Wireless Telephone Industry Opens Doors for Cable

Matthew Waight
General Instrument Corporation

Abstract

The wireless industry is a leader in the development of new technology for low-power communications equipment. The integration of microwave frequency circuitry and new SMD filters for wireless has created new opportunities for other industries. These new components offer tremendous opportunities to improve and simplify cable products. A 860 MHz Dual-Conversion tuner is described which uses wireless technology to meet the requirements of all cable transmission formats, including NTSC, PAL, and 64 QAM, while eliminating all adjustments.

Cable Tuner Technology

Dual-Conversion tuners are used in cable systems in order to achieve the required composite distortion performance. These tuners have traditionally been designed using discrete oscillators, balanced diode mixers using ferrite baluns, and aperture HI-IF filters. General Instrument's 550 MHz tuner, using traditional technology, required tuning of the HI-IF aperture filter, Up-Converter mixer and oscillator, Down-Converter oscillator, and IF filter section. A total of seven separate adjustments were required for each tuner.

Predicting the performance of mixers is difficult when mixing multiple signals (1), (2) regardless of the technology used. Eliminating the variable of discrete diode based mixers and replacing them with a MESFET based Gilbert-Cell mixer makes the performance more predictable. Using GaAs technology (3), we were able to integrate an oscillator with the Up-Converter mixer and a differential RF amplifier in a single RF ASIC, eliminating the need for a separate pre-amplifier. Figure 1 shows a differentail amplifier driving a Gilbert-Cell MESFET mixer. This device takes advantage of a FET's superior third-order distortion performance while the Gilbert Cell's structure improves second order distortion. This change was implemented in 1992 and reduced the number of components in the Up-Converter section from 124 to 64 while eliminating two adjustments. Over 20 Million tuners have been manufactured using the integrated GaAs Up-Converter IC, making General Instrument a leading user of GaAs ICs.

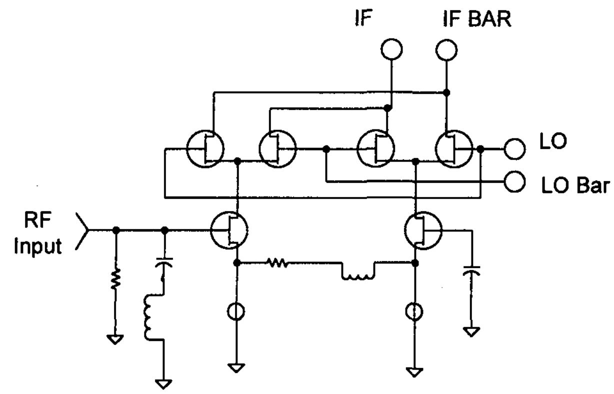

Fig. 1 Gilbert-Cell Mixer with Diff-Amp Input

The trend towards integration continued in our 1 GHz tuner which used an integrated Up-Converter, Down-Converter, and two single-chip synthesizers. As 1 GHz cable systems proved to be more marketing than reality this product was modified to a 860 MHz tuner. While we had increased the bandwidth and achieved a significant amount of integration we still retained a single-sided PCB and aperture HI-IF filter design.

General Instrument had two basic tuners (550 MHz and 860 MHz), with different versions for NTSC, PAL B, or PAL I output. Each version had different tuning procedures and Bill of Materials (BOM). These products used single-sided PCBs and a wave-soldering process which required a significant amount of inspection and touch-up. The total cost of supporting these products was becoming non-competitive due to labor costs.

A goal was set to design a single tuner for all converters, regardless of format, including digital terminals such as the DCT-1000 (64 QAM). The tuner needed to significantly reduce the direct labor requirement and eliminate all adjustments. In order to achieve this goal all cost items were considered, including manufacturing costs, test requirements, alignment cost, and indirect labor costs. Switching from a single-sided PCB to a double-sided PCB, which was traditionally rejected automatically due to the increased cost, was left open to consideration if the total cost was reduced. The basic block diagram can be seen in Fig. 2, showing the key sections of the tuner.

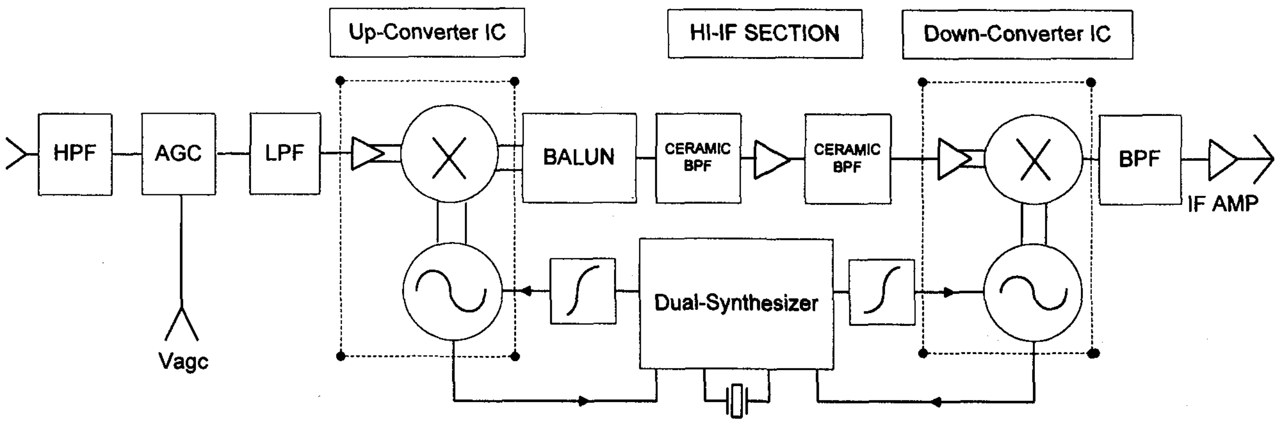

Fig. 2 V-860 Block Diagram

RF Transistors

The tuner being described has two key amplifier requirements. The HI-IF amplifier is used in-between the ceramic filters, (to be discussed), and the IF amplifier which follows the Down-Converter section. The traditional narrow-band high-frequency amplifier uses an air-coil between the supply and the collector and this part is often hand inserted. Using design notes for wireless amplifiers (4), (5), a quarter-wavelength transmission-line design was used to eliminate the air-coil. Using both voltage feedback and a constant base current source, emitter resistors were eliminated which helped achieve a noise figure performance of less than 2.5 dB with a low-cost bipolar transistor (Siemens BFP 183).

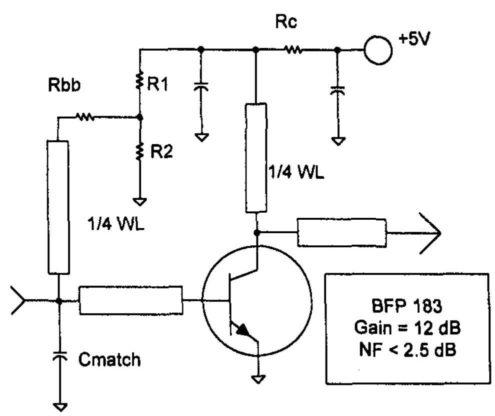

Fig. 3 HI-IF Amplifier Circuit

The IF amplifier typically uses a 3 dB pad on the output to improve the output return-loss but the wide-band filter design and 5V supply make the loss of 3 dB of gain impractical. The new design used an old design note, (6) which describes both series and parallel feedback techniques. By using non-linear models of the transistor (Siemens BPF 193) with HP's MDS RF design system, the circuit met all requirements with a 5V supply. The design achieved an output return-loss of 15 dB, gain of 15 dB, and met the X-MOD distortion requirement while eliminating the pad and offering a 6 dB improvement in third-order distortion performance.

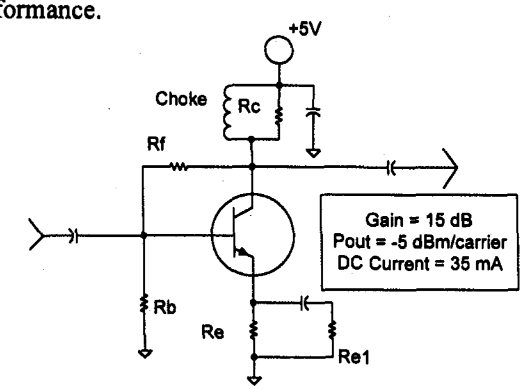

Fig. 4 IF Amplifier Circuit

RF ASICS

Our GaAs IC supplier, ANADIGICS, is also supplying the wireless industry which typically requires 5V technology. In 1995 they developed a Down-Converter ASIC which required only 5V instead of both 5V and 9V supplies, simplifying the design and lowering the power dissipation. As the first active device, the Up-Converter IC essentially determines the noise figure and distortion performance of the tuner as well as the phase noise degradation of the signal. The 64 QAM system used with our DCT-1000 digital terminal limits the phase noise degradation due to the tuner (7). Since the Down-Converter is narrowband, the phase noise performance is typically 9 dB better than the wideband Up-Converter oscillator circuit. The distortion requirements have previously required the differential amplifier/mixer section to use 9V.

By using new bias techniques, a 5V Up-Converter ASIC has been developed, allowing the tuner to use only 5V for all devices except for the varactor tuning voltage. This greatly simplifies the tuner design by minimizing the number of external inputs while further reducing the power dissipation in the tuner. By using advanced test equipment each RF ASIC is tested for critical RF and DC parameters including phase noise, 2nd and 3rd order distortion, gain, and noise figure. By using tested ASICs the number of parameters tested at the tuner level is reduced. As the wireless industry grows, vendors such as ANADIGICS should be able to further lower the price of GaAs devices which are still widely regarded as too expensive for consumer electronics.

Frequency Synthesizers

The use of phase locked loops to synthesize the oscillators needed in tuners is not new (8). The early TV and cable tuners placed a pre-scalar IC in the tuner while more recent designs have the entire PLL circuit, including the synthesizer IC, in the tuner itself. Bipolar technology was traditionally used for lowest cost. The wireless industry has generated a large market for very low power synthesizers which has been filled by BiCMOS devices having power consumption of less than 100 mW (9), by vendors such as National Semiconductor's LMX233X line of devices. Replacing two bipolar devices with one dual-synthesizer device can lower the power consumption by over 700 mW while lowering the parts count. As the wireless industry expands, these BiCMOS devices will continue to be lower in cost as manufacturers move to ever smaller device geometries and larger wafers. By adopting this technology the V-860 will enjoy the cost benefits of the wireless market while offering vendors a more stable demand for existing technology.

Ceramic Filters

While aperture filters can have excellent performance they require complicated mechanical designs and have to be tuned by hand. This limits the throughput of the line and adds a human variable to the product quality. While the cable tuner does not have stringent size requirements, any reduction in size is helpful. The wireless industry has severe size limits which has created a large market for ceramic filters which use high dielectric materials to realize very small filters with the required response (10). While these filters can not easily achieve the desired image attenuation in a single device they can be used in pairs with an amplifier in-between to more than achieve the required response. By using existing technology which is used in large volumes by the wireless industry, the cable industry can greatly simplify their products in a cost effective manner.

The V-860 was able to use an existing filter product and by slightly modifying the center frequency and bandpass limits, within the vendor's limits, achieve an acceptable response for use of two filters with an amplifier in-between. By buying a filter with a specified response, rather than manually tuning an aperture filter, all tuning was eliminated while improving the variance in the response. With the tuner's flatness over 6 MHz typically better than 0.5 dB, the ceramic filters have been a critical element in meeting this requirement. Each filter has a typical image rejection of 40 dBc, a 1 dB bandwidth of 35 MHz, and an insertion loss of 1.5 dB.

Another critical element is being able to work with PAL B (7 MHz bandwidth) and PAL I (8 MHz bandwidth) systems. Using a wide filter response is necessary to work with all of these systems. The same wider response is also needed for digital QAM systems to avoid amplitude and group delay distortion. A wider passband does increase the second and third-order distortion requirement of the Down-Converter but the result is a very repeatable product with no adjustments at a competitive price.

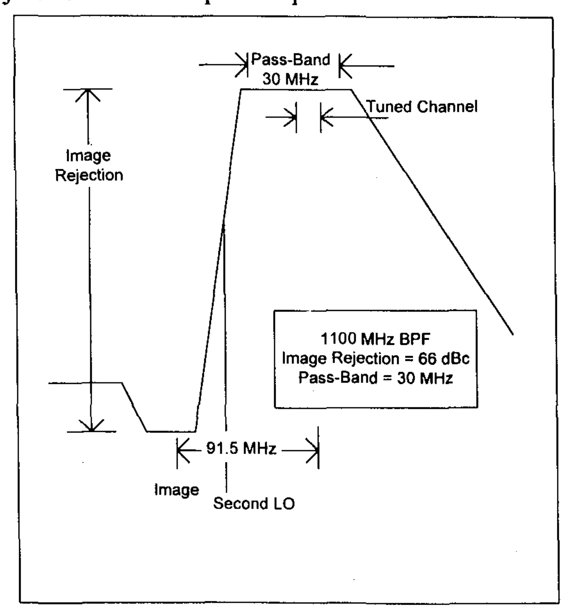

Fig. 5 HI-IF Response for Two Ceramic Filters

Design for Manufacture

Any attempt to lower the number of hand-inserted components and the number of adjustments will likely increase the bill of material (BOM). While the total cost of a product is what should be measured it is the BOM which is most easily measured and as a result is the most commonly monitored item. This can result in significant friction to any attempt to dramatically change the product design to reduce the labor cost. By gathering all costing information prior to proposing any change, quick rejections of ideas were prevented. Items such as direct labor rate increases, material overhead, failure rates, and indirect labor costs were be investigated. A key argument was comparing an increasing labor cost to a decreasing BOM over time and volume. This allowed us to argue for increasing the SMD percentage and investing in auto-insert equipment to reduce the amount of labor. By working with the manufacturing engineers from the start, better decisions were made early in the product development, avoiding cost increases later-on.

General Instrument's new tuner achieved 100% auto-insert of electrical components by primarily using SMD components with some auto-insertable chokes and crystals. Compared to the 860 MHz tuner it replaced, the V-860 resulted in a significant reduction in labor cost while increasing the build rate on a shorter production line. This was achieved by using a double-sided PCB and reflowing all SMD's while wave-soldering only the leaded components. All inductors less than 50 nH are printed to reduce the number of chokes. The use of 0603 chip resistors was introduced to decrease the size of tuner. The number of components was reduced with a significant reduction in leaded components.

The process of building a tuner starts with screen printing solder paste on a panel of PCBs, followed by placement of all SMDs. The panel is then reflowed. The leaded components are then auto-inserted. The PCB's can then be separated and inserted into a chassis and the assembly is then wave-soldered. Covers are added and the finished tuner is auto-tested. The new process eliminates all glue and all hand-insertion of components. There are no adjustments to slow the line rate and by eliminating the wave-soldering of the SMD components the amount of inspection and touch-up is minimal. As important as improving the cost structure of the tuner is, the increase in build capacity is also critical. By having one tuner for all products, forecasting is easier and delivery times are improved.

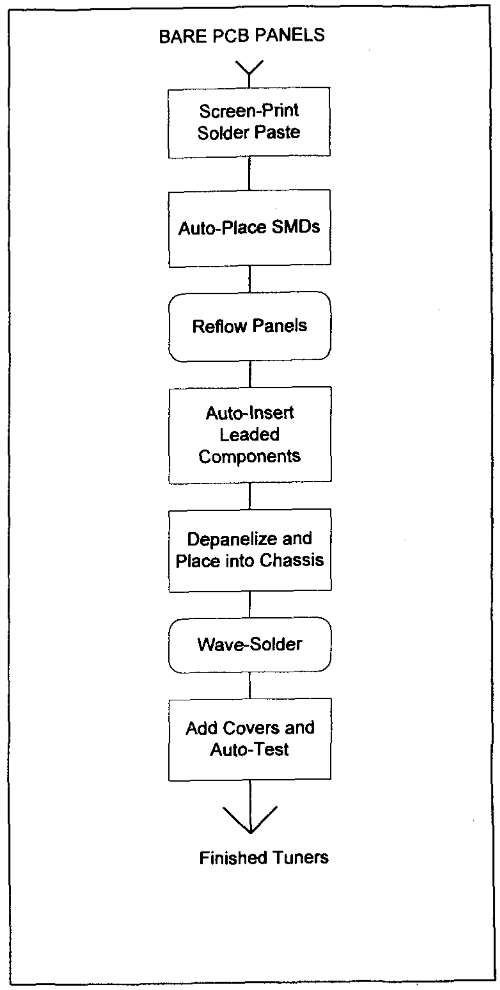

Fig. 6 Process Flow for Tuner

Universal Tuner Design

While wireless cable may sound illogical, wireless for cable makes a lot of sense. By using devices developed for the wireless telephone industry a 860 MHz Dual-Conversion Cable tuner has been developed which eliminates all adjustments and all hand-inserted components. The filters and RF ASICs have allowed for significant reductions in direct labor while reducing the parts count. The wireless technology has allowed the tuner to be used with all broadcast formats, including digital QAM systems. If a mature technology, such as dual-conversion tuners, can be dramatically improved by using technology from the wireless industry, one can only wonder what other advances are possible for the cable industry if we bother to look.

References

1. Barrie Gilbert, Rupert Baines, "Fundamentals of Active Mixers" Applied Microwave & Wireless, Winter 1995, pp. 10-36.

2. Michael Leffel, "Intermodulation Distortion in a Multi-Signal Environment" RF Design, June 1995, pp. 78-84.

3. N. Scheinberg, "A GaAs Up Converter Integrated Circuit for a Double Conversion Cable TV "Set-Top" Tuner", IEEE Journal of Solid-State Circuits, Vol. 29, No. 6, June 1994, pp. 688-692.

4. Terry Cummings, "Designing a Low Cost GPS LNA Using the NE68519", RF Design, June 1994, pp. 36-45.

5. Hewlett Packard Application Note 944-1.

6. Richard S. Hughes, "Unique Properties of the Series-Parallel Feedback Video Amplifier", EDN.

7. Kamilo Feher, Advanced Digital Communications, Prentice-Hall,New Jersey, 1981.

8. J.G.N. Henderson and E.N. Monacchio, "Frequency Synthesis for Television Receivers" RCA Laboratories, ER-166, January 1975

9. Jack Browne, "BiCMOS PLLs Conserve Current in Wireless Designs", Microwaves & RF, October 1996, pp. 136-140.

10. Darioush Agahi, "Monolithic Ceramic Block Combline Bandpass Filters", RF Design, March 1989, pp. 35-41.