Transistors at Radio Frequency

- How to describe transistors at radiofrequency.
- Equivalent circuits and S-parameters
- Y-parameters and SOLVE
- Stability of transistor amplifiers (brief)
- The Klapp RF Oscillator
- SOLVE Example: The Klapp Oscillator

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Transistors at Radio Frequency

- Transistors are more complex at high frequencies due to the effects of internal parasitic inductance and capacitance.
- Always try first to seek S-parameters from manufacturers.
- Or use a simulation package that has them in its database.
- Failing all this.. do a model. Here's how.
- We try to glean enough information from datasheets and independent measurements to form a physical model to predict S-parameters.

BF199 VHF Transistor

Philips Semiconductors | Product specification

NPN medium frequency transistor — BF199

FEATURES

- Low current (max. 25 mA)
- Low voltage (max. 25 V).

APPLICATIONS

- Output stage of a vision IF amplifier.

DESCRIPTION

NPN medium frequency transistor in a TO-92; SOT54 plastic package.

PINNING

PIN	DESCRIPTION
1	base
2	emitter
3	collector

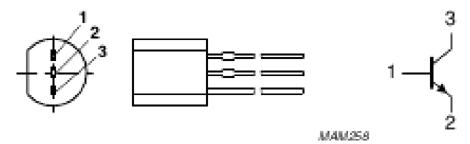

Fig.1 Simplified outline (TO-92; SOT54) and symbol.

QUICK REFERENCE DATA

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter	–	–	40	V
V_{CEO}	collector-emitter voltage	open base	–	–	25	V
I_{CM}	peak collector current		–	–	25	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C	–	–	500	mW
h_{FE}	DC current gain	$I_C = 7$ mA; $V_{CE} = 10$ V	38	–	–	
f_T	transition frequency	$I_C = 5$ mA; $V_{CE} = 10$ V; f = 100 MHz	–	550	–	MHz

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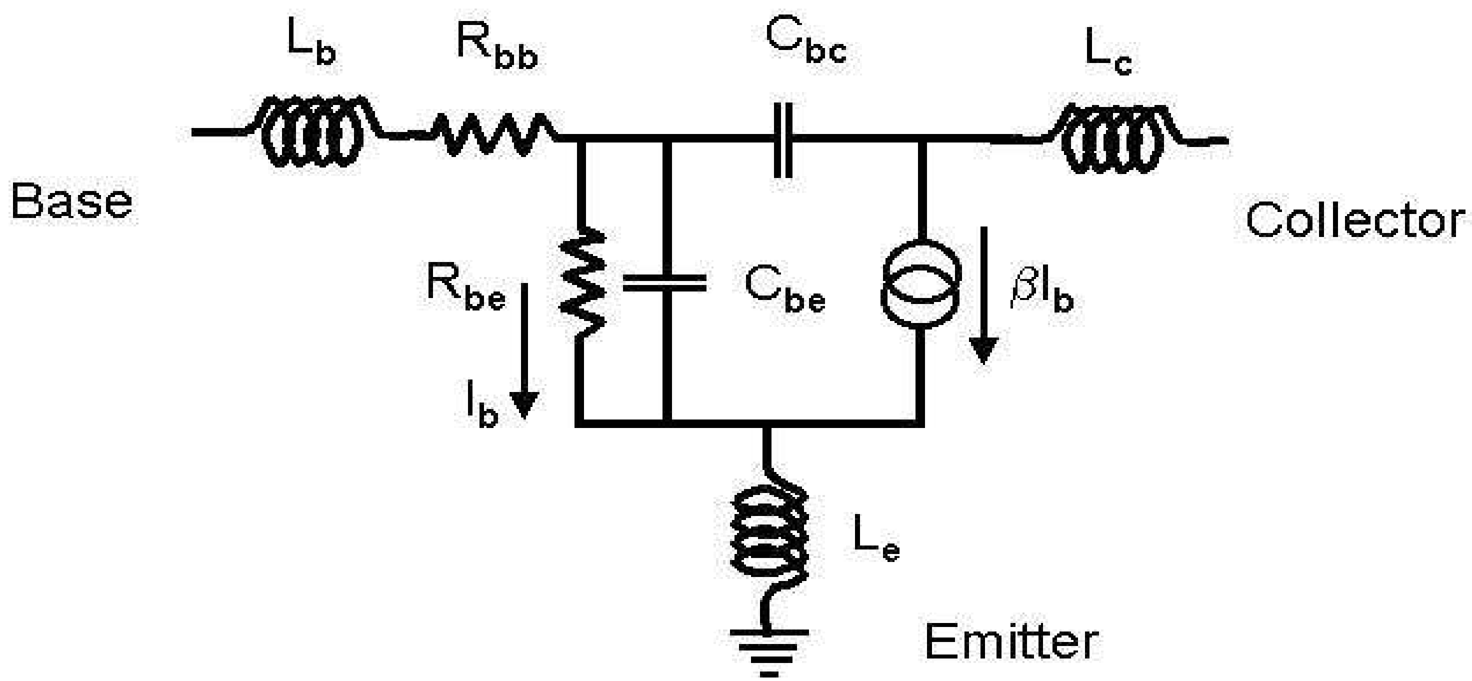
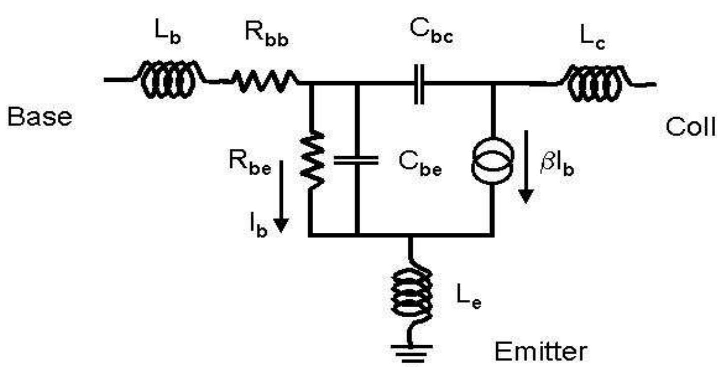
Radio Frequency Transistor circuit model



BF199 Datasheet



Philips Semiconductors — Product specification

NPN medium frequency transistor — BF199

LIMITING VALUES

In accordance with the Absolute Maximum Rating System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.	UNIT
V_{CBO}	collector-base voltage	open emitter	–	40	V
V_{CEO}	collector-emitter voltage	open base	–	25	V
V_{EBO}	emitter-base voltage	open collector	–	4	V
I_C	collector current (DC)		–	25	mA
I_{CM}	peak collector current		–	25	mA
P_{tot}	total power dissipation	$T_{amb} \leq 25$ °C; note 1	–	500	mW
T_{stg}	storage temperature		−65	+150	°C
T_j	junction temperature		–	150	°C
T_{amb}	operating ambient temperature		−65	+150	°C

Note

1. Transistor mounted on an FR4 printed-circuit board.

THERMAL CHARACTERISTICS

SYMBOL	PARAMETER	CONDITIONS	VALUE	UNIT
$R_{th\ j\text{-}a}$	thermal resistance from junction to ambient	note 1	250	K/W

Note

1. Transistor mounted on an FR4 printed-circuit board.

CHARACTERISTICS

$T_{amb} = 25$ °C unless otherwise specified.

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
I_{CBO}	collector cut-off current	$I_E = 0$; $V_{CB} = 40$ V	–	–	100	nA
I_{EBO}	emitter cut-off current	$I_C = 0$; $V_{EB} = 4$ V	–	–	100	nA
h_{FE}	DC current gain	$I_C = 7$ mA; $V_{CE} = 10$ V	38	–	–	
V_{BE}	base-emitter voltage	$I_C = 7$ mA; $V_{CE} = 10$ V	–	775	925	mV
C_{re}	feedback capacitance	$I_C = 0$; $V_{CB} = 10$ V; f = 1 MHz	–	–	0.5	pF
f_T	transition frequency	$I_C = 5$ mA; $V_{CE} = 10$ V; f = 100 MHz	–	550	–	MHz

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Networks: Y-parameters vs S-parameters

- Y-parameters and S-parameters are related:

$$y_i = \frac{(1 + S_{22})(1 - S_{11}) + S_{12}S_{21}}{\Delta Z_0}$$

$$y_r = \frac{-2S_{12}}{\Delta Z0}$$

$$y_f = \frac{-2S_{21}}{\Delta Z0}$$

$$y_o = \frac{(1 + S_{11})(1 - S_{22}) + S_{12}S_{21}}{\Delta Z_0}$$

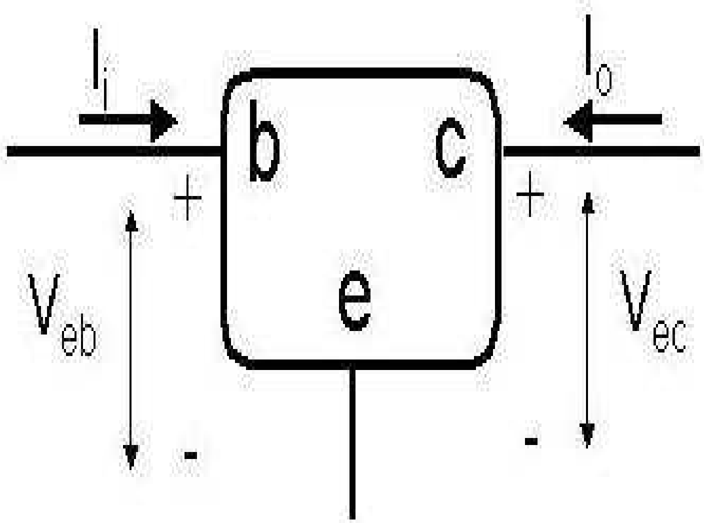
where $\Delta = (1 + S_{11})(1 + S_{22}) - S_{21}S_{12}$.

Definition of Y-parameters

- Need these for employ solve.

$$I_i = y_i V_{eb} + y_r V_{ec}$$

$$I_o = y_f V_{eb} + y_o V_{ec}$$



Using Solve For Transistors

- Consider the base node

$$I_b = (y_i + y_r)V_{eb} - y_r V_{cb}$$

- Consider the collector node

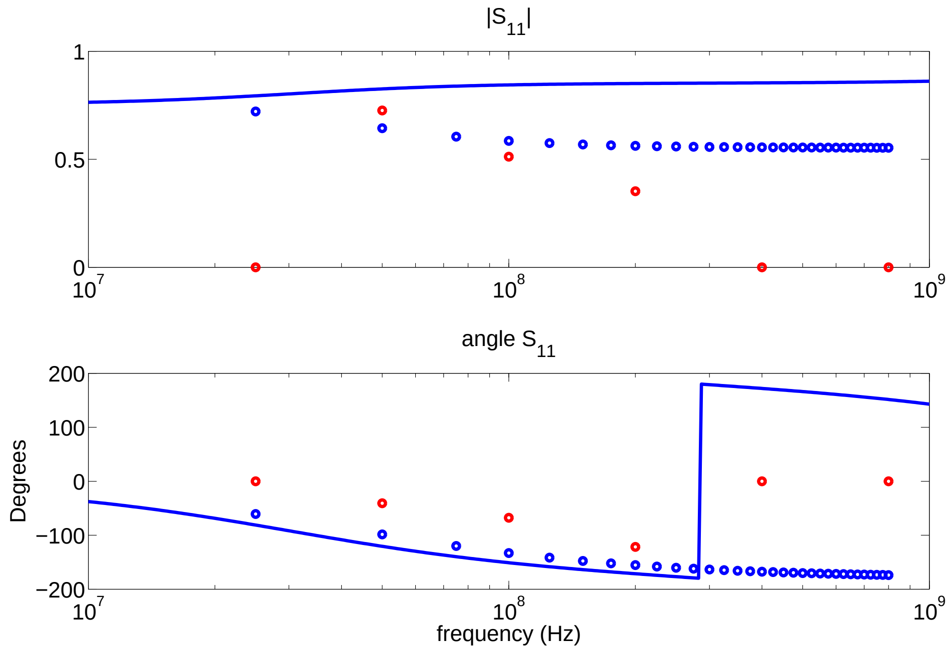
$$I_c = (y_o + y_f)V_{ec} - y_f V_{bc}$$

- Consider the emitter node

$$I_e = (y_i + y_f)V_{be} + (y_r + y_o)V_{ce}$$

BF199 S-parameters

- Use $C_{be} = 100pF$ ($f_T = 550MHz$), $C_{bc} = 0.5pF$, $I_c = 7mA$ and $h_{fe} = 100$.



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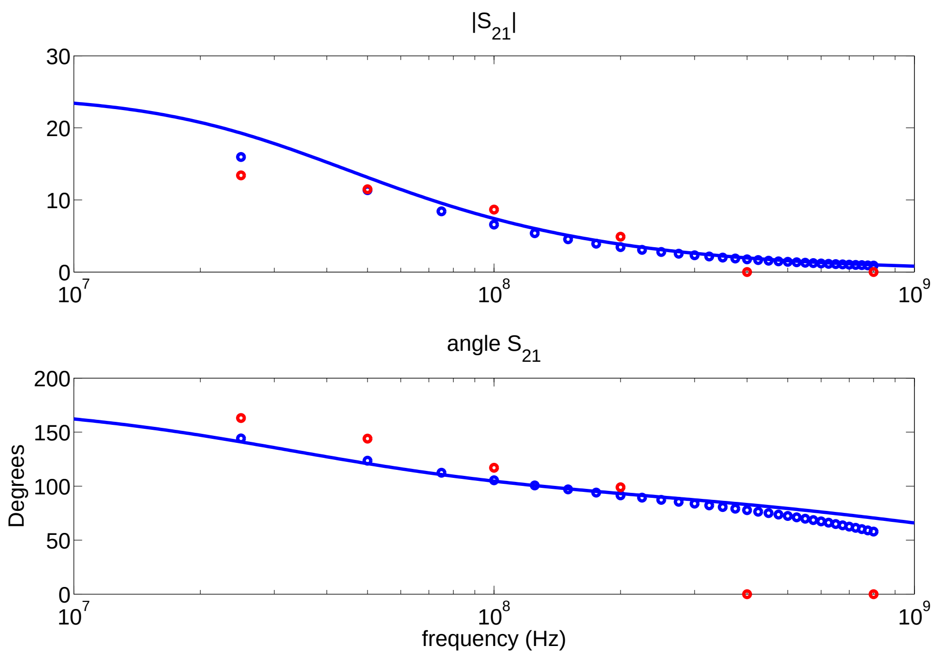

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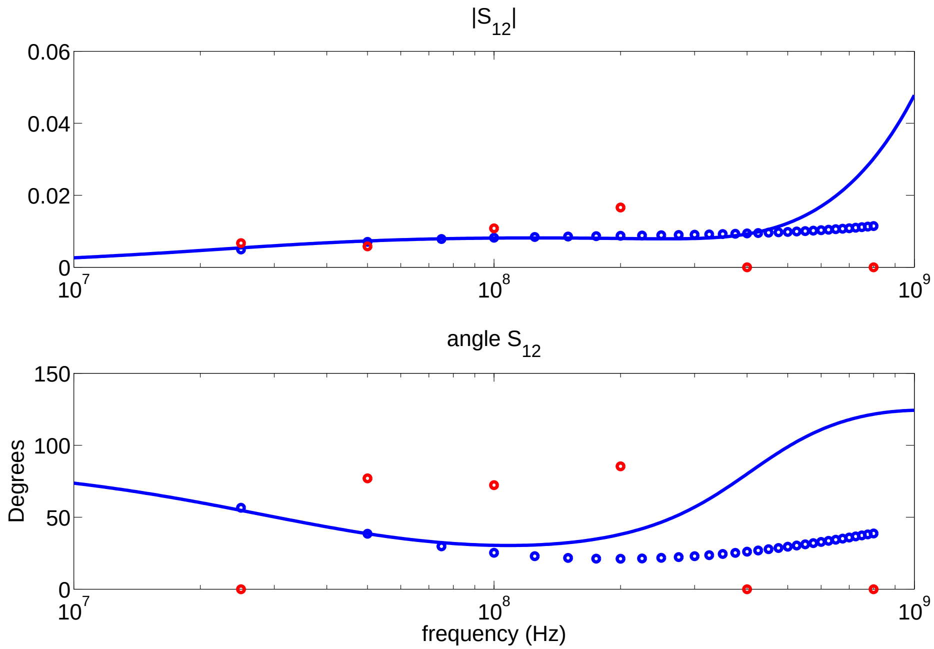

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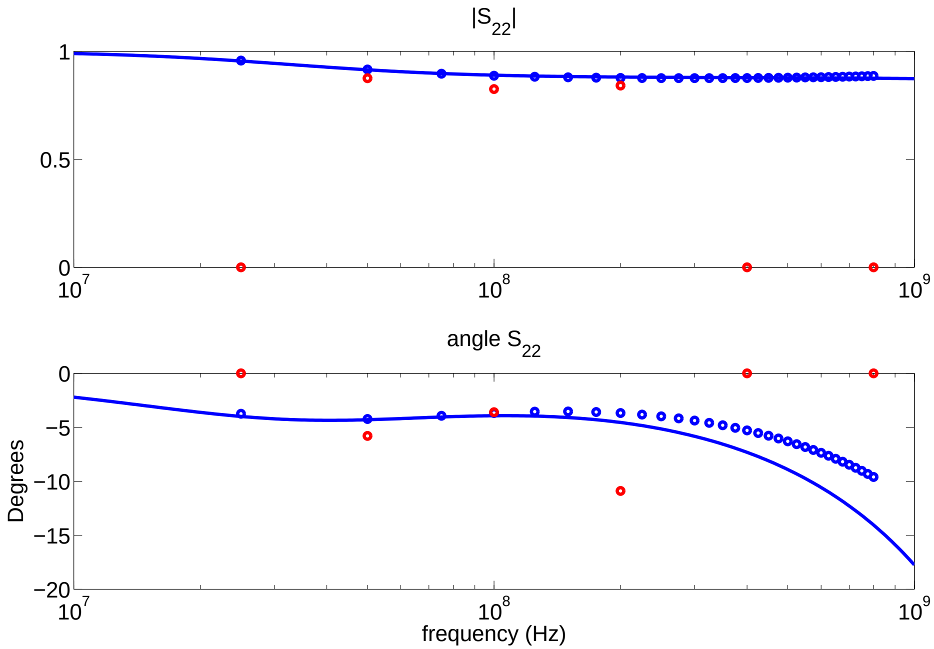
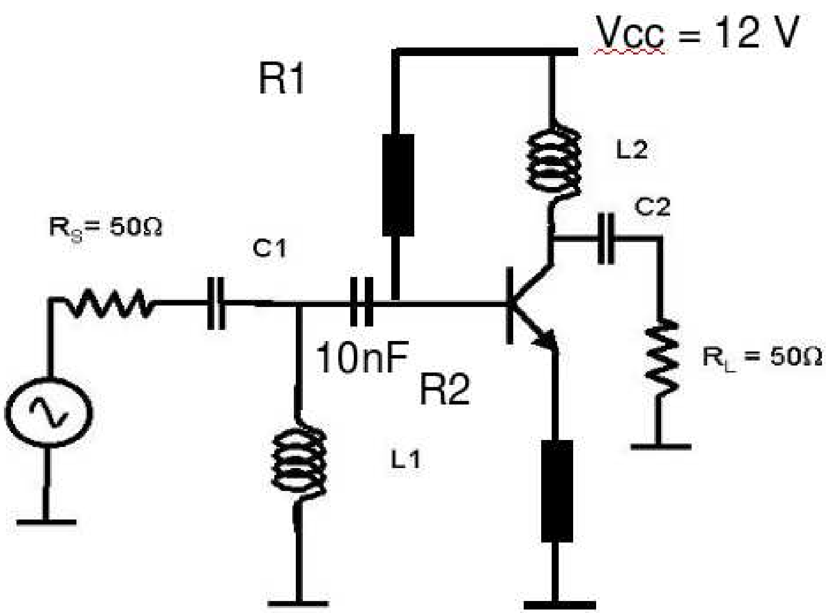
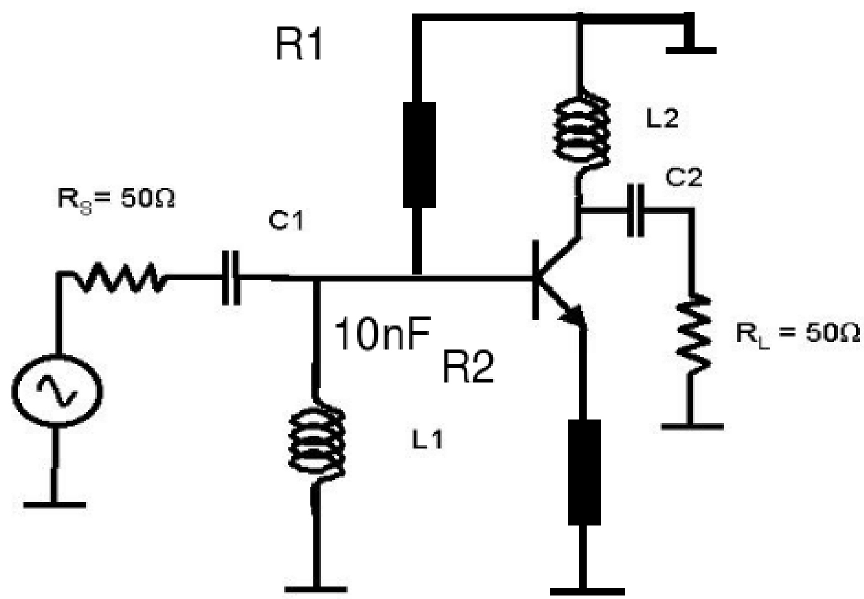


Example: A BF199 Common Emitter Amplifier

- Use the large signal equivalent (left) to set the bias point.
- Use the small signal equivalent (right) to set up SOLVE.





Stability Criteria

- Is the transistor stable in isolation? **Linville criterion**

$$C = \frac{|y_r y_f|}{2 g_i g_r - real(y_r y_f)}$$

- Often we need to know if a transistor amplifier is stable.
- If a transistor with given y-parameters is loaded by source and load admittances $Y_S = G_S + jB_S$ and $Y_L = G_L + jB_L$, then the transistor circuit is unconditionally stable if,

$$K = \frac{2(g_i + G_S)(g_o + G_L)}{|y_r y_f| + real(y_r y_f)} > 1$$

- **The Stern Stability Criterion**
- A number of useful related formulae.. see the web brick.

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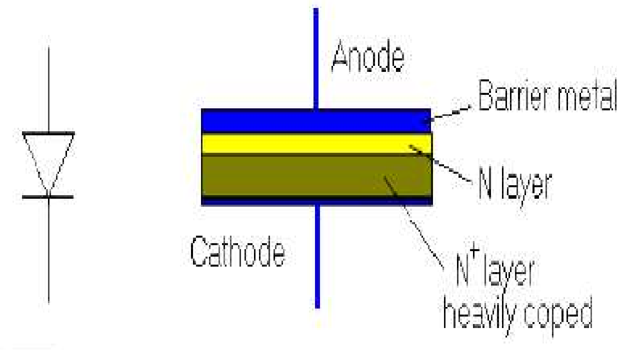
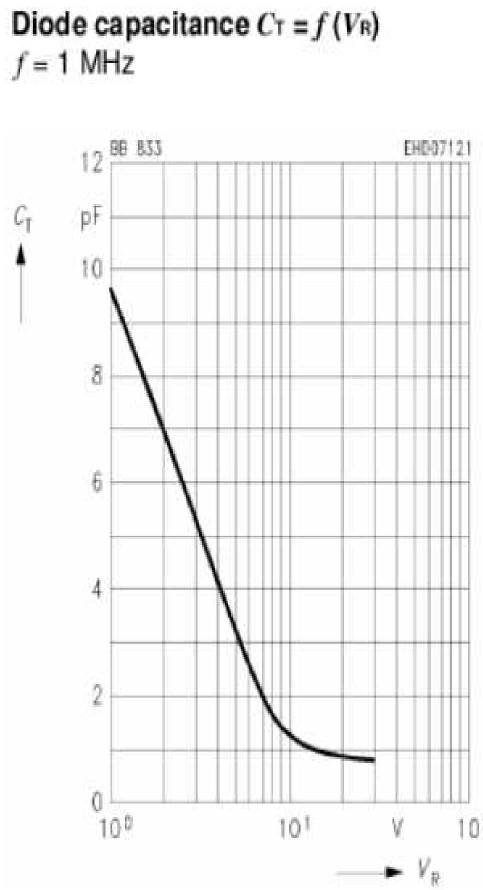
Klapp RF Oscillator

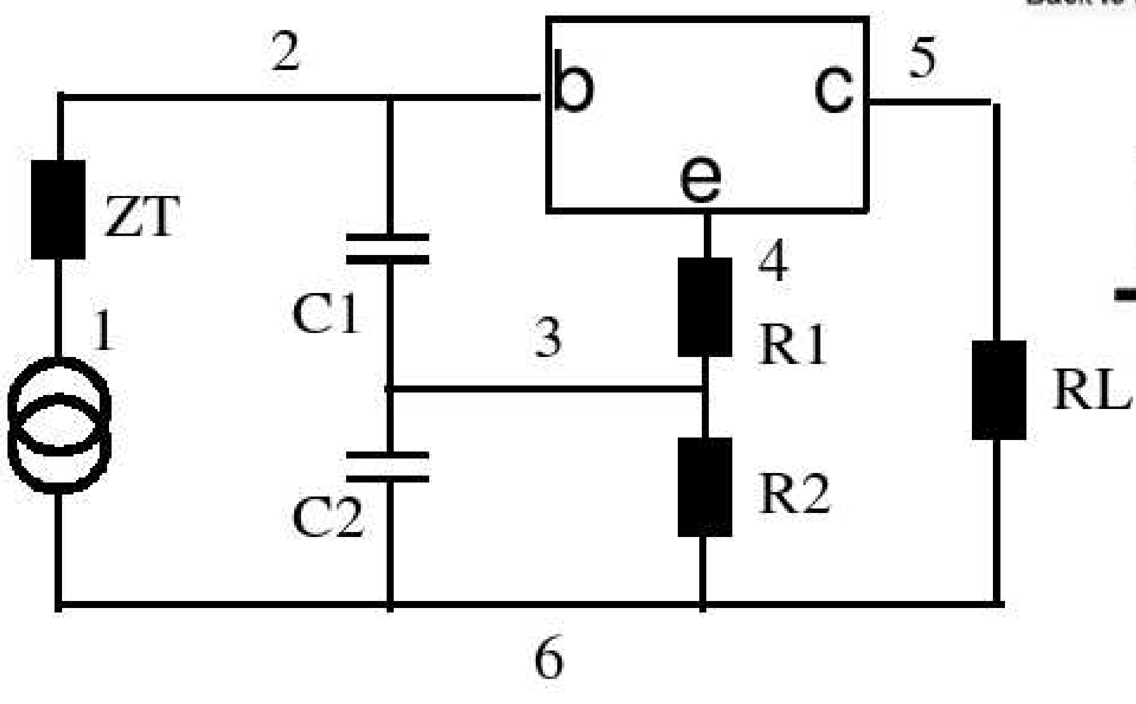
- Model the transistor using S and Y parameters in exactly the same way as the transistor amplifier.
- In the project the oscillator is a VCO: the MC145170 PLL has to control the frequency of the oscillator by applying a voltage to a **varactor diode** or **voltage variable capacitor (VVC)**.
- We need to prove that the oscillator will oscillator and at what frequency.
- In SOLVE we inject a current into the tank circuit of the oscillator and determine the frequency at which the ractance of the input impedance is **zero** and the resisitance is **negative**. **WHY?**

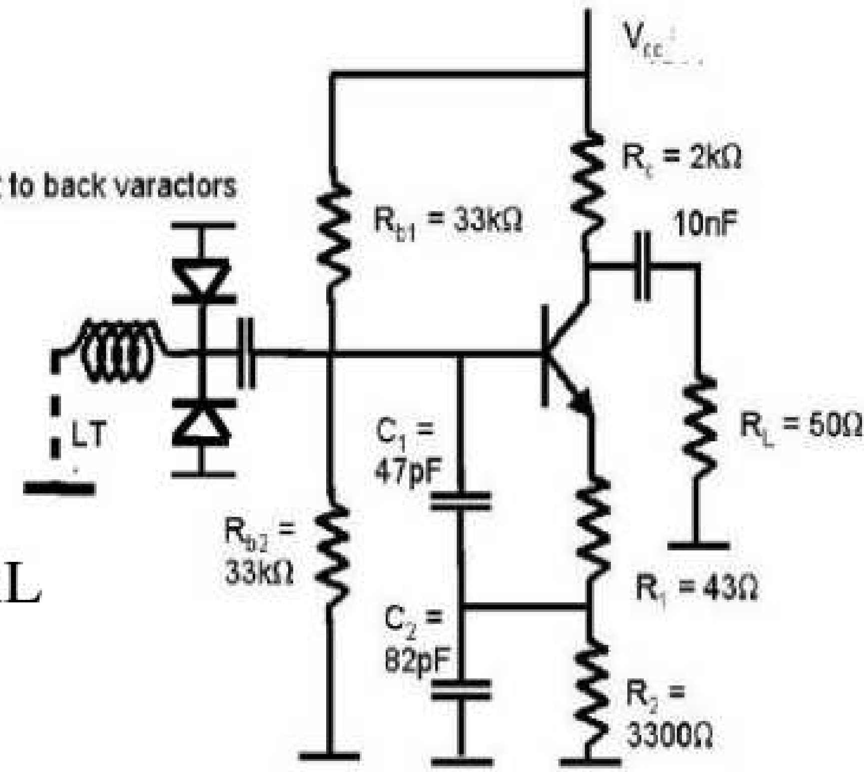
Varactor Diode





Klapp RF Oscillator





Using SOLVE: Compute S-parameters and Y-parameters

```
% The parameters of the oscillator circuit

%Step 1 Run S_parameters to generate the S-parameters for
% the transistor.

clear all
S_parameters_BF199

det = (1 + S11).*(1 + S22) - S21.*S12;

%Step 2 calculate the y-parameters
yi = ((1 + S22).*(1 - S11) + S12.*S21)./det/Z0;
yr = -2*S12./det/Z0;
yf = -2*S21./det/Z0;
yo = ((1 + S11).*(1 - S22) + S12.*S21)./det/Z0;

N = 6;            %number of nodes
y = zeros(N,N,Nvals); %The admittances
omega = 2*pi*frequency;
```

Using SOLVE: Set circuit values

```
CT = 2e-12;
LT = 8000.e-9;
CLT = .1e-12;

ZCLT = 1./j./omega/CLT;
ZLT = 1.+j*omega*LT;
ZT = (ZCLT.*ZLT)./(ZCLT + ZLT) + 1./j./omega/CT;
YT = 1./ZT;

C1 = 10.0e-12;
Z1 = 1/j./omega/C1;

C2 = 20.0e-12;
Z2 = 1/j./omega/C2;

R1 = 43.;
R2 = 3300.;
RL = 50.;
```

Using SOLVE: Set SOLVE admittances

```
y(1,2,:) = YT;
y(2,1,:) = YT;
y(3,2,:) = 1./Z1;
y(2,3,:) = 1./Z1;
y(4,2,:) = yi+yr;
y(5,2,:) = -yr;

y(2,3,:) = 1./Z1;
y(3,2,:) = 1./Z1;
y(4,3,:) = 1/R1;
y(3,4,:) = 1/R1;
y(6,3,:) = 1/R2 + 1./Z2;
y(3,6,:) = 1/R2 + 1./Z2;

y(2,4,:) = yi+yf;
y(5,4,:) = yr+yo;
y(3,4,:) = 1/R1;
y(4,3,:) = 1/R1;

y(2,5,:) = -yf;
y(4,5,:) = yf+yo;
y(6,5,:) = 1/RL;
y(5,6,:) = 1/RL;
```

KLAPP oscillator input impedance