Octave and One-Third Octave Filters for Sub-sonic Frequencies

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Circuits have been developed for transistorized active band-pass filters of octave and one-third octave bandwidths. The basic design consists of two stagger-tuned parallel-T feedback amplifiers, and, since no inductors are used, it is suitable for operation at low frequencies. Examples have been constructed with centre frequencies down to 1c/s and give a satisfactory performance.

(Voir page 417 pour le résumé en français: Zusammenfassung in deutscher Sprache auf Seite 424)

IN the measurement and analysis of sound and vibration frequent use is made of band-pass filters, and where fixed frequency filters are employed these are most commonly of either octave or one-third octave bandwidth.

An octave filter is defined as one in which the upper and lower passband limits f_h and f_l are related by $f_h = 2f_l$. The filter is described by its mid-band frequency $f_o = (f_h f_l)^{\frac{1}{2}}$. These definitions lead to the results $f_h = (2)^{\frac{1}{2}} f_o$ and $f_l = (2)^{-\frac{1}{2}} f_o$.

For the case of the one-third octave filter the passbands are such that three adjacent filters make up one octave and for each filter $f_h' = (2)^{1/3} f_l'$. Hence $f_h' = (2)^{1/6} f_o' = 1{\cdot}12 f_o'$ and $f_l' = (2)^{-1/6} f_o' = 0{\cdot}89 f_o'$ where the primed frequencies refer to the passband limits and mid-band frequencies of one-third octave units.

The ideal shape of the passband for most purposes is rectangular, the filter having zero loss between the band limits and zero transmission outside them; however, all practical filters have finite rates of attenuation and the limits of the passband must be defined in some way. One way is to define the limits as the half power frequencies, i.e. the frequencies at which the response is 3dB lower than at the mid-band frequencies. Alternatively, bandwidth can be defined in terms of the power transmission of the filter with a white noise input. In this case the equivalent noise bandwidth is the bandwidth of an ideal (rectangular passband) filter which has the same mid-band frequency and transmits the same power, as the actual filter, with a white noise input.

When filters with mid-band frequencies from about 50c/s upwards are required, very satisfactory units can be constructed using passive elements. However, at frequencies below 50c/s the increasingly large inductors needed make passive filters rather less attractive, and at the same time the performance deteriorates since it is difficult to produce high Q resonant circuits at lower frequencies. The practical lower limit of passive filters seems to be in the region of 15c/s.

For lower frequencies it is therefore necessary to turn to active filters, i.e. amplifiers with frequency dependent feedback; such units can be designed without inductors and for this reason are particularly convenient at low frequencies. The most widely used band-pass active filter appears to be that consisting of an amplifier with a parallel-T feedback loop[1], and has a response of the type shown in Fig. 1(a). The Q of the peak in the response can be adjusted by altering the gain of the amplifier. In order to obtain a response closer to the 'ideal' rectangular characteristic it is necessary to use two or more feedback amplifier units, with staggered centre frequencies. In general the best overall response can be obtained by using many stagger tuned filter units, each with a high Q, however, this approach must be regarded with some

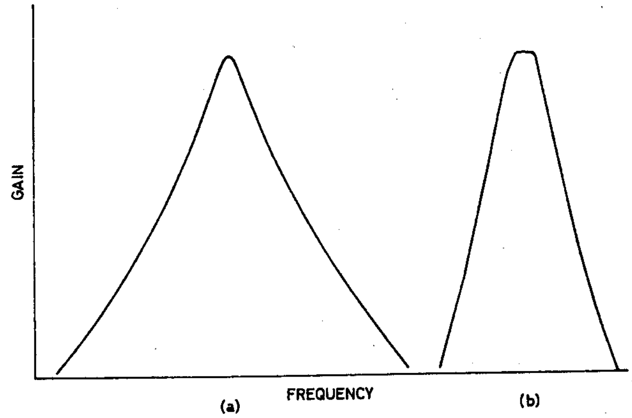
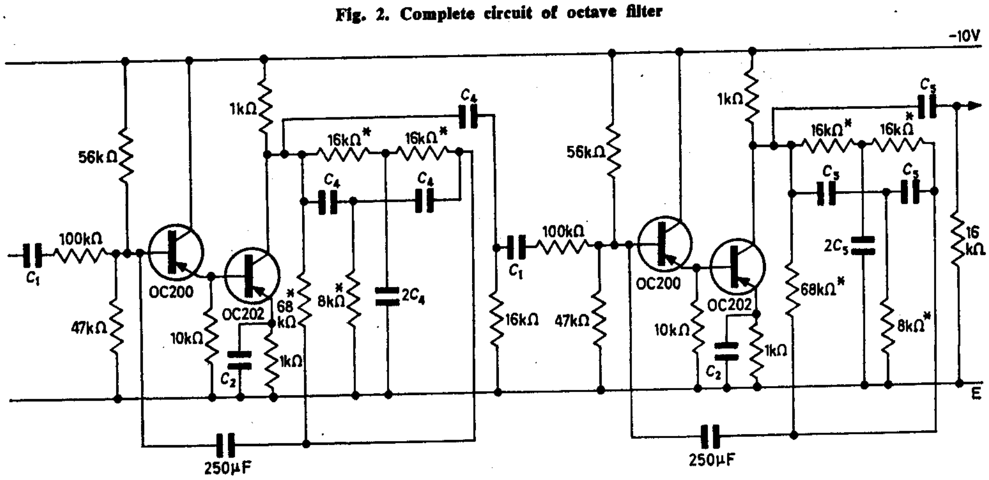


Fig. 1 (a). Response of amplifier with parallel-T feedback loop
(b) Response of two cascaded parallel-T feedback amplifiers with staggered frequencies

Fig. 2. Complete circuit of octave filter



* = 1 percent tolerance

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TABLE 1
Component Values for Octave Filters

FREQUENCY (c/s)	$C_1 \pm 20\%$ (μF)	$C_2 \pm 20\%$ (μF)	$C_4 \pm 1\%$ (μF)	$C_5 \pm 1\%$ (μF)
32	1	1000	0·47	0·30
16	1	2000	0·94	0·60
8	1	2500	1·88	1·19
4	1	5000	3·76	2·38
2	2	10000	7·52	4·76
1	4	20000	15·04	9·52
f	$\geqslant \frac{4}{f}$	$\geqslant \frac{20000}{f}$	$\frac{15 \cdot 04}{f}$	$\frac{9 \cdot 52}{f}$

caution since, by comparison with passive tuned circuits, active filters are more noisy and less stable, which two effects could combine to produce a filter which is both unstable in characteristic and limited in dynamic range.

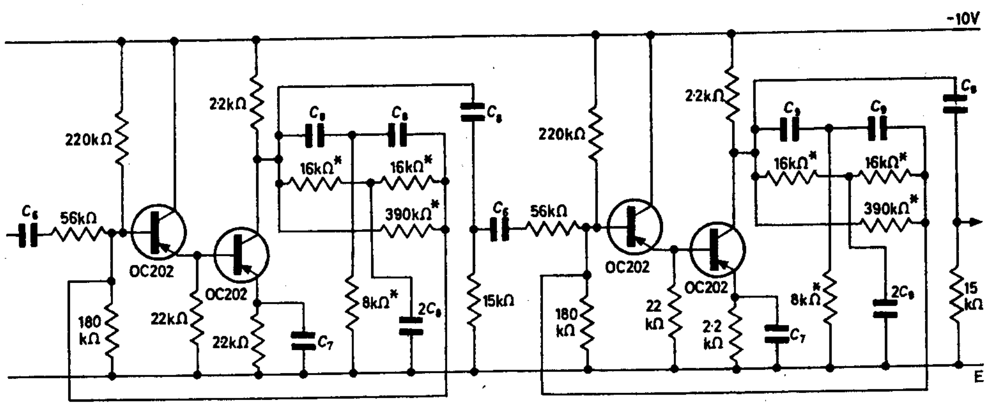
The aim of the filter design described here was to produce a simple filter, with a good enough characteristic for acoustic measurements, which could be constructed without any complex setting up procedure, and which was cheap enough to make the construction of a whole bank of filters for simultaneous operation feasible. It was found that a satisfactory result could be obtained by using two parallel-T feedback units in cascade, with the response shown in Fig. 1(b). For the octave filters the units had Q values of 1·7 and for the one-third octave units 7.

Octave Filters

The complete circuit of an octave filter unit is shown in Fig. 2. Each section of the filter consists of a two transistor amplifier with feedback through a parallel-T network. The 68kΩ resistor across the parallel-T provides overall negative feedback which reduces the Q to 1·7. In this form the section has a slightly asymmetrical response which is corrected by the high-pass RC networks used between sections and at the output. Table 1 sets out the values of the frequency dependent components for the octave filters from 1 to 32c/s together with the formulae for other frequencies.

One-Third Octave Filters

The design of the one-third octave filters is basically similar to the octave units, the main differences being the use of a higher gain transistor in the emitter-follower in each section and also a larger feedback resistor (390kΩ) connected across the parallel-T. These two modifications increase the Q of the section to 7 without impairing the stability. The amplifier sections were designed to give high input impedance, low output impedance, and high gain from a simple circuit. It was found in practice that with the feedback loop connected there was about 15dB of feedback at the frequency of maximum gain. The complete circuit of a one-third octave filter is shown in Fig. 3 and the necessary component values are set out in Table 2.



* = 1 percent tolerance

Fig. 3. Complete circuit of one-third octave filter

Performance

A set of six octave filters, from 1 to 32c/s, was constructed and Fig. 4 shows the measured frequency responses. In the case of the one-third octave filters a number of units were constructed with frequencies ranging from

Fig. 4. Measured response of bank of octave filters

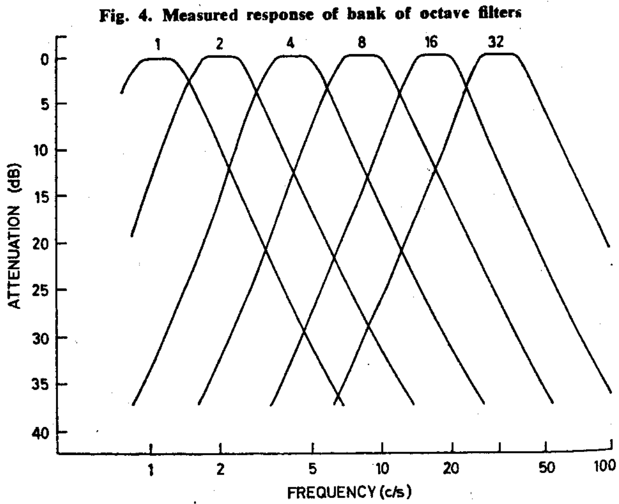


TABLE 2
Component Values for One-Third Octave Filters

f	$C_6 \pm 20\%$ (μF)	$C_7 \pm 20\%$ (μF)	$C_8 \pm 1\%$ (μF)	$C_9 \pm 1\%$ (μF)
32	1	1000	0·347	0·291
25·4	1	1000	0·437	0·366
20·2	1	1000	0·550	0·460
16	1	2000	0·695	0·581
f	$\geqslant \frac{4}{f}$	$\geqslant \frac{20000}{f}$	$\frac{11 \cdot 1}{f}$	$\frac{9 \cdot 3}{f}$

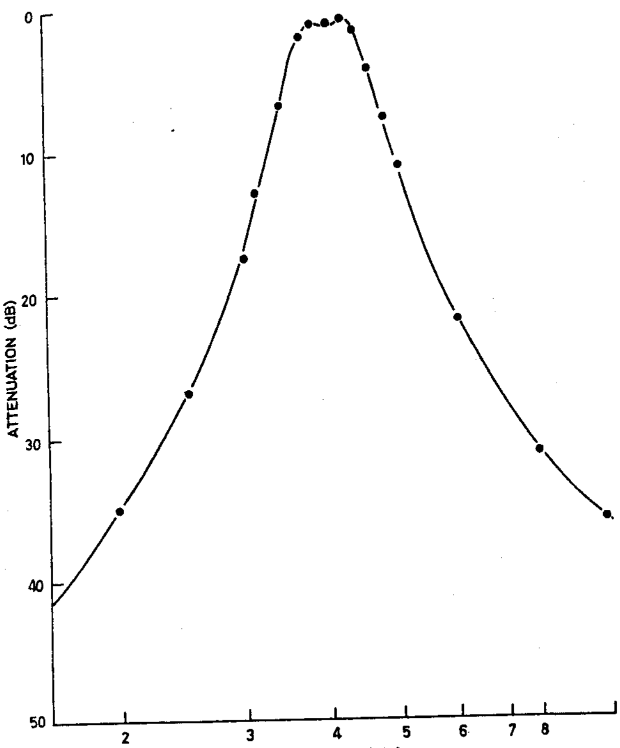


Fig. 5. Measured response of a typical one-third octave filter

2 to 40c/s. No setting-up procedure was used and it was found that the mid-band frequencies were within 3 per cent of nominal and the bandwidths ranged from 22 to 25 per cent (nominal value 23 per cent). A typical measured response curve is shown in Fig. 5. It was found that in some cases the response was slightly asymmetrical due to departures of the *Q*s of the individual filter sections from their nominal value of 7. This effect was quite small (less than 1dB tilt in the pass-band) but could be corrected by adjusting the value of the resistor shunting the parallel-T in the range 330 to 470kΩ.

Measurements were made of the maximum input levels, output noise level and harmonic distortion of the filters. It was found that output noise was at least 70dB below maximum output signal, the actual output was mostly hum and could no doubt have been improved further by better shielding and power supply filtering. Harmonic distortion could not be measured accurately with the equipment available but was not worse than 80dB below fundamental for a 1V r.m.s. input. Maximum input signal level was 3V r.m.s. for the octave filters.

The overall gain of a typical octave filter was measured for a period of 40 hours. The change in the period was less than 0·1dB. For the filters described here the half-power definition of bandwidth has been used, the equivalent noise power bandwidth was calculated from the measured response curve of one filter and is approximately 12 per cent greater than the half-power bandwidth.

REFERENCE

1. Scott, H. H. *Proc. Inst. Radio Engrs. 26,* 226 (1938).

Self-monitoring for Air Data Systems

An air data computer made up from modular sub-units and incorporating a high degree of built-in self-monitoring is currently being proposed by Elliott-Automation to US transport and military aircraft manufacturers. Monitoring of the output of the pressure sensing capsule is already available and specified by ARINC characteristic 545, but an Elliott patented system for the first time provides monitoring of the sensing capsule itself in a simple way.

Monitoring of the pressure capsule is accomplished by using the normal mechanical feedback shaft in the pick-off servo of the main capsule to drive the pick-off on a second capsule mounted alongside with its own independent pressure source. Failure of the primary capsule would therefore produce a signal at the second pick-off and indicate a fault at the monitor amplifier, which is set to operate a warning circuit at a given threshold. In fact, the monitor pick-off is biased by a fixed amount so that certain power and signal line failures would raise a difference voltage in the same way as a difference in capsule displacement.

The monitor can be applied to both static and pitot static capsules and can be bolted on to the transducer frame in a space already available in the existing air data computers.

This new degree of self-monitoring is an optional feature of the Elliott modular air data system, which can be made up to provide a wide variety of autopilot sensors as well as automatic height encoding systems to meet ARINC characteristic 549 Mk 1 and Mk 3. From a range of modules the customer can choose the facilities he requires and have them packed in an ATR case size allowing spare capacity for the addition of further modules, either during the development of a particular aircraft or to up-date the system at a later stage. Modular arrangement also reduces maintenance costs.

The modules have standard size formats, with output gears positioned to mesh automatically with those of neighbouring units. Electrical contacts are made by plugs in the base of each module.

BAC One-Eleven airliners operating with American airlines are already fitted with Elliott 2000 series autopilots as well as modular air data systems, and these can be fitted with encoders required for automatic height reporting. The modular system has also been selected for a large new British military aircraft.

The addition of a monitoring capsule to the pitot transducer in the BAC One-Eleven air data computer raises the integrity of the signals used for autothrottle control to the level required for Category 3 operations.

The Elliott-Automation modular air data system assembled in an ARINC 549 Mk 1 automatic height encoder for secondary radar height reporting. It is in a short 3/8 ATR case. A similar unit to ARINC 549 Mk 3 would be contained in a short 1/2 ATR case.