Tunable (Operational-Band and Bandwidth) RF Bandpass Filter

I. Topology

The proposed filter topology is illustrated in Figure 1. In general, the higher filter-Q (Q_{filter}) at an amplifier's load increases the load impedance, boosting signal gain and potentially disturbing the amplifier's dynamic range. Our topology that has been devised to best compromise filter linearity and quality-factor (Q) controls, provides several unique merits that serve best for the program. *1. In the proposed, the high-Q LC-section is sitting inside an emitter-follower buffer and increasing the Q_{filter} will not amplify signal gain, not disturbing system's dynamic range over the wide range of the Q_{filter} variations (0.5 ~ 100) required by the program.* The maximum gain is limited to unity. *2. The cross-coupled HBT pair compensates losses from the finite Q of inductor and varactor, hence overall Q_{filter} will not be limited by the passives*. *3. A selectivity (i.e., Q_{filter}) can be increased by increasing the resistance R*. *4. This essentially provides more degeneration to the emitter-follower stage, resulting in system's linearity enhancement tracking the increase of Q_{filter}, which maximally optimize system's dynamic range.* The LC-section is isolated by input and output emitter-followers so that it can be cascaded to achieve a higher-order (Q> 50) filtering with minimal loading between the cascaded LC-sections.

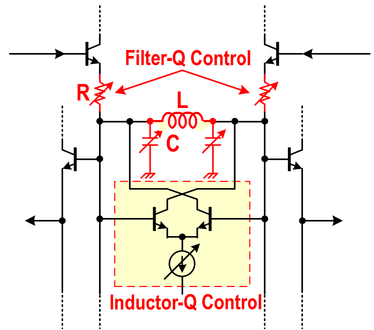

Figure 1. Tunable RF filter topology.

II. Operational Band Scalability

Traditional 2nd-order LC-tuned filters suffer from a tradeoff between *selectivity and tunability*. Namely, the characteristic impedance ($Z_o = \sqrt{L/C}$) of the LC-section needs to be smaller to achieve a higher Q_{filter} ($\propto 1/Z_o$), and therefore for a better selectivity. However, when we decrease capacitance to increase operational frequency (assuming a fixed inductance), the Q_{filter} decreases and the filter bandwidth becomes spreading. To cope with the tradeoff, we propose to use filter arrays. Figure 2 illustrates one example of our approach to cover more than 2-22 GHz of frequency range.

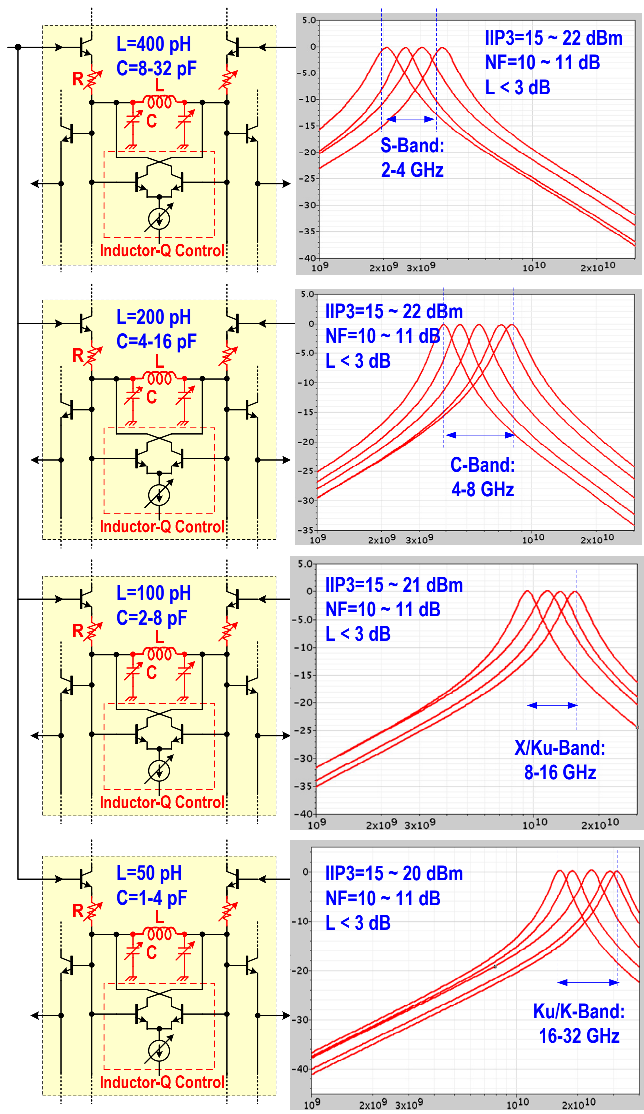

Figure 2. Example of 4 RF-filter arrays to cover 2-32 GHz frequency range. For every case, Q is set as ~4-5.

Table I. Nominal L-C values and characteristic impedance of the RF filters

Freq. (GHz)	2-4 (S-Band)	4-8 (C-Band)	8-16 (X/Ku-Band)	16-32 (Ku/K-Band)
Inductance (pH)	400	200	100	50
Capacitance (pF)	8 – 32	4 – 16	2 – 8	1 – 4
Z_o [√ (L/C)] (Ω)	3.5 – 7			

Our strategy is to limit the operational frequency band of each filter to an octave-band so that necessary capacitance variation is confined to 4x range. In such way, overall Q-spreading can be contained within 2x variations which can be easily calibrated by adjusting R with minimal compromise of noise performance. We achieve a continuous frequency tuning in the same manner as in standard VCO tuning: switched capacitor arrays tunes the filters' center frequency in a coarse discrete manner, and varactors will be used for continuous tuning between the discrete frequency steps. As mentioned, we are relying on the cross-coupled pair to compensate finite loss in the varactors.

Table I summarizes nominal L and C values and filter characteristic impedance at each operational band. The choice of the relatively small inductance in each filter is the outcome of an optimal compromise of linearity performance, while minimizing area penalty. A larger inductor tends to be more lossy in silicon technologies, which requires a larger negative transconductace from the cross-coupled pair. While the cross-coupled pair is indispensable to calibrate out the inductor loss, hence to achieve a higher Q_{filter} than Q_{ind}, it is potentially non-linear source and the large transconductance variation could hurt linearity of the system substantially. By choosing a small high-Q inductor, we want a minimum use of the positive feedback to contain IIP_3 degradation by the cross-coupled pair under 1-3 dBm range, achieving >15 dBm of IIP_3 over the entire bands targeted by the program.

III. Bandwidth Scalability

Bandwidth can be scalable by scaling the parallel L-C tank resistance by a joint control of the resistance R and bias current (and therefore transconductnace, g_m) of the input transistor (Fig. 1). The 3.5-7 Ω of small L-C characteristic impedance allows us to control the Q_{filter} [$=(R+1/g_m)/Z_o$] over a wide range with a relatively small resistance changes: for instance, changing R from 0 to 150 Ω could result in ~10x of Q-scaling depending on the

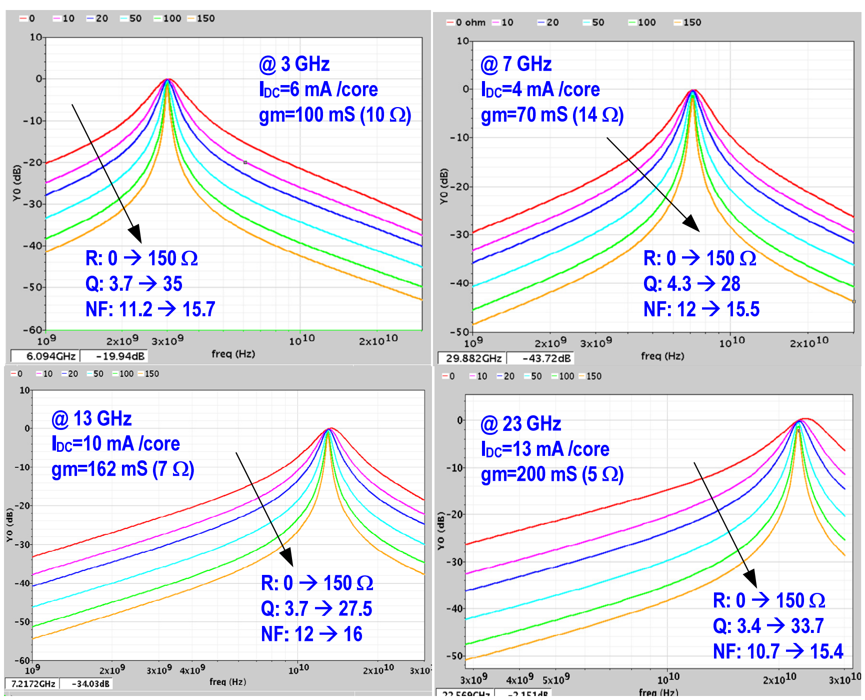

Figure 3. Exemplary simulation results of Q-tunings of individual filters at different operational band.

combination of bias currents and operational frequency bands (Figure 3).

In the bandwidth control, the traditional tradeoff of linearity and noise comes into play: e.g., increasing R to narrower bandwidth will increase linearity at the expense of NF degradation (Figure 3). Our Phase 0 efforts include system-level study on the impact of the tradeoff on the overall system performance and the commonality of a common module seek by the program. Phase 0 effort also includes cascading the filter section to realize higher Q (> 50), and investigating any performance compromise by the cascading.