Modem Bauds & Bits

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(8 Bit ASCII graphics use code page 437 or 850, Terminal Font)

BASEBAND

This is the starting point for data transmission. If the comms channel can handle DC & have a flat phase & amplitude response in Hz to beyond half the data rate in bits/S then the link should work. Over very long lines repeaters may be needed to straighten up the rounded edges & these can be straight Schmitt triggered amplifier or better still re-clocked (retimed) gated amplifiers.

```
 ┌─────┐     ┌       _.─┐           ┌────┐
 │  1  │  0  │     /' 1  \._0  /    │ 1  │  0    │
       └─────┘              '─┘          └───────┘
  GOOD DATA        ROUNDED DATA      TIMING ERRORS
```

The trouble with the need to find edges in the data to reclock & sync, means either a clock must be included with the data, or the data must have enough alternations (0 & 1s) that the clock can always be extracted.

When no DC path is available then all is not lost if the data is short & has no substantial DC component, then a DC clamp & restore circuit will work, as will random encrypted data system (spread spectrum) that has no net DC.

Anything else needs a Modulator & Demodulator "Modem" to translate the baseband to higher frequencies suitable to telephone line or radio path.

VSB (AM)

It is possible to send the data as Vestigial Side Band (part of AM signal), utilising nearly all the available spectrum to carry an information sideband. With VSB a carrier is sent near to the edge of the passband, this ensures the DC component is sent OK.

```
          Channel Width
 │  |.-~│~-._            |
 │  |   │    ~-._        |
 │  |LSB│  USB   ~-._    |
 │  |   │            ~-._|
─┼──┼───┼────────────────┼──
 300  400            2700Hz
```

Only a tiny fraction of the LSB is sent enough to make the carrier in the linear phase & level part of the channel bandwidth. This gives the maximum Baud rate possible for any channel.
BAUD is the changes per second, & DATA RATE is the number of bits per second.
In single level AM, AFSK or FSK there is a 1:1 relationship, 1 bit/S = 1 baud.

In this example 2300 Bauds or 4600 bits/S is possible on a narrow SSB channel.

However there are loads of problems with AM & VSB modes for data, so FM with its 2 sidebands became the dominant mode...

FSK 1200B/S

```
            0          1
 │    600Hz /│\        /│\ 600Hz
 │     of  / │ \      / │ \  of
 │    LSB /  │  \    /  │  \ USB
 │       /   │   \  /   │   \
─┼───────┼───┼──────────┼────┼──
 0 300 600  1k2  1k8  2k4   3k
```

This is fairly typical of what happens as the FM idle carrier at 1800Hz causes 2 AM CW signals to appear at the deviation set points representing the data 0 & 1.
Each of these carries full double AM side-bands up to the baud rate/2 in Hz, as it needs 2 bits to form a cycle.
(1800Hz carrier is used as it is the fastest)
(frequency on most telephone lines.)

In this example the data rate would be locked to the carrier frequency, if not locked system then similar but not exactly the same modem frequencies are used.

For this FSK to work, a bandwidth of 600Hz - 3kHz is needed, it does not have to be too level flat, as FM can be hard limited, that removes level changes & almost all noise effects.

So a bad line/comms link with more than 15dB frequency spread & worse than 15dB S/N is still error free despite being very poor for phone use.

However differing delay times for the 2 tones is critical, & a Group Delay difference of less that 1mS between 1200Hz & 2400Hz will garble the data, as the modem will Rx no tone, then 2 tones etc. This has no affect on comms audio!

Typical Group Delay of a long loaded line, or via a comms Rx IF filter!

```
   Delay
 1200uS-| \ Transformers              / Channel
  900uS-|  \  & caps                 /  Low pass
  600uS-|   ~-_                     /   Filtering
  300uS-|      ~~──..__         _.─~
    0uS-|              ~~────-─~
        +───┬───┬────┬────┬────┬─────┬───┬───┬───┬───>Frequency
        300 500 800  1k2  1k6  2k   2k4 2k7 3k 3k2 3k4  Hz
```

```
Sent data                                 Rx Data with 833uS of group delay!

______~~~~~~____________~~~~~~~~~~~~    ______????????????______??????~~~~~~
  0     1     0     0     1     1         0      no    0+1     1     no     1
1200  2400  1200  1200  2400  2400      1200    Sig 1k2+2k4        Sig   2400
```

Even so this is one of the simplest & robust standards around (this why it is still used), however it is important to have all the sidebands that make up the signal turning up all at the same time & at simular levels & also not completely drowned out in noise or over distorted.

GOING FASTER

If we look at what a telecomms line can pass e.g. 300Hz - 3.3kHz with some frequency attenuation & group delay. Then that would support a max baud rate of 3000 baud, e.g. an 1800Hz carrier with double sidebands up to ±1500Hz.

```
 |    1500Hz /|\ 1500Hz
 |    of   /  | \ of
 |    LSB/    |   \USB
 |     /      |     \
-+───┴───────┴───────┴───> Frequency
 0  300     1k8      3k3   Hz
```

Alternating baud signals of 010101 @ 3000 baud forms the highest side bands of ±1500Hz.

However this is not the data rate, but the max baud rate. Using Phase Modulation PM on 4 phases (Quadriture Phase Shift Keying) you get 1 of 4 states per baud or 2 bits per Baud (Dibits)

00	01
10	11

But by using AM multiple levels as well as PM together, it is possible to make a "single baud of carrier" represent 1 of many states, e.g. 16 AM levels & 16 phase angles, gives 256 states or symbols, which is equal to 8 bits of data per baud! That would make a data rate of 8x3k = 24kB/S.

Phase & level diagram (dartboard vector) for just 4x 4 (16 symbols)

```
 +4-  [0]                     [1]
 +3-     [4]               [5]
 +2-        [8]         [9]
 +1-           [C]   [D]
  0-               0
 -1-           [F]   [E]
 -2-        [B]         [A]
 -3-     [7]               [6]
 -4-  [3]                     [2]
LEVELS-4 -3 -2 -1  0 +1 +2 +3 +4
```

This give 16 pigeon holes (0-F) for each burst of carrier signal (baud) to drop into.

In practice the 4 phase are rotated per level shell to give the bigger pigeon holes.

Note that the carrier level of 0 can't be uses as it would not give any phase info.

```
 +4-  [ ][ ][ ][ ]   [ ][ ][ ][ ]
 +3-  [ ][ ][ ][ ]   [ ][ ][ ][ ]
 +2-  [ ][ ][ ][ ]   [ ][ ][ ][ ]
 +1-  [ ][ ][ ][ ]   [ ][ ][ ][ ]
  0-               0
 -1-  [ ][ ][ ][ ]   [ ][ ][ ][ ]
 -2-  [ ][ ][ ][ ]   [ ][ ][ ][ ]
 -3-  [ ][ ][ ][ ]   [ ][ ][ ][ ]
 -4-  [ ][ ][ ][ ]   [ ][ ][ ][ ]
LEVELS-4 -3 -2 -1  0 +1 +2 +3 +4
```

By using variable number of phases per carrier level, you can fill all the pigeon holes as close as possible, giving the biggest number of symbols, here 64, or 6 bits per Baud.

Noise, distortion, poor frequency/phase response will move the carrier into the wrong pigeon hole, & produce 6 errors at once!

However you don't get something for nothing, using 16 levels means the distortion & all noise must put the level into the next 6.25% level window, or 3.1% (-31dB peak). And the same goes for multiple phase mod, due to jitter & multipath etc. that must not to exceed 1/32 of a cycle peak @ 1800Hz! A very tight specification for radio path!

EQUALISING (training)
As the line will not be flat or have no group delay it is important that the modem has an equaliser that has the opposite characteristics to the line. This used to be an analogue nightmare, but with digital A-D convertion of the line audio signal, it is relatively simple to flatten in software!

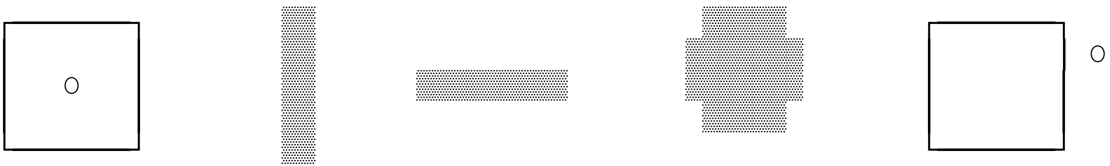
e.g. a Line with bump at 1kHz

```
Level
 |          /~\
 |    .------~   ~----.
 |   /                 \
-+----+-----+----+----+-----
 0  250   500   1k   2k    4kHz
```

Add in a % of signal data from 500mS ago & the bump will go. But then you get a bump @ 2kHz, so add in some signal data from 250mS ago, keep doing this until all bumps are above 3.4kHz.

Training can also be done on live data, by making small adjustments & seeing if the data quality (how near Rx symbols are to their pigeon hole's ideal centres)

Ideal Symbol in Centre of Pigeon Hole | Amplitude Trouble | Phase Trouble | Noise & Distortion | a Symbol in Error



So you see that although modern modems are super at equalising & giving 56kB/S max on a good short line, they can only do that over clean copper circuits, & high quality PCM audio systems that give <1% THD >50dB S\N & no phase jitter!

In practice most lines can't do this, so the modem is designed to drop back the baud (symbol rate) & or the number of levels/phase angles (symbols). Also the modem has error detection/correction, so missed errors that are passed through are low. The use of an encryption algorithm in some modems also minimises continuous retries of data patterns that might have high error rates.

BROADBAND

These systems are different & use much wider frequency range & multiple carriers each carrying some of the data in QPSK. But there are similarities, & nasty line problems will greatly reduce the usable data rate. A common cause of broadband data rate changing/hiccups is the need for the modem to reestablish what frequencies can be use due to changing QRM, e.g. Nightime AM station, or an old analogue cordless phone occasionally in use sending signals on the same cable as your broadband.

Why Don't U send an interesting bul?

73 de John G8MNY @ GB7CIP