TP 12.6: 60 MHz Common-Mode Self-Tuned Continuous-Time Filter for Mass-Storage Applications

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Mass-storage channels with bit rates in excess of 100Mb/s require continuous-time filters with cutoff-frequencies above 40MHz [1, 2]. At those frequencies, even for Q-factors as low as 2, phase errors may justify the use of a separate Q-control if the required linear phase response of the filter is to be guaranteed. Because of the tight power budget, bipolar designs may have an advantage over CMOS and BiCMOS designs, combining high speed, low power, and low noise levels.

The filter, built using a 9GHz bipolar process, is furnished with both frequency- and Q-tuning schemes. It operates up to 60MHz, and so can be applied in higher-order channel filters working in the 25 - 40MHz range. The filter is truly self-tuned, i.e., it can be tuned while processing signals by simultaneously applying to the input a differential-mode (DM) signal and a common-mode (CM) reference. At the output, if the signals from both sides are added, the filtered reference is recovered, while by subtracting the two signals, with the exception for a small residuum, the filtered signal is free from the reference. Since the main filter is directly tuned, masters are eliminated, which may result in improved accuracy, reduced die area and dissipated power.

Consider the lossy g_m - C bipolar integrator shown in Figure 1 [3]. It consists of a transconductor (G_M) built as a voltage buffer OTA1 - Q_1 controlling resistor R1. High gain of OTA1 results in a linear V - I conversion even though the circuit is single-ended. OTA1 is built as a pnp differential pair with a Schotky diode level shift at the input. The G_M is also provided with an emitter-follower level shift at the output. The input and output swings are ±0.7V, but they could be extended if additional devices are available to realize larger input and output shifts. The g_m-tunability is achieved by a current driven pair Q_3 - Q_4. The phase errors are compensated initially by the resistor R_Q in series with the integrating capacitor C_1. For the purpose of Q-tuning, the phase is further adjusted by changing the tail current I_2 of OTA1.

The output resistance of the load source Q_5 - R_5 does not have to be very high since the dc output level is defined by loading the G_M with $1/g_m$-resistor OTA_2 - Q_2 - R_2, and using a replica-bias shown in Figure 2. The bias scheme repeats the circuitry of loaded G_M with addition of the amplifier B_OTA setting the dc output level close to $V_{out,ref}$. This eliminates CM-feedback circuitry, improves stability, and may result in die area and power savings.

Since both capacitors of Figure 3 are loaded with $1/g_m$-resistors the biquad transfer function tends to have lower Q-factor and gain, but both parameters can be compensated for by choosing appropriate values of g_m's. With tunable $1/g_m$-loads, the transfer function is preserved while tuning over a wide range of frequencies. The CM-self-tuned filter system, shown in Figure 4a, consists of two single-ended biquads fed with differential input signal and CM-reference, terminated by a differential buffer rejecting the CM-reference output component, plus the frequency- and Q-tuning schemes. The frequency-tuning scheme realized as a phase-locked loop maintains in quadrature the phase-difference between the reference frequency and the sum of the lowpass (LP) outputs of both filters. The summing is by highpass (HP) summers shown in Figure 4b. To make the frequency-tuning insensitive to variation of the reference amplitude, the phase detector (Gilbert cell) works as an EXOR gate driven digitally via two high-gain paths. The active loop filter uses solely on-chip capacitance. The Q-tuning scheme built as an amplitude-locked loop contains a summer that adds bandpass (BP) outputs of both filters, followed by full-wave rectifiers and peak detectors. The reference is processed by an identical system and the outputs of two peak detectors are forced to be equal by a high-gain differential amplifier.

The measured LP transfer functions for different tuning frequencies are shown in Figure 5. In Figure 6, the BP is measured at one frequency while Q-factors are tuned. Non-zero transmission of BP at dc is caused by $1/_{gm}$-loss. The results of Figs. 5, 6 prove that both control schemes operate independently. The noise spectrum of the filter with both tuning schemes operating is shown in Figure 7. The typical output residuum of a $20mV_{pp}$-input reference is 300µV rms. Note that for higher-order LP filters the reference frequency falls well in the stopband where its presence is not critical.

The output residuum of the input reference is caused by the CM-DM conversion-gain resulting from the mismatch between the two filters. For resistor and capacitor matching of 1%, the mismatch between the two filters measured at the reference frequency is 2 - 6%. The simple way to reduce this residuum is to decrease the input level of the CM-reference, but this has a limit imposed by the DM-CM conversion-gain introducing the signal component into the CM-reference output. HP transfer of summers reduces this component, and lowers the limit for the input CM-reference level.

Design parameters of small devices are given in Table 1. Table 2 summarizes results of measurements. A micrograph of the chip realized as a transistor-array is shown in Figure 8.

Acknowledgments

The authors are grateful to the ICO Division of Tektronix Inc., (currently, Maxim Integrated Products,) for the chip fabrication, and D. Haerle and M. Persun for contributions in layout and measurements.

References

[1] DeVeirman, G. A., et al., "A 27MHz Programmable Bipolar Continuous-Time 0.05° Equiripple Linear Phase Lowpass Filter," ISSCC Digest of Technical Papers, pp. 64-65, Feb., 1992.

[2] Laber, C. A., et al., "A 20 MHz 6th Order BiCMOS Programmable Filter Using Parasitic Insensitive Integrators," Int. Symp. on VLSI Circuits, Seattle, pp. 104-105, 1992.

[3] Wyszynski, A., "Low-Voltage CMOS and BiCMOS Triode Transconductors and Integrators with Gain-Enhanced Linearity and Output Impedance," IEE Electronics Letters, vol. 30, no. 3, pp. 211-213, 1994.

Parameter	npn	pnp
β_{Fpeak}	95 - 165	20 - 36
LV_{ceo}	≥8V	≥8.5V
V_A	15 - 23V	8 - 15V
f_T	9.3GHz	5.5GHz

Table 1. Device parameters.

Parameter	Measurement	Comment
Power supply	0 - 5V	±10 %
Tuning range	10 - 60MHz	typical
Differential input	2Vpp	for 1% THD
Dynamic range	61 - 71dB	with tuning on
Dissipated power	85mW	filter + tuning

Table 2. Measured performance.

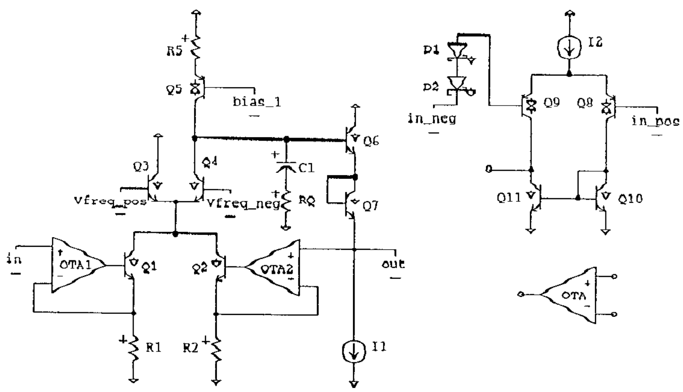

Figure 1: Bipolar lossy g_m-C integrator:
a) G_M loaded with $1/g_m$-resistor and capacitor.
b) pnp OTA with Schotky diode input level shift.

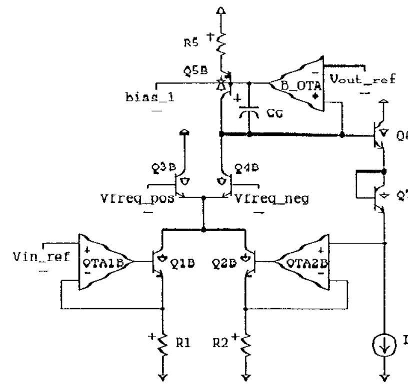

Figure 2: Bias scheme using the replica of loaded G_M.

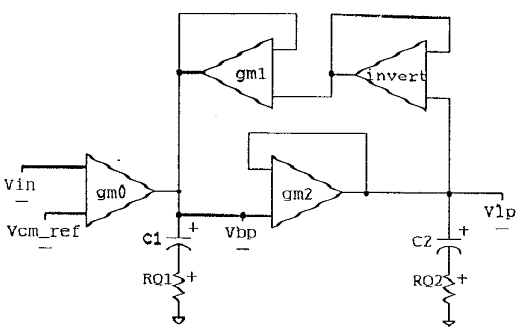

Figure 3: Single-ended biquad with two lossy integrators.

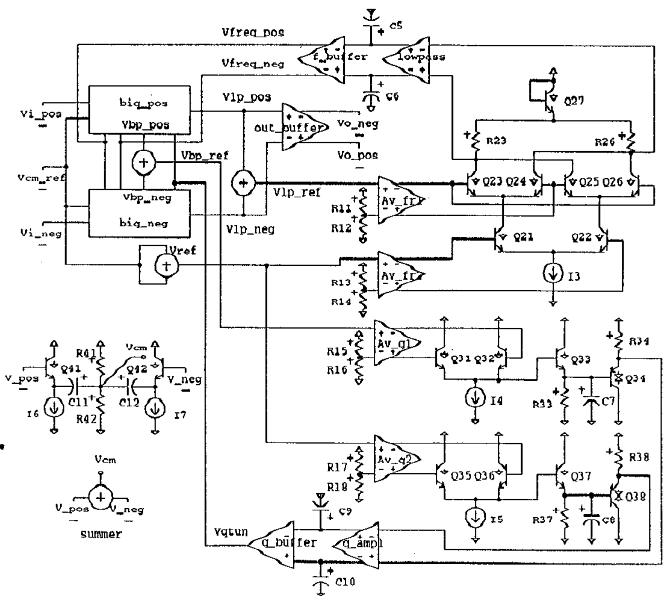

Figure 4: Schematic of CM-self-tuned filter system:
(a) 2 single-ended filters; frequency- and Q-tuning.
(b) HP summers used in frequency- and Q-tuning.

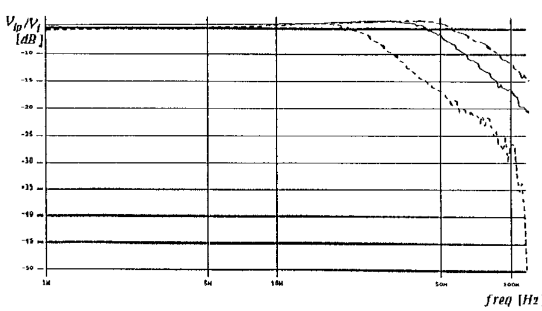

Figure 5: Measured LP output (reference freq. at 20MHz, 40MHz, 60MHz and Q-tuning on).

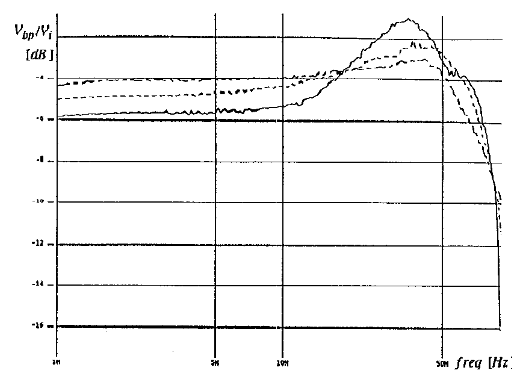

Figure 6: Measured BP output (3 reference amplitudes and frequency-tuning at 60MHz).

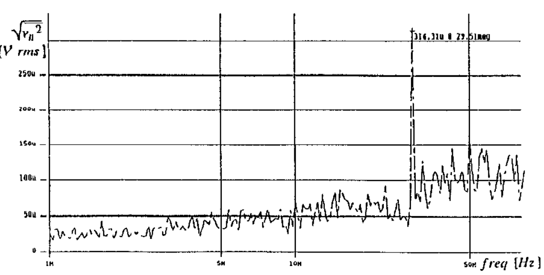

Figure 7: Measured filter noise spectrum (tuning schemes at 30MHz).

Figure 8: See page 370.

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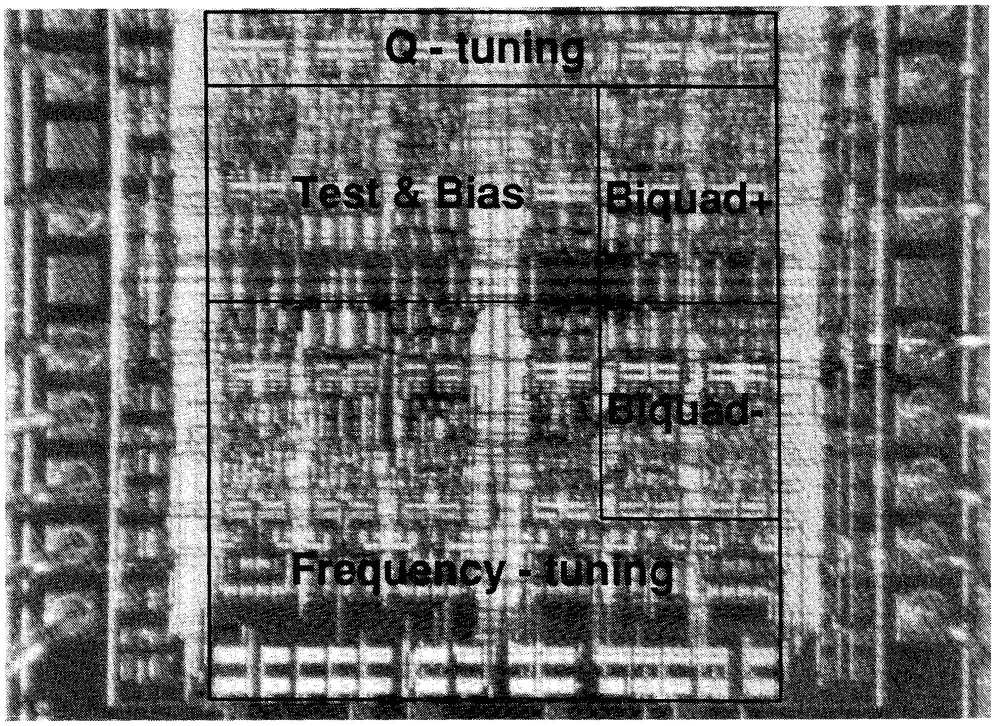

Figure 8: Micrograph of transistor-array filter chip.

TP 13.1: A 1/3-inch 630k-pixel IT-CCD Image Sensor with Multi-Function Capability

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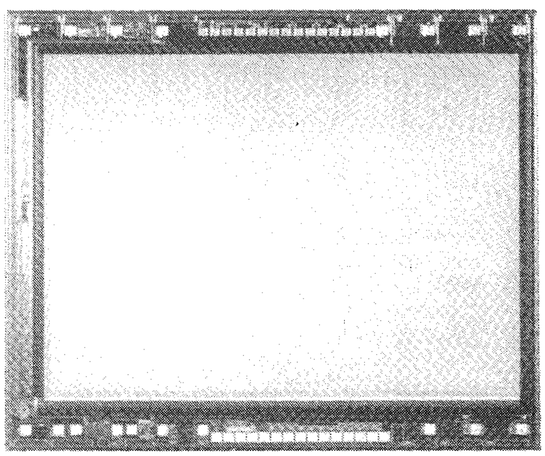

Figure 6: Micrograph of a 630k-pixel IT-CCD image sensor.

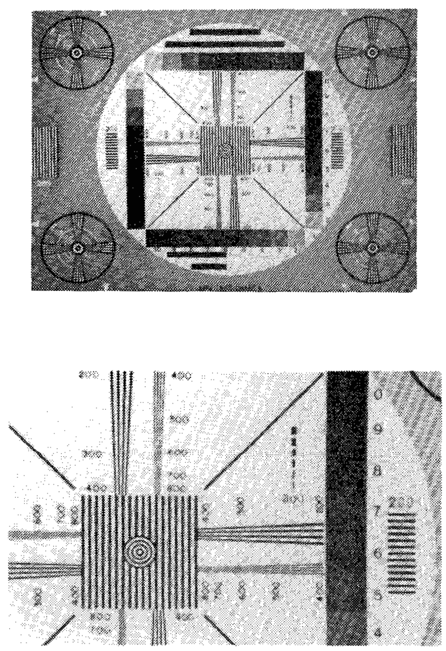

Figure 7: Reproduced image of RETMA chart using full pixels without color filter.