to stabilize the receiver gain against a varying input RF signal. A feedback signal from the detector is injected via the base bias resistance, R_{b2}, to stabilize the output audio power against input RF signal fluctuations. Before we simulate the complete receiver let us look at the different parts of the system in order to appreciate how the receiver produces an audio signal from an RF signal. We have already looked at mixing so consider the RF amplifiers first.

4.3.3 JFET-Tuned Radio Frequency Amplifier

Single tuned RF amplifiers select and amplify weak RF signals and are the main parts of a receiver. We need to calculate unloaded and unloaded Q-factors and tuning capacitance C_T, if the circuit is to achieve maximum amplification at 100 kHz. You may assume an inductance of 1 mH. What is the −3 dB bandwidth and maximum voltage gain? The **VSIN** is set to 0.1 V at the resonant frequency f_0, and is applied to the circuit in Fig. 4.12 by renaming the input wire segment to **vin**. Set the Analysis tab to Analysis type: **Time Domain** (Transient), **Run to time** = 10 ms, and **Maximum step size** = 10 μs, press F11.

4.3.4 RF-Tuned Amplifier Measurements

Separate the input and output waveforms as shown in Fig. 4.13 using **alt PP** to open up a new plot. Copy the variable you want moved using **ctrl X** and then paste with **ctrl V**. Measure the maximum gain.

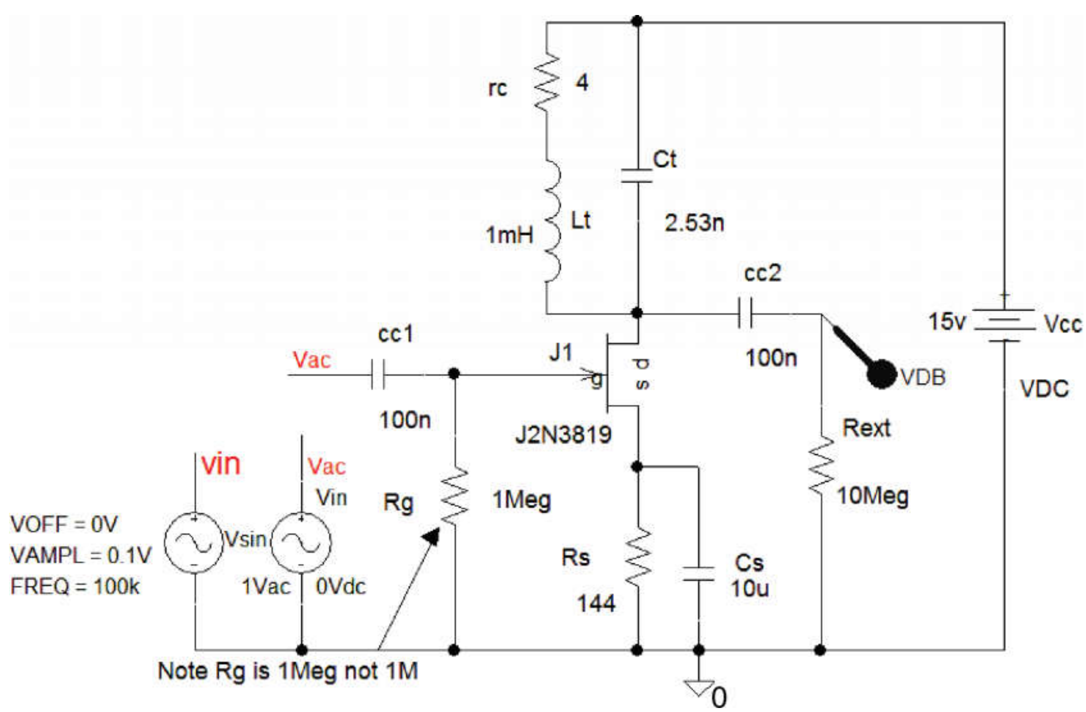

FIGURE 4.12: Selective RF amplifier tuned to 100 kHz

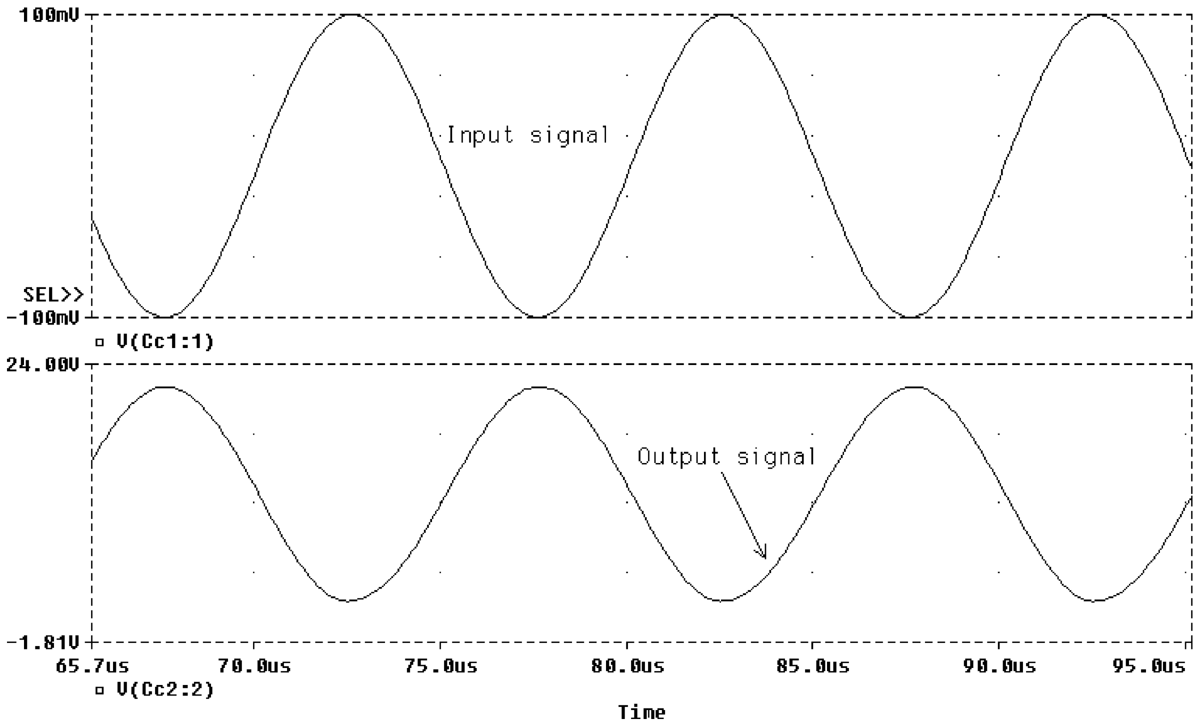

FIGURE 4.13: Input and output signals

This little symbol beside the variable name at the bottom is for locating the cursor on a trace. Name the input line segment vac to connect the **VAC** generator with amplitude set 1 V (20log 1 = 0 dB) to the input, and carry out an AC analysis centered at the resonant frequency. The **VSIN** generator may be used for an AC frequency response, but you cannot use the **VAC** generator for transient analysis. Change the output marker to vdB. From the **Analysis Setup,** select **AC Sweep** and **Linear, Points/Decade** = 1001, **Start Frequency** = 95k, and **End Frequency** = 105k. Simulate with **F11** to produce the response shown in Fig. 4.14. Measure the resonant frequency, the −3dB bandwidth, and the maximum gain. Determine the loaded Q-factor from these measurements, and compare the theoretical and simulated values. Check the DC conditions by selecting the **V** and **I** icons.

The maximum gain at the resonant frequency is

$$A_v|_{\mathrm{dB}} = 20\log(g_m R) = 47.7\ \mathrm{dB} \qquad (4.9)$$

where R is the parallel combination of the dynamic impedance $R_p = L/Cr_c$ and the FET output source impedance r_{ds} (the drain–source impedance is measured from the inverse of the output FET characteristic). The bandwidth, resonant frequency, and loaded quality factor are related as

$$Q_{\mathrm{loaded}} = \frac{f_o}{BW} = \frac{100\ \mathrm{kHz}}{1.47\ \mathrm{kHz}} = 68. \qquad (4.10)$$

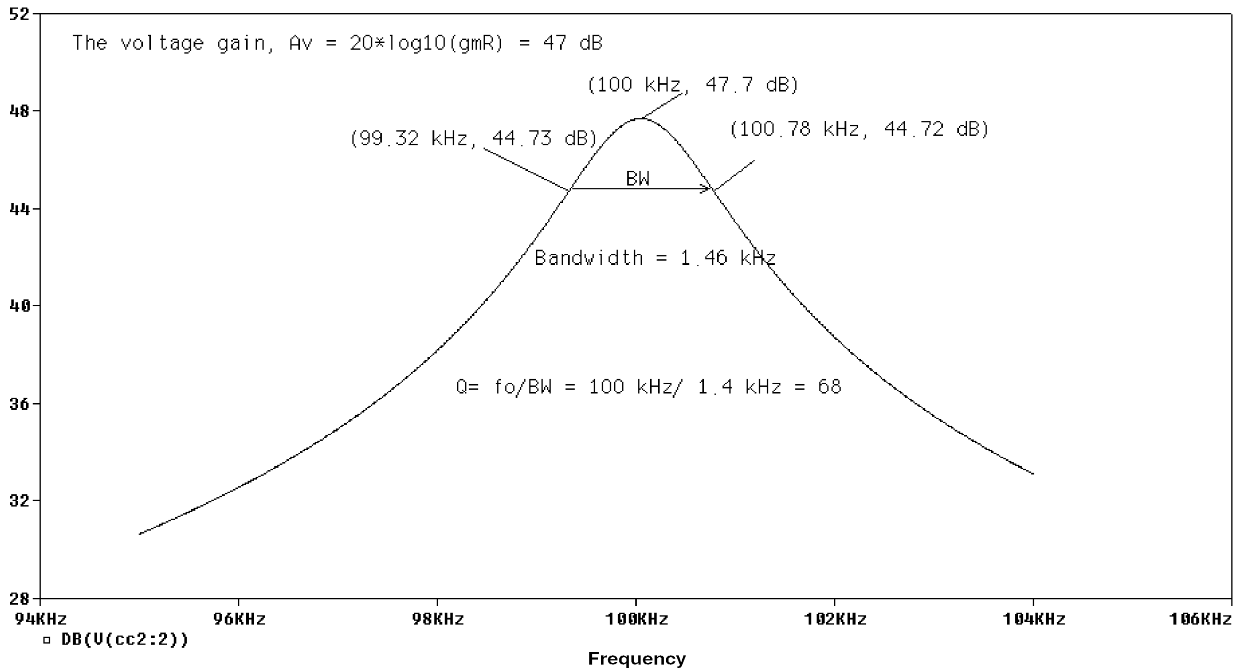

FIGURE 4.14: RF amplifier frequency response

Determine a suitable value for an external resistance R_{ex} when placed across the tuned circuit doubles the bandwidth (half the Q-factor). Remember the loaded Q-factor is defined as

$$Q_L = \frac{R}{X_{LP}} \approx \frac{R}{X_{Ls}} = \frac{r_{ds} R_p/(r_{ds} + R_p)}{2\pi f_o L} = \frac{R_p}{2\pi f_o L}\left(\frac{r_{ds}}{rds + R_p}\right) = \frac{Q_{UL}}{1 + R_p/r_{ds}}. \qquad (4.11)$$

(Clue: two 10-kΩ resistors in parallel are 5 kΩ.) Measure the bandwidth and gain for the new loading conditions [ref: 1 Appendix A].

4.4 MEASURING THE OUTPUT IMPEDANCE OF AN RF AMPLIFIER

This is a useful measurement technique that can be applied in different applications. Apply a 1-V **VAC** generator **vout** across the output, as shown in Fig. 4.15. The input signal generator is replaced by a source impedance (a short-circuit representing an ideal voltage source). A very large capacitance will do the same job. A coupling capacitor Cc_2 avoids changing the bias conditions by the low impedance of the **VSIN** generator when connected. Another reason for this capacitor is that PSpice will replace all sources with their internal resistance when doing a bias point calculation. If a current source is used instead, then the coupling capacitor is not required, as the source impedance is very large.

From the **Analysis Setup**, select **ACSweep** and **Linear, Total Points** = 1001, **Start Frequency** = 95k, and **End Frequency** = 105k. Simulate with **F11** to plot the the response

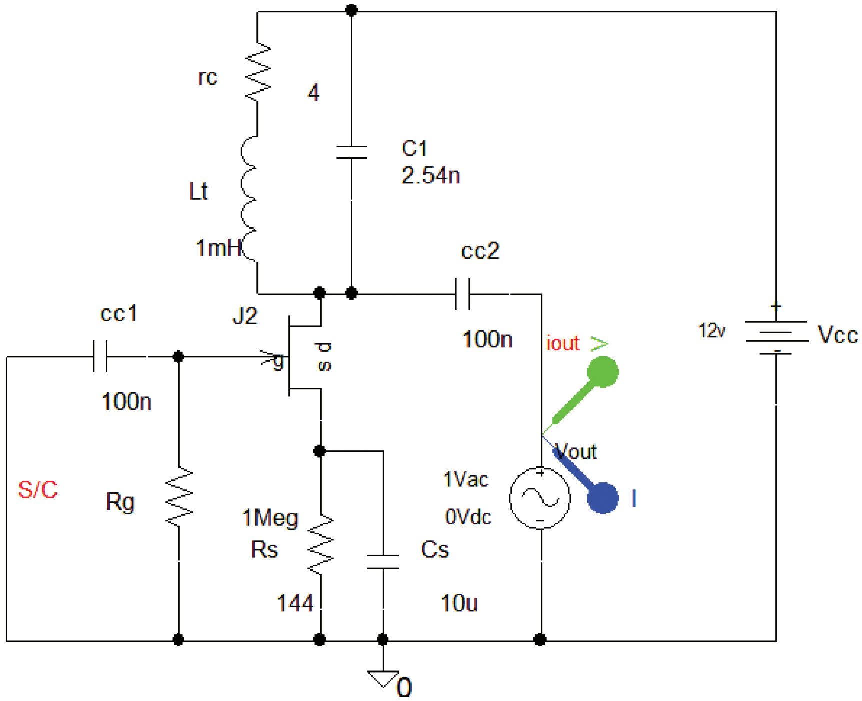

FIGURE 4.15: Measuring the output impedance

shown in Fig. 4.16. Select the **Trace Add** facility (alternatively, press the insert button on your computer) and add the two variables **vout/iout** from the list in the **Trace Expression** box to plot the impedance. Compare the measured 42.78 kΩ maximum impedance to the parallel combination of the dynamic impedance and the output drain–source impedance.

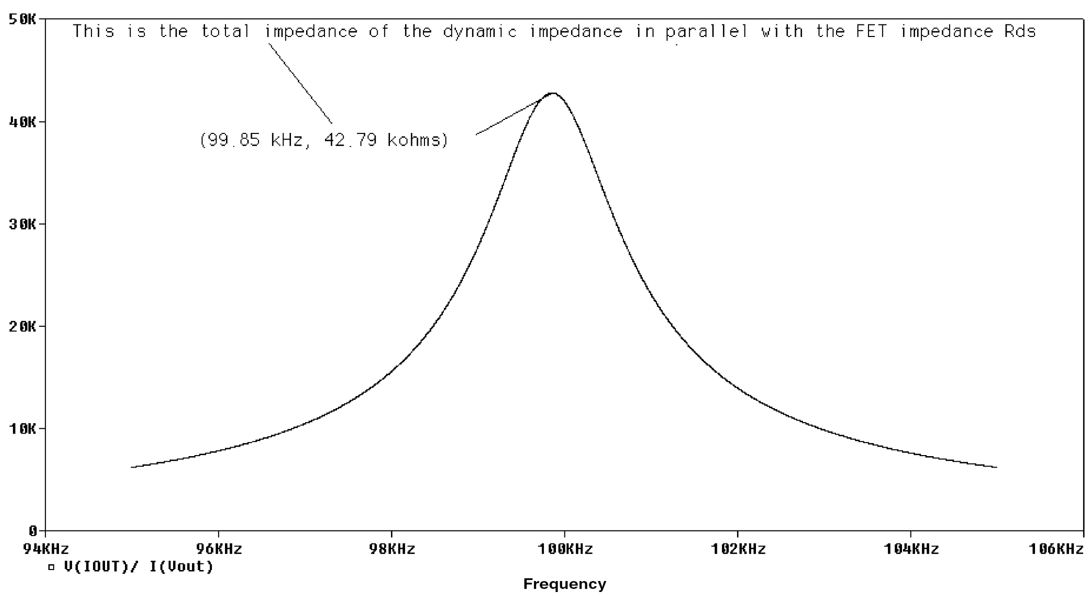

FIGURE 4.16: Plot of the output impedance

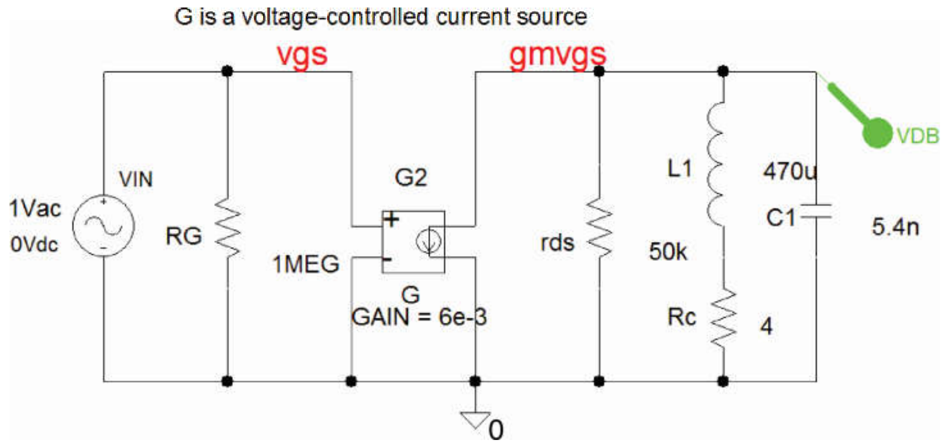

FIGURE 4.17: AC equivalent circuit

4.4.1 AC Equivalent Circuit

The JFET equivalent tuned RF amplifier in Fig. 4.17 is constructed from the parameters measured from the FET characteristics [ref: 1 Appendix A].

The voltage-controlled current source **G** has the gain set to the transconductance g_m from the transfer characteristic ($g_m = 6$ mS). The amplifier output resistance is the FET output resistance, r_{ds}, measured as 50 kΩ from the inverse of the slope of the output characteristic. From the **Analysis Setup**, select **ACSweep and Linear, Points/Decade** = 1001, **Start Frequency** = 95k, and **End Frequency** = 105k. Simulate by pressing **F11**, or press the little triangle. Measure the resonant frequency, gain, BW and Q-factor from the frequency response shown in Fig. 4.18.

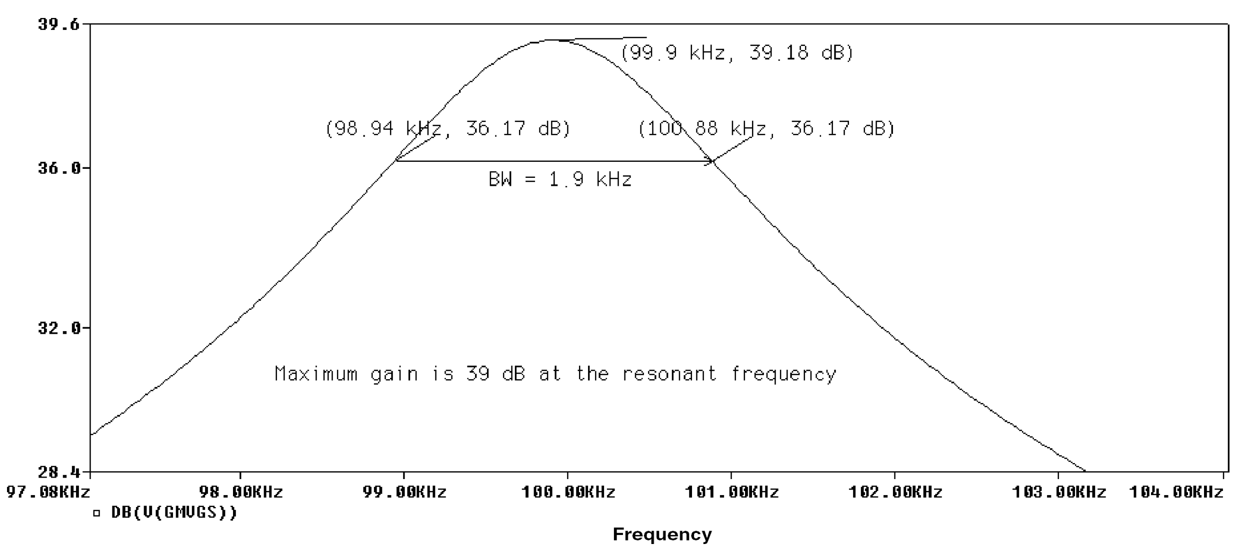

FIGURE 4.18: Frequency response of equivalent circuit

4.5 BJT BANDPASS AMPLIFIER

RF amplifiers generally use BJT devices, rather than FET devices, because they have a much higher gain. From the **Analysis Setup**, select **ACSweep** and **Linear, Total Points** = 1001, **Start Frequency** = 95k, **End Frequency** = 105k and simulate by pressing **F11**. Measure the tuned RF amplifier DC conditions shown in Fig. 4.19.

Measure the maximum gain and bandwidth from the bandpass frequency response in Fig. 4.20 and compare the results to those from the tuned JFET amplifier response.

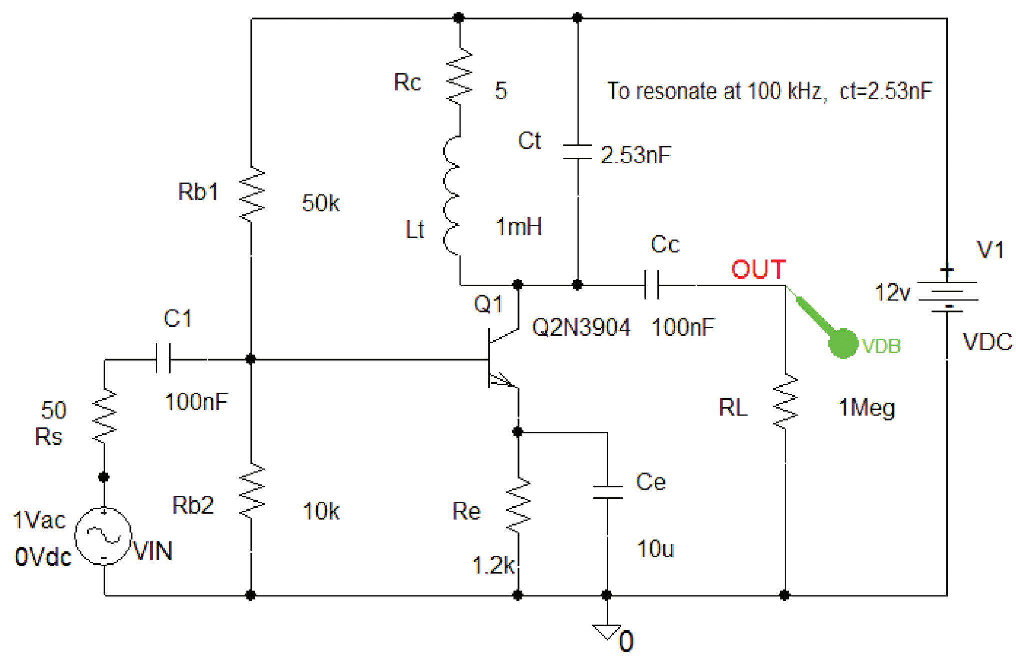

FIGURE 4.19: RF amplifier using an NPN device

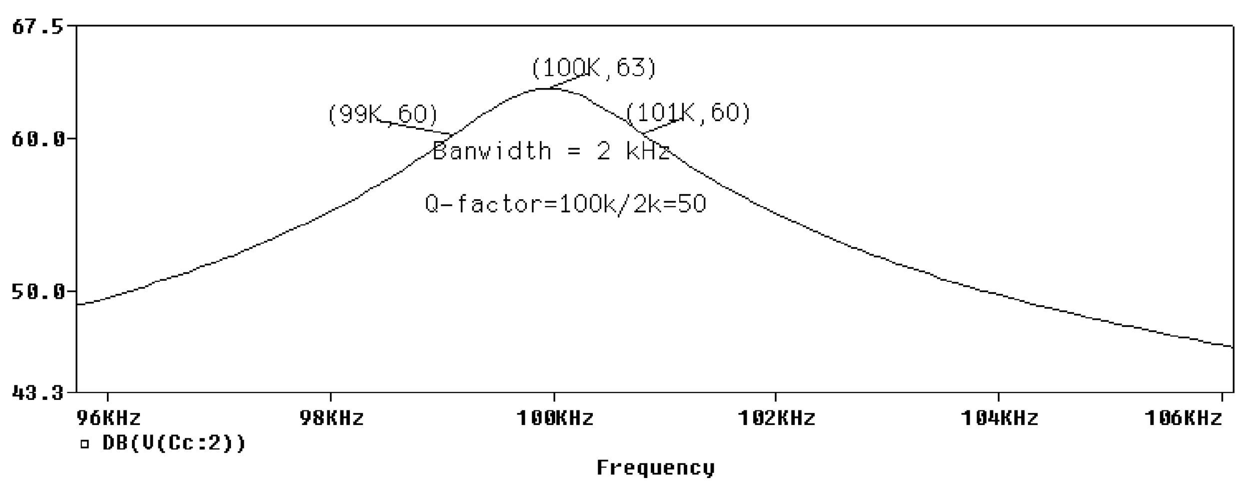

FIGURE 4.20: Amplifier response

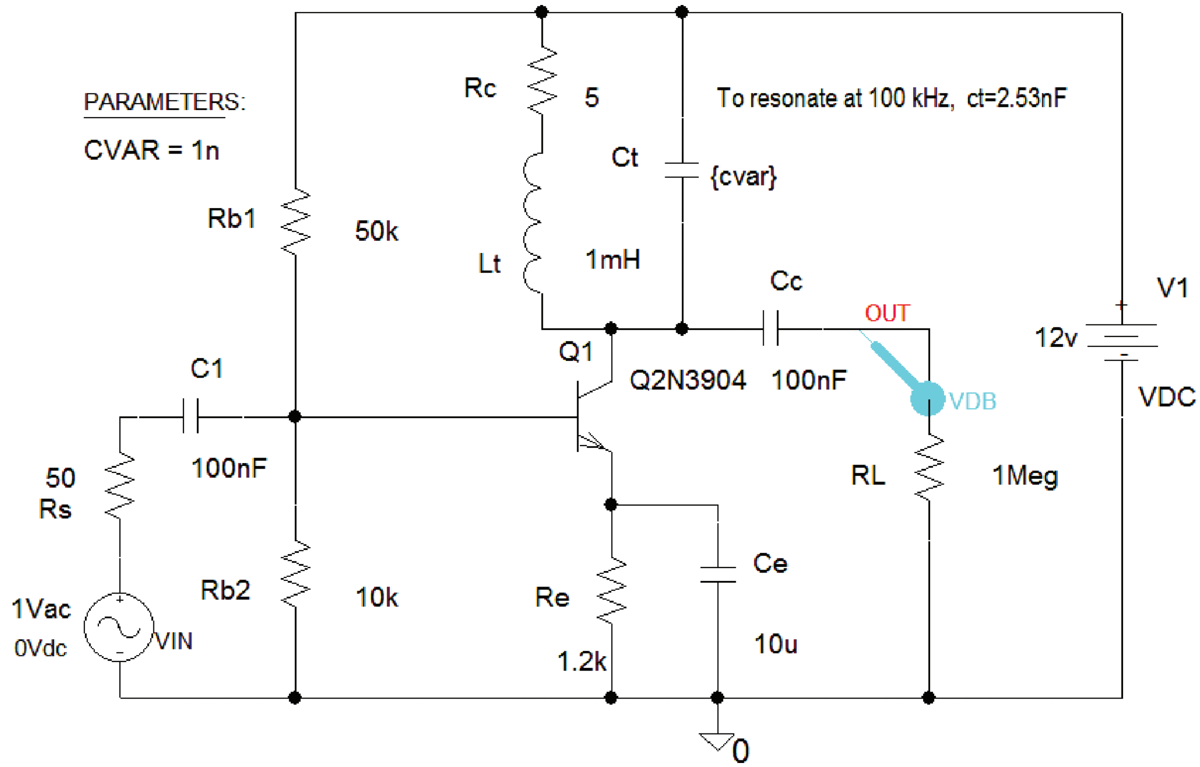

FIGURE 4.21: The PARAM part defines the tuning capacitance C_t

4.5.1 Tuning Capacitance

This schematic in Fig. 4.21 demonstrates how the tuning capacitance *Ct* changes the resonant frequency. Select the **Param** part, **Rclick,** and select **Edit Properties**. **Press New Row** and in the **New Row** and fill in **Name** = **cvar** and **Value** = 1 nF. The tuning capacitance value is replaced with {**var**} (you must use the curly brackets). From the **Analysis Setup/Parametric** menu set **Name** equal to cvar (no curly brackets), **Start Value** = 0.1 nF and **End Value** = 50 nF, **Increment** = 5 nF. From the **Analysis Setup**, select **ACSweep** and **Linear, Total Points** = 1001, **Start Frequency** = 95k, and **End Frequency** = 105k. Simulate with **F11** to plot the the response shown in Fig. 4.22.

The resonant frequency shifts for each tuning capacitor value as shown in Fig. 4.22. The *Q*-factor is expressed as

$$Q_L = \frac{R}{X_L} = \frac{R}{\omega_o L} \approx \frac{R}{L/\sqrt{LC}} = R\sqrt{\frac{C}{L}}. \tag{4.12}$$

The gain is also dependent on the tuning capacitance, since the dynamic impedance changes $(R_d = L/R_c C_t)$.