RF Tuner Technology

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Introduction

Today, we are the Consumer Technology Society (CTSoc). However, the parent of today's CTSoc started life 1952 as the IRE Professional Group on Broadcast and Television Receivers. Electronics of the time was radio and phonographs. The first commercial TV broadcasts in the USA in New York City were in 1939. The TV was a newly emerging technology that was a complex and challenging mix of technologies: display, audio, RF, high voltage, signal processing, and power thermal management, that suggested it would a productive target of an IEEE focus. This early focus from 1952-1974 was on the consumer electronics of the time– broadcast receivers.

Just as we evolved from The IRE Group to today's CTSoc, today's IEEE Transactions on Consumer Electronics began life as the 15-page, July 1952 Vol. 1, Nbr .1 IRE Transactions of the IRE Professional Group on Broadcast and Television Receivers. The foreword to our first transactions introduced the content of our first publication[1]

> *A Round-Table Discussion sponsored by the Professional Group on Broadcast and Television Receivers (G8) of the Institute of Radio Engineers, took place in the Grand Ballroom, Waldorf-Astoria Hotel, New York, N.Y., on Thursday morning, March 6, 1952. The subject was "UHF TV receiver considerations". A stenographic transcript was made, and this transaction was prepared from that record.*

As you can understand it was in the early 1950's that the FCC (Federal Communications Commission) expanded the allocation of spectrum for TV broadcasting from the existing VHF TV broadcast band into new spectrum in the UHF band. The legacy VHF spectrum provided twelve 6 MHz wide channels from 54 to 216 MHz (72 MHz of spectrum) while the new UHF band provided 52 new channels extending from 470 to 890 MHz (312 MHz of spectrum). It was the technical challenges associated with accommodating UHF tuners that gave rise to the parents of the CTSoc. As stated in our first transactions[2]:

> *As I mentioned last September, at the symposium in Philadelphia, methods of mechanical tuning at UHF may be classified in three basic groups: First, the continuously tunable type, over the whole band from 470 to 890 MHz, with a single tuning dial. Second, semicontinuous tuning, in which there are a number of fixed positions, each one tunable over a portion of the band. And third, fixed position channel tuning, in which there is a separate position, with vernier compensation, for each of the desired channels.*
> * * *

1 IRE Transactions of the IRE Professional Group on Broadcast and Television Receivers, Vol 1 Nbr 1, July 1952
2 Ibid. IRE Transactions

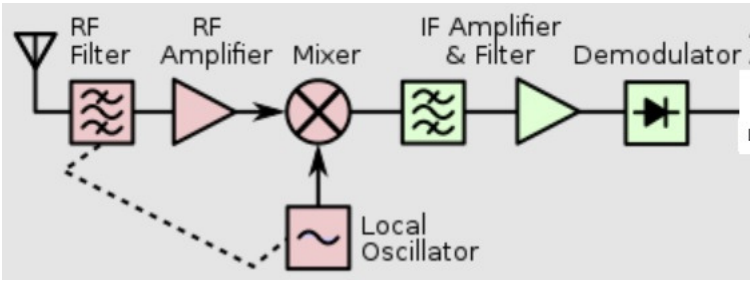
Perhaps it would be reasonable to consider, also, the general preferences of the viewer, and we all know of the quite large percentage of VHF receivers having tuners of the channel selection type. It appears to me that this can be even more important in the much larger frequency coverage of the UHF band which, as you know., is nearly six times as great as the whole of the VHF band, that is, 420 MHz as compared to 72 MHz in our present VHF.

Back in 1952, as today, tuners were at the heart of every RF receiver and presented technical challenges that were addressed with a series of innovations which responded to expansions in spectrum and improving the end user experience in using our consumer electronics products.

Receiver Block Diagram

Much has changed since 1952 but the Fig. 1 basic block diagram of the front end of a superheterodyne RF receiver has remained largely the same.

Fig 1 Generic RF Receiver Front End

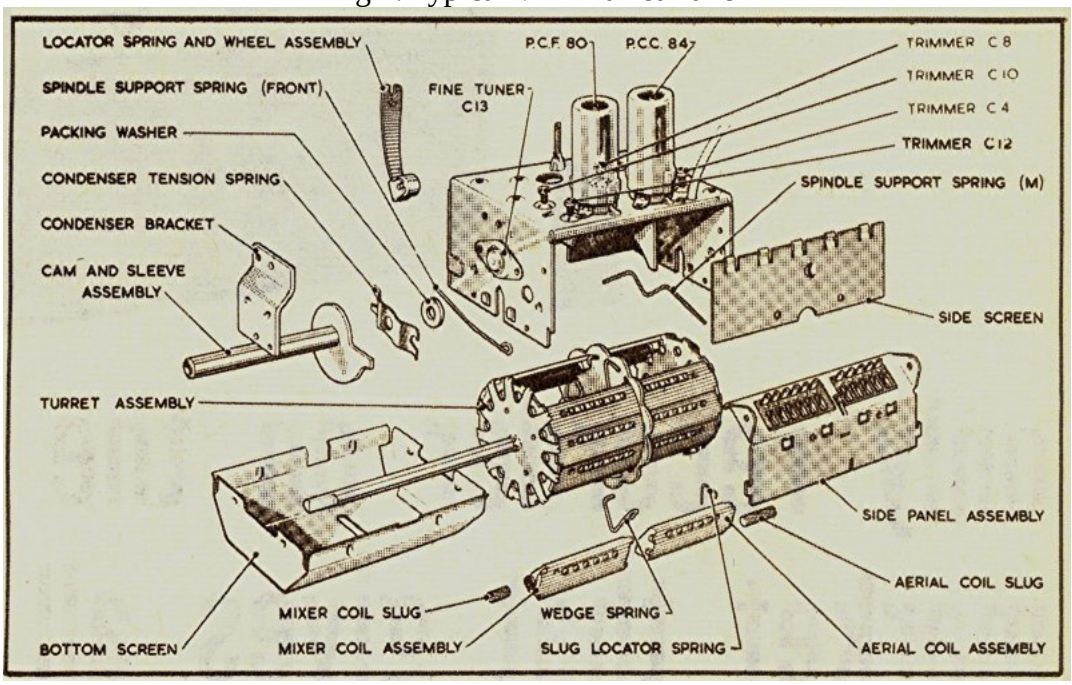


With the replacement of vacuum tubes by semiconductor devices and RF receivers now being used in all matter of electronic devices beyond TV receivers much innovation in the RF receiver front ends has occurred in improvement of dynamic range, increased sensitivity, selectivity and other areas. However, a deep dive into the history of the Local Oscillator (LO)block in TV receivers is of particular interest to the CTSoc. The LO block is one element of TV receivers that most contributes to the end user experience and with each innovation unlocked features such as remote controls and access to additional channels.

First Generation VHF TV Tuners

As mentioned above, the legacy over-the-air broadcast spectrum consisted of 12 channels of 72 MHz of bandwidth over 54 to 216 MHz. In the VHF range lumped LC tuning elements were a practical choice and indeed the first generation TV tuners employed a continuously tuned LO. It was not long however when a major improvement was made to support an end user interface of a tuning dial with a detent for each of the 12 fixed channel positions. A typical design employed a rotatable drum of LC strips where each strip had an LC circuit that controlled the frequency of the LO. A typical such design was called a turret tuner as shown in the Figure 2 example below.

Fig 2. Typical VHF Turret Tuner



Source: https://www.vintage-radio.net/forum/showthread.php?t=132770

The main technical challenge here was frequency stability of the LO. Although the channels were 6 MHz wide, you still needed to be within a few 100KHz of the channel frequency so best design practices were employed to temperature compensate the LC tuned circuits in each strip of the turret and even so, the end user was provided with the fine-tuning knob to home-in on the channel.

The industrial designers made a cosmetic decision to move the tuning knob from the bottom front of the TV to the top. Since heat rises, once the TV was turned on this subjected the LC circuits in the tuner to variable heat that made it so much more difficult to maintain frequency stability.

These were vacuum tube devices using a single conversion architecture with a typical 41 MHz IF (Intermediate Frequency). They had limited selectivity and dynamic range. Although the FCC allocated twelve six MHz channels to USA VHF TV, not all of them were usable in the same metropolitan area. For example, no two adjacent channels could be assigned in the same city.

Since the LO frequency in these tuners was controlled by LC circuits, electronic remote-control was not possible. Some variations on the turret design employed mechanical push-buttons to select a specific LC circuit to tune the LO. But these mechanical push-button tuners still required the viewer to get up from the chair and touch the TV.

However, there were several early remote control product introductions that employed mechanical means to spin the dial. A 1950's Fig. 3 example was the "Lazy Bones" remote control that used a cord connecting the remote control device to the television set.

Figure 3, The Zenith Lazy Bones Remote Control

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THIS MIRACLE TURRET TUNER IS THE SECRET . . . and only Zenith has it!

You sit anywhere in the room . . . blissfully relaxed . . . with Zenith's wonderful "Lazy Bones" Remote Control in your palm. You press lightly with your thumb, and change programs one after another! No jumping up, not one knob to touch or re-tune! This operation of the tuner by remote control is possible because Zenith's Turret Tuner is truly a miracle of automatic precision and stability!

Yes, *all* the necessary adjustments are made for you automatically, all at one time . . . and this tuner is so heavy—so sturdy—that even years of constant use will not cause its contacts to lose their precision and let the picture drift and fade!

And that's not all . . . this tuner is so much *more sensitive* that even in far outlying locations, it takes signals too weak for most other sets to handle, and turns them into beautifully clear, steady pictures!

What's more, there is *no other tuner in television* so easily, quickly, inexpensively adapted in your home to receive the proposed new ultra-high frequencies on present standards, without an external converter!

Please remember—ONLY ZENITH HAS THIS TURRET TUNER. So regardless of what you read or hear, before you invest in television be sure to see for yourself that Zenith *is* different from all others . . . indeed, the Royalty of Television. Your Zenith dealer invites you to prove this in your own home, before you buy.

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TIME, JANUARY 29, 1951 9

First Generation UHF Tuners

A first generation UHF tuner design need to make major departures from the legacy 12 channel LC controlled tuners. Not only did the 890 MHz range greater exceed the 216 MHz top end of the VHF band making the lumped LC circuits in the VHF tuners less practical, the much wider bandwidth of 312MHz for UHF tuners versus the 72MHz of the VHF tuners created a challenge to build an LO that could be stable and controlled over this wide range. To keep costs in range, the first generation UHF tuners were simple mixer stages with little isolation between the LO and the antenna. The LO was a continuously tuned device that covered the entire frequency range less the 41MHz IF frequency.

Although the FCC allocated 52 new UHF channels for various reasons, only a few small number could be allocated to a single metropolitan area. The FCC established channel allocation rules that came to be known as the UHF Taboos.[3] The Taboos were expressed as the minimum separation in miles from 20-70 miles between UHF TV stations on certain channels. There were so many criteria that it was rare to be able to operate more that 3 or 4 UHF channels in the same city. The Taboos were due to the selectivity and dynamic range of these simple UHF tuners as well as the lack of isolation from the LO to the TV's antenna. The taboos fell into these six categories:

- Same-channel separation
- Adjacent channel separation
- IF beat
- First-order image response
- Third-order intermodulation products
- Local oscillator radiation

As you might expect future generations of UHF tuners addressed design limitations to obviate these taboos.

Second Generation TV Tuners

From 1962 onward the first transistorized tuners were put into mass production. Television sets began incorporating electronic tuning technology in 1971 with electronic turning using varactor diodes to adjust the frequency of the LO. With electronic tuning the tuner could be located anywhere in the chassis out of the hot zone at the top of the TV. And with electronic tuning a new world non mechanical light touch push buttons and also wireless remote controls were easily enabled.

Conventional abrupt junction diodes did not have the capacitance range needed to tune the full UHF frequency range until it was possible to fabricate Hyper-abrupt GaAs varactor diodes in the 1980's.

Fast following designs with varactor diode LO tuning, frequency-synthesized TV tuner technology began to become popular into the 1980's in higher end TVs. Today we find frequency-synthesized LO control as standard in all TV tuners and other RF receivers. However, the introduction of frequency-synthesized LO's was not the end of TV tuner technology innovation.

Modern TV Tuners

The limitations of legacy tuner selectivity and dynamic range prevented all the FCC allocated channels from being used for over-the-air broadcasts. However, the most recent evolution of TV tuners was driven by the transition in the late 1980's from over-the-air broadcasts to cable TV which exceeded the

3 UHF-TV TABOOS: THE FCC ELECTROMAGNETIC COMPATIBILITY PLAN FOR UHF TELEVISION by Julian T. Dixon, IEEE TRANSACTIONS ON ELECTROMAGNETIC COMPATIBILITY, January 1964

over-the-air upper limit of 216 MHz. Initial cable TV transmissions stayed within the FCC allocated 12 channels for broadcast TV. This was soon expanded to 20 channels by using the so-called mid-band between channels six and seven. Not long after cable channels expanded in steps to upper limits of 300, 330, 400, and 450 MHz.

What was very different about cable TV tuners however was unlike the wide dynamic range of over-the-air TV signals, all the cable TV channels could be sent to arrive at the input to the tuner at the same signal level. Also, unlike the small number of over-the-air channels per city, the cable systems used nearly all the 6 MHz channels from 54 MHz and up.[4] The design requirements for cable-ready TV tuners needed to support 70+ channels without them interfering with each other. The innovation in these tuners was to eliminate interference from the first IF mixer image by adopting a double-conversion architecture in the 1980's. This architecture was expensive and not widely deployed in TV receivers but instead just in cable TV converter set-top-boxes. When TVs began to incorporate cable ready internal tuners, these new double-conversion tuners were also added to broadcast television receivers.

Instead of a single-conversion to a 41.25 MHz IF, the first mixer stage up-converted the input signal way up into the 900 MHz range and a second mixer down-converted the signal to a second IF frequency back in the 41MHz range. The up-conversion did cure the unwanted first image response but dynamic range issues associated with 2nd order products and 3rd order inter-modulation products. To deal with the dynamic range issues, the frequency plan on cable systems was changed from the FCC over-the-air assignments to "Harmonically Related Carriers (HRC)". The FCC assignments started with a VSB (Vestigial Side-Band) picture carrier centered at 1.25 MHz above the channel edge, for example at 55.25 MHz for the channel 2 band edge of 54 MHz. The sound carrier was centered at 4.5 MHz over the picture carrier.

In HRC systems, the picture carrier was centered at the band edge, for example right at 54 MHz for channel 2. By having all the channels now harmonically related by an integer number, the distortion products produced less noticeable interference on cable subscriber TV sets allowing higher signal levels in the cable plant.

What's Next

With so much video now coming via IP streams into TV receivers, most of the TVs sold today have basic cable ready TV tuners but are mainly used with baseband video such as via HDMI interfaces. As opposed to legacy turner's of mostly lumped circuits, modern tuners are more highly integrated even to the level of a single integrated circuit. The RF tuner technology of today is no longer being driven by the needs of over the air or cable TV but instead by the diverse needs of cellphones, WiFi transceivers, and other communications devices. They owe a legacy to the TV tuner evolution but with different cost, size, power dissipation, bandwidth, and other demands.

4 Channels which over-lapped assignments to aeronautical frequencies in the area were blocked out to prevent leakage from the cable system from interfering with aircraft operations.

About the Author

Stuart Lipoff is an IEEE Life Fellow and past president of The Consumer Electronics Society (now the Consumer Technology Society. He was previously Editor in Chief of CTSoc World. He currently serves as the historian for The Society. He has been a practicing engineer for the last 55 years engaged in product development and technology assessment in a wide variety of industries where he is able to apply his expertise in communications technology.

Among his major accomplishments were leading the project that developed first generation DOCSIS cable modem specifications, developing recommendations resulting in regulations adopted by the FCC mandating digital tuners into new TV receivers, and leading the Next Generation Architecture Project for the cable industry resulting in a road map for the introduction of advanced subscriber premise equipment.

The author gratefully acknowledges the review and contributions by Wayne Luplow, former Editor-in-Chief for 35 years of The IEEE Transaction on Consumer Electronics. Wayne started his career with Zenith in 1964 and after Zenith was acquired by LG he took on the role of vice president for the LG Electronics' Zenith R&D Lab before retiring.