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The Optimum IF Selectivity for Coherent Telegraphy (CCW)

This article presents a further contribution to the subject of coherent telegraphy.

Coherent telegraphy allows a considerable reduction of the transmit and receive bandwidth. The main selectivity in the receiver (bandwidth less than 10 Hz) can only be achieved easily at AF-level (digital filter). As is known, these extremely small AF-bandwidths are only of limited value without sufficient pre-selectivity in the VHF and IF chains. This is because unwanted signals will pass through all stages up to AF-level and can cause desensitisation, intermodulation, and unwanted control of the AGC-circuit.

This article is firstly to show how the minimum bandwidth of a IF-crystal filter is determined for telegraphy, and especially for CCW. Finally, various filter characteristics are compared with respect to their suitability. Part 2 of this article will then bring a proved circuit for home-construction.

1.

LIMITING OF THE MINIMUM BANDWIDTH DUE TO THE CHARACTERISTICS OF THE CRYSTALS

Two important crystal parameters determine the lowest possible relative bandwidth of a crystal filter: The Q of the crystal, and the temperature response of the crystal frequency.

An insufficiently hig Q of the crystal will cause a marked rounding of the passband curve, and reduces the slope. Furthermore, it will increase the insertion loss of the filter **(Figure 1)**.

A basic rule is that the crystal Q (Q_q) is at least 5 to 10 times the inverse value of the relative bandwidth b_3/f_0:

$$Q_p \geqq 5 \text{ to } 10 \times \frac{f_0}{b_3}$$

At a center frequency of 9 MHz, filter crystals have Q-values of approximately 120 000 to 150 000 which corresponds to a minimum bandwidth of 300 to 600 Hz. When using special crystal designs (e.g. overtone crystals), it is possible to increase the Q to 500 000 and more, which results in narrower filters.

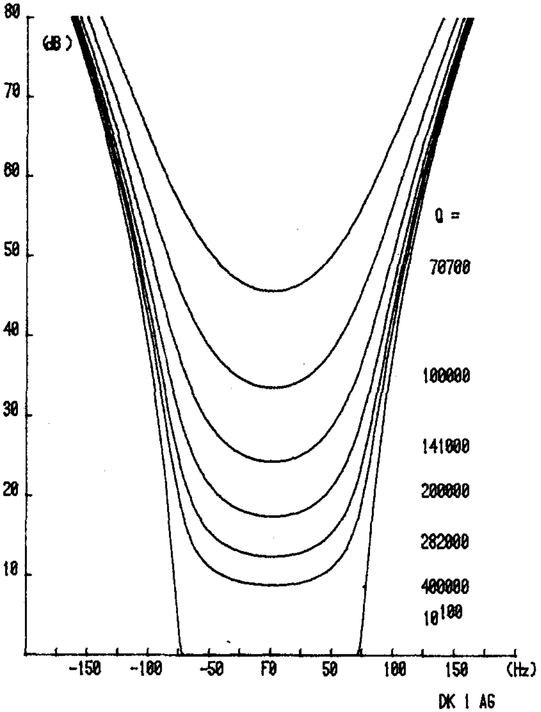

Fig. 1:
Filter curves as a function of Q of the crystals used

The temperature response of common filter crystals amounts, for example, in a temperature range of 0°C to 50°C, to ± 5 to ± 10 ppm; at a frequency of 9 MHz, this results in ± 45 to ± 90 Hz that the crystals can run, sometimes in opposite directions (1).

For this reason, the temperature response of the crystals used in very narrow crystal filters must be operated at their theoretical limits, which is in the order of ± 1.0 to 1.5 ppm (9 to 15 Hz) in our example. For higher demands, such filters are often placed in crystal ovens.

Another alternative would be to select a further lower intermediate frequency below 1 MHz. Crystals in this range have, it is true, a somewhat lower Q, however, the relative bandwidth is lower for a certain bandwidth and thus the demands on the crystals are lower. On the other hand, good crystals are expensive in this frequency range, and are also larger. The main disadvantage is, however, the additional conversion.

2.
LIMITING OF THE MINIMUM BANDWIDTH DUE TO THE PULSE BEHAVIOUR

Every CW-man will know that narrow-band filters tend to ring at higher transmission speeds. This means that the »clean« CW-signal from the transmitter is distorted: Rise and fall slopes are flatter, and overshoots will appear.

The frequency spectrum of a periodically keyed HF-carrier possesses a number of lines spaced at multiples of the keying frequency in addition to the carrier frequency. In the case of CW-transmissions, these lines will form a virtually continuous spectrum. If the group delay (which is the delay time required for the envelope of the CW-signal to pass from the filter input to output) is not equal for all spectrum components, this will mean that these components will arrive at the output at different times. They will then be combined at the output and result in a distorted waveform.

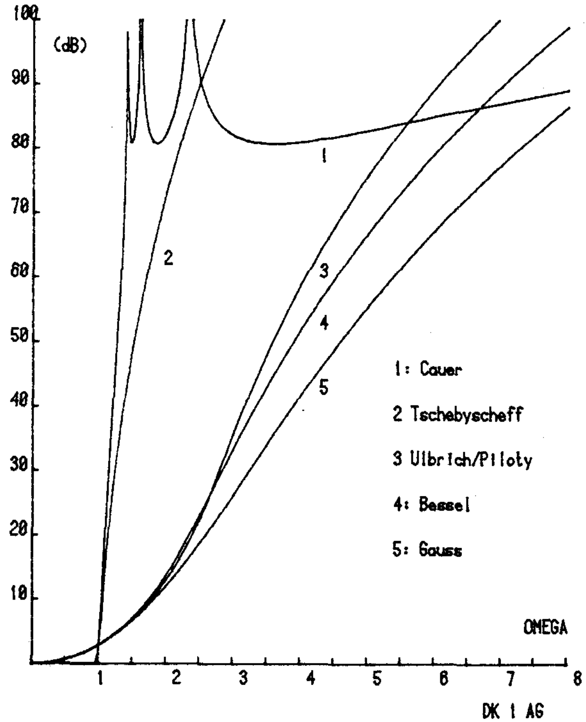

Fig. 2:
Comparison of the passband curves of five common filter characteristics

With normal filters, the group delay is at a minimum in the center of the passband range, and increases to a multiple of this at the edge of the passband range (see Section 3). The narrower the filter, the greater the effect of these group delay distortions, since they distort the low-order spectrum components, which have the greatest effect on the waveform.

3.
PULSE BEHAVIOUR AND SELECTIVITY OF VARIOUS TYPES OF FILTER

An ideal CW-filter would be a filter having a most constant group delay over the whole passband range (2), as well as a bandpass characteristic that was as narrow as possible and possessed the steepest possible slopes.

Unfortunately, these two demands cannot be achieved at the same time: A filter with a good pulse behaviour will have a poor selectivity, and a steep filter will have a poor pulse behaviour; Both characteristics are connected together mathematically, and every practical solution represents a compromise between both demands.

This is now to be discussed in conjunction with various, common filter characteristics. An 8--pole filter with a bandwidth of 150 Hz is to be assumed in the examples. The appropriate bandpass curves are given in **Figure 2**, whereas **Figure 3a and 3b** show the group delay in the passband range, and **Figure 4** the pulse behaviour of these filters.

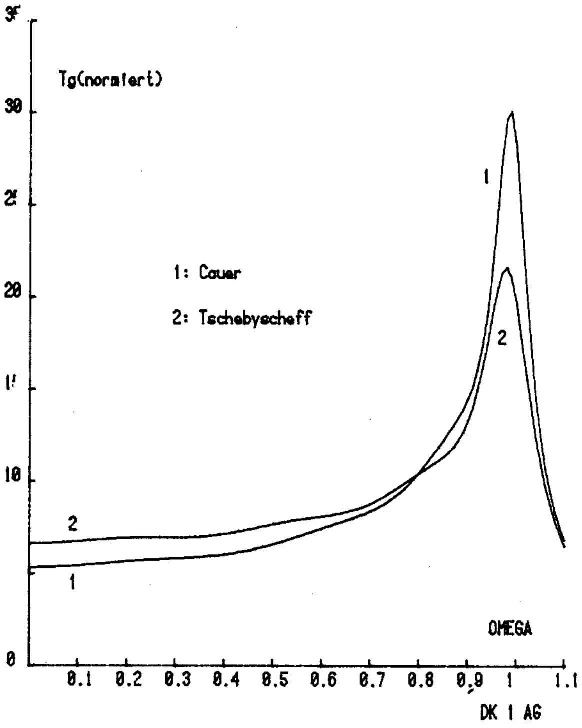

Fig. 3a:
Group delay of Cauer and Chebishev-filters

All curves are given in standardized form. In the case of the frequency axis, $\Omega = 0$ corresponds to the center frequency, and $\Omega = \pm 1$ to the 3 dB points on the filter characteristics. The axis is therefore calibrated in multiples of half the 3 dB bandwidth.

The group delay τ_g is also standardized as T_g: the group delay τ_g (in sec) is obtained for a certain filter having a 3 dB bandwidth b_3 (in Hz) from the following equation:

$$\tau_g = \frac{T_g}{\pi \times b_3}$$

The pulse behaviour is the shape of the output signal (i.e. the demodulated envelope), which results when the carrier f_0 at the input having an amplitude »1« is suddenly (ideally square-wave«) switched on.

The time axis is also given in standardized units T and can be recalculated into seconds using the following equation:

$$t = \frac{T}{\pi \times b_3}$$

Table 1 shows a list of the most importants data. The first four columns give the stopband-width in Ω-units (shape factor). The following columns contain the most important data about the standardized group delay: The value at the center frequency T_{go}, the maximum value, the value at the 3-dB-points, and the point at which the group delay has fallen off by 10 % with respect to T_{go}.

Table 1

The lowest part of the Table describes the pulse behaviour: The overshoot in % and the (standardized) times after which 50 % and 90 % of the final amplitude »1« is achieved.

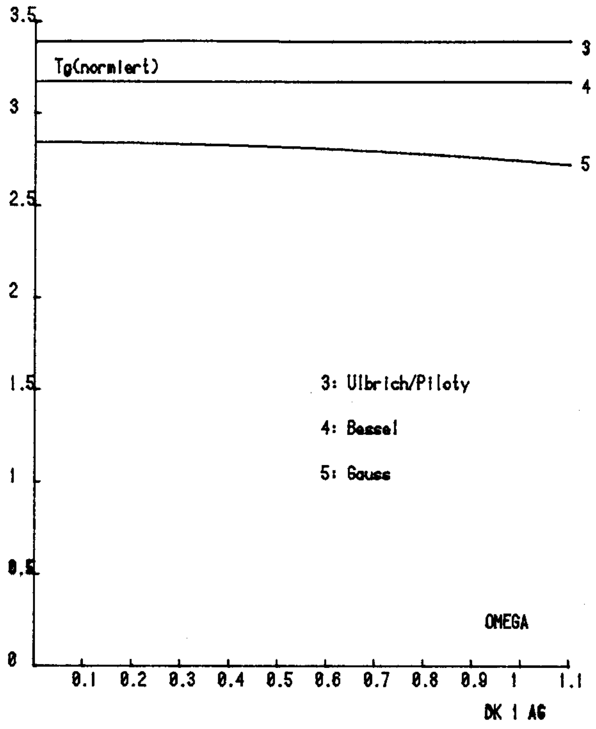

Fig. 3b:
Group delay of Ulbrich/Piloty, Bessel, and Gauss filters

Type of Filter / Characteristics	Cauer C 0815b-45°	Tschebyscheff C 0815b-T	Gauß 8 Pol	Bessel 8 Pol	Ulbrich/Piloty d = 0,01 / 8 Pol
Selectivity					
Ω (20 dB)	1,085	1,136	2,60	2,35	2,40
Ω (40 dB)	1,201	1,362	3,90	3,34	3,17
Ω (60 dB)	1,314	1,700	5,38	4,53	4,07
Ω (80 dB)	1,380	1,884	7,28	6,08	5,30
Group delay					
T_{go} (Ω = 0)	5,359	6,630	2,842	3,174	3,389
T_{max}	30,117	21,600	–	–	–
$T_{g\,3\,dB}$ (Ω = 1)	28,185	19,737	2,741	3,174	3,394
(10 %)	–	–	1,63	2,07	2,51
Pulse behaviour					
Overshoot	19,82 %	18,49 %	0	0,45 %	0,44 %
T (50 %)	5,9	7,1	2,67	3,04	3,26
T (90 %)	7,4	8,5	3,83	4,16	4,36

Table 1: Selectivity, group delay, and pulse behaviour of various filter characteristics

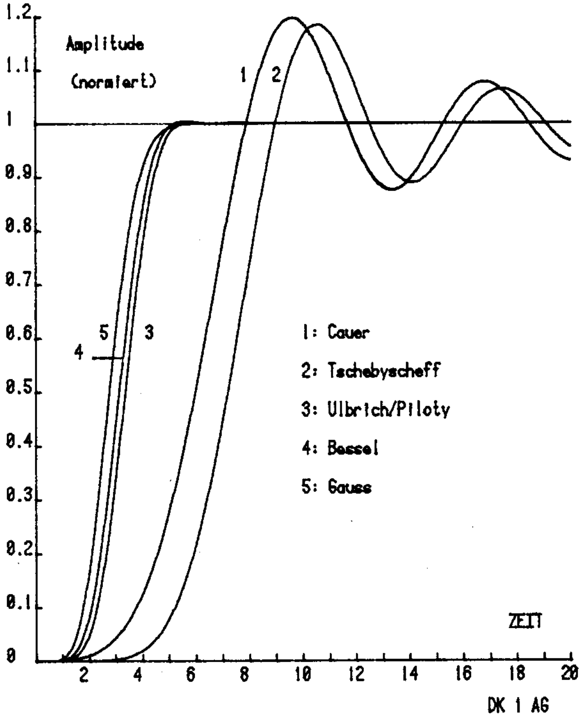

Fig. 4:
Comparison of the pulse behaviour of the previously mentioned five types of filters

3.1.
CHEBISHEV-FILTER

This is the most commonly used filter characteristic. Most of the CW-filters on the market are of this type. Chebishev-filters have a very good selectivity, with steep slopes, where a slight (the theoretic !) ripple is permissible in the flat top of the passband range. In our example, the ripple is 0.0988 dB (≙ 15 % reflection). The actual ripple is usually higher due to component and alignment tolerances.

In the stopband range, the attenuation will continue to increase. In the given case, the shape factor amounts to (60 dB : 3 dB) = 1.7, with a 60 dB bandwidth of 425 Hz; the designation of this filter is: C 0815b-T (see[5]). The group delay increases, however, steeply at the edge of the passband range and achieves a maximum of 45.8 ms in our example with respect to 14.1 ms at the center frequency. When one observes the pulse behaviour, one will see that the filter reacts after a very large delay: 90 % of the final amplitude is achieved only after 18.0 ms. Furthermore, it overshoots greatly by 18.5 % and the oscillation is reduced slowly what generates the well-known ringing effect. When one considers that the dotlength is only 40 ms (4) at a speed of 150 letters per minute and that with RTTY at a speed of 45.45 (100) Baud the unit length amounts to 22 (10) ms, the resulting output signal can be assumed !

If the (theoretical) ripple is reduced to zero, one will obtain the so-called potential or Butterworth-filters. However, these are not to be dealt with here, since they do not bring any improvement of the pulse behaviour.

3.2.
CAUER-FILTER

In order to increase the slope steepness further, additional attenuation poles are generated in the stopband range with Cauer-Filters

(»elliptical filters«). In the example, the first pole position was set at $\Omega = 1.403$, and the ripple in the passband range was selected to be the same as that of a Chebishev-filter (filter terminology: C 0815b-45°, see [5]). The resulting shape factor amounts to 1.31, which means that the 60 dB bandwidth amounts to only 328 Hz !

The group delay is similar to that of the Chebishev-filter, however, with a higher overshoot of 11.3 ms (center frequency) to 63.8 ms at the limit. The pulse behaviour is even worse: it is true that the pulse appears somewhat faster (90 % after 15.7 ms) however, the overshoots are stronger (19.8 %) and take more time to decay. The improved selectivity is obtained at the cost of the pulse behaviour.

3.3.
GAUSS-FILTER

With this type of filter, the passband curve approximates the well-known Gaussian distribution curve – the larger the number of poles, the better –. Gauss-filters have an ideal pulse behaviour with very fast rise time (90 % after 8.13 ms) and without overshoot. However, the selectivity is very poor: 60 dB are achieved firstly at 5.38 times the bandwidth (1345 Hz) !

The group delay sinks very little at the 3-dB-point (6).

3.4.
BESSEL-FILTER

In the case of Bessel-filters, (also called Thomson-filters), the group delay is optimized to have the best flat characteristic (7). In our example, it amounts to 6.73 ms over the whole passband range. It falls off by 10 % first at 2.07 times the bandwidth. The pulse behaviour has only a very slight overshoot of 0.45 %, which ceases immediately; the rise time is slightly slower (90 % after 8.83 ms) as was the case with the Gauss-filter.

However, the selectivity is much better: The shape-factor 60 dB : 3 dB is 4.53, corresponding to a bandwidth of 1130 Hz.

3.5.
ULBRICH/PILOTY-FILTER

This filter is also called an »Equiripple-Phase-linear Filter«, and is a further development of the Bessel-filter by allowing the group delay to have a certain ripple (as was the case for the attenuation of the Chebishev-filter). This means that the group delay is constant over a far wider range, and the selectivity is also improved (8). In our example (standardized ripple 0.01), the 60 dB : 3 dB shape factor amounts to 4.07 (1018 Hz), the group delay amounts to 7.20 ms, and falls off by 10 % firstly after 2.5 times the bandwidth.

The pulse behaviour is very similar to that of the Bessel-filter: Overshoot 0.44 %, 90 % of the amplitude is achieved after 9.25 ms.

In addition to these filter characteristics, there are any number of further compromises, which would be far to extensive to be described in this article. To summarize, one can say that the cause of »ringing« of a filter is usually not that the bandwidth is too low, but more that the filter characteristic is not optimized.

4.
HOME-CONSTRUCTION OF A CCW CRYSTAL FILTER

The previously discussed 8-pole filter cannot be achieved in home construction, since the limits are in the order of a 4-pole filter. In order to still achieve a sufficient selectivity, two four-pole filters of the Ulbrich/Piloty type are to be connected in series using an intermediate

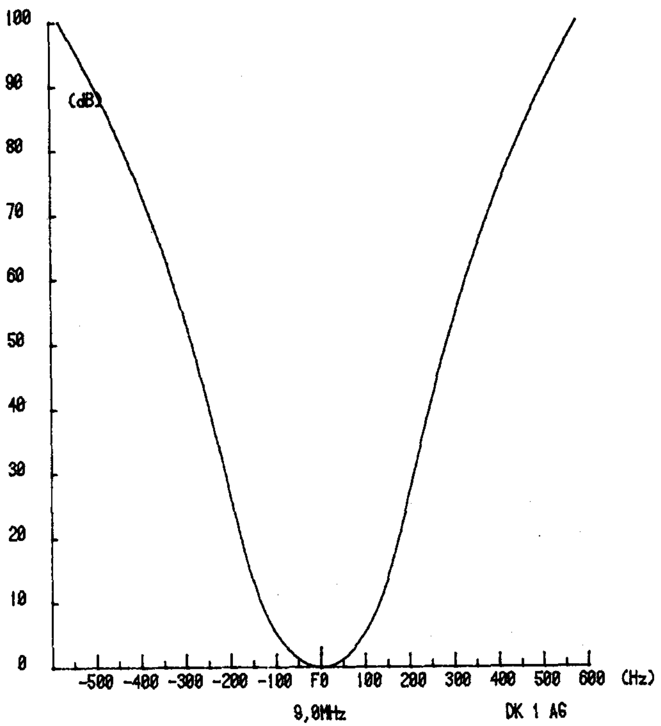

Fig. 5a:
Passband curve of the home-made filters described in part 2

large-signal amplifier stage as buffer. The amplifier stage has two tasks: Firstly it is to provide both filters with a pure ohmic termination – which would not be the case if they were connected directly in series: and secondly, it must compensate for the total insertion loss of the two filters of approximately 12 dB.

When using this circuit, one achieves virtually the same selectivity, with only a slight deterioration of the pulse behaviour when compared with an 8-pole filter.

Part 2 of this article will describe a 9 MHz-filter with a bandwidth of 150 Hz at – 3 dB (measured using both filters). In order to recalculate this filter for other center frequencies it is necessary to know the crystal equivalent data that can be realized (especially the dynamic capacitance C_1 or inductivity L_1) (9).

Figure 5 shows the theoretical selectivity curves and the appropriate group delay. The practical construction and the measurement will be carried out by F. Krug, DJ 3 RV as soon as the special crystals are received. This will be followed by a constructional article.

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(2) Exactly speaking, it is not sufficient to have a constant group delay to obtain an ideal pulse behaviour, but it is necessary, at the same time, to have a rounded shape of the passband curve. This is the so-called Gibbs phenomena: The Gauss filter will have a better pulse behaviour than the Bessel-filter although its group delay is not so constant

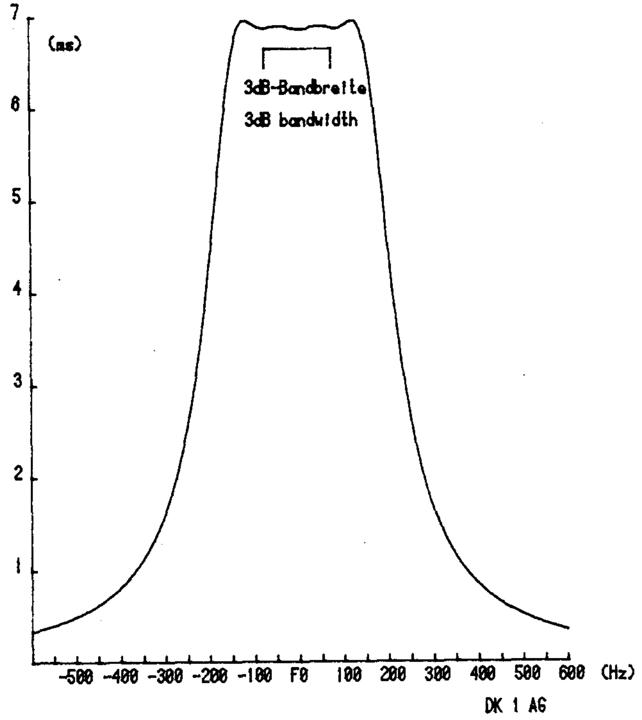

Fig. 5b:
Group delay of the final filter

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