PRECISION THICKFILM ACTIVE RC FILTERS

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The application of hybrid thickfilm technology to the realization of precise active RC filters with passband frequencies up to 3.5 kHz is described and it is shown that relatively expensive thin-film technology can often be replaced by the simpler thickfilm process.

1. INTRODUCTION

In this paper the application of hybrid thickfilm technology for realizing precise active RC filters with passband frequencies up to 3.5 kHz is described.

The following examples of filters used in communication and audio-frequency measurement systems show that relatively expensive thinfilm technology can be replaced by the simpler thickfilm process in several cases.

The circuit design procedure has to take the thickfilm properties into account and a great amount of effort is required to reduce the sensitivities of the attenuation with respect to component variations. Because of their low-sensitivity properties doubly-terminated LC-prototypes¹ are used for the active simulation.

2. GYRATOR PCM LOWPASS FILTER

In order to simulate the grounded or floating inductors of the 5th-order elliptic LC lowpass (LP)

FIGURE 1 LC-prototype for the gyrator PCM LP filter.

filter shown in Figure 1 by gyrators and capacitors, two gyrators are realized on 0.33 in $\times$ 1 in substrates by blocks. These circuits consist of two or three op-amps and eight or ten resistors, respectively. Figure 2 shows these building blocks. The capacitors are to be connected externally in the case of a CCITT PCM LP filter because of the high price and the required volume of $\pm 1\%$ chip-capacitors with element values from 2.5 nF to 11.2 nF. Only one resistor ink (10 kohm/ $\square$) is used. The cuts were trimmed automatically by a YAG-laser system² and, by a proper selection of the geometries, an R-accuracy of $\pm 2\%$ can be achieved.³ For $R_{\min} = 3.16$ kohm and $R_{\max} = 27.2$ kohm an R-accuracy of $\pm 5\%$ (including the long-time stability) is obtained. The entire active filter circuit (see Figure 3) consists of five op-amps, eighteen resistors and six capacitors. The measured attenuation curves are shown in Figure 4 together with the attenuation restrictions.

3. PCM LP FILTER SIMULATING THE SIGNAL-FLOW GRAPH (SFG) OF AN LC-PROTOTYPE

To obtain an active circuit with a minimum number of capacitors, the SFG of the elliptic LC filter in Figure 5 (refer to Saal and Entenmann⁴) is simulated by a canonical circuit.⁵ In order to reduce the number of printing processes a universal layout (0.5 in $\times$ 1 in) is used for two subcircuits. By laser cutting of conductive paths the layout is adapted to the special requirements. Seven op-amps are ultrasonic wire-bonded and the five chip-capacitors are connected with a printed solder paste. One of the advantages of this filter concept is that only the RC-product of each integrator influences the frequency

FIGURE 2 Gyrator circuits for the simulation of grounded (a) and floating inductors (b).

FIGURE 3 Circuit of the gyrator PCM LP filter (R in kohm, C in nF, used op-amps μA 741).

FIGURE 4 Measured attenuation curves of the gyrator PCM LP filter.

FIGURE 5 LC-prototype of the SFG PCM LP filter with additional amplifier. $V = 4.266$, $V = 12.6$ dB.

response of the filter. Thus roughly tolerated capacitors and adapted laser-trimmed resistors yield the required time constants $T_i = R_i C_i$. Two resistor inks (10 kohm/ $\square$, 50 kohm/ $\square$) and five chip-capacitors with equal values of $C = 680$ pF $\pm 10\%$ are used. Figure 6 shows the photograph of one subcircuit, of the complete PCM LP filter circuit is shown in Figure 7, while the measured attenuation curves of this filter are shown in Figure 8.

4. VARIABLE OCTAVE FILTER

A variable 6th-order bandpass filter with specially approximated attenuation curves is designed to satisfy the requirements of DIN 45 651 (see Figure 9) for octave filters with centre frequencies in the range from $10 \text{ Hz} \leq f_m \leq 1 \text{ kHz}$. The lowpass—bandpass transformation is applied to the SFG of

FIGURE 6 Subcircuit for the SFG PCM LP filter.

FIGURE 7 Circuit of the SFG PCM LP filter.

FIGURE 8 Measured attenuation curves of the SFG PCM LP filter.

FIGURE 9 Attenuation requirements for octave filters (DIN 45 651).

FIGURE 10 Variable 2nd-order analogue-computer bandpass filter circuit.

the reference LC lowpass filter. The resulting second-order transfer functions are realized separately on 0.5 in $\times$ 1 in substrates using the analogue-computer principle. A voltage-controlled network containing resistors and pn junction diodes (connected in odd symmetrical pairs) allows the variation of the centre frequency. The bonding and soldering processes are the same as in the preceding examples. Additional layout problems caused by the fixed pin sequence requires a two-layer technique. Two prints of the insulating material separate the layers. Figure 10 shows a second-order section with four pn junction diodes. The realization of a second-order bandpass filter section is shown in Figure 11. Measured attenuation curves with the control voltage U_{st} as a parameter are shown in Figure 12.

5. CONCLUSION

In all cases mentioned in the preceding sections functional trimming can be avoided because the accuracy of thickfilm resistors ($\Delta R/R \approx 5\%$, $TK_R \approx 100$ ppm/K) yields very stable attenuation curves in view of the low-sensitivity properties of active-simulated terminated LC filter circuits. Within the temperature range from 0°C to +70°C, both the gyrator filter and the SFG filter meet the requirements very well. Their excellent dynamic range of more than 100 dB (power consumption ≈ 250 mW, $V_{CC} = \pm 15$ V) should be mentioned especially. The proposed octave filter allows a continuous variation of the centre frequency by a factor of 100 without violating the tolerance requirements.

FIGURE 11 Analogue-computer bandpass filter circuit.

FIGURE 12 Measured attenuation curves of an octave filter ($\vartheta = 20^\circ\text{C}$).

REFERENCES

1. H. J. Orchard, "Inductorless filters." *Electron. Lett.* 2 (1966), pp. 224–225.
2. E. Schmidt, "Trimmen von Schichtwiderständen mit einem automatischen Laser-Abgleichsystem." *Funktechnik* 34 (1979), pp. T36–T43.
3. W. Ulbrich, "Resistor geometry comparison with respect to current noise and trim sensitivity." *Proc. Europ. Hybrid Microelectronic Conf.* 1977, pp. XV-1/XV-8.
4. R. Saal, W. Entenmann, *Handbuch zum Filterentwurf* (Elitera, Berlin, 1979).
5. E. Müller, *Mehrfach rückgekoppelte aktive RC-Filter-schaltungen. Diss.* Technische Universität München, 1979.