Hellschreiber Modes
-
Technical Specifications

Contents

1. Preamble

Hellschreiber is a non-coded direct printing text transmission technique, invented in Germany in 1927. The equipment was widely used during WWII and after, until gradually overtaken by coded teletype equipment. Time domain variants date from a French system demonstrated in 1937, but were never developed commercially.

Hellschreiber means "bright writing", a pun on the name of the developer Rudolf Hell.

Three variants of Hellschreiber are enjoying increasing use on Amateur bands, thanks to the arrival of DSP and the use of sound cards. Hellschreiber (usually abbreviated "Hell") offers significant advantages on low HF bands, where interference severely disrupts the more widely used radio-teletype. Hell is simple to operate, does not require much equipment, and is relatively inexpensive. There is, however, a shortage of reliable commercial quality software to allow the average ham to venture into this field.

The three common variants are ***Feld-Hell*** (traditional on-off keyed, time domain), ***C/MT-Hell*** (Concurrent Multi-Tone frequency domain Hell), and ***S/MT-Hell*** (Sequential Multi-Tone frequency domain Hell). The three systems have slightly different properties and offer different advantages.

Feld-Hell is not compatible with the other systems. The two frequency domain techniques can be used interchangeably, given the correct parameters.

Feld-Hell and C/MT-Hell are currently the most widely used variants, with C/MT-Hell favoured by power users and for DX. EVM compatible S/MT-Hell is favoured by those with limited equipment.

All three modes are direct printing, and therefore *human readable*, not intended for machine interpretation, and exhibit best performance when human eye/brain character and context recognition are used to best advantage. For best performance, implementations of these modes should ideally follow the Human Readable Text Mode Philosophy.

Human Readable Text Mode Philosophy

1. ***The transmitter uses no coding***. Received noise and path distortion only introduce character distortion, and cannot make a change of interpretation to a different character, or cause sync problems. Coding is not used for the data, for synchronism or for any start-stop mechanism.
2. ***The receiver does not decide when data is present***. The use of over-sampling and mathematical and/or optical integration allows the eye to reconstruct the image, despite transmission path and equipment timing variations.
3. ***The receiver does not decide what data is present***. The use of analogue to digital conversion and grey-scale image presentation allow the receiver to display as a brightness value the statistical likelihood of a data pixel being present in the radio channel at any time.

---

2. Feld-Hell

a. Definition

Feld-Hell is an on-off keyed uncoded text transmission system. Individual text characters are defined by dots in a dot matrix, and the matrix is transmitted in a fixed raster-scanned sequence. The transmission of dots is nominally timed at 122.5 baud, but no synchronising system is used. The receiving system operates quasi-synchronously, ie. is adjusted to run at about the same speed, and small errors in speed are compensated for by displaying the received image twice, so that phase errors have limited effect. The system is thus immune to the sync-related errors of many text transmission systems

Feld-Hell is relatively immune to noise interference, does not require complex transmission equipment, and performs well with low power.

b. Coding

Feld-Hell is uncoded, but sent as a raster scan of text characters. At the receiving end the received data, with errors, is displayed for visual interpretation. Since no coding is used, errors introduce noise, and thus effect the readability of the text, but cannot change the characters from one to another, as happens in coded systems, such as radio teletype.

The character set (called a *font*), defines each character as a collection of rectangular dots or *pixels* (picture elements) in a rectangular grid or matrix. The height of each pixel is represented by the duration of the transmitted pulse. The characters are transmitted by scanning up each column of the character, then each successive column, in the order the text is read. For example, in Fig. 1, the pixel transmission order is A1, A2…A7, B1, B2 etc. Printed "black" elements or pixels are transmitted as key down (carrier), while non-printed "white" pixels are not sent (key up), but maintain the same duration as a transmitted element.

In a simplistic system there are seven pixels per character column, and seven columns per character, as illustrated in the dotted matrix of Fig. 1, but neither of these is necessarily fixed. Typically, five of the seven pixels per column may contain data bits (the rest remain white), and five of the seven columns per character may contain data bits (the rest remain white). Thus there are 25 useable pixels in a matrix of 49 dot periods per character.

Most systems, including the traditional mechanical system[1][2], nominally employ twice as many pixels per column, and transmit 10 (half sized) pixels out of 14 per column, with the text font designed so that half size pixels are never transmitted alone (either black or white). This limits the transmitted bandwidth, while improving the vertical text resolution. This is clearly illustrated in the following diagram, where the F column of letters “B” and “D” exhibit extra half pixels, and column F of the letter “C” exhibits pixels shifted by one half dot-time:

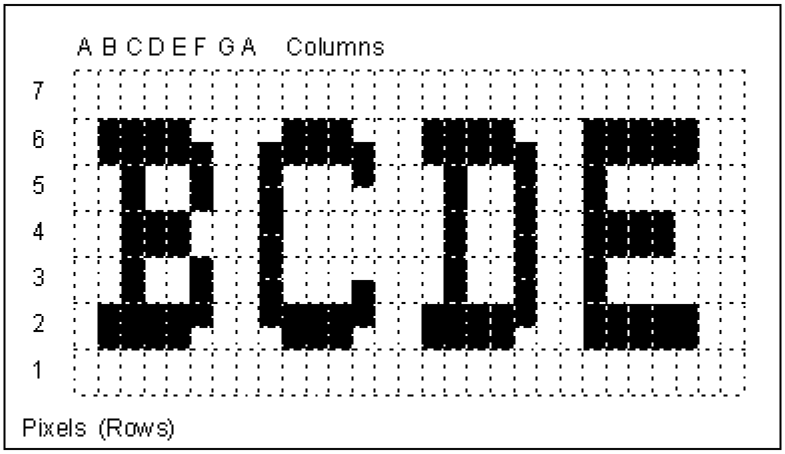
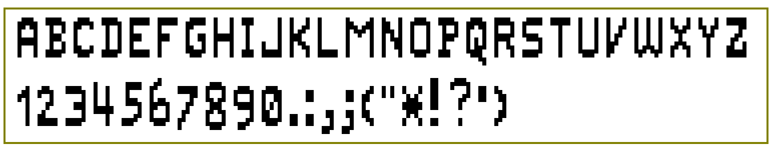


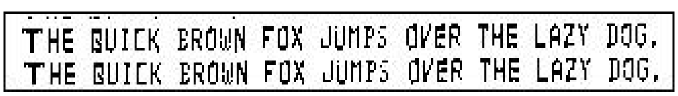
Fig. 1 Character Matrix

Some systems are limited to transmitting upper case text and a limited range of punctuation. The receiver, by its very nature, will however portray any transmitted character faithfully. It is of course difficult to adequately define lower case characters in a 5 x 5 matrix, however there is no reason why the normally non-printing dot time slot below the text (row 1 in Fig. 1) cannot be used for lower case descenders. The traditional Feld-Hell font did this for characters "Q" and "7", and above for the characters “4” and “6”:



Traditional Feld-Hell font

This font is available.[3] Versions exist with extended characters. Many systems offer a "double sized" mode, where each column of dots is transmitted twice consecutively, at the same column rate (baud rate) as in normal mode. This halves the transmission speed for the same baud rate, makes the characters twice as long, but no higher. It does improve readability. Some systems (that do not offer lower case) treat this technique as "Upper Case", ie. to differentiate capitals, as seen in the example below, where the initial “T” is double width:



Feld-Hell received text example

Other systems offer a half sized receive mode which displays each received character using half width pixels, so offering the ability to display normal looking text with enhanced (eye integrated) noise immunity whenever text is sent in "double sized" mode.

c. Timing

All Feld-Hell transmissions are at 122.5 baud for a hypothetical 7 x 7 dot matrix. The traditional fixed spaced font thus transmitted 2.5 characters/sec (122.5÷49), or 25 WPM. ***The only fixed parameter is the vertical column timing, 17.5 columns per second***. Provided the minimum transmitted element size is 8.16ms (122.5 baud), there is no reason why greater dot resolution cannot be achieved per column, nor why more or less columns should be sent per character, thus leaving significant room for enhanced characters using high resolution and proportional fonts.

The timing accuracy of transmitter and receiver should be within 0.1%, and preferably better.

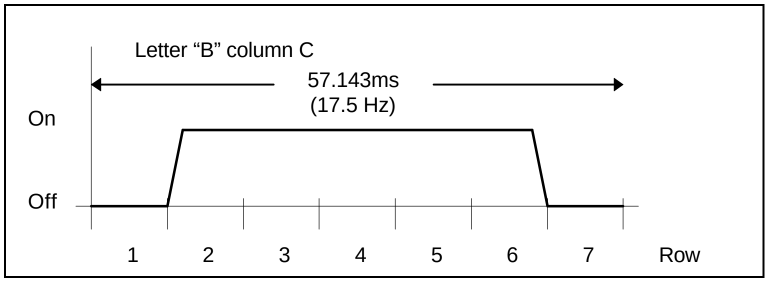


Fig. 2 Column timing

The character aspect ratio is such that a single 7 x 7 pixel will be 1.5 units high and 1.0 units wide, so the letter “B” is 1.5 times as high as wide. This is clearly seen in Fig. 1. Thus most characters look “right” in a 5 x 5 matrix. Some characters, such as “W” and “M” could benefit from more columns; others such as “I”, “l”, “1” and much punctuation could benefit from fewer columns (proportional font). Transmitter font design is crucial in giving the received display a tidy and highly readable appearance.
Despite not being a proportional font, the traditional Feld-Hell font is very clear, tidy and readable.

Each transmitted element should preferably have a raised cosine profile for minimum bandwidth, but it has been found in practice that trapezoidal pulses with 2ms edges are adequate. Note that the dot time (for seven dots per column) is only 8.16ms, which highlights the vertical resolution restriction and therefore the need to define the font with care.

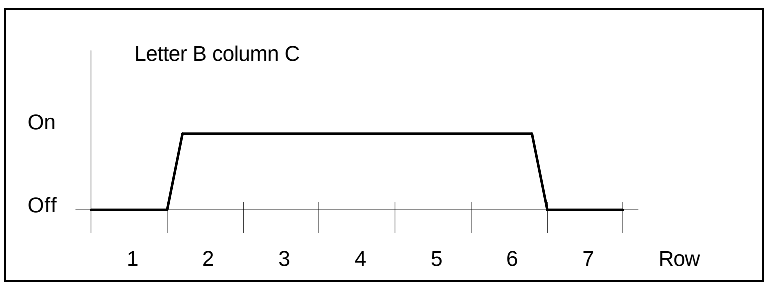


Fig. 3 Element timing

Sequentially transmitted dots without intervening non-printing gaps should not be sent as individual dots, but as a single continuous dash. This is illustrated in Fig. 3. This rule improves the received image, since the quasi-synchronous reception does not sample data synchronously with the transmitted bits. In addition, the transmitted bandwidth is (on average) reduced by this technique.

The next diagram illustrates the timing using the “half dots” to improve vertical resolution. No data element may be shorter than 1/7 of the column period:

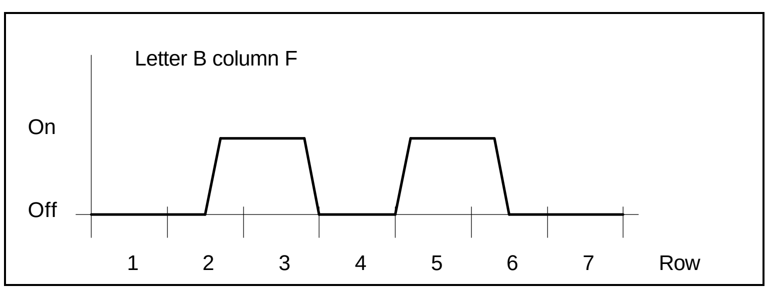
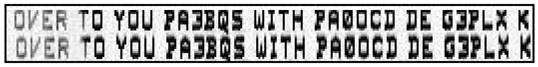


Fig. 4 Half dot timing

Where no characters are waiting in the buffer for transmission, the transmitter sends nothing.
When a new character arrives in the buffer its transmission should be delayed and sent synchronous with the last transmitted character, ie. maintaining constant column phase. Column timing is thus equivalent to HFFAX or SSTV line timing. The delay between characters need not be for a full character; any number of complete column times is sufficient.

The receiver must sample the received data an integral number of times per column period, at least 14 times, and preferably more. The received data reconstructs the transmitted data twice: each received sample is displayed in two displayed locations, spaced vertically apart by the number of samples per column - ie. if there are 20 samples per column period, the samples are displayed twice 20 samples apart vertically, with the subsequent sample displayed on the next pair of locations up. This can be illustrated with the following off-air example:



Grey scale double text example

The purpose of this technique, which is as old as the mode, is to defeat the random phase of the receive sampling clock with respect to the transmitter column timing. It also helps to retain text readability when the timing is badly in error:


1% timing error example

The purpose of the non-sent rows at the top and bottom of the character can be seen, in that they separate the two lines of text, particularly as it wraps around due to incorrect phasing or timing. This example also illustrates the double width "capital" letters.

Received text tends to lean slightly to the right due to the sequential scanning process, but this is generally compensated for in the transmitter font design. The example below illustrates the lean, in that for example, the bottom of the upper letter "I" is not directly above the top of the lower letter "I".


Example of leaning text

d. Modulation

The transmission consists of an on-off keyed sine wave audio sub-carrier, typically at 1000 Hz, but traditionally at 900 Hz. The actual frequency is unimportant. Zero crossing switching or data element synchronous switching of the sub-carrier would be useful for bandwidth reduction, but not necessary if a profiled pixel envelope is used. This keyed sub-carrier is used at low level to drive the microphone audio circuits of an SSB transmitter, thus in effect producing keyed carrier high speed CW (A2).

e. Demodulation

The receiver should provide adequate bandwidth for the received signal (about 400 Hz), and the filters must have excellent phase propagation near the filter edges. FIR filters are ideal in this respect. The filters should be preferably adjustable in bandwidth (to at least 600 Hz bandwidth) to make tuning easier when conditions are good. The centre frequency should match the transmitter sub-carrier frequency.

A full wave sub-carrier demodulation technique should deliver base-band data to an over-sampling A-D converter and display. Synchronous detection (DSP base-band heterodyning) would be appropriate. A post-detector low pass filter should limit the base band bandwidth to 2ms rise-time to match the transmitted data and avoid unnecessary noise and aliasing problems.

The traditional electromechanical receiver contained a 900 Hz LC band-pass filter, a full wave detector and an electromechanical printing mechanism which printed a black picture element whenever, and for as long as, the signal reached or exceeded about 90% of the peak pixel height. Thus the system did not provide property (3) of the human readable modes philosophy.

3. S/MT-Hell

a. Definition

Sequential tone Multi-Tone Hellschreiber is a frequency domain technique, and as such requires FFT demodulation. It represents something of a half-way house between Feld-Hell and C/MT-Hell. On the one hand, like Feld-Hell, it is a sequential transmission technique, yet like C/MT-Hell, it is a frequency domain technique. Unlike Feld-Hell and C/MT-Hell, S/MT-Hell is believed to be a modern (1998) invention[4].

S/MT-Hell characters are sent using a modified raster scan method, where the timing of the pixels is unimportant, so long as the sequence is maintained and the speed kept relatively constant, both to preserve character shape. There is no synchronism, and no accurate timing of the scanning process is necessary. In addition, within limits, the non-printing pixels can be omitted, ie. not sent at all!

The advantages of S/MT-Hell are speed, immunity to timing and time domain interference, simplicity of signal generation and ease of transmission. In addition the transmitted power is concentrated in a single dot, like Feld-Hell, so performs well with low power.

b. Coding

S/MT-Hell is uncoded, but sent as a raster scan of text characters. The received data, with errors, is displayed for visual interpretation. Since no coding is used, errors introduce noise, and thus effect the readability of the text, but cannot change the characters from one to another, as happens in coded systems, such as radio teletype.

The character set (called a *font*), defines each character as a collection of rectangular dots or *pixels* (picture elements) in a rectangular grid or matrix. The length of each pixel is represented by the duration of the transmitted pulse. There is no width information in each pixel - they exist at a certain frequency, and therefore at a certain height within the character. The characters are transmitted by scanning up each column of the character, then each successive column, in the order the text is read. The pixel transmission order is the same as for Feld-Hell, but the unused white pixels above and below the printed are neither used or necessary. Printed "black" elements or pixels are transmitted as key down (carrier), while non-printed "white" pixels are not sent (key up). What differentiates S/MT-Hell is that (a) the “white” pixels need not be transmitted, and (b) the elements in each row are transmitted at different sub-carrier frequencies. This latter property is illustrated in Fig. 5.

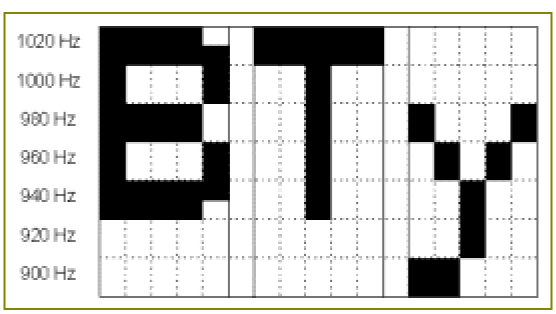


Fig. 5 Character Matrix

In a simplistic S/MT-Hell system there are seven pixels per character column, and five columns per character, plus a white inter-character column, as illustrated in Fig. 5, but neither the number of pixels nor the number of columns is necessarily fixed. All seven pixels per column may contain data bits, and all five of the columns may contain data bits. Thus there are 35 useable pixels in a matrix of 35 + 7 dot periods per character.

It was stated above that the “white” pixels need not be transmitted. It has been found that, provided the character shape is retained, this is generally true. This of course significantly enhances the transmission speed relative to the pixel duration. Problems occur with distortion of the characters if this is taken to extreme, for example on receive, the letter “T” in the above example will look like the letter on the right in Fig. 6 if white pixels are given full duration, and like the letter on the right if no white pixels are transmitted. The centre letter has about half the white pixels transmitted:

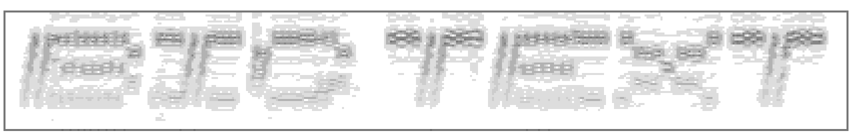
Fig. 6 White Pixel Deletion

The gap in the top row of the “T” occurs because the time taken to send each of the pixels in the vertical stroke delays the rest of the top row after the first two elements. Several techniques are successful in reducing the problem without compromising the speed advantages of omitting white pixels. Note in Fig. 6 that the left character is much narrower, as less time is taken to transmit it.

Few successful examples of S/MT-Hell exist[2][3]. Those that do, use very few rows (different tones) in order to improve the transmission speed. The most successful system[2] employs five rows for upper case, and two rows for lower case descenders, as illustrated in Fig. 5. In general, only five tones are transmitted per column, whether the letters are upper case, or lower case.

S/MT-Hell systems invariably employ proportional fonts, as they considerably improve throughput. This is achieved by reducing the number of columns for some characters, but retaining the non-printing inter-character column. Lower case is practical, but is generally not as readable as upper case:

Double width print is achieved in a similar manner to Feld-Hell. Double column text is less affected by the distortion due to omitted white pixels:



All S/MT-Hell text leans to the right as a result of the sequential raster scanning process. The effect is more marked than Feld-Hell, but is considered an advantage, as the text is easier to identify in severe lightning noise, which generally takes the form of vertical bands.

c. Timing

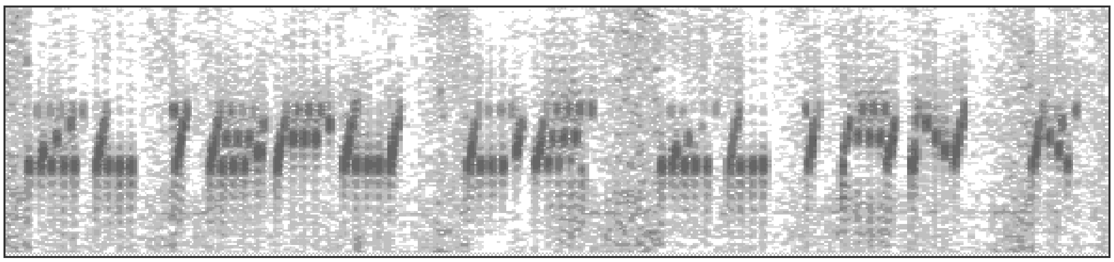
There is no timing definition (in the conventional sense) for S/MT-Hell. The pixel rate affects the text throughput, and the compatibility with different receiving equipment, but need not be accurate or constant. Timing restrictions are rather more internal, ie. the pixel transmission rate and row spacing are interrelated.

Since each of the rows of S/MT-Hell consist of on-off keyed carriers in the time domain, the keying sidebands have a significant effect in the frequency domain. S/MT-Hell text suffers from interference from this keying, and best readability has been found to occur when the pixel rate and the row separation are numerically the same. For example, the tones illustrated in Fig. 5 are spaced 20 Hz, so the data should be transmitted at 20 pixels/sec, or 20 baud. Speeds from 10 to 50 pixels/sec are common, but 30 px/sec with 30 Hz tone spacing is compatible with most systems. With double transmitted columns, 50 px/sec and 50 Hz spacing is reasonably compatible.

S/MT-Hell at 30 px/sec single column (compatible mode)

S/MT-Hell at 40 px/sec double column (compatible mode)

It may seem that S/MT-Hell (at 30 px/sec) is slow compared with Feld-Hell. This is not so, since there are on average only 11 pixel periods per character for S/MT-Hell (since generally only black pixels are transmitted), whereas there are always 49 pixel periods per character for Feld-Hell. The throughput of 30 px/sec S/MT-Hell is about 2.7 (30÷11) characters/sec (27 WPM).
If full duration white pixels are used, an additional effect occurs on reception, where the keying sidebands of adjacent pixels add to create a graph-paper like grid about the text:



Grid structure visible about S/MT-Hell text when full white pixel duration is used

This is avoided by various white pixel deletion techniques, and the sidebands tend to form a less noticeable clutter of noise below the text:

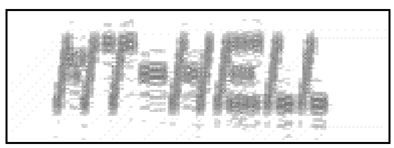


Fig. 7 Merged Pixels with no Sideband Grid

All the pixel generation rules of Feld-Hell apply to S/MT-Hell. No element (sent or not sent) should be shorter than one nominal pixel period. Pixels should have a raised cosine or 2ms rise-time trapezoidal profile. Text reception quality is best when sequentially transmitted elements are generated by sliding the tone from one row value to another (as a chirp), rather than generating individual keyed pixels.

d. Modulation

The transmission consists of multiple on-off keyed sine wave audio sub-carriers, in the range 800 - 1100 Hz. The actual frequencies are unimportant, but only one tone is generated at a time. Zero crossing switching or data element synchronous switching of the sub-carriers would be useful for bandwidth reduction, butis not necessary if profiled pixel envelopes and chirps are used. The keyed sub-carriers are used at low level to drive the microphone audio circuits of an SSB transmitter in LSB mode.

Tone frequencies are chosen to match most receiving systems. The range 800 - 1100 Hz is normal. Tones are equally spaced in frequency. The convention is to generate lower tones for the bottom of characters and higher tones for the top. There is no need to provide an inverted character option.

The sub-carrier tone generation can be effected in software, using an FM generator such as a PC sound card, or by using an amplitude and frequency controlled audio oscillator.

The signal can also be generated by direct base-band modulation of a frequency shift keyed VFO or VCO controlled transmitter. This is convenient for LF and QRP transmissions.

It is conventional to use LSB on all bands. This implies that direct FSK transmissions must place the bottom of each character higher in frequency than the top.

e. Demodulation

The receiver should provide adequate bandwidth for the received signal (about 400 Hz). The centre frequency should match the transmitter sub-carrier frequencies. Tuning is very non-critical. If the incorrect sideband is used, the text will appear inverted.

The sub-carrier signal from the receiver is passed through a bandpass filter for anti-aliasing purposes, and directly processed by a fast repetitive FFT processor. The results are displayed in grey-scale as a waterfall plot. The display can be windowed, as it need only display a range of about 500Hz. The sample rate, bin size and bandwidth depend on the transmission characteristics, but (for example) for 30 px/sec 30 Hz/row transmissions, 5.5 kHz sample rate, 1024 point FFT (with only about 50 points displayed) will give about 5 Hz vertical resolution.

The FFT conversion speed should be adjusted to provide the correct character aspect ratio. If the conversion rate is limited, the display should directly print each conversion result as a column of grey pixels. 16 level grey is just sufficient. At faster conversion speeds, narrower pixels can be displayed (for eye integration), or conversions can be mathematically averaged and higher grey scale resolution used. User adjustments of the column printing speed is useful.

The computer screen display should portray multiple lines of the received graphics image, which can be achieved by copying each completed line up by one line, with the top line being lost and the bottom line being cleared for the next line of text. There is no notion of line feed - the display simply moves up one line as each line is completed.

The FFT conversion rate is not synchronised to the transmission rate, but must be fast enough to accurately sample the pixels, ie. at least twice the dot rate. The effect of this non-synchronism is to blur the transmitted pixels into smooth characters, as is illustrated in Fig.7.

Spectrogram 4.2[9] is widely used to demodulate and display S/MT-Hell, as it is simple to use, sensitive and adaptable to computers of different capability and different transmission rates.

4. C/MT-Hell

a. Definition

Concurrent tone Multi-Tone Hellschreiber is a frequency domain technique, and as such requires FFT demodulation. It was first described in 1937[6].

C/MT-Hell characters are sent using a parallel row scan method, where the timing of the pixels is unimportant, so long as the pixels of the same column occur together and the speed kept relatively constant, to preserve character aspect ratio. The shape is not otherwise affected by pixel timing. There is no synchronism, and no accurate timing of the scanning process or receiving process is necessary.

The advantages of C/MT-Hell are high resolution, immunity to timing and time domain interference, and font flexibility. The transmitting and receiving equipment must be very linear to handle multiple tones concurrently.

b. Coding

S/MT-Hell is uncoded, but sent as a parallel row scan of text characters. The received data, with errors, is displayed for visual interpretation. Since no coding is used, errors introduce noise, and thus effect the readability of the text, but cannot change the characters from one to another, as happens in coded systems, such as radio teletype.

The character set (called a *font*), defines each character as a collection of rectangular dots or *pixels* (picture elements) in a rectangular grid or matrix. The length of each pixel is represented by the duration of the transmitted pulse. The position of the pixel within the character is represented by the timing (horizontal) and frequency (vertical) of the pixel. The characters are transmitted by scanning each row of the character simultaneously, in the direction the text is read. Printed "black" elements or pixels are transmitted as key down (carrier), while non-printed pixels are transmitted as key up.

The nature of C/MT-Hell is such that the text quality benefits from the use of many rows. Systems with nine and 16 rows are common. The use of many rows allows for many different fonts in several sizes to be used, for example the 16 row system[7] utilises Windows fronts from 8pt to 14 pt.

G3PLX MTHELL uses 14 pt Windows fonts

Nine row systems[8] suit the use of dot matrix printer fonts. Typically the full ASCII character set is available, in proportional or fixed spacing.

G3PPT MTHKBD uses a nine dot printer font

c. Timing

The pixel column stroke rate affects the text throughput and compatibility with different receiving equipment. The stroke rate need not be particularly accurate. The stroke rate is chosen so that the stroke and row spacing are similar, which allows for the maximum possible throughput for the bandwidth used (Nyquist criterion).

The most widely used system[7] uses 16 tones spaced 15.625 Hz apart, and 15.625 Hz column stroke rate. Utilising the formula **(column rate = bandwidth ÷ pixels/column)**, this provides a 250 Hz bandwidth signal. Using a 16 x 9 font, a throughput of 1.75 characters/sec (17.5 WPM) is achieved.

Smaller fonts can be used, so a 10 point font (10 x 6) will increase the throughput to about 2.5 characters/sec at reduced resolution.

G3PLX MTHELL with 10 pt font

Parameters for faster and slower alternative speeds should be chosen by applying the above formula for different bandwidths and numbers of tones (rows). Speeds of 1, 2 and 4 characters/sec are common. A 9 x 5 dot-matrix font operating at 2 characters/sec (20 strokes/sec) occupies about 200 Hz bandwidth and is compatible with the G3PLX system.

Since each of the rows of C/MT-Hell consist of on-off keyed carriers in the time domain, the keying sidebands have a significant effect in the frequency domain. C/MT-Hell text suffers far less from interference from this keying than S/MT-Hell, as the keying rate is lower for the same throughput. For best readability the column stroke rate and the row separation are numerically the same, which coincidentally leads to greatest throughput.

No element (sent or not sent) should be shorter than one nominal column period. Pixels should have a raised cosine or 2ms rise-time trapezoidal profile. Text reception quality is best when sequentially transmitted elements in each row are generated by one continuous tone, rather than generating individual keyed pixels.

d. Modulation

The transmission consists of multiple on-off keyed sine wave audio sub-carriers, in the range 800 - 1100 Hz. The actual frequencies are unimportant, and all tones can be conceivably be generated at one time. It is important therefore to design the tone frequencies and their phasing to limit as much as possible the peak excursions of the combined sub-carrier signal. The keyed sub-carriers are used at low level to drive the microphone audio circuits of an SSB transmitter in LSB mode.

Tone frequencies are chosen to match most receiving systems. The range 800 - 1100 Hz is normal. Tones are equally spaced in frequency. The convention is to generate lower tones for the bottom of characters and higher tones for the top. There is no need to provide an inverted character option.

The sub-carrier tone generation can be effected in software, using an FM generator such as a PC sound card[8], or by using an external DSP device[7].

e. Demodulation

The receiver should provide adequate bandwidth for the received signal (about 500 Hz). The centre frequency should match the transmitter sub-carrier frequencies. Tuning is very non-critical. If the incorrect sideband is used, the text will appear inverted.

The sub-carrier signal from the receiver is passed through a bandpass filter for anti-aliasing purposes, and directly processed by a fast repetitive FFT processor. The results are displayed in grey-scale as a waterfall plot. The display can be windowed, as it need only display a range of about 500Hz. The sample rate, and bandwidth depend on the transmission characteristics, but should result in at least 32 points displayed and at least 32 conversions/sec. DSP heterodyning to base-band prior to windowed FFT conversion is one way to achieve this.

The FFT conversion speed should be adjusted to provide the correct character aspect ratio. 16 level grey is just sufficient. At faster conversion speeds, narrower pixels can be displayed (for eye integration), or conversions can be mathematically averaged and higher grey scale resolution used. User adjustments of the column printing speed is useful.

The computer screen display should portray multiple lines of the received graphics image, which can be achieved by copying each completed line up by one line, with the top line being lost and the bottom line being cleared for the next line of text. There is no notion of line feed - the display simply moves up one line as each line is completed. To simplify tuning, one widely used system[7] displays a 500 Hz wide display line at the bottom of the screen, with guide lines for tuning, and copies only the centre 250 Hz up to subsequent lines.

The FFT conversion rate is not synchronised to the transmission rate, but must be fast enough to accurately sample the pixels, ie. at least twice the column rate.

5. Bibliography

[1] **Hellschreiber - What it is and how it works**, S.A.G. Cook G5XB, *Radio Communications*, April 1981.
[2] **The Hellschreiber - a rediscovery**, Hans Evers PA0CX, *Ham Radio Magazine*, December 1979.
[3] FELDHELL.FON, Windows font by Peter Martinez, G3PLX
[4] MOSAIC II, 124.EXE for DOS by Murray Greenman, ZL1BPU
[5] SMTHEL8.EXE for DOS by Lionel Sear, G3PPT
[6] **Seven-Frequency Radio-printer**, by L. Devaux and F. Smets, Les Laboratoires, Le Matériel Téléphonique, Paris, France, *"Electrical Communication", 1937.*
[7] MTHELL for Win3.x and EVM56002 by Peter Martinez, G3PLX
[8] MTHKBD2 for DOS by Lionel Sear, G3PPT
[9] Spectrogram 4.2 ("GRAM") for Windows 95/98 by Richard S Horne