The Brilliant Light Bulb

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Objective:
Prove that the ordinary light bulb (incandescent lamp) has a brain.

Equipment:
- Agilent 54600B Oscilloscope with GPIB or RS-232 module
- Agilent 33120A Function/Arbitrary Waveform Generator
- Agilent BenchLink/Suite Software
- Personal Computer with GPIB or RS-232 card and cable
- 14v / 0.12A bayonet based lamp (type #53) , with base, or 14v/ 0.06 A lamp
  (Important: lamp must be close to the above value, since output power of Agilent 33120A is limited)

Exercise I: How fast are our eyes?
Set the function generator to: Frequency: 4 Hz; Zout=50 Ohms, Amplitude: 10v p-p. Connect the Agilent 33120A directly to the light bulb. Notice that the light bulb blinks off and on.

Question: Now raise the frequency of the function generator until you can no longer see the light bulb blink (i.e., lamp's glow appears steady). Record the value of the frequency above which the blinking stops.

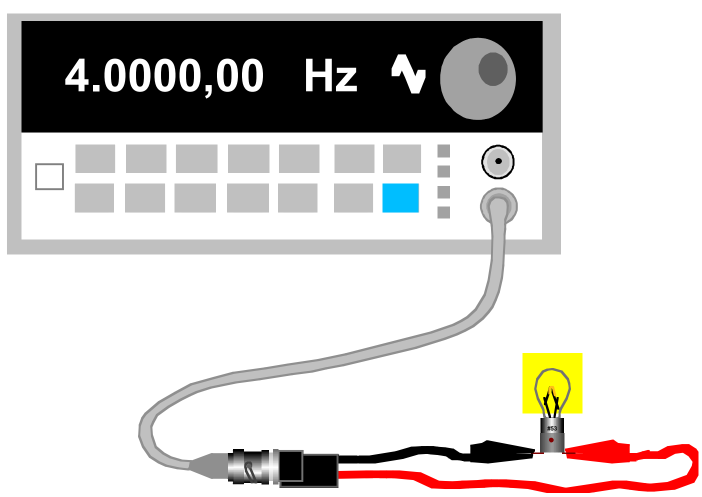

FIG 1: Lamp flickers with a 4 Hz sine wave.

Write the answer: My eye can no longer see the lamp flicker when the frequency of the driving sine wave goes above _________ Hz. (A)

Now lower the function generator's sine wave frequency to 1 Hz. Look at the lamp. Does it appear to be blinking at a 1 Hz rate or a 2 Hz rate? **What's happening?**

Exercise II: The SINE/SQUARE puzzle

Now let's try a puzzle. Create a unique waveform… one consisting of a set of sine wave cycles followed by an equal set of square wave cycles, both of the **same** peak-peak amplitude. If we can set this waveform such that the number of zero-crossings is identical to the sine wave we used earlier, then we should expect the lamp to stop flickering at the equivalent of a 15-16 Hz rate. Right? **What do you predict?**

My Prediction:

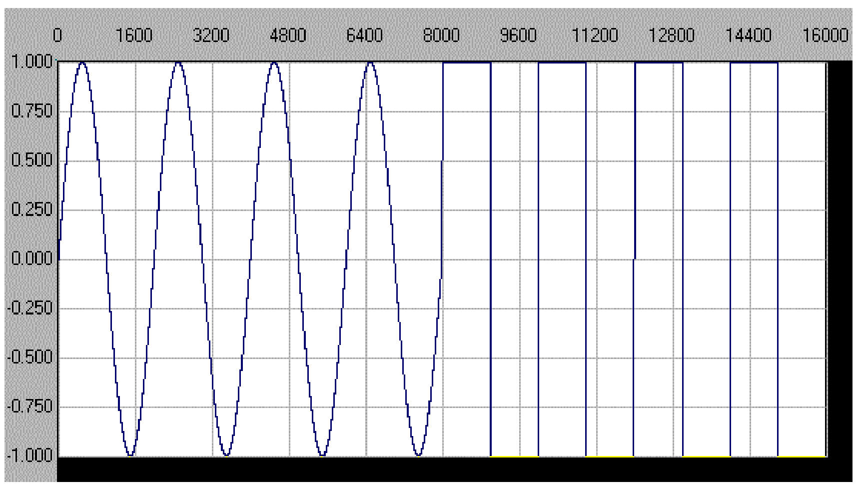

FIG 2: BenchLink screen of arb. with 4 sine cycles followed by 4 square cycles. (named SINSQ100)

Download an Arbitrary Waveform: Use a PC with BenchLink/Suite software and an GP-IB card, connect an GPIB cable to the Agilent 33120A Function/Arb Generator. From the main page of BenchLink/Arb software, create a waveform by clicking 4 times in succession on the sine wave icon, then 4 times on the square wave icon. Using I/O "Download Waveform" and "Non-volatile Memory", designate this waveform's name as "SINSQ100" and download it to the Agilent 33120A.

Connect the Agilent 33120A output directly to the lamp.
Set the Agilent 33120A AMPLitude to 10Vp-p, FREQuency = 5 Hz
Choose SHIFT / ARB LIST. Turn the knob, and touch ENTER when you see the SINSQ100 waveform that you downloaded.

*[IMPORTANT: Remember that since we have 8 total cycles in the arbitrary waveform (4 sine waves followed by 4 square waves), the function generator will reproduce this entire waveform 5 times/second, so the apparent frequency seen on the scope will be about (4+4)*5Hz = 40 Hz.]*

Set the oscilloscope to measure frequency automatically. To do this, first you'll have to externally trigger the scope from the Agilent 33120A. Hook the SYNC output from the Agilent 33120A to the EXT TRIG input on the Agilent 54600 scope. With the SOURCE button on the scope, select the softkey for EXT. You should see a steady waveform on the oscilloscope display.

Now select the TIME button under MEASURE on the scope. Hit the soft key labeled "Freq". The oscilloscope will now measure frequency "on the fly".

With the Agilent 33120A still set to 5 Hz, the oscilloscope should indicate approximately 40 Hz. *Notice that for each 1 Hz set on the Agilent 33120A, the scope indicates 8 times that frequency. This is correct, since the Agilent 33120A treats each arbitrary waveform as a single cycle, and we have programmed the arbitrary waveform to contain 8 cycles (4 sin and 4 square).*
So the lamp is "seeing" a waveform that is changing at a 40 Hz rate. Notice what's happening to the lamp. Is it flickering? Increase the frequency on the function generator until the lamp stops flickering. **What is that frequency, as indicated by the oscilloscope?**

Frequency shown on oscilloscope (number of full cycles of either the sine wave or the square wave) above which lamp stops flickering: _________________ Hz.

**How does this frequency compare with the first measurement (A).
WHY?**

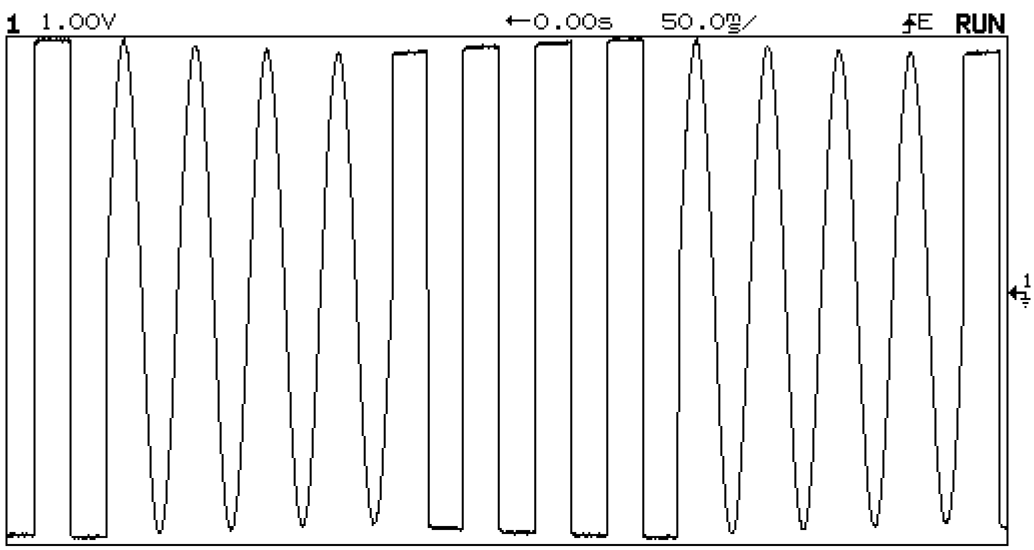

FIG 4: SINSQ100 Scope Display with equal amplitudes of sine and square waves set on arb.

There are two phenomena occurring here. First, the lamp is flickering. Second, the waveform appears to "grow" when it's a square wave and "shrink" when it's a sine wave. What's going ON?

Maybe we can explain it with a different arbitrary waveform:

With a new screen on the BenchLink/Arb software, start a new waveform by using the icons to generate four identical sine waves in a row and four square waves, just as before. But this time, mark all the square waves with the mouse and use "MATH RESIZE" to change the amplitude from 2 V p-p to 1.414 V p-p. The waveform should look something like FIG 5.

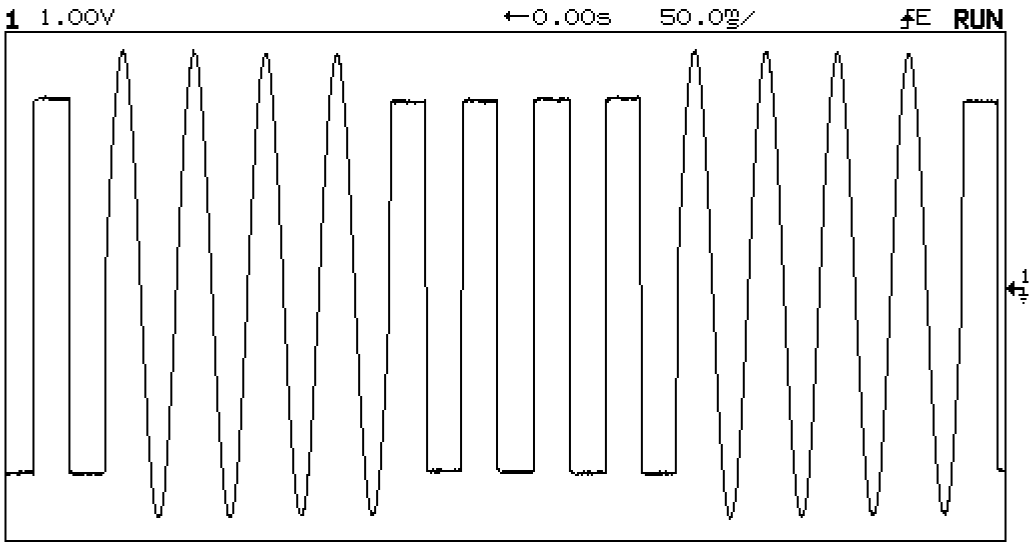

FIG 5: SINSQ707 Square wave amplitude (p-p)= 0.707 X Sine wave (p-p) amplitude

Now send the new waveform to the Agilent 33120A by using I/O ; SEND WAVEFORM. Before you send it, key the "Non-volatile Memory" button under the SEND WAVEFORM screen to give the waveform a name. Call it SINSQ707. This name will now appear on the function generator whenever you call it from the ARB menu.

Hit OK to download the waveform. Select the new waveform SINSQ707 with the function generator's ARB LIST. What happens? **Is the lamp still flickering? WHY or WHY NOT?**

THE ANSWERS: JUST ASK THE LAMP.
So what's happening here? It's obvious. The filament has a brain. A little genie in the lamp KNOWS to take the square root of the integral of the squared value of the waveform. The light bulb understands calculus! If a light bulb can learn calculus, anybody can learn calculus!

You're not buying that? Ok, what's your explanation?
The oscilloscope indicates a flicker at a much higher frequency because…

Exercise III: The "Modulated" waveform.

What about the "growing" square wave in FIG 4? Why does the waveform in Fig 5 appear to be more stable.
My explanation: Although I "told" the Agilent 33120A to generate sine and square waves of equal, constant amplitude, the amplitude in Fig 4 appears to be changing during each repetition period.
My reason is:

____

____

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Exercise IV: Lamp Resistance

Technically, Equation 1 above is incorrect. The value of R is not a constant. It changes with power. We assumed all along that the resistance of the lamp was constant. But the resistance of a filament is very nonlinear and therefore not constant with power, so we have to measure it at its operating point.

Think of a way to measure the lamp's resistance.
[Hint: With the Agilent 33120A and the scope, we have everything we need to make the resistance measurement.] Lamp resistance at 20 Hz repetition rate, 10 Vp-p: _______ Ohms.
[Note: 10 Vp-p setting is with Agilent 33120A output impedance set to 50 Ohms.]

Exercise V: How Sensitive are our eyes to Power Changes?

TRY THIS:
See if you can tell how sensitive the lamp is to different values of RMS voltage. Construct a waveform where the square wave is 0.8 times the Vp-p of the sine wave. Does the filament still flicker?

Conclusion: It's remarkable how the eye can pick up even a small difference in the RMS value of the waveforms.

Exercise VI: Following the Waveform

With any of the complex waveforms (SINSQ707, SINSQ800 OR SINSQ100), change the frequency of the Agilent 33120A so it displays about 0.5 Hz. Notice what happens to the lamp. Explain what you see.

Exercise VII: Measuring RMS

Let's verify the RMS value of the waveform by using the DMM and the oscilloscope's VRMS capability. Using the SINSQ707 waveform (square wave peak = 0.707 x sine wave peak), measure the RMS value with the AC function of the DMM. Ours came out 4.42 volts on the Agilent 34401A.

Now let's do the same on the scope. Select the VOLTAGE key and measure VRMS with the softkey.

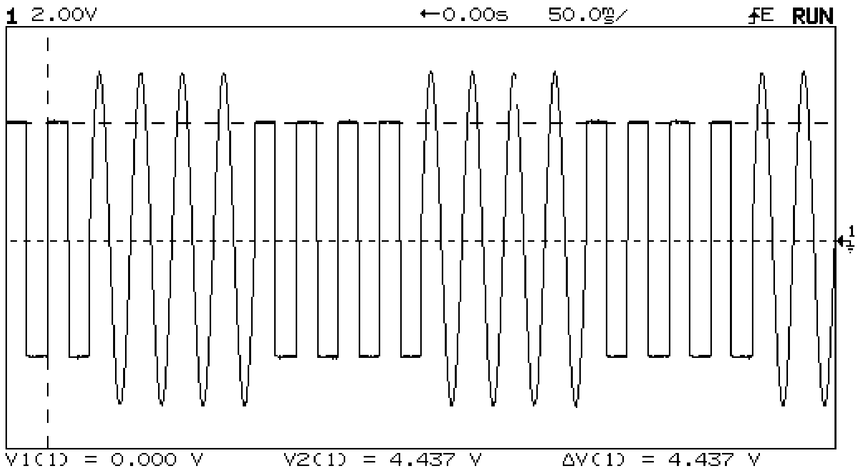

FIG 6: Measuring the peak value of the square wave.

It should be somewhere near the number we saw on the Agilent 34401A; that is, about 4.4 volts.

Now let's look at the square wave part of the waveform. Using the voltage cursors on the Agilent 54600B oscilloscope, we see something like FIG 6. As we expected, the delta from V1(1) to V2(1) is 4.437 volts--- very close to the 4.42 volts we measured with the Agilent 34401A

Light Bulb Trivia: 

Someone who is really into light bulbs will tell you that it's really a "lamp". The "bulb" is just the glass part.

The resistance of a tungsten lamp is not linear. It increases as the 3/2 power of the voltage.

The lifetime of a tungsten lamp decreases as the 13^{th} power of the voltage!

Think of the lamp as a transducer: It converts electrical power to heat and light. There are a number of transducers that do the opposite:

The bolometer is a device that converts radiated energy to a change in resistance. It is used as an rf power transducer.

The thermopile, a group of thermocouples placed in series and mounted to a black body, is similar: Put an ac signal into a heating element that drives the thermopile, and it produces a dc signal that is nonlinearly proportional to the ac input. Use a differential amplifier with a pair of matched thermopiles and a dc reference, and you can build an accurate, very high bandwidth ac-to-dc converter.

EXPLANATIONS

Explanation for Exercise I

If we look at the actual INSTANTANEOUS power in the lamp:

$p = (v \wedge 2)/R$, where p and v are instantaneous values of Power and Voltage.

[Equation 1]

If *v*= sin wt
then *p*= (1/R)(sinwt)^2 = (1/R)(_- _*cos2wt)

Each time the voltage reaches a peak, whether the peak is positive or negative, the power peaks. So the power waveform is twice the frequency of that of the driving voltage. That means the lamp flickers at twice the driving frequency in (A) above, and this higher frequency is what we can resolve with our eyes.

In other words, if we drive the lamp with a 15 Hz sine wave, and this is the frequency at which we can no longer see the flicker, then our eyes can actually detect a lamp that is flickering in intensity at a 30 Hz rate.

Explanation for Exercise II: The SINE/SQUARE Puzzle

There are two phenomena occurring here. First, the lamp is flickering. Second, the waveform appears to "grow" when it's a square wave and "shrink" when it's a sine wave. What's going ON?

The RMS value of a waveform corresponds to its heating value, and the waveform in FIG 1 has two different RMS values, hence two different heating values. Although the two waveforms have the same peak voltages, their RMS voltages differ by a factor of 1.4. **That translates to a power difference of 2X.**

If we look at the RMS values of the two waveforms:
Sine Wave RMS value = 0.707 x Vpeak.
Square Wave RMS value = 1 x Vpeak.
Power = (V^2)/R

Assume the lamp's hot resistance is about 90 ohms and that Vp-p of the full waveform is 20 V. Then..

Sine RMS = 0.707 x 10 = 7.07 volts. Power = 50/90 = 0.56 watts
Square RMS = 1 x 10 = 10 volts Power = 100/90 = 1.11 watts

It suddenly becomes clear exactly why the lamp is flickering. It's a function of the repetition rate of the two waveforms. The waveform SINSQ100 effectively changes from a sine to a square wave of equal Peak-Peak magnitude every 200 milliseconds, so the RMS Power delivered to the lamp differs by 2X every 200 milliseconds, and we see a flicker rate of 5 Hz. If we load the SINSQ707 waveform, the two sections of the waveform, Sine wave and Square wave, have identical RMS values, and the flicker disappears.

Explanation for Exercise III: The "modulated" appearance of the Sine/Square waveform

As all good function generators do, the Agilent 33120A has a 50 ohm resistor in series with the output. [Note 1]. This 50 ohm resistor in series with the lamp makes a voltage divider. As the lamp heats up, its resistance increases [Note 2]. The voltage division ratio is being changed by the lamp resistance, and the oscilloscope is showing us that phenomenon by letting us see the square wave "grow". When the sine wave begins, the lamp starts to cool and the resistance goes down, causing the sine wave to "droop" or "shrink".

Note 1: At high frequencies, the 50 ohm output impedance minimizes ringing and reflections. RF circuits are designed to be connected with cabling that has 50 ohms of characteristic impedance.

Note 2: This phenomena is useful in measuring temperature… a Platinum RTD is nothing more than a piece of platinum wire whose resistance increases with increasing temperature. All metals have a positive temperature coefficient of resistance.

<u>Solution to Exercise IV: How to compute the resistance of the lamp:</u>

The lamp forms a voltage divider with the function generator's output resistor. If we simply set the generator to 20 Vp-p at some reasonable frequency, say 50 Hz, we can measure the voltage across the lamp and compare it with the function generator's output. It is then a simple matter to compute the lamp resistance. In our case, we measured 12.63 Vp-p across the lamp.