RF and Millimeter-Wave Circuit Design

Wireless Tin Can Telephone - System Analysis

Prepared By

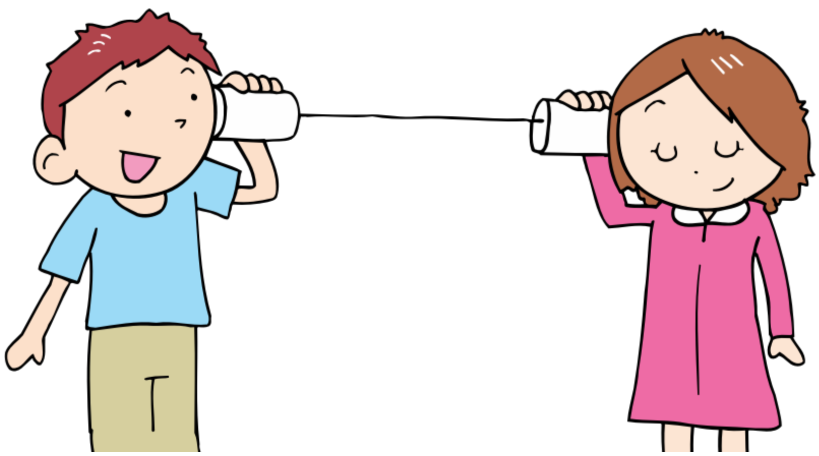
- Shenal Ranasinghe

Date of Submission,

- 2024/06/20

Derive System Specifications from the Problem Definition

- Problem Definition:
  - You want to have live, audible, and private communication with your neighbor but cannot use any available ready-to-use communication systems (e.g., cell phone). You need to design a system from specifications to implementation on a breadboard. The device must be simple, portable, and capable of at least a 10-meter range.



- System Specifications:
  - Live Communication: Real-time wireless voice transmission.
  - Audible Communication: Must transmit and receive audio signals in the human hearing range (20 Hz to 20 kHz).
  - Private Communication: Ensuring privacy through dedicated frequency.
  - Range: Should be able to communicate at least within 10 meters
  - Simplicity: Simple to build using common components.
  - Portability: Lightweight and battery powered. So our design need to be a Low power consuming one.
  - Noisy Environment: Should be able to withstand reasonable noise interferenc

Derive System Requirements from the Specifications

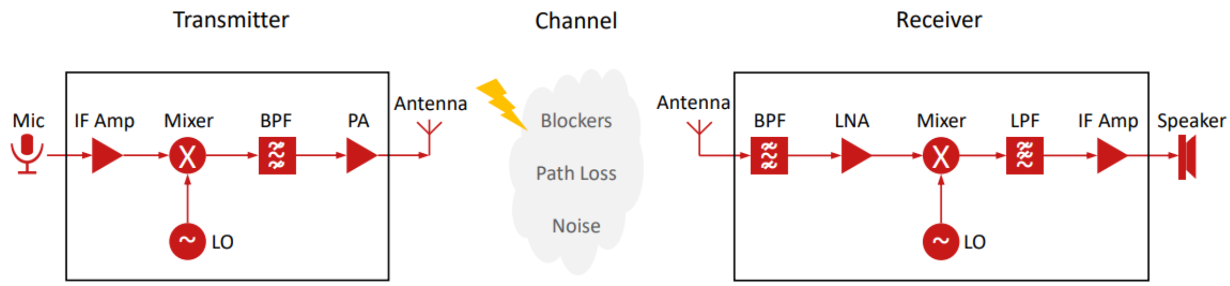
- **System Requirements:**

1. Live Communication:
    - Low latency transmission and reception.
    - Real-time audio processing.
2. **Audible Communication**:
    - Microphone sensitivity suitable for capturing voice (e.g., condenser microphone).
    - Speaker or earphone with sufficient power for clear audio output.
    - Bandwidth: Sufficient to cover human voice frequencies with clarity (3-4 kHz minimum).
3. **Private Communication**:
    - Use a dedicated AM frequency to avoid interference.
4. **Range**:
    - RF transmitter and receiver capable of 10-meter range.
5. **Simplicity**:
    - Use off-the-shelf analog components (microphone, amplifiers, RF modules).
    - Simple modulation scheme (AM).
6. **Portability**:
    - Battery-powered.
    - Low power consumption components. Otherwise we wont be able to use it for a longer period because batteries will drain out quickly. The defined target of the DC Power consumption (PDC) is PDC < 1W.
7. **Noisy Environment**:
    - Starting with target of SNROUT ≥ 40 dB

Choose Adequate System Architecture for the Wireless System

- **System Architecture:**

  The same architecture which was provided in the lecture series will be used in here



- **System Architecture - Transmitter:**

Deciding Which bandwidth to use:

- When deciding the bandwidth we have few options.
  - 3 – 4 KHz
  - 15 – 20 KHz
  - 30 – 50KHz
- Since we're not trying to send music or something that needs high fidelity there is no need to use 30 – 50 KHz.
- So, we're now left with 2 options. We know that 3 – 4 KHz is the bare minimum requirement for proper communication and enough to send voice. But it makes our Filter design Bit Complex.
- ***So, in order to avoid complex filter design and have a good audio quality I decided to use 15KHz as the bandwidth.***

System Analysis Calculator Eindhoven Unversity of Technology - Integrated Circuits Group - CMJ - PB				
Signal	Carrier (Hz)	Bandwidth (Hz)	Type	Modulation
	1E+6	15E+3	Analog	Amplitude (AM)
Conditioning	Noise Floor (dBm)			
	-132			
Constants	Boltzmann ($J \cdot K^{-1}$)	Temperature (K)	Impedance (Ω)	
	1.38065E-23	300	50	

Deciding Which Microphone to Use:

There are several microphones to choose from. Such as,

- Dynamic Microphones
- Electret Condenser Microphones
- Electret Microphones
- Ribbon Microphones

But for our project, which involves designing a portable, live, audible, and private communication system over a 10-meter range, a **Electret condenser microphone** is likely the most suitable choice

Why a Condenser Microphone?

1. **Higher Sensitivity**:
    - Compared to dynamic ones, condenser mics have a higher sensitivity, which means they can pick up quieter sounds more effectively. This is useful to make sure that we have clear audio transmission in a communication system.
2. **Wide Frequency Response**:
    - Condenser microphones typically have a wider, flatter frequency response, making them the suitable option for capturing a full range of audible frequencies, which results in good quality.
3. **Voltage Levels**:
    - The peak voltage output of condenser microphones is suitable for interfacing with audio amplifiers and modulation circuits without requiring excessive amplification. (Typically in the range of 10 to 50 mV)

- ***So Finally, the peak Voltage from mic is considered to be <u>40mV</u> assuming our system will be used for talking only and there won't be any gigantic sounds.***

Transmitter Analysis Calculator
Eindhoven Unversity of Technology - Integrated Circuits Group - CMJ - PB

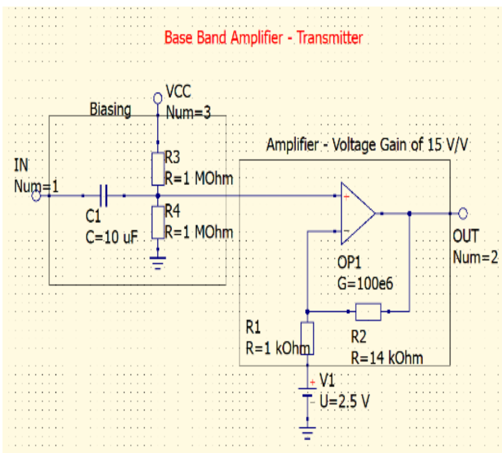
TX Signal	Vin (Vp)	Pin (dBm)	Vout (Vp)	Pout (dBm)
	40E-3	-18	1E+0	10
Conditioning	Antenna Gain (dB)	TX Gain (dB)	Noise Floor (dBm)	TX SNR Out (dB)
	0	28	-132	142

Changes done to the Transmitter in QUCS-S Simulation

- Since we Changed few parameters of the transmitter, we must change the gain of transmitter section in our QUCS-S Simulation. So, instead of 20dB TX gain now we need a 28dB TX gain.

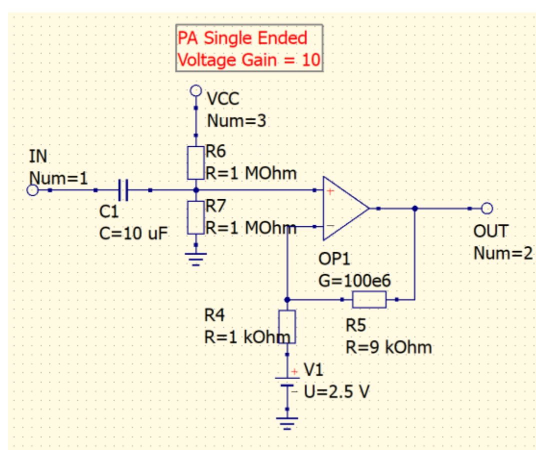
- Which means 25V/V gain. We need to achieve this by using power amplifier and the base band amplifier of the transmitter.

So, I modified it as below,



- 10V/V Gain from the baseband amplifier
- Using R1 = 1kOhm and R2 = 14kOhm

- 15V/V Gain from the Power Amplifier
- Using R5 = 9kOhm and R4 = 1kOhm

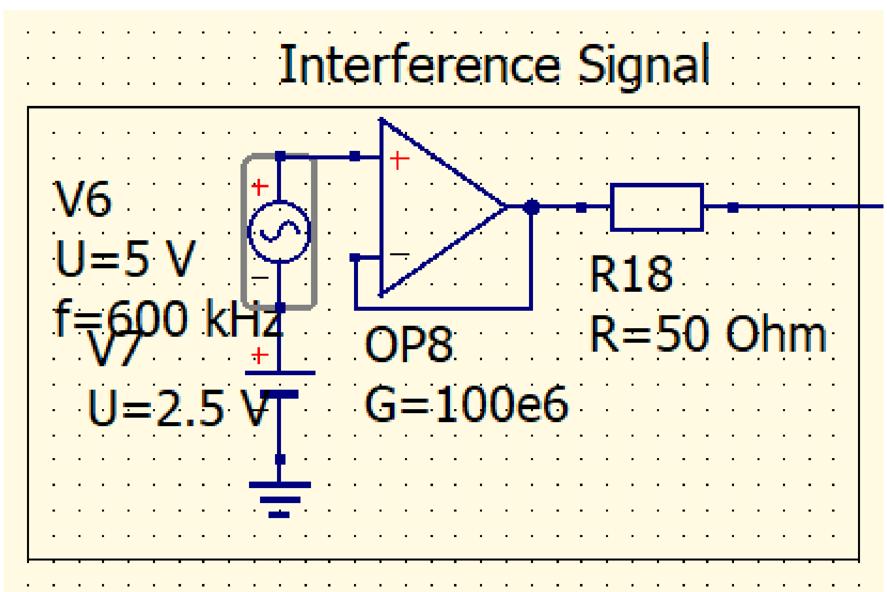


System Architecture- Channel:

- Blockers (from AM station) = 30 dBm at 600 kHz, 10 Vp (Changed the interference frequency)
- Path Loss (from two loop antennas 10 meters apart) = 70dB
- Man-made noise = 55 dB

Channel Analysis Calculator Eindhoven Unversity of Technology - Integrated Circuits Group - CMJ - PB				
Interference Signal	Frequency (Hz)	Power (W)	Power (dBm)	Voltage (Vp)
	600 kHz	1	30	10
Conditioning	Path Loss (dB)	Man-Made No. (dB)	Noise Margin (dB)	
	70	55	20	

- ✓ **In order to simulate the 600Khz interference signal I changed it here in QUCS-S**



System Architecture- Load:

When it comes to the load, here we have to make a wise decision.

There are wide range of load impedances to choose from,

1. 4 Ohm
2. 8Ohm
3. 16Ohm

So, how are we going to select the speaker that were going to use?

We cant use 4 Ohm speakers because of high current usage.

And 16 Ohm speakers are rarely used.

So, the best option is to use 8 Ohm speakers. They give balanced output, they're compatible with most of the Op-Amps , and they're power efficient

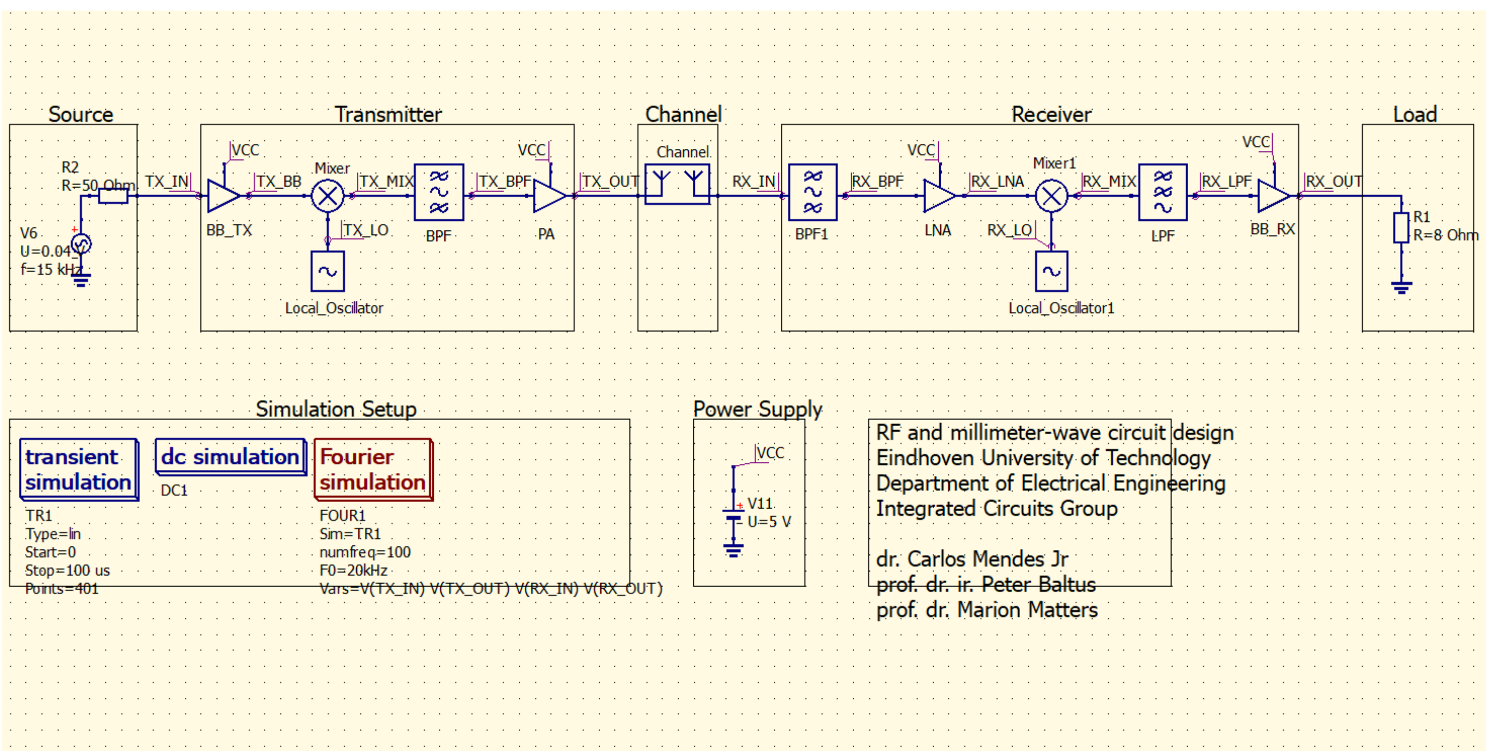
Here I changed the Power margin to 4dB.

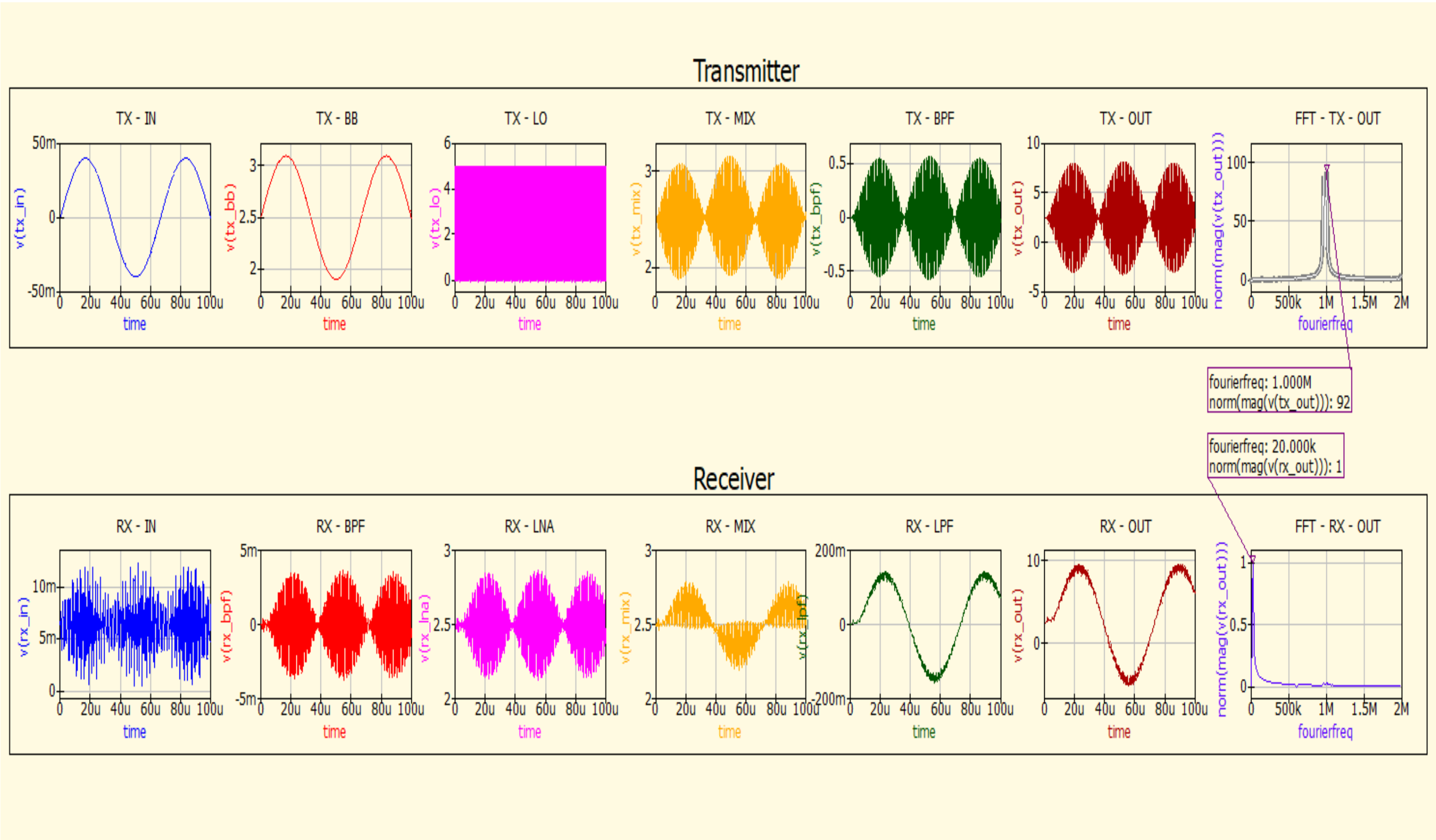
Load (Speaker) Analysis Calculator Eindhoven Unversity of Technology - Integrated Circuits Group - CMJ - PB				
Audio Signal	Target SPL @ 1m (dB)		Required Load Power (dBm)	
	Minimum	Maximum	Minimum	Maximum
	40	80	-15	29
Conditioning	Target Distance (m)	Power Margin (dB)	Sensitivity 1W/1m (dB)	Load (Ω)
	1.0	4	85	8

System Architecture- Receiver:

Receiver Analysis Calculator Eindhoven Unversity of Technology - Integrated Circuits Group					
RX Signal	From the Channel	Pin Min (dBm)	Vin Min (Vp)	Pin Max (dBm)	Vin Max (Vp)
		-60	316E-6	0	0.32
	To the Load	Pout Min (dBm)	Vout Min (Vp)	Pout Max (dBm)	Vout Max (Vp)
		-15	22E-3	29	3.57
Conditioning		RX Gain Min (dB)	RX Gain Max (dB)	RX DR Out (dB)	
		29	89	44	
		Antenna Gain (dB)	Filter Loss IB (dB)	Filter Loss OB (dB)	
		0	0	30	
		Noise Floor (dBm)	RX SNR In (dB)	RX SNR Out (dB)	Noise Figure (dB)
		-97	37	30	7

Derive Important Sub-System Requirements




Transmitter
TX - IN
TX - BB
TX - LO
TX - MIX
TX - BPF
TX - OUT
FFT - TX - OUT
v(tx_in)
v(tx_bb)
v(tx_lo)
v(tx_mix)
v(tx_bpf)
v(tx_out)
norm(mag(v(tx_out)))
time
fourierfreq
fourierfreq: 1.000M
norm(mag(v(tx_out))): 92
fourierfreq: 20.000k
norm(mag(v(rx_out))): 1
Receiver
RX - IN
RX - BPF
RX - LNA
RX - MIX
RX - LPF
RX - OUT
FFT - RX - OUT
v(rx_in)
v(rx_bpf)
v(rx_lna)
v(rx_mix)
v(rx_lpf)
v(rx_out)
norm(mag(v(rx_out)))
time
fourierfreq