The Growing Family of Federal Standards for HF Radio Automatic Link Establishment (ALE)

Part II: A Compact Disc for Testing HF ALE Radios

An ALE test signal can be generated in a variety of ways, as the authors describe.

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Introduction: Testing Methods

Federal Standard 1045 and companion Military Standard 188-141A define sophisticated adaptive HF radios that can perform automatic link establishment (ALE) with other ALE compatible radios whose addresses are known. All ALE radios procured by the US Government must comply with certain mandatory features in these two standards. This ensures that regardless of vendor, all ALE radios will interoperate successfully. Hence the systems must be tested to determine if the radios meet the mandatory requirements of the standard.

These two government standards for HF Radio ALE have been described in open literature for several years.[1,2,3,4] The interoperability testing and performance evaluation techniques initially used by the government were complex and required the transportation of test equipment to each manufacturer's location; this was a very time consuming and expensive task.[5,6] Because the goal of the testing was to determine only the interoper-ability and performance of each unit, compliance testing against the standards was not done. The scope of the two federal standards is very broad, with a rich set of features. Both standards have something for everyone. The features are either mandatory or optional, and most radio manufacturers tend to focus only on the mandatory features to minimize the product cost.

For the initial government procurement (drug interdiction program) in 1990, the government provided a test team and equipment to perform interoperability and performance testing at six different vendor locations. Interoperability normally implies that two different systems can perform the same functional tasks, and one is considered the "standard" system. A quick review of the three-way handshaking required by the radios to establish a link is shown in Fig 1. After a preliminary checkout of two identical systems provided by a vendor, one was placed on line with an antenna, in order to test the selected

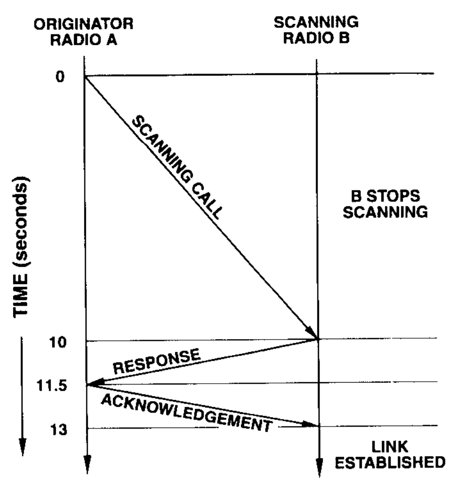

Fig 1—Three-way handshake used by ALE radios to establish a link.

[1]Notes appear on page 14.

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functions over-the-air with a system in Boulder, Colorado. While this method worked for the most part, it certainly was not a very satisfying procedure. The performance testing required the use of government-furnished equipment—including a portable, narrowband, propagation channel simulator (Watterson model). Because performance is measured between two radio systems, and the ALE technique uses the bidirectional handshake shown in Fig 1, two channel simulators were required—each costing about $60,000! A typical test set up is shown in Fig 2.

The interoperability tests using one standard radio, and the performance tests using two of the vendors' radios with two channel simulators, were not once-in-a-lifetime occurrences. As each new standard in the family of adaptive radio standards is issued, there must be at least two more sets of tests. The first is the "Proof of Concept" prior to the release of the standard, and then the "Acceptance" testing as described in note 5. After the 1990 testing, it appeared obvious that there must be a better way to perform the tests, with a technique that could reduce the transporting of equipment to each location. The remainder of this paper considers a method to solve many of the difficulties of this testing problem.

The Need for a Standard Set of Test Stimull

The need for a standard method of testing new ALE radios prompted the High Frequency Industry Association (HFIA) to organize their efforts under the Armed Forces Communications and Electronics Association (AFCEA) and propose a set of 12 types of tests which cover all the mandatory features of the two government ALE radio standards. The document was approved at their meeting on January 7, 1993, in San Diego, California. One of the features of the testing is the need for a standard test tape or audio compact disc (CD) with the various types of calls, emulating an ALE radio, encoded as ALE modem tones on the tape or CD. Table 1 lists the 12 types of tests as itemized in the document that was approved. The first 11 tests may fit on one or two CDs, but the 12th test for performance could require a dozen CDs if fully implemented. Each of the 12 types of tests will have multiple calls placed by the emulated radio recording. Generally, these calls will use different combinations of addresses for the calling tape and responding radio. Except for two cases, all the tones will be at the required level (0 dBm into 600 ohms) to be considered a "clean tone" (599). The 12th test measures the ability of the radio to link in a disturbed environment with noise, multipath and fading. Table 2 presents the various channel conditions required by the government standards for measurement of performance, established by how many links will occur with 100 attempted calls. The clean tones are used to determine the interoperability

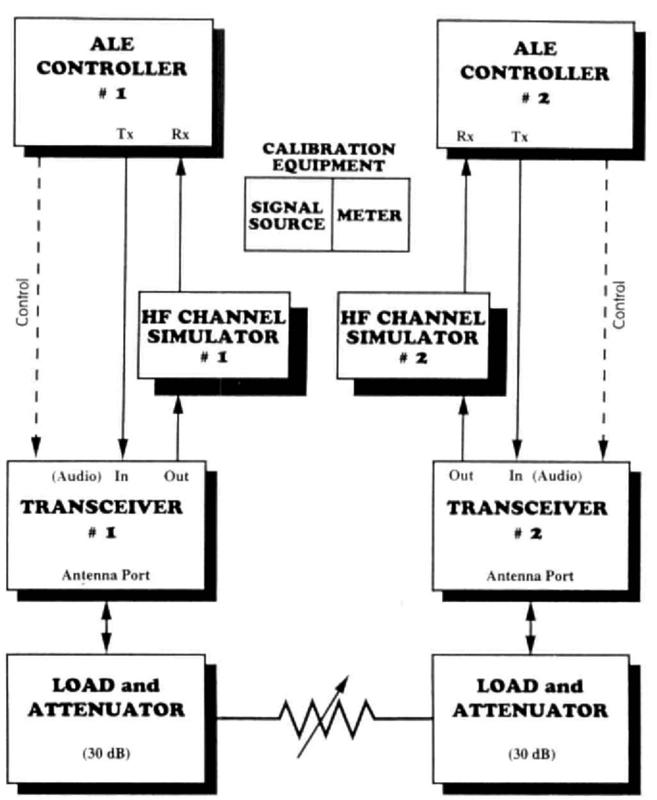

Fig 2—Test setup for performance testing of ALE radios.

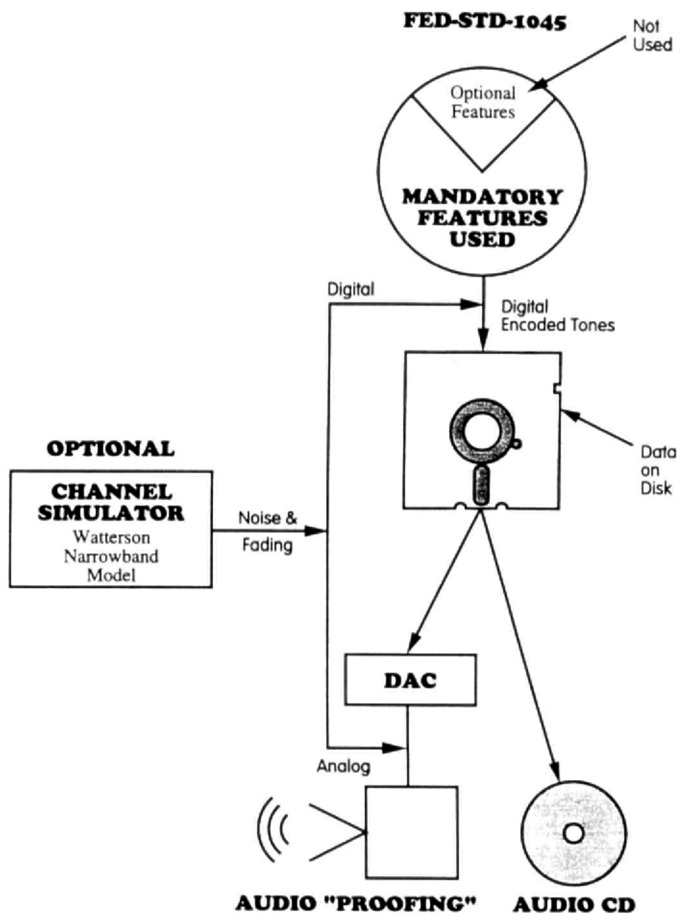

Fig 3—NTIA/ITS method to generate ALE tones for testing radios.

of the tested radio, while the disturbed tones will be used to test the performance of the radios in adverse conditions.

One of the questions that arises when using a one-direction or one-way test technique like this is: What happens to the value of the probability of linking? The subjective answer is easy: The probability of linking increases over the two-direction, three handshake linkup testing by some constant value. The theoretical value has not been solved at this time. Any theoretical values should obviously be verified by empirical data from several brands of radios. This computed/measured factor could be used as guideline to extrapolate the expected two-direction, three-way handshaking performance, but not in place of the actual performance required by the government standards for ALE radios.

Why an Audio CD?

There are many methods that could be used for storing and reproducing the ALE audio tones. These are:

1. audio cassette tape and player,
2. digital audio tape (DAT) and player,
3. audio compact disc (CD) and player,
4. computer sound file and sound card.

The first two are sequential techniques, while the latter two use random access for playback. For testing, especially repetitive testing, the random-access device has advantages over the tape. A good analog audio tape cassette deck may have sufficient accuracy to do some of the testing, but because of wow and flutter it should be looked at with suspicion. The DAT and CD, being digital devices, when used in a good quality home system can reproduce tones with an accuracy on the order of 5 to 30 parts per million (ppm). The analog cassette tapes may fall in the range of 1500 to 4000 ppm accuracy. The computer sound-card alternative is viable if the sound card provides sufficient accuracy. The first generation of sound cards that were available in 1992 were very dependent on the host processor chip and speed. Even with an 80386/486 at 33 MHz, the measured frequency accuracy was only slightly better than the better cassette tape decks. New-generation sound cards using digital signal processing (DSP) can achieve accuracies close to that of the CD player.[7] That type of accuracy may allow their use in the ALE radio tests.

The CD has a major feature that can prove advantageous in some test situations, and a detriment in others. The CD is the only medium that can not be altered. A great amount of security is provided to the entire HF industry and government agencies by using a common test source. The disadvantage is that if it is necessary to design a test on-the-fly with different addresses, etc, the other media can be altered; the CD cannot. The most flexible medium is the PC sound card, since the parameters may be modified and a new set of tones computed. This will be explained in more detail in the next section.

Several important factors remain, regardless of which medium is used, that provide motivation for producing a test tape or CD. It would:

1. meet the requirements of the HFIA test plan,
2. reduce the test equipment needed to verify interoperability,
3. eliminate the need for an expensive channel simulator for initial performance tests,
4. clarify, by example, several parts of the standard that have been misunderstood,
5. promote more widespread use of the government standards,
6. serve as a method to transfer technology from the government to smaller companies desiring to enter the market,
7. become the spring-board for future automatic testing of new features and next-generation government standards for ALE radios.

Table 1 HFIA Suggested Format of Standard Test Tape or CD.

Section	*Type of Call*	*Comments*
1	Sounds	Many addresses using all valid characters in the allowed set Noise added at three S/N levels for a selected address
2	100 Quick Sounds	Mix of long and short addresses
3	All Call	Simple and with AMD
4	Selective All Call	With known and foreign address
5	Individual Calling	With four levels of LQA in ackn.
6	Net Calls	Simple and with LQA and AMD
7	Group Calls	Same as above
8	Any Calls	Same as above
9	Selective Any Calls	With known and foreign address
10	Wild Card Calls	With length = 3 and 6 characters
11	Automatic Message Display (AMD)	90 Character message in Response of Call
12	Performance Tests	100 calls for each of the 12 sets with All Call & AMD of conditions in FED-STD-1045 matrix

Computer Generation of ALE Tones

Various methods were considered to generate clean tones for interoperability testing. All the modem/radio manufacturers use digital signal processing (DSP) boards with a development effort typically measured in man-years. Furthermore, all their code is proprietary and therefore not available. In spite of the industry's careful efforts to implement the standards, several operational differences were found in the initial tests between vendors (see note 5). We did not want to reinvent the wheel in our effort to make a standard audio test tape or CD, and we had a goal of doing the development in man-months, not man-years. It was apparent that a complete audit trail of input protocol, encoded tone values, and, of course, the output audio tones, would be mandatory for a standard test tape. Since we started the task in October, 1992, rapid progress has been made in both design and implementation, with about 3 man-months completed.

This paper focuses on the method used to generate the clean tones for the first 11 types of tests in Table 1. The subject of generating the tones through a disturbed set of channel conditions is beyond the scope of this paper and would not satisfy the intended purpose of this series of articles on ALE radios. In very general terms, as shown in Fig 3, the mandatory features of the ALE radio standards are used to generate a set of sound files which are stored on (magnetic) disk or tape. The actual format of the files depends on how the data is to be converted into audio. One format is the WAVE file (technically a RIFF file with sound data) defined by Microsoft and used in the *MS-DOS / Windows* 3.1 system. Any of the better-quality plug-in audio sound cards can play the files to external speakers. An extremely important point in this technique is that the files are made off-line, placed in a RAM drive on the computer, and then played from the RAM disk. It is *not* a real-time process; rather it is a "compute now, play later" philosophy. It is wise to use a 80386 or 80486 processor with a math coprocessor when doing the calculations. Depending on the number of bits and sampling speed, the computations can take 1 to 4 times the playback time.

Table 2 Government-required performance tests for ALE radios
FED-STD-1045 Probability of Liking

Signal-to-Noise Ratio (dB) in 3 kHz BW			*Required Probability of Linking with 100 Attempts*
Gaussian Noise Channel	*CCIR Good Channel*	*CCIR Poor Channel*	
–2.5	+0.5	+1.0	≥ 25%
–1.5	+2.5	+3.0	≥ 50%
–0.5	+5.5	+6.0	≥ 85%
0.0	+8.5	+11.0	≥ 95%

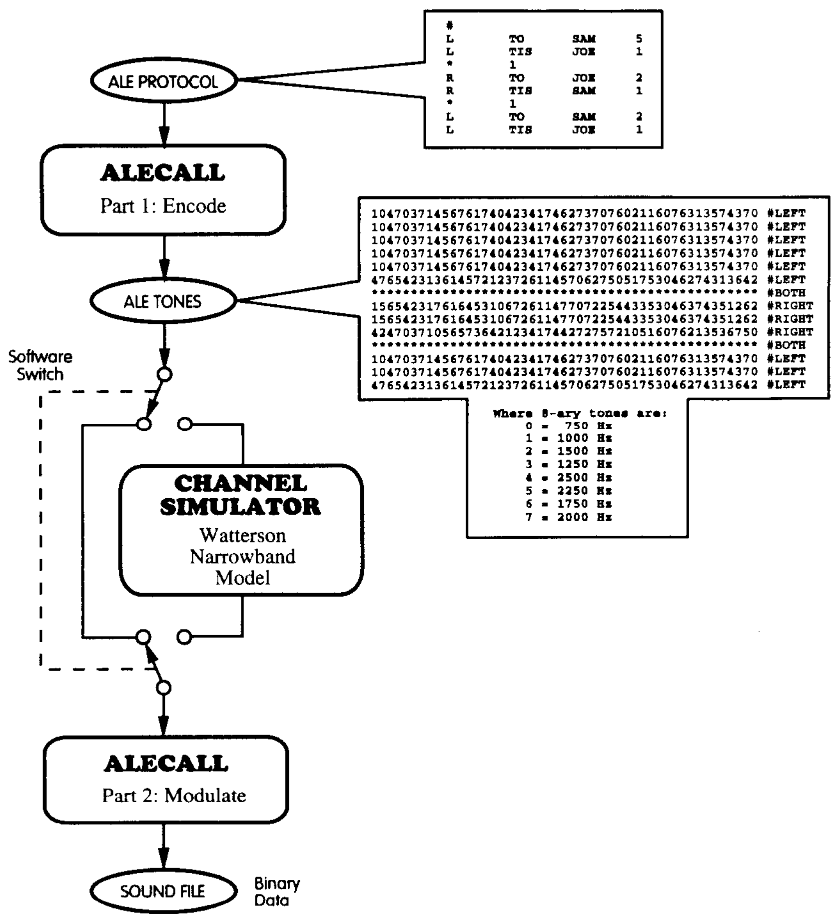

Fig 4—Overview of process to make a datafile of ALE modem tones.

The protocol defined in the Government ALE radio standards names 8 types of preambles to create an ALE call. Two types will be mentioned in this paper for the purpose of illustrating the technique of encoding the message. Fig 4 presents the overview of the method used to make the sound files. For simple ALE calls, a single program, ALECALL, reads an ASCII text protocol file of preambles and addresses and converts the information into the 8 tones used by the standards. These tones are then digitized in the modulator section of the ALECALL software program and written to the computer disk as a sound file. Although it would not be necessary to output the tones in numeric form, we chose to write them to a disk file as part of the audit trail for the user of the sound files. The two preambles in the example in Fig 4 are "TO" and "TIS" (TIS = THIS IS), which represent the addressee (TO) and the sender (TIS). Four single-character letters may be used in the first column of the input protocol file:

1. the "#" defines a comment line for informational purposes,
2. "L" or "R" directs the data on that line to the left or right speaker,
3. an "*" causes a delay of 49 bauds or 392 ms, since each symbol is 8 ms.

The preamble type for left and right audio channels is the second word of the line, followed by 3 characters of data or address. The last number in the line is the number of times to repeat the data for that line. The example protocol file begins on the left channel with 5 sets of "TO SAM" followed by one "THIS IS JOE" for the initial call. The response on the right channel from SAM is 2 sets of "TO JOE" followed by one "THIS IS SAM." The final acknowledgement by JOE is similar to the response. This type of file documents without any question the input to the encoder software. It also makes it possible to generate a stereo sound file with the originating radio on one channel (left in this example) and the radio being tested on the other channel. In actual testing, the right channel data would not be used, except as reference if desired.

The ALE standards define the modem tones as an 8-ary system with tones from 750 to 2500 Hz in steps of 250 Hz. The sequence is gray-scaled or mixed to help prevent selective fading destruction of a particular range of tones. Each tone may be represented by an octal number from 0 to 7 as shown in Fig 4. The ALE system uses 24 bits of data from each line in the protocol file and encodes these bits, along with a stuff bit, three times with interleaving into a 49-tone word. Each tone (baud) is on for 8 ms, so the entire data word is 392 ms. The sample tone file in Fig 4 shows 49 octal tone values per record, with the comment following them for the right or left channel. The time delays created by the "*" apply to both channels.

If the data is to be used for a DAT or CD, the choice of the sampling rate is the standard CD rate of 44,100 samples per second. Using a 16-bit digital-to-analog converter (DAC), and stereo for two-channel data, the example shown here is exactly 5.488 s in playing time, but took 9.6 s to generate and is slightly less than 1 Mbyte in size. We plan to use the computer model channel simulator shown in Fig 4 to create the disturbed tones that actual propagation conditions would cause. This portion of the software is still under development and is not discussed in this paper.

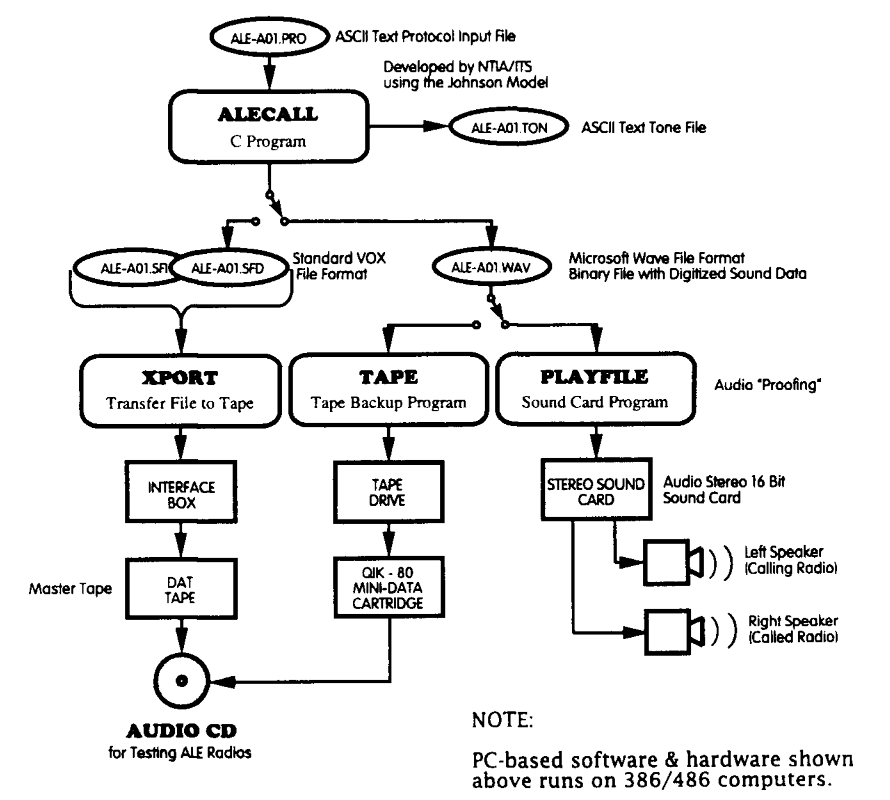

Fig 5—Emulation of ALE radio tone generation for laboratory testing.

Putting it Together

This section describes the complete technique used for making the audio data file for the DAT or CD, and use of the tones to actually place a call and link with a real ALE radio. The process consists of four steps:

1. create an ASCII text protocol file describing the ALE call (usually the 3-way handshake),
2. run the ALECALL program with the appropriate software switch to build a sound file and, if using the DAT, transfer the file to the tape,
3. set up a transceiver (with voice actuated keying) on an authorized frequency. The sound card (or CD or DAT) output should be plugged into the microphone jack of the transceiver, with proper impedance matching and levels to key the transmitter,
4. while the real ALE radio is operating (and scanning its pre-programmed frequencies), play the file of ALE tones into your transceiver. The ALE radio should stop scanning, respond, answer your call, and think it is linked with another ALE radio.

The diagram in Fig 5 shows steps 2 and 4. It will be assumed that the readers of this article will have equipment to perform step 3, or could improvise an equivalent with a balanced mixer and an RF amplifier. The simplest of calls, such as the type described in the previous section, use an ASCII text protocol which may be typed into the computer with any text editor. That satisfies step 1. More complex calls, such as a request for link quality analysis (LQA) score, require a preprocessor program to convert what we call a Level 1 protocol file (user-friendly English) into an ASCII Level 2 protocol file. The Level 2 file may include non-printable characters which are expressed by a printable combination of ASCII characters. An example is the SHIFT OUT character (decimal 14 = CONTROL N) which is written as the doublet "^N." This coding provides a powerful technique for creating the protocol files for a large number of the mandatory features in the Government ALE standards.

The ALECALL software used in step 2 will currently generate either a sound file of audio data (a format used by CCITT as a digitized voice file) with the ".SFD" extension or the WAVE file RIFF format with the ".WAV" file extension. The run-time choice depends on which method in step 4 will be used to reproduce the digital data into analog.

While the first generation of sound cards using DMA appear to be inadequate for precise audio generation of the ALE tones, the new generation of sound cards, with both a microcomputer and DSP chip on board, appear to work acceptably for the interoperability tests.

Summary

This paper describes the need for a simple standardized method of testing the ALE radios as they are developed and new features are added. The paper also presents a relatively simple and inexpensive technique for creating digitized data for a set of test tones using a personal computer and special software. The audio tones may be played by using a good quality audio sound card, or the digital data can be transferred to DAT (tape) and/or audio CD and played through a good quality DAT or audio CD player. Each file of digitized tones will exercise or test a different function of the ALE controller and radio. While the immediate goal of this effort is testing ALE radios, it would be a rather simple matter to use the same technique for testing many types of modems and related audio applications. The rapid turn-around time to modify an address and generate an actual call using the sound card is ideal for experimenters and for laboratory work. The reduction in test equipment and inventory of radios for preliminary testing of new features in the ALE controller is appreciable. Automation of repetitive tests controlled by a computer may be a simple matter when using the sound card which is already installed in the computer. On the other hand, using an inexpensive compact disc provides all vendors and customers with exactly the same unchangeable source of audio tones to test the operation (and performance) of new or existing systems.

A potential application for Amateur Radio operators could be in conjunction with passing messages into an operational ALE network. Assume that the MARS network had ALE repeaters, and an amateur had the ALE software and a sound card. The ham could call the repeater, form a link, and then pass traffic with whatever modems were normally used to exchange data. If you can think of other applications, the authors would appreciate comments sent to NTIA.

Acknowledgements

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Notes

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