphene,nonlinear electromagnetic response,frequency multiplier,high efficiency, branch recovery.

1.Introduction

Microwave and millimeter wave signal sources are widely used.Including wireless routers,satellite communications, radar and other electronic systems frequency multiplier is one of the methods of signals processor.In the microwave and millimeter wave band,Schottky diode is usually used to design frequency multiplier.Compared with high frequency active oscillator,Schottky diode is the ideal choice for making odd harmonic multipliers.

In recent years,graphene as a two-dimensional material has attracted much attention of many researchers due to its unique electrical characteristics.This makes signal source applications possible [6].2007,S.A.Mikhailov put forward to the proposal.

Graphene has a strong nonlinear electromagnetic response.In 2008,2014 and 2015,S.A.Mikhailov further proved its theory.He pointed out that the output harmonic current of the graphene nonlinear device became slower with the decreased of harmonic orders of frequency,which is compared with the traditional nonlinear dual port devices,such as the Schottky diode.In addition, under the stimulation of electromagnetic waves,the output current of the graphene circuit contains only fundamental and odd harmonic waves (such as 1wt,3wt,5wt,7wt,etc.).Graphene circuits have the characteristics of suppressing even harmonic waves.It is suitable perfectly for making nonlinear devices(such as frequency multipliers,etc.).

In 2010,Utilizing the nonlinear electromagnetic properties of graphene,M.Dragoman developed a graphene multiplier based on CPW which working at the range of millimeter wave,He verified the nonlinear theory [11] of graphene for the first time.In 2011,R.Camblor developed a three frequence multiplier [6] with microstrip gap which is loaded with multilayer graphene.When the input power is 20 dBm,the minimum conversion loss of the three frequency multiplier is -25.32dBm.

In 2017,Graphene frequency tripler design using reflector networks a frequency tripler based on graphene nonlinear electromagnetic response is developed.The non-linearity of graphene is similar to that of antiparallel diodes.The output frequency of this tripler can cover 12–30GHz.The harmonic signals recovery using the reflector networks can significantly reduce the conversion loss[15].

From the above analysis,it can be seen that due to the strong nonlinear electromagnetic response of graphene,the output signals of graphene circuits include only basic harmonics and odd harmonics.Graphene is very suitable for frequency multiplier,However,the efficient of the reported graphene frequency multiplier is low.This paper optimizes the design of graphene multiplier.Finally,an optimized graphene frequency multiplier was manufactured and tested.

2.Explanation of the GFT

2.1 Analysis of the nonlinear characteristics of GFM

The AC current of the graphene's electron nonlinear behavior can be expressed as Eq.

$$j_x(t) = en_s V \operatorname{sgn}(\sin \omega t) = en_s V \frac{4}{\pi}\left(\sin \omega t + \frac{1}{3}\sin 3\omega t + \frac{1}{5}\sin 5\omega t + \cdots\cdots\right) \quad (1)$$

It can be seen from equation (1) that the output signal of the graphene circuit contains only fundamental and odd harmonics.The power ratio of output harmonic signal is shown in Figure.1.For the output signal,the power ratio of fundamental signal accounts for about 100%,the power ratio of the third harmonic signal accounts for about 11.11%,and the power ratio of the fifth harmonic signal accounts for about4%.The third and fifth harmonic signals account for about 15% of the total power.Therefore,in order to improve the efficiency of the frequency multiplier,it is an effective way to recover the low order harmonic signal.

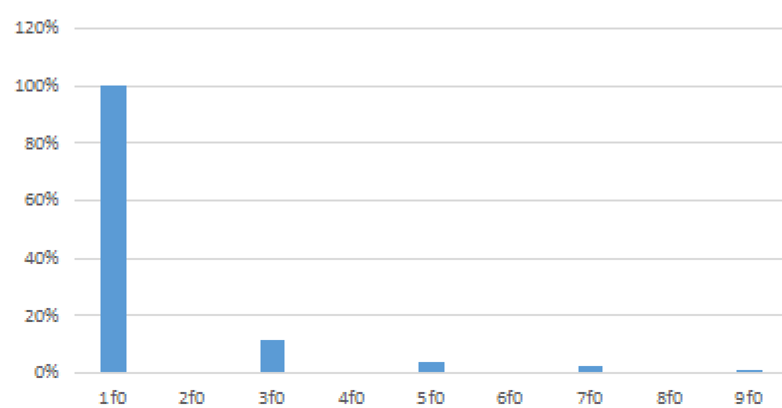

Fig.1. The power ratio of output harmonic signal

2.2 Optimal design of GFM transform loss

The design method of graphene odd harmonic frequency multiplier is that it uses the way of the graphene odd harmonic frequency multiplier to determine the recovered signal frequency component according to the input signal and frequency doubling times;the input signal is the fundamental wave and the frequency doubling times is N,in which the output signal is Nf_0 after frequency doubling,and the signal needed to be recovered of the frequency component is $(2n+1)f_0$,N=1,2,3,4...and (2n+1) N.

The input reflection network is the matching state with the frequence f_0 and the frequency component of the recovered signal is the grounding state.

The output reflection network is matched state with the frequence Nf_0,the fundamental wave and the harmonic components which is needed to be recovered are fully reflected,and the full reflection means that the basic wave and the recovered harmonic components are reflected to the input reflection network through the graphene.

2.3 The work of Graphene frequency multiplier

The graphene multiplier is connected with the excitation signal source and it generates the fundamental wave.After the fundamental wave stimulates the graphene for the first time through the input reflection network,The fundamental waves and odd harmonic components are generated at the back-end of the graphene.The odd harmonic components includes the output signal Nf_0,and the signal frequency component $(2n+1)f_0$ which needs to be recovered,n=1,2,3,4...and $(2n+1)\neq N$.

The output reflection network matches the output signal,it makes the fundamental wave and the recovered harmonic component reflect to the front-end of the graphene.

The signal frequency component that needs to be recovered is grounded by the input reflection network.The fundamental wave is reflected back to the front-end of the graphene.When it passes through the graphene,it can stimulate the graphene for the second time and produce the odd harmonic components at the back-end of the graphene again,and the fundamental wave itself continues to be grounded through the excitation signal source.

In order to recover the fundamental and fifth harmonic power signals,the topology of the,proposed GFM is shown in Figure 2.GFM consists of three parts:input signal reflection network,graphene,output signal reflection network.The reflected network of the input signal mainly contains the third and fifth harmonic signals and the fundamental wave is grounded through the microwave source.and the fundamental wave is grounded through the microwave source.The reflected network of the output signal is mainly to restore the fundamental and fifth harmonic signals,it matches the impedance of the third harmonic signals at the same time.According to formula(1) and combined with the nonlinear electromagnetic response of graphene,there are two ways to improve the efficiency of GFM.

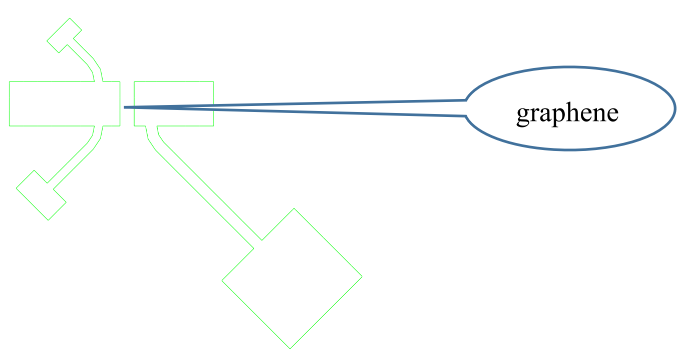

Figure 2.the topology of the GFM

GFM can be equivalent to anti-parallel diode pairs multiplier circuit,it is shown in Figure.2b.Then output signal of the GFM contains only the frequency(mwf0 ± nwfs),(M + n) is an odd number.For example,M = 2 and N = 1,and the total current of GFM contains the third harmonic signal.

By multiplier mode and mixer mode,GFM gains the third harmonic signal.Therefore,output reflector network enhances the output power of the third harmonic signal.Figure.3 shows the scattering parameters of input and output reflector network which is simulated using An soft HFSS [14].

3.The test of frequency multiplier

First,the third frequency multiplier test requires complete circuit structure.It includes the output of the radio frequency of fundamental signal,Bandpass filter,frequency multiplier,and it needs to observe the spectrum and record the data in a spectrum analyzer.We can clearly see the whole test process through figure.3.

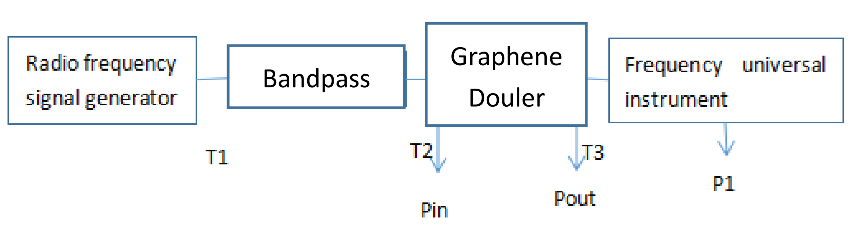

Fig.3.Three frequency doubling test flowchart

The output power of RF signal generator is 19dBm,T1 is the coaxial line connecting the signal generator and filter.T2 is the coaxial line connecting the output-end of the filter and the input-end of the frequency multiplier cavity,T3 is the coaxial line connecting the output-end of the cavity and the spectrum instrument,Pin is the power of the microwave signal when inputing cavity and Pout is the power of signal output cavity Pout is the power for the signal to output the cavity and P1 is the power of the signal recorded by the spectrum analyzer.

The test range is from 750MHz to 1.1GHz.We take 830MHz test as an example ,as shown in Fig.4.The output frequency is 830MHz and the output power is set to 19dBm on the N9310A RF generator.

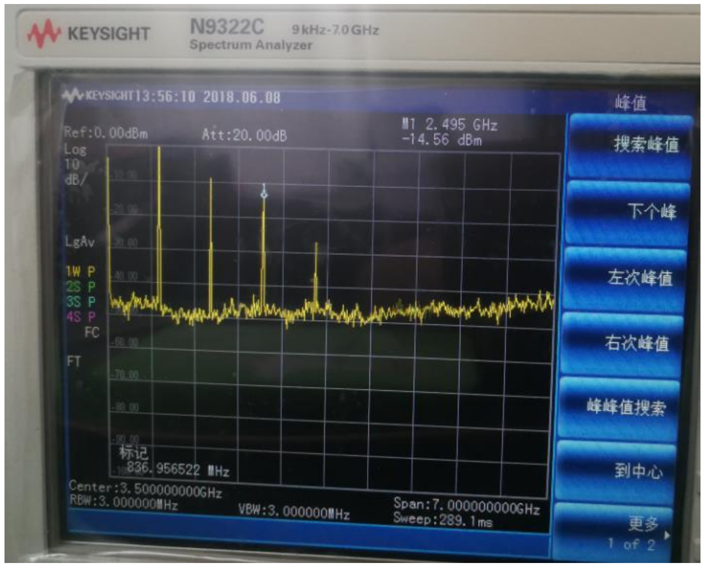

Fig.4.830MHz three harmonic spectrum diagram

From the diagram,we can observe that,except for the fundamental wave of the experimental operation,the frequency spectrum of 2.49GHz is very obvious,the spectrum purity is very high and its power is -14.56dBm.

In addition to the 900MHz fundamental wave signal,Multiple sets of signals are also tested,As shown in Fig.5,a total of 15 frequency bands from 750MHz to 1.1GHz are tested.The basic power settings are 19dBm,and the datas include 1st,2nd,3rd and 4th harmonic frequence spectrums,as shown in Fig.5.

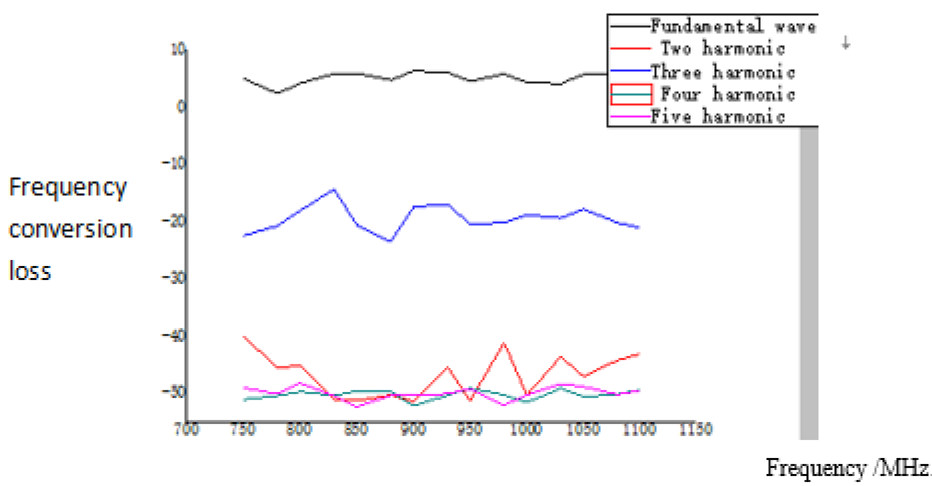

Fig.5.Test results of graphene doubler

4.Conclusion

A frequency multiplier based on nonlinear electromagnetic response of graphene is studied in this paper.The nonlinearity of graphene is similar to that of anti parallel diode.The use of branch recovery can significantly reduce conversion loss.With the increase of input power,the conversion loss gradually decreases.The graphene doubler is optimized to a large extent.

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