

**A Description of  
Pulse Width Modulation  
Motor Control  
for  
Model Locomotives**

Covers all NCE N-Scale through O-Scale decoder models  
with version numbers from 1.0 - 2.9

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## HOW MOTOR SPEED IS CONTROLLED BY A DECODER

Most DCC decoders control motor speed by using what is called Pulse Width Modulation or **PWM**. Pulses of voltage are sent to the motor to make it run slower or faster depending upon the width of the pulse. The pulse width determines the amount of power supplied to the motor which in turn determines how fast the motor will run. A short pulse runs the motor slowly, longer pulses cause it to run faster. Ultimately, at top speed the pulses grow so long that they run together and become pure DC voltage.

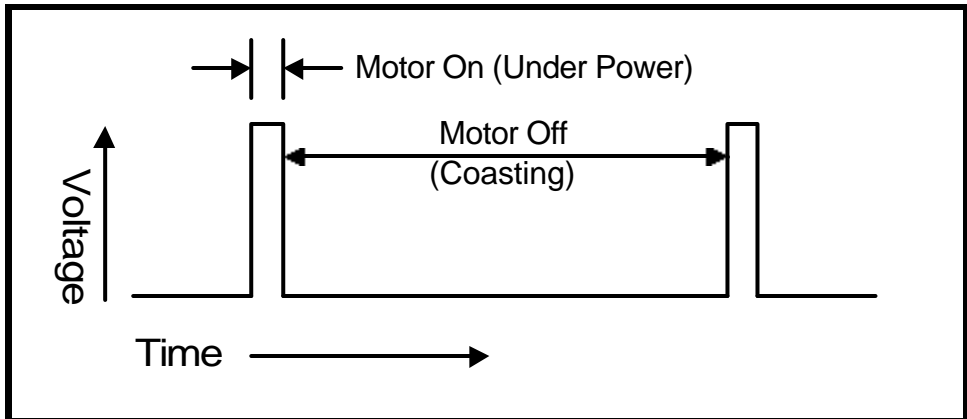


Figure 1

**Figure 1** shows the voltage supplied by a decoder running a motor slowly. As you can see the motor is getting power only a very small percentage of the time. The pulses are supplied to the motor at a fast enough rate so that the motor will coast between pulses giving the appearance of continuous smooth

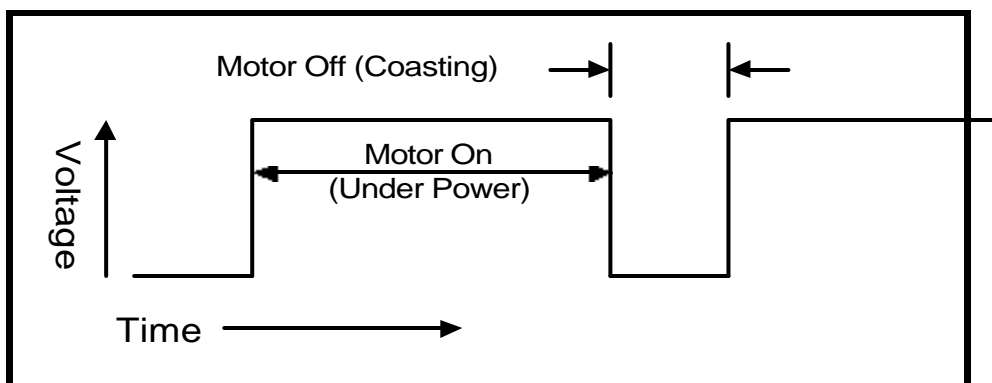


Figure 2

operation.

**Figure 2** shows a motor being run at a much higher speed. Power is being supplied to the motor a large percentage of the time. The motor spends much less time coasting and more time being driven so it runs faster.

## FREQUENCY

The rate at which pulses are repeated is called the **frequency** of the PWM. Frequency is expressed in cycles per second, or using the more modern term, "Hertz" (abbreviated Hz). Frequency is determined by simply dividing 1 second by the **period** (pulse rate). NCE™ decoders come preset from the factory with a period of .014 seconds.

Using the formula: 1 divided by .014 = 71.428 Hz

This is a frequency of just about 71 Hz. Pulses are sent to the motor at a rate of about 71 times per second. Generally speaking for model railroad use, frequencies between 30 and 200 Hz are useful.

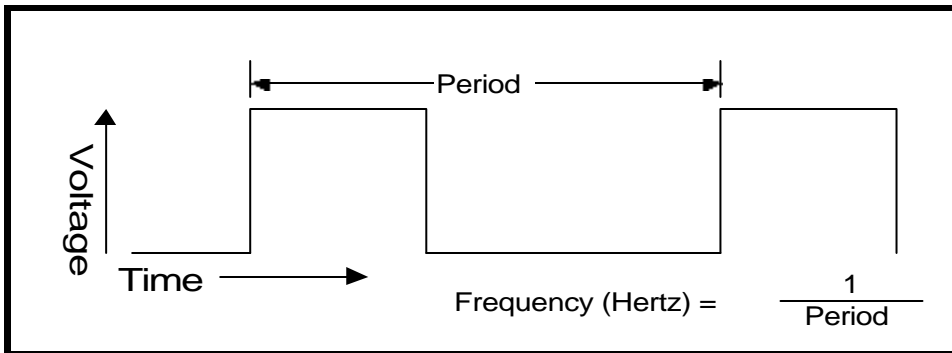


Figure 1 Relationship between period and frequency

## DESCRIPTION OF SPEED STEPS

NCE™ decoders support all speed modes 14, 28 and 128 speed step operation. We will discuss 28 speed step operation. This means that pulses are supplied to the motor in 28 different widths for 28 different speeds. These different speed steps are stored within the decoder in a form called a **speed table**. The speed table is simply a chart (or 'lookup table' as it is sometimes called) that the decoder uses to determine what pulse width to supply to the motor for each speed step. In order to keep the number of zeroes after the decimal point down, and make the numbers easier to read, we will refer to time in thousandths of a second or **milliseconds** (abbreviated mS). The decoder supplies pulses to the motor in 'slices' of 0.128 mS. This means that the shortest possible

pulse to the motor is 0.128 mS. The speed table tells the decoder how many .128 mS slices out of the total period that power will be supplied to the motor. The total PWM period of 14 mS can contain a maximum of 109 of these increments (14 divided by .128 equals 109).

## STANDARD SPEED TABLE

The standard speed table that is factory supplied in NCE™ decoders looks like this:

71 Hz Standard Speed Table

Speed Step	Number of .128 mS 'slices'		Pulse Width (out of 14 mS)
	Decimal	Hexadecimal	
1	5	05	0.64 mS
2	7	07	0.90 mS
3	9	09	1.15 mS
4	11	0B	1.41 mS
5	12	0C	1.54 mS
6	14	0E	1.79 mS
7	16	10	2.05 mS
8	18	12	2.30 mS
9	20	14	2.56 mS
10	22	16	2.81 mS
11	25	19	3.20 mS
12	27	1B	3.46 mS
13	30	1E	3.84 mS
14	33	21	4.22 mS
15	36	24	4.61 mS
16	39	27	4.99 mS
17	41	29	5.25 mS
18	45	2D	5.76 mS
19	48	30	6.14 mS
20	53	35	6.78 mS
21	57	39	7.30 mS
22	63	3F	8.06 mS
23	68	44	8.70 mS
24	74	4A	9.47 mS
25	81	51	10.37 mS
26	89	59	11.39 mS
27	96	60	12.67 mS
28	109	6D	13.95 mS

Note: Hexadecimal numbers are provided for Digitrax users.  
All other systems use normal decimal numbers

## START VOLTAGE

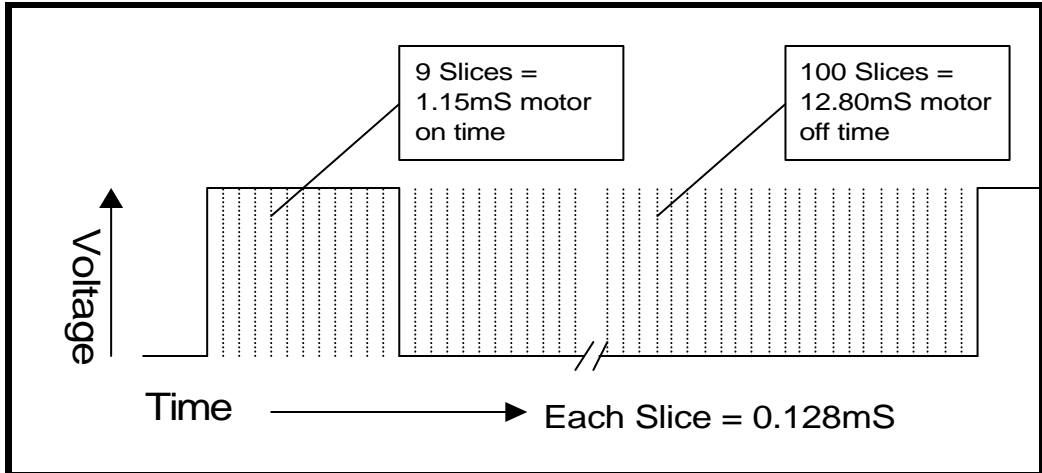


Figure 2 - illustrates the motor drive for speed step 3

The start voltage is the number of .128 mS time slices added to each speed step. For example: if the start voltage is set to 7 then speed step 1 will have 12 slices of 'on time' instead of 5. Speed step 3 (see figure 4) will not have 9 slices of 'on time' but it will have 16 slices of 'on time'. If the start voltage causes the speed step to exceed 109 (as with speed step 27) the decoder will "max out" at 109 slices rather than go over the maximum number of slices. The start voltage only applies to the standard and 128 speed tables

## ALTERNATE SPEED TABLE

**NCE™** decoders actually come with **two** speed tables. While the **standard** speed table is recorded in the unchangeable, permanent memory of the decoder the **alternate** speed table is stored in changeable memory and may be modified to suit different locomotive motor requirements. Both the pulse widths of each speed step and the period (frequency) may be customized for a particular locomotive. The pulse widths for the alternate speed table are stored in Configuration Variables (CV) 66-94 and the Total Period (which determines the frequency of the PWM) is stored in CV9. The table on the following page contains the factory programmed alternate speed table. If you decide to use the alternate speed table *be sure to activate it by programming CV29*. With NCE Powerhouse and Master Series command stations this is done by programming the decoder CFG (configuration) using either the programming track or program on the main menu selections.

## FACTORY SETTINGS FOR THE ALTERNATE SPEED TABLE

These settings may be changed to suit the requirements of different locomotives.

40 Hz Alternate Speed Table

CV Number <sup>(1)</sup>	Speed Step	Number of .128 mS slices		Pulse Width (out of 24.96 mS)
		Decimal	Hexadecimal	
66	STOP	0	0	0.00 mS
67	1	2	2	0.26 mS
68	2	4	4	0.51 mS
69	3	5	5	0.64 mS
70	4	9	9	1.15 mS
71	5	12	C	1.66 mS
72	6	16	10	2.17 mS
73	7	20	14	2.68 mS
74	8	23	17	2.94 mS
75	9	27	1B	3.46 mS
76	10	31	1F	3.97 mS
77	11	36	24	4.61 mS
78	12	39	27	4.99 mS
79	13	44	2C	5.63 mS
80	14	50	32	6.40 mS
81	15	55	37	7.04 mS
82	16	60	3C	7.68 mS
83	17	64	40	8.19 mS
84	18	71	47	9.09 mS
85	19	77	4D	9.86 mS
86	20	86	56	11.08 mS
87	21	93	5D	11.90 mS
88	22	103	67	13.18 mS
89	23	112	70	14.34 mS
90	24	123	7B	15.74 mS
91	25	135	87	17.28 mS
92	26	150	96	19.20 mS
93	27	168	A8	21.50 mS
94	28	195	C3	24.96 mS

1. NMRA RP-9.2.2 offers a complete description of the functional configuration variables. This document is available to NMRA members free of charge from the Chattanooga, TN office.

Note: Hexadecimal numbers are provided for Digitrax users.  
All other systems use the normal decimal numbers

**With NCE decoders - ALWAYS PROGRAM CV66 = 0. Other wise your locomotive will not be able to stop!**

## INITIAL FACTORY SETTING OF THE TOTAL PWM PERIOD

CV Number	Speed Step	Number of .128 mS 'slices' in the Total PWM Period		Total PWM Period (# slices times .128mS)
		Decimal	Hexadecimal	
9	--	195	C3	24.96 mS (40 Hz)

There are various ways the Total Period (CV9) can be played against the pulse widths of the speed steps (CVs 67-94):

- If the locomotive already operates at the desired top speed then CV94 (speed 28) should be set equal to CV9. This will give full available power to the motor (speed step 28 pulse width will be 100% of the Total Period) on speed step 28.
- If the locomotive runs faster than desired at top speed CV94 can be set to a number smaller than CV9. This will give less than full available power to the motor when it reaches speed step 28. Note: Start Voltage (CV2) is not used with the alternate table, Speed step 1 should be programmed to the starting voltage.
- Selection of the total period is a trial and error process for different types of motors. Some motors respond well to higher frequencies others to lower frequencies. One motor may "rattle" or buzz at 90Hz but not at 84Hz. We have pre-programmed the alternate table with 40Hz for (usually) good operation with standard Athearn and LifeLike Proto 2000 and Atlas locomotives.
- Generally a lower frequency will yield less rattle or buzz.

## PROGRAMMING THE ALTERNATE SPEED TABLE

It is less labor intensive to determine the best Total PWM Period first before rushing in and reprogramming all the speed steps. As a general, but not hard-and-fast, rule we have found that most motors respond well to longer Total PWM Periods.

In HO start out by trying Total PWM Periods in the range of 100 (70Hz) to-195 (40Hz). Try various settings of CV9 and see how the motor runs at lower speeds (higher speeds are not critical at this point). After determining what you think is a good trade-off between noise and performance it is time to set the speed steps for the decoder.

The next action is to find the correct first speed step (CV67) for the motor. The correct first value is the one that makes the locomotive move at what you feel is the "right" speed for speed step 1. Contrary to what seems obvious, the "right" speed for speed step 1 is *not* the same for everyone.

When you have determined speed step 1, then pick a number for the last speed step (CV94). If you are happy with the loco's top speed, program CV94 will be to the same value as the Total PWM Period (CV9). If the top speed is too fast then choose a number proportionally smaller than that in CV9.

To fill in the remaining speed steps 2-27: Subtract the value for speed step 2 from the value for speed step 28. Divide the result by 27 to get the incremental value for each speed step. This will divide the locomotive speeds equally (linearly, for the mathematicians among us) from step 1 to step 28. Any value from 0 to 255 may be programmed into any speed step.

The decoder does not check to make sure the next speed step has a higher value than the previous one. This will allow some pretty wild speed tables even up to the point of having the speed table run 'backwards' from full speed at step 1 to a crawl at step 28. CV66 (speed 0) should *always* be programmed to 0 to be sure the decoder will be able to stop.