Realization of THz Band Mixer Using Graphene

Ensieh Ghasemi Mizuji¹, Ali Abdolali¹, Fateme Aghamohamadi¹, Mohammad Danaefar², Soheil Hashemi¹, and Kimia Nikooei Tehrani¹

¹Department of Electrical Engineering, Iran university of science and technology, Tehran, Iran
²Department of Electrical Engineering, K.N.Toosi university of technology, Tehran, Iran
*corresponding author, E-mail: ensiyeh.ghasemi@ee.iust.ac.ir

Abstract
In this article a new method for creating mixer component in infrared and THz is suggested. Since the nonlinear property of admittance creates frequency components that do not exist in the input signal and the electrical conductivity is associated with admittance, in our work we have proven and simulated that the nonlinear property of graphene admittance can produce mixer component. The simulation results show that the mixer component is larger than other components, therefore the mixer works properly. Because of nano scale of graphene structure, this method paves the road to achieve super compact circuits.

1. Introduction
Mixers are used to shift signals from one frequency range to another range of frequencies. For example mixer converts the intermediate signals produced by a generator to RF signals, This procedure is named Up Conversion. The same operation is performed in receiver.

Graphene is the first example of two dimensional structures with one atom thickness that have received much attention in recent years[1,10]. Its unique electrical and photonic properties have several usages in the optical and THz circuits and systems. One basic parameter in describing graphene optical properties is its complex conductivity, \( \sigma_e^{\omega} \), which depends on frequency \( \omega \) of incident wave, \( \Gamma \), and chemical potential \( \mu_c \) which depends on the carrier density and can be controlled by a gate voltage that produces electric field, magnetic field and/or chemical doping [11,12], hence conductivity is frequency dependent and controllable by varying its chemical potential. Due to the complex conductivity, equivalent circuit including a resistor and a capacitor or an inductor may be considered. Graphene is suitable for realizing transistor actions due to High intrinsic carrier mobility and speed[13,14,15]. Recently, graphene has been utilized for devising subharmonic resistive mixers[16]. In this article we demonstrate that the nonlinear conductance property can make biased graphene suitable for mixer application.

There are other technologies such as schottky barrier diodes and Hot-Electron bolometer for mixers. A small area barrier between a metal and a semiconductor can be used as Schottky barrier diode. A strongly nonlinear current-voltage characteristic makes Schottky barrier diode useful for mixing application. A major disadvantage is that relatively high level of LO power is required for SBD (Schottky Barrier Diode) to act as a nonlinear device for optimum performance as a mixer. Furthermore, SBD is more sensitive than other types of devices which have stronger nonlinearities. The other method is Hot-Electron bolometer. In this method, the bolometer output signal is proportional to the power of the incident radiation. To utilize it as heterodyne detector the bolometer should be fast enough to follow the fast IF amplitude modulation of a RF signal. The major disadvantage of this type of mixer is poor electrical stability. Our mixer is 2D and can reduce the scale of the circuits to nano. Also due to tunable nature of graphene this scheme would be broadband. Its strong nonlinearity has given graphene good performance as a mixer. Simulation results confirm our conclusion. Section II describes the electronic model of graphene. Section III is a brief explanation of the action of nonlinear conductivity in mixer application. Section IV surveys graphene as a nonlinear conductivity and this characterization is proved analytically and in simulation.

2. Electronic model of graphene
Graphene is the 2D kind of graphite and modeled as one atom thickness material sheet with a surface conductivity tensor[17]. Graphene electrical conductivity is considered as[17]:
\[
\sigma(\omega, \mu_c(E_b), \Gamma, T, B_z) = \sigma_0 \sigma_{xx} + \gamma \sigma_{xy} + \gamma \sigma_{yy} + \gamma \sigma_{xy} + \gamma \sigma_{xx},
\]
(1)

Where \( \omega \) is the radian frequency, \( \mu_c \) is the chemical potential (which may vary by the electric and/or magnetic fields), \( E_b = E_0 \) and \( B_z = 0 \) are the induced electric and magnetic fields, respectively, \( \Gamma \) is the electron scattering rate and T is temperature. Three general cases for graphene conductivity are considered. We assume the graphene conductivity in three types of bias such as: without any electric bias or magnetic bias with spatial dispersion, with an electric bias and with a magnetic bias. Here we consider second type for graphene. So the formulation for the electrical conductivity of graphene will be[11]:
\[
\sigma_{xx} = \sigma_{yy} = \sigma_x(\mu_c(E_b)) = \sigma_x(\mu_c(E_b))
\]
(2)
\[
\sigma_{xy} = \sigma_{yx} = 0
\]
(3)