INDIVIDUAL CONSTRUCTION PROJECT | REPORT *(Word Count = 1762)*

Introduction

The purpose of this lab is to design (partially), build and test an infrared (IR) receiver circuit that receives, amplifies and demodulates an amplitude modulated signal from an IR transmitter for the decoder to process. The contextual use of this circuit is the IR receiver in a remote-controlled car, where it receives signals to control the car from an external IR transmitter. The receiver circuit receives an amplitude modulated signal, where the information (sub-carrier) to be transmitted is carried on a frequency between 40kHz and 100kHz, which modulates the amplitude of a **carrier frequency** at **300THz**. Since multiple remote-controlled cars will be used at the same time, multiple transmitters/receivers at the same frequency would not enable the cars to be controlled individually. To resolve this problem, each car transmitter/receiver must operate on a different signal frequency so that each of the cars can only receive the correct information from its corresponding transmitter. [1]

Theory

The practical circuit for the IR receiver is shown in *figure 1:*

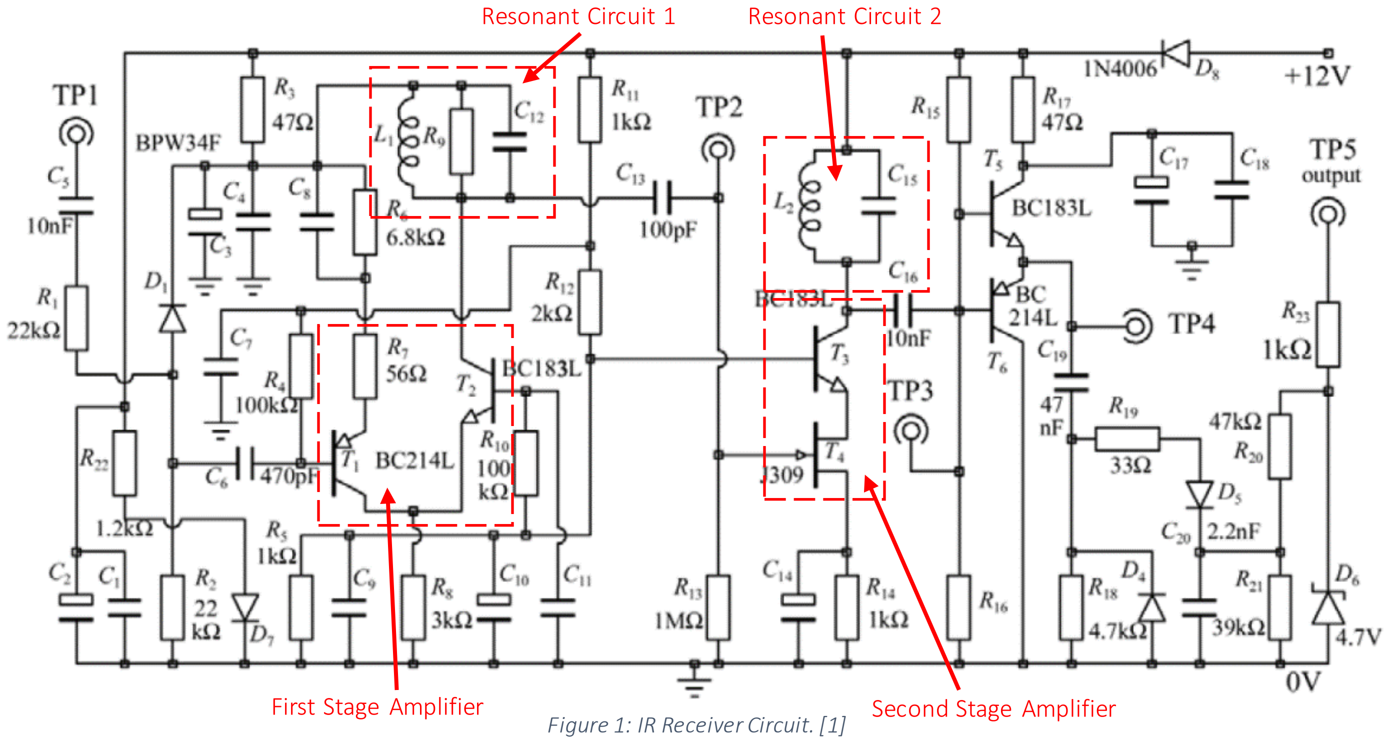

Figure 1: IR Receiver Circuit. [1]

There are two LC resonant circuits within the receiver circuit that act to filter out any unwanted noise by removing signals with frequencies above or below the chosen signal frequency. In the context of this report, the **signal frequency** is **50kHz**, meaning the LC filters should be designed to **resonate** at 50kHz whilst rejecting other frequencies.

In order to determine the values of capacitance and inductance to achieve a resonant frequency of 50kHz, the equation shown below can be used:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

Where f_0 is the resonant frequency (Hz), L is the inductance (H) and C is the capacitance (C).

Which can be rearranged to find L and C individually:

$$L = \left(\frac{1}{2\pi f_0 \sqrt{C}}\right)^2 \tag{2}$$

$$C = \left(\frac{1}{2\pi f_0 \sqrt{L}}\right)^2 \tag{3}$$

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The capacitor values have already been defined for each LC filter circuit, so each corresponding value of L can be calculated to achieve the desired resonant frequency using (2).

The Q factor of a resonant circuit gives its current magnification and is effectively a measurement of its ability to filter out frequencies other than its resonant frequency. A higher Q factor results in more **selective filtering** and a **narrower bandwidth**, where unwanted frequencies are blocked more effectively.

The Q factor of a parallel LCR circuit is define by:

$$Q = \frac{f_0}{\Delta f} = R\sqrt{\frac{C}{L}} \tag{4}$$

Where Δf is the -3dB Bandwidth (Hz) and R is the resistance (Ω).

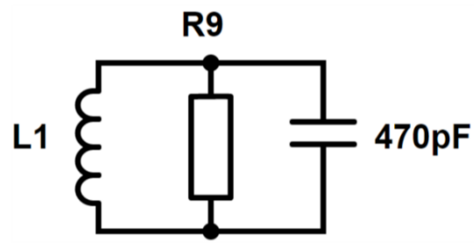
The specification for the circuit states that **both resonant circuits** must give a **-3dB bandwidth** of **7.5kHz**. Therefore, since the values of L and C are known, the value of R for each resonant circuit can be found using (4). However, the values of **R15** and **R16 appear in parallel** with **L2** and **C15**, and need to be the **same value** to bias T5 and T6 correctly.

R can be found by rearranging (4) to give:

$$R = \frac{f_0}{\Delta f\sqrt{C/L}} \tag{5}$$

The calculations to find the unknown inductor and resistor values are shown below:

Resonant Circuit 1:



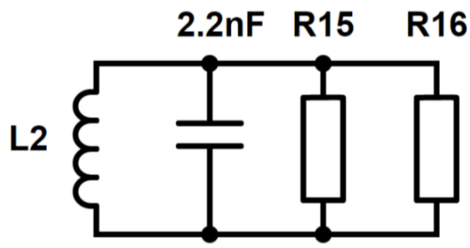
$$L_1 = \left(\frac{1}{2\pi\times(50\times10^3)\times\sqrt{470\times10^{-12}}}\right)^2$$

$$\boldsymbol{L_1 = 21.56mH = 22mH\ (Component\ Value)}$$

$$R = \frac{50\times10^3}{7.5\times10^3\sqrt{470\times10^{-12}/22\times10^{-3}}}$$

$$\boldsymbol{R_9 = 45.6k\Omega = 47k\Omega\ (Component\ Value)}$$

Resonant Circuit 2:



$$L_2 = \left(\frac{1}{2\pi\times(50\times10^3)\times\sqrt{2.2\times10^{-9}}}\right)^2$$

$$\boldsymbol{L_2 = 4.61mH = 4.7mH\ (Component\ value)}$$

$$R = \frac{50\times10^3}{7.5\times10^3\sqrt{2.2\times10^{-9}/4.7\times10^{-3}}}$$

$$R_{15//16} = 9.74k\Omega$$

R15 & R16 are equal and in parallel:

$$\frac{R^2}{2R} = 9.74k\Omega$$

$$\boldsymbol{R_{15,16} = 19.49k\Omega = 20k\Omega\ (Component\ Value)}$$

The performance of both filters and their respective first stage and second stage amplifiers can be predicted using: [1]

$$\mathit{First\ Stage\ Gain} \approx 0.002 \times R_9 \frac{jf/(f_0 q)}{1 - (f/f_0)^2 + jf/(f_0 q)} \tag{6}$$

$$\mathit{Second\ Stage\ Gain} \approx 0.0045 \times R_{15}//R_{16} \frac{jf/(f_0 q)}{1 - (f/f_0)^2 + jf/(f_0 q)} \tag{7}$$

Where j is the complex number operator, and q is the Q factor of the resonant circuit.

The constants before each gain equation are approximations of certain transistor parameters, which may vary compared to the practical circuit.

The gain in decibels (dB) can be found by:

$$Gain(dB) = 20\log(Voltage\ Gain) \tag{8}$$

To visualise the frequency response of both the amplifier stages, the gain is calculated over a frequency range of 10kHz to 400kHz, with the gain being the sum of both the first stage and second stage gain in dB.

The graph that these calculations produce is shown in *figure 2:*

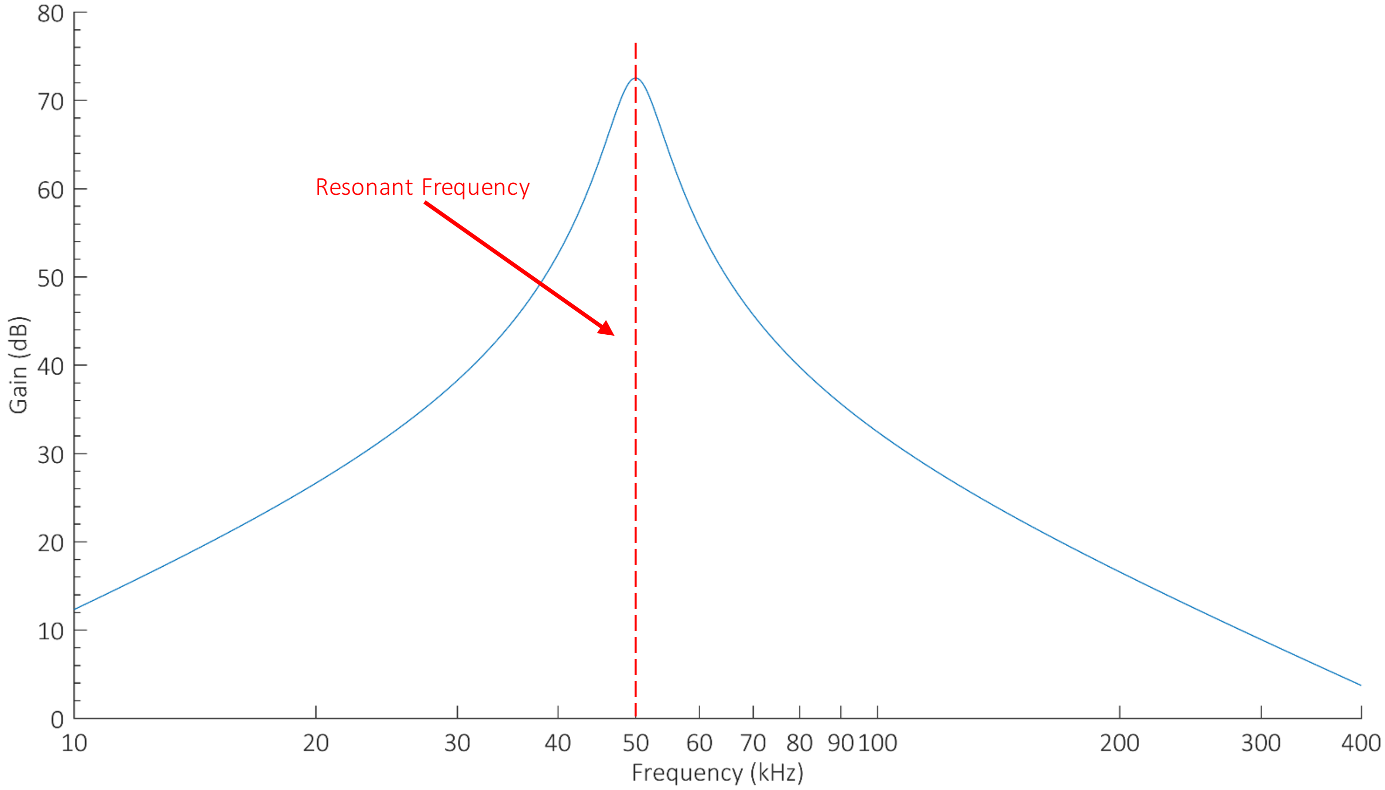


Figure 2: Theoretical Frequency Response.

The curves maximum can be seen to occur at a frequency of 50kHz, and the gain reduces either side of this, which shows how the circuit should amplify the signal frequency and reject other frequencies.

Results:

To test the receiver circuit, the gain of both the first stage and second stage amplifiers are measured. To measure the gain of the first stage amplifier, a **small sinusoidal signal** of **0.2**$V_{pk\text{-}pk}$ is fed into **test point 1**, labelled as TP1 in *figure 1*. The output voltage is then measured at **test point 2** (TP2) and the gain in dB can be calculated using (8) over a range of frequencies from **10kHz to 400kHz**. The method is then repeated for the second stage by feeding the sinusoidal signal into **test point 3** (TP3) and measuring the output at **test point 4** (TP4).

The practical measured frequency response vs the theoretical frequency response for the first stage amplifier is shown below in *figure 3:*

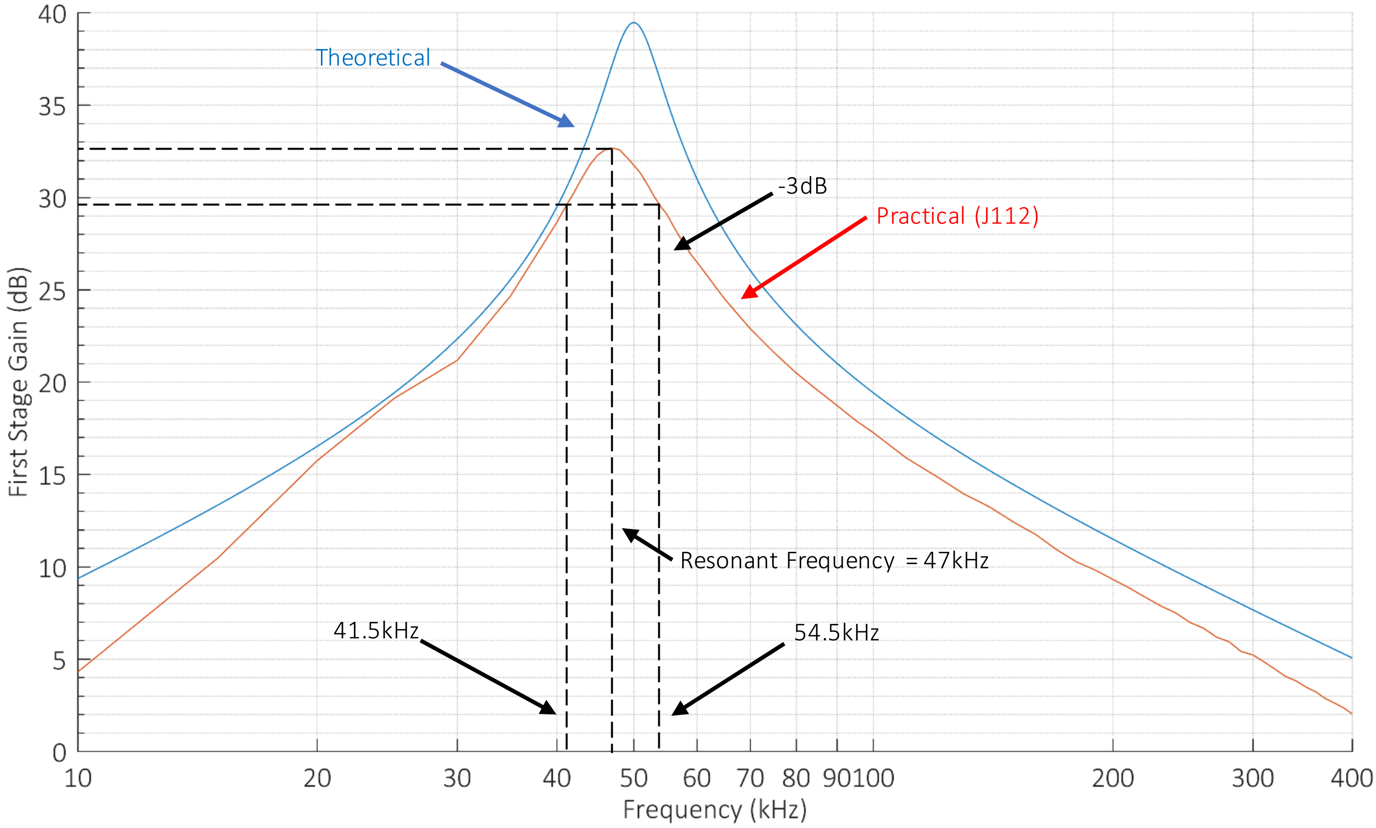


Figure 3: First Stage Amplifier Frequency Response.

As seen in *figure* 3, the measured **peak gain** is **32.7**, compared to the **predicted 39.5**, which could be due to the theoretical equation (6) not taking into account all the transistors characteristics. Furthermore, unwanted resistances and component tolerances within the circuit from test point 2 to test point 3 could alter amplifiers performance.

The measured **resonant frequency** is approximately **47kHz** compared to the **predicted 50khz**, which is due to having the use values of inductors and resistors that are **closest to the actual measured desired values**. For example, L1 and R9 were calculated to be 21.56mH and 45.6kΩ respectively, but the closest components values were 22mH and 47kΩ.

The Q-factor should be approximately **6.67** from the **specification**, but the actual Q-factor is:

$$Q = \frac{f_0}{\Delta f} = \frac{47000}{54500 - 41500} = 3.62$$

A possible reason for the measured Q-factor being significantly lower than predicted is **dampening**, maybe from a small **loading effect**, which can reduce the **selectiveness** of filter circuits, hence lowering the Q-factor.

The practical measured frequency response vs the theoretical frequency response for the second stage amplifier is shown below in *figure 4:*

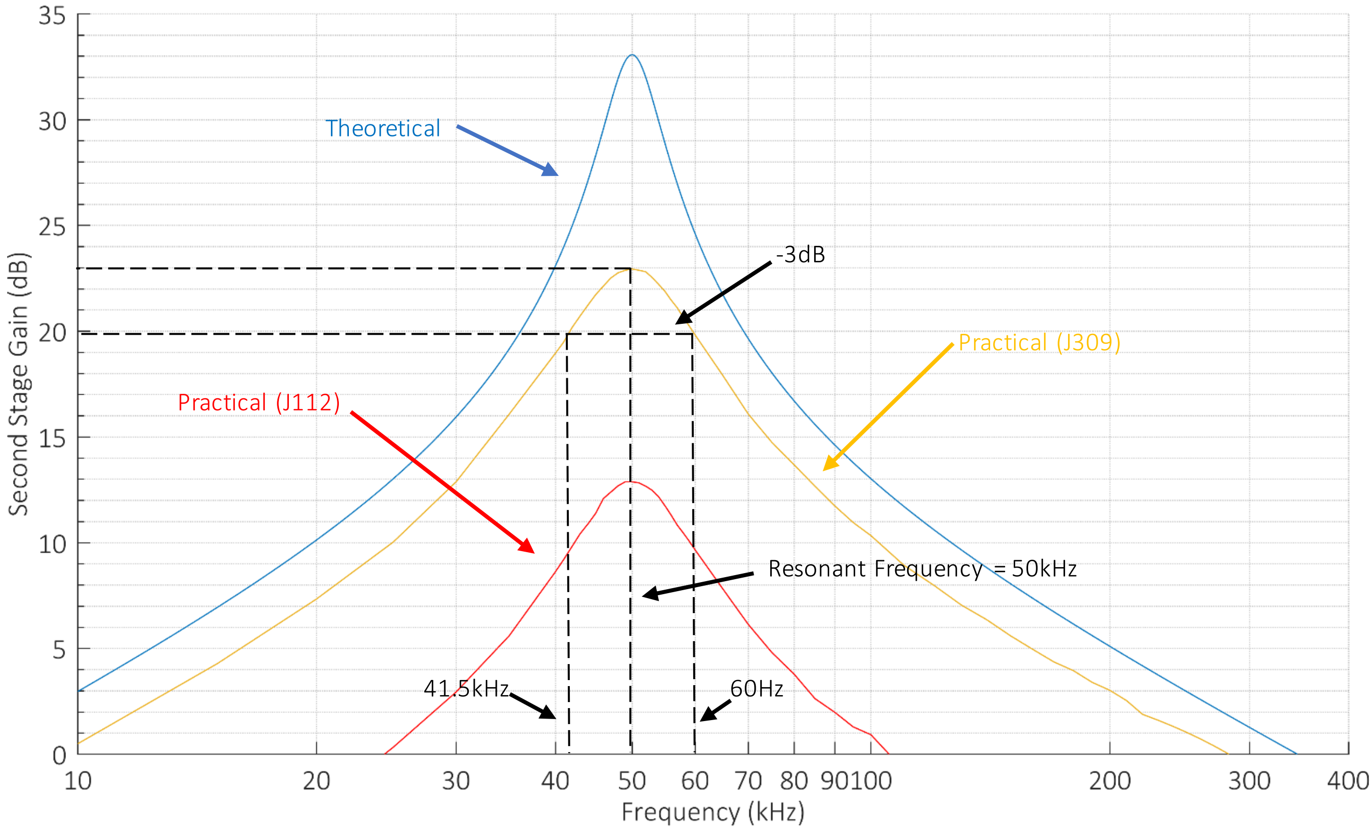


Figure 4: Second Stage Amplifier Frequency Response.

As seen in *figure* 4, the measured peak gain is for the J112 transistor is 13, compared to the predicted 32, which is improved when the J112 is replaced with the J309, increasing the gain up to 23. The difference between the measured and theoretical gain is due to the equation (7) not taking into account all the transistors characteristics. Furthermore, unwanted resistances and component tolerances within the circuit from test point 3 to test point 4 could alter amplifiers performance.

The measured resonant frequency is approximately 50kHz compared to the predicted 50khz, which is very close compared to the first stage, due to being able to use inductor and resistor values that are very close to the measured values. For example, L2 and R15,16 were calculated to be 4.61mH and 19.49kΩ respectively, and the closest components values were 4.7mH and 20kΩ.

The Q-factor should also be approximately **6.67** from the **specification**, but the actual Q-factor when using the **J309 transistor** is:

$$Q = \frac{f_0}{\Delta f} = \frac{50000}{60000 - 41500} = 2.70$$

The main reason for this value being significantly lower than expected is due to **human error**, where during construction of the circuit board, **R15** and **R16** were **10kΩ each** rather than **20kΩ each**. Using only half the resistance required would effectively half the Q factor from equation (4).

The total gain is then calculated using (9):

$$Total\ Gain\,(dB) = First\ Stage\ Gain\,(dB) + Second\ Stage\ Gain\,(dB) \tag{9}$$

The practical measured frequency response vs the theoretical frequency response is shown below in *figure 5*:

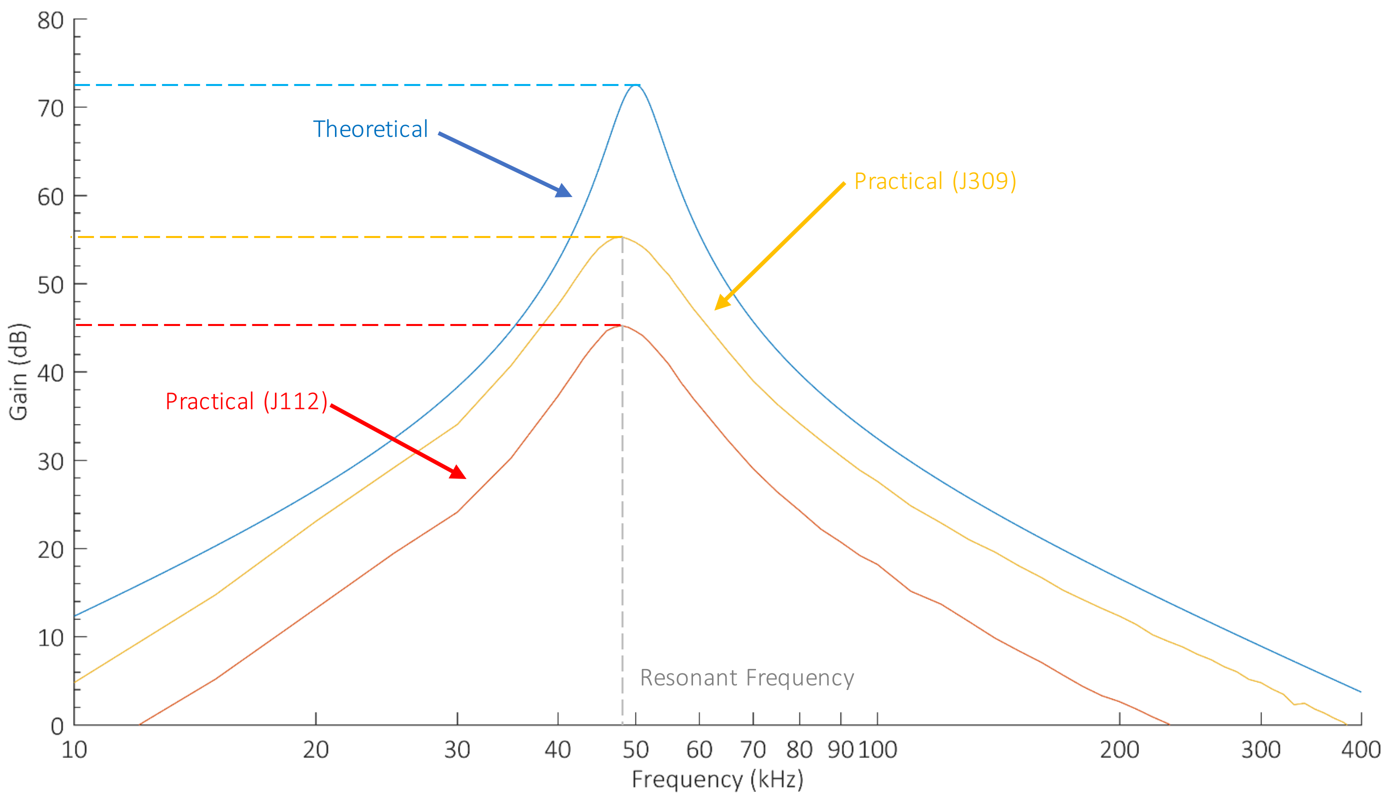


Figure5: Practical vs Theoretical Frequency Response.

In *figure 5*, there are two practical measured frequency responses shown and the theoretical response. Initially, for the second stage gain, a **J112 transistor** was used, which only produced a **peak gain** of approximately **45** shown by the **red line** in *figure 5*, and during practical testing gave a **usable range of only one metre**. To improve this, the **J112 transistor was replaced with a J309 transistor**, which is shown with the **yellow line** in *figure 5*. In doing this, the **peak gain** at the resonant frequency **increased from 45 to 55**, which is still not the theoretical peak gain of **72**, but increased the **useable range to approximately three metres**.

A possible reason for the practical peak gain being lower than predicted is because the equation (6) and (7) are **only approximations** and don't take all the **transistors parameters** into account. Using higher gain transistors for the second stage gain could possibly achieve a peak gain closer to the theoretical, because from *figure 3* and *figure 4*, the second stage gain is **dampened** more than expected compared to the first stage gain.

Furthermore, via the grey vertical line on *figure 5*, the **resonant frequency** is slightly lower at **48kHz** compared to the predicted 50kHz. This is due to not being able to use the exact values calculated for the inductors used in both the resonant filters, especially from the first stage filter with a resonant frequency of 47kHz. Instead, the **closest physical value inductor in the available series had to be selected**, hence alternating the resonant frequency.

Conclusion:

In conclusion, the circuit successfully received and demodulated the signal transmitted from the transmitter with reasonable reliability. However, I would not consider the circuit with its current performance to be suitable for its contextual application of being a receiver for an RC car. Firstly, the range, even when the second stage transistor was upgraded, is not large enough to enable reliable operation, which is mainly down to the gain of both the first and second stage amplifiers. Secondly, the receiver is **very directional**, meaning connectivity was not reliable because a slight change in the transmitters angle would could the circuit to disconnect. This would not be suitable for use with RC cars because the orientation of the vehicle would be constantly changing, hence there would be intermittent signal. Lastly, the **wide bandwidth of 7.5kHz** means that each channel has to be a wide distance apart on the frequency spectrum, hence **decreasing the number of cars that can be operated simultaneously within a certain frequency range**.

References:

[1] The University of Sheffield, Second Semester Practicals 2017; Electronic and Electronic Engineering. Sheffield: Print & Design Solutions, 2017, pp. 107-117.

Appendix:

Frequency (kHz)	Vin (Vpk-pk)	Vout (Vpk-pk)	Gain (Vout/Vin)	Gain (dB)
10	0.211	0.346	1.639810427	4.29587287
15	0.211	0.704	3.336492891	10.46580408
20	0.209	1.28	6.124401914	15.74127367
25	0.207	1.87	9.033816425	19.11742522
30	0.207	2.37	11.44927536	21.17556001
35	0.207	3.54	17.10144928	24.66065833
40	0.207	5.59	27.00483092	28.62882925
41	0.207	6.15	29.71014493	29.45809541
42	0.207	6.71	32.41545894	30.21504349
43	0.207	7.36	35.55555556	31.01814938
44	0.207	8	38.647343	31.74239283
45	0.207	8.5	41.06280193	32.26897161
46	0.207	8.8	42.51207729	32.57024653
47	0.207	8.9	42.99516908	32.66839322
48	0.207	8.8	42.51207729	32.57024653
49	0.207	8.4	40.57971014	32.16617881
50	0.207	8	38.647343	31.74239283
51	0.207	7.6	36.71497585	31.29686494
52	0.207	7.1	34.29951691	30.70576007
53	0.207	6.6	31.88405797	30.0714718
54	0.207	6.2	29.95169082	29.52842688
55	0.207	5.9	28.50241546	29.09763332
56	0.207	5.5	26.57004831	28.48784688
57	0.207	5.15	24.87922705	27.91673767
58	0.207	4.86	23.47826087	27.41331848
59	0.207	4.58	22.12560386	26.89790265
60	0.207	4.38	21.15942029	26.5100753
65	0.207	3.48	16.8115942	24.51217797
70	0.207	2.89	13.96135266	22.89854995
75	0.207	2.49	12.02898551	21.60458003
80	0.207	2.19	10.57971014	20.48947539
85	0.207	1.97	9.516908213	19.56991761
90	0.207	1.79	8.647342995	18.73765371
95	0.207	1.63	7.874396135	17.92434518
100	0.207	1.51	7.29468599	17.26013204
110	0.207	1.29	6.231884058	15.8923873
120	0.207	1.15	5.555555556	14.8945499
130	0.207	1.03	4.975845411	13.93733758
140	0.207	0.95	4.589371981	13.2350652
150	0.207	0.865	4.178743961	12.42091524
160	0.207	0.8	3.8647343	11.74239283
170	0.207	0.728	3.516908213	10.92322068
180	0.207	0.675	3.260869565	10.26666855
190	0.205	0.635	3.097560976	9.820397285
200	0.205	0.599	2.92195122	9.313459227
210	0.205	0.567	2.765853659	8.836583957
220	0.205	0.535	2.609756098	8.331998419
230	0.205	0.507	2.473170732	7.865081966
240	0.205	0.486	2.370731707	7.497648164
250	0.205	0.458	2.234146341	6.982232339
260	0.205	0.442	2.156097561	6.673368166
270	0.205	0.418	2.03902439	6.188448414
280	0.205	0.406	1.980487805	5.93544345
290	0.205	0.382	1.863414634	5.406190037
300	0.205	0.374	1.824390244	5.222354823
310	0.205	0.358	1.746341463	4.842583312
320	0.205	0.342	1.668292683	4.4454449
330	0.207	0.33	1.594202899	4.050871888
340	0.205	0.318	1.551219512	3.813465179
350	0.205	0.306	1.492682927	3.479351309
360	0.205	0.297	1.448780488	3.220051765
370	0.205	0.285	1.390243902	2.861819979
380	0.205	0.277	1.351219512	2.61451816
390	0.205	0.269	1.312195122	2.359968379
400	0.205	0.259	1.263414634	2.030918061

First Stage Measured Gain

Frequency (kHz)	Vin (Vpk-pk)	Vout (Vpk-pk)	Gain (Vout/Vin)	Gain (dB)
10	0.215	0.079	0.36744186	-8.69622737
15	0.213	0.116	0.544600939	-5.27843228
20	0.213	0.159	0.746478873	-2.53964958
25	0.209	0.217	1.038277512	0.326268955
30	0.209	0.293	1.401913876	2.934426685
35	0.209	0.398	1.90430622	5.594735719
40	0.209	0.563	2.693779904	8.607242175
41	0.209	0.603	2.885167464	9.203420521
42	0.209	0.647	3.09569378	9.815159891
43	0.207	0.687	3.31884058	10.41972783
44	0.209	0.732	3.502392344	10.8872959
45	0.209	0.776	3.71291866	11.3943087
46	0.209	0.84	4.019138756	12.08266
47	0.209	0.87	4.162679426	12.38745933
48	0.209	0.9	4.306220096	12.68192447
49	0.209	0.92	4.401913876	12.87283082
50	0.209	0.92	4.401913876	12.87283082
51	0.209	0.915	4.377990431	12.82549616
52	0.207	0.89	4.299516908	12.66839322
53	0.207	0.87	4.202898551	12.47097814
54	0.207	0.84	4.057971014	12.16617881
55	0.207	0.8	3.8647343	11.74239283
56	0.207	0.76	3.671497585	11.29686494
57	0.207	0.72	3.47826087	10.82724302
58	0.207	0.69	3.333333333	10.45757491
59	0.207	0.66	3.188405797	10.0714718
60	0.207	0.63	3.043478261	9.66740408
65	0.207	0.51	2.463768116	7.831996613
70	0.207	0.42	2.028985507	6.145578899
75	0.207	0.36	1.739130435	4.806643106
80	0.207	0.32	1.54589372	3.783592657
85	0.207	0.28	1.352657005	2.623753718
90	0.207	0.26	1.256038647	1.98006005
95	0.207	0.24	1.15942029	1.284817925
100	0.207	0.23	1.111111111	0.915149811
110	0.207	0.19	0.917874396	-0.74433489
120	0.207	0.18	0.869565217	-1.21395681
130	0.207	0.16	0.77294686	-2.23700726
140	0.207	0.14	0.676328502	-3.3968462
150	0.207	0.13	0.628019324	-4.04053986
160	0.207	0.121	0.584541063	-4.6636995
170	0.207	0.113	0.54589372	-5.25783804
180	0.207	0.105	0.507246377	-5.89562093
190	0.207	0.098	0.473429952	-6.4948854
200	0.207	0.096	0.463768116	-6.67398225
210	0.207	0.092	0.444444444	-7.04365036
220	0.207	0.088	0.425120773	-7.42975347
230	0.207	0.085	0.410628019	-7.73102839
240	0.207	0.078	0.376811594	-8.47751486
250	0.207	0.076	0.367149758	-8.70313506
260	0.207	0.074	0.357487923	-8.93477251
270	0.207	0.07	0.338164251	-9.41744611
280	0.207	0.069	0.333333333	-9.54242509
290	0.207	0.068	0.328502415	-9.66922866
300	0.207	0.064	0.309178744	-10.1958074
310	0.207	0.061	0.29468599	-10.6128102
320	0.207	0.06	0.289855072	-10.7563819
330	0.207	0.059	0.285024155	-10.9023667
340	0.207	0.058	0.280193237	-11.050847
350	0.205	0.056	0.273170732	-11.2713167
360	0.205	0.056	0.273170732	-11.2713167
370	0.205	0.055	0.268292683	-11.4278234
380	0.205	0.053	0.258536585	-11.7495598
390	0.205	0.053	0.258536585	-11.7495598
400	0.205	0.05	0.243902439	-12.2556771

Second Stage Measured Gain (J112 transistor)

Frequency (kHz)	Vin (Vpk-pk)	Vout (Vpk-pk)	Gain (Vout/Vin)	Gain (dB)
10	0.209	0.221	1.057416268	0.484919751
15	0.209	0.342	1.636363636	4.277596399
20	0.209	0.486	2.325358852	7.329799663
25	0.209	0.663	3.172248804	10.02734485
30	0.209	0.92	4.401913876	12.87283082
35	0.209	1.33	6.363636364	16.0741071
40	0.209	1.85	8.851674641	18.94050885
41	0.209	1.97	9.425837321	19.4863988
42	0.209	2.13	10.19138756	20.16466635
43	0.209	2.27	10.86124402	20.71759142
44	0.209	2.41	11.53110048	21.23741513
45	0.209	2.55	12.20095694	21.72787789
46	0.209	2.67	12.77511962	22.12729951
47	0.209	2.79	13.3492823	22.50915834
48	0.209	2.87	13.73205742	22.75471221
49	0.209	2.91	13.92344498	22.87493406
50	0.209	2.93	14.01913876	22.93442668
51	0.209	2.91	13.92344498	22.87493406
52	0.207	2.86	13.81642512	22.80791375
53	0.207	2.77	13.38164251	22.53018847
54	0.207	2.67	12.89855072	22.21081832
55	0.207	2.57	12.41545894	21.87925556
56	0.207	2.45	11.83574879	21.46391478
57	0.207	2.35	11.352657	21.10195034
58	0.207	2.23	10.77294686	20.64669035
59	0.207	2.13	10.28985507	20.24818516
60	0.207	2.03	9.806763285	19.83051385
65	0.207	1.63	7.874396135	17.92434518
70	0.207	1.32	6.376811594	16.09207171
75	0.207	1.13	5.458937198	14.74216196
80	0.207	1	4.830917874	13.68059309
85	0.207	0.89	4.299516908	12.66839322
90	0.207	0.8	3.8647343	11.74239283
95	0.207	0.73	3.526570048	10.94705029
100	0.207	0.68	3.285024155	10.33077134
110	0.207	0.579	2.797101449	8.934164365
120	0.207	0.519	2.507246377	7.983940248
130	0.207	0.466	2.251207729	7.048311425
140	0.207	0.43	2.077294686	6.349962202
150	0.207	0.394	1.903381643	5.590517527
160	0.207	0.366	1.768115942	4.950214799
170	0.207	0.342	1.652173913	4.361115212
180	0.207	0.326	1.574879227	3.944945092
190	0.207	0.306	1.47826087	3.39502162
200	0.207	0.293	1.415458937	3.017945498
210	0.207	0.277	1.338164251	2.530188472
220	0.207	0.257	1.241545894	1.879255557
230	0.207	0.249	1.202898551	1.604580033
240	0.207	0.241	1.164251208	1.320933942
250	0.207	0.233	1.125603865	1.027711511
260	0.207	0.225	1.086956522	0.724243453
270	0.207	0.217	1.048309179	0.409787768
280	0.207	0.209	1.009661836	0.083518813
290	0.207	0.201	0.971014493	-0.25548576
300	0.207	0.197	0.951690821	-0.43008239
310	0.207	0.189	0.913043478	-0.79017083
320	0.207	0.185	0.893719807	-0.97597234
330	0.207	0.169	0.816425121	-1.76167282
340	0.207	0.177	0.855072464	-1.35994158
350	0.205	0.169	0.824390244	-1.67734313
360	0.205	0.165	0.804878049	-1.88539834
370	0.205	0.161	0.785365854	-2.0985597
380	0.205	0.157	0.765853659	-2.31708417
390	0.205	0.149	0.726829268	-2.77135185
400	0.205	0.153	0.746341463	-2.5412486

Second Stage Measured Gain (J309 transistor)