ASCII, BAUDOT AND THE RADIO AMATEUR

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The 1970's have brought a revolution to amateur radio RTTY equipmant and techniques, the latest being the addition of the ASCII computer code. Effective March 17, 1980, radio amateurs in the United states have been authorized by the FCC to use the American Standard Code for Information Interchange (ASCII) as well as the older "Baudot" code for RTTY communications. This paper discusses the differences between the two codes, provides some definitions for RTTY terms, and examines the various interfacing standards used with ASCII and Baudot terminals.

Construction of RTTY Codes

Mark and Space

Newcomers to amateur radio RTTY soon discover a whole new set of terms, unique to RTTY equipment. Chief amoung these are the words MARK and SPACE. To be fair, these terms really are not unique to RTTY since they originated with land-line telegraph service before 1900. However, current usage associates mark and space with something RTTY'ers do to or with machines.

The terms mark and space date from early pen and moving paper strip recording of telegraph signals. The pen was solenoid operated so that the pen was lowered when the sending key was down, marking the moving strip; keyup time was represented by the blank space between marks. Of course, an operator familiar with Morse code would then have to read the tape. One "tale" has it that the strip recording came first in telegraph operation and was used until the operators discovered that they could mentally decipher the code by listening to the rythem of the mechanical sounder. Some strip-pen telegraph recorders are still to be found in use today.

Teleprinter machines also use solenoids (called Selector Magnets) that open and close in response to a signal current (Loop Current) . Following the convention of telegraph recording, the current-on condition of the signal circuit, or loop, is called the mark state of the TTY signal and the current-off condition is called the space. However, the TTY codes differ from telegraph codes in that variable length mark or space conditions (dot, dash, and spaces between them in telegraph codes) are not used to from the character. Rather, the TTY codes use equal time length pulses which can be set to either mark or space. Letters, numbers, and symbols are encoded by different combinations of mark or space pulses.

Start, Data, Stop Pulses

In a teleprinter machine, the normal "rest" condition of the selector magnet solenoids is with the loop current on. Interruption of the loop current releases the selector magent, allowing rotation of a cam in the machine. Transmission of a TTY character begins with a space pulse (current off), called a start pulse. The start pulse signals to the machine that reception of a character has begun. Immediatly after the start pulse, a series of data pulses are transmitted with mark or space condition as indicated by the encoding for the desired character. The number of data pulses used to represent the letters, numbers, and symbols varies with the TTY code being used; "Baudot" code uses five data pulses, ASCII uses eight. Immediately after the last data pulse, a stop pulse is included which is always a mark pulse. The stop pulse therefore always occurs a fixed time after the start pulse (after 5 data pulses in Baudot and 8 in ASCII) and gives the machine a "rest time" to prepare for the beginning of the next character, maintaining receive maching synchroniztion

with the transmitted signal. The time length of the start and each data pulse are the same and are often called the unit pulse or select pulse time. The stop pulse length varies from code to code and even with speeds within a code as will be explained later. In general, the minimum stop pulse length can be one to two times as long as the unit pulse time; stop pulses may be as long as desired since the machine is "at rest" until the next start pulse is received. This type of TTY code that uses start, data, and stop pulses in the construction of each character is called an asynchronous or start-stop serial code. Other codes aslo in commercial use include synchronous serial codes, in which start and stop pulses are not attached to the data pulses for each character and parallel data codes in which each data pulse is assigned a separate wire to and from the terminal device. Such codes are found in common use with computer and line printer devices. Radio amateurs in the United States are currently authorized to use either the Baudot or ASCII serial asynchronous TTY codes.

The Baudot TTY Code

One of the first codes used with mechanical printing machines uses a total of five data pulses to represent the alphabet, numerals, and symbols. This code is commonly called the Baudot or Murray telegraph code after the work done by these two pioneers. Although commonly called the Baudot code in the United States, a similar code is usually called the Murray code in other parts of the world and is formally defined as the Internation Telegraphic No. 2 Baudot Code in part 97.69 of the FCC Rules and Regulations. This standard defines the codes for letters, numbers, and the slant or fraction bar but allows variations in the choice of code combinations for punctuation. U.S. amateurs have generally adopted a version of the so-called "Military Standard" code arrangement for punctuation, due largely to the ready availability of military surplus machines in the post 1945 years. Amateurs in other countries (particularly in Europe) have standardized on the CCITT No. 2 code arrangement which is similar to the U.S. standard, but has minor symbol and code arrangement differences.

Since each of the five data pulses can be in either a mark or space condition (two possible states per pulses) , a total of 2x2x2x2x2 = 2 to the fifth = 32 different codes combinations are possible. Since it is necessary to provide transmissions of all 26 letters,10 numerals, plus punctuation, the 32 code combinations are not sufficient. This problem is solved by using the code twice; once in the Letters (LTRS) case and again in the Figures (FIGS) case. Two special characters, LTRS and FIGS, are used to indicate to the printer whether the following characters will be of the letters or figures case. The printer has a latching mechanism so that it remains in the last received case until changed. Control operation such as LTRS, FIGS, Carriage Return (CR), Line Feed (LF), Space Bar (SP), and Blank (BLNK = no carriage movement) are assigned to both the LTRS and FIGS case so that they can be sent in either case. The remaining 26 code combinations have different letter or numeral/symbol meanings depending upon whether preceded by a LTRS or FIGS character.

Keyboards on Baudot machines such as the Teletype Corporation Models 15 or 28 differ from standard typewriter keyboards, having only three rows of keys with related letter and number/sumbol on each keytop (Q and 1, K and (, etc). The typest soon discovers this difference! Newer electronic terminals such as the HAL DS2000 and DS3100 have standard keyboard arrangements and automatically insert LTRS and FIGS characters as they are needed. The Baudot code itself is restricted to upper case letters only since insufficient codes are available to represent lower case letters.

The Baudot code has seen extensive commercial use throughout the world and is still actively utilized for international wire communications, press, and weather. Due to the ready availability of Baudot mechanical equipment, this code will continue to be quite popular amoung radio amateurs. However, the lack of code space for control, extended punctuation, or lower case letters is a severe limitation of the 5-unit baudot code. These limitations are particularly inconvenient in computer terminal applications. Various serial and parallel data coding schemes have been used with computers, but the ASCII data code is by far the most common. Figure 1 shows the current waveform with mark representated by the upper deflection. If the same data were observed on a RS232 data line, mark would be represented by a downward or negative deflection. Also, the bits in Figure 1 are arranged in a left-to-right order as would be observed on an oscilloscope. The bits in Table 1, however, are arranged in descending order (b5 to b1), conforming to the standard binary representation. Thus, the letter "D" shown in Figure 1 would be written as the binary character "01001".

The ASCII Code

In 1968, the American National Standards, Inc. (ANSI) adopted the American national Standard Code for Information Interchange (ASCII - commonly pronounced "as-key"), ANSI Standard X3.4-1968. This code uses seven data pulses to

specify the letter, number, symbol, or control operation desired. An eighth data pulse is provided for optional error checking, called the parity bit. As with the baudot code, the standard ASCII code approved for U.S. amateur use is asynchronous and serial with both start and stop pulses.

Whereas the five-unit "baudot" code was arranged by Murray so that the most frequently used letters are representated by the least number of mark holes punched in paper tape, the ASCII code has been arranged to optimze computer applications. The code has been particularly designed for rapid collation of alphanumeric lists, one data bit difference between upper and lower case letters, and isolation of all control operations from printing operations. A time diagram of a typical ASCII character is shown in Figure 2. Table 2 shows the ASCII Date Code. As noted for the Baudot waveform drawing, Figure 2 shows the loop current with mark represented by the upward deflection; an oscilloscope trace of a RS232 data circuit would be inverted with mark as the more negative deflection. Also, the bits in Table 2 are arranged in binary order (b7 to b1). Thus, the letter "S" in Figure 2 would be written as the binary number "0101 0011", with the eighth, parity bit, set to space (0).

As can be seen from the code table, many more punctuation symbols are included in the ASCII code (compared to Baudot). Also, the ASCII code includes a large number of control characters designed for print control of the terminal itself, formatting of data to the computer, and control of other hardware devices by the terminal. Although these control functions are defined by the ANSI definition, variations in the use of the control characters abound in the differing commercial appliactions.

The keyboards of both mechanical and electronic ASCII terminals are arranged similar to the "standard" typewrited keyboard, thus minimizing any operator re-training required when transitioning from a typewriter to a terminal. The "extra" ASCII keys are arranged around the periphery of the standard keyset if they are provided by the terminal.

A common abbreviation of the full 128 character ASCII code restricts the alphabetic letters to upper case only, often called CAPS-LOCK or CAPLK. In general, these terminals transmit the upper case ASCII code for a letter whether the SHIFT key is used or not; they may not be capable of transmitting all of the control codes. These terminals usually print (or display) the upper case letter when either the upper or lower case letter ASCII code is received. The Teletype Model 33 is an example of a popular upper case only ASCII terminal. Other terminals, such as the Teletype Model 43 or the HAL DS3100 ASR, have user selectable upper/lower case or upper case only (CAPSLK) transmit/receive features.

The optional eighth data bit may be set to four conditions; (1) always mark, (2) always space, (3) odd parity, or (4) even parity. All four choices are in common usage. Simple, non-error detecting terminals usually set the eight bit to be always a mark or space (usually space). Parity is sometimes used with computer and data interconnections where error detection is desired. When used, the parity bit is controlled so as to set the total number of mark data bits in the ASCII characted to be always even or odd (even or odd parity). For example, if odd parity is used with the ASCII character "C" (first seven bits = 1000011), the eight bit will be set to space to give an odd number (3) of data bits (0100011). Conversely, the odd eight bit code for the letter "B" would be 11000010. (Logic convention has it that lowest order bits are placed to the right; thus the bit order in the binary representation is"87654321" .) Upon reception, the receiving terminal simply counts the number of mark pulses in each ASCII 8 bit character. If an odd number is counted, it is assumed that no errors occured. Notice, however, that even if a bit error is detected, there is insufficient data to determine which bit was wrong and therefore no error correction is provided by the parity check itself. Also, if there are two bit errors in the same ASCII character, the parity will still be odd and no error indication is given even though two occured. Thus, parity checking will not give complete error detection and does not provide for error correction. Some applications require more sophisticated error dection and correction schemes. Even parity works in a similar manner except that the eight bit is chosen to make the total number of mark pulses even rather than odd. The U.S. amateur regulations do not specify a requirement for use of the eighth bit; it may be set to mark, space, odd or even parity, depending upon the preference of the operator and the capability of his equipment. Relatively simple terminals do not provide parity options; more sophisticated equipment such as the DS3100 ASR do.

Speeds and Baud Rates

The transmission rate of Baudot TTY signals is usually specified in words-per-minute, much like that used for telegraph codes. Actually, the speed is given in the approximate number of five letter plus space combinations transmitted in a continuous sequence of start-stop characters in a one minute interval. Convenient choices of gear ratios and motor shaft rpm resultated in the use of non-interger wpm rates. Common usage, however has rounded the exact speeds to easily remember numbers. Thus, "60 speed" Baudot is actually sent at 61.33 wpm and "75 Speed" is really 76.67 wpm.

A major problem occurs with the use of words-per-minute (wpm) as a TTY spped specification because of the varying length of stop pulses in use. For example, "60 Speed" Baudot TTY has a 22 ms (millisecond) long start pulse and a 31 ms stop pulse, the Western Union "65Speed" also has a 22 ms start pulse, but the stop pulse is also 22 ms long; electronic terminals commonly use the 22 ms start and data pulses and 33 ms stop pulses (1.5 times the data pulse width). ALL three of these codes are compatible and can received on the same terminal or printer since the stop pulse length is a minimum time. The common factor between these codes is the 22 ms length of the data, or unit pulse. Therefore, a new data rate specification has been adopted, the baud rate; in this case, the reciprocal of the data or unit or select pulse width:

Baud rate = 1/t; t= lenght of unit pulse

Using this definition, ALL three of the above codes have a data rate of 45.45 baud, commonly abbreviated to "45" baud.

As noted above, the length of the stop pulse varies between codes, being from 1.0 to 2.0 times as long as the unit (or data) pulse; multipliers of 1.0, 1.42, and 1.5 are commonly used with the Baudot codes. Standard Baudot data rate and speeds are shown below in Table 3.

U.S Amareurs are authorized to use all of the above Baudot data rates with the exception of 100 baud. This rate has limited commercial use in Europe. The 45 baud data rate is by far the most popular world-wide amateur data rate. A limited amount of amateur use of 74 baud ("100 Speed" has been noted on the high frequency bands. Most commercial RTTY transmissions on high frequencies use 50,57, and 74 baud, with little 45 baud activity.

ASCII data rates are commonly specified as a baud rate, although a character-per-second (cps) or words-per-minute (wpm) may also be sometimes given. The lowest standard ASCII data rate in common useage is 110 baud. ASCII characters sent at 110 baud are usually sent with a 2 unit wide stop pulse, although the one unit stop pulse may also be found in some applications. Above 110 baud, it is common to make the stop pulse one unit pulse in length. The standard ASCII data rates commonly used with asychronous serial transmission are show in Table 4 below:

The ASCII data rates up to 300 baud are Authorized for U.S. amateur use on frequencies between 3.500 and 21.250 MHz. Data rates up to 1200 baud are permitted between 28 and 255 MHz; up to 19,600 baud may be used above 420 MHz. The 110 baud rate is by far the most practical for 3.5 to 21.5 MHz use, again due to the ready availablity of equipment as well as to the increased susceptibility of the higher data rates to noise, static, interference, ect. VHF-FM amateur activity finds 110 and 300 baud useful for terminal-to-terminal communications and 300 and 1200 baud for computer related activities such as exchanging programs, ect. The very high data rates (1800, 2400, 4800, and 9600 baud) really find their best application in high speed computer-terminal data links. The 150 and 600 baud rates are recognized ANSI and EIA standards, but have seen limited use to date. Some "home-computer" systems are also using 250,500 and 1100 baud for cassette interfaces, not necessarily with ASCII encoding of the data. The FCC regulations (Part 97.69) specify maximum baud rates for each frequency range, but do not require use of the standard rates. Therefore, "non-standard" baud rates may be used with ASCII encoding, but this may not be practical due to lack of compatibility with existing terminal equipment.

Terminal Interfacing Standards

Loop Circuit:

The first commercial applications of teleprinter machines used direct telegraph wire connections between machines. A simple series circuit was used to connect the two machines and a dc power supply. This simple loop circuit is shown in Figure 3 below. This connection is also called a neutral loop circuit.

As discussed earlier, the printing mechanisms use solenoids or selector magnets to sense the presence (mark) or absence (space) of the loop current. The letters typed on the sending keyboard are encoded with the proper mark and space pulses by mechanically driven keyboard contacts. Since the keyboards and selector magnets of both machines are series connected, text typed on one keyboard is reproduced on both printers. Connection of the keyboard directly to its associated printer is called a local loop and results in what is called Half Duplex (HDX), giving local copy of transmitted text, termed local echo. The two machines could be connected with two signal circuits so that keyboard #1 is connected through a loop supply and wire to the selector magnets of printer #2; keyboard #2 is then connected to printer #1 with a second loop circuit. This type of connection is called Full Duplex (FDX). Note that the full duplex connection uses two signal, or loop circuits and does not provide local reproduction or echo of transmitted text. Most radio amateur

connection of teleprinters is in the half duplex configuration. The full duplex connection is commonly used with computer terminals. the computer itself may then supply a reproduction of the transmitted text to the printer, but in this case, the remote or computer generated echo provides confirmation that typed text has been properly processed in the computer.

The battery or dc loop supply in Figure 3 is used to maintain the current in the selector magnets during mark pulses. The actual current in the loop is adjusted with the series loop resistor. Selector magnets have been designed for mark loop currents of 60 or 20 mA dc with 60 mA being by far the most common for older machines such as the Model 15 or 28. Newer Baudot machines and most ASCII machines and terminals use electronic interface circuits that accept a wide range of loop currents (10 to 120 mA for the HAL DS3100, for example); a 20 mA loop current is quite commonly used with ASCII terminals.

Since the dc resistance of the machine magnets is rather low (100 to 300 ohms, typically), it would at first seem that a low voltage loop supply could be used. However, the inductance of the magnet is usually quite high (of the order of 4 Hy for a Model 15), causing a delay in the current rise time. This in turn delays the selector magnet's response to a mark pulse, distorting the signal. This distortion can be severe enough to cause misprinting of received text, particularly if other forms of distortion are present (such as caused by variations in the radio signal). The effect of this inductive distortion is reduced considerably if the L/R ratio (L is solenoid inductance and R is total loop resistance) is reduced by increasing R. Increasing R requires the dc voltage to be increased to maintain the required 60 mA loop current. In general, the higher the loop voltage and loop resistance used, the lower the distortion. In practice, loop power supply voltages between 100 and 300 vdc are common. 130 and 260 volt supplies were often used the Model 15, 19 and 28 Teletype machines. Modern TTY systems use a 150 to 200 volt loop power supply and a 2000 to 3000 ohm loop resistance to set the 60 mA loop current. Because of the related keying circuitry, the demodulator unit of a good RTTY system usually includes the loop power supply and current limiting resistor.

The simple circuit of Figure 3 has proven impractical for long distance wire use because of the inclusion of ground resistance in the loop circuit; variations in ground resistance due to rain, terrain, etc. cause variations in loop current and therefore in machine performance. Two telegraph wires could be used to provide a totally wire circuit, but at the expense of twice as many wires per signal circuit. Another approach, commonly used in telegraph circuits involves reversing the current flow in the loop between mark and space pulses. Thus, in an East-West circuit, current flowing to the West might represent mark and current flow to the East represent space. Current polarity sensing devices, called polar relays are then used to sense the direction of current flow. The polar relays then key the local loops to operate the machines at each end. This considerably complicates the connections at both ends and requires local loop supplies at each station as well as supplies to generate the two polarities of signal current. Properly adjusted polar relays are very sensitive and can give excellent low distortion operation. Fortunately, amateur RTTY operations do not need the polar relay and such devices are best removed from surplus printers when they are encountered; the RF hash generated in a polar relay can be considerable!

Virtually all of the commonly available Baudot machines can be used with 60 or 20 mA high voltage loop circuits. Therefore, to maintain compatibility with this existing equipment, use of the high voltage current loop interface is strongly recommended, even if electronic terminals are also used. Well designed Baudot electronic terminals will include a high voltage loop interface circuit.

On the other hand, the newer ASCII machines (such as the Models 33,35, and 43 Teletypes) are available with a variety of input/output (I/O) interfaces. These devices usually include a high current, low voltage selector magnet assembly (500 mA, 10-30 volts is typical), and internal magnet driver transistor and power supply, and an electronic interface to the data connections. These machines may be supplied with a 20 mA loop interface circuit (or RS232, TTL, or other interface standards).

RS232 Data Interface:

The Electronic Industires Association (EIA) has defined a new standard for interconnection of terminals, modems,and computers, the EIA Standard RS232-C (August 1969). This interface standard specifies voltage levels for mark and space, rather than the current levels used in a loop circuit. The basic RS232-C voltage ranges are shown in Figure 4.

Note that mark, normally considered to be a logical "1" is represented by a negative voltage and the logical "0" by a positive voltage. Thus, the RS232 interface standard can be thought of as a polar voltage standard. Also, note that RS232 voltage levels are really are NOT TTL logic compatible! (In spite of some claims you may read to the contrary!) Users should carefully examine "psuedo RS232 compatible" equipment to make sure no damage will be caused to his

RS232 interfaced equipment.

The RS232-C standard also includes definition of control signals to pass between originating and receiving devices and even defines the connector pin assignment. The RS232 connector signal and pin assignment is shown in Table 5.

< Use of a 25 pin connector is assumed but not defined in the RS232-C standard. Commercial usage has seen the adoption of the TRW-Cinch D-subminiature connector series (DB25P and DB25S), also manufactured by many other firms (Amphenol 17-10250 and 17-20250, for example). In general, the male pin connector (DB25P or 17-20250) is installed on the data terminal, but either polarity may be found on some equipment.

The control signals such as Data Terminal Ready(DTR), Request To Send (RTS), ect. are often called handshaking signals; they provide status indicators between data devices (terminal to a modem, for example). All control signal voltage and impedance levels also conform to the RS232-C standard shown in Figue 4. Control signals are considered to be active or on when the voltage is positive; a negative voltage control signal is off or inactive. The terms "mark" and "space" are usually not used when describing RS232 control signals. Thus a positive voltage on pin 5 (CB = Clear To Send) is the terminal's signal to the data circuit that the terminal is ready to receive data. Also, an open circuit or no voltage condition on a RS232 signal is interpreted as a "mark" or "active" condition.

Other Data Connection Standards:

A number of other data connection standards may be found in use in commercial equipment. Chief amoung these would be an interface that is compatible with the popular Transistor-Transistor-Logic integrated circuits, a TTL Compatible interface. TTL interconnections are particulary useful when directly interfacing computers or other digital devices. Although TTL and RS232 interface standards are not directly compatible, a number of line receiver and line driver integrated circuits are available.

A common data standard used in U.S. military applications is the MIL188 Data Standard. MIL188 is very similar to the RS232 standard with the exception that logic voltages are inverted. Mark is represented by positive voltages and space by negative voltages.

Other data interfaces are to be found for CMOS logic intergrated circuit connections; interfaces for both +5 and +12 volt CMOS operation are in use.

Summary

This paper has discussed the construction of the two common amateur radio teleprinter codes, Baudot and ASCII. The similarities and differences of the two codes have been discussed and a number of terms unique to RTTY have been explained. Data rates and code variations have been presented; standard loop and RS232 data interfacing standards have been compared and discussed.