CSIRO DIVISION OF RADIOPHYSICS

AT/22.1.1/004

I.F. ANALOG FILTERS: THEIR BANDSHAPE

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Introduction

The bandshape of the wideband I.F. channels of the AT must be determined by analog filters. For those bandwidths less than 10 MHz, it is possible that digital filters may be used. However, the question of the optimum bandshape is common to all these filters and will be investigated in this report.

Sections of this report were discussed in the AT Symposium "Digital Vs Analog Filters and the Implications on the LO Design", held on 24 May 1984 (Ref. 1). Parts of an accompanying report "IF Conversion and Narrow-band Analog Filtering" (Ref. 2) were also used at that Symposium.

Filters and Samplers

The bandwidth of any analog signal must be controlled before it is sampled.

To illustrate the problem, consider the IF band from 160 to 320 MHz, with a sampler at 320 MHz. This is shown in Figure 1(a). If the sampler had many levels, its digital output could be converted back to analog form and its spectrum examined. It would consist mainly of a band from 0 to 160 MHz. (However, if the input to the sampler was within the bands 0 to 160 MHz or 320 to 480 MHz, or 480 to 640 MHz, etc. (as shown in Fig. 1(b)) the output would also consist of a band from 0 to 160 MHz. If the input bandwidth were not controlled accurately by a filter, the output from the sampler would consist of a mixture of all these bands. That is, aliasing, or folding, of the bands occurs. To be able to determine where the spectral component of the output of the sampler originated, it is necessary to control the bandshape of the spectrum to the input of the sampler. A filter is required.

Ideal and Practical Filters

So far, the bands have been defined by ideal rectangular band shapes. Unfortunately, filters to generate these shapes do not exist and the useable bandwidth is always less than the maximum available bandwidth.

Consider the 160 - 320 MHz band again. The same problems occur for bandpass, low pass or high pass filters. Here I'll consider a bandpass filter. If the cutoff frequencies of the filter are made to be 160 MHz and 320 MHz, all the available 160 MHz bandwidth is sampled. However, as shown by the dotted lines in Fig. 1(c), parts of the bands above 320 MHz and below 160 MHz will be aliased into the output from the sampler. That is, for spectral components in the output of the sampler near 0 Hz or near 160 MHz, it is not possible to know if they originated above or below 320 MHz or above or below 160 MHz respectively. For the aliased signals to be more than 40 dB below the required signals, the useable bandwidth is much less than the 160 MHz. This bandwidth is shown in Fig. 1(c).

A much greater useable bandwidth is obtained if the filter cutoff frequencies are made greater than 160 MHz and less than 320 MHz, as shown in Fig. 1(d). By selecting the filter cutoff frequency to be equal to the 40 dB attenuation point of the aliased band, the maximum useable bandwidth is achieved. The high rejection of the image (aliased) bands is required in order to have high dynamic range in the maps. John O'Sullivan in the report "Image Rejection Requirements for the AT" (Ref. 3) looked at the requirements for image rejection. The rejection could be enhanced by 90° phase switching and demultiplexing, as suggested at the symposium (Ref. 1). However, the requirement for the IF filters to attenuate, to some specified value, the out-of-band frequencies will always be present. The complexity and type of filter may change, but the ideas expressed in this report will still be relevant.

Filter Complexity

By increasing the complexity of the filter, its bandshape may be made to be closer to the ideal rectangular bandshape, and the useable bandwidth approaches the maximum available bandwidth. However, higher order filters are dearer to buy, or more difficult to make, and their stability (phase and amplitude) tends to become worse as the complexity increases. Therefore a compromise on the order of the filter is required.

Filter Requirements

The filters need to have the following properties:

1. The stability (phase and amplitude) needs to be very good. The noise source injection system will correct for (small) variations in the amplitude. However, variations in the phase may only be corrected by pointing the telescope at a calibration source. Therefore, the phase stability of the filters is important.

2. The useable bandwidth is to be as great as possible.

3. The image bands are to be attenuated by at least 40 dB.

3.

4. Phase Response

Provided each antenna has the identical phase variation across the pass-band, the phase characteristics are not important.

5. Amplitude response, in-band, to be as flat as possible.

Order and Type of Filter

The dominant factors in the choice of a suitable design for the filters are the need for high image rejection, wide useable bandwidth and high phase stability.

Although the phase characteristics are not important, it is desirable, for two reasons, to have the smallest phase slope across the band. Firstly, the sensitivity of the phase to a change in components tends to be greater if the phase slope is high. Second, the extra insertion loss in the filter due to dissipation in the resonators (i.e. their finite Q) is proportional to the phase slope. Considering filters that have the same Q resonators, the higher the phase slope, the greater tends to be the in-band insertion loss.

For Tchebyscheff filters that have large ripple (greater than about 0.5 dB), the phase slope increases rapidly as the frequency approaches the cut-off frequency. This produces a higher insertion loss towards the edges of the band and the pass-band shape is distorted. The highest ripple that I think should be used is 0.1 dB. K & L Microwave (Ref. 4) use a 0.05 dB Tchebyscheff design.

It must be remembered that for ALL analog filters, the attenuation and phase characteristics are interrelated. (For FIR digital filters, the phase response may be independent of the attenuation characteristics). An analog filter with a linear phase response does not produce the desired attenuation characteristics. For practical filters with finite Q resonators, an optimum phase and attenuation characteristic may be obtained by using designs with a small ripple in the pass-band.

Tchebyscheff and Elliptic (Cauer) filters, with low ripple, are to be considered.

As the order of the filter is increased, the useable bandwidth increases.

The useable bandwidth is defined as the bandwidth between the cut-off points of the filter, where the cut-off is the equi-ripple attenuation corner point. The 3 dB bandwidth is the bandwidth to the 3 dB attenuation points. The maximum bandwidth, for the 160-320 MHz band, is 160 MHz.

It would be possible to use the data in the spectral channels beyond those given by the 'useable' bandwidth. However, as there would be greater uncertainty in the amplitude and phase, the maps may not be as good.

Tchebyscheff Filter Order	Ripple (dB)	Useable Bandwidth as % of Maximum	3 dB Bandwidth as % of Maximum
6	0.1	71	77
8	0.1	82	86
6	0.2	74	78
8	0.2	84	86

From this, it is seen that a change from 0.1 dB ripple to 0.2 dB ripple does not have much effect on the useable bandwidth. An 8th order 0.1 dB Tchebyscheff filter would satisfy the requirements.

However, elliptic filters have properties which would make them more suitable.

Consider the attenuation curves given in Fig. 2(a) which were derived from data given by Hansell (Ref. 5). These are for 8th order Tchebyscheff and 5th order elliptic (Cauer) low pass filters, with 0.099 dB ripple, and 45 dB minimum stopband attenuation for the elliptic filter. The low pass filter characteristic may be mapped to a bandpass if required. At the 40 dB attenuation point, both filters have about the same bandwidth. However, the phase characteristics of the filters are vastly different, as shown in Fig. 2(b). At the cutoff frequency the elliptic filter has only 220° phase shift, but the Tchebyscheff has 450° phase shift. The phase slope of the elliptic filter is much less and the attenuation due to dissipation should be much less across the band. The filters could be built with less inductive components and so be smaller.

The attenuation and phase characteristics for a 0.044 dB ripple Tchebyscheff (8th order) and elliptic (5th order) filter is given in Fig. 3(a) and Fig. 3(b). The useble bandwidth is less for filters with this low ripple, and for this reason, they do not satisfy the requirements as well as ones having slightly large ripple.

5th order elliptic filters with 0.1 dB ripple and 45 dB minimum stopband appear to be the best compromise to the conflicting requirements.

Commercially Available Filters

Most filter companies do not make filters with such high skirt attenuation. Satisfactory filters are not easy to produce and many of the commercially available ones, which are not good enough to meet our RF requirements, have insertion loss of many dB.

K & L Microwave Inc. (Ref. 4) have a series of miniature cavity filters that use small helical resonators and comb-line coupling which are suitable. These have a centre frequency in the range 80 to 2000 MHz with suitable bandwidth and may be used for 3 of the IF filters. Their insertion loss is very low - less than 1 dB for the filters that we require, and they are small. For the narrower IF bands, at lower frequencies, lumped component filters may be used.

Tubular Bandpass filters may also be considered. Their phase characteristics for a change in temperature needs to be considered carefully. The only low frequency bandpass filter that I have tested, a 10% bandwidth 100 MHz device, changed phase dramatically for a change in temperature.

Component Sensitivity and Filter Characteristics

No accurate analysis of the phase variations for changes in components has been done for any of the filters in this report. With computer programs now available within this AT group, this may be simulated fairly easily for the lumped-component devices. Commercial and 'in-house' filters will be tested.

Conclusion

To meet the requirements for the maximum useable bandwidth, image rejection of at least 40 dB and good phase stability, 5th order elliptic filters with 0.1 dB ripple and a stop band attenuation of 45 dB will probably be the most suitable.

Commercially available filters are usually of Tchebyscheff design, although elliptical designs may be made when desired.

References

1. AT/23.4.1/006, AT/01.10/009: "A.T. One Day Symposium on Digital Vs Analogue Filters and the Implications on L.O. Design".

2. AT/22.1.1/003: G. Graves, "I.F. Conversion and Narrow-Band Analog Filters".

3. AT/22.3/004, AT/23.2.3/004: J. O'Sullivan, "Image Rejection Requirements for the A.T."

4. K & L Microwave Inc., 408 Coles Circle, Salisbury, Maryland 21801, USA, TWX 710-864-9683.

5. Hansell, G.E., "Filter Design and Evaluation", Van Nostrand Reinhold Co. (USA), 1969.

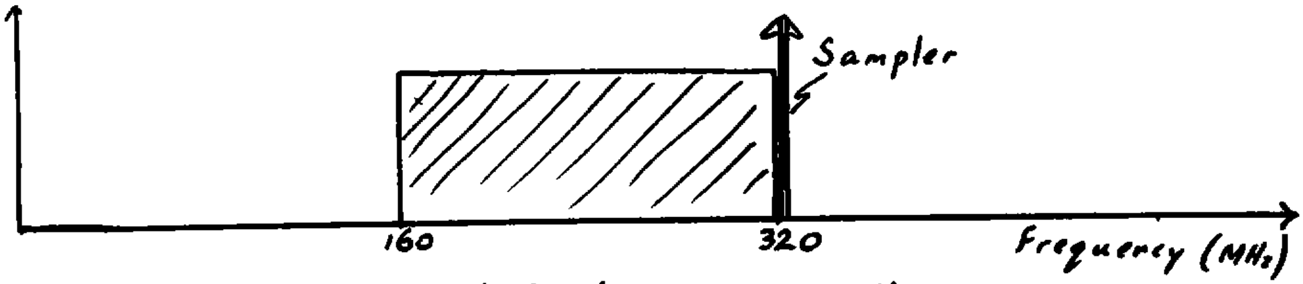

Figure 1(a): Input Band 160-320 MHz

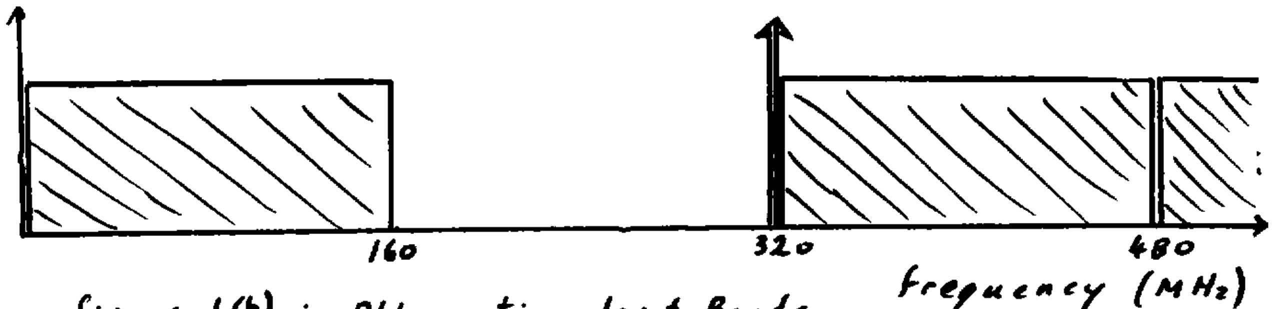

Figure 1(b): Alternative Input Bands

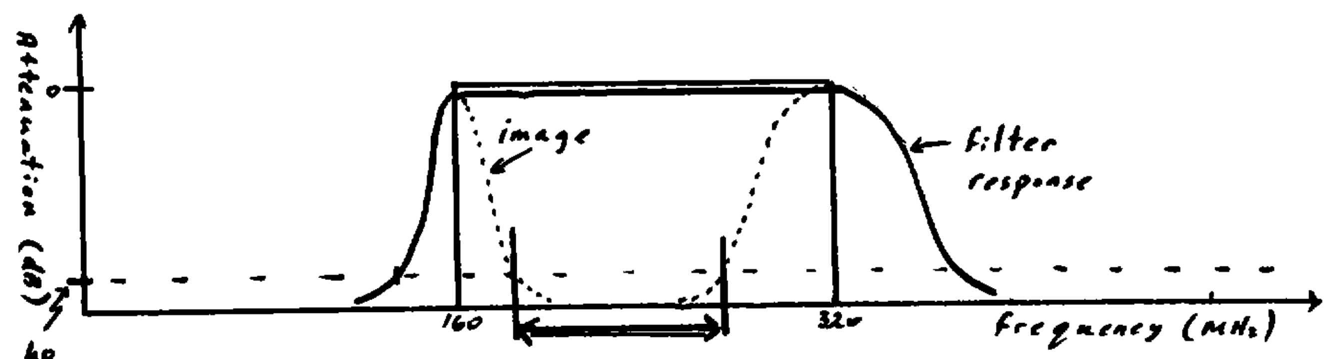

Figure 1(c): Useable bandwidth; cut-off at 160 and 320 MHz

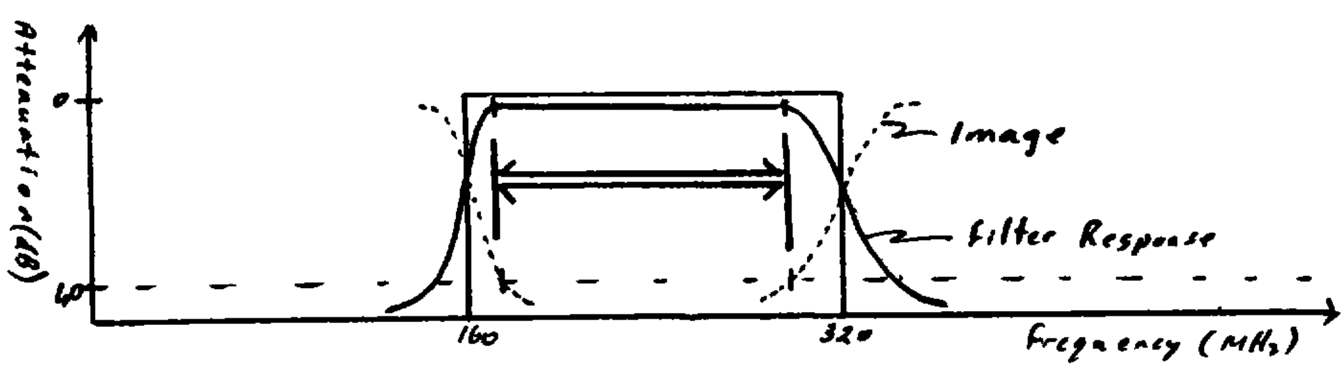

Figure 1(d): Larger Useable Bandwidth

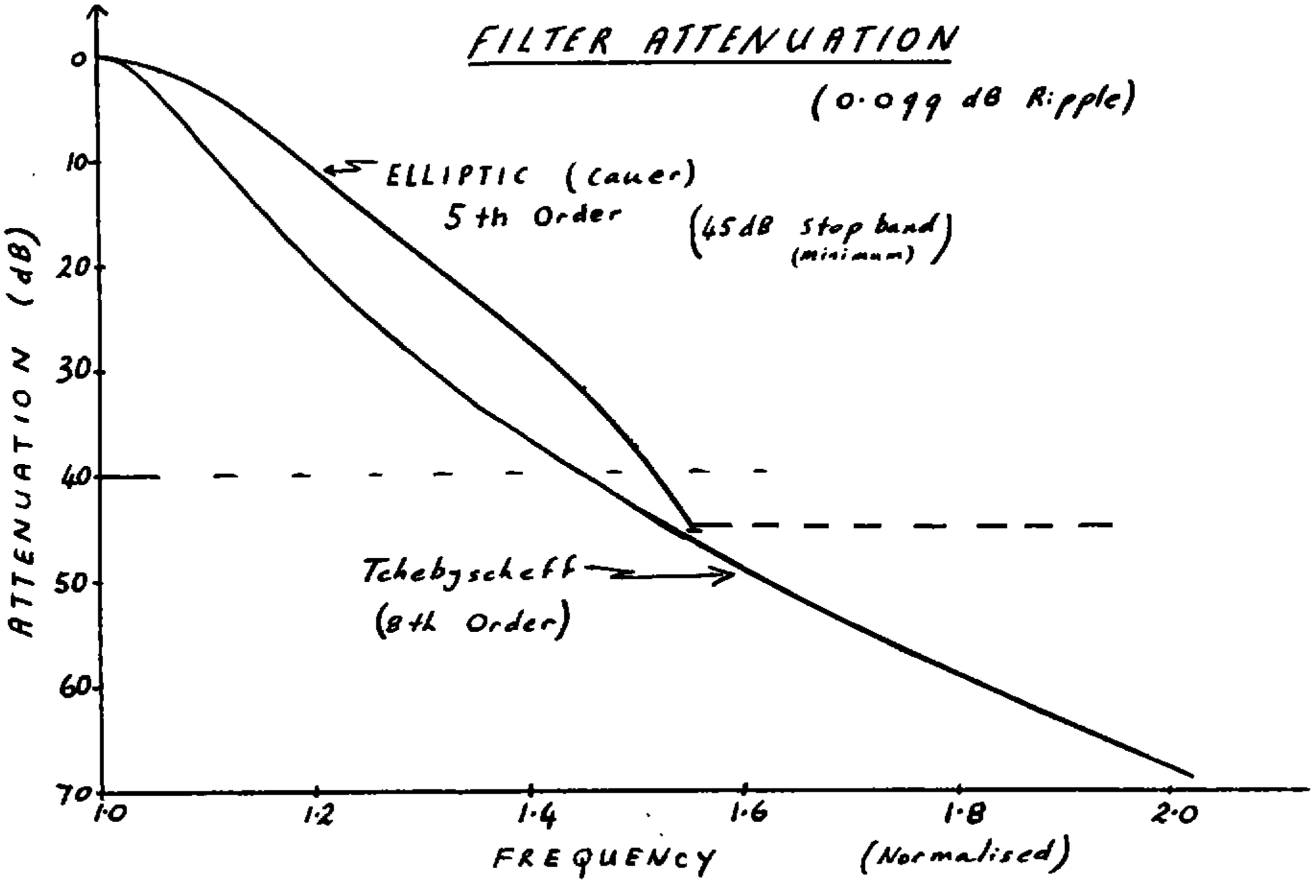

FIGURE 2(a): 0·099 dB Ripple Filters (amplitude Response)

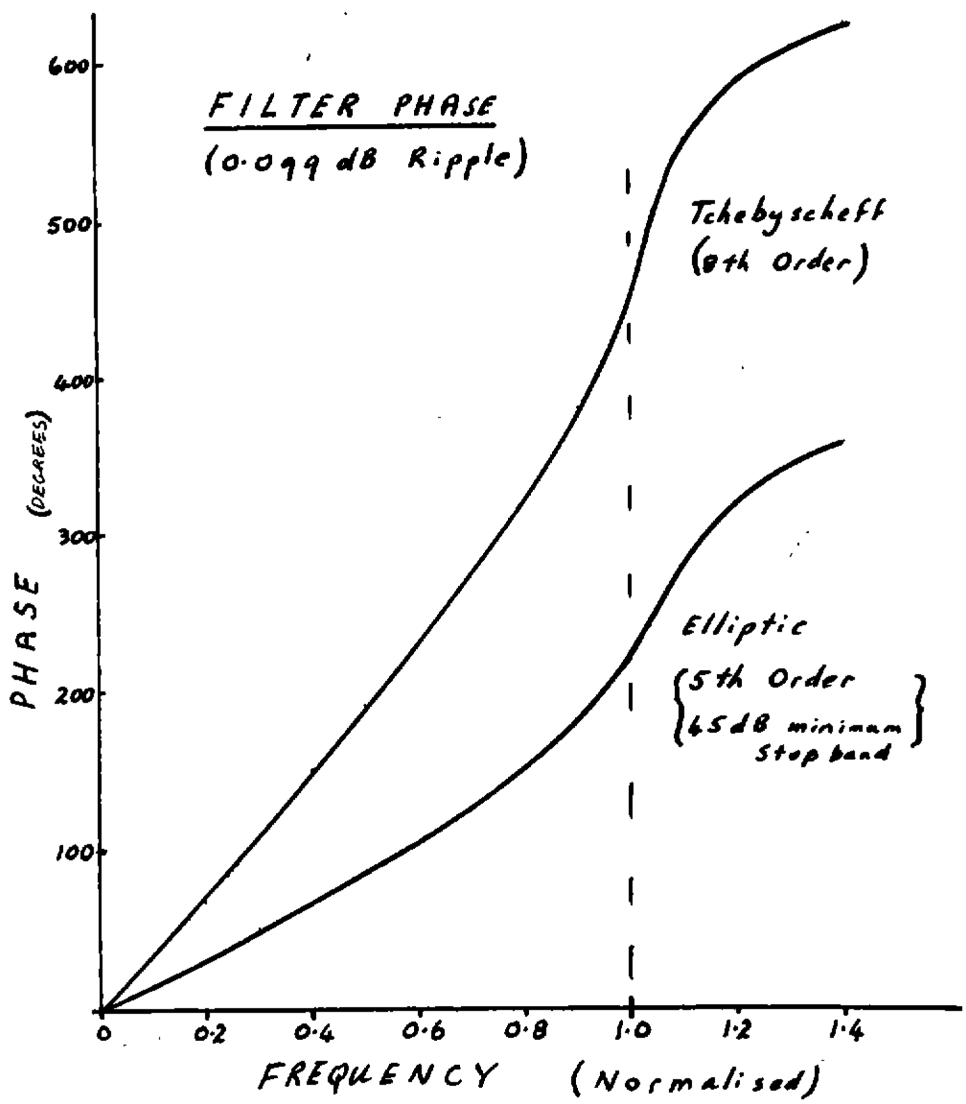

Figure 2(b) Phase Response

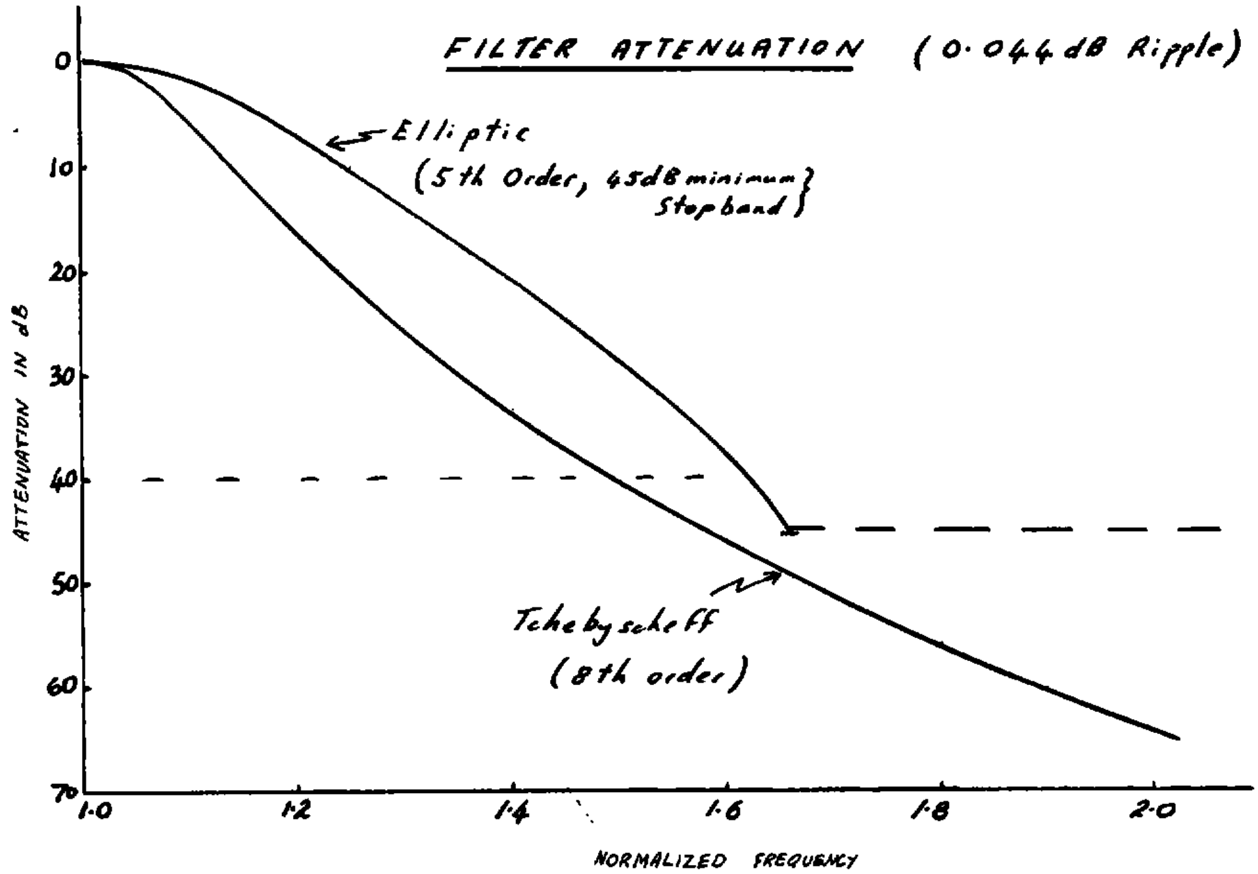

Figure 3(a): Amplitude Response (0·044 dB Ripple)

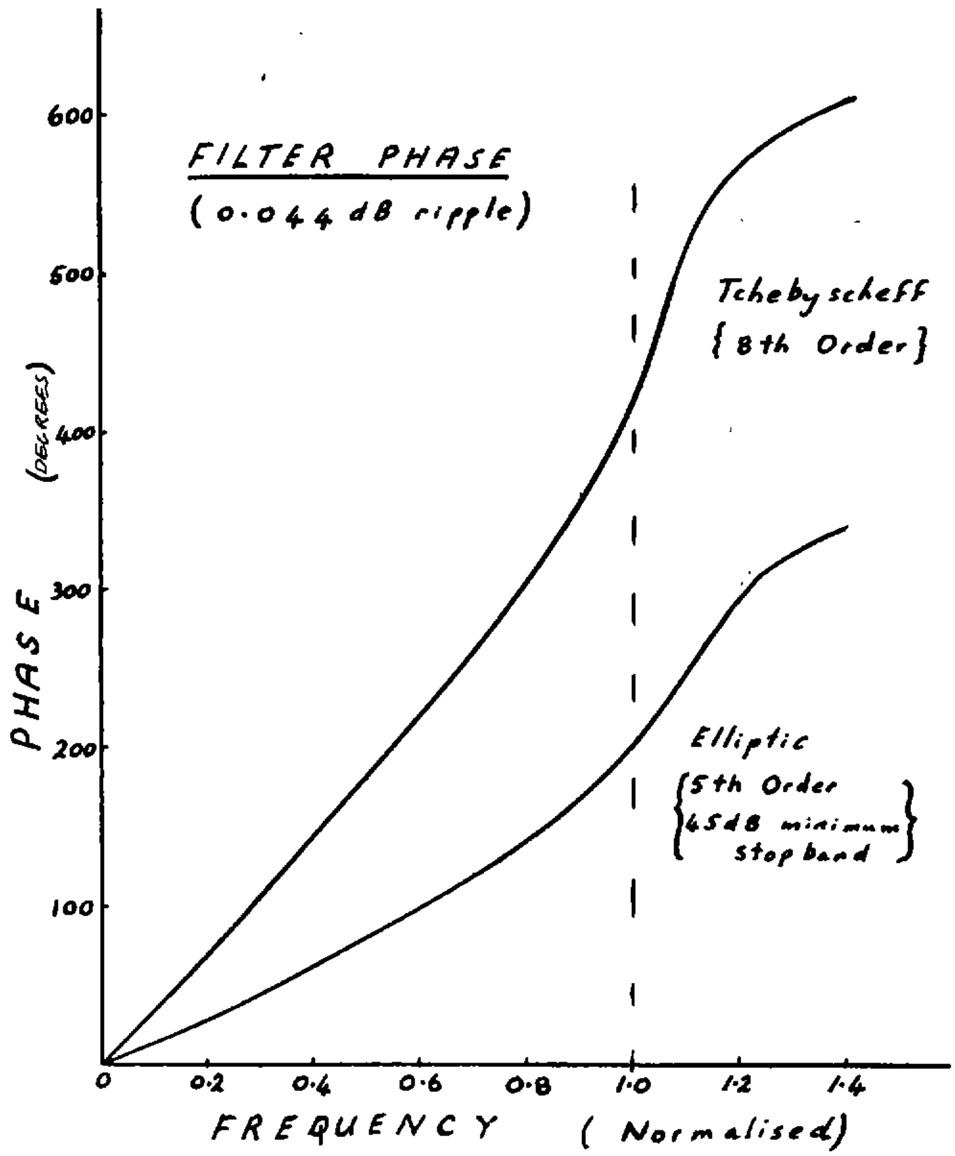

Figure 3(b): Phase Response