The Design of CMOS Radio-Frequency Integrated Circuits

szerző: Thomas H. Lee

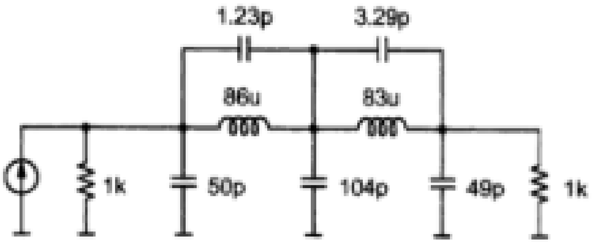


FIGURE 19.22. Elliptic IF filter prototype.

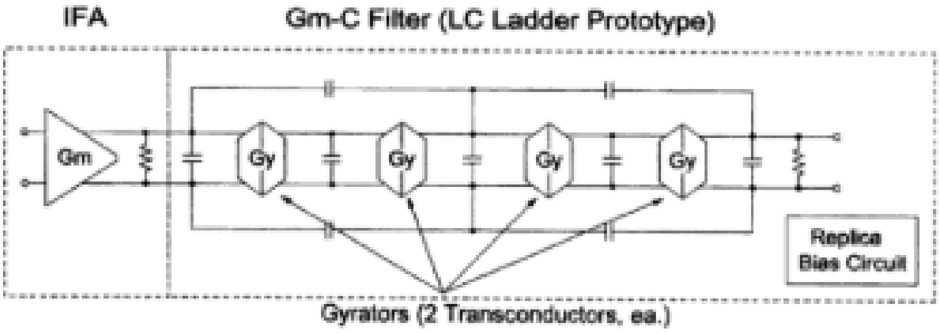


FIGURE 19.23. IF filter architecture.

In the actual filter, the inductors are replaced by gyrators, which are two-port elements capable of converting available capacitors into otherwise unavailable inductors.[21] Gyrators are usually implemented as two cross-connected transconductors, each converting one port's voltage into another's current. See Figure 19.23. By thus exchanging port voltages and currents, the gyrator presents at one port an impedance that is proportional to the reciprocal of an impedance connected to its other port. In the present example, differential amplifier structures are used throughout. Some economies might be afforded by using single-ended implementations, but we will not consider those here.

The gyrator-based inductor, along with its corresponding noise model, thus appears as shown in Figure 19.24. The dynamic range of a receiver can be constrained very easily by the linearity of the filters. If preceded by sufficient gain, a filter will be overdriven and produce nonlinear behavior. Consequently, power-efficient and

German telephone system. Legend has it that Bell Labs engineers, upon reading of Cauer's invention in a patent, rushed over to the New York Public Library to bone up on the then- and (still-) obscure mathematics of elliptic functions so they could understand what he had done. The underlying intuition is straightforward enough (use the response notches of imaginary zeros to produce a rapid transition to stopband), but figuring out exactly where all the poles and zeros should go is a decidedly nontrivial problem.

[21] The gyrator was first named and studied as an element by the famous Dutch theoretician, Bernard D. H. Tellegen, in "The Gyrator, a New Electric Element," *Philips Research Reports*, v. 3, 1948, pp. 81–101. However, gyration of capacitors into inductors is actually the basis of many early FM generators that predate the explicit naming of these elements by Tellegen. Countless "reactance tube" modulators were used before the word *gyrator* entered the engineering lexicon. Tellegen formalized and extended the concept.

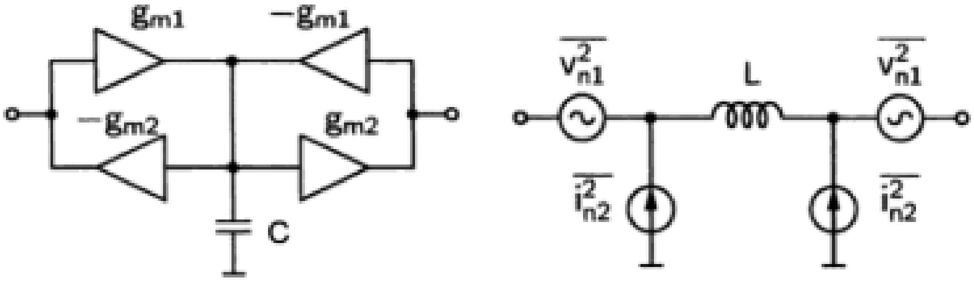
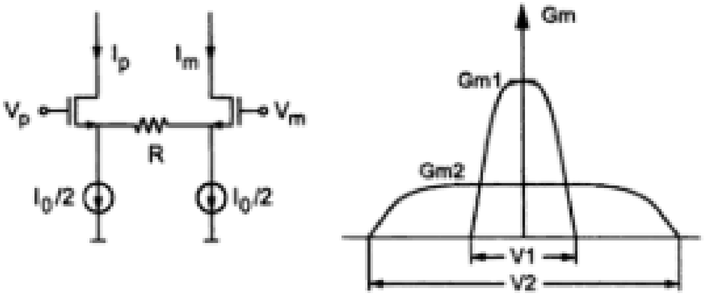


FIGURE 19.24. Gyrator architecture and noise model.



$$G_{m1}V_1 = G_{m2}V_2 \propto I_0$$

FIGURE 19.25. Degenerated differential pair.

linear transconductors are essential to realizing good filters of this type. In the present context of a GPS receiver, the filter we are designing is vast overkill, and significant power and die area reductions may be achieved by seeking a more modest design. Nevertheless, artificially inflating the requirements gives us an excuse to identify some design concepts that are broadly applicable.

Assuming that we do seek linear transconductors, a quick survey of the literature reveals several popular candidates. One is the venerable degenerated differential pair (Figure 19.25). To first order, with or without degeneration, the edge of the linear region is defined by a differential twist sufficient to cause a significant fraction of the bias current to be steered to one side. Degeneration does nothing to change this fundamental behavior; all it does is increase the input differential voltage required to reach this limit. Consequently, the product of transconductance and linear input voltage range stays roughly constant – and proportional to the bias current. Stated another way, the mere presence of a limiting bias current assures a bounded linear range.

A variation on that theme replaces the fixed linear degeneration resistor with triode-operated MOSFETs whose gates are tied to the differential pair's inputs. This way, as the differential twist increases, the value of the effective degeneration resistor decreases, partially offsetting the effects of nearly complete current steering. This simple trick can provide large improvements over fixed degeneration. However, the optimum conditions are relatively narrow and so the improvements available in practice are not as large as theory predicts.