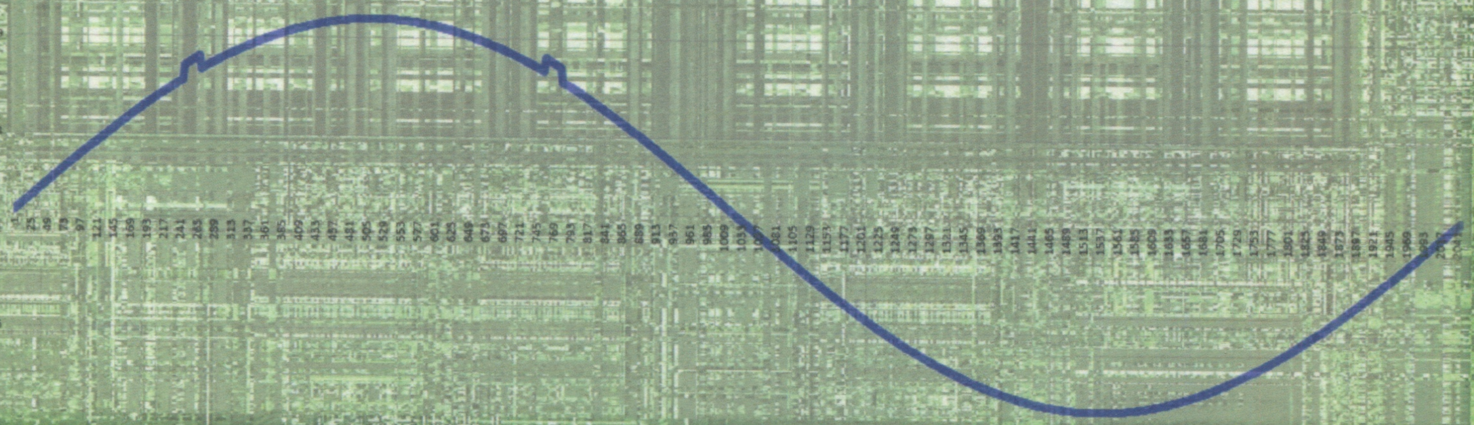
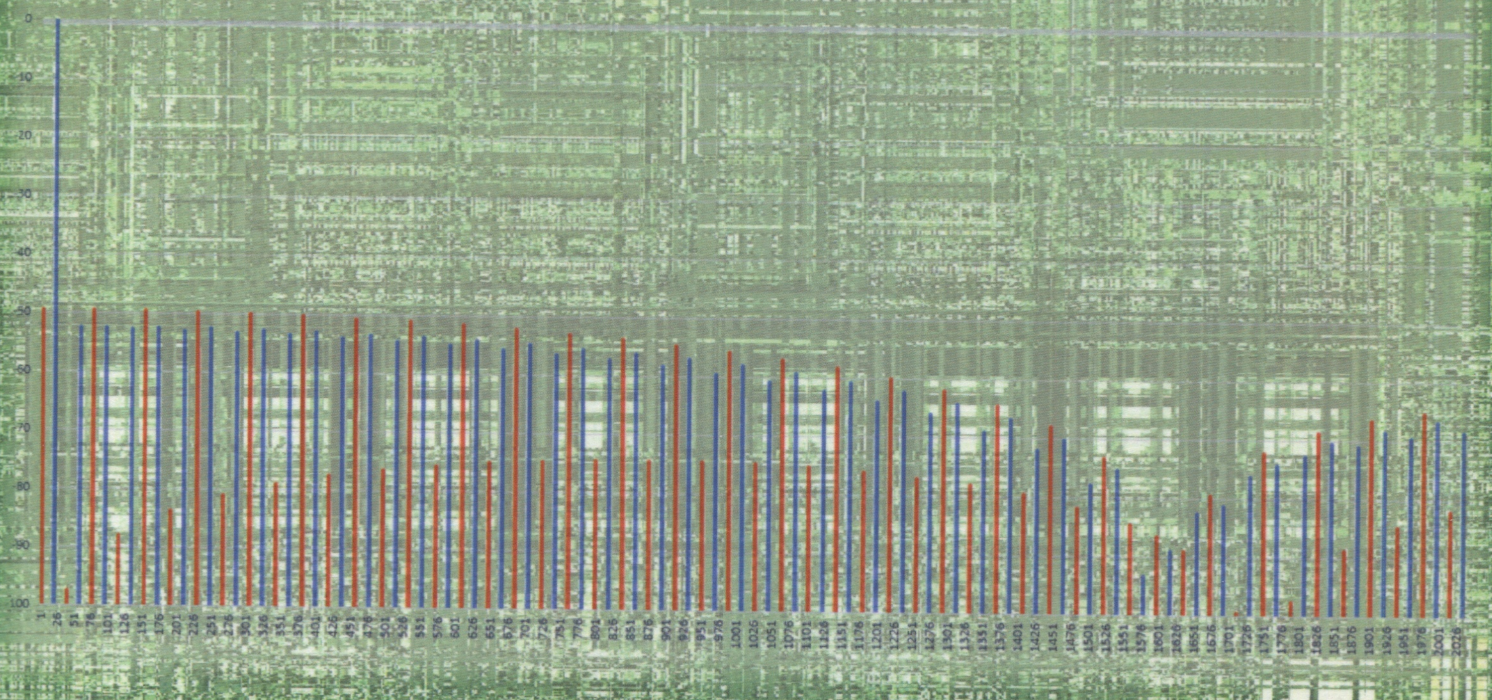
# Distortion



## The Cause Of Harmonics and the lie of THD



Dan P. Bullard

"This book shows a determination for answers, truth, and solutions, and provides them. Dan has given much effort and time to provide needed answers to outdated guidelines on how this area of research and industry approaches these issues. *Distortion* is a piece of true scientific research. The author shows a decided effort to help you to understand and comprehend exactly what the research is questioning, what it hopes to resolve. and invites you to see for yourself. It is outlined, graphed, detailed, and explained very well. Dan has done an exceptional piece of work."

— Brent David Cartwright

Where do harmonics come from? Distortion, right? But *how*? What creates harmonics? What kind of distortion causes *which* harmonics? Is there any way to reconcile a good THD spec but poor quality sound? Is THD, a specification derived in the 1950s, really the right way to assign a stamp of quality to an electronic product designed and produced 60 years later? This book answers all those questions to show that your professors lied to you. They had no answer to the question of where harmonics come from other than *Distortion*.

ISBN 9781511628457

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# Introduction

## Harmonics - A misunderstood phenomenon

Harmonics are the bane of most engineers. When stimulated by a sinusoid, a perfectly linear electronic circuit should output a sinusoid with no additional harmonic content. Everyone seems to know this, but the source of the harmonics in a non-perfect circuit seems to elude us. What causes the harmonics to form? What circuit faults cause which harmonics? Can I forgive a non-linearity knowing that the harmonics created will not impact my application? If I see harmonics can I get a clue to the problem I face from the *harmonic signature*?

Most texts on the subject make generalizations that are not very helpful. In Audio Precision's 1992 book *The Audio Measurement Handbook,* which I skewered in my YouTube video Audio Quality and Total Harmonic Distortion[1] the statements are made that:

"non-linearities which are not symmetrical around zero produce dominantly even harmonics" and

"non-linearities which are symmetrical around zero produce odd harmonics"

Both of these statements are wrong (for different reasons), and my video proved this. Other books dealing with the topic are similarly flawed and vague, a bad combination for some poor soul working late into the night trying to figure out how to fix a high THD failure in his circuit.

This book will show you exactly how harmonics are created by non-linearities, which commonly found non-linearities create which harmonics, and how a harmonic signature can be interpreted to correctly assign blame to particular non-linearities allowing the user to spend his time wisely in identifying and fixing non-linearities in his circuit.

The information in this book was gleaned from experiments performed with an Excel spreadsheet that replicates the function of a sinusoid applied to a theoretical transfer function that can be manipulated at will, as well as years of working with real electronic circuits and various DSP based tools during my long career in electronics.

Throughout the book you will find links you can click on with your E-reader, which is one reason I published this as an E-book as well as a print book. If you are reading the print book, select hyperlinks are listed at the bottom of the page as footnotes (see below). Text is nice, but I have gone to a lot of trouble creating videos that can say more in a few seconds than hours of reading, so please take advantage of these links while reading this book. Throughout the book it is assumed that you have, at the very least, watched the video listed in the footnote below, for this video holds the key to this very interesting story of discovery—the story of how I figured out how harmonics are created. Join me now and prepare to be permanently changed by this journey.

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[1] http://youtu.be/CHfeMGQC6WI

addition to the always present **odd** harmonics (1st, 3rd, 5th, etc). As mentioned in "A note on graphics" above, I will color code the words **odd** and **even** in this book to help you identify the harmonics in the graphs that follow.

You cannot have **even** harmonics without **odd** harmonics. The reason is simple. The fundamental is always the 1st harmonic, and as you might have figured out, the number 1 is **odd**!

There is one way to generate a waveform that consists of only **even** harmonics (sort of), and that is to perform full wave rectification of a sinusoid. Most engineers remember the old full wave rectifier analog power supply.

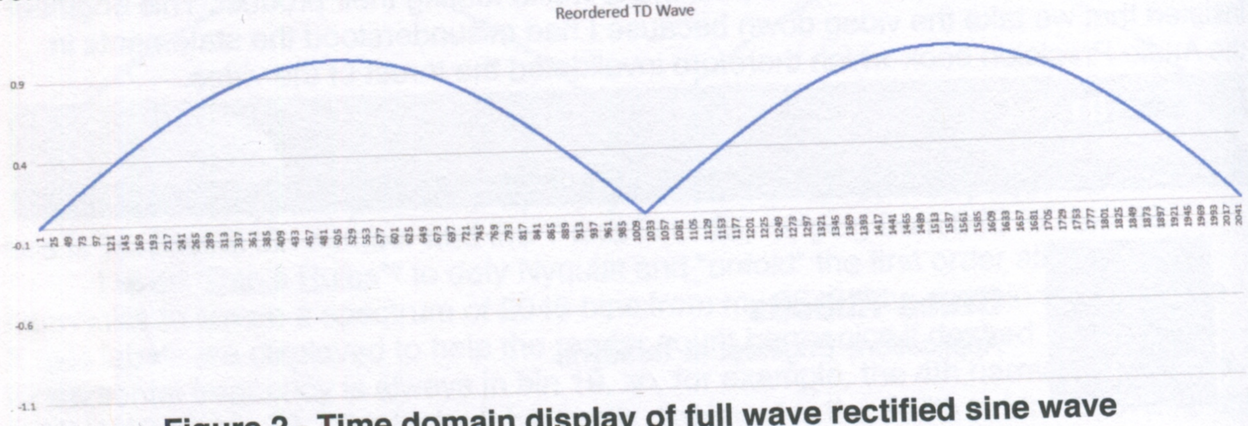


**Figure 2 - Time domain display of full wave rectified sine wave**

In most cases, a diode bridge converts the negative half cycle of the incoming line frequency to a positive half cycle, utilizing diode steering to get two positive half cycles which yield a positive output voltage. The advantage of this circuit over the half wave rectifier is that the frequency of the line input is doubled, making it easier to filter out the alternations to provide a nice smooth DC output with smaller capacitors and inductors. Linear power supplies are well known for their large size and bulk partly because 60 Hertz is such a low frequency. Airplanes replace 60 Hertz AC with 400 Hertz AC which is easier to filter using lighter inductors. However you would be hard pressed to note the improvement when you hear a PA announcement from the pilot because you can often hear the 800 Hertz ripple on the PA system overlaid on top of the pilot's voice.

Now for the spectrum of the full wave rectified wave above:

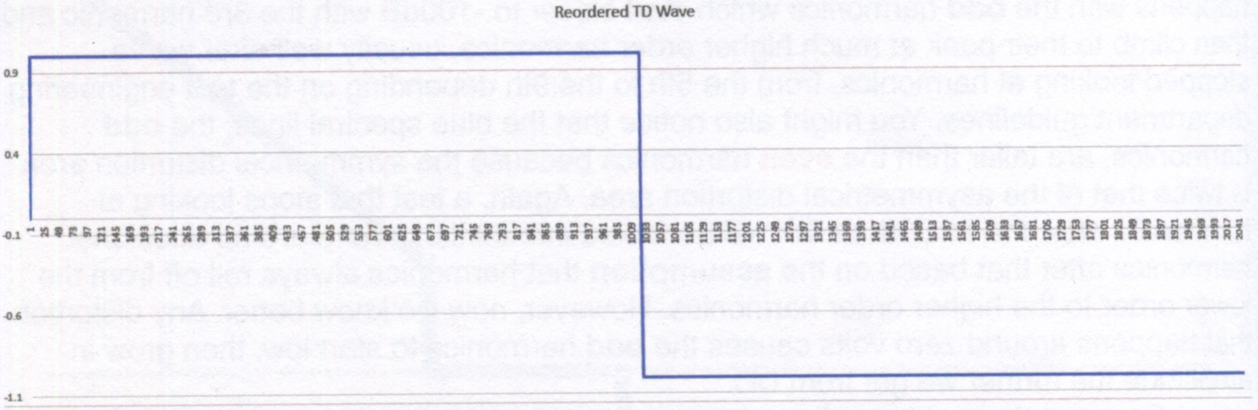


**Figure 10 - Time domain display of 50% duty cycle square wave**

Do an FFT on it. What do you get?

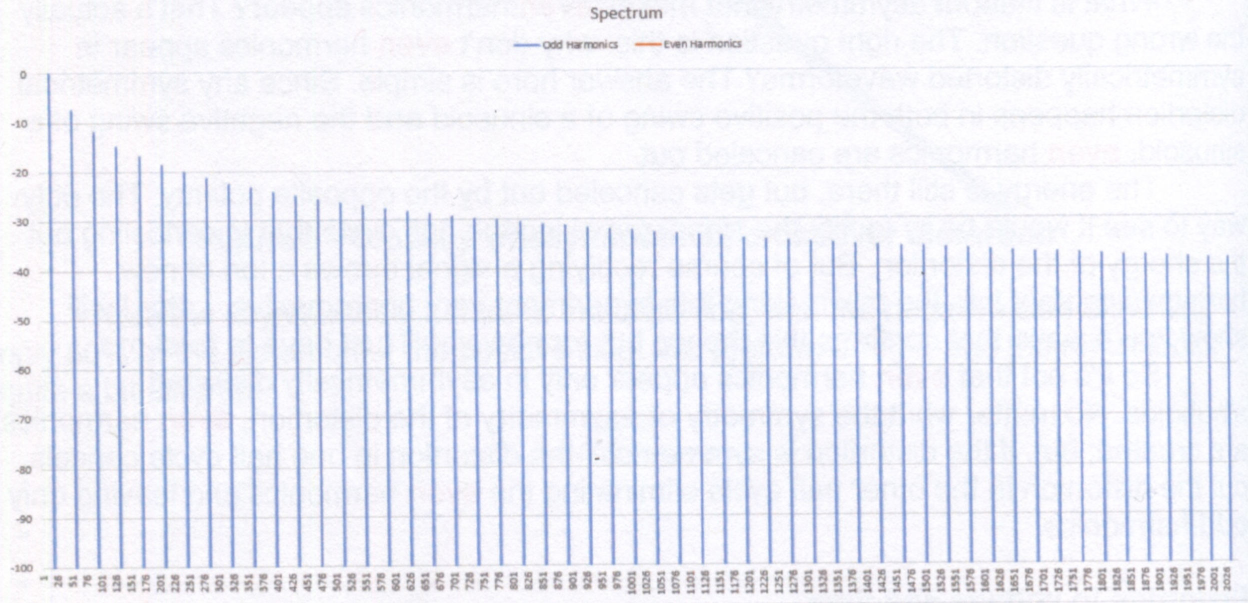


**Figure 11 - Spectrum of 50% duty cycle square wave**

You get only **odd** harmonics with amplitudes of 1/harmonic# relative to the fundamental. Note that the above graph shows amplitude plotted in dB, so the scale might not match your expectations. So, if the fundamental amplitude is 1V, the third harmonic would be 1/3rd or 0.333333V, the fifth harmonic would be 1/5th or 0.2V, the seventh would be 1/7 or 0.142857V and so on. There will be no **even** harmonics visible, although now we know they are there, but they are canceled out by the symmetry of the distortion (extreme clipping).

Now, change the duty cycle to 51% (or 49%, makes no difference). What happens?

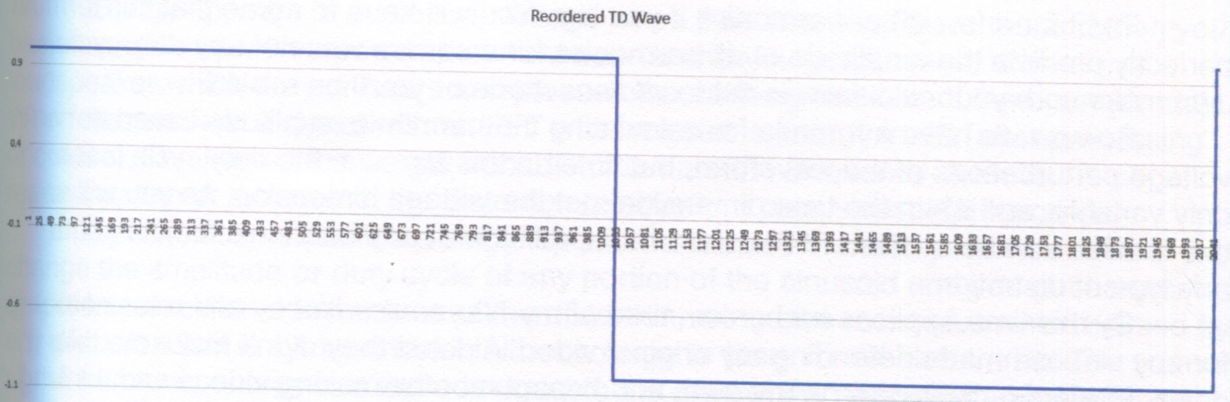


**Figure 12 - Time domain display of 51% duty cycle square wave**

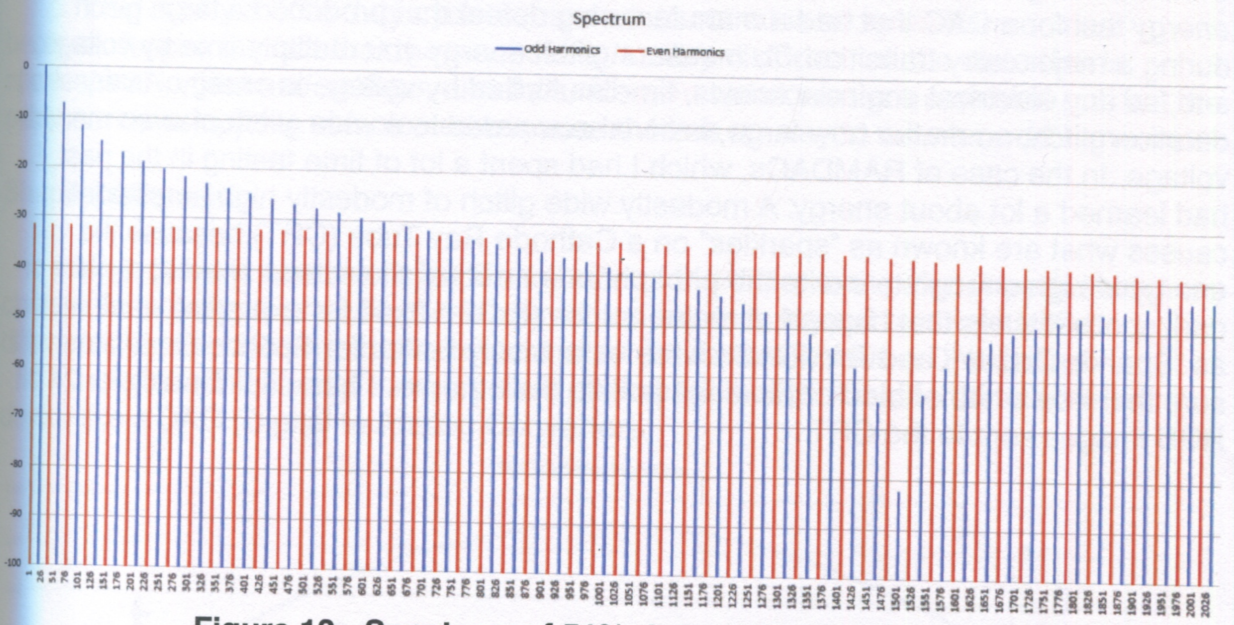


**Figure 13 - Spectrum of 51% duty cycle square wave**

Suddenly **even** harmonics appear (again, in red). But that makes no sense because the implication in the Audio Precision book (and others) was that **even** harmonics only appear with asymmetries in **voltage**; but, a square wave has only two voltage states, 1 or 0, plus or minus, and whatever the actual levels are, there is no voltage variation in a square wave.

So the asymmetry that allows **even** harmonics to appear does not just apply to voltage, but to *time* as well. In fact, the formula for predicting the harmonic content of a square wave is;

**VHarmonic = abs(sin(π*Harmonic#*Duty_Cycle))/Harmonic#**

Duty cycle is calculated as High_Time/Total_Time, so if we calculate the amplitude of the third harmonic relative to a fundamental amplitude of 1.0 we calculate;

**VHarmonic = abs(sin(π*3*0.5)/3) = 0.33333333**

But when we calculate the amplitude for an **even** harmonic, like the 2nd;

**VHarmonic = abs(sin(π*2*0.5)/2) = 0.0**