Negative resistance feedback oscillator design for Internet Over TV (IOTV) application

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***Abstract-* The aim of this research is to design a down frequency converter to shift WiFi frequency (2.45 GHz) into 720 MHz which is suitable for transmission of internet data over TV band white spaces. In this paper a 1.73 GHz negative resistance oscillator has been designed and simulated. This oscillator is used as a part of down frequency converter.**

Keywords: TV white spaces, negative resistance oscillator, down frequency converter

I. INTRODUCTION

In the past two decades the world witnessed a massive growth of wireless communication applications. Such applications include GPS navigation, social media applications, online banking, shopping and many other fields. The growth of these applications requires a massive growth of bandwidth over a limited radio spectrum. One way to support wireless communications with large bandwidth is to transmit the internet data over multiple frequency carriers. Unfortunately, most of the spectrum frequency carriers have already been licensed for use [1]. The Federal Communication Committee FCC began considering freeing up some of the previously licensed frequency bands [2]. Unused television channels, which are known as the TV white spaces (TVWS) is one of the selected bands that the FCC opened up for unlicensed communication in 2009 [2]. Also, the use of digital devices and digital TV broadcasting will spare much TV frequency band for the use of other applications [1].

In TVWS the available bandwidth is relatively large bandwidth contains tens of MHz which is expected to be available almost everywhere. Also, the TVWS offers a superior coverage to the licensed and unlicensed bands such as the Industrial Science Medical (ISM) bands used for local area networks (WiFi) and personal area networks (Bluetooth and ZigBee). The frequencies of the TVWS are relatively low, therefore it can easily penetrate obstacles compared with higher frequency bands.

TV spectrum is the best available spectrum that can be used for internet transmission for users located far away from the nnetwork access points. TV spectrum also can be used to connect multiple devices separated by obstacles due to the excellent propagation properties of the TV spectrum. TV bands can be used for a wide range of applications, such as business/home femtocell network, cellular-WLAN, seamless wireless services, indoor localization systems, smart grids, and so on. This could bring enormous social and economic benefits [1].

In this research the authors aim to use TV bands for the transmission of internet data. To achieve this goal, an internet signal taken from a WiFi router operating at 2.45 GHz is down converted into 720 MHz and transmitted over TV channel using the down frequency converter shown in Fig. 1. To recover the internet data, a demodulator operating at 720 MHz can be used.

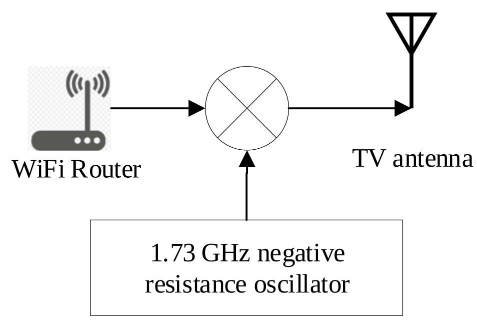

Fig. 1 Down converter circuit.

This research focuses on the design and implementation of the oscillator circuit used within the down frequency converter.

A transistor oscillator is designed and simulated using ADS to generate a 1.73 GHz signal. This is a part of down frequency converter which shifts the WiFi frequency down from 2.45 GHz (WiFi signal) to 720 MHz. The 720 MHz is used to transmit internet data because this frequency might be available for use in many countries around the world.

I. LITERATURE REVIEW

In this section, a brief review on the TVWS and the oscillator design will be outlined briefly.

A. OVERVIEW OF TV WHITE SPACES

The analog TV broadcasting channel over the world are broadcasting in the Ultra High Frequency (UHF) band with carrier frequencies starting from (470-806) MHz [3]. However, recently; many of the assigned TV channels are un-used for TV broadcasting. This TV spectrum is known as TVWS, which is available for secondary transmission (secondary users, SU) [4].

Electromagnetic waves used in TVWS are considered robust because of the its relatively large wavelength which allow them to cross natural and artificial obstacles with certain ease. The TVWS signals are less affected by diffraction, rain attenuation, temperature and clouds loss [5]. The (TVWS) has an improved propagation capabilities due to their low carrier frequency (UHF band) compared with the telecommunication technologies operating at 2.45 GHz and other giga-Hertz frequencies which is used for WiFi and other telecommunication technologies. Transmitting and receiving internet data over TVWS frequencies can be the solution of choice that provides an affordable internet access in rural areas [5,6,7]. Some of the benefits of broadcasting internet data over TVWS include large bandwidth being allocated for each TVWS, hence provides fast internet browsing compared with traditional WiFi. One of the very clear benefits of the TVWS is that the network can easily and quickly be designed and implemented in areas where traditional networks cannot be easily implemented at reasonable cost. The TVWS network can cover a radius of up to 10 kilometers [8].

B. OSCILATOR DESIGN

The oscillator is the principal element for all RF and microwave systems such as radars, communication systems, and many electronic systems [9-11]. The oscillator design can be considered as the hardest step in the design of RF system, because it is an active circuit that requires the optimization of many parameters such as polarization, input-output matching networks, etc. [12-14].

In this research the oscillator is designed as potentially unstable amplifier. From the literature, it's known that any unstable amplifier would have a negative input resistance in series with either capacitive or inductive reactance. However, if the transistor is unconditionally stable it can be forced to became potentially unstable by adding a proper feedback network [6].

A negative resistance one-port network can be created by terminating a potentially an unstable transistor with a load impedance designed to drive the transistor into the unstable region. The circuit model of a transistor oscillator is shown in Fig. 2 [15].

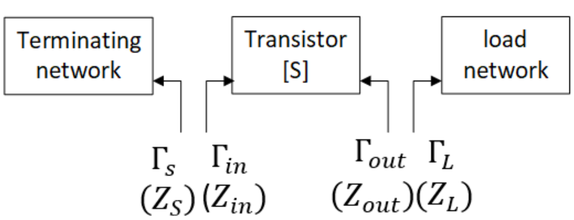

Fig. 2 Circuit for a two-port transistor oscillator [15].

The oscillator was designed to generate a 1.73 GHz sinusoidal signal. The design was simulated using Keysight Advanced Design System (ADS).

The oscillator was designed using BJT HBFP0450 transistor because of its large gain, and low noise figure at the desired frequency [16]. The transistor was biased to have relatively large current in order to increase the instability. The quiescent point of the transistor was selected such that $V_{CE_Q} = 2\ V$ and $I_{CQ} = 20\ mA$ as recommended by the manufacturer data sheet [16].

Correct transistor biasing and choosing a proper Q-point are necessary so that the transistor could work efficiently and produce an undistorted output signal.

The biasing network is composed from a voltage divider biased network as shown in Fig. 3

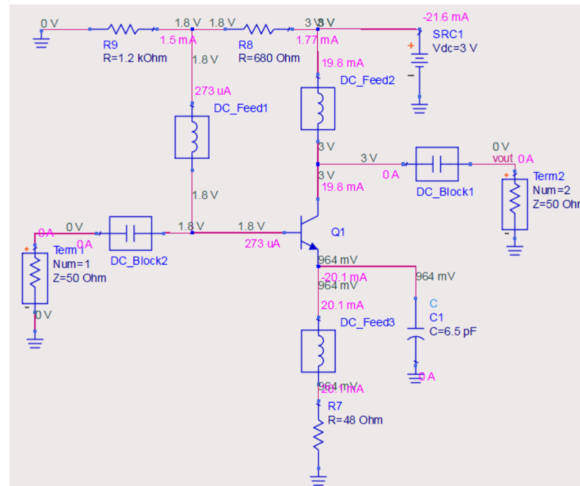

Fig. 3 DC bias network.

Voltage divider bias network is used to bias the transistor because of its good thermal stability compared with other biasing networks.

After setting the biasing network, the stability of the transistor is simulated using Keysight ADS simulator. The stability simulation setup is illustrated in Fig. 4.

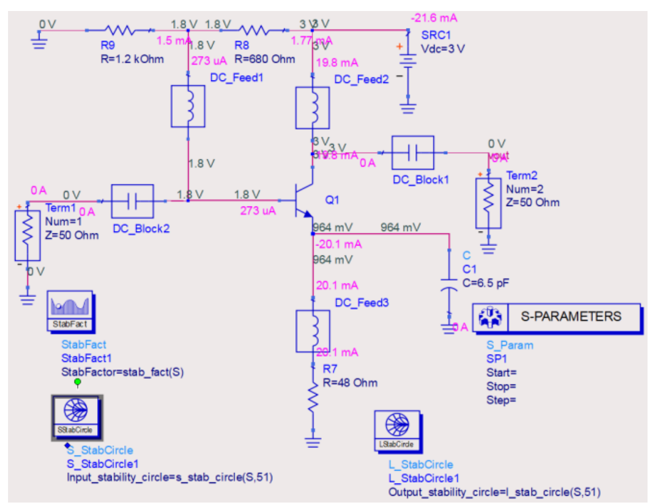

Fig. 4 stability simulation in ADS.

The stability of the transistor is determined by computing the stability factor; K test; or by plotting the input and output stability circles. The stability factor can be computed mathematically by using equations (1) and (2)

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|S_{11}S_{22}-S_{12}S_{21}|^2}{2|S_{21}S_{12}|} \quad (1)$$

$$\Delta = S_{11}S_{22} - S_{12}S_{21} \quad (2)$$

Where $[S] = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$ are the scattering parameters of the transistor. A given transistor amplifier is potentially unstable if $K < 1$ and $\Delta \geq 1$

To complete the oscillator design at the desired frequency an output matching network is selected within the output stability network. Afterwards the input matching network is selected such that $Z_S = Z_{in}^*$. The completed oscillator schematic is show in Fig. 5.

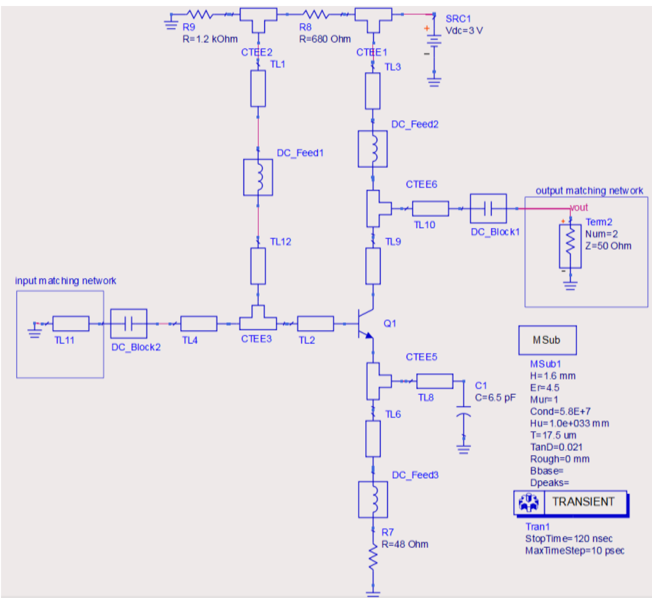

Fig. 5 Complete oscillator circuit.

In Fig. 5, the oscillator circuit is also showing the bias network, input and output matching network. The input and output matching networks were simply open and short-circuited stubs.

II. SIMULATION RESULTS

Based on the initially stated conditions, the simulation begins by determining the transistor stability which is performed by plotting both the input and output stability circles as shown in Fig. 6.

As it can be seen from Fig. 6, the transistor is potentially unstable because both the input and output stability circles intersect the smith chart. The regions of the intersections are the unstable regions because the magnitudes of S_{11} and S_{22} are less than unity [15] as shown by simulation. The simulated S-parameters are listed in Table 1.

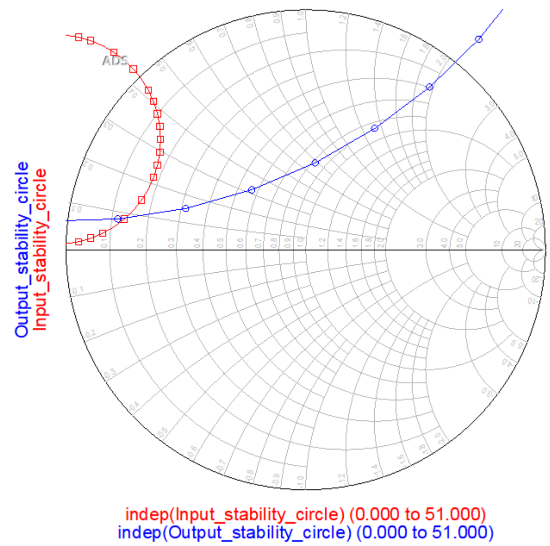

Fig. 6 input and output stability circles of the HBFP0450 transistor biased at $V_{CE_Q} = 2\,V, I_{C_Q} = 20\,mA$.

Table 1 simulated S-parameters at 2 GHz

Frequency	1.73 GHz
S_{11}	$0.912\angle-13.66°$
S_{12}	$0.069\angle-61.92°$
S_{21}	$4.11\angle147.03°$
S_{22}	$0.885\angle-54.55°$

Simulation also shows that the stability factor for this transistor at different frequencies is less than one as illustrated in Table 2.

Table 2 Simulated stability factor

Frequency	Stability factor
1 GHz	0.063
1.5 GHz	0.092
1.73 GHz	0.105
2 GHz	0.121
2.5 GHz	0.151

Since the stability factor is less than one, this implies that the transistor is potentially unstable, therefore it would oscillate easily at the desired frequency.

As the real and imaginary parts of the input impedance are also simulated for the proposed oscillator circuit, one might observe that the real part of the impedance is negative for frequencies ranging between 1.5 GHz to 2.2 GHz as illustrated in Fig. *7*. Moreover, the imaginary part is negative (capacitive) for the same frequency range as shown in Fig. *7*. Capacitive input impedance requires an input matching network with inductive reactance to guarantee oscillation at the desired frequency. This implies that the input matching network can be implanted by short circuited stub. Fig. 7 also shows us that there is a clear resonance at the desired 1.73 GHz oscillation frequency because the input matching stub added to the input of the transistor oscillator forms a resonance network at the input of transistor.

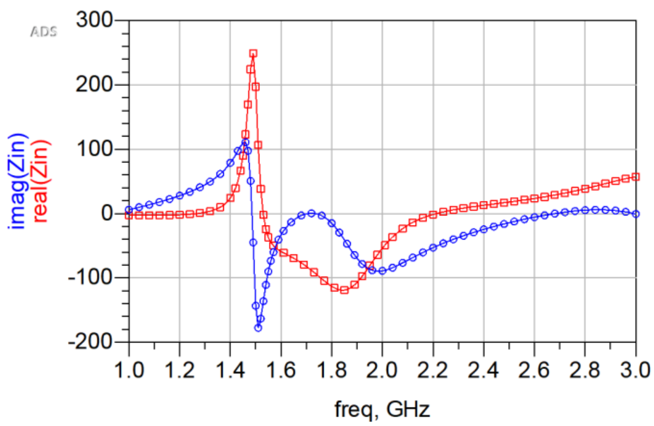

Fig. 7 Simulated real and imaginary part of the input impedance.

The simulated time domain signal of the proposed oscillator is shown in Fig. 8.

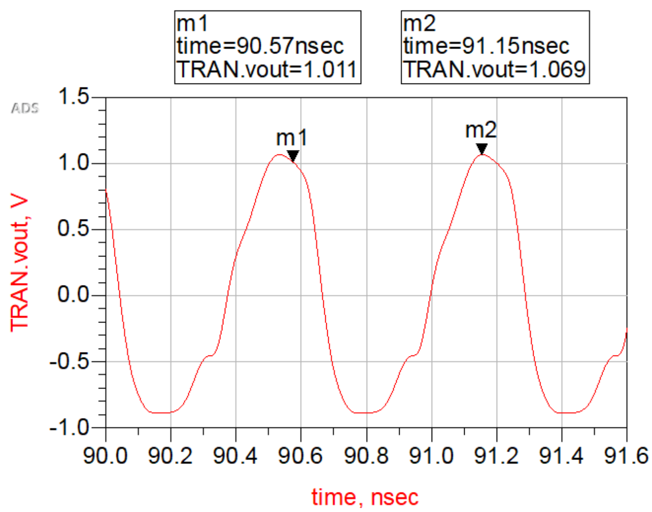

Fig. 8 Time domain signal.

The resulting time-domain simulated signal is not purely sinusoidal signal as illustrated in Fig. 8. The reason for the deviation of the signal shape from the pure sinusoidal signal refers to presence of an unwanted harmonics as indicated by the spectrum analysis shown in Fig. 9. However, the harmonics can be minimized by using a relatively a high-quality factor bandpass filter at the oscillator output.

Since the magnitude of the generated harmonics is relatively small and their interaction with the 2.45 WiFi is outside the desired TV frequency band, the filter can be ignored.

It can also be noted that from the resulting spectrum plot of Fig. 9 that the resulting fundamental frequency is 1.73 GHz which is the desired design frequency.

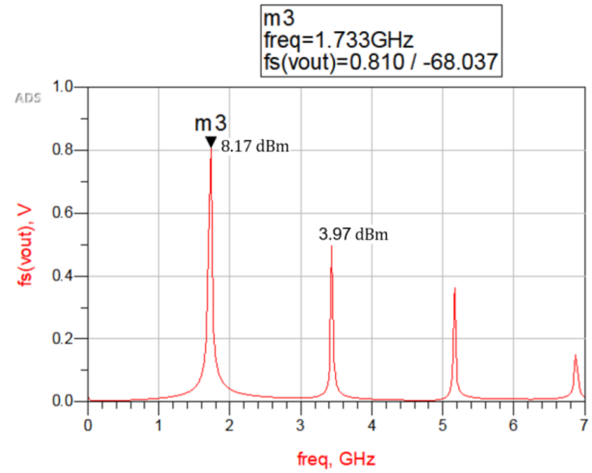

Fig. 9 Spectrum of the resulting output signal.

The output signal of the LO satisfy the requirement oscillation at frequency 1.73 GHz.

The power of the generated signal at the 1.73 GHz across 50 Ω load can be computed mathematically by

$$P = \frac{1}{2} \times \frac{V_{peak}^2}{50} \quad (3)$$

For this particular designed oscillator, the magnitude of the power at 1.73 GHz is 6.56 $mWatt$ which corresponds to 8.17 dBm.

III. CNCLUSION

A transistor oscillator was designed and simulated using ADS to generate a 1.73 GHz signal. The Oscillator is designed as a part of down frequency converter which shifts the WiFi frequency down from 2.45 GHz (WiFi signal) to 720 MHz. The 720 MHz is used to transmitt interne data over TV band (470-806) MHz in order to make use of the available TV white spaces.

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