



# Designing Oscillator for an Antenna at $\sim 3.5[GHz]$

2896

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# Milestones completed so far

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## List of Milestones completed

- Selected the transistor we will use
- Simulated the oscillator we designed in PSpice
- Designed Matching network for the load(antenna)
- Optimised matching network for efficiency

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# Choosing the BJT

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## Required characteristics

- The transistor needs high-frequency performance, including  $f_{\max}$  and  $f_t$ , well above 3.5[GHz].
- Low parasitic capacitance at collector, base, and emitter terminals is crucial.
- Low noise figure is essential.
- High gain, especially at the operating frequency, is necessary for stable oscillation.
- Ensure appropriate biasing for Colpitts oscillator operation, including DC voltages and currents.



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## **BFP520** from Infenion<sup>1</sup>

- Surface mount low voltage silicon NPN RF bipolar transistor
- Transition frequency  $f_T$  of 45[GHz]
- High Gain, with  $|S_{12}|$ ,  $G_{ma}$ ,  $G_{ms} > 16[dB]$  at 3.5[GHz] under  $V_{ce} = 2[V]$
- Low Noise Figure,  $NF < 1.2[dB]$  at 3.5[GHz], 2[V], 2[mA]

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<sup>1</sup>[https://www.infineon.com/dgdl/Infineon-BFP520-DS-v02\\_00-EN.pdf?fileId=5546d462689a790c01690f035fe2391a](https://www.infineon.com/dgdl/Infineon-BFP520-DS-v02_00-EN.pdf?fileId=5546d462689a790c01690f035fe2391a)

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# Oscillator Circuit

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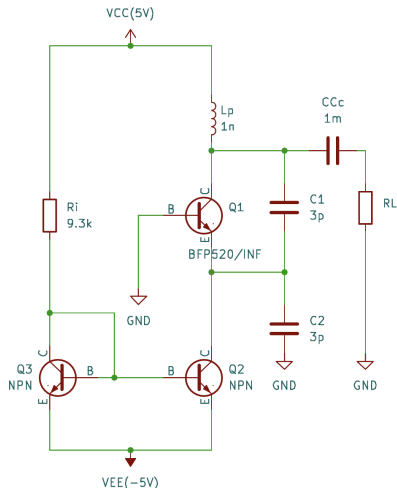
# Collpit's Oscillator

- The circuit was tested with some high impedance load attached
- Values of  $L_p$ ,  $C_1$  and  $C_2$  were computed using the operating frequency formula

$$f_c \approx \frac{1}{2\pi \sqrt{L_p \frac{C_1 C_2}{C_1 + C_2}}}$$

*a*

- $C_1 = C_2$  was chosen since it gave the highest oscillation frequency



<sup>a</sup>In-depth analysis in Appendix

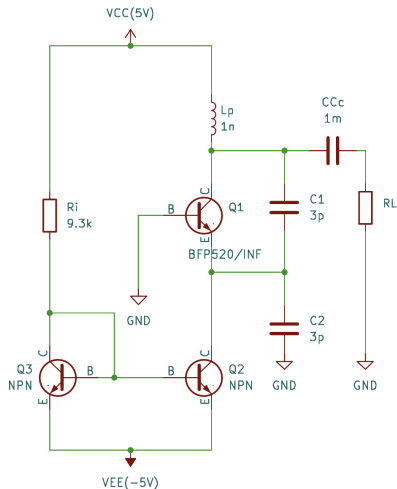
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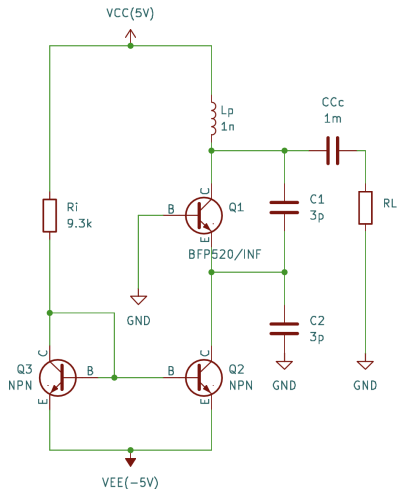
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# Output Waveform

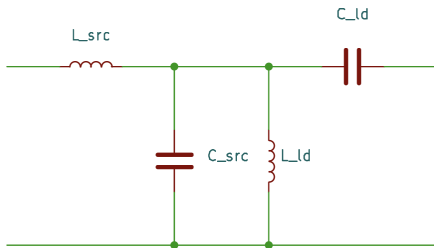
# Choosing a Matching Network

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# Matching Network

T-matching is better for matching a load to a source impedance when there's a large disparity because it provides efficient power transfer, minimizes losses, and offers impedance transformation with stability.<sup>2</sup>

- $L_{src} = 2.03361[nH]$
- $C_{src} = 2.02955[fF]$
- $L_{ld} = 10.4421[nH]$
- $C_{ld} = 0.208424[pF]$

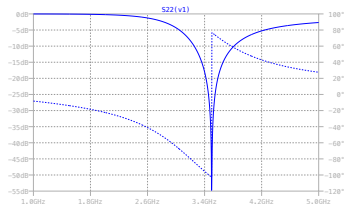
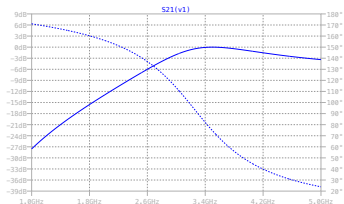
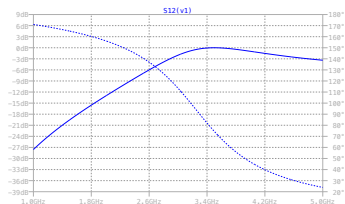
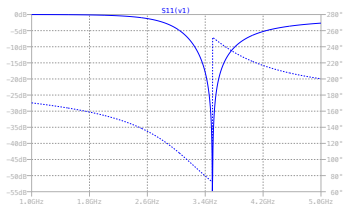


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<sup>2</sup>Design method in Appendix



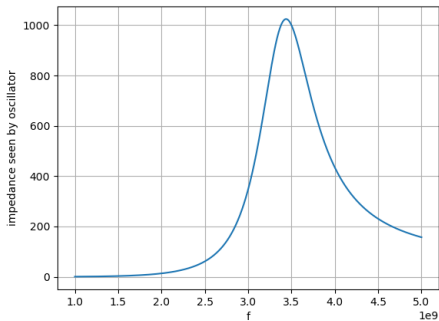
# S-parameters of the Matching Network<sup>3</sup>



<sup>3</sup>Simulated using .net parameter in LTSpice

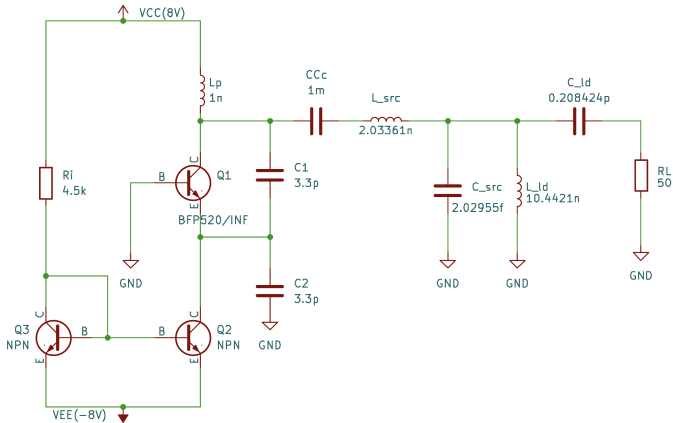
# Input impedance through the Matching Network

- Attains max value of  $\approx 1000[\Omega]$  at  $3.5[GHz]$
- Tapers quickly for the non-central frequencies



# Oscillator using Matching Network as $50[\Omega]$ load

After making adjustments to supply and current to maximize efficiency, we have the following system<sup>4</sup>



<sup>4</sup>Efficiency  $\eta$  is defined in the next section

## Output of Oscillator using Matching Network as $50[\Omega]$ load

# Efficiency

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## Calculation of $\eta$

- **Input:**  $P_{DC} = V_{CC}I_C$
- **Output:**  $P_{ac} = \frac{V_{rms}^2}{R_L}$  where  $V_{rms} = \frac{V_{max}}{\sqrt{2}}$  for the output waveform
- **Efficiency:**  $\eta = \frac{P_{ac}}{P_{CD}}$

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For  $V_{CC} = -V_{EE} = 8[V]$ , and current mirror set to give  $3.36[mA]$ , we have  $v_p = 1.6[V]$ , giving us

$$\eta \approx 20\%^5$$

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# Antenna Design

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# Patch Microstrip Antenna

- Directional Antenna with good efficiency and high gain when used in an antenna array
- Input impedance of  $50[\Omega]$

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- Layout the PCB
- Fabrication and Testing

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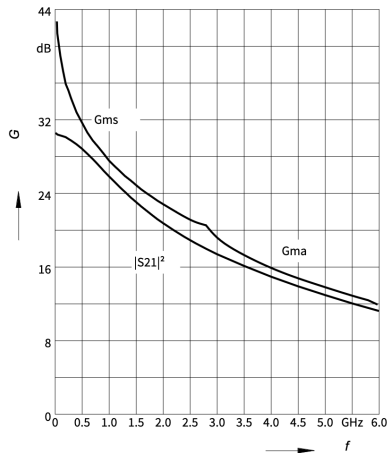
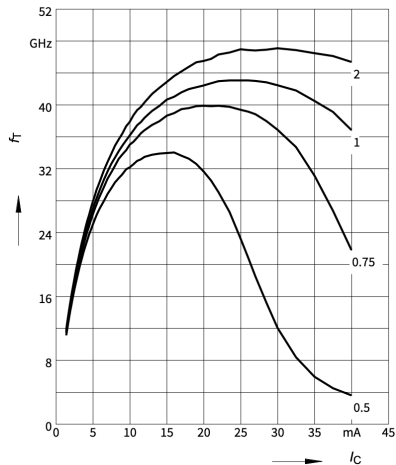
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# Appendix

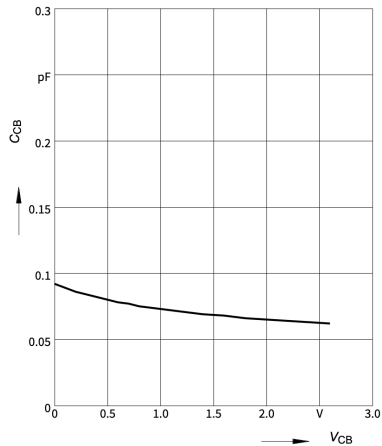
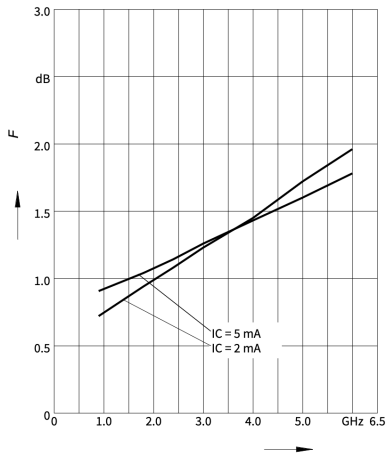
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# Data from Infenion - 1



## Data from Infenion - 2

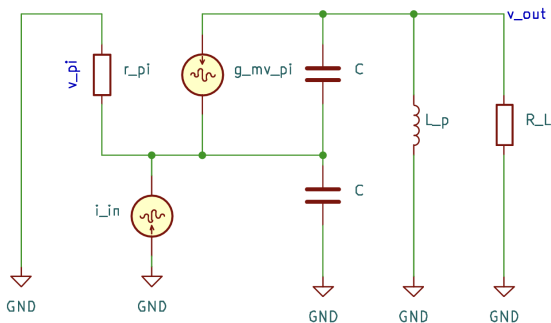


# BFP520 Spice File

```
.SUBCKT BFP520/INF 200 100 300
L1      1      10      0.47nH
L2      2      20      0.56nH
L3      3      30      0.23nH
C1      10     20      6.9fF
C2      20     30      134fF
C3      30     10      136fF
L4      10     100     0.53nH
L5      20     200     0.58nH
L6      30     300     0.05nH
Q1      2 1 3 BFP520
.ENDS
.MODEL BFP520 NPN(
+ IS =1.5E-17      NF =1      NR =1
+ ISE=2.5E-14      NE =2      ISC=2E-14
+ NC =2            BF =235    BR =1.5
+ VAF=25           VAR=2      IKF=0.4
+ IKR=0.01         RB =11     RBM=7.5
+ RE =0.6          RC =7.6    CJE=2.35E-13
+ VJE=0.958        MJE=0.335  CJC=9.3E-14
+ VJC=0.661        MJC=0.236  CJS=0
+ VJS=0.75         MJS=0.333  FC=0.5
+ XCJC=1           TF=1.7E-12 TR=5E-08
+ XTF=10           ITF=0.7    VTF=5
+ PTF=50           XTB=-0.25  XTI=0.035
+ EG=1.11)
```

## Proof of operating frequency - 1

We have the following small signal model of Collpit's oscillator, with  $C_1 = C_2 = C$ <sup>6</sup>



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<sup>6</sup>In all the results, we try to ignore effects of  $r_{\pi}$  and then adjust the values accordingly to get required response

## Proof of operating frequency - 2

$$i_{in} = -\frac{v_{\pi}}{r_{\pi}} - sC(v_{out} + 2v_{\pi})$$

$$g_m v_{\pi} + sC(v_{out} + v_{\pi}) + \frac{v_{out}}{sL_p} + \frac{v_{out}}{R_L} = 0$$

This gives us the following frequency response

$$\frac{v_{out}}{i_{in}} = \frac{r_{\pi} L_p R_L (s^2 C + s g_m)}{r_{\pi} C^2 L_p R_L s^3 + (-r_{\pi} C L_p R_L g_m + 2r_{\pi} C L_p + C L_p R_L) s^2 + (2r_{\pi} C R_L + L_p) s + R_L}$$

Put  $s = j\omega$  and let  $Im$  of denominator  $\rightarrow 0$

$$\omega_0 = \sqrt{\frac{2r_{\pi} C R_L + L_p}{r_{\pi} C^2 L_p R_L}}$$

Assuming  $r_{\pi} \rightarrow \infty$ , as is the case is MOS, we reach the well-known expression  $\omega_0 = \sqrt{\frac{1}{L \frac{C \cdot C}{C+C}}}$

## Proof of operating frequency - 3

For sustained oscillations, we need

$$-(-r_{\pi}CL_pR_Lg_m + 2r_{\pi}CL_p + CL_pR_L)\omega_0^2 + R_L > 0$$

This gives us

$$^7R_Lg_m - \frac{R_L}{r_{\pi}} - 2 > 0$$

Thus, we need to set  $R_L$  accordingly at the oscillating frequency, giving us a lower bound for load and thus a need for a matching network

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<sup>7</sup>This is similar to the condition found in Razavi, but for NMOS in place of NPN BJT

# Calculation of matching network - 1

We have a source impedance  $Z_s$ , a load impedance  $Z_L$ , and operating frequency  $f_0$  and we need to match  $Z_L$  to  $Z_s$  at  $f_0$  using a T-Matching Network. We assume a central impedance  $Z_c$  such that  $Z_c > \max(Z_s, Z_L)$ , and then calculate the series and parallel reactive components on both sides.<sup>8</sup>

Source:

$$Q_{src} = \sqrt{\frac{Z_c}{Z_s} - 1}$$

$$X_{src}^{parallel} = \frac{Z_c}{Q_{src}}$$

$$X_{src}^{series} = Q_{src} Z_s$$

Load:

$$Q_{ld} = \sqrt{\frac{Z_c}{Z_L} - 1}$$

$$X_{ld}^{parallel} = \frac{Z_c}{Q_{ld}}$$

$$X_{ls}^{series} = Q_{ls} Z_L$$

Then,  $L = \frac{X}{2\pi f_0}$  and  $C = \frac{1}{2\pi f_0 X}$  for chosen  $X$  series/parallel

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<sup>8</sup>In our case, all impedances are real

## Calculation of matching network - 2<sup>9</sup>

After this, the values of  $V_{cc}$ ,  $V_{ee}$ , and  $I_c$  were changed so as to get the maximum efficiency.  $R_L$  was matched to  $1[K\Omega]$ .

Variable	Value
$f_0$	$3.5 \times 10^9$
$Z_{out\_osc}$	1000
$Z_{load}$	50
$Z_{center}$	1002
$Q_{src}$	0.0447214
$X_{paralle\_src}$	22405.4
$X_{series\_src}$	44.7214
$L_{src}$	$2.03361 \times 10^{-9}$

Variable	Value
$C_{src}$	$2.02955 \times 10^{-15}$
$Q_{ld}$	4.36348
$X_{paralle\_ld}$	229.633
$X_{series\_ld}$	218.174
$L_{ld}$	$1.04421 \times 10^{-8}$
$C_{ld}$	$2.08424 \times 10^{-13}$
$C_{com}$	$2.10454 \times 10^{-13}$
$L_{com}$	$1.70212 \times 10^{-9}$

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<sup>9</sup>Values generated using .py script that we made



# Calculation of parameters of Patch Antenna

$$1. W = \frac{1}{2f\sqrt{\mu_0\epsilon_0}} \sqrt{\frac{2}{\epsilon_r+1}}$$

$$2. \epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2\sqrt{1+\frac{12h}{W}}}$$

xnsxsj

$$3. \frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

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