MICROWAVE FREQUENCY TRIPLER BASED ON A MICROSTRIP GAP WITH GRAPHENE

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Abstract—In this work, a 3x frequency multiplier implemented with a microstrip gap covered with defoiled graphene is presented. The behaviour of the multiplier has been experimentally characterized for the input signal frequency band between 2.5 GHz and 5 GHz. Several graphene-based tripler devices have been implemented with different values for the line width and gap of the microstrip line in order to evaluate the influence of these parameters on the power of the output signal. The output power of the different devices has been measured in the band from 7.5 GHz to 15 GHz for different values of the input power. An almost flat frequency behaviour for the output power is observed along the whole input frequency band.

1. INTRODUCTION

During the last years, novel nanomaterials have been presented enabling the development of compact, lightweight, and low DC power consuming devices for microwave and millimetre/submillimetre wave applications. Among them, graphene, known as a two-dimensional material consisting of a monolayer of sp2-bonded carbon atoms arranged in a hexagonal lattice, has aroused great interest due to its exceptional electrical properties. The very large carrier mobility ($\cong 200.000\ \mathrm{cm^2V^{-1}s^{-1}}$ around 300 K if extrinsic disorder is eliminated)

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of graphene, being at least one order of magnitude greater than in Si and GaAs [1], makes it an interesting material for high frequency applications. Theory on the nonlinear electromagnetic behaviour of graphene [2–4] predicts the existence of frequency multiplication effects through harmonic generation in nonlinear microwave components that integrate graphene films. These novel nonlinear components can be an attractive alternative for avalanche [5–7], PIN [8, 9], tunnel [10, 11], or Schottky diodes [12, 13], especially for millimetre/submillimetre-wave devices where parasitic effects of component packages can be avoided through a direct implementation of graphene films in the nonlinear frequency multiplying device. The absence of these parasitic effects makes graphene based multipliers attractive for their integration in millimetre/submillimetre wave imaging systems and applications [14–18].

In this work, the third harmonic generation using graphene films of microwave input-signals in the frequency range from 2.5 GHz to 5 GHz (third harmonic between 7.5 GHz and 15 GHz) is studied in different microstrip line structures. Section 2 describes the proposed topology for the graphene based frequency tripler. In Section 3 the frequency multiplying behaviour is studied with respect to the main parameters of the structure, the input power and the input frequency.

2. TOPOLOGY OF THE GRAPHENE BASED FREQUENCY MULTIPLIER

The topology of the graphene based frequency multiplier device is shown in Fig. 1. The nonlinear component of the device consists in a microstrip line with a small gap covered by a few layer graphene film exfoliated from highly oriented pyrolithic graphite (Fig. 1(a)). The few layer graphene film sample has been selected to have a number of layers, although variable, between one and five, along the dimensions of the whole microstrip gap. The microwave input and output ports are connected to the component through a 50 Ohm microstrip line and a tapered section ending in the microstrip line with Z_L characteristic impedance, which feeds the gap.

The microstrip structures have been implemented on the 765 μm thick Arlon 25N substrate, with $\varepsilon_r = 3.38$ and $\tan\delta = 0.0025$ at 10 GHz. The small gaps have been etched in the microstrip structure by laser.

The nonlinear behaviour of the device is studied with respect to the gap length d and the characteristic impedance of the microstrip line Z_L for different values of the input power at f_0, using the measurement setup of Fig. 2.

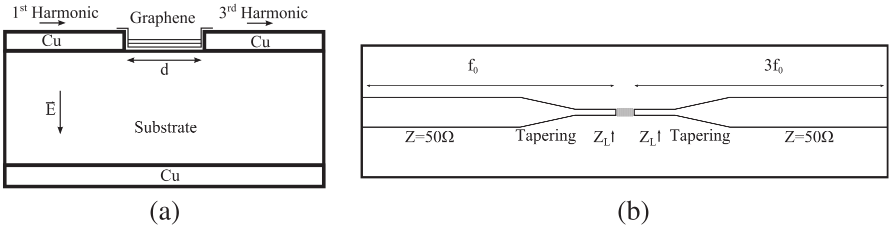

Figure 1. Topology of the graphene based frequency multiplier. (a) Microstrip gap covered with a few layer graphene film. (b) Microstrip structure feeding the graphene covered gap.

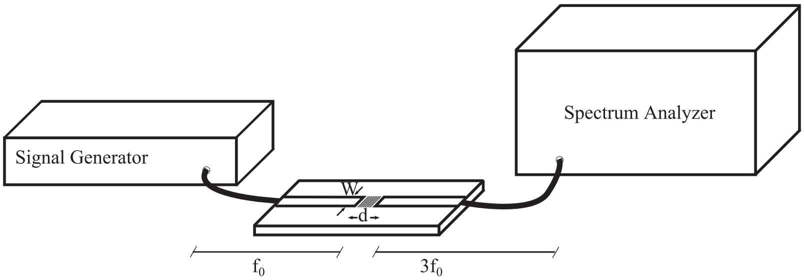

Figure 2. Measurement setup for the analysis of the graphene based frequency tripler.

3. BEHAVIOUR OF THE FREQUENCY TRIPLER

For the analysis of the behaviour of the frequency tripler, several microstrip structures have been manufactured with different values for the gap length d (Fig. 3) and characteristic impedance of the microstrip line Z_L (Fig. 4). The influence of the gap size on the performance of the frequency tripler has been evaluated through the manufacturing and measurement of four devices with the same $Z_L = 50$ Ohms and different values for the gap length d: 150 µm, 300 µm, 400 µm and 500 µm. The influence of the characteristic impedance of the microstrip line feeding the gap has been evaluated by manufacturing and measuring four circuits with a fixed gap size $d = 300$ µm and different values for the microstrip line width and thus for Z_L: 50 Ω, 70 Ω, 90 Ω and 110 Ω.

The variation of the performance of the frequency tripler with respect to the gap length, when varying the input frequency between 2.5 GHz and 5 GHz and the input power between 4 dBm and 20 dBm can be observed from Fig. 5. Higher values of the output power at $3f_0$ are found for a gap size $d = 300$ µm.

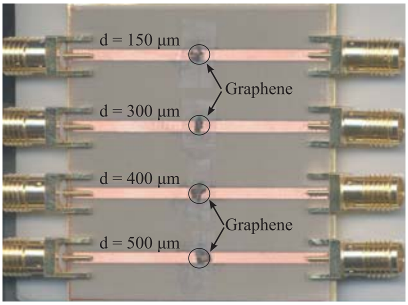

Figure 3. Manufactured graphene based frequency tripler circuits with different gap lengths d: 150 µm, 300 µm, 400 µm, 500 µm and fixed characteristic impedance $Z_L = 50\,\Omega$.

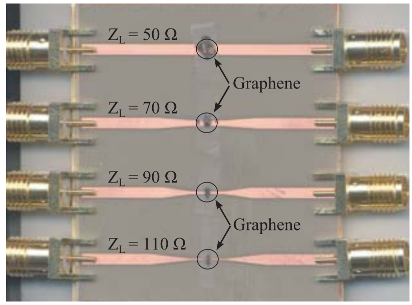

Figure 4. Manufactured graphene based frequency tripler circuits with fixed gap length $d = 300$ µm and different characteristic impedance Z_L: 50 Ω, 70 Ω, 90 Ω and 110 Ω.

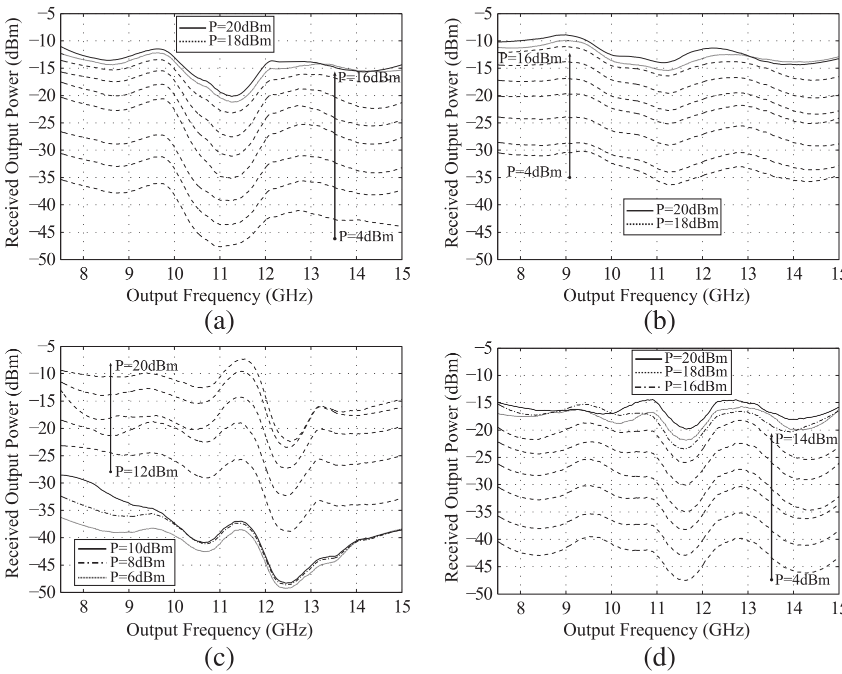

Figure 5. Measured output power versus output frequency for different values of the input power $P_{in} = 4$ to 20 dBm. (a) Gap length $d = 150$ µm, (b) $d = 300$ µm, (c) $d = 400$ µm, (d) $d = 500$ µm.

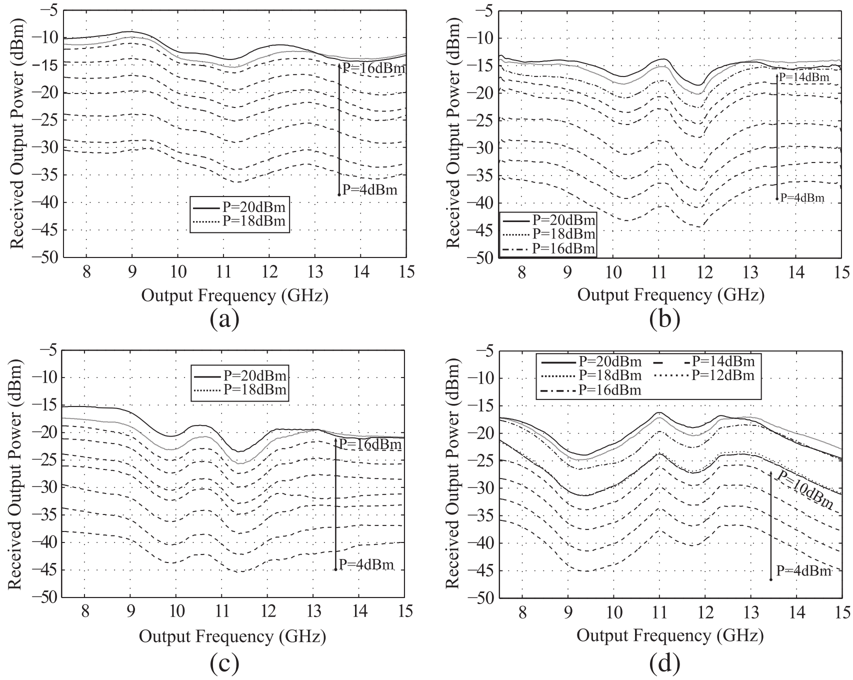

Figure 6. Measured output power versus output frequency for different values of the input power $P_{in} = 4$ to $20\,\mathrm{dBm}$. (a) Characteristic impedance $Z_L = 50\,\Omega$, (b) $Z_L = 70\,\Omega$, (c) $Z_L = 90\,\Omega$, (d) $Z_L = 110\,\Omega$.

The performance of the graphene based frequency triplers with different values of the characteristic impedance Z_L and fixed gap length $d = 300\,\mu\mathrm{m}$ is shown in Fig. 6. The selection of the best value for Z_L depends on the operation frequency. For higher frequencies, higher values for the output power are obtained with higher Z_L values.

In Fig. 5 and Fig. 6 a slight saturation of the output power is observed at high values of the input power. Fig. 7 and Fig. 8 represent this saturation effect in the conversion efficiency $E_c = P_{out}/P_{in}$ with respect to the input power at $3f_0 = 8\,\mathrm{GHz}$ and $14\,\mathrm{GHz}$. As can be observed, the most efficient designs for the frequency tripler are obtained with small gaps ($d = 300\,\mu\mathrm{m}$, $400\,\mu\mathrm{m}$). The selection of the optimum characteristic impedance Z_L depends on the operation frequency. At lower frequencies, higher values of the efficiency are found for low Z_L values ($Z_L = 50\,\Omega$), while at higher frequencies the maximum efficiency is obtained for higher Z_L values (Fig. 8).

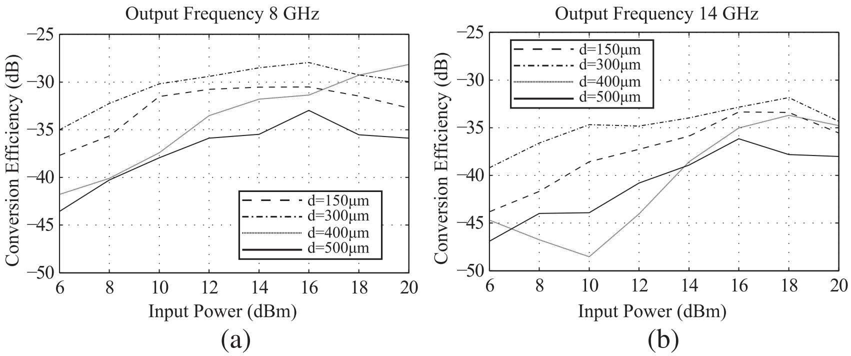

Figure 7. Saturation of the conversion efficiency in frequency multiplier designs with different gap length. (a) Output frequency $3f_0 = 8\,\text{GHz}$, (b) $3f_0 = 14\,\text{GHz}$.

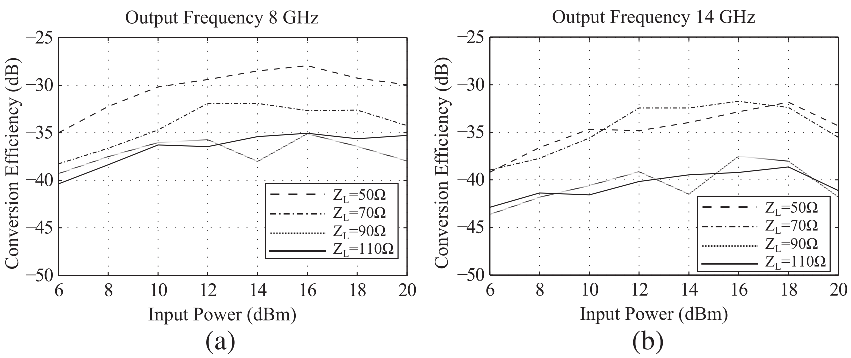

Figure 8. Saturation of the conversion efficiency in frequency multiplier designs with different characteristic impedance. (a) Output frequency $3f_0 = 8\,\text{GHz}$, (b) $3f_0 = 14\,\text{GHz}$.

A summary of the maximum values of the conversion efficiency E_c obtained with the different configurations of the graphene based multiplier is shown in Table 1, together with the corresponding values for the input power and output frequency.

Table 2 shows a comparison between this work and others found in the state of the art literature, where N is the order of the used harmonic component, BW is the frequency bandwidth at Nf_0 over which the harmonic generation has been studied, and Type refers to the type of the nonlinear element used.

Table 1. Performance of the graphene based frequency tripler.

d [µm]	$E_{c,\max}$ [dB]	P_{in} @ $E_{c,\max}$ [dBm]	$3f_0$ @ $E_{c,\max}$ [GHz]
150	−29.44	18	9.63
300	−27.02	18	9.01
400	−25.32	20	11.56
500	−31.19	18	7.50
Z_L [Ω]	$E_{c,\max}$ [dB]	P_{in} @ $E_{c,\max}$ [dBm]	$3f_0$ @ $E_{c,\max}$ [GHz]
50	−27.02	16	9.01
70	−30.96	16	7.53
90	−34.77	16	7.50
110	−33.57	12	7.50

Table 2. Comparison with other works found in the state of the art literature.

	THIS WORK	[19]	[20]
Type	few layer graphene film	GFET	GFET
N	3	2	2
max. Nf_0	15 GHz	400 KHz	40 KHz
max. E_c	−25.32 dB	−26.02 dB	−24.43 dB
output BW	7.5 GHz	380 KHz	38.8 KHz

4. CONCLUSIONS

A microwave frequency multiplying device has been presented using a nonlinear component implemented with a microstrip gap covered with a few layer graphene film exfoliated from a highly oriented pyrolytic graphite. The frequency multiplying performance of the device has been studied with respect to the gap-width and characteristic impedance of the feeding microstrip line for different values of the input power. Depending on the configuration of the device, an almost flat frequency behaviour can be obtained in the whole output frequency range from 7.5 GHz to 15 GHz. A slight saturation of the frequency multiplying efficiency has been observed for higher input power values. A maximum efficiency in the frequency conversion of −25.32 dB has been obtained.

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