Agenda

- Announcement: Second Mini-test Wed 06.10 or Thu 7.10 at 15-17 in SM221

We discuss

- questions raised in previous Minute reports,
- some words about oscillator design,
- a recipe for scaling up in frequency,
  - example: Phase shifter scaled up to 18 MHz
- Video about oscilloscope probes.

Why does the oscillator's sinusoidal waveform wander in simulations but not in practice? Is that the fault of a simulation model that causes two resonant circuits, the waves of which interfere with each other and that effect is eliminated in the real world?

Oscillator is inherently a singular system (recall the oscillation condition where we divide by zero).

That makes it not easy for numerical simulations:

- I suppose that some of you noticed how slowly the simulation time increased compared to “real time”.
- Often a general solution method is not the best for singular systems.
- Notice also that it takes some time also for the real circuit before the transients vanish and steady state operation is achieved.

I actually presented my question on the Monday session, but I think the others might also be interested in the answer I received from Jari, and so I decided to ask it again, but this time publicly: What are the key differences between the use cases of 2N3904 and TSP10 transistors we have used so far and why?

See next slides

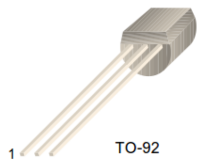
Do we need two different transistors?

- We use KSP10 for
  - amplifier
  - oscillator
  - Modulator

FAIRCHILD
SEMICONDUCTOR®

KSP10

VHF/UHF transistor



1. Base 2. Emitter 3. Collector

NPN Epitaxial Silicon Transistor

KSP10

- We use 2N3709 for
  - audio amplifier

2N3904

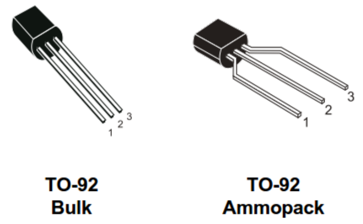
SMALL SIGNAL NPN TRANSISTOR

PRELIMINARY DATA

Ordering Code	Marking	Package / Shipment
2N3904	2N3904	TO-92 / Bulk
2N3904-AP	2N3904	TO-92 / Ammopack

- SILICON EPITAXIAL PLANAR NPN TRANSISTOR
- TO-92 PACKAGE SUITABLE FOR THROUGH-HOLE PCB ASSEMBLY
- THE PNP COMPLEMENTARY TYPE IS 2N3906

APPLICATIONS
- WELL SUITABLE FOR TV AND HOME APPLIANCE EQUIPMENT
- SMALL LOAD SWITCH TRANSISTOR WITH HIGH GAIN AND LOW SATURATION VOLTAGE



Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I_{CEX}	Collector Cut-off Current (V_{BE} = -3 V)	V_{CE} = 30 V			50	nA
I_{BEX}	Base Cut-off Current (V_{BE} = -3 V)	V_{CE} = 30 V			50	nA
$V_{(BR)CEO}$*	Collector-Emitter Breakdown Voltage (I_B = 0)	I_C = 1 mA	40			V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage (I_E = 0)	I_C = 10 μA	60			V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage (I_C = 0)	I_E = 10 μA	6			V
$V_{CE(sat)}$*	Collector-Emitter Saturation Voltage	I_C = 10 mA I_B = 1 mA I_C = 50 mA I_B = 5 mA			0.2 0.2	V V
$V_{BE(sat)}$*	Base-Emitter Saturation Voltage	I_C = 10 mA I_B = 1 mA I_C = 50 mA I_B = 5 mA	 0.65		0.85 0.95	V V
h_{FE}*	DC Current Gain	I_C = 0.1 mA V_{CE} = 1 V I_C = 1 mA V_{CE} = 1 V I_C = 10 mA V_{CE} = 1 V I_C = 50 mA V_{CE} = 1 V I_C = 100 mA V_{CE} = 1 V	60 80 100 60 30		 300	
f_T	Transition Frequency	I_C = 10 mA V_{CE} = 20 V f = 100 MHz	250	270		MHz
C_{CBO}	Collector-Base Capacitance	I_E = 0 V_{CB} = 10 V f = 1 MHz		4		pF
C_{EBO}	Emitter-Base Capacitance	I_C = 0 V_{EB} = 0.5 V f = 1 MHz		18		pF
NF	Noise Figure	V_{CE} = 5 V I_C = 0.1 mA f = 10 Hz to 15.7 KHz R_G = 1 KΩ		5		dB

2N3904
0.31 €

“

Transition frequency is a measure of the high-**frequency** operating characteristics of a **transistor**, usually symbolized as f_T

“

Electrical Characteristics T_a=25°C unless otherwise noted

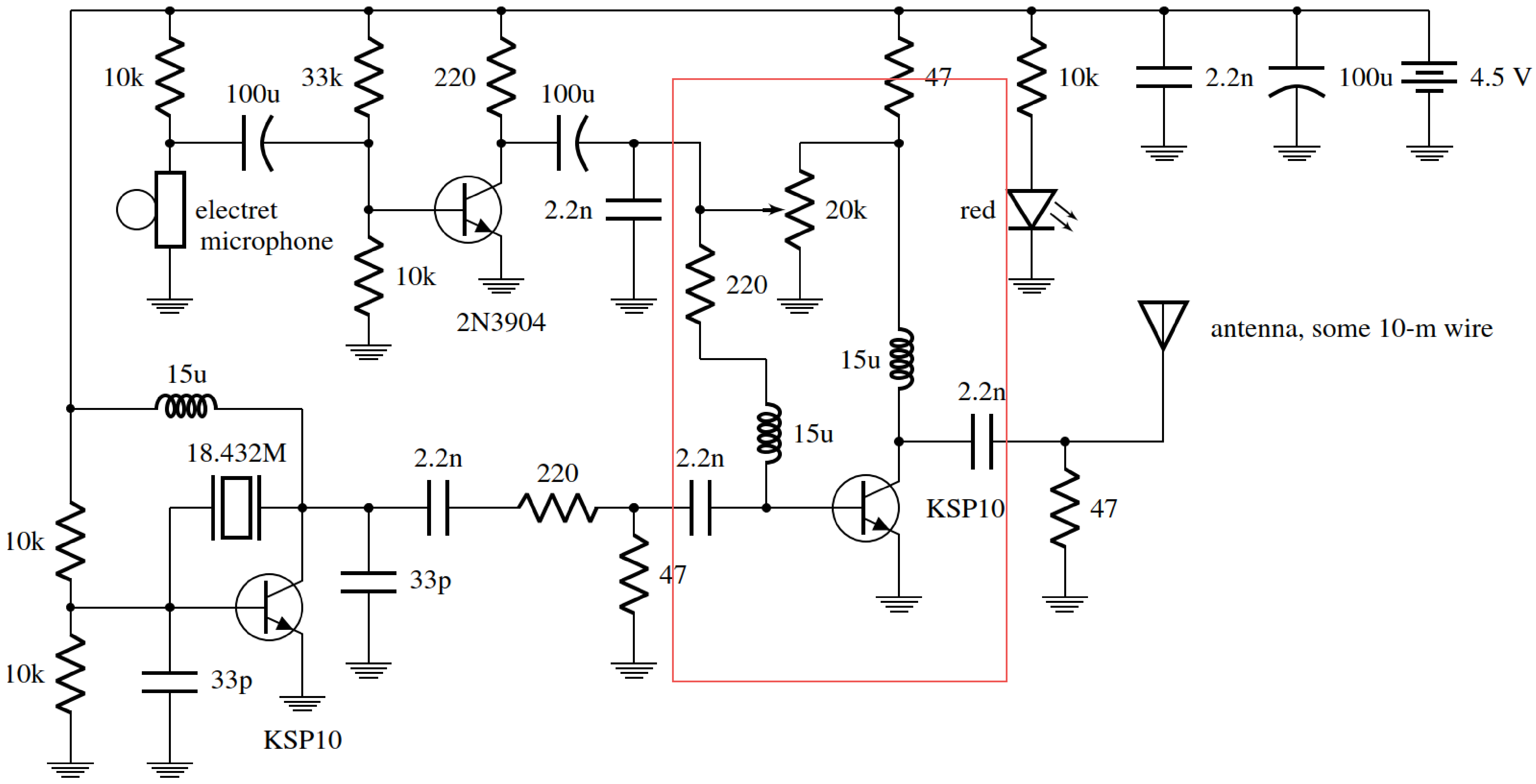
Symbol	Parameter	Test Condition	Min.	Max.	Units
BV_{CBO}	Collector-Base Breakdown Voltage	I_C=100μA, I_E=0	30		V
BV_{CEO}	Collector-Emitter Breakdown Voltage	I_C=1mA, I_B=0	25		V
BV_{EBO}	Emitter-Base Breakdown Voltage	I_E=10μA, I_C=0	3.0		V
I_{CBO}	Collector Cut-off Current	V_{CB}=25V, I_E=0		100	nA
I_{EBO}	Emitter Cut-off Current	V_{EB}=2V, I_C=0		100	nA
h_{FE}	DC Current Gain	V_{CE}=10V, I_C=4mA	60		
V_{CE} (sat)	Collector-Emitter Saturation Voltage	I_C=4mA, I_B=0.4mA		0.5	V
V_{BE} (on)	Base-Emitter On Voltage	V_{CE}=10V, I_C=4mA		0.95	V
f_T	Current Gain Bandwidth Product	V_{CE}=10V, I_C=4mA, f=100MHz	650		MHz
C_{ob}	Output Capacitance	V_{CB}=10V, I_E=0, f=1MHz		0.7	pF
C_{rb}	Collector Base Feedback Capacitance	V_{CB}=10V, I_E=0, f=1MHz	0.35	0.65	pF

KSP10
0.27 €

In the 10 kHz-oscillator design, what is the reason to leave out the R1 resistance when building the circuit?

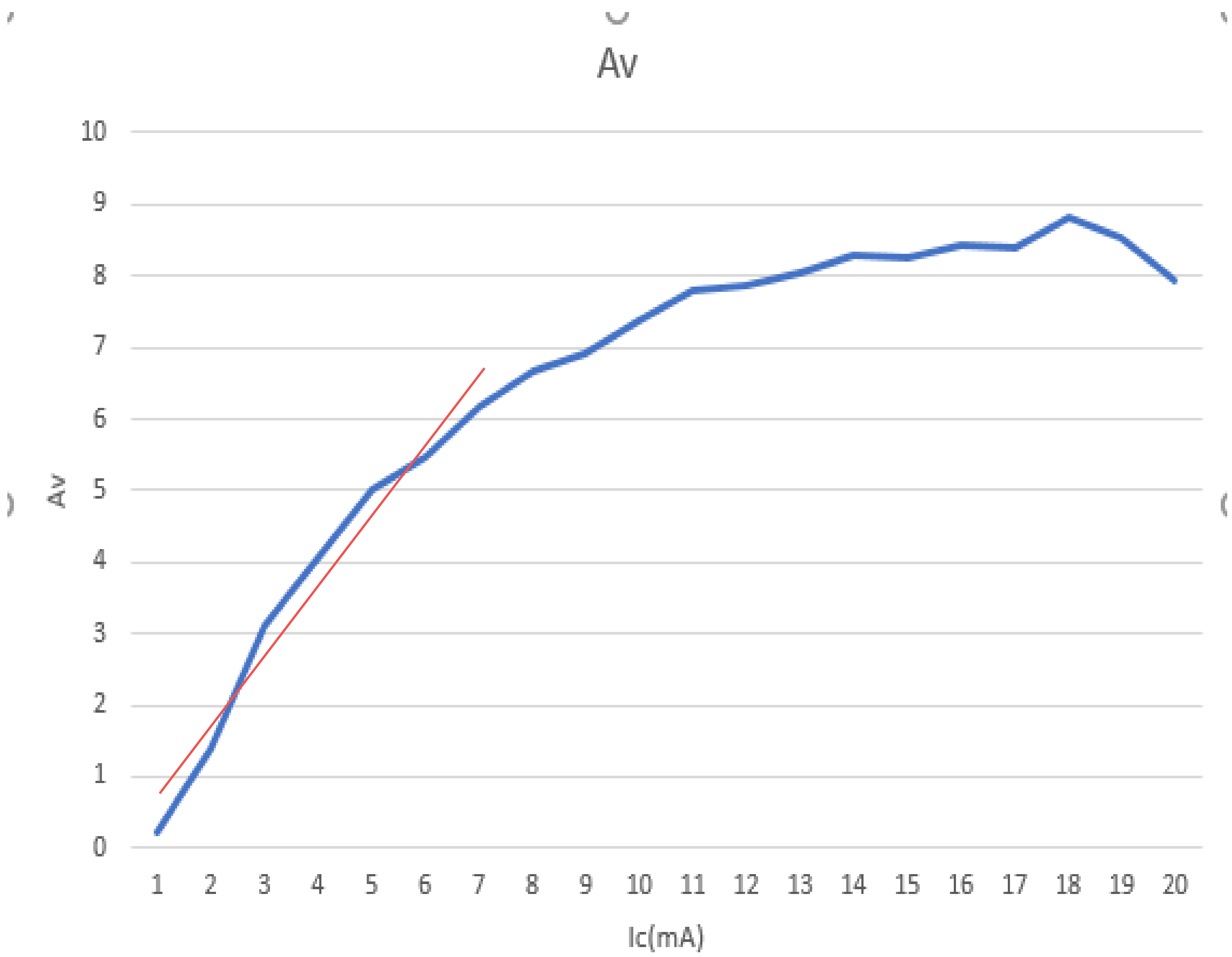
Resistor R1 represents the losses in the real inductor and needs to be taken into account in the simulations.

Some of you changed the value of R1 closer to the measured in wk2, => simulations and measurements matched better.



10k
100u
33k
220
100u
47
10k
2.2n
100u
4.5 V
electret
microphone
2.2n
20k
red
10k
220
2N3904
antenna, some 10-m wire
15u
15u
2.2n
18.432M
15u
2.2n
220
2.2n
KSP10
47
10k
33p
47
10k
33p
KSP10

AM biasing



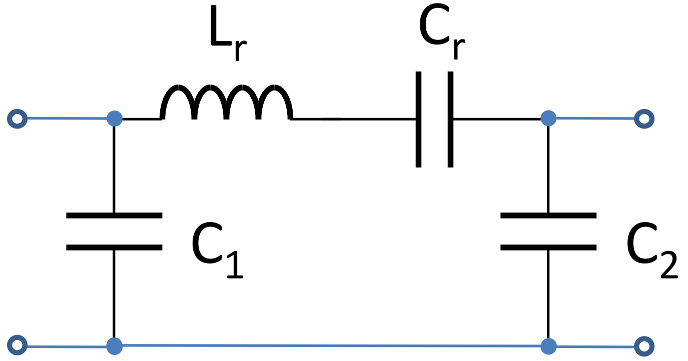
Av
10
9
8
7
6
5
4
3
2
1
0
Av
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Ic(mA)

Oscillator, phase shifter design

Tampere University

Oscillator

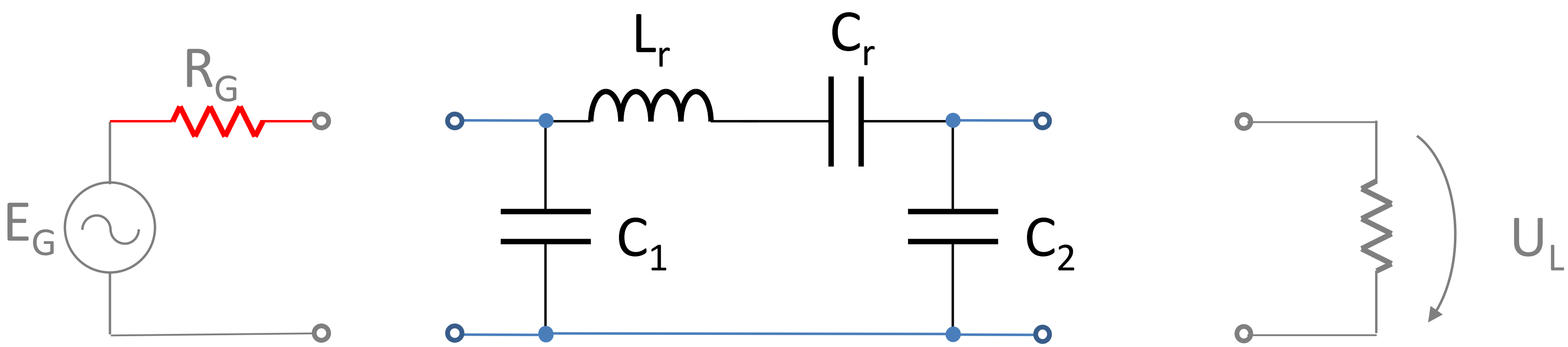
- How to find the best C_1, C_2, C_r and L_r?



LC phase shifter for an oscillator

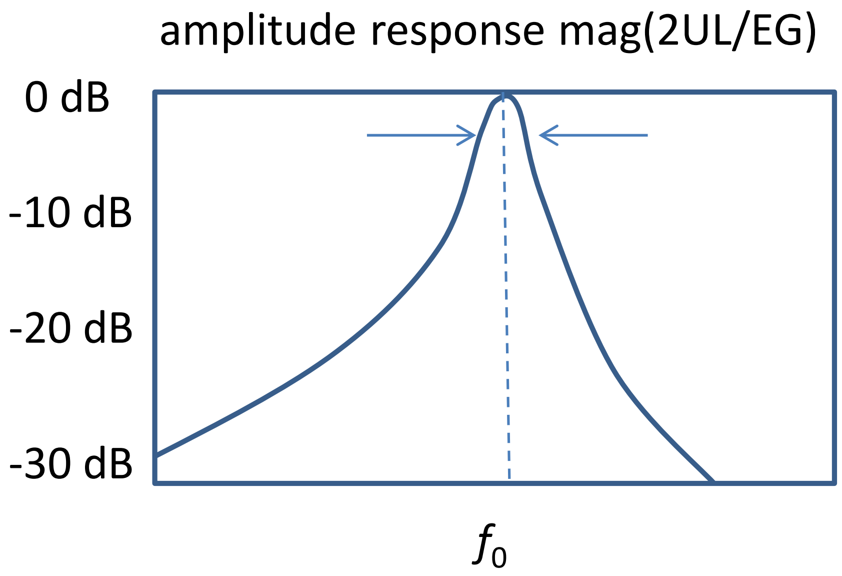
Oscillator

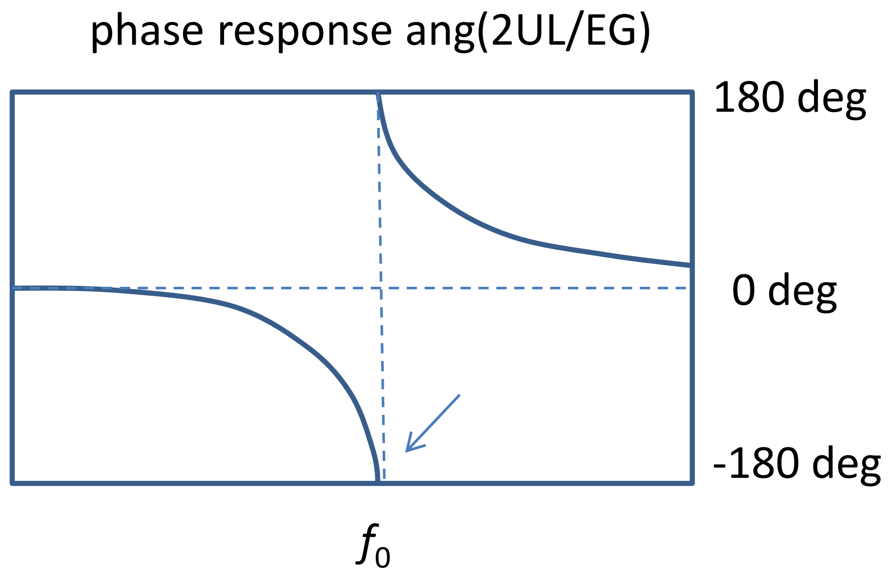
- How to find the best C_1, C_2, C_r and L_r?



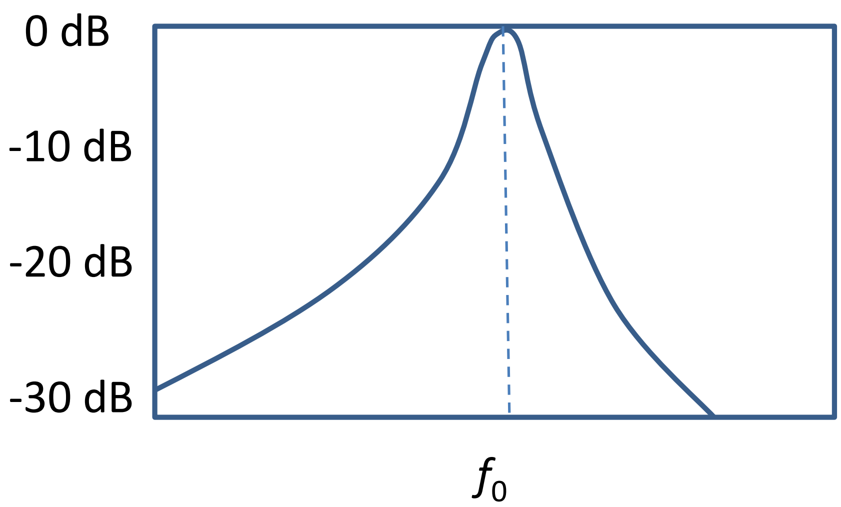
- In the oscillator application, the phase shifter should provide
  - bandpass response around f_0
    - the pass band should be narrow
  - 180-degree phase shift (between Eg and UL) at f_0
    - phase response curve should be steep around f_0.

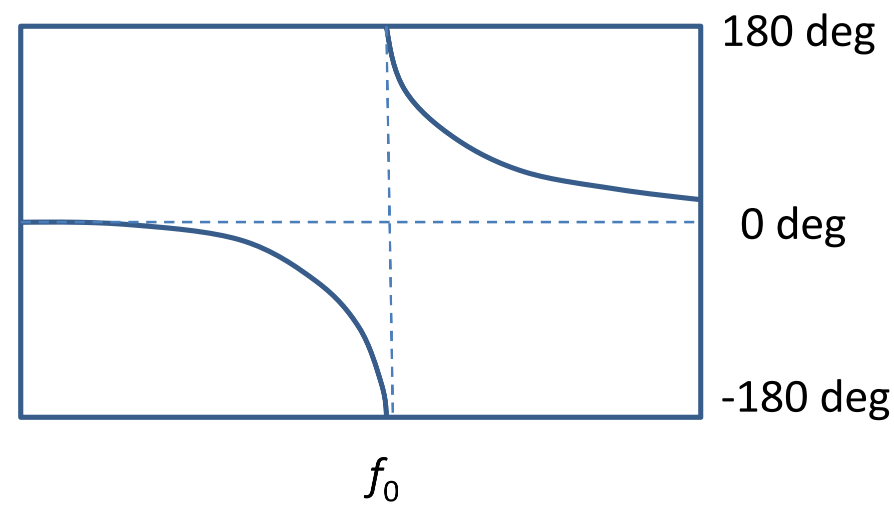
Oscillator


amplitude response mag(2UL/EG)
0 dB
-10 dB
-20 dB
-30 dB
f_0


phase response ang(2UL/EG)
180 deg
0 deg
-180 deg
f_0

Oscillator

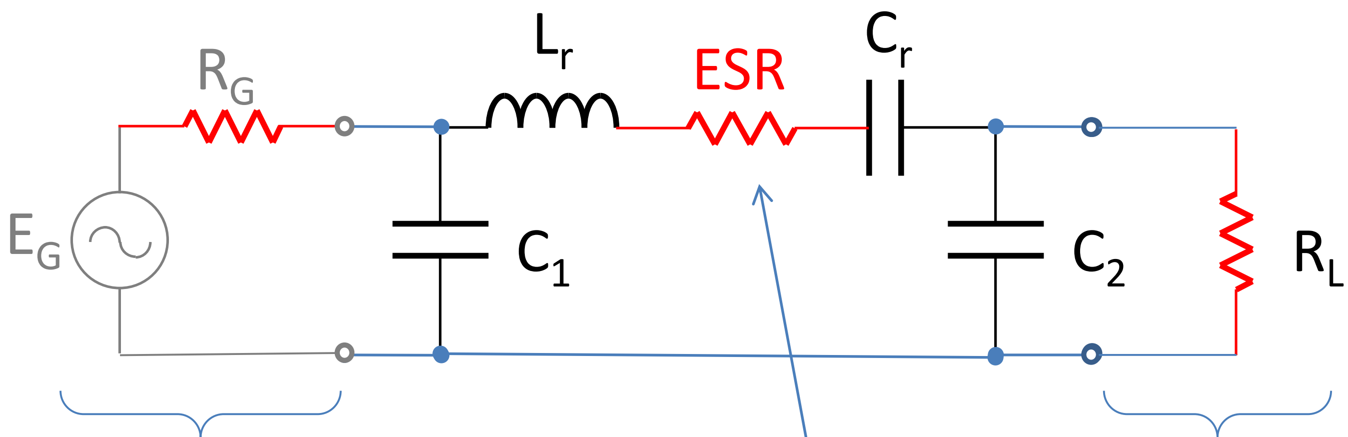




- For narrow-band amplitude response and steep phase response, make:
  1. The LC circuit store a high amount of energy.
  2. Minimum dissipation in all the resistors involved…

Oscillator

- Resistors involved?

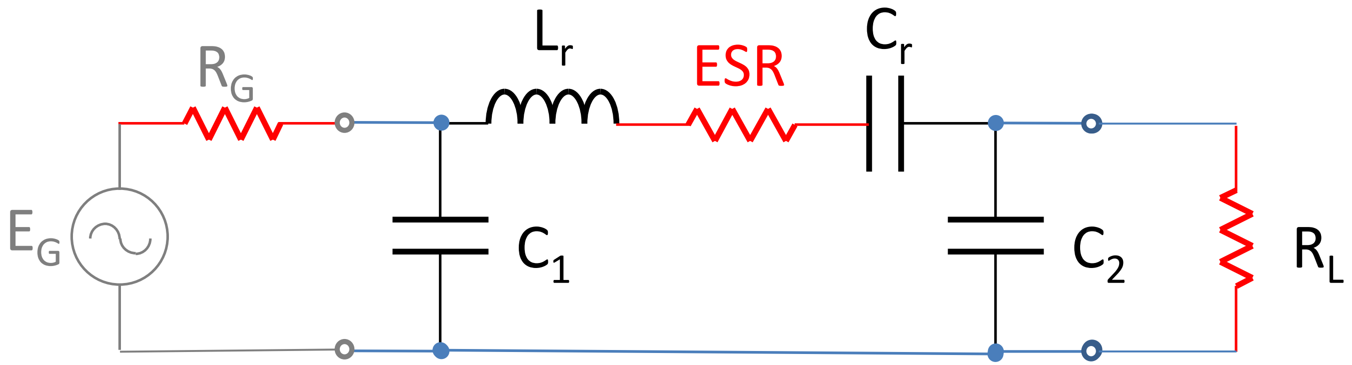


In the oscillator application, this is the model of the transistor output,

… and this is the model of the transistor *input*.

… and this is the equivalent series resitance of the inductor Lr (and capacitor Cr, although that is usually having less losses).

Oscillator

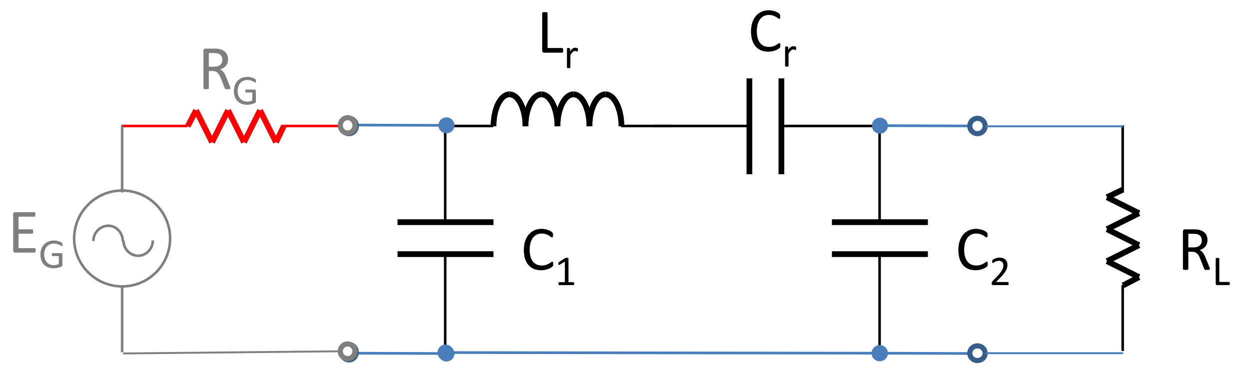


So, how do you mitigate the "Q-spoiling effect" of these resistors?

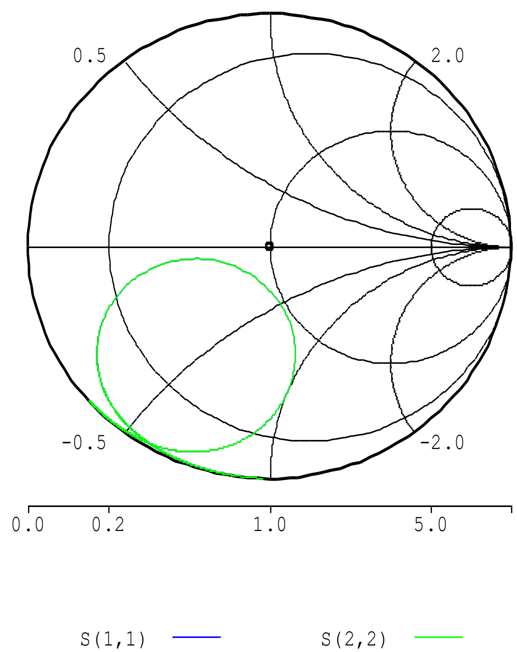
1. You can bypass (to large degree) R_G and R_L by choosing **large C_1 and C_2**
   – They should be large but, of course, C_1 and C_2 should not *completely* short the signal to ground!

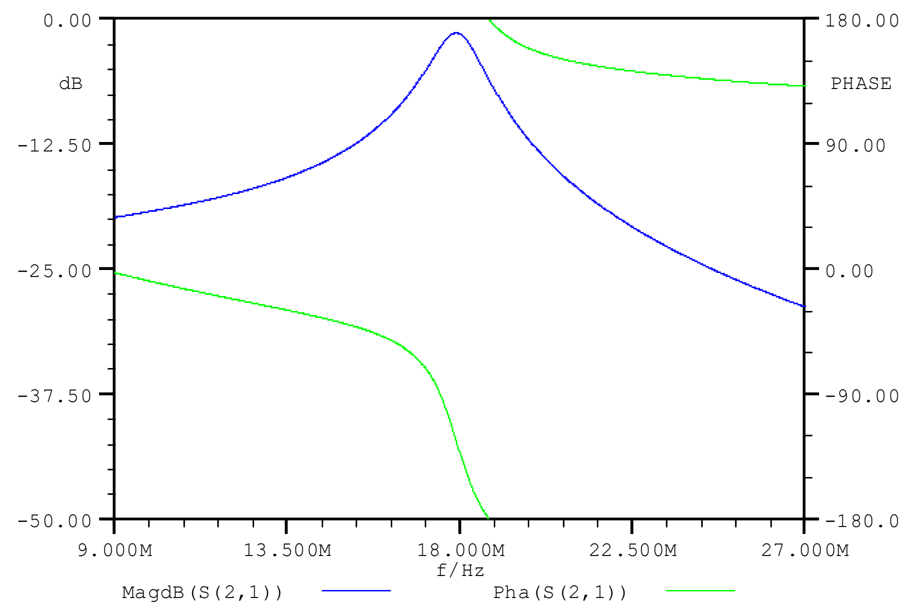
2. You allow large energy storage by choosing **large L_r**
   – Consequenctly: you need **low C_r** to maintain $f_0 \approx 1/(2\pi \cdot \mathrm{sqrt}(L_r C_r))$

Oscillator



Rg = 50 Ω
RL = 50 Ω
Lr = 3u3
Q = 100
(ESR = 3.7Ω)
Cr = 27p
C1 = 330p
C2 = 330p





Scaling up in frequency

When scaling the component values from f_1 to f_2 in a frequency selective circuits we can use criteria that the *impedance* of a reactive component must stay same

$$\boxed{Z_{f_1} = Z_{f_2}.}$$

We obtain "good" initial values for components; in conclusion,

$$\begin{aligned} &\text{When frequency changes} \\ \Rightarrow \quad &\text{Component values must change!} \end{aligned}$$

Example: Phase shifter scaling

Consider as an example scaling the 10 kHz phase shifter to work at 18 MHz. We obtain "good" initial values for components. Identify the reactive components in the 10 kHz phase shifter and gather the information to the table below.

Component	@ 10 kHz	@ 18 MHz	E12–value @ 18 MHz
C_1 & C_2	**470 nF**	260 pF	270 pF
C_r	**27 nF**	15 pF	15 pF
L_r	**10 mH**	5.5 μH	5.6 μH
DC block	**22 μF**	12.2 nF	12 nF
RF choke	27 mH	**15 μH**	–

Table 1: Example: scaling up in frequency

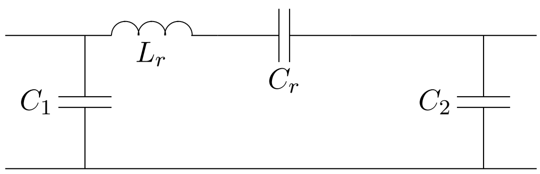
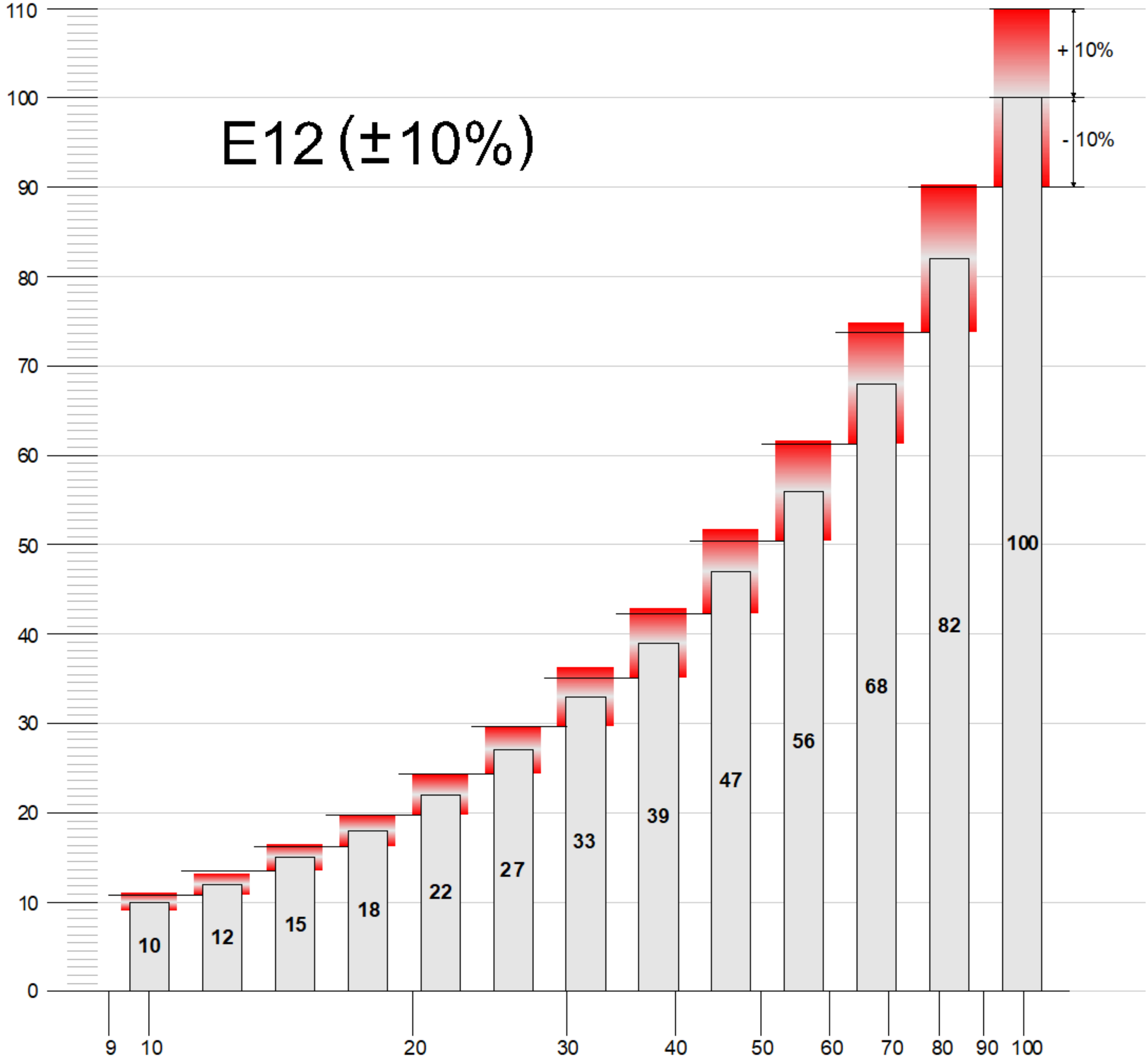


Figure 1: Phase shifter circuit


E12 (±10%)
+ 10%
- 10%
10
12
15
18
22
27
33
39
47
56
68
82
100
0
10
20
30
40
50
60
70
80
90
100
110
9
10
20
30
40
50
60
70
80
90
100

Homework:

Watch an interesting video about oscilloscope probes

Basic 1X and 10X Oscilloscope Probe tutorial