Experiment No. 2

Batteries, Telephone Systems and Dialing Tones

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Purpose

1. Test a battery and measure its internal resistance.
2. Test a touch-tone telephone keypad and determine the frequencies sent when you press 1, 2, ... 0, #, *.

❏ Read Chapters 1-3 in the additional course notes (Audio Electronics & Batteries).
❏ Read this experiment and answer the pre-lab questions before you come to the lab.

Introduction:

The circuit diagram of a telephone circuit is shown in Fig. 1. The telephone is generally connected to the central office using a pair of twisted wires. However, new installations are using a coaxial-fiber system for wide bandwidth communications. Unlike audio systems with bandwidths of 20 Hz – 20 kHz for high fidelity sound, a telephone operates over the 300 Hz – 3.3 kHz bandwidth. The reason is that most of the energy of human voice is within this frequency bandwidth and a 3 kHz bandwidth is enough for reliable conversation (Reliable: yes, but not excellent!). The bandwidth limitation is the main reason why we have trouble distinguishing "b" from "p" from "d" over a telephone. The audio voltage swing is 5-500 mV peak, leading to a dynamic range of 40 dB, which is much lower than hi-fi system (dynamic range of 70-90 dB).

The telephone operates on a 48 V DC system supplied over a pair of lines from the central telephone office. This is historical since the telephone was invented before the AC 60 Hz power distribution system and could not be changed anymore. To grab your attention, the central office sends bursts of a 20 Hz sinusoidal signal with a 75 V rms voltage to activate the ringer. The bursts are on for 2 sec and off for 4 seconds. When a party answers the phone, the telephone switch closes, the central office detects a DC current in the circuit and stops the ringing signal. You could ask why 75 V? It is huge! The answer is that this signal was needed to activate inefficient ringers on old telephones. In newer phones with electronic ringers, a TTL (5 V) digital signal is enough to activate the ringer. However, this telephone system will not be compatible with old phones!

Note: A color .pdf file for this experiment can be downloaded from the Agilent Educator's Corner Website, www.educatorscorner.com. Access http://www.educatorscorner.com/

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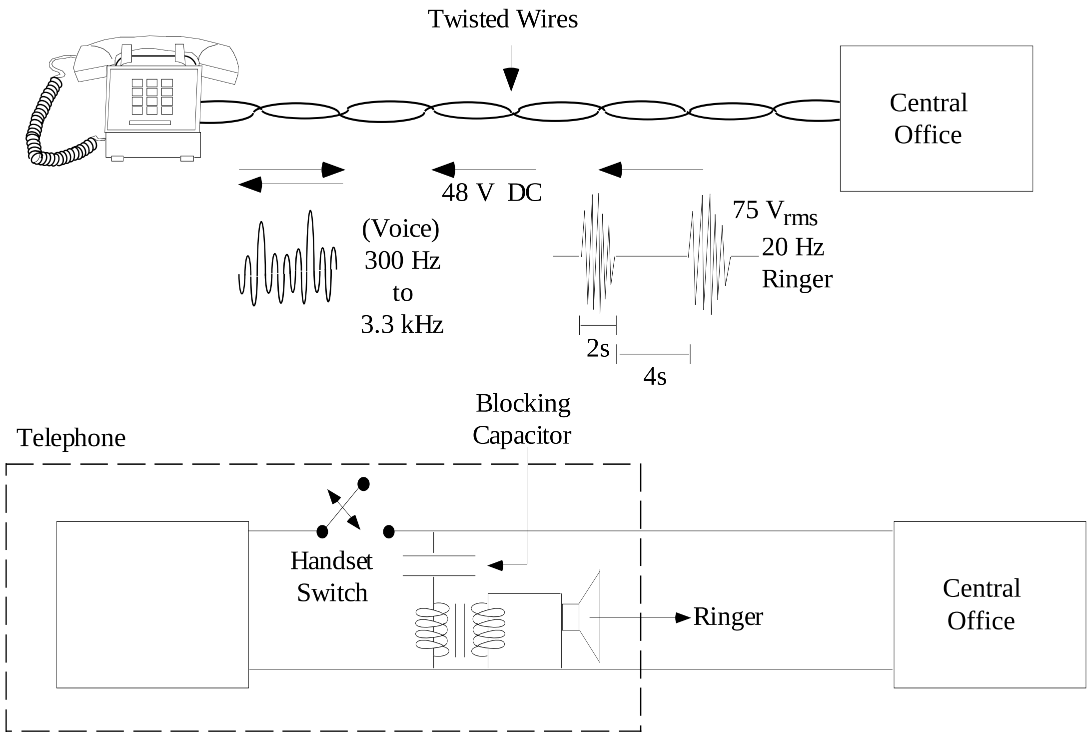


Fig. 1. The home telephone system.

The lines between the central telephone office and your home therefore carry:

DC (0 Hz) at 48 V:	Powering the phone
20 Hz Bursts at 75 V_{rms}:	For activating the ringer
300-3,300 Hz at 5 mV – 0.5 mV:	Voice signal

In order to dial a phone number, you need to transmit specific frequencies which are within the 300 Hz – 3,300 Hz range. However, if you assign a simple frequency to each number, then somebody whistling when you are dialing (or a large clean sound) can actually cause you to misdial! A very nice way to solve this interference problem is to send two frequencies for each number. The probability that two specific frequencies with a ratio equal to a rational number are present in the background noise when you are dialing is really very low!

The dial pad of a telephone is shown in Fig. 2. When a button is pushed, the two tones corresponding to the intersection of the vertical and horizontal axes are sent. Notice that no frequency is the harmonic of any other frequency thereby avoiding problems due to distortion and harmonic generation (see Lab. 2.2). Also, no frequency can be synthesized from the sum or difference of any two frequencies, thereby avoiding misdialing problems due to intermodulation products (see Lab. 3.2).

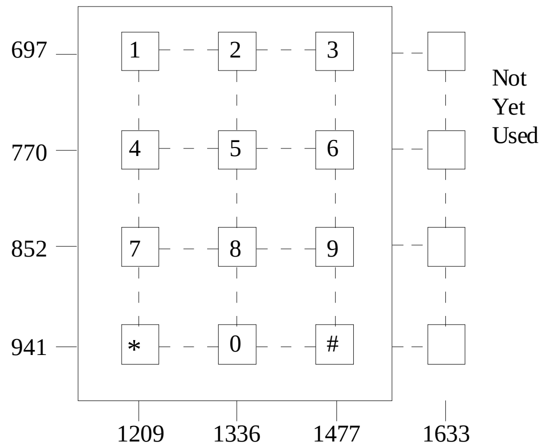
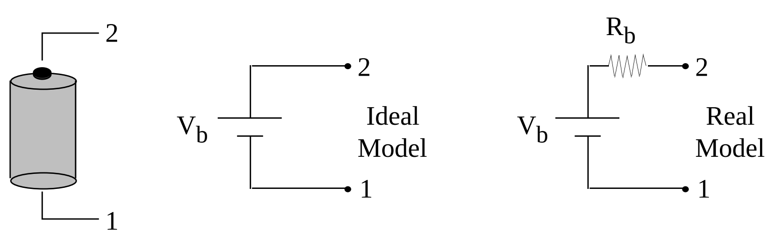


Fig. 2: A telephone dial-pad. (All frequencies are in Hz.)

2.1 Batteries and Internal Resistance:

Equipment: Agilent 34401A Multimeter

As seen in Chapter 2 of additional notes, the battery voltage may be around 1.4-1.5V when open circuited (no current) and drops to 1.3–1.4V when in operation. Actually, the battery voltage depends on the discharge current and time. A nice way to model this voltage drop is to include an internal resistance (R_b) in the battery model. Figure 1 shows an ideal battery and a real battery. Notice that we cannot access the inside nodes of R_b and therefore, the internal resistance is calculated from measured external V/I values:



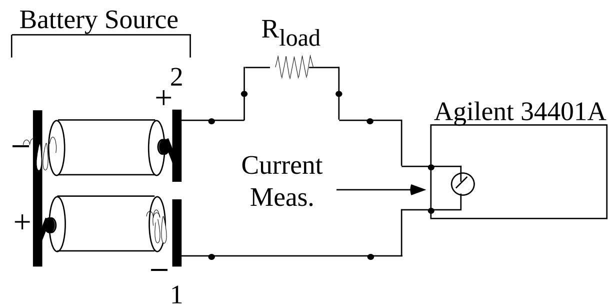
For a new C-type battery with a full rated capacity of 7100 mAH, the internal resistance can be as low as 0.1-0.2 Ω at a 500 mA discharge current (50 mV–100 mV drop). When the battery is 1/3 full (66% of the capacity is *removed*), the internal resistance will increase to around 0.6 Ω (0.3 V drop). If the battery is nearly empty, the internal resistance will be as high as 1–2 Ω resulting in a voltage drop of 0.5–1 V (from a 1.5V source) and making the battery useless.

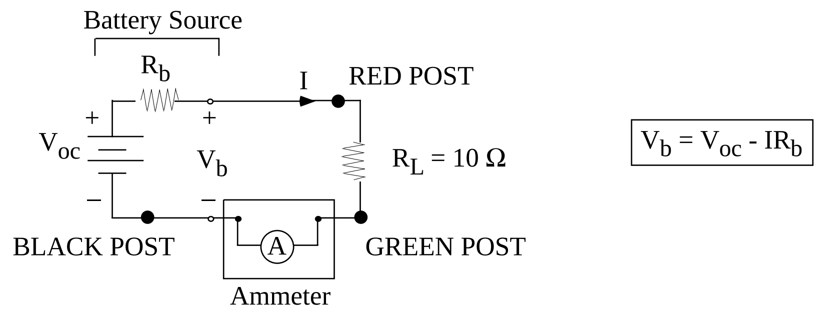
Experiment Set-Up:

1. Take two C-type batteries and connect them in series.
   a. Measure the open-circuit voltage, $V_b = V_{oc}$ (no current from the batteries). It should be around 2.5–2.9V, depending on the "age" of the batteries.
2. Connect a 10 Ω load resistor across the battery terminals.
3. Connect an ammeter in the circuit loop.

Remember: Current is measured **in series** in a circuit loop.
Voltage is measured **in parallel** across an element.

The experiment should look like this:





Before you start, ask your lab instructor to check the circuit!

For a load resistor of 10 Ω:

- ❑ Measure the current in the loop (I).
- ❑ Measure the voltage across the battery terminals (V_b).
- ❑ Repeat every minute or so for a total of 3 measurements.
- ❑ Calculate the internal resistance of the "battery source" for all three measurements. Notice, this is the resistance of <u>two</u> C-cell batteries in series. What is the internal resistance of one C-cell battery?

2.2 Telephone Dialing Tones:

Equipment: Agilent 34401A Multimeter
Agilent E3631A Triple Power Supply
Agilent 54645A Digital Sampling Scope

Experiment Set-Up:

1. Connect the Agilent 33120A signal generator to the digital scope and measure any signal you wish at around 2 kHz in time and frequency domain. (This is to get back in the groove!)

2. Set the Agilent E3631A power supply at 4 V. Set the current limit to 100 mA (see p. 7). Make sure that the (–) terminal of the Agilent E3631A power supply is connected to the ground (⏚) terminal. Check the voltage on the Agilent 34401A multimeter before you connect it to the telephone dialer unit. The LED on the dialer unit should turn on when properly connected.

3. Dial any number(s) you wish and listen to the generated tones.

4. ❏ Measure in time domain the signal resulting from the number 8. Choose a time span which results in a signal with many periods on the screen and "STOP" the triggering of the scope (top right section). Go into the cursor mode and try to determine the "period" of this complex waveform (this is a bit tricky) and the corresponding "frequency" ($f = 1/\Delta T$).

   ❏ Sketch the time waveform on your notebook and compare it to your pre-lab exercise.

   ❏ Now, "RUN" the oscilloscope again and set the FFT correctly. Go into the cursor mode and measure the two frequencies (~852 Hz, ~1336 Hz), amplitudes (dBV) and the first five (5) harmonics/intermod. products of decent amplitude (not noise) which you see on the screen.

   ❏ Sketch the frequency spectrum on your notebook (do not include the noise) and label the axes and put the measured values on the graph.

5. Repeat above exercise with any other number of your choose (but <u>not</u> on the same column or row as #8).

   ❏ Sketch the time waveform and frequency spectrum on your notebook and label only the two peaks in frequency domain.

6. You are now free to play for 5-10 minutes with the dialer but do not take any data. See how the frequencies jump around but are understandable. See how <u>different</u> the time waveforms are from number to number, and that we cannot quickly get a lot of information from them. This is yet another indication that WE THINK IN FREQUENCY DOMAIN!

Experiment No. 2.

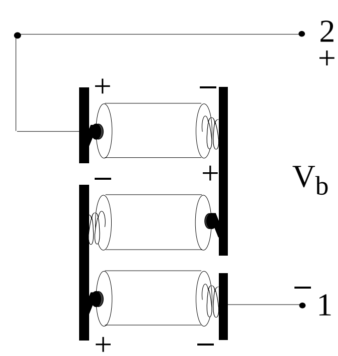
Batteries, Telephone Systems and Dialing Tones

Pre-Lab Assignment:

1. a. Calculate the time it takes for the C-type battery with a full rated capacity of 7100 mAH to reach its 1/3 capacity value, at a discharge current of 500 mA.

   b. The measured open-circuit voltage of a battery ($V_b = V_{oc}$) is 1.5 V. The measured output voltage is 1.24 V for a 500 mA discharge current. Calculate the internal resistance value (R_b).

   c. A unit requires three AA 1.5 V batteries connected in this fashion. What is the operating voltage (V_b) of the unit?



2. ❏ Take two sinusoidal signals at 852 Hz and 1336 Hz (number 8).

$v_1(t) = \cos(2\pi(852)t)$

$v_2(t) = \cos(2\pi(1336)t)$

Plot: $v(t) = v_1(t) + v_2(t)$ Using MatLab (or any program you wish).

x-axis = 0 - 0.01 sec. (choose small time steps)

y-axis = –2 to + 2 V

The resulting waveform is complex. Look *carefully* at the graph: Can you find the period, T, of the complex waveform? What are the peak voltages?

3. ❑ If a circuit exhibits non-linear behaviour, it will generate harmonics and intermodulation products between two signals. For f_1 = 852 Hz and f_2 = 1336 Hz (number 8), calculate the following harmonic and intermodulation frequencies:

   $2f_1$, $2f_2$, $f_2 - f_1$, $f_2 + f_1$, $2f_2 - f_1$, $2f_2 + f_1$, $2f_1 - f_2$, $2f_1 + f_2$.

   The $(2f_1)$, $(3f_1)$, ... and $(2f_2)$, $(3f_2)$, ... are called the *harmonics* of the signals.

   The $(f_1 - f_2)$, $(f_1 + f_2)$, $(2f_1 + f_2)$, ... are called the *intermodulation products* of the signals.

Do not be surprised if you find some of these frequencies on your dial-tone spectrum

Lab Report Assignment

1. ❑ Using the measured spectrum of digit #8 in the telephone dialer, determine the harmonic/intermod. product ($nf_2 \pm mf_1$) corresponding to each of the seven measured frequencies (for example: f_1 = 852 Hz, f_2 = 1336 Hz, then 2304 Hz = $3f_2 - 2f_1$, ...). Remember the FFT and the inexpensive dialer are accurate to ± 50 Hz (or more), so your calculations need to be only correct to ± 100 Hz (or more). (This is very similar to problem #3 in your pre-lab but with real measured values.)

2. ❑ Translate the measured dB of the spectrum of #8 into V_{rms} for all the measured frequencies. Plot the following two functions (a) and (b) on the same graph. (Choose appropriate x and y-axis.)

   a) $V_1(t) = \sqrt{2}\left(V_{rms_{(f_1)}}\cos\left(2\pi(f_1)t\right) + V_{rms_{(f_2)}}\cos\left(2\pi(f_2)t\right)\right) \quad f_1 = 852\,\text{Hz}, f_2 = 1336\,\text{Hz}$

   This is the ideal #8 waveform as per your pre-lab (but with a different vertical scale).

   b) $V_2(t) = V_1(t) + \sqrt{2}$ (measured values of the five harmonics/intermod. products)

   This is the true measured #8 waveform.

   c) Now, plot $V_2(t) - V_1(t)$ on a different graph and note the peak amplitude(s).

   This is the difference due to non linearities in the speaker. Comment on $V_2(t) - V_1(t)$.