Example 13.2. Design a 3-bit R-2R DAC and use it to create a 100 Hz sine wave.

VIDEO 13.5A. DESIGN OF A SYSTEM THAT PRODUCES A 100HZ SINE WAVE

C13 5a 1 Design of an R-2R DAC

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DR. JONATHAN VALVANO: Let's build a system.

We'll use our life cycle, which means we'll

begin with the design of the system.

We'll develop a prototype.

We'll test to make sure it works, and then we'll deploy the embedded system.

DR. RAMESH YERRABALLI: So the system we are going to build

is controlled by a switch, and it's going to produce a sound, a 100 Hertz

sound, which is our sound that we are going to look at.

And we will design both the software and hardware that goes into it.

And we will use systick interrupts in the software,

and we will design a DAC as part of the hardware.

DR. JONATHAN VALVANO: All right.

Show me the DAC.

DR. RAMESH YERRABALLI: So we will take

a different approach to the DAC here.

We've seen two designs for the DAC that are possible.

One, which is a binary-weighted design.

DR. JONATHAN VALVANO: And that's the one you're going to use in lab.

DR. RAMESH YERRABALLI: And now we look at a different design, which

is called an R-2R ladder design, which is a design that a lot of the chips

have in them that produce sound.

DR. JONATHAN VALVANO: So how does the R-2R work?

DR. RAMESH YERRABALLI: So let's take a look at this R-2R ladder circuit.

As described, it's going to be a bunch of resistors

that are hooked up this way, which is--

DR. JONATHAN VALVANO: Don't talk while you're erasing.

DR. RAMESH YERRABALLI: -that are hooked this way.

We have our three signals, and we have our resistors.

And this is where we're going to connect our headphones or our speakers.

DR. JONATHAN VALVANO: So why is it called an R-2R ladder?

DR. RAMESH YERRABALLI: So the resistors that we use will be in the ratio R-2R.

So there's an R here to our 2R.

This will be a 2R.

And this is a 2R, and this is a 2R also.

And so if, let's say, we picked our R to be 11k.

And that's a good choice because of the way our voltages work.

And so the 2R is going to be simply a 22k.

So the way we are going to connect this to our microcontroller

is we have our three bits.

This is bit 2, bit 1, bit 0.

And we connect this to our bit 0.

We connect this to our bit 1, and we connect this to our bit 2.

And we connect this to the ground.

DR. JONATHAN VALVANO: So the lowest bit is furthest away from the headphones--

DR. RAMESH YERRABALLI: That is correct.

DR. JONATHAN VALVANO: -physically.

DR. RAMESH YERRABALLI: And we'll see why that's

the case once we do our computation.

Now, the analysis of this is done easily using the Principle of Superposition.

DR. JONATHAN VALVANO: So what does that mean?

DR. RAMESH YERRABALLI: So let's take a look at how superposition works.

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Solution: We begin by specifying the desired input/output relationship of the 3-bit DAC. Table 13.3 shows the design specification. It will be able to generate 8 different current outputs with a resolution of about 12.5 µA. The circuit is presented in Figure 13.13.

N	Q_2 Q_1 Q_0	I_{out} (µA)
0	0 0 0	0.0
1	0 0 3.3	12.5
2	0 3.3 0	25.0
3	0 3.3 3.3	37.5
4	3.3 0 0	50.0
5	3.3 0 3.3	62.5
6	3.3 3.3 0	75.0
7	3.3 3.3 3.3	87.5

Table 13.3. Specifications of the 3-bit R-2R DAC.

We assume the output high voltage (V_{OH}) of the microcontroller is 3.3 V, and its output low voltage (V_{OL}) is 0. A 3-bit R-2R DAC will use two R resistors (11kΩ) and five 2R resistors (22kΩ), as shown in Figure 13.13. The maximum current output will be (1/2 + 1/4 + 1/8)*3.3V/33kΩ = 87.5 μA.

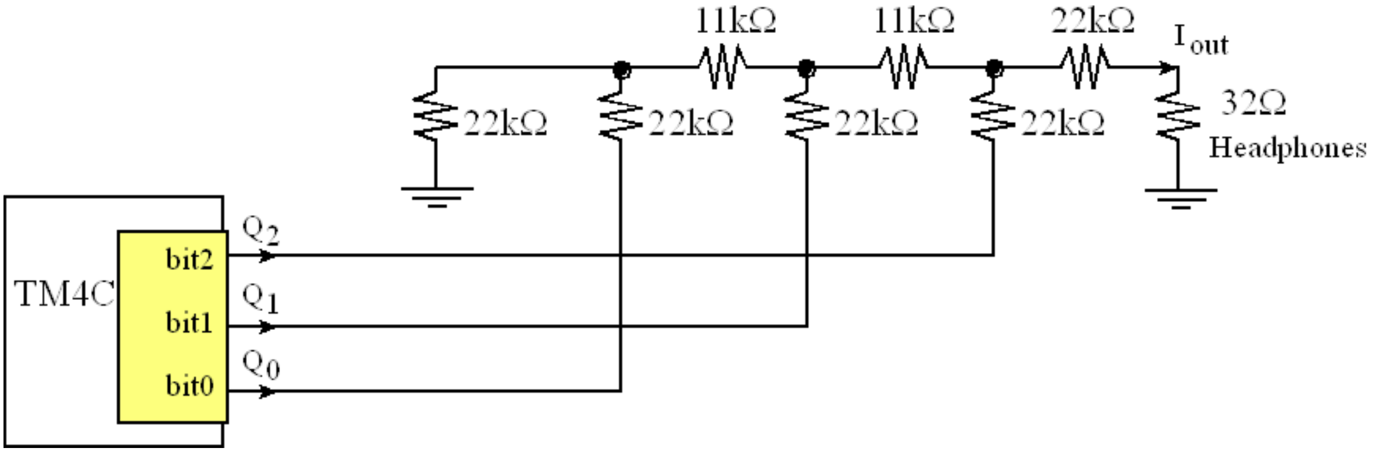

Figure 13.13. A 3-bit R-2R DAC.

The way to analyze an R-2R DAC is to employ the Law of Superposition. We will consider the three basis elements (1, 2, and 4). If these three cases are demonstrated, then the Law of Superposition guarantees the other five will work. When one of the digital inputs is true then V_{ref} (3.3V) is connected to the R-2R ladder, and when the digital input is false, then the connection is grounded. See Figure 13.14. Since 22,000 is much bigger than 32, we can neglect the 32-Ω resistance when calculating current.

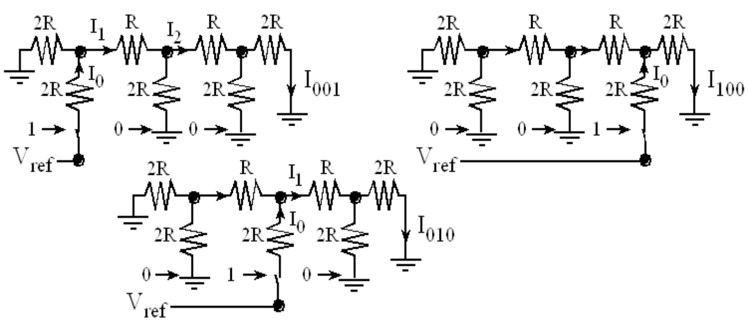

Figure 13.14. Analysis of the three basis elements {001, 010, 100} of the 3-bit unsigned R-2R DAC

VIDEO 13.5B

DR. RAMESH YERRABALLI: So let's analyze

the R2R ladder circuit

that we've used for our design.

So we have three situations here.

The three situations correspond to our bit2 bit1,

bit0, being 0,0,1, which is my first one; 0,1,0, which is this scenario;

and a 1,0,0, which is the third scenario.

DR. JONATHAN VALVANO: So the Law of Superpositions

says if we look at these three basis elements,

and prove that these three work, the other five, which

are combinations of these three will also work.

DR. RAMESH YERRABALLI: So we see that, in this circuit

here, let's analyze this one first, we see

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