Enhanced WWVB Broadcast Format

John Lowe (john.lowe@nist.gov)
Time and Frequency Services
National Institute of Standards and Technology

September 2012

1. Introduction

The WWVB broadcast of the official time of the US government has existed since 1965. Since then, NIST has upgraded the broadcast system and modified the signal several times making the service more accessible to the public, and resulting in large numbers of radio-controlled clocks (RCCs). The most recent improvements included a significant increase in broadcast power and an increase in the modulation factor used for the amplitude-modulation, both of which served to improve reception coverage for existing RCCs and increase their reliability. Nevertheless, it has been realized that these popular devices still often encounter difficulties in reception, which depend on the geographical location, time of day, type of structure, and interference sources that may be present in a given environment. All of these factors determine what is called the signal-to-noise-and-interference-ratio (SNIR) that a receiver experiences at a given instance.

In order to address the reception challenges and provide the public with a much improved system, NIST is now introducing an enhanced communication protocol, to which phase modulation was added, offering significantly improved performance in new products that are designed according to the new protocol. The new protocol maintains the amplitude-modulation (AM) and pulse-width modulation (PWM) of the legacy protocol, the details of which have been made available in NIST Special Publication 250-67 (http://tf.nist.gov/general/pdf/1969.pdf) from 2005, where much additional information about the WWVB station may be found. This backward compatibility ensures that typical existing consumer-market products, based on conventional envelope detection, are not impacted. This means that although legacy receivers cannot benefit from these improvements, their performance will not be degraded, either.

However, receivers designed to lock to the carrier's phase and perform coherent detection, which are typically common only in more-professional equipment, are impacted by the introduction of the phase-modulation defined in the protocol. Based on the early notification provided by NIST and trials that were performed throughout 2012, it is expected that these receivers will either be modified or replaced. In the transitional period, to extend at least until the end of 2012, the phase modulation will be disabled for 30 minutes twice a day, at noon and at midnight Mountain Standard Time (MST), allowing carrier-locked based time-keeping devices to resynchronize to the broadcast in its legacy form (i.e., having only amplitude and pulse-width modulations).

This document specifies the data content, physical properties and scheduling features of the phase-modulating (PM) time code that will soon be added to the WWVB broadcast. It is intended to allow users to correctly interpret the various components in the PM code. It should be noted that there are differences between the information made available through the PM code and what has been available through the legacy AM/PWM protocol. For example, while the time and date may be extracted from both, the leap year indication is not duplicated in the PM code, whereas the PM code contains a new field that provides advance notification for daylight-saving time (DST) transitions.

Additional features, offering further enhancements to the user experience in various SNIR conditions, will be described in a future public release in 2013.

2. General Properties of the Phase Modulation (PM) Protocol

The signal properties of the new broadcast are designed to maintain backwards compatibility with the common envelope detector-based receivers that were designed to operate with the legacy AM/PWM WWVB protocol. These receivers, found in many low-cost consumer market products, are typically based on a crystal filter centered at 60 kHz and having a bandwidth narrower than 10 Hz, which is followed by a non-linear envelope detection operation (rather than a coherent detector, which is based on multiplication with a locally generated 60 kHz signal that is phase-locked to the modulated carrier).

The PM protocol was designed to allow for flexibility/scalability (i.e., optimized operation at a very wide range of SNR values), while also making provisions for additional features and extensions. It is anticipated that details for additional features will be published before the end of the year. These features will allow faster and more accurate synchronization, as well as address the problems of receivers with particularly low SNR.

2.1. Definition of the Phase Modulation

The PM format is based on antipodal binary phase shift keying (BPSK), i.e., the two symbols are 180° apart. A “0” is represented by the carrier’s non-modulated phase, as with the phase modulation turned off, whereas a “1” is represented by an inverted carrier. The hourly 45° phase shift that had existed in the legacy broadcast for station identification is eliminated, as station identification becomes possible based on the many unique signatures in its new PM code, detailed in the following sections, which distinguish it from other broadcasts.

2.2. Physical Properties of the Modulating Baseband Signal

As can be seen in Figure 1, the baseband signal, which combines the two-level legacy AM/PWM signal and the phase (sign) inversions, may experience at least four different levels in a phase-modulated frame. These correspond to the legacy AM levels V_H and V_L, having the ratio $V_H / V_L \cong 7$, each of which may be multiplied by either a +1, representing a “0” in the BPSK modulation, or -1 for phase reversal, representing a “1” in the BPSK modulation.

The phase transition between each bit and the next one in the 1 bps (bit per second) PM frame occurs 100 ms after the AM amplitude drop that indicates the end of that second, as shown in Figure 1, illustrating an example baseband version of a transmitted symbol, where the information in the PM is shown to transition from a “0” to “1”, while the transmitted AM bit is a “1”. The baseband signal shown in this figure is multiplied by the 60kHz carrier in the transmitter, thereby resulting both in variations in the carrier’s amplitude and in sign reversals in it whenever the baseband signal assumes negative values.

Figures 2-5 illustrate the modulated carrier for all of 4 combinations of 0/1 bit values for the legacy and the PM frames (markers not shown).

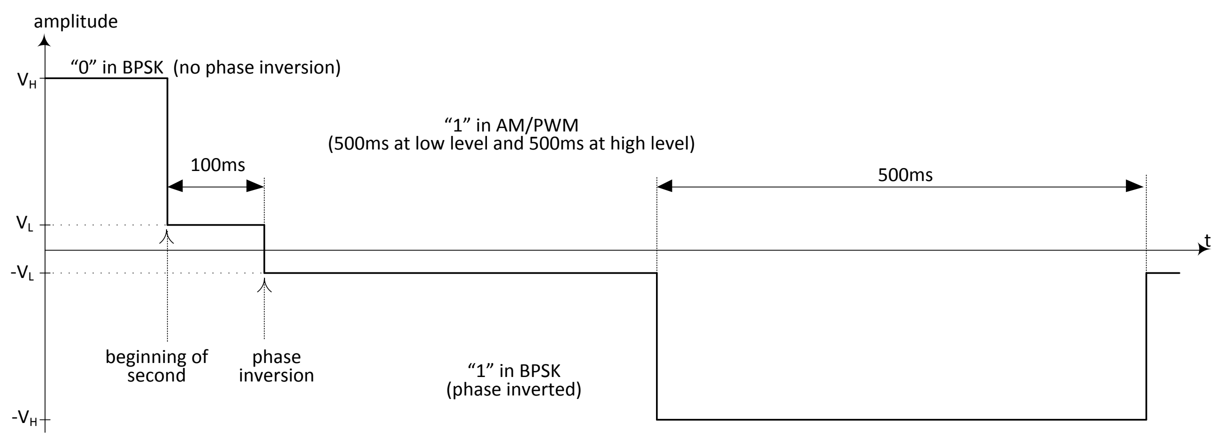

Figure 1 – The baseband signal when the bit transmitted both in the legacy protocol and in the PM is “1”

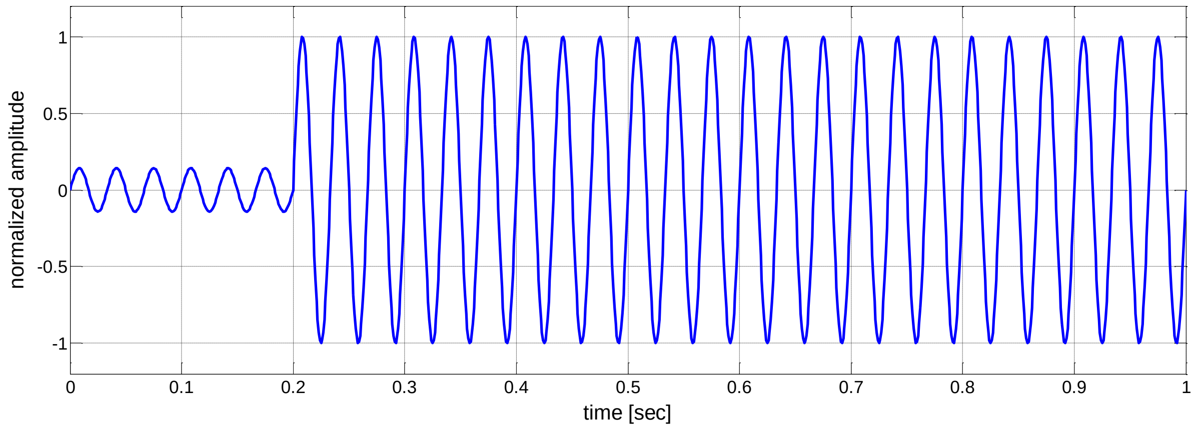

Figure 2 – The modulated carrier for a “0” both in the legacy protocol and in the PM

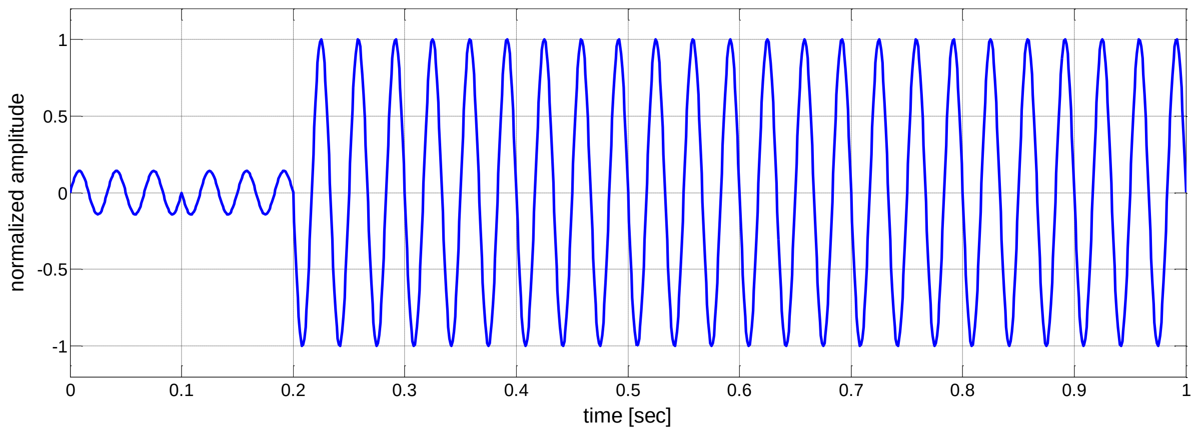

Figure 3 – The modulated carrier for a “0” in the legacy protocol and a “1” in the PM

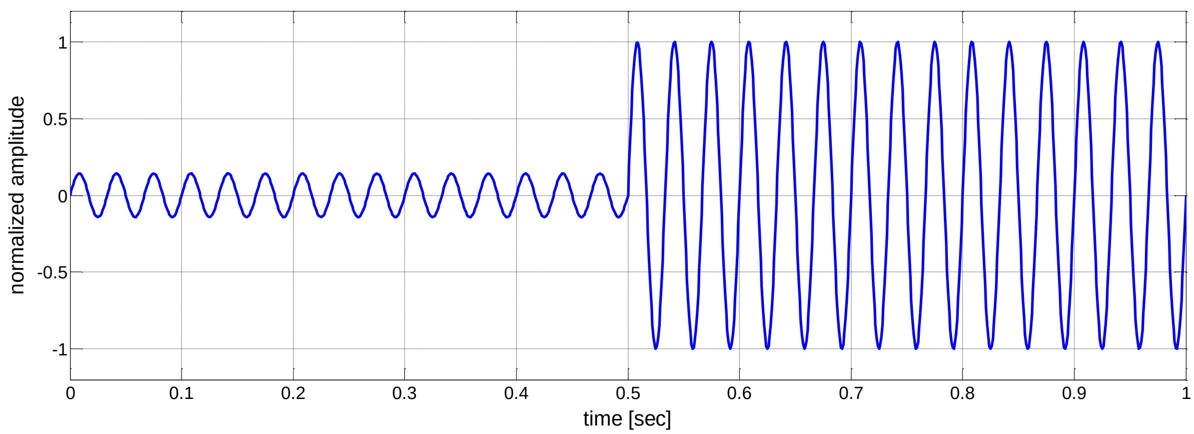

Figure 4 – The modulated carrier for a “1” both in the legacy protocol and a “0” in the PM

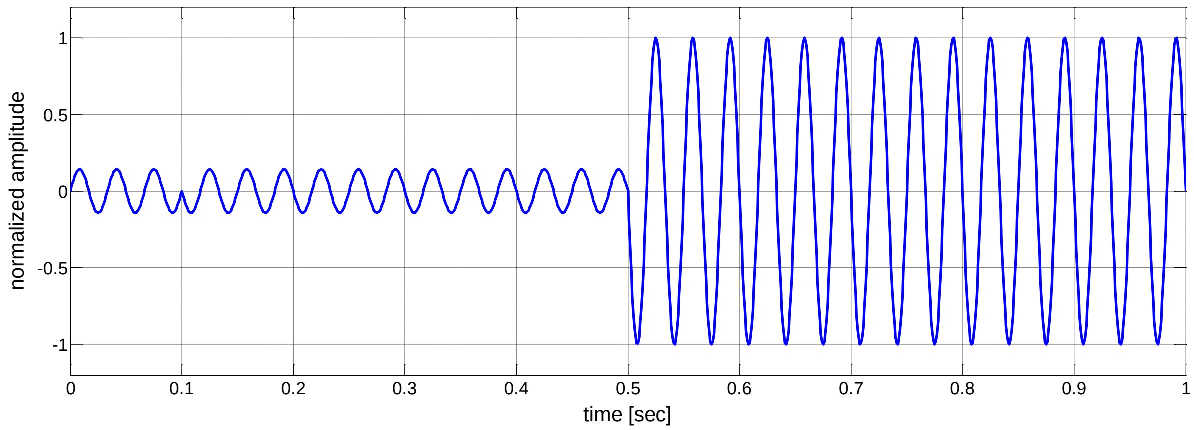

Figure 5 – The modulated carrier for a “1” both in the legacy protocol and in the PM

Since the lower-power portion of each bit, transmitted with an amplitude of V_L, is about 50 times weaker in power than the high-power portion, it is recommended that the phase of the carrier for each data bit be determined in the receiver based only on its high-power interval.

3. Scheduling of Phase-Modulated Frames

The 60-second phase modulated time information frames coincide with the legacy AM/PWM 60-second frames. However, while the legacy AM/PWM modulation is present 100 % of the time, the normal phase modulation on the carrier may be briefly interrupted for various purposes.

During the transitional period, to extend at least until the end of 2012, PM interruptions for durations of 30 minutes will be scheduled to occur daily at noon and at midnight MST, to allow for existing carrier-locking based equipment to resynchronize or relock to the legacy AM/PWM signal.

Messages for various purposes, such as emergency notices, may be incorporated into the broadcast and scheduled to specific instances. A message frame, transmitted at the rate of 1 bps, replaces a normal time frame. Therefore, it may not be used for time acquisition in a phase-modulation based RCC. However, it may still be used for timing correction (tracking), because it starts with a known synchronization word, as detailed in the next section. A message may also exceed a single frame and span over multiple frames. The broadcasting of messages will be limited to a low duty cycle (e.g., below 10 % of the time), particularly during times assumed to be most critical for reception in RCC devices.

4. Bit Allocation and Notation in 1 bit/s Time Frame

The PM bit allocation for a 60-bit 1 bps frame dedicated to time information is described in Table 1 against the bit allocation of the legacy AM/PWM protocol. This section describes the contents and significance of the various fields in the one-minute time frame, while Section 5 and Table 9 describe the message frames, which may infrequently replace time frames in the PM signal.

Note that bits in N-bit words are numbered from 0 for the least-significant bit (LSB) to N-1 for the most significant bit (MSB), with the MSB being transmitted first. For example, the 26-bit time word (minute counter) is numbered from 0 (LSB) to 25 (MSB), with the 25^{th} bit (MSB) being transmitted first.

Table 1 - Allocation of bits in one-minute **time** frame (**legacy protocol** in **black**, **PM** in **red**)

Second	0	1	2	3	4	5	6	7	8	9
Legacy AM/PWM	Marker	min_40	min_20	min_10	0	min_8	min_4	min_2	min_1	Marker
Phase	sync_T[12]	sync_T[11]	sync_T[10]	sync_T[9]	sync_T[8]	sync_T[7]	sync_T[6]	sync_T[5]	sync_T[4]	sync_T[3]
Second	10	11	12	13	14	15	16	17	18	19
Legacy AM/PWM	0	0	hour_20	hour_10	0	hour_8	hour_4	hour_2	hour_1	Marker
Phase	sync_T[2]	sync_T[1]	sync_T[0]	time_par[4]	time_par[3]	time_par[2]	time_par[1]	time_par[0]	time[25]	time[0]
Second	20	21	22	23	24	25	26	27	28	29
Legacy AM/PWM	0	0	day_200	day_100	0	day_80	day_40	day_20	day_10	Marker
Phase	time[24]	time[23]	time[22]	time[21]	time[20]	time[19]	time[18]	time[17]	time[16]	R
Second	30	31	32	33	34	35	36	37	38	39
Legacy AM/PWM	day_8	day_4	day_2	day_1	0	0	UT1_S[2]	UT1_S[1]	UT1_S[0]	Marker
Phase	time[15]	time[14]	time[13]	time[12]	time[11]	time[10]	time[9]	time[8]	time[7]	R
Second	40	41	42	43	44	45	46	47	48	49
Legacy AM/PWM	UT1_C_0.8	UT1_C_0.4	UT1_C_0.2	UT1_C_0.1	0	year_80	year_40	year_20	year_10	Marker
Phase	time[6]	time[5]	time[4]	time[3]	time[2]	time[1]	time[0]	dst_ls[4]	dst_ls[3]	notice
Second	50	51	52	53	54	55	56	57	58	59
Legacy AM/PWM	year_8	year_4	year_2	year_1	0	LYI	LSW	DST[1]	DST[0]	Marker
Phase	dst_ls[2]	dst_ls[1]	dst_ls[0]	dst_next[5]	dst_next[4]	dst_next[3]	dst_next[2]	dst_next[1]	dst_next[0]	0

- The significance of each of the fields in the legacy AM protocol is given in previous NIST publications (referenced in the Introduction section) and is not repeated here.
- Bits 29 and 39, designated “R”, are reserved for future use and have not been assigned at this time.
- Bits 4, 14, 24, 34, 44 and 54 in the legacy AM system were historically reserved for future use, but are now set permanently to 0.

4.1. Listing of the Fields in a Time Frame

Table 2 lists the six different fields in a time frame, lasting 60 s in duration.

Since the duration of the high power level in markers, as defined by the legacy protocol, is only 200 ms (compared to 500 ms and 800 ms for the “1” and “0” symbols respectively), none of the time information bits rely on a marker. The purpose of each field is described in the subsequent subsections.

Table 2 - List of fields in a one-minute time frame

	purpose of field	bits allocated	total number of bits (and seconds in duration)
1	synchronization word (may include last bit of previous frame)	0-12, 59	14
2	time word (includes 5 parity bits and repeated LSB)	13-28, 30-38, 40-46	32
3	daylight saving time (DST) state and leap second notification	47-48, 50-52	5
4	advance notice for next DST transition (or message word)	53-58	6
5	NIST notice indication	49	1
6	reserved bits (coincide with markers in AM/PWM)	29, 39	2
		total:	**60**

4.2. Synchronization Word

The known 13-bit synchronization word, **{sync[12], sync[11],… sync[0]}**, populating bits 0-12, is used for the purpose of timing (marks the beginning of a minute) and conveys no information. The last bit in every frame (bit 59, which is a marker in the AM frame), is always 0, and may be considered an extension to the sync word, extending it to a total of 14 seconds (i.e., the last bit from a previous frame may be appended to the first 13 bits in the next frame). One of two synchronization words may be used, denoted **sync_T** and **sync_M**, for time frames and message frames respectively, as specified in Table 3.

Table 3 - 13-bit synchronization words in **time** and **message** frames

bit #	12	11	10	9	8	7	6	5	4	3	2	1	0
sync_T	**0**	**0**	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**0**
sync_M	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**1**	**0**	**1**	**0**

4.3. Time Word

The time word, from which the year (excluding century), the date, and the hour and minutes may be extracted, is represented by a 26-bit minute counter that is reset at the turn of the century, i.e., the current value in it should be considered to represent the number of minutes that have elapsed since this century began at 00:00 UTC on January 1^{st} 2000.

For example, as the time turns from 21:29:59 UTC to 21:30:00 UTC on July 28^{th}, 2016, the minute counter will be incremented from 8717609 to 8717610 (decimal). The binary representation of 8717610 will appear within the 60 s frame that starts at that instance (i.e., the 21:30:00 UTC instance is announced after it has already occurred). This timing of the frame contents with respect to the beginning of the minute frame (the "on time" mark at the beginning of the first second of the minute) is identical to the convention defined in the legacy protocol.

The 26-bit time word is encoded into a 31-bit code-word, by calculating five additional parity bits that are appended to it because of the error-correcting linear block code Hamming(31, 26), based on the equations provided below. This code provides the receiver with the capability to correct one error and to detect up to two errors in the 31-bit word.

- **time_par[0]** = sum(modulo 2){**time**[23, 21, 20, 17, 16, 15, 14, 13, 9, 8, 6, 5, 4, 2, 0]}
- **time_par[1]** = sum(modulo 2){**time**[24, 22, 21, 18, 17, 16, 15, 14, 10, 9, 7, 6, 5, 3, 1]}
- **time_par[2]** = sum(modulo 2){**time**[25, 23, 22, 19, 18, 17, 16, 15, 11, 10, 8, 7, 6, 4, 2]}
- **time_par[3]** = sum(modulo 2){**time**[24, 21, 19, 18, 15, 14, 13, 12, 11, 7, 6, 4, 3, 2, 0]}
- **time_par[4]** = sum(modulo 2){**time**[25, 22, 20, 19, 16, 15, 14, 13, 12, 8, 7, 5, 4, 3, 1]}

The sum(modulo 2) operation is equivalent to an exclusive OR logic operation.

The 31-bit word is placed in the time frame in locations **{time_par[4], time_par[3],…time_par[0], time[25], time[24],…time[0]}**, corresponding to bits 13-28, 30-38, and 40-46, as shown in Table 1. The LSB, bit **time[0]**, is repeated on bit 19, which is a marker in the legacy protocol (i.e., the duration of its high power portion is only 200 ms).

4.4. Indications for Daylight Saving Time (DST) and Leap Second

The 5-bit word **{dst_ls[4], dst_ls[3]… dst_ls[0]}** in locations 47-48 and 50-52 is used to indicate whether DST is in effect or not or whether it is starting or ending today, and is also used to indicate whether a leap-second is to be added to the last minute of this month. These four different possible indications for the DST state and the two for the leap second are all merged into a single 5-code word that allows for the detection of errors, particularly for the two most common combinations to be found in this 5-bit field (highlighted in Table 4). Table 4 maps each of the eight legitimate values for the 5-bit **dst_ls** word into the corresponding values of the 2-bit indication **dst_on** and the bit **leap_sec.** Table 5 and Table 6 list the significances for the various values of these two fields respectively.

Table 4 - Decoding table for DST and leap second indication word **{dst_ls[4], dst_ls[3]… dst_ls[0]}**

DST and leap second code word					DST and leap second indications		
dst_ls[4]	dst_ls[3]	dst_ls[2]	dst_ls[1]	dst_ls[0]	dst_on[1]	dst_on[0]	leap_sec
0	0	0	0	0	0	0	0
0	1	1	1	0	1	0	0
1	1	0	1	1	1	1	0
1	0	1	0	1	0	1	0
1	1	1	0	0	0	0	1
1	0	1	1	0	1	0	1
0	0	1	1	1	1	1	1
0	1	1	0	1	0	1	1

Bits **{dst_on[1], dst_on[0]}**, which are to be extracted from the **dst_ls** word according to the decoding scheme provided by Table 4, indicate the DST state, as shown in Table 5 and explained as follows: Bit **dst_on[1]** is set to 1 at 00:00 UTC on the first Sunday of the DST period (in the spring) and is reset at 00:00 UTC on the last Sunday ending the DST period (in the fall). It is to be noted that since 00:00 UTC occurs a few hours before midnight in all time zones in the United States, and the DST transitions are to be implemented after midnight, the transitions in the **dst_on[1]** bit occur a number of hours before a receiving device is required to make the appropriate 1-hour correction, depending on which time zone the device is in. For this reason, the second bit, **dst_on[0]**, serves to identify the period of time in which **dst_on[1]** has indicated that the DST period has started (or ended), but this change is not to take effect yet, since the time for that (currently set at 2 AM on a specific Sunday) has not yet been reached.

In the absence of this second bit, a device that first receives the time in the afternoon/evening on the last Saturday of the DST period (or the last one before a DST period starts), after 00:00 UTC, which is still before 6PM PST, for example, might incorrectly apply the DST time change a few hours prematurely.

Bit **dst_on[0]** follows the transitions on bit **dst_on[1]** with a delay of 24 hours (i.e., transitions occur on the night between Sunday and Monday), in alignment with the corresponding 2-bit indication of the legacy AM/PWM protocol. The state of **dst_on[0]** allows the receiver to determine whether the DST state indicated by **dst_on[1]** has been valid for over a day, in which case the appropriate time correction is to be implemented immediately. If **dst_on[0]** indicates that the first day since the last DST transition is not over yet, then the RCC should not apply the new DST state in the time calculation until the appropriate time is reached (currently set at 2 AM in the local time zone).

Table 5 - DST state/transition word **{dst_on[1], dst_on[0]}**

dst_on[1]	dst_on[0]	significance
0	0	DST has not been in effect for over a day → Apply standard time correction with respect to UTC. Next transition is into DST
1	0	DST starts today → Do not apply the 1 hour DST correction until the appropriate time has been reached. *
1	1	DST has been in effect for more than a day → Apply one hour less of time correction with respect to UTC. Next transition is out of DST.
0	1	DST ends today → Continue to apply the DST correction and return to standard time only once the appropriate instance has been reached. *

* The combinations 01 and 10 can only be present for 24 hours (during the entire Sunday of the transition).

Bit **leap_sec**, when set to 1, indicates that a leap second is scheduled to be added at the end of the current month, as indicated in Table 6. At 00:00 UTC at the beginning of each month its value is reset to zero if no leap second is to be added that month, or is set to 1 at that instance if the last minute of that month is to be extended to 61 seconds. Historically, only the months of June and December have been occasionally extended by one second, but the broadcast format can accommodate a leap second in any month.

Table 6 - Leap second advance notification bit **leap_sec**

leap_sec	significance
0	no leap second at the end of this month
1	leap second scheduled for the last minute of this month

The time frame representing the extended 61-second minute will have bit 59 repeated (a marker in the legacy broadcast and a "0" in PM), after which bit **leap_sec** will be reset to 0. The timing of subsequent frames will reflect the correct time (i.e., after the implementation of the leap second) and no further indication will be found in the frame for the leap second that has been implemented (the UT1 correction that is available in the legacy frame in the AM/PWM modulation is not provided in the PM signal).

4.5. <u>Notice Bit</u>

Bit 49, which is a marker in the legacy AM/PWM signal, indicates when a notice from NIST is posted at the website, as specified in Table 7. When set to 1, it may indicate that a change is imminent, a temporary shutdown is planned, or whatever other message, the details of which may be found at a known webpage on NIST's website. It is expected that most consumer market products will ignore this bit.

Table 7 - **Notice** Bit (bit 49)

Notice	significance
0	nothing to report
1	notice regarding WWVB broadcast may be found at NIST website

4.6. Advance Notification for Next DST Transition

Bits 53-58, **{dst_next[5], dst_next[4]…dst_next[0]}**, usually represent one of eight possible schedules for the upcoming DST transition (i.e., either when the DST period is to start or end), but may also convey one of 8 other possible messages, as specified in Table 8. When DST is in effect, as is the case during the summer, the DST schedule word provides advance notification for the end of the DST period in the fall, whereas when DST is not in effect, as is the case in the winter, the DST schedule word provides advance notification for the beginning of the next DST period in the upcoming spring.

The start/end times for the DST period are always during the night between a Saturday and a Sunday, but the specific Sunday has changed over the years and may change again in the future.

As can be seen in Table 8, 24 combinations of day and time are supported for possible start/end times for the DST period, resulting in a total of 48 different 6-bit combinations. Historically, the DST transition in the US is to be implemented at 2 AM (local time), but combinations have been reserved for the possibility of this time being set at 1 AM or 3 AM, as is done in other countries. A total of eight Sundays are covered by the 24 combinations, both for the beginning as well as for the end of the DST period.

For combinations 49-56 the **dst_on** state has no relevance, as these do not represent specific start/end times. Message 49 is reserved for the case of a new DST schedule being defined that is not among the 24 predefined ones, message 50 is reserved for the possibility of DST being cancelled, while maintaining standard time, and message 51 has been reserved for the case of DST being permanently on (i.e., ahead of standard time by one hour). Additionally, five different words (messages 52-56) have been reserved, for which specific messages may be defined in the future, such as emergency messages.

Table 8 - DST transition schedule word (and reserved messages)

	***dst_on* [1]**	**DST schedule word *dst_next* (or reserved message)**						**time and action for implementation of next DST transition**	
		[5]	**[4]**	**[3]**	**[2]**	**[1]**	**[0]**	**day**	**time (local)**
1	0	1	1	0	0	0	1	1st Sunday of March	after 0:59AM, skip from **1:00AM** to 2:00AM
2	0	1	0	0	1	1	0	**2nd Sunday of March**	
3	0	1	0	0	1	0	1	3rd Sunday of March	
4	0	0	1	0	1	0	1	4th Sunday of March	
5	0	1	1	1	1	1	0	4th Sunday since “M”	
6	0	0	1	0	1	1	0	5th Sunday since “M”	
7	0	1	1	0	1	1	1	6th Sunday since “M”	
8	0	1	1	1	1	0	1	7th Sunday since “M”	
9	0	1	0	1	0	1	0	1st Sunday of March	after 1:59AM, skip from **2:00AM** to 3:00AM
10	0	**0**	**1**	**1**	**0**	**1**	**1**	**2nd Sunday of March**	
11	0	0	0	1	1	1	0	3rd Sunday of March	
12	0	0	0	0	0	0	1	4th Sunday of March	
13	0	0	0	0	0	1	0	4th Sunday since “M”	
14	0	0	0	1	0	0	0	5th Sunday since “M”	
15	0	0	0	1	1	0	1	6th Sunday since “M”	
16	0	1	0	1	0	0	1	7th Sunday since “M”	
17	0	0	0	0	1	0	0	1st Sunday of March	after 2:59AM, skip from **3:00AM** to 4:00AM
18	0	1	0	0	0	0	0	**2nd Sunday of March**	
19	0	1	1	0	1	0	0	3rd Sunday of March	
20	0	1	0	1	1	0	0	4th Sunday of March	
21	0	1	1	1	0	0	0	4th Sunday since “M”	
22	0	0	1	0	0	0	0	5th Sunday since “M”	
23	0	1	1	0	0	1	0	6th Sunday since “M”	
24	0	0	1	1	1	0	0	7th Sunday since “M”	
25	1	1	1	0	1	1	1	4th Sunday before “N”	after 0:59AM, instead of **1:00AM** move back to 0:00AM
26	1	0	1	0	1	0	1	3rd Sunday before “N”	
27	1	1	1	0	0	0	1	2nd Sunday before “N”	
28	1	0	1	0	1	1	0	1st Sunday before “N”	
29	1	1	0	0	1	1	0	**1st Sunday of November**	
30	1	1	1	1	1	1	0	2nd Sunday of November	
31	1	1	0	0	1	0	1	3rd Sunday of November	
32	1	1	1	1	1	0	1	4th Sunday of November	
33	1	0	0	1	1	0	1	4th Sunday before “N”	after 1:59AM, instead of **2:00AM** move back to 1:00AM
34	1	0	0	0	0	0	1	3rd Sunday before “N”	
35	1	1	0	1	0	1	0	2nd Sunday before “N”	
36	1	0	0	1	0	0	0	1st Sunday before “N”	
37	1	**0**	**1**	**1**	**0**	**1**	**1**	**1st Sunday of November**	
38	1	0	0	0	0	1	0	2nd Sunday of November	
39	1	0	0	1	1	1	0	3rd Sunday of November	
40	1	1	0	1	0	0	1	4th Sunday of November	
41	1	1	1	0	0	1	0	4th Sunday before “N”	after 2:59AM, instead of **3:00AM** move back to 2:00AM
42	1	1	0	1	1	0	0	3rd Sunday before “N”	
43	1	0	0	0	1	0	0	2nd Sunday before “N”	
44	1	0	1	0	0	0	0	1st Sunday before “N”	
45	1	1	0	0	0	0	0	**1st Sunday of November**	
46	1	1	1	1	0	0	0	2nd Sunday of November	
47	1	1	1	0	1	0	0	3rd Sunday of November	
48	1	0	1	1	1	0	0	4th Sunday of November	
49	**x**	1	0	0	0	1	1	DST transition occurs at different time*	
50	**x**	0	0	0	1	1	1	no DST period scheduled this year	
51	**x**	1	0	1	1	1	1	DST in effect for this whole year	
52	**x**	1	1	0	0	0	0	reserved 1	
53	**x**	1	0	0	1	0	0	reserved 2	
54	**x**	0	1	0	1	0	0	reserved 3	
55	**x**	1	1	0	1	1	0	reserved 4	
56	**x**	1	1	0	1	0	1	reserved 5	

x = either 0 or 1, "M"=first Sunday in March, "N"=first Sunday in November

* DST transition to occur outside of defined schedules, so no advance notification available.

5. Bit Allocation in Message Frame

Table 9 specifies the bit allocation for the message frames. The message frame starts with a 13-bit synchronization word, as defined in subsection 4.2. The LSB of the time word, **time[0]**, is available on bit 19 (marker) in message frames too, as in time frames. This allows receivers that are resolving timing uncertainties only below one minute to be able to use message frames for that purpose, assuming that they are experiencing sufficiently high SNIR for this single 200 ms symbol to suffice.

The **Notice** bit in location 49 (marker), functions in message frames as defined for time frames in subsection 4.5.

The 42 bit word in the remaining locations, **{data[41], data [40],…data[0]}**, defines the contents of the message and may contain fields indicating the address to which the message is intended, the total length of the message (may extend over multiple frames), etc.

Table 9 - Allocation of bits in one-minute **message** frame - (**legacy protocol** in **black**, **PM** in **blue)**

Second	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Legacy AM/PWM	Marker	min_40	min_20	min_10	0	min_8	min_4	min_2	min_1	Marker
Phase	**sync_M[12]**	**sync_M[11]**	**sync_M[10]**	**sync_M[9]**	**sync_M[8]**	**sync_M[7]**	**sync_M[6]**	**sync_M[5]**	**sync_M[4]**	**sync_M[3]**
Second	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Legacy AM/PWM	0	0	hour_20	hour_10	0	hour_8	hour_4	hour_2	hour_1	Marker
Phase	**sync_M[2]**	**sync_M[1]**	**sync_M[0]**	**data[41]**	**data[40]**	**data[39]**	**data[38]**	**data[37]**	**data[36]**	**time[0]**
Second	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**
Legacy AM/PWM	0	0	day_200	day_100	0	day_80	day_40	day_20	day_10	Marker
Phase	**data[35]**	**data[34]**	**data[33]**	**data[32]**	**data[31]**	**data[30]**	**data[29]**	**data[28]**	**data[27]**	**R**
Second	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
Legacy AM/PWM	day_8	day_4	day_2	day_1	0	0	UT1_S[2]	UT1_S[1]	UT1_S[0]	Marker
Phase	**data[26]**	**data[25]**	**data[24]**	**data[23]**	**data[22]**	**data[21]**	**data[20]**	**data[19]**	**data[18]**	**R**
Second	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**
Legacy AM/PWM	UT1_C_0.8	UT1_C_0.4	UT1_C_0.2	UT1_C_0.1	0	year_80	year_40	year_20	year_10	Marker
Phase	**data[17]**	**data[16]**	**data[15]**	**data[14]**	**data[13]**	**data[12]**	**data[11]**	**data[10]**	**data[9]**	**notice**
Second	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**
Legacy AM/PWM	year_8	year_4	year_2	year_1	0	LYI	LSW	DST[1]	DST[0]	Marker
Phase	**data[8]**	**data[7]**	**data[6]**	**data[5]**	**data[4]**	**data[3]**	**data[2]**	**data[1]**	**data[0]**	**0**

6. Example for Transmitted Time Frame

Table 10 clarifies the use of the different fields in the PM protocol through an example, which is explained here. For binary words shown in this example in "{ }", the most-significant bit (MSB) appears to the left and is broadcast first.

The date and time encoded in this example correspond to July 4, 2012 at 17:30 UTC, and would have been broadcast between the instances 17:30:00 and 17:31:00. In other words, the minute being encoded in the broadcast is the one that has already started, as has always been the case with the legacy protocol.

The encoded time is referenced to minute 0, which started at the instance of the turn of the century (00:00:00 UTC on January 1st in the year 2000). Therefore, this example date and time correspond to the 6,578,970th minute of the century, when considering 60 minutes per hour and 24 hours per day. Hence, the 26-bit field **time[25:0]**, corresponding to this instance, holds the binary representation equivalent to the decimal value 6,578,970. Bit **time[25]**, in location 18, represents the MSB and is zero in this example (will not be set to one until after the middle of the century), and bit **time[0]**, in location 46, represents the LSB and is zero in this example since this minute count is an even number. Note that **time[0]** also appears in location 19, which is a marker in the legacy protocol.

Using the parity equations provided in section 4.3, the parity bits for time-word are found to be {1 0 0 1 0}, placed in **time_par[4:0]**, where **time_par[4]** is the MSB.

The sync word bits are represented by the 13-bit word **sync_T[12:0]** (since this is a time information frame rather than a message). As specified in Table 3, these 13 bits have the fixed values of {0 0 1 1 1 0 1 1 0 1 0 0 0}, and are independent of the time.

Since July 4th falls while daylight-saving-time (DST) has been in effect for over one day, the **dst_ls[4:0]** bits are set to {1 1 0 1 1 } indicating, as shown in Table 4, that the DST state bits **dst_on[1:0]** are both set to 1, and **leap_sec** is set to 0. The **dst_ls[1:0]** bits, being set to { 1 1 }, signify that DST has been in effect for more than one day, and that the next DST transition would be the end of the DST period. The **leap_sec** notification bit being 0 indicates, as shown in Table 4, that there will be no leap second added to the last minute of this month (July). It is to be noted that the previous month, June 2012, had a leap second added at its end (the minute starting at 23:59:00 UTC on June 30th had 61 seconds), following which the leap second notification bit was to be reset from 1 to 0 until another leap second is decided upon and is to be announced.

The **dst_next[5:0]** field is set to {0 1 1 0 1 1} which, as shown in Table 8, indicates, along with **dst_on[1]** being set to 1, that the transition out of DST is to occur on the first Sunday of November at 02:00AM local time (at the local time zone, if DST is observed, the time is to be moved back to 01:00AM).

The notice bit in location 49, which is a marker, is set to 1, indicating the NIST has a notice posted at http://www.nist.gov/pml/div688/grp40/wwvb.cfm, notifying of changes to the WWVB broadcast signal, anticipated downtime, etc.

In this example, the bits at locations 29 and 39, which are markers, are arbitrarily set to 0 and 1, respectively, carrying no information at this time, as these are reserved for future used.

The bit in location 59, which is a marker, is always set to 0.

The assignment of the AM bits adheres to the legacy protocol, which may be found at this link: http://tf.nist.gov/general/pdf/1383.pdf.

Table 10 - Example of one-minute time frame **(legacy protocol in black, PM in red)**

Second	0	1	2	3	4	5	6	7	8	9
Legacy AM/PWM	Marker	min_40	min_20	min_10	0	min_8	min_4	min_2	min_1	Marker
bit value	-	0	1	1	0	0	0	0	0	-
Phase	sync_T[12]	sync_T[11]	sync_T[10]	sync_T[9]	sync_T[8]	sync_T[7]	sync_T[6]	sync_T[5]	sync_T[4]	sync_T[3]
bit value	0	0	1	1	1	0	1	1	0	1

Second	10	11	12	13	14	15	16	17	18	19
Legacy AM/PWM	0	0	hour_20	hour_10	0	hour_8	hour_4	hour_2	hour_1	Marker
bit value	0	0	0	1	0	0	1	1	1	-
Phase	sync_T[2]	sync_T[1]	sync_T[0]	time_par[4]	time_par[3]	time_par[2]	time_par[1]	time_par[0]	time[25]	time[0]
bit value	0	0	0	1	0	0	1	0	0	0

Second	20	21	22	23	24	25	26	27	28	29
Legacy AM/PWM	0	0	day_200	day_100	0	day_80	day_40	day_20	day_10	Marker
bit value	0	0	0	1	0	1	0	0	0	-
Phase	time[24]	time[23]	time[22]	time[21]	time[20]	time[19]	time[18]	time[17]	time[16]	R
bit value	0	0	1	1	0	0	1	0	0	0

Second	30	31	32	33	34	35	36	37	38	39
Legacy AM/PWM	day_8	day_4	day_2	day_1	0	0	UT1_S[2]	UT1_S[1]	UT1_S[0]	Marker
bit value	0	1	1	0	0	0	0	0	0	-
Phase	time[15]	time[14]	time[13]	time[12]	time[11]	time[10]	time[9]	time[8]	time[7]	R
bit value	0	1	1	0	0	0	1	1	0	1

Second	40	41	42	43	44	45	46	47	48	49
Legacy AM/PWM	UT1_0.8	UT1_0.4	UT1_0.2	UT1_0.1	0	year_80	year_40	year_20	year_10	Marker
bit value	0	0	1	0	0	0	0	0	1	-
Phase	time[6]	time[5]	time[4]	time[3]	time[2]	time[1]	time[0]	dst_ls[4]	dst_ls[3]	notice
bit value	0	0	1	1	0	1	0	1	1	1

Second	50	51	52	53	54	55	56	57	58	59
Legacy AM/PWM	year_8	year_4	year_2	year_1	0	LYI	LSW	DST[1]	DST[0]	Marker
bit value	0	0	1	0	0	1	0	0	0	-
Phase	dst_ls[2]	dst_ls[1]	dst_ls[0]	dst_next[5]	dst_next[4]	dst_next[3]	dst_next[2]	dst_next[1]	dst_next[0]	0
bit value	0	1	1	0	1	1	0	1	1	0