VIDEO 13.3. DESIGN OF A DAC CIRCUIT

Help

12:10 / 12:12 1.0x

DR. JONATHAN VALVANO: Hey, Ramesh.

Let's build something.

DR. RAMESH YERRABALLI: OK, so let's build a DAC.

Remember what a DAC does.

A DAC is a digital to analog converter, which

means when I have my microcontroller produce a digital value,

we write to the DAC and the DAC produces an analog value.

So maybe it produces one particular value on a signal.

Some signal.

So, we want to see how to do this.

And we will do this by using this circuit for it.

There are two designs that we can do for the analog circuit.

One is a binary-weighted circuit.

The other, which is more popular in systems, is an R-2R ladder circuit.

The binary weighted design is intuitive, so we will do this first.

So our goal is to produce a signal, so

we've said.

Let's say we're working with a three bit DAC, which

means that I have eight levels.

So our precision-- so we have a three bit DAC.

We have eight levels, and the eight levels are from zero to the seven.

And we are going to write that down here- 0, 1, 2, 3, 4, 5, 6, and 7.

And we want to produce a voltage.

And let's assume our voltages are between 0 and 3.3 volts.

So we want to use an analog value-- this is our digital--

and we want to produce an analog value, Vout,

which ranges between 0 and 3.3 volts.

Well, each of these then will be a fraction of that.

So this will have a value of the 3.3 times 1 over 7.

This will be 3.3 times 2 over 7, and so on.

So when we get here, it'll be 3.3 times 7 over 7.

That will be my voltage.

So that's my behavior that I want to get.

DR. JONATHAN VALVANO: So what's the resolution of this DAC?

DR. RAMESH YERRABALLI: So, as we see the smallest change we can capture

is a difference between consecutive values, which in our case

is 3.3 divided by 7.

So our resolution delta is 3.3 divided by 7.

And our precision, again, is eight.

So that's the design we're looking for.

So let's design this.

So again, here is our schematic, microcontroller.

And we're going to use three bits for now.

It doesn't matter.

I'm going to call them bit two, bit one, bit zero.

So this is our bit two, bit one, and bit zero.

So, we're going to use the three bits, and we're

going to produce our output, which is

going to be our Vout.

And the way we're going to do that is we're going to connect resistors.

And we make an observation that each of these bits-- this bit

has a position of one, this bit has a position of two,

and this bit has a place significance, or place value of four.

So when we choose our resistors, we will choose them

in that ratio, which is 4 is to 2 is to 1.

So we will use the-- bit two will have 11 K, we'll have 22 K here,

and this will be a 44 K

DR. JONATHAN VALVANO: So which one is twice as much as the other one?

DR. RAMESH YERRABALLI: So bit zero is-- remember

that bit zero has a place value of one.

So the resistance, that is, whatever signal comes out of here for a one

has half the significance as bit one.

So in order to do that, we subject it to a higher resistance.

And so the lower the significance, the higher the resistance.

So bit two has the highest significance, so it has the least resistance, which

is 11 K. And notice the ratio between these three is 11 is to 22

is to 44, which is 1 is to 2 is to 4, which is exactly what we want.

So let's analyze this circuit to see how it behaves.

So let's take our table again.

This is our N. This is the bit values.

And I'm going to represent them by Q2, Q1, and Q0,

which is basically what I see here.

Q2, Q1, and Q0.

So, if I have zero, this is a 0, 0, 0, and this is my Vout.

Now if I have an N value of one, then what I have is 0,

0, 1, which makes this a 0, this a 0, and this

is a 3.3 volts-- I'm going to make because I have a one here.

And similarly, I have a two, which is a 0, 1, 0,

so that's 3.3, and 0, and three which is 0, 3.3, and 3.3, and so on.

And I'm just going to write one more.

Four, which is 3.3, 0, and 0.

And so on, all the way up to seven, which is all three bits

are on- 3.3, 3.3, and 3.3.

So we'll calculate how our Vout is.

So first, I'm going to do an analysis for one of these.

So let's do an analysis of our four.

So the circuit for this situation is we have a 3.3 here, a 0 here, and a 0

here, which gives us a equivalent circuit-- I'm

going to draw the equivalent circuit here, which is our 11K with a 3.3.

And we have these two, which are in parallel,

and they connect to our zero volts.

Help

And we want to find out what Vout is.

And Vout is with respect to zero, so we want to find out this voltage.

So if I were to convert this-- and remember these are 22 K,

and this is a 44 K. So if I were to convert this,

the equivalent circuit looks like this, where I have 22 times 44.

Remember these are in parallel by 22 plus 44, which

gives me a value of 44 by three kilohms.

OK, so I have 44 by 3 here, and I have 11 K

they are in series, and what I have is a voltage divider.

So I know that Vout is going to be given by a value, which

is 44 by 3 divided by 11 plus 44 by 3 times 3.3, which comes out

to be 4 over 7 times 3.3.

So that's my 4 over 7 times 3.3.

Now it's a good idea to do one where-- there are two of them that have a one.

So let's take this example of three, which says now my equivalent circuit is

going to be one where I have a 0 here, a 3.3 here, and a 3.3 here.

So now I have this circuit, which is my 0.

And I'm going to draw it this way-- let me clear it.

So the equivalent circuit is this, where I have my two resistances, which

are 22 K and the 44 K, which are in parallel with 11 K.

And 11 K is at 0 volts.

One end of it is at 0 volts, and this is my 3.3 volts,

and I want to find out what the voltage here

is, which is my Vout, which, by the way, is

the voltage across the resistance, 11 K.

So, again, my circuit is similar because we already calculated it.

So this is a 44 by 3, this is 11 K, and this is my V out,

and that's 3.3 and 0 volts.

And so it's a voltage divided.

But now my Vout is given by 11 divided by 11 plus 44

by 3 times 3.3, which gives me a 3 over 7 times 3.3 volts, which

is 3 over 7 times 3.3 volts.

So similarly, we can fill in the rest of my analysis.

So this is a three bit DAC using a weighted design.

DR. JONATHAN VALVANO: So Professor Yerraballi, what will they do in lab?

DR. RAMESH YERRABALLI: So in the lab, you will take this idea of the design

and extend it to four bits, which means that you will add an extra bit, which

is B3, and you will make a four bit DAC, which

will be much better, because it'll be better

at more levels, more precision, more resolution.

Therefore, when we hook it up to a sound,

you can produce really high quality sound.

DR. JONATHAN VALVANO: Ah, sweet.

A DAC converts digital signals into analog form as illustrated in Figure 13.2. Although one can interface a DAC to a regular output port, most DACs are interfaced using high-speed synchronous protocols, like the SSI. For more information about SSI, see Embedded Systems: Real-Time Interfacing to ARM® Cortex™-M Microcontrollers, 2013, ISBN: 978-1463590154. The DAC output can be current or voltage. Additional analog processing may be required to filter, amplify, or modulate the signal. We can also use DACs to design variable gain or variable offset analog circuits.

The DAC **precision** is the number of distinguishable DAC outputs (e.g., 16 alternatives, 4 bits). The DAC **range** is the maximum and minimum DAC output (volts, amps). The DAC **resolution** is the smallest distinguishable change in output. The units of resolution are in volts or amps depending on whether the output is voltage or current. The **resolution** is the change in output that occurs when the digital input changes by 1. For most DACs there is a simple relationship between range precision and resolution.

Range(volts) = Precision(alternatives) • Resolution(volts)

Help

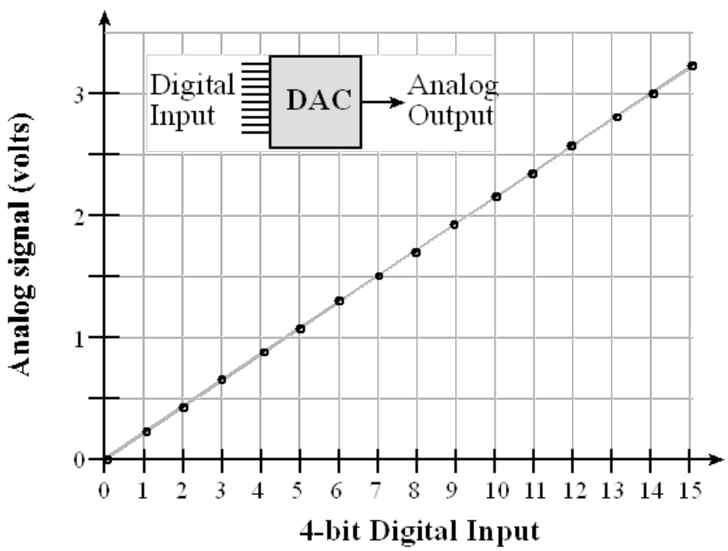

Figure 13.2. A 4-bit DAC provides analog output.

The analog output is fixed in the range 0 to 3.3V. You may adjust the number of bits from 1 to 10 to see how close the fit is to the straight line.

To learn more about DAC precision with an interactive tool, please visit:

http://users.ece.utexas.edu/~valvano/Volume1/E-Book/C13_DACSound.htm#ITool13.2 (http://users.ece.utexas.edu/~valvano/Volume1/E-Book/C13_DACSound.htm#ITool13.2)

The DAC **accuracy** is (Actual - Ideal) / Ideal where Ideal is referred to the National Institute of Standards and Technology (NIST). One can choose the full scale **range** of the DAC to simplify the use of fixed-point math. For example, if an 8-bit DAC had a full scale range of 0 to 2.55 volts, then the resolution would be exactly 10 mV. This means that if the DAC digital input were 123, then the DAC output voltage would be 1.23 volts.

CHECKPOINT 13.5

A 10-bit DAC has a range of 0 to 2.5V, what is the approximate resolution?

Hide Answer

2.5V/1024 is about 0.0025 V or 2.5 mV.

CHECKPOINT 13.6

You need a DAC with a range of 0 to 2V, and a resolution of 1 mV. What is the smallest number of bits could you use for the DAC?

Hide Answer

2V/1mV is 2000 alternatives. This is about 11 bits.

Help