An accurate Quality Factor Tuning Scheme for IF and High-Q Continuous-Time Filter

- This is an improvement of the magnitude-locked-loop Q tuning scheme.
- It uses a modified version of the continuous-time adaptive least-mean square algorithm.
- Measured Q accuracy is less than 1% error

Previous Q-tuning techniques using Master-Slave

Magnitude Locked Loop Tuning Scheme

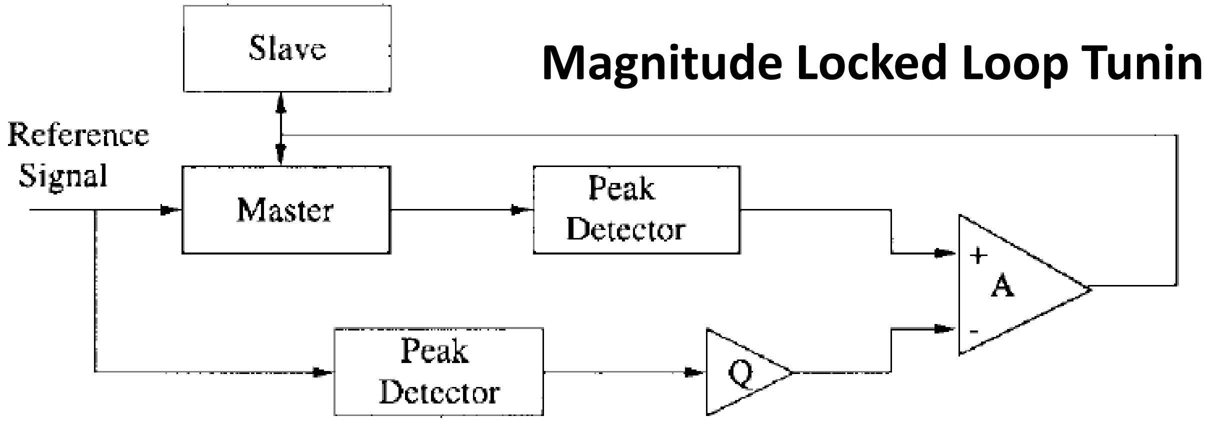


Fig. 1. Block diagram of MLL Q-tuning method.

$$H(s) = \frac{\omega_o s}{s^2 + \frac{\omega_o}{Q} s + \omega_o^2} \tag{1}$$

$$H(s)|_{s=j\omega_o} = \frac{j\omega_o^2}{-\omega_o^2 + \frac{j\omega_o^2}{Q} + \omega_o^2} = Q. \tag{2}$$

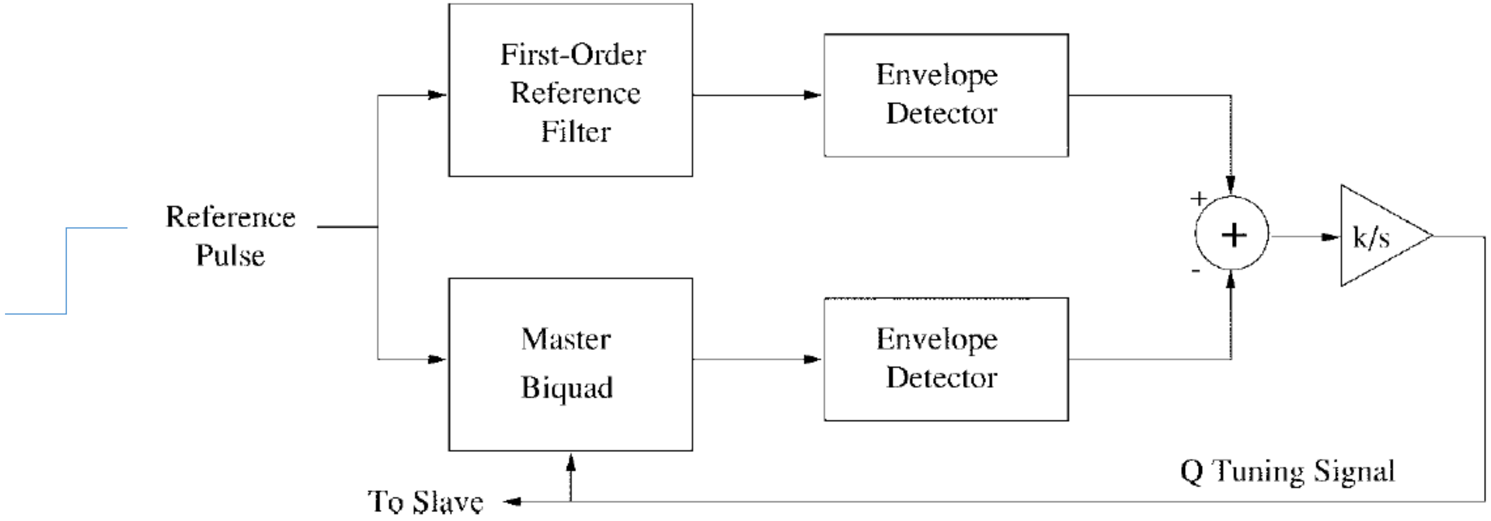


Fig. 2. Block diagram of impulse response Q-tuning method.

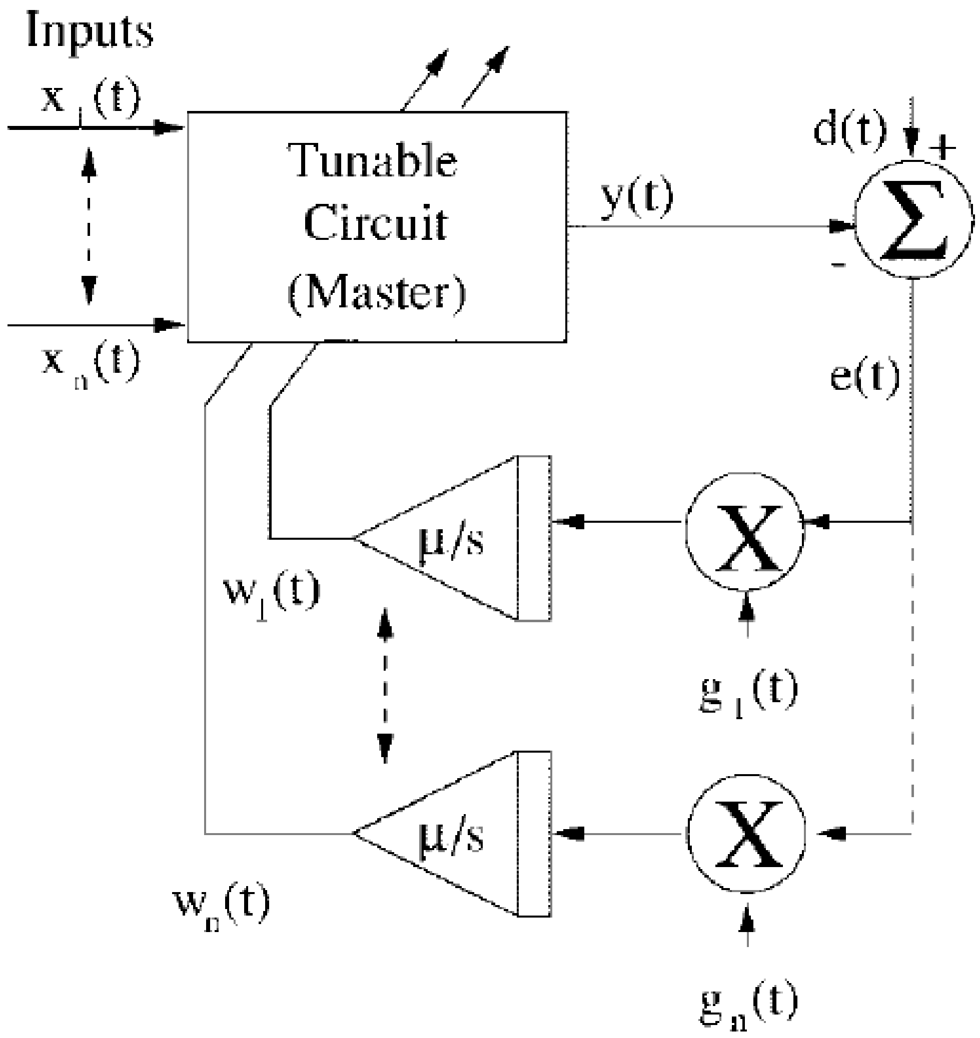
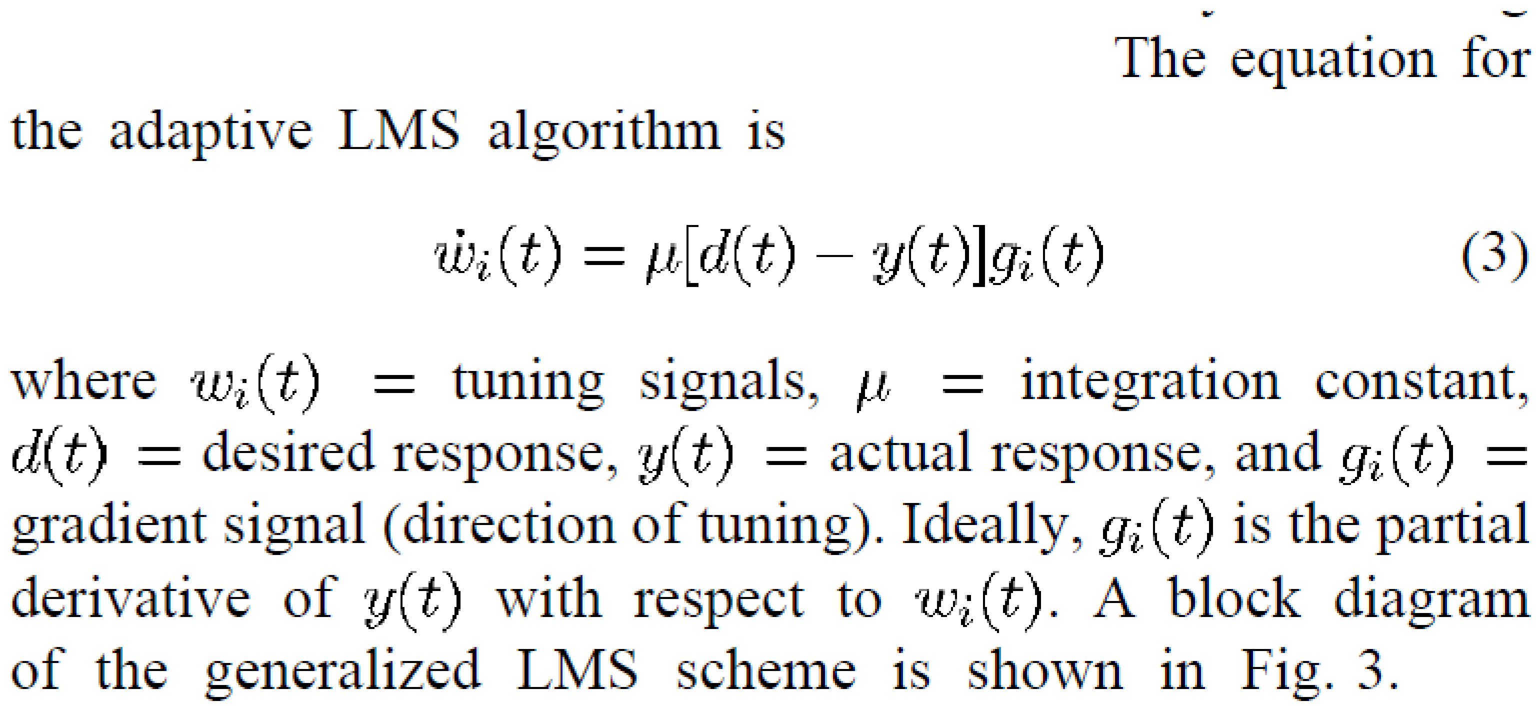


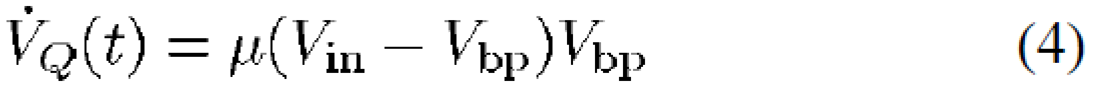
Fig. 3. Block diagram of adaptive LMS algorithm.



The equation for the adaptive LMS algorithm is

$$\dot{w}_i(t) = \mu[d(t) - y(t)]g_i(t) \tag{3}$$

where $w_i(t)$ = tuning signals, μ = integration constant, $d(t)$ = desired response, $y(t)$ = actual response, and $g_i(t)$ = gradient signal (direction of tuning). Ideally, $g_i(t)$ is the partial derivative of $y(t)$ with respect to $w_i(t)$. A block diagram of the generalized LMS scheme is shown in Fig. 3.



$$\dot{V}_Q(t) = \mu(V_{\mathbf{in}} - V_{\mathbf{bp}})V_{\mathbf{bp}} \tag{4}$$

The input reference can be any periodic signal, not necessarily a sinusoidal. This input signal should contain the wo frequency component.

It is a combination of the MLL and the LMS techniques.
Note that no peak detectors are involved. Only wo tuning is needed.
g(t) is simply the bandpass output

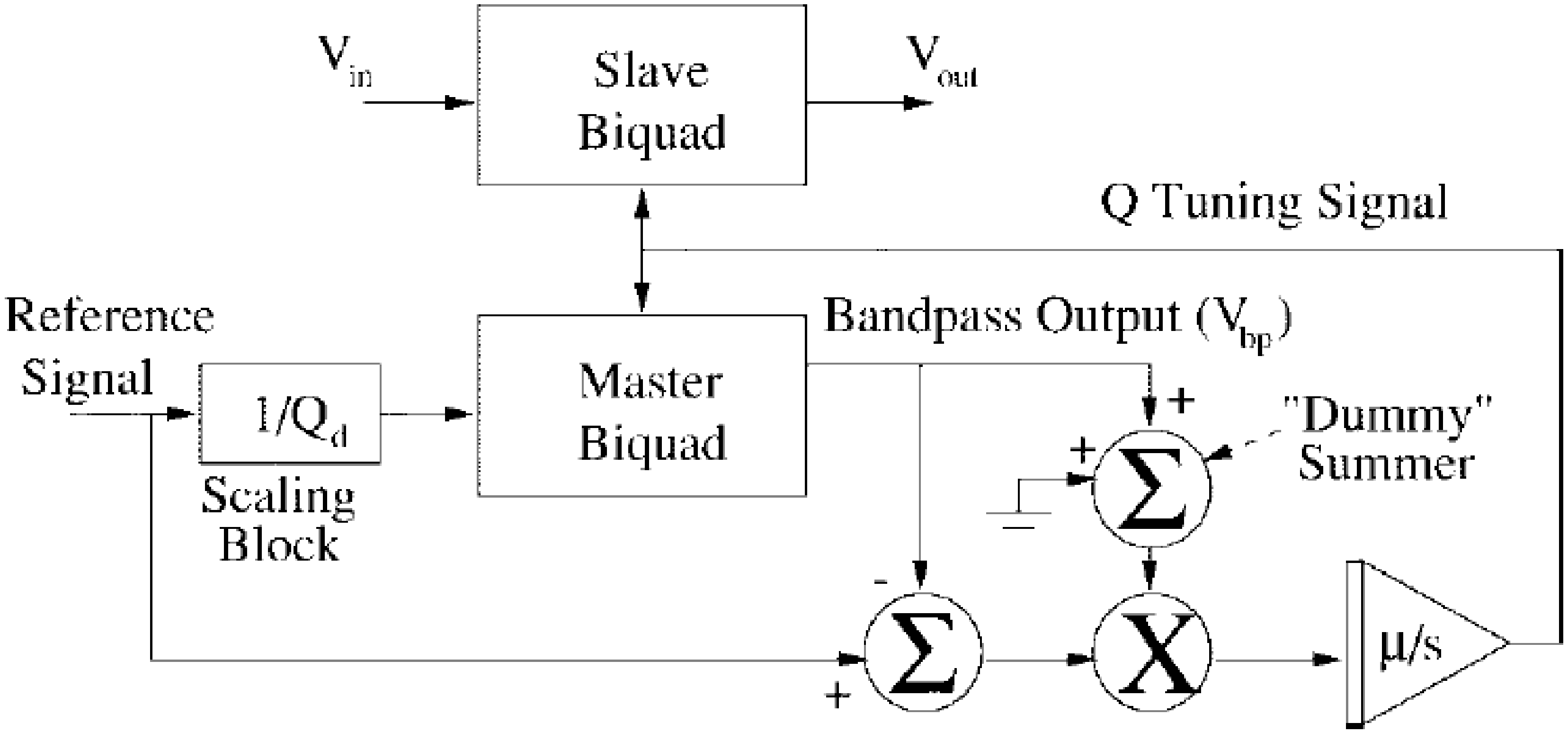


Fig. 4. Block diagram of proposed adaptive Q-tuning technique.

$$V_{\mathrm{bp}} = \hat{V}_{\mathrm{bp}} \sin(\omega_o t) = \frac{Q_a(V_Q)}{Q_d} \hat{V}_{\mathrm{in}} \sin(\omega_o t) \tag{5}$$

or

$$\hat{V}_{\mathrm{bp}} = \frac{Q_a(V_Q)}{Q_d} \hat{V}_{\mathrm{in}} \Big|_{\omega=\omega_o} \tag{6}$$

where

$Q_a(V_Q)$	actual Q of filter (function of V_Q);
Q_d	desired Q of filter.

Notice in the above equation that the Q will be tuned, i.e., $Q_a(V_Q) = Q_d$, when $\hat{V}_{\mathrm{bp}}$ is equal to $\hat{V}_{\mathrm{in}}$. Therefore, the LMS algorithm will work by trying to match the filter output (V_{bp}) to the desired signal (V_{in}) and making the overall gain equal to one.

If wo has an error, then this is reflected as a phase shift error

$$\hat{V}_{bp} = |H_{\mathbf{bp}}(s)|\hat{V}_{\mathbf{in}} = \frac{Q_a}{Q_d}\hat{V}_{\mathbf{in}} \cos[\phi(\omega)] \tag{7}$$

$$\dot{V}_Q(t) = \mu[V_{\mathbf{in}}(t) - V_{\mathbf{bp}}(t)]V_{\mathbf{bp}}(t) \tag{8}$$

where

$$V_{\mathbf{bp}}(t) = \hat{V}_{\mathbf{bp}} \sin(\omega t + \phi)$$
$$V_{\mathbf{in}}(t) = \hat{V}_{\mathbf{in}} \sin(\omega t)$$

Note that when tuning is complete, $\dot{V}_Q = 0$ and V_Q is a constant

$$\dot{V}_Q(t) = \mu \left[\frac{\hat{V}_{\mathrm{in}} \hat{V}_{\mathrm{bp}} \cos \phi}{2} - \frac{\hat{V}_{\mathrm{bp}}^2}{2} \right] = 0 \tag{9}$$

$$\hat{V}_{\mathrm{bp}} = \hat{V}_{\mathrm{in}} \cos \phi. \tag{10}$$

Ideally, the Q is tuned correctly even in the presence of frequency tuning errors.

Another large advantage is the ability to use highly distorted input reference signals such as clock pulses. For implementation purposes, all that would be needed is a limiter to bring the clock signal amplitude down into the dynamic range of the tuning circuitry. It can also be shown mathematically that a square wave reference will be sufficient for Q-tuning.

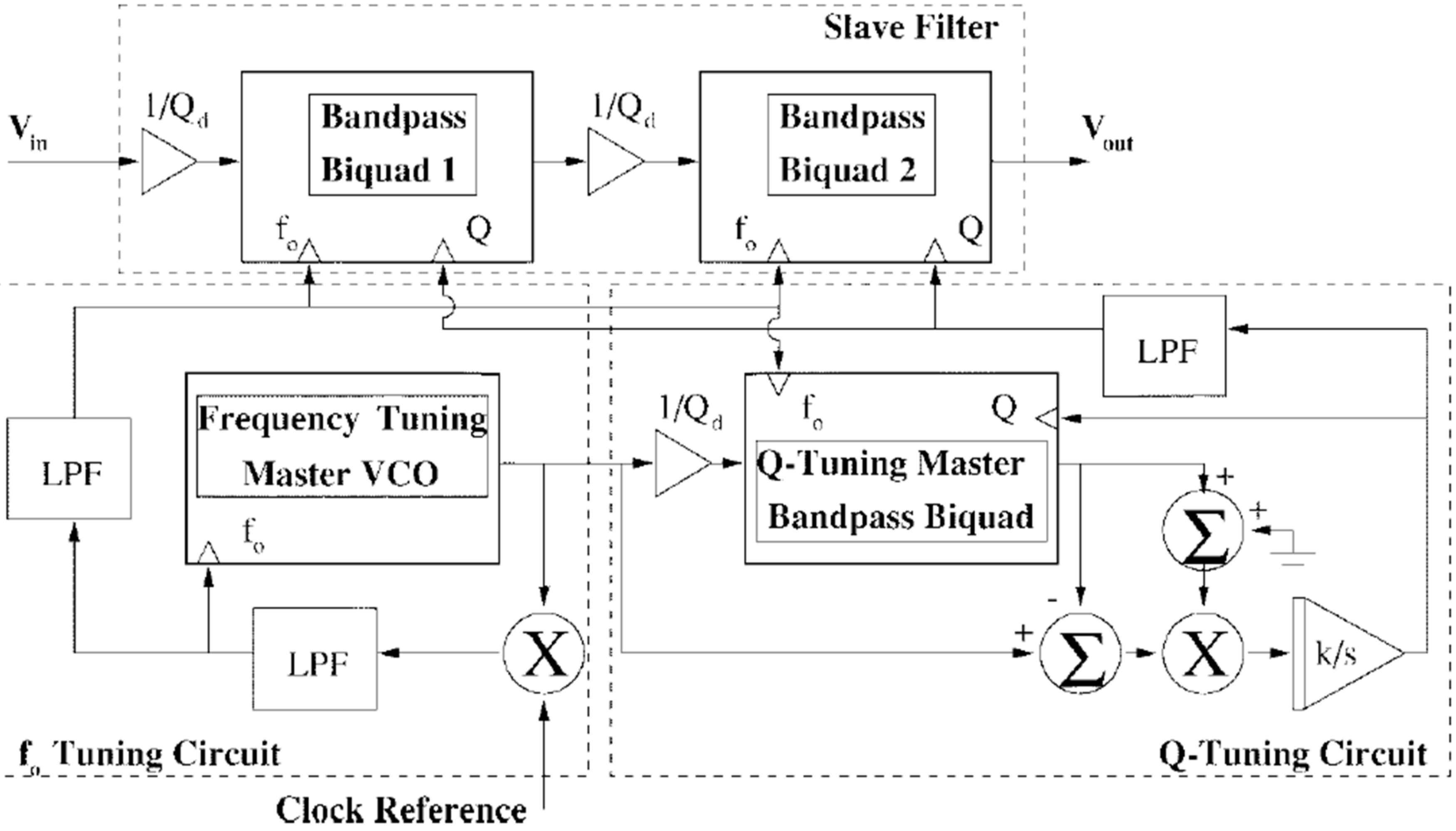


Fig. 5. Block diagram of overall filter.

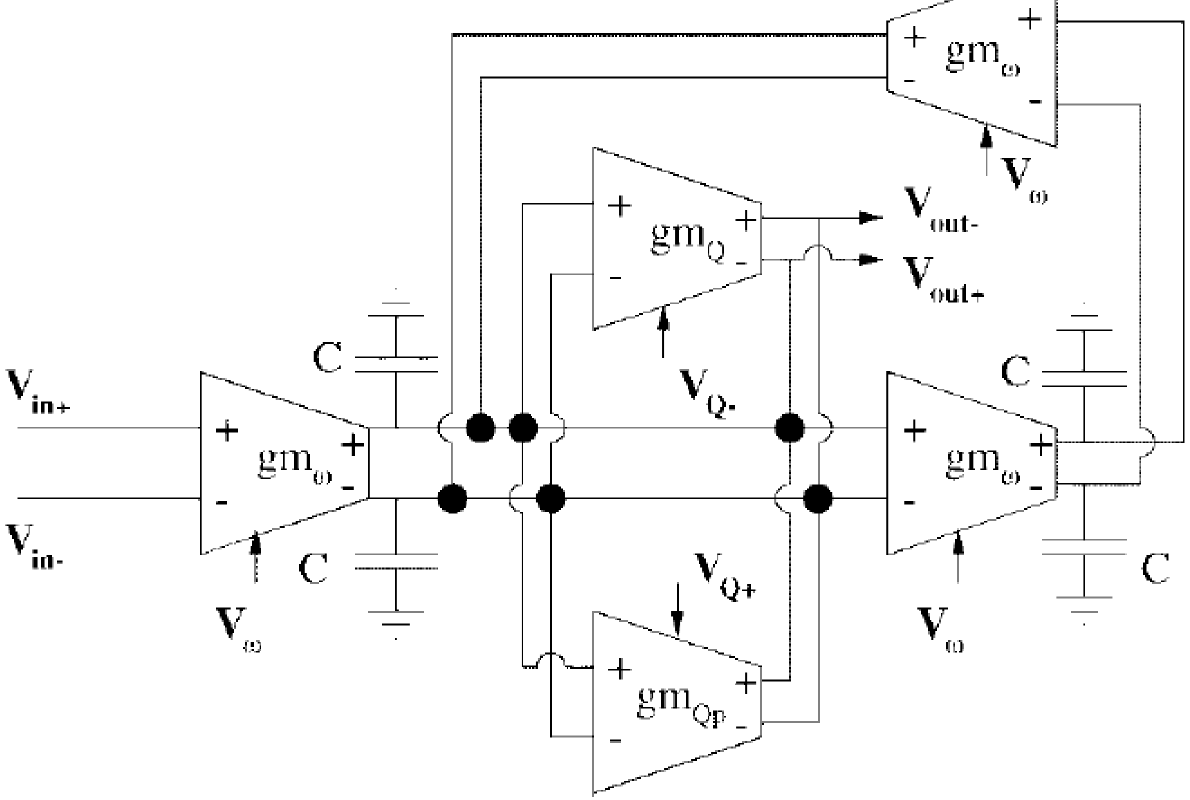


Fig. 6. Fully differential OTA-C two-integrator loop biquad with pa positive feedback.

$$H(s) \approx \frac{\frac{gm_\omega}{C}\left(s + \frac{g_{ds}}{C}\right)}{s^2 + \frac{5g_{ds} + gm_Q - gm_{Qp}}{C}s + \frac{gm_\omega^2}{C^2}}. \tag{15}$$

The center frequency is, therefore

$$\omega_o \approx \frac{gm_\omega}{C} \tag{16}$$

and the quality factor is

$$Q \approx \frac{gm_\omega}{5g_{ds} + gm_Q - gm_{Qp}}. \tag{17}$$

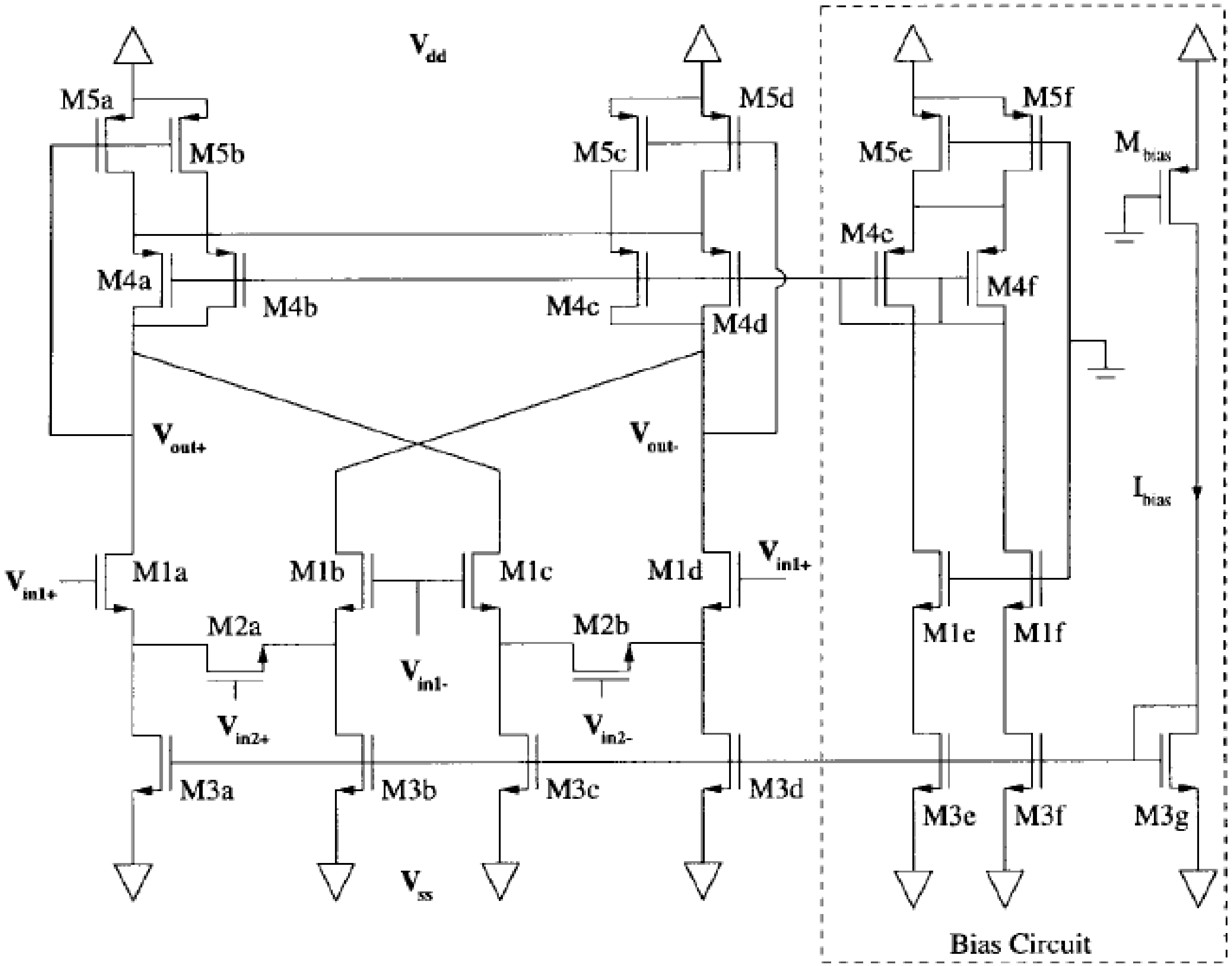


Fig. 8. Multiplier used in fabricated test chip.

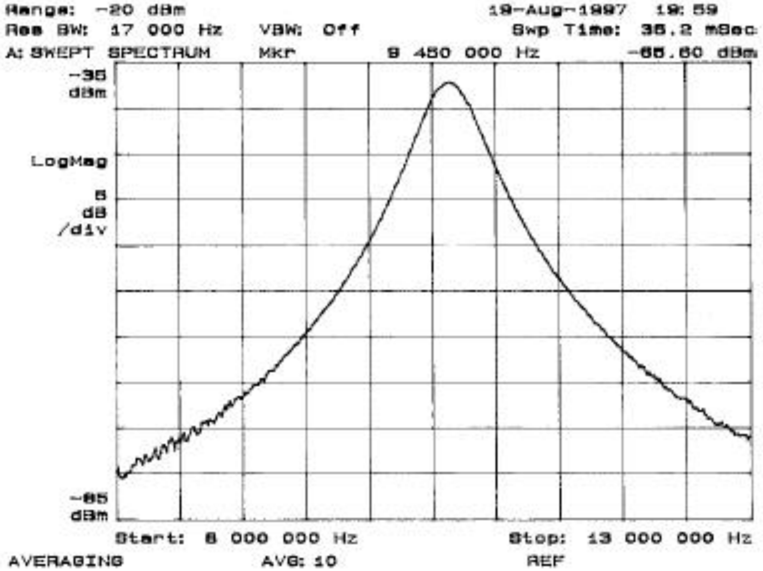


Fig. 11. Experimental frequency response of the 10.7-MHz filter.

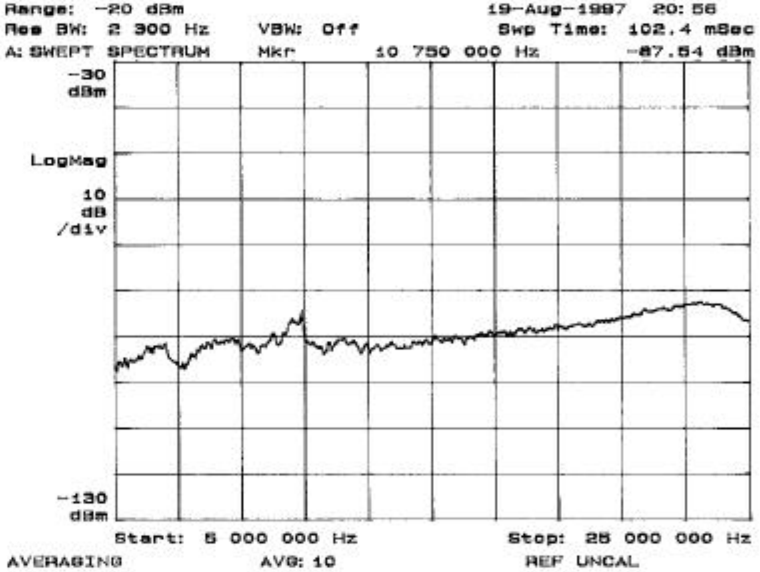


Fig. 12. Noise floor of the 10.7-MHz filter.

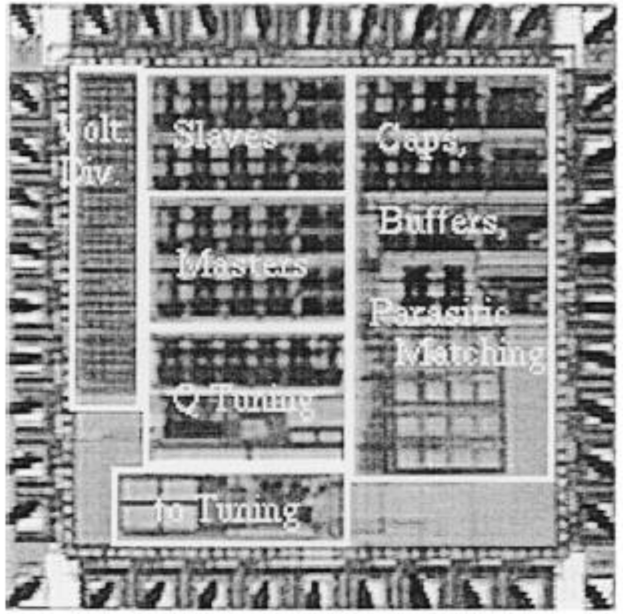


Fig. 13. Chip micrograph of the 10.7-MHz filter.

TABLE I
EXPERIMENTAL RESULTS OF THE 10.7-MHz FILTER

f_o desired	$10.7MHz$
f_o actual	$10.64MHz$
f_o error	0.56%
Q desired	20
Q actual	19.85
Q error	0.75%
Power consumption	$108mW$
Power supply	$\pm 1.5V$
Chip area	$3.24mm^2$
SNR	$47dB$
CMRR	$\approx 40dB$

VI. CONCLUSIONS

An accurate method for the tuning of quality factors in high-Q and high-frequency filters has been proposed. The

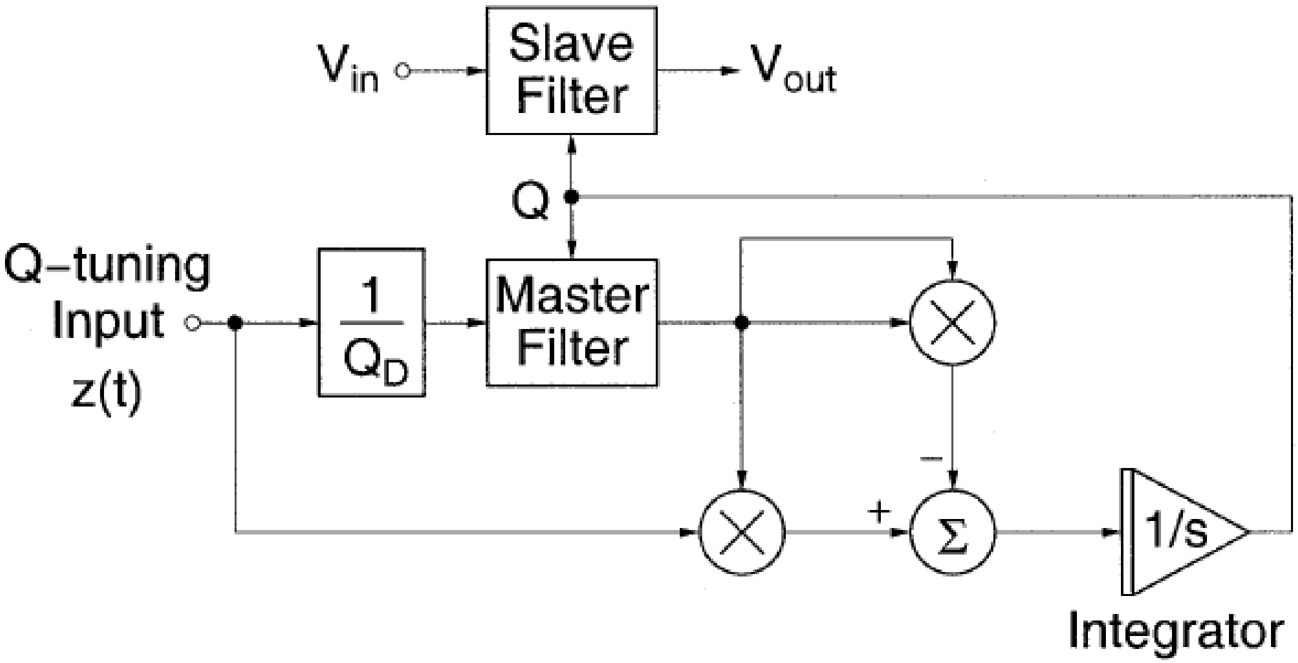


Fig. 3. Improved implementation of the modified-LMS Q-tuning scheme.

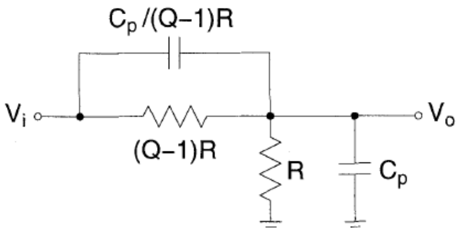


Fig. 14. $1/Q_D$ circuit as an attenuator.

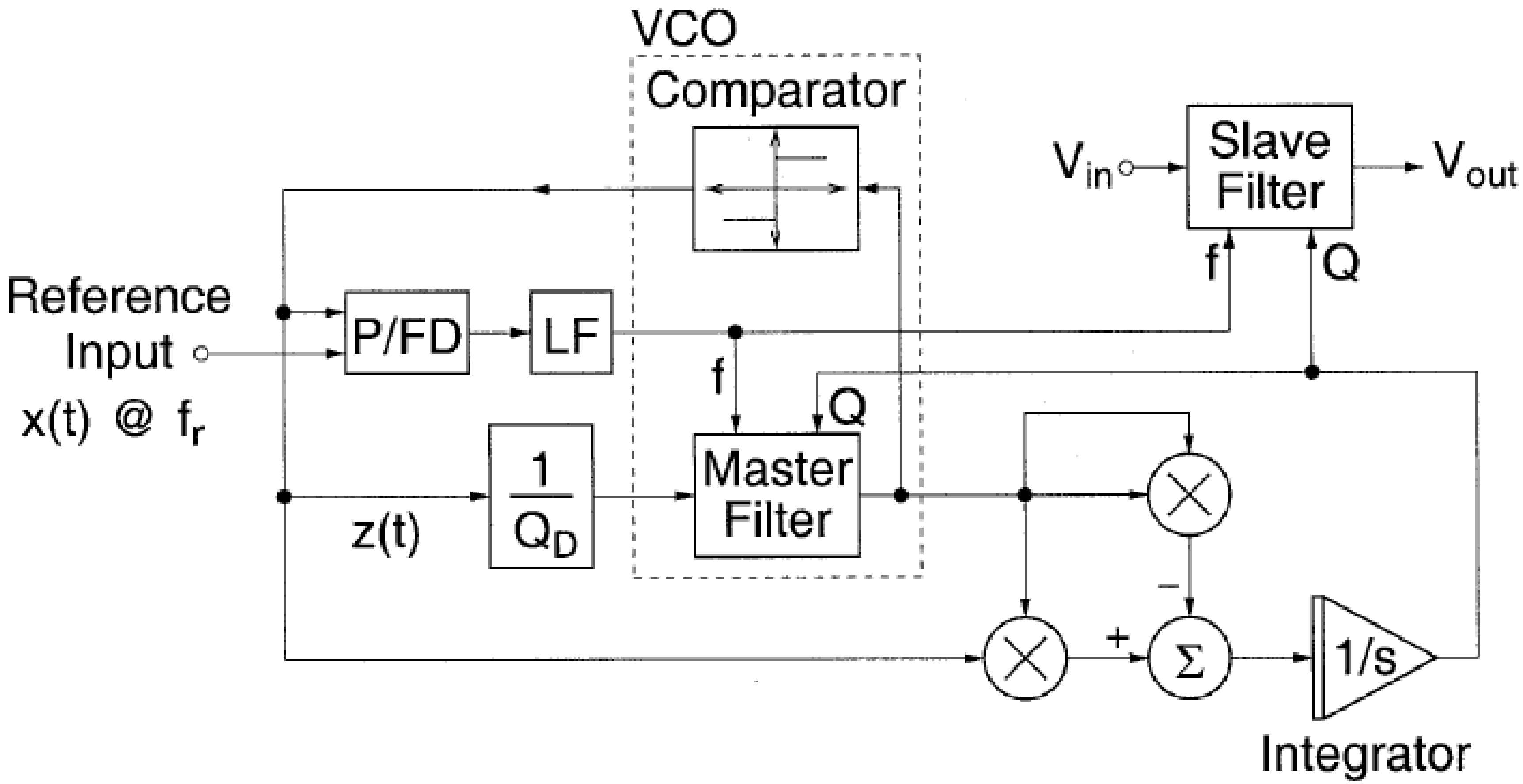


Fig. 4. Proposed unified f_0- and Q-tuning scheme.

Comparator

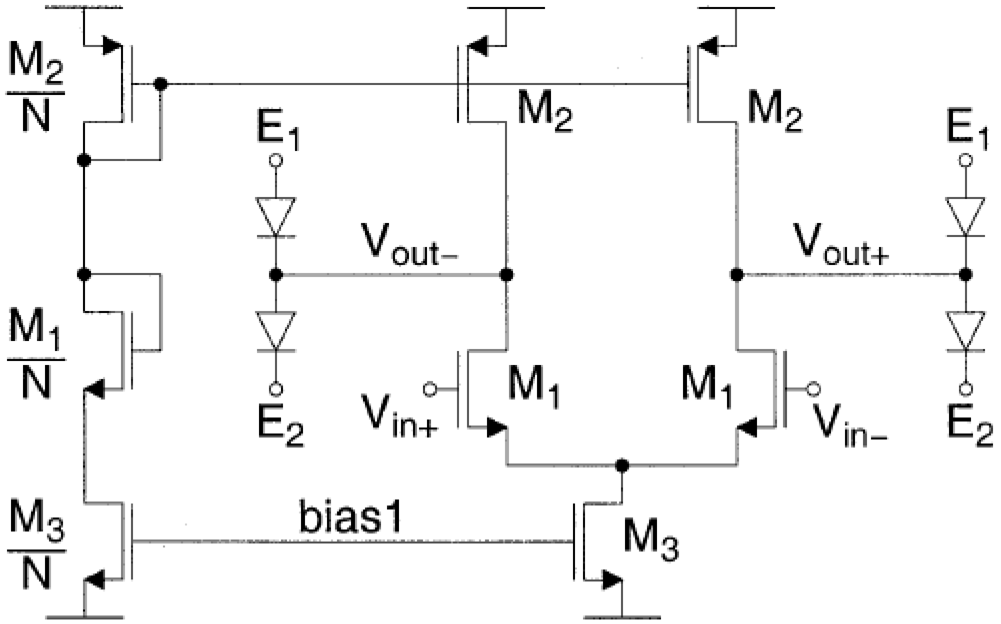


Fig. 13. Schematic of the comparator of Fig. 4.

Summary of Results

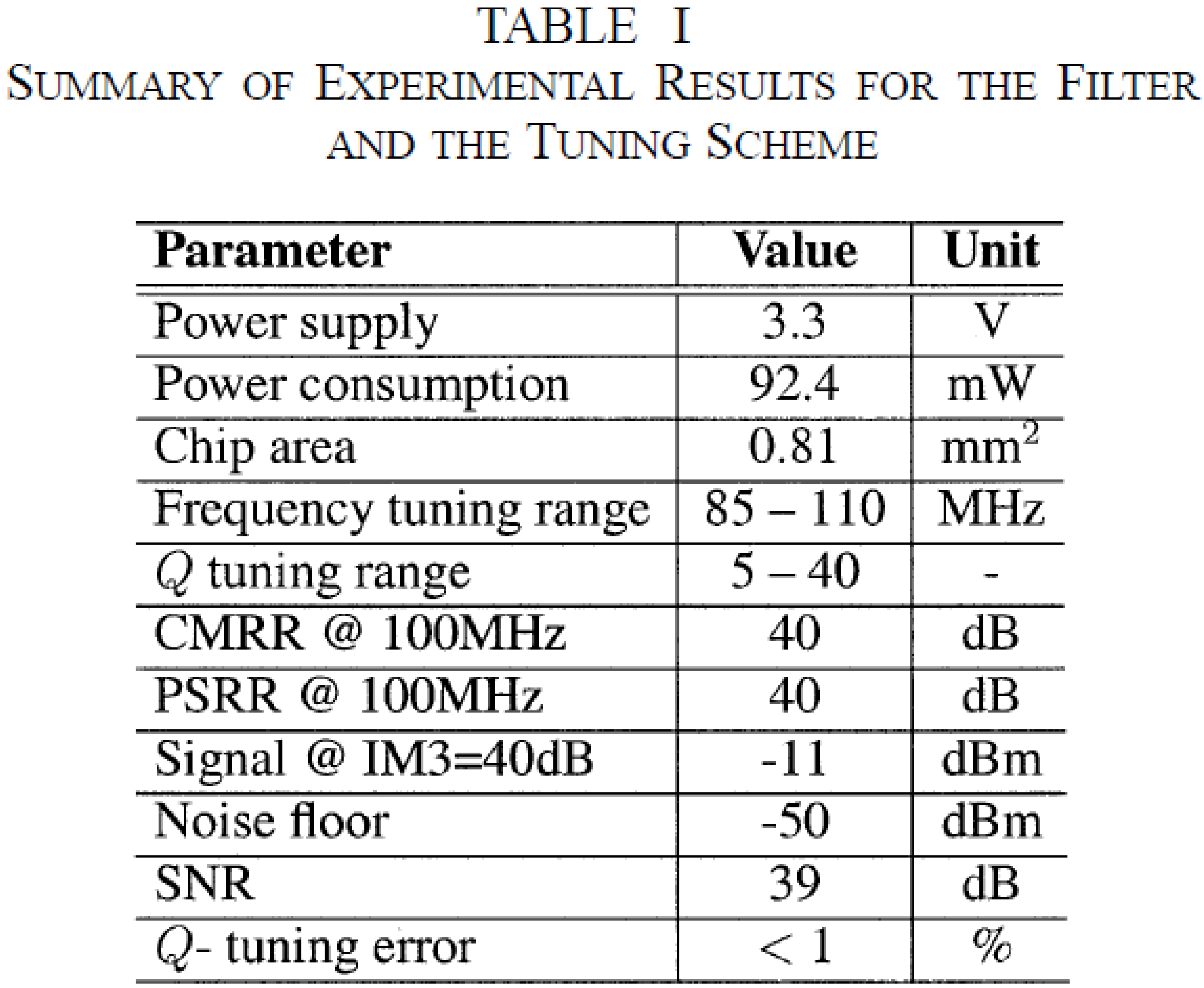
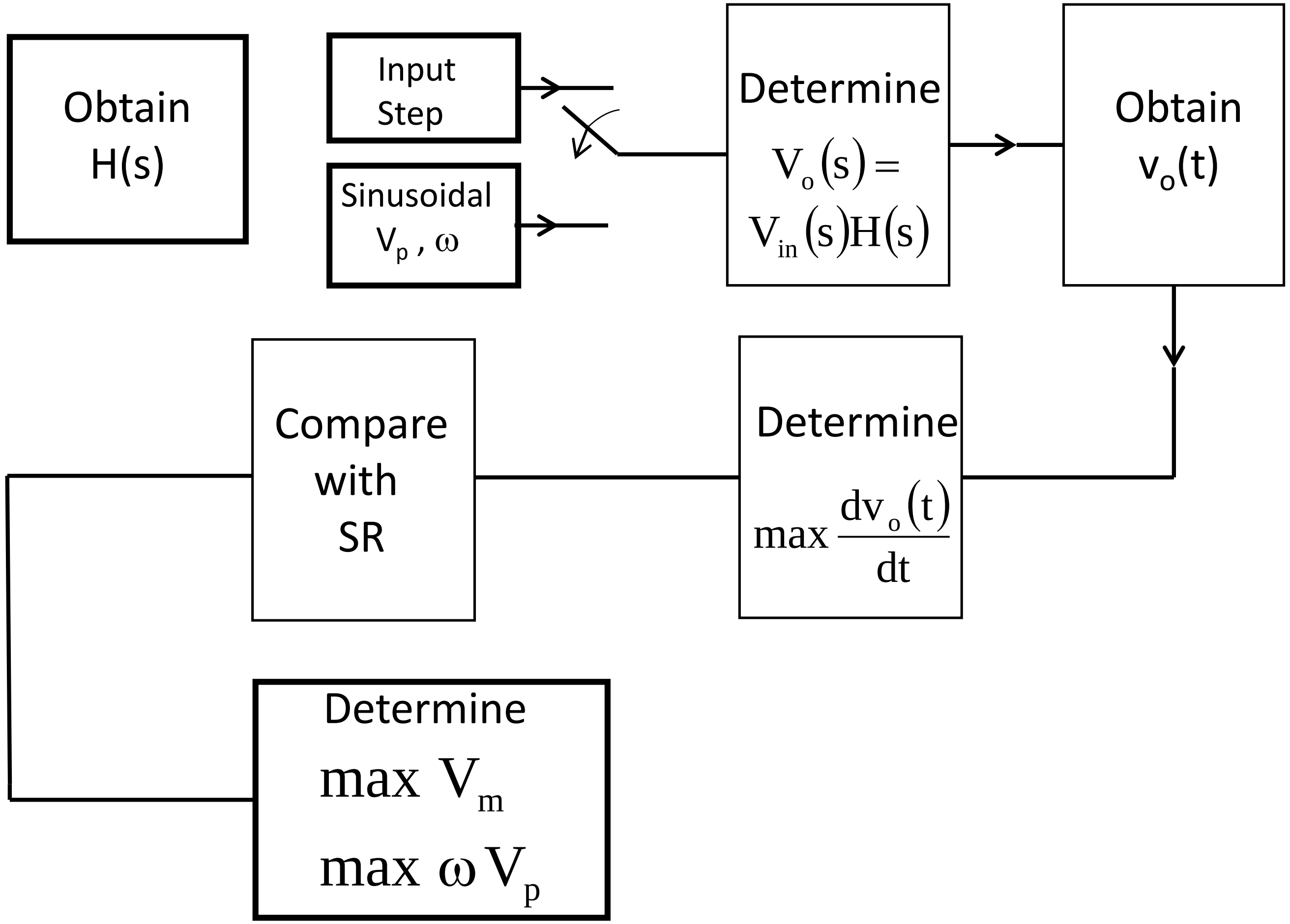


TABLE I
SUMMARY OF EXPERIMENTAL RESULTS FOR THE FILTER AND THE TUNING SCHEME

Parameter	**Value**	**Unit**
Power supply	3.3	V
Power consumption	92.4	mW
Chip area	0.81	mm^2
Frequency tuning range	85 – 110	MHz
Q tuning range	5 – 40	-
CMRR @ 100MHz	40	dB
PSRR @ 100MHz	40	dB
Signal @ IM3=40dB	-11	dBm
Noise floor	-50	dBm
SNR	39	dB
Q- tuning error	< 1	%

HOW TO DETERMINE SLEW-RATE AND GB LIMITATIONS



Obtain H(s)

Input Step

Sinusoidal V_p , ω

Determine $V_o(s) = V_{in}(s)H(s)$

Obtain $v_o(t)$

Determine $\max \frac{dv_o(t)}{dt}$

Compare with SR

Determine $\max V_m$ $\max \omega V_p$

References

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