

## DESIGN AND ANALYSIS OF HIGH FREQUENCY OSCILLATOR WITH DISTRIBUTED OUTPUT USING SIMULATION METHOD

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### ABSTRACT

*An approach to analysis and design of high frequency silicon bipolar oscillator using CE with distributed output is carried out. The general condition for oscillation is derived, resulting into analytical expressions for the frequency of oscillators. Special attention is paid to transmission line design using Butterworth LC filters in which the normalized values  $L_n$  and  $C_n$  where used to obtain the actual values of the inductors and capacitors used; this largely determines the performance of distributed oscillators. The values of inductor and capacitors in the phase shift network are used in tuning the oscillator. The simulated results show that the oscillator operates at 26MHz, dissipating 15mW power. The result indicates that distributed amplification methodology is viable at high frequency.*

**KEYWORDS:** Common emitter amp, Transmission lines, Distributed amp, Distributed oscillator

### INTRODUCTION

The rapid-increasing demand for large bandwidth in today's electronics device market (digital and analogue), wired or wireless is making it necessary to operate these circuits at higher frequencies. Formally, these high frequencies circuits have been designed using compound semiconductor technologies e.g. GaAs. In today's electronics world, silicon specifically complementary metal oxide semi conductors (CMOS), has emerged as a promising low-cost alternate for RF and microwave Circuits. Moreover, silicon based circuits are highly suitable for system on-chip implementations. However, silicon suffers from large parasitic elements both in active and passive devices, and therefore new design approaches are highly needed at such high frequency. Distributed circuits can achieve higher operation frequency, lower sensitivity to passive energy losses, and more robustness to process variations (Wu and Hajimiri, 2001). The term *distributed* has been used in various contexts with different meanings. In our treatment, a system will be called distributed if it uses multiple parallel signal paths and devices working in harmony to perform a desired task (Hajimiri, 2002). In this paper, analysis and design of silicon bipolar Oscillator

with distributed output, operating at high frequency is presented, graphs showing the frequency response of single stage, distributed amplifier together with simulated waveform are all presented.

### OSCILLATORS

An electronic oscillator may be defined in any one of the following four ways

It is a circuit which converts dc energy into ac at very high frequency.

It is an electronic source of alternating current or voltage having sine, square or saw-tooth or pulse shapes;

It is a circuit which generates an ac output signal without requiring any externally applied input signal;

It is unstable amplifier.

These definitions exclude electromechanical alternators producing 50Hz ac power or other devices which convert mechanical or heat energy in to electric energy.

### COMPARISON BETWEEN AN AMPLIFIER AND AN OSCILLATOR

An amplifier produces an output signal whose waveform is similar to the input signal but whose power level is generally high. This additional power is supplied by the eternal dc source.

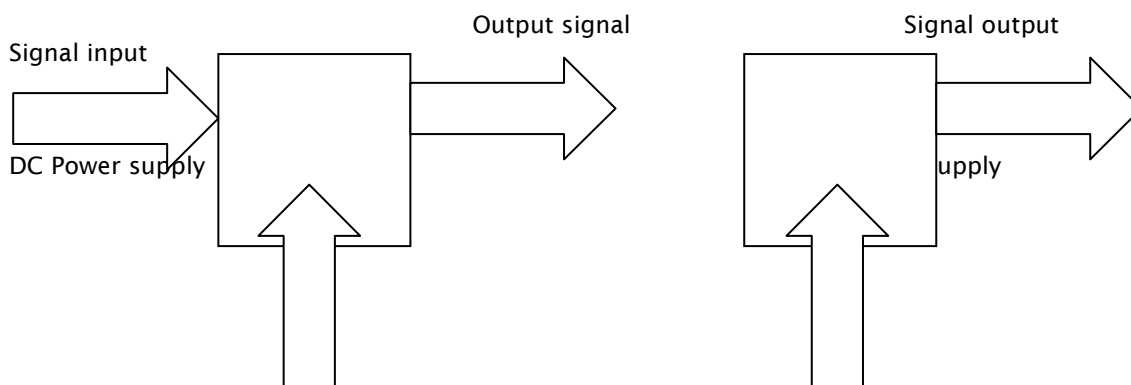


Figure 1: Comparison between an amplifier and an oscillator

Hence, an amplifier is essentially an energy converter i.e. it takes energy from the dc power source and converts it into ac energy at signal frequency the process of energy conversion is controlled by the input signal. If there is no input signal, there is no energy conversion and hence there is no output signal.

An oscillator differs from an amplifier in one basic respect. The oscillator does not require an external signal either to start or maintain energy conversion process (Fig.1). It keeps producing an output signal so long as the dc power is connected.

Moreover, the frequency of the output signal is determined by the passive components used in the oscillator and can be varied at will.

## MATERIALS AND METHODS

The method used was the simulation method using Multism 8.0 Electronics workbench.

**BC107 PNP** Transistor is chosen from the bipolar transistor family. This transistor is selected due to the fact that it is a general purpose transistor with high forward current gain and small saturation current. Using the data obtained for the output characteristics, a graph of  $I_C(\text{mA})$  versus  $V_{CE}(\text{V})$  is plotted and a family of the characteristic curves drawn Figure 2, the bias voltage  $V_{CE}$  is determined. The  $V_{CC}$  (dc supply) battery was chosen along  $V_{CE}$  axis, the  $V_{CE}$  equal to halve  $V_{CC}$  i.e.  $V_{CE} = \frac{1}{2} V_{CC}$  (Robert, et al, 2006). The remaining amplifier component parameters are calculated using the Benedict procedure (Benedict, 1976) as follows:

The value of  $R_E$  is chosen i.e.  $R_E \approx 0.2R_C$

The load line is drawn for  $(R_C + R_E)$  on the collector characteristics

The Q point excursion on the load line is chosen

Power dissipation is determine,  $P_d = V_{CE} I_C$

(1)

The value of  $I_C$  is determined from the graph

$$R_B = 0.3\beta R_E$$

(2)

$$V_{BB} = I_B R_B + V_{BE} - I_E R_E$$

(3)

$$R_1 = \frac{V_{CC} R_B}{V_{CC} - V_{BB}}, \quad R_2 = \frac{V_{CC} R_B}{V_{BB}}, \quad R_C = \frac{V_{CE}}{I_C}$$

(4)

$C_C$  and  $C_E$  are calculated as

$$C_C = \frac{10}{\omega(h_{ie} + R_s)}, \quad C_E = \frac{h_{fe}}{\omega(h_{ie} + R_s)}$$

(5)

$$g_m r_\pi = \beta, \quad \text{where } \beta = \frac{I_C}{I_B}, \quad \text{Also}$$

(6)

$$g_m = \frac{I_{CQ} q}{KT} \approx 40 I_C (\text{mA})$$

(7)

$$r_\pi = h_{ie}$$

(8)

Where  $R_B$ ,  $I_B$  and  $\beta$  are the base resistance, base current and current gain respectively.  $R_E$  is the emitter resistance.

Table 1: Output characteristics

		BC107 OUTPUT CHARACTERISTICS						
		$V_{CE}(\text{V})$	$I_C(\text{mA})$					
S/N			$I_b = 15\mu\text{A}$	$I_b = 30\mu\text{A}$	$I_b = 45\mu\text{A}$	$I_b = 60\mu\text{A}$	$I_b = 75\mu\text{A}$	$I_b = 90\mu\text{A}$
1	00		-15.42	-29.71	-44.84	-59.37	-74.56	-88.63
2	0.2		2.75	5.49	8.3	10.92	13.56	15.9
3	0.4		3.11	6.22	9.58	12.84	16.28	19.42
4	01		3.15	6.31	9.71	13.02	16.49	19.72
5	02		3.22	6.45	9.93	13.31	16.86	20.17
6	03		3.29	6.59	10.15	13.6	17.23	20.61
7	04		3.36	6.73	10.37	13.9	17.6	21.05
8	05		3.43	6.88	10.59	14.1	17.98	21.56
9	06		3.5	7.02	10.81	14.48	18.35	21.94
10	07		3.58	7.16	11.03	14.77	18.72	22.38
11	08		3.65	7.3	11.24	15.07	19.09	22.83
12	09		3.72	7.44	11.46	15.36	19.49	23.27
13	10		3.79	7.58	11.68	15.65	19.83	23.71
14	11		3.86	7.73	11.9	15.94	20	24.16
15	12		3.93	7.87	12.12	16.24	20.57	24.6

Table 1 continue

		BC107 OUTPUT CHARACTERISTICS					
	$V_{CE}$ (V)	$I_C$ (mA)					
S/N		$I_B = 15\mu A$	$I_B = 30\mu A$	$I_B = 45\mu A$	$I_B = 60\mu A$	$I_B = 75\mu A$	$I_B = 90\mu A$
16	13	4	8.01	12.34	16.53	20.94	25.04
17	14	4.07	8.15	12.56	16.82	21.31	25.49
18	15	4.14	8.29	12.77	17.12	21.68	25.93
19	16	4.21	8.43	12.99	17.42	22.06	26.38

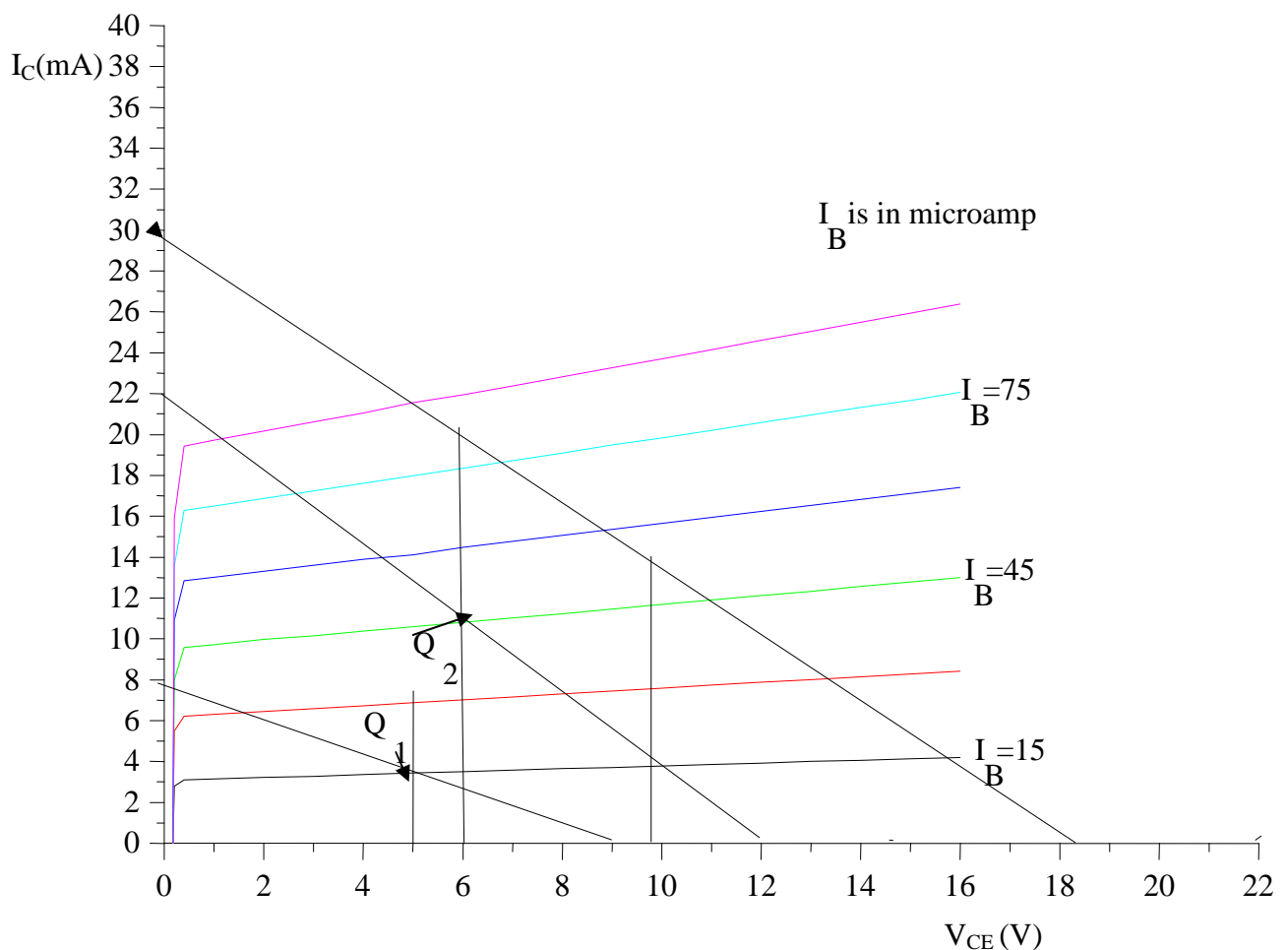


Fig. 2 Output characteristics curves for BC 107

**FREQUENCY RESPONSE OF THE SINGLE STAGE CE AMPLIFIER**

Having obtained all the component parameters of the amplifier, the next stage is to determine its

frequency response. The response is obtained by plotting a graph of voltage gain ( $\frac{V_2}{V_1}$ ) in (dB) versus frequency (Hz) (Fig.3), the bandwidth of the amplifier is calculated as

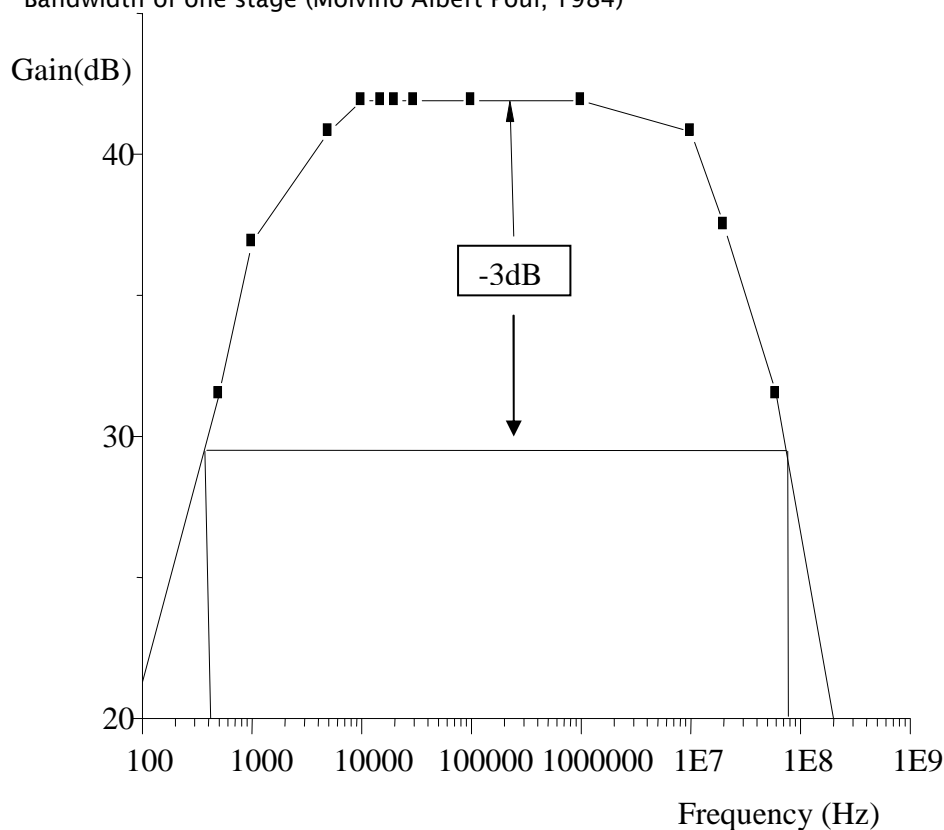
$$\text{Bandwidth}(BW) = f_H - f_L \tag{9}$$

where  $f_H$  and  $f_L$  is the higher and lower cut-off frequencies respectively, for n identical stage the bandwidth is obtained as

$$B_n = B \sqrt{2^n - 1} \tag{10}$$

Where  $B_n$  = overall bandwidth

**B** = Bandwidth of one stage (Molvino Albert Poul, 1984)



**Fig. 3 Simulated Graph of frequency response of single stage CE amplifier.**

**TRANSMISSION LINE DESIGN**

We now develop methods whereby the normalized filters can be converted into filters which meet arbitrary cut-off frequency and impedance level specifications (Butterworth filter-Wikipedia, the free encyclopaedia 20/12/2009)

$$R = R_L R_n \tag{11}$$

$$C_n(\text{actual}) = \frac{C_n}{R_L \omega} \tag{12}$$

$$L_n(\text{actual}) = \frac{R_L L_n}{\omega} \tag{13}$$

$C_n, L_n$  are the normalized capacitor and inductor respectively.

Using the normalized Butterworth low-pass filter table ( $R_L = 1\Omega$ ), the values of C and L are calculated.

**ANALYSIS OF FREQUENCY OF OSCILLATION**

To develop a general theory for an Oscillator, the equivalent circuit (Fig. 3.1) is drawn with the following two assumptions (Gupta, 2006-2007)

$h_{re}$  of transistor is negligibly small, and therefore, the feedback source  $h_{re} V_{out}$  is negligible.

$h_{oe}$  of the transistor is very small i.e. the output resistance  $\frac{1}{h_{oe}}$  is very large and therefore,  $\frac{1}{h_{oe}}$  is omitted from the equivalent circuit.

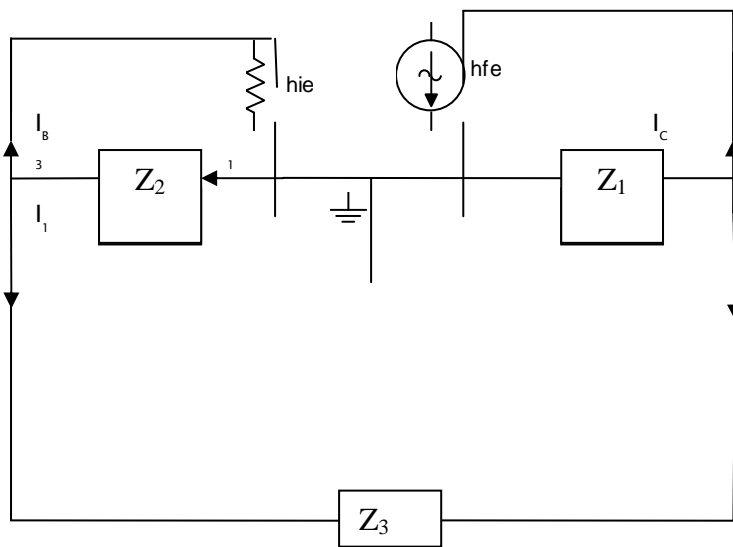


Fig. 4 equivalent circuit

Here  $z_2$  and  $h_{ie}$  are in parallel and their resultant impedance are in series with impedance  $Z_3$ . The equivalent impedance is in parallel with impedance  $Z_1$ .

$$h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 (1 + h_{fe}) + Z_2 Z_3 = 0 \quad (14)$$

This is the general equation for the oscillation

In case of colpitt oscillator

$$Z_1 = \frac{1}{j\omega C_1} = \frac{-j}{\omega C_1} ; \quad Z_2 = \frac{1}{j\omega C_2} = \frac{-j}{\omega C_2} \quad \text{and} \quad Z_3 = j\omega L \quad (15)$$

Substituting these values in equation (14) we have

$$\left[ \frac{-j}{\omega C_1} - \frac{j}{\omega C_2} + j\omega L \right] + \left[ \frac{-j}{\omega C_1} \frac{-j}{\omega C_2} \right] (1 + h_{fe}) + j\omega L = 0 \quad (16)$$

$$\text{Or} \quad -jh_{ie} \left[ \frac{1}{j\omega C_1} + \frac{1}{j\omega C_2} - j\omega L \right] - \frac{1 + h_{fe}}{\omega^2 C_1 C_2} + \frac{L}{C_2} = 0 \quad (17)$$

Equating the imaginary component of the above equation to zero, we have

$$h_{ie} \left[ \frac{1}{j\omega C_1} + \frac{1}{j\omega C_2} - j\omega L \right] = 0 \quad (18)$$

$$\text{Or} \quad \frac{1}{j\omega C_1} + \frac{1}{j\omega C_2} = j\omega L \quad (19)$$

$$\text{Or} \quad \frac{C_1 + C_2}{\omega C_1 C_2} = \omega L \quad \text{Or} \quad \omega^2 = \frac{C_1 + C_2}{LC_1 C_2} \quad \text{or} \quad \omega = \sqrt{\frac{C_1 + C_2}{LC_1 C_2}} = \sqrt{\frac{1}{LC_1} + \frac{1}{LC_2}} \quad (20)$$

$$\text{Or} \quad f = \frac{1}{2\pi} \sqrt{\frac{1}{LC_1} + \frac{1}{LC_2}} \quad (21)$$

The above equation (21) gives the frequency of oscillation. Equating the real component of equation (17) to zero we have

$$\frac{1 + h_{fe}}{\omega^2 C_1 C_2} = \frac{L}{C_2} \quad (22)$$

$$\text{Or} \quad 1 + h_{fe} = \omega^2 C_1 L \quad (23)$$

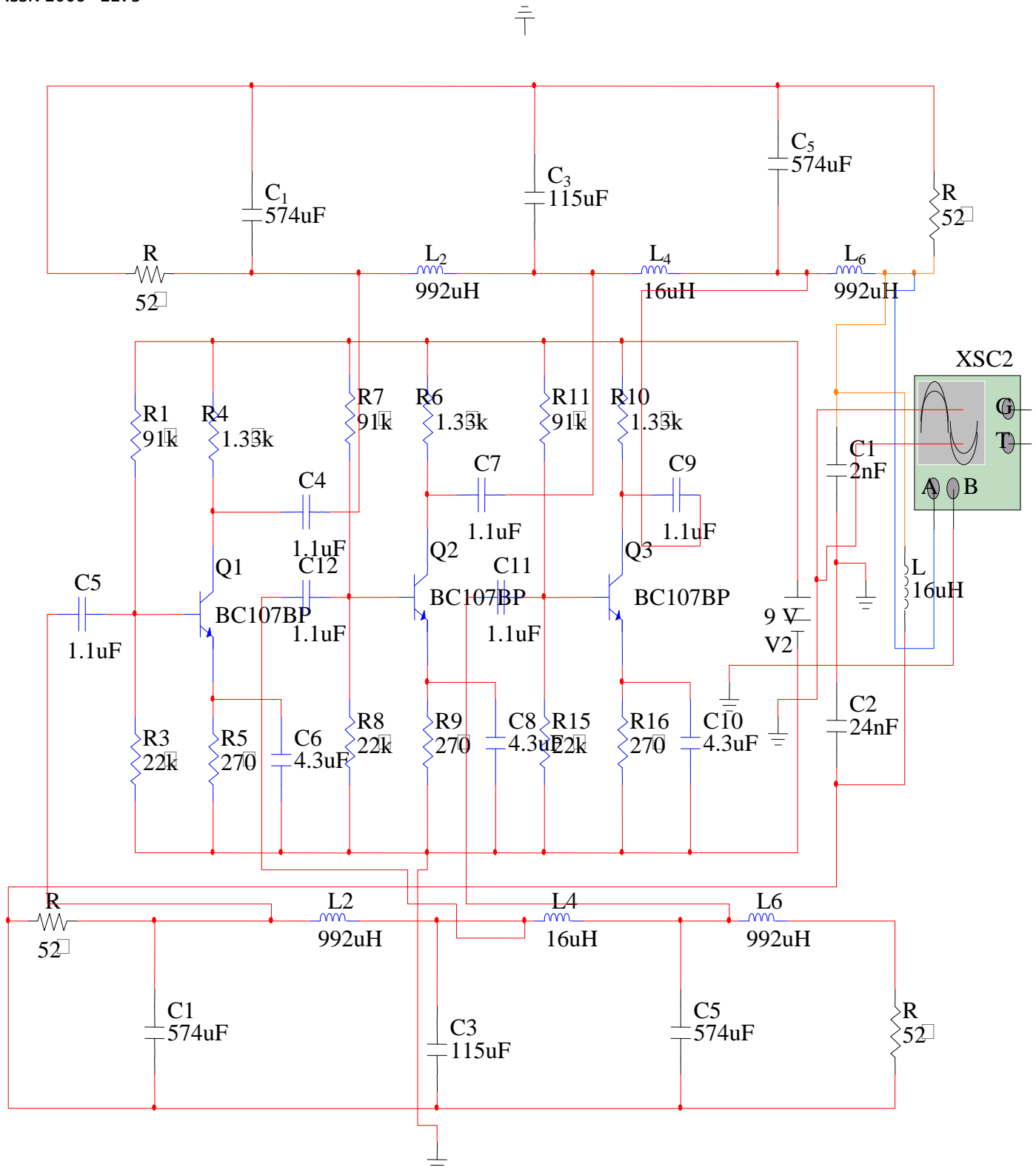
$$\text{Or} \quad 1 + h_{fe} = \frac{C_1 + C_2}{LC_1 C_2} \times C_1 L = \frac{C_1 + C_2}{C_2} = 1 + \frac{C_1}{C_2} \quad \text{or} \quad h_{fe} = \frac{C_1}{C_2} \quad (24)$$

As for other oscillator circuits, the loop gain must be greater than unity to ensure that the circuit oscillates

So  $AB \geq 1$  or  $A \geq \frac{1}{\beta} \approx \frac{C_1}{C_2}$  112

#### THE DISTRIBUTED OSCILLATOR

A distributed oscillator operates in the forward-gain mode of a distributed amplifier. The forward wave on the base line is amplified by each transistor and appears on the collector line. The travelling wave on the collector line travels to the right in synchronization with the travelling wave on the base line. Each transistor adds power in phase to the signal at each tapping point on the collector line. Thus, the forward path can have an overall gain larger than unity while the gain of each transistor may be less than one. To sustain oscillations, the output of the collector line is fed back to the input of the base line.



**Fig.5 Distributed oscillator**

When collector supply voltage  $V_{cc}$  is switched on , the capacitor  $C_1$  and  $C_2$  are charged. These capacitors  $C_1$  and  $C_2$  discharged through L setting up Oscillations

$$f = \frac{1}{2\pi} \sqrt{\frac{1}{LC_1} + \frac{1}{LC_2}}$$

frequency

the oscillator capacitor  $C_2$  is applied to the base input transmission line (input T.line ) and appear in the amplified form in the collector output transmission line (out-put T.line) circuit. Of course, the amplified output in

the output transmission line is of the same frequency as that of the oscillator circuit (LC tank). This amplified output in the collector is supplied with energy from the circuit to make up for the losses occurring in it. If  $A\beta$  exceeds unity, oscillations are sustained in the circuit. (Gupter 2006 - 2007)

**RESULTS**

Using equation(s) (1) to (8) the value of the parameters of the amplifier components were calculated and they are

$V_{CC} = 9V, V_{CE} = 4.5V, V_{BE} = 0.7V(\text{Silicon})$

$I_C = 3.4mA \cong I_E, I_B = 15\mu A, V_{BB} \approx 1.8(V), P_d = 0.0153w \approx 15mw, R_E = 265\Omega, \beta \approx 227$

$g_m = 0.136, R_1 = 22K\Omega, R_2 = 90K\Omega, C_B \approx 3\mu F, C_C \approx 1.2\mu F$

For the transmission line(s), using equations (12) and (13) we have

$C_1 = C_7 = 1.146 \times 10^{-14} = 144pF$

$C_3 = C_5 = 5.739 \times 10^{-14} = 574pF$

$L_2 = L_6 = 9.992 \times 10^{-8} = 992\mu H$

$L_4 = 1.5913 \times 10^{-7} = 15.913 \times 10^{-6} \approx 16\mu H$

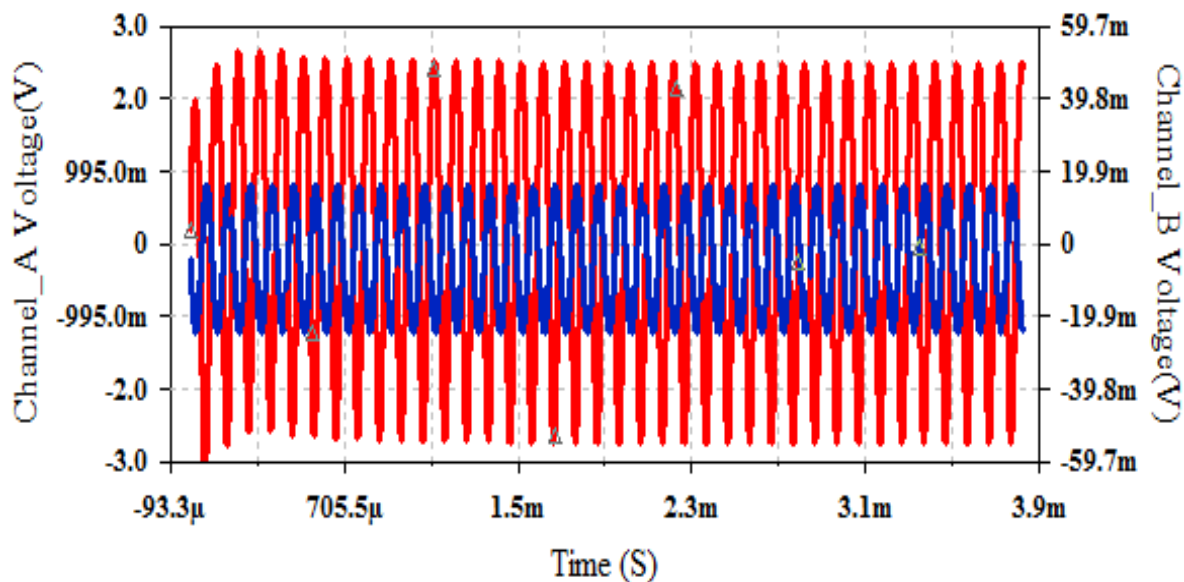


Fig. 6 simulated waveform of CE amplifier



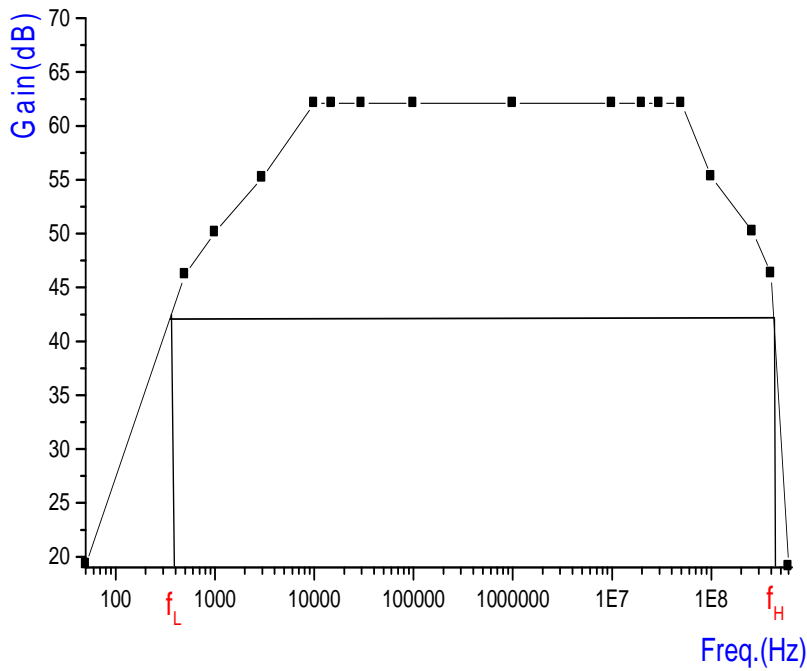


Fig. 7 Simulated Graph of distributed amplifier

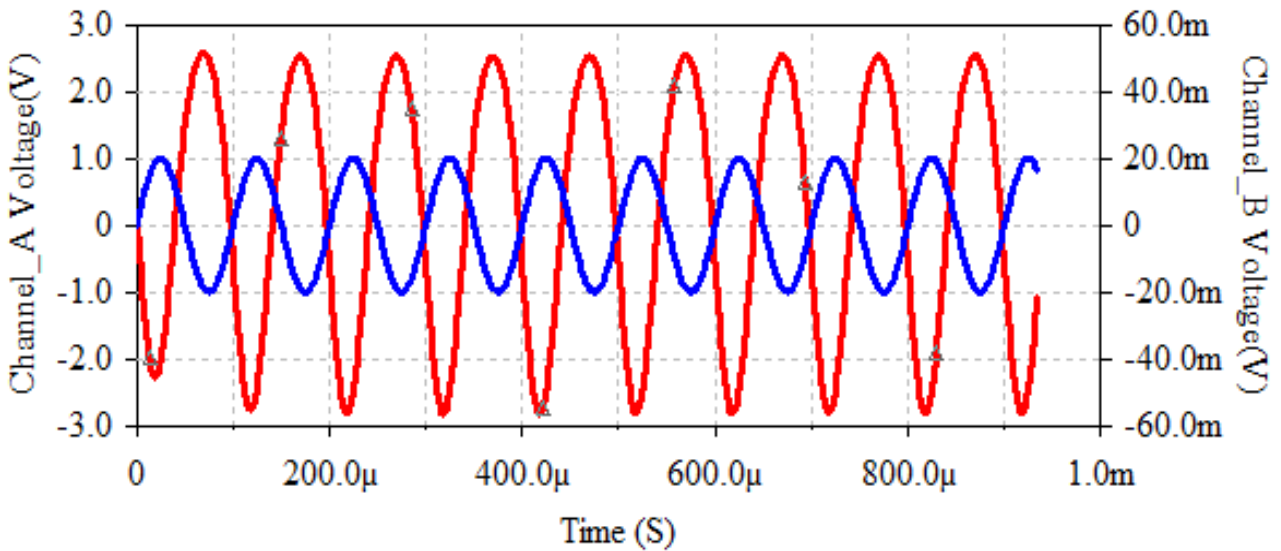


Fig. 8 Distributed amplifier simulated signal wave-form

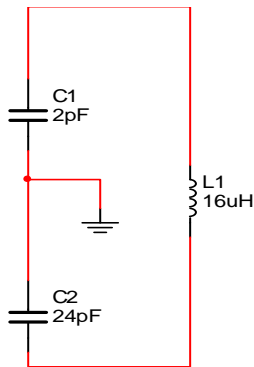


Fig.9 Phase shift circuit

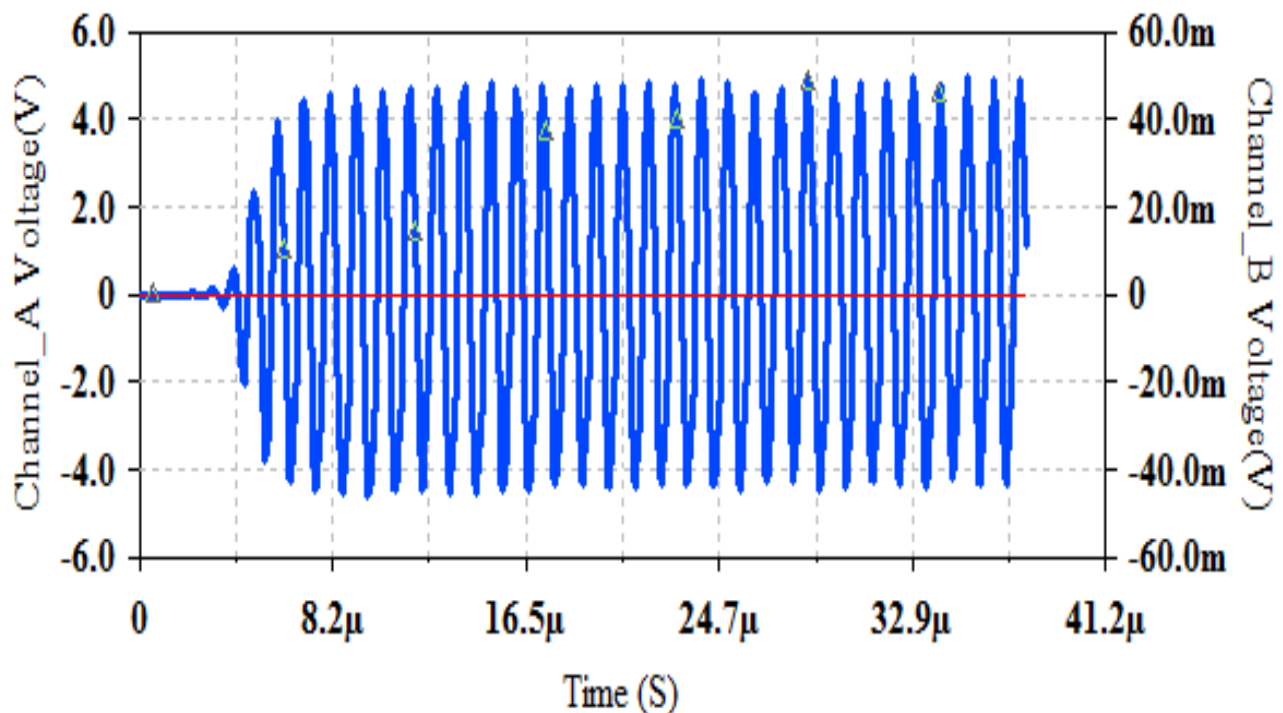


Fig. 10 Simulated waveform of the distributed oscillator

### CONCLUSION

An attempt to design and analysis of silicon bipolar oscillator with distributed output is carried out. The general condition for oscillation is derived; also the expression for the frequency of oscillation is obtained. Special attention is paid to transmission line using Butterworth LC filter that largely play role in the performance of distributed oscillators.  $C_1$ ,  $C_2$  and  $L$  Which are the elements of the phase shift network are used to compute the frequency of oscillation. A distributed oscillator operating at high frequency is designed. The simulated results show that the

oscillator operates at 26MHz (Fig.10), dissipating 15mW power and it is working well, meeting design goals and it has good signal purity. The idea of a distributed amplification methodology towards design of bipolar distributed oscillator is found viable in high frequency region. Distributed oscillators are used in many RF and high data rate communication systems including Cellular phones, pulsed radar systems, optical receivers and so on

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