The Joys and Challenges of Tuning Analog Radios

As recalled by Bob Colegrove

Abstract

A thoughtful consideration of analog radios from the listener's perspective is presented. Analog radios having crude mechanical representation of the tuned frequency were the only practical option available to consumers and hobbyists until the 1980s. Nevertheless, this seeming handicap did not deter the avid listener from his or her appointed search for mystery and intrigue on the radio. In fact, it likely bated one's interest and aroused a level of determination to identify the elusive source of an incoming signal. The allure and challenge of analog radio dials is described, leading to a discussion of how analog radio tuning mechanisms were, and to an extent, still are constructed; consequently, how this results in their inherent limitations of design and production. A few military-grade and high-end commercial receivers are cited as examples of optimal analog tuning. Some of the means listeners have used over the years to resolve an analog radio's tuned frequency are considered, including the incorporation of bandspreads on shortwave radios, development and use of graphic plots, and the addition of crystal-controlled calibrators. Finally, the author suggests a simple trick using a modern digital receiver as a means of tuning an old analog radio to a specified frequency.

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How It All Began

Many of us of a certain age started with an antique radio festooned with an elegant, Art Deco, wooden cabinet. It likely belonged to our parents. These radios began life as the focal point in “the front room,” but by the 1950s they were replaced by a TV set and relegated to the attic or basement.

With apologies to H. G. Wells, in a sense, radio was like *The Time Machine*; only in this case it was *The Space Machine*. It could transport you through its portal to some strange distant land. Like the time machine, it was operated with difficulty and was unpredictable, leaving you to your own devices of discovery.

With the space machine, unaccounted machinations take place amid the steady candle fires of each vacuum tube. With your coarse tuning knob, you can enter or leave one place and go to another. The choices, however, are often unpredictable.

You are naturally drawn to this space portal through a warmly illuminated, but numerically complex dial. The focal point is a fine needle or pointer which responds to your turn of a knob and traverses the dial, finally locating itself above or below a number. Your action produces an ever-changing cacophony of sound from the speaker, some intelligible, some not. Tuning the local broadcast band provides the best results. The language is familiar and there are many voices. As you tune up or down, it is like walking through a crowded room where various conversations enter and leave the range of your hearing.

As your curiosity is perked, you begin to investigate. A peek behind the formidable wooden cabinet produces a warmth of glowing filaments, which cast their light against the wall backing the radio, and you find a trace of knotted wire leading from the chassis down the wall and under the rug. Somehow, this wire, this infernal chassis, and this dial combine to carry you off to distant places.

The visual attraction was more than natural. The marriage of industrial design with radio was a good fit, and fine examples abound. In the post-World War II era for example, Raymond Loewy Associates was employed by the Hallicrafters Company to spruce up the rigidly functional design of the Company’s early shortwave receivers to more inviting appearances. In the case of Hallicrafters, the designers sometimes included little dots or red labeling to indicate the “default” setting of each control – that to maximize the chance that some intelligible sound could be achieved. Nevertheless, the overall impression was still confounding. Whether or not it was intended to be, it was, and that ironically is part of the attraction.

What is Analog Radio?

More than one generation of radio enthusiasts has now grown up with no more than a vague awareness of analog radio. By analog I mean those radios having nothing more than a crude dial for frequency readout. Digital radios by contrast can numerically display frequency with high precision. New analog radios have virtually disappeared from the marketplace. Multiband digital radios dominate sales and can be purchased for as little as twenty dollars, tax and shipping included.

Tuning analog radios presented a significant challenge to radio enthusiasts of an earlier age. There are a couple of reasons for this: First, it was not always easy to mechanically position the tuning apparatus to the point where the station was perfectly tuned in. These radios generally lacked fine tuning. Second, it was next to impossible to determine the tuned frequency. Knowing the frequency of a tuned station is a good clue in identifying it. Conversely, not knowing the frequency can be an enigma.

An example of the problem is shown in Figure 1. The red line is the dial pointer. Where is it set, 8.18, 8.20, 8.24…? Is the dial perfectly calibrated? Is there any parallax between the viewer and the dial? Is there any lag or backlash in the tuning mechanism when the knob is rotated? These are a few of the problems which arise when trying to determine the tuned frequency of an analog radio.

Figure 1. 8.18, 8.20, 8.24…?

Ironically, this seeming handicap was often an attraction to the hobby of radio. It created a mystique surrounding the unidentified transmission coming from some obscure point on the globe. Somewhere lurking between two markings on the dial was a weak, foreign voice teasing to be identified.

What follows mainly refers to what are now derisively called “boat anchors,” old multiband analog receivers. However, the same handicaps to tuning ambiguity apply to the so-called “all American fives” and any other analog radio produced down through the ages.

So, before those of us with any recollection are no longer around to talk about it, I thought it might be useful to document what life was like with analog radios. To start, I would place the cusp of the transition from analog to digital sometime in the late 1960s. Some may argue for another date, but that is the timeframe when I became aware of digital frequency display and was certainly most affected by the change.

My mother and father purchased a Howard Radio Company Model 308 Combination Radio-Phonograph Console when they were first married in 1939. By 1958 it had long since been relegated to the basement. That’s when this writer rediscovered it and began to putter with the knobs. I remember my father saying they could pick up London and Rome during the War years. I could go on reminiscing about this old radio and the early days, but I want to focus on the ways and means we use to identify stations on analog radios.

You can see from Figure 2 that the old Howard is a 2-band radio, the quintessential AM broadcast band on top of the dial, plus a large chunk of shortwave spectrum which was becoming an increasingly popular feature of these old consoles at that time. My interest was, of course, the shortwave band.

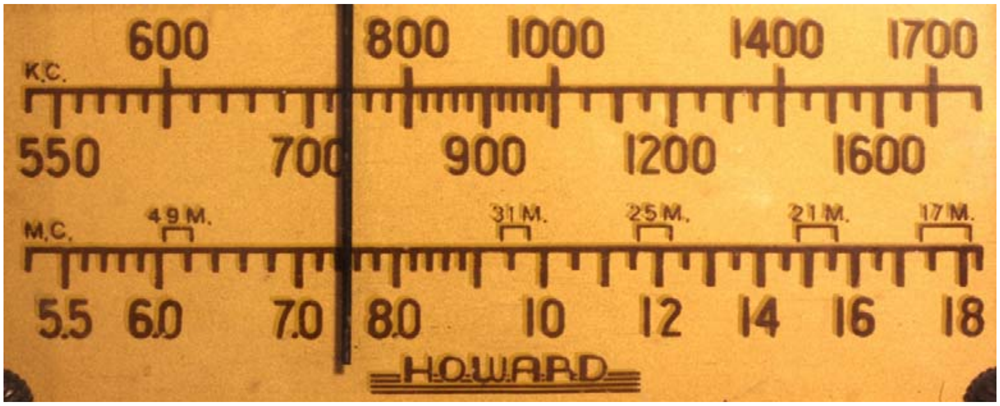


Figure 2. Dial of a Howard Radio Company Model 308

One of the first things I noticed was that it took some care to tune in a shortwave station, somewhat more care than for the broadcast band. The tuning on the shortwave band was so sharp that a slight turn would completely detune a signal. A look at the dial tells why. The shortwave tuning range extended from 5.5 to 18 MHz, a span of 12.5 MHz. Let's say for example that stations were separated by 5 kHz. Potentially this much spectrum could accommodate 2,500 stations. Of course, there was no way that many stations could be received at the same time, but if two stations were separated by as little as 15 or 20 kHz, there was a real problem mechanically separating them, the selectivity of the radio notwithstanding. I would also point out that the entire band was tuned with no more than four 360-degree rotations of the 1-inch diameter tuning knob. Further, the radio featured push-button tuning, which required that the manual tuning knob have a clutch, which had to be pushed in and engaged with the tuning mechanism before rotation would produce any tuning change.

One thing about the old Howard that helped a lot was the "magic eye" tube, an electronic tuning meter, which showed the strength of the incoming signal, Figure 3. When a station was approached from the high or low side of the band, the dark wedge at the top of the tube would contract or narrow. The strength of the signal determined the narrowness of the angle. On better shortwave radios, this function was provided by an S-meter. Still, neither device gave much of a clue as to frequency.

Figure 3. Magic Eye Tuning Tube

The Cold War was approaching its peak, shortwave listening was coming into its glory days, ham radio operators were already regarded wizards, and international broadcasters abounded. The old Howard, like many of its contemporary radios took on a second life and became a basic training device, the *entrepot* to mystery and intrigue. The difficulty of making these old radios work and understanding the results of our experiments only made it more exciting. Like a dog dancing on its hind legs, Sam Johnson observed, "It is not done well; but you are surprised to find it done at all.”

On the Cusp of the Digital Age

The time was August 1967. I had recently returned to the University of Maryland after four years’ service in the Air Force. By this time, the old Howard was again consigned to a shelf, and I had progressed through a Hallicrafters S-38E, an S-40B and an SX-43.

I took a part-time job as a mechanical assembler with Communications Electronics, Incorporated (CEI) of Rockville, Maryland, which not long after became a division of Watkins-Johnson Company. CEI primarily marketed military-grade receivers and their accessories. These ranged from ELF models through microwave units. Everything was handmade of the highest quality. Fabrication costs were *not* primary design factors.

Digital frequency readout was being implemented in a couple different ways at that time, although CEI still produced a number of radios with good old fashioned circular dials inscribed with frequency markings. These dials were at the end of precision gear trains which produced negligible lag or backlash. However, they still required some arbitrary interpolation, if you wanted to guess a frequency between two marks on the dial.

The RS-111-1B line of receivers is an example of the quintessential mechanical dial receivers; see Figure 4. They are interesting for a couple of reasons. First, let’s face it, multiband analog radios are typically a compromise between wide frequency coverage and economy. On less expensive radios, a band switch connects various sets of components necessary for tuning each frequency range covered by the radio. By necessity, this extends the distance between some critical components, and consequently opens up numerous possibilities for signal degradation, mutual interference, and possible oscillation.

Figure 4. CEI Receiver RS-111-1B-7 – Source: CEI 1968 Catalog

In contrast, the RS-111-1B covers four bands from 30 MHz to 1000 MHz. It does this by dividing the spectrum into four separate bands, each band having its own separate tuner, which in turn is optimized for its own tuning range. The front panel shows four separate dials and four separate tuning knobs. Incidentally, the radio sold for $6,250 in 1968 (48,000 in 2021 dollars), and was so good, one unit was purchased to monitor Democratic headquarters at the Watergate.

Other manufacturers solved potential band switch problems in innovative ways. The early top-of-the-line National HRO series uses separate plug-in modules for each band; each module contains separate coil and capacitor tuning components for the oscillator, converter, and RF stages. To switch bands, the listener must unlatch a subchassis containing a set of tuning components and plug in a set with the components for the desired band.

On the military grade Hammarlund SP-600, the “band switch” is a massive turret occupying fully 1/3 of the chassis. Since the radio has six bands, there are six sets of tuning modules arranged radially around the turret. There are four sections of each module which are arranged parallel to the turret’s center axis, one section each for the oscillator, converter, and each of two RF stages. Contact pins for each of the 24 modules extend radially outward from the modules. When the band switch is turned, the turret rotates and the pins mate with the tubes, resistors and capacitors in the stationary RF chassis.

Returning to the CEI RS-111-1B, the second interesting feature is its signal monitor in the upper left corner of the front panel, Figure 4. This is a nominal 1-inch by 3-inch cathode ray tube which produces peak traces for each signal within the intermediate frequency bandpass. This visual presentation is a primitive precursor of today’s waterfall display on a modern receiver or SDR radio. Though not precise, it provided some further frequency resolution, beyond that of the dial.

Another CEI technique offered a higher frequency resolution than a circular dial. This ingenious arrangement was analogous to a 35-mm film camera, where the film is advanced by a cog gear, which engages a set of mating holes in the film. In the case of the radio, a spring steel tape comprising the dial, and analogous to the film, was wound like a coil and driven by a cog gear past a little window in the front panel; see Figure 5. The tuning knob simultaneously turned the cog, transported the dial (film), and adjusted the tuner. The length of the dial was about 3 feet, and thus could display frequency readout at much smaller intervals than a 4-inch diameter dial.

Figure 5. CEI Tuner ST-1045 with Tape Dials – Source: CEI 1968 Catalog

The first genuine digital readouts consisted of a set of Nixie tubes; see Figure 6. Nixie tubes are about the size of 7- or 9-pin miniature vacuum tubes or “peanut tubes,” and operate on the same anode-cathode principle. Each tube contains ten cathodes shaped like the numbers 0 through 9, which can be alternately connected by control logic to illuminate the desired number. The tubes can be cascaded to produce multi-digit numbers. Eventually, LED and liquid crystal readouts would replace Nixie tubes and greatly increase the economy of future applications. Understand that these early digital receivers were still solid-state superheterodynes, containing traditional tuned circuitry, and did not bear much resemblance to today’s synthesized digital tuning techniques and computer control.

Figure 6. CEI Receiver R-357 with Nixie Frequency Display – Source: CEI 1968 Catalog

It wasn't until a couple years ago I found out one of CEI's products was a Model DRO-50 Digital Readout, which was designed specifically to operate in conjunction with the Hammarlund SP-600. It would not be until 1973 that I would acquire my first SP-600, so the timing just was not right, and I'm still looking for a cheap, serviceable DRO-50.

There were purely mechanical attempts to provide precise frequency readout prior to the digital age. My favorite memory, and arguably one of the most famous and capable receivers of all time was the R-390A, a Collins Radio design for the military, which was ultimately produced by several other manufacturers under Government contract. The R-390A will be described later on.

Methods of Tuning

I told you all that to tell you this; the real history of analog tuning began with the earliest radios. From the outset, it was difficult for a listener to determine the tuned frequency of a radio with more than a fair degree of precision. Fortunately, there was not much of a need to bother with frequency, for the simple reason there were not many stations on the air, and there was not much of a problem keeping them separated. The problem naturally developed as stations began to multiply and with that the corresponding need for the listener to identify them.

The earliest superheterodynes as a rule had two or three dials, which had to be aligned to precisely tune a signal. These dials, as a minimum controlled an oscillator circuit and a converter circuit. Higher-priced radios had a third circuit which gave the signal some amplification at the front end. Often, the dials were labeled using a scale from 0 to 100, which was inscribed on a 180-degree arc over the knob and bore no relationship to frequency. Knowing the frequency of the station was not much help, as you had to "fish" for it. If you did not get the oscillator and converter aligned at the correct points, you would not hear much. Not long after this, someone came up with the idea of a "ganged" capacitor, which could tune the stages simultaneously.

Inductive Tuning

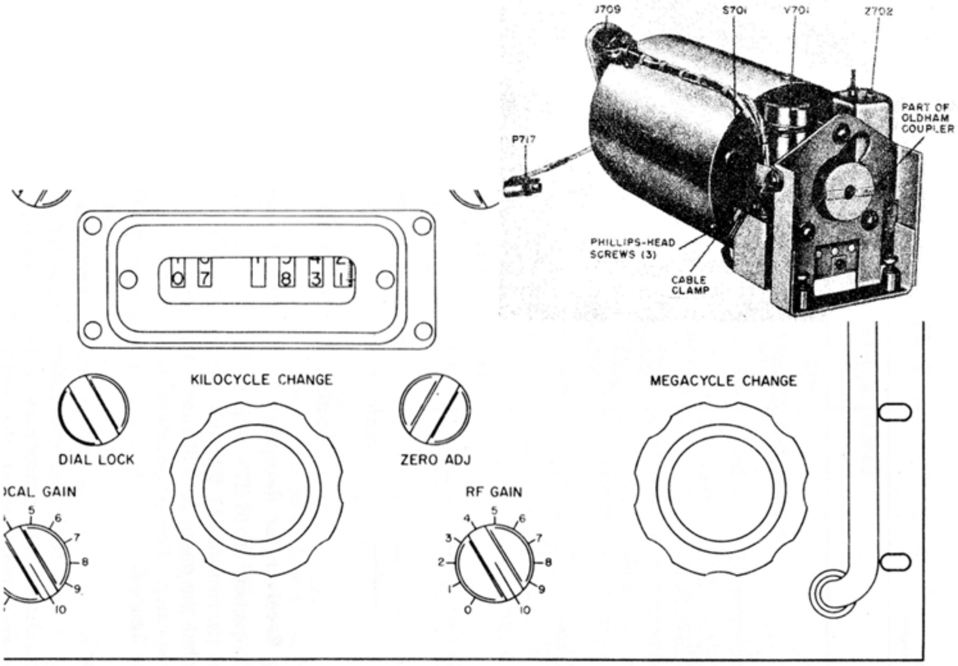
There are two ways to change the frequency of an analog radio, by adjusting either the amount of inductance or capacitance in each resonant circuit. In practice, variable capacitors are much more common. Over the years, this writer has only owned one radio with variable inductors. That was a somewhat unusual 4-tube table radio marketed by Montgomery Ward.

With inclusion of some considerable gearing and comparable expense, variable inductors can be used to tune the radio with excellent linearity making the determination of frequency quite accurate. Very simply, the permeability tuned oscillator (PTO) as it is called functions by inserting a ferrite cylinder inside the coil and attaching it to a threaded screw. As the screw is rotated by turning the tuning knob, the insert changes its position and therefore the inductance of the coil. If the coil is wound in a logarithmic pattern, this translates to linear movement of the core and screw. It does however require an elaborate mechanism. Dials routinely rotate several times requiring an auxiliary turns counter.

The Collins Radio Company was notable for manufacturing PTO receivers such as the 51J-1 and R-390A. Figure 7 shows a portion of the front panel of an R-390A. The inset shows the PTO subchassis. The large cylinder in the rear houses the coil and screw. The oscillator tube and circuit are forward of the coil and a coupler extends out the front which mates with a myriad of gears, shafts and other components culminating in a mechanical odometer-style dial, two digits for MHz and three digits for kHz. Needless to say, the mechanism that made this work was complex, heavy, and expensive.

After the military was through with R-390As, they became the coveted property of hams and SWLs, and still bring respectable prices at auction or resale. In 1971, as a young technical writer, I was given a project at Treasure Island Naval Station in San Francisco Bay requiring me to play with some R-390As at salary – some of the most enjoyable work I have ever done.

As the cost and availability of high-end PTOs were beyond the experience of many of us, the remaining discussion focuses on the more mundane capacitor-tuned radios.



Source: *Technical Manual for Radio Receiver R-390A/URR*, NAVSHIPS 93053, 1963.

Figure 7. Radio Receiver R-390A/URR Portion of Front Panel (line drawing) and PTO (inset)

Capacitive Tuning

A serious limitation regarding dial markings lies in the nature of most tuning capacitors. Figure 8 shows a typical 2-gang variable capacitor consisting of two sets of stator plates, two sets of rotor plates mounted on a single shaft, and a metal frame. All things considered, it was a marvelous component for its time. It had to be both rugged and precise. As the shaft is rotated by the turning knob, the rotor and stator plates interleave with one another, but must not touch. Electrically, they form the plates of the capacitor with air as the dielectric. Fully open (unmeshed), they contribute minimum capacitance to the circuit. Conversely, fully closed (meshed) the capacitance is at its maximum value.

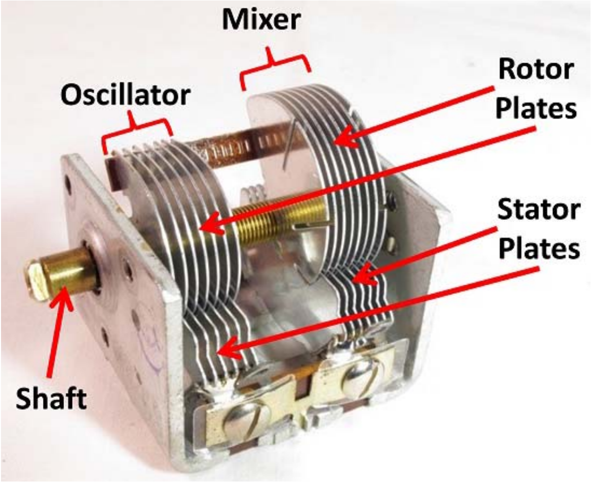


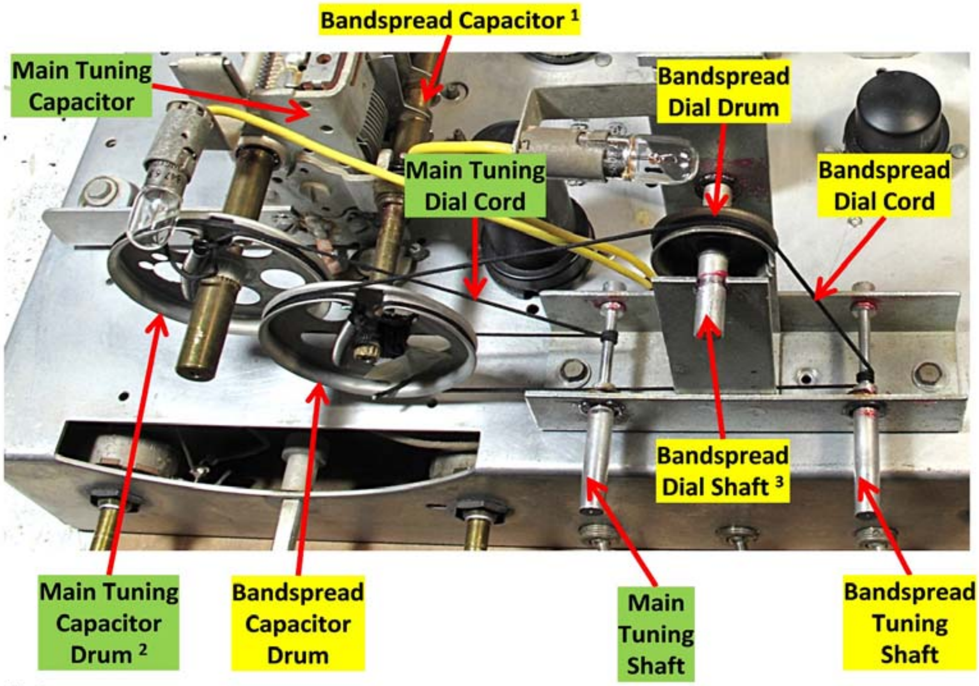
Figure 8. Typical Tuning Capacitor

Figure 9. Typical Medium Wave Dial

You can visualize that from the fully open position, the tuning shaft can only be rotated 180 degrees, at which point the plates are fully meshed. If the shaft is turned further, the plates would begin to open again and produce less capacitance. There is no point in rotating the shaft past this point, as every possible value of capacitance can be achieved in 180 degrees of rotation. So, there is a mechanical stop at each end.

Now look at Figure 9. It shows a typical dial connected to the shaft of a capacitor. This one shows frequencies for the medium wave band at arbitrary points throughout the 180-degree rotation of the tuning capacitor. The dial is simply not big enough to show all the 118 channels currently available on the medium wave band in the Americas (Region 2). We could, of course, make the dial larger in diameter, but that soon becomes impractical and still would not entirely solve the problem.

Notice also that the dial shown is intended to be turned by hand. This adds to the difficulty of tuning, particularly at high frequencies, where, due to the nature of the tuning process, channels are mechanically spaced more closely. On larger radios this has been solved by additions to the tuning mechanism. The dial is augmented by a large drum mounted on the tuning shaft. A dial cord is wrapped around the drum and, in turn, runs around a second shaft, which is much smaller in diameter than the drum. The tuning knob is then attached to the second shaft. Rotation of the second shaft effectively creates a “low gear” by which more hand rotation is required to move the shaft on the tuning capacitor. A good analogy is a bicycle chain drive. In its lowest gear it takes more cranks on the pedals to turn the back wheel. A typical dial cord drive system would improve the tuning ratio to 4:1 or more.



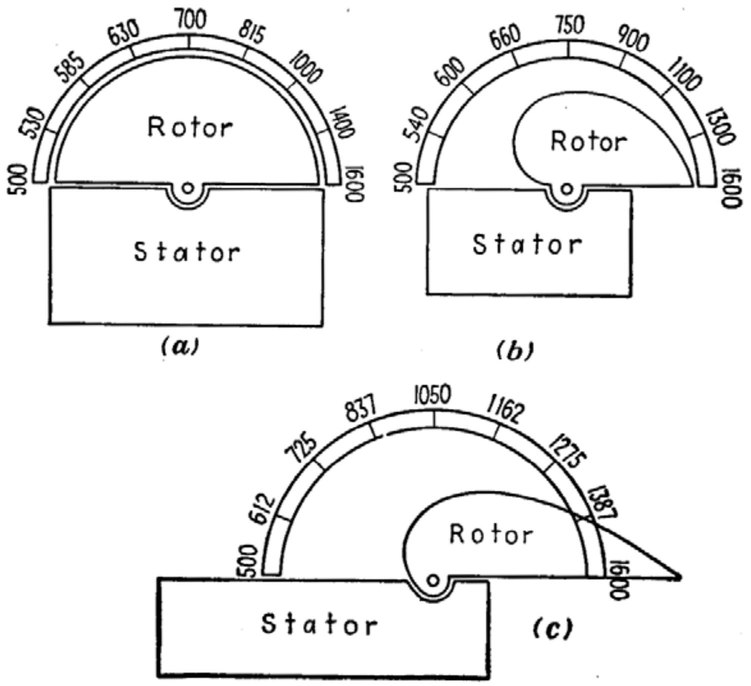
Notes:

1. Bandspread capacitor consists of rotor plates which mesh with main tuning capacitor stator plates.
2. Main tuning dial (not shown) mounted at end of shaft.
3. Bandspread dial (not shown) mounted at end of shaft.

Figure 10. Hallicrafters S-40B Dial Cord System

As an example, the chassis of a Hallicrafters S-40B is shown in Figure 10. It is typical of many shortwave receivers of the early post-WWII era, which have dial cord systems to provide some mechanical tuning reduction, that is, fine tuning. This discussion focuses on the main tuning (components identified in green); the bandspread portion (components identified in yellow) will be described later.

Observe that the main tuning drum and cord are behind the corresponding components of the bandspread. The large drum is mounted on the main tuning capacitor shaft. The main tuning shaft near the center of the figure is ¼” in diameter. The tuning shaft and drum are connected with a dial cord. Note that the tuning shaft diameter is reduced to about 1/8” inside the mounting bracket where the dial cord is wound. The dial cord makes approximately 2 ½ turns around the shaft and it moves by friction with the shaft rotation. One end of the cord is attached to the capacitor drum with a coil spring. This provides some tension on the dial cord. Ideally, the dial cord starts to move when the tuning knob is turned. A full rotation of the tuning knob and shaft will only produce about 3/8” rotation in the outer circumference of the drum on the capacitor shaft. It will take approximately 8 full turns of the tuning knob to turn the drum 180 degrees through the full range of the capacitor.



Source: *Essentials of Radio*, Slurzeberg & Osterheld, McGraw Hill, 1948.

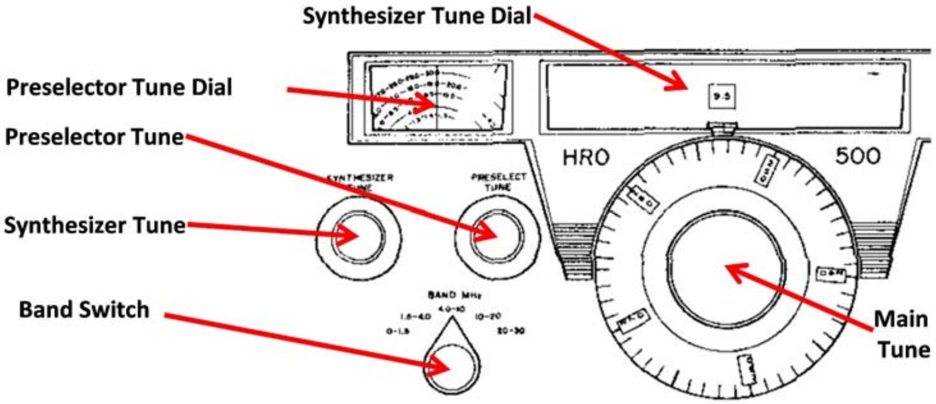
Figure 11. Geometry of Variable Capacitor Rotors (a) Straight line – capacity, (b) Straight line – wavelength, (c) Straight line – frequency

Looking at the analog dial in Figure 9 again, recall the frequency markings are not evenly distributed. There is more change in frequency when tuning at the high end of the band. This is because a linear change in capacitance does not produce a linear change in tuned frequency in a capacitance-inductance circuit. Figure 11 shows the frequency distribution throughout the tuning range for various shapes of rotor plates. Figure 11 (a) has semi-circular rotor plates with the shaft mounted at the center. A 30-kHz change in rotation at the low end is equivalent to 200 kHz at the high end. Figure 11 (b) has eccentric rotor plates with the shaft mounted off center. Less capacitance is added when the dial is tuned between 1600 kHz and 1300 kHz than between 540 kHz and 500 kHz. The frequency distribution is better than Figure 11 (a), but still not linear. Figure 11 (c) has even more eccentric rotor plates with the shaft mounted off center. This produces near linear frequency response throughout the tuning range of the capacitor.

In practice, for reasons of size, nearly all capacitors designed for consumer radios conform to Figure 11 (a) or (b). The size of the rotors required for near perfect linear response for most radios is prohibitive. Note that the only requirement for the shape of the stator plates is that they completely cover the rotor plates when the capacitor if fully meshed.

The National HRO-500 is notable for achieving frequency resolution to within 1 kHz using a variable capacitor. Regarding the VFO capacitor, "The special plate shape, wide spacing, and use of a noncumulative serrated tracking section provide excellent stability and a linear frequency characteristic (National Radio Co., 1965)."

A partial view of the HRO-500 front panel is shown in Figure 12. Briefly, the band switch is set to the range corresponding to the desired frequency. This lines up circuitry for RF stage tuning. A synthesized oscillator produces a base signal and harmonics at 500 kHz intervals extending through 30 MHz. To tune the radio, the base frequency or harmonic, which is immediately lower than the desired received signal is selected with the synthesizer tune knob. The main tune knob is then rotated to the desired frequency. The tuned frequency is determined by adding the synthesized oscillator frequency to that of the VFO.



Source of drawing: *HRO-500 Solid State Communications Receiver*, operator's manual, 1965.

Figure 12. Front Panel of a National HRO-500

In this example, the desired frequency is 9.7532 MHz. The synthesizer has been tuned to the 9.5 MHz output, which is lower than the desired frequency and 9.5 appears in the synthesizer tune dial. The main tune dial is then rotated to 253.2 kHz. Thus, 9.5 MHz + 253.2 kHz = 9.7532 MHz. Note that the main tuning dial always tunes the VFO linearly through the same 500 kHz frequency range. There are 50 kHz marks around the main tune dial, so a complete coverage of the VFO requires 10 turns of the main tune. Numbers in the five windows on the main tune dial increment on each revolution to indicate the VFO frequencies for each turn. After the oscillator frequencies are set, the preselector tune knob is rotated to peak the RF circuits for maximum output. Although the system was highly accurate, addition of the two oscillators was somewhat inconvenient.

As with the description of the R-390A, I have digressed with the description of the HRO-500, which commanded $1,295 in 1965 dollars. For those of us who were forced to make do with something less, let us return to problems of the real world and how we deal with them.

Problems and Some Partial Solutions

Dial Calibration

I alluded to a dial problem earlier, namely calibration. Simply, how accurate are the dial markings? Are they skewed to one side? Is the problem constant across the dial? Likely it is not. Dial calibration is almost entirely determined by what goes on in the factory. A prototype dial is designed to fit a prototype radio chassis, and it probably fits very well. Problems occur when a radio goes into production. Not all parts are created equal. They all have acceptable tolerances on the order of ±1%,

±5%, ±10% or higher - the lower the tolerance, the higher the cost. So, a radio targeted for a particular sale price will determine the quality of its parts.

A further problem is that these tolerances "stack." A group of parts acting in a circuit having slightly different values, all within their respective tolerances, will produce slightly different results from unit to unit. This may not be very noticeable in an audio amplifier, but the results can have quite an effect in the tuner, where various capacitors and inductors must interact to produce a desired resonant frequency.

The solution to this problem is simply to include adjustable capacitors and coils which permit the circuits to be aligned to a design specification. Thus, bench alignment is a process which normally takes place when a radio is nearly complete, and is intended to bring the radio into reasonable compliance with the design specification. I say reasonable, because even with this effort it is not often possible to make a dial read correctly across its tuning range. A good description of this, which includes a do-it-yourself alignment process, is contained in William I. Orr's classic *Better Shortwave Reception* (Orr, 1957). Going back to the design of the prototype dial, the uniform dial copies made in the production process may not conform exactly to the production units.

Key to dial calibration is the alignment of the variable frequency oscillator. A trimmer capacitor is used to calibrate the dial near the high end, and either a coil or padder capacitor calibrates the low end of the dial. These are not perfect solutions, as they don't always produce accurate frequency tracking across the entire tuning range.

To speed the production and repair processes along, manufacturers generally provide instructions indicating where to set the dial and align the circuits. Using the AM broadcast band as an example, manufacturers often specify setting the oscillator high end at 1400 kHz on the dial and at 600 kHz for the low end. But these calibration points may result in significant error in the middle of the band. On a per case basis, slightly different dial calibration points may produce better overall results. Trial and error on the part of a patient technician can produce a better compromise, but time for experimentation with each radio is not available on a production line.

Depending on the quality of the radio, an RF circuit alignment process may or may not compensate for all the potential dial discrepancies. More expensive radios will have more alignment components. Using the Hammarlund SP-600 again as an extreme example, there are six bands, four RF circuits on each band, and each band can be aligned at its high and low end, that's 6 × 4 × 2 = 48 adjustments, just for the RF section of the radio.

Armed with the foregoing information, and, as Bill Orr suggests, lest you contemplate "tweaking an adjustment - just for fun", first consider the possibility of a common problem and its simple solution. If the calibration error appears to be nearly the same distance along the entire dial, it is possible that a circular dial has come loose on the tuning capacitor shaft, or the pointer has slipped on a linear dial.

A further impediment to dial calibration is the fact that components change value over time, particularly over the first year or two of life. A periodic trip to the shop or workbench is often a worthwhile endeavor for an analog radio.

Bandspreads

The dial system described above works tolerably well on medium wave, but the problem is greatly compounded on shortwave, where the amount of radio spectrum on each succeeding band of a typical 4-band receiver increases by a factor of three or four. For example, the medium wave band (lowest frequency band) on a 4-band shortwave radio barely tunes 1 MHz, while its highest band may tune a range up to 30 MHz. Needless to say, this greatly compounds the twofold problem of physical tuning and determination of frequency.

Enter the bandspread, a clever way to provide an electronic “low gear” or fine tuning and make possible some reasonable determination of the frequency. Bandspreads are simply small values of variable capacitance added in parallel with the main tuning capacitor. By tuning the main capacitor to a point just above the highest frequency of interest, then rotating the bandspread from its fully open position to its closed position, the listener can tune a small portion of the entire band with relatively large mechanical separation between stations. Think of putting a magnifying glass on a small portion of the band.

For example, say one wants to tune through the 31-meter broadcast band. Ensuring the bandspread is initially set to its minimum value (fully open plates), the main tuning dial should be set to the upper end of the 31-meter band. WWV or some other standard time signal on 10 MHz is a very convenient frequency. Then the bandspread is progressively closed. This effectively lowers the frequency towards 9.9, 9.8, 9.7 MHz, etc. Note that the range of the bandspread may not cover the entire 31-meter band. In that case, the main tuning would have to be adjusted downward to provide bandspread at the lower end of the band. This problem is more prevalent on lower frequency bands.

The problem with a bandspread is simply that you need some way to translate its position into frequency, that is, calibration markings like those on the main tuning dial. Since the bandspread can be operated with the main tuning dial set anywhere in its range, the possibilities for marking the bandspread are infinite. Most of the time however, the listener is only interested in the international broadcast bands or the amateur bands. This somewhat simplifies the design of shortwave radios. In nearly all cases, at least on the more expensive shortwave receivers, the manufacturers chose to calibrate the bandspread dials for the commonly used amateur bands, 80, 40, 20, 15 and 10 meters; see Figure 13. Note the position of the pointer at the high end of each band. This is the point of the bandspread’s minimum capacitance.

SWLs interested in the international broadcast bands were left out. One compensation for SWLs was that a 0-to-100 scale was generally included on the dial so that it could be used to log frequencies for any desired range; see the bottom of Figure 13. Recall the 0-to-100 scales included on the oscillator and converter dials on the pioneer radios. Likewise, the use of the 0-to-100 scale on bandspreads requires some math. If two known frequencies of stations can be determined, it is possible to interpolate the frequency of an unknown station operating between the two known stations. Again, there is often a serious pitfall here. As described above, few capacitors provide linear tuning, that is, where a fixed angle of rotation of the capacitor shaft provides the same change in frequency at either end of its range. Consequently, a linear interpolation will contain some error. Refer to Figure 11, if necessary.

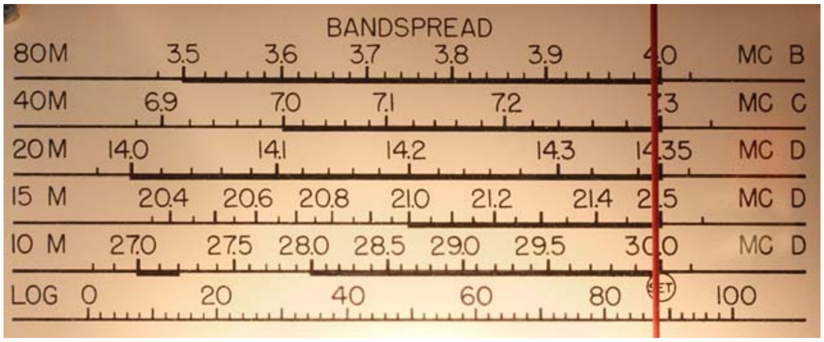


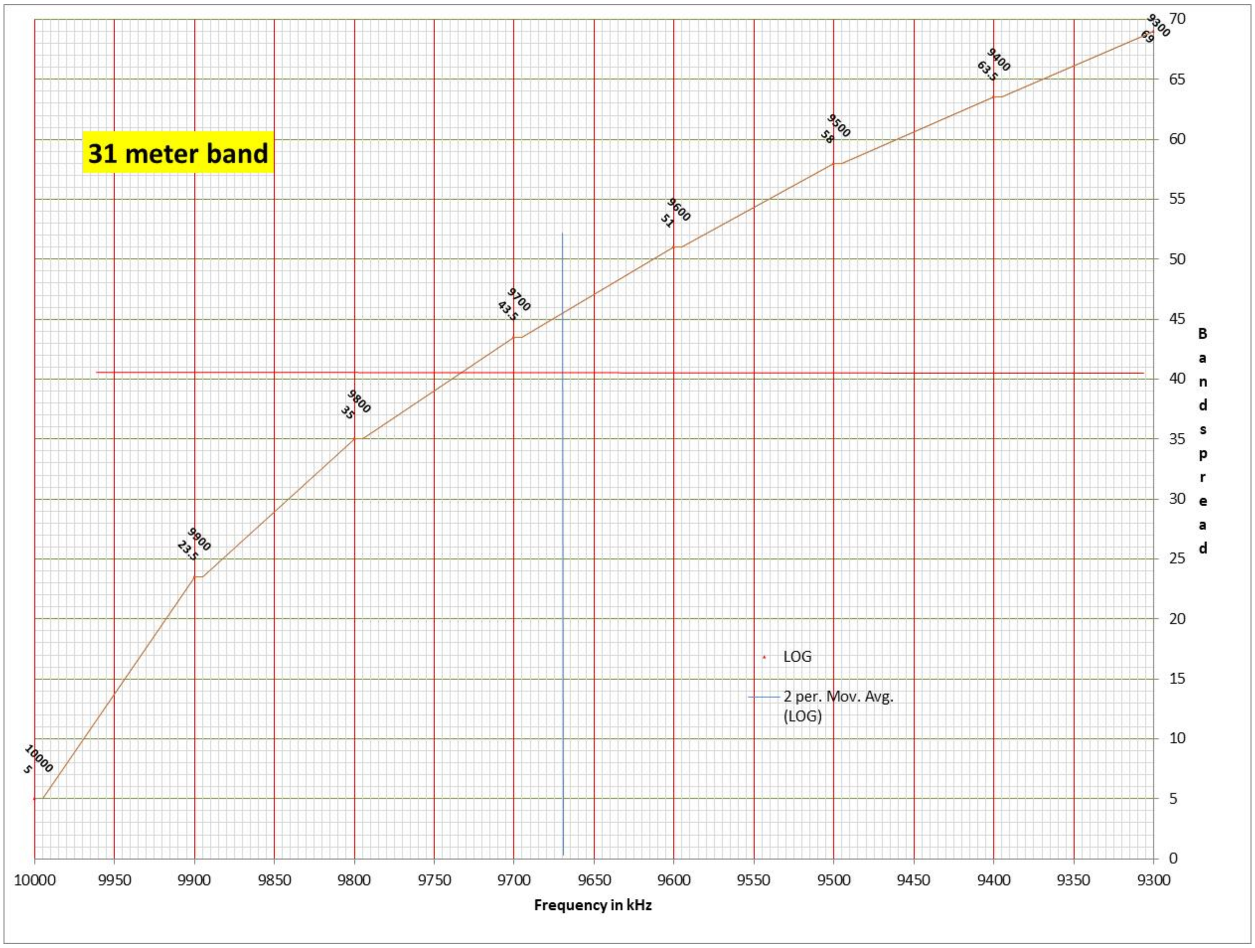
Figure 13. Bandspread Portion of a National NC-109 Dial

Returning to the cord, Figure 10, the bandspread dial cord is in front of the main tuning dial cord. The system is similar to that of the main tuning. However, an idler drum (bandspread dial drum) and shaft have been added to the circuit formed by the bandspread cord. As the bandspread knob is turned through the full range, the idler drum will make one full turn, approximately 360 degrees. The bandspread dial is mounted to the idler drum shaft. Since the bandspread capacitor only rotates 180 degrees, the bandspread dial will provide some added surface space for marks. In the case of the S-40B, there are no marks for amateur bands, just a 0-to-100 logging scale, so a graph or table of log-scale-to-frequency is necessary.

Frequency Graphs

One trial-and-error method which came into wide use was the preparation of graphs, which plot frequency against the dial scale reading; see Figure 14. In the days before computer spreadsheets, these had to be painstakingly developed by hand over time. Each point on the graph represented the confirmed frequency of a station. After a graph was developed a known station on a known frequency could be tuned by setting the bandspread to the correct point on the 0-to-100 bandspread scale and tweaking the main tuning so the station came in exactly at the plotted point. The bandspread was then properly aligned and all the frequencies along its plot could be determined with some reasonable accuracy using the graph. Note that the nonlinearity of the capacitor resulted in a graph plot which was generally parabolic having most of its curvature at the high frequency end.

How accurate are these graphs? If you are careful with the 31-meter graph, you can often get within 5 kHz. The 16- and 19-meter bands are troublesome. These are often located on “Band 4” which covers the most spectrum, sometimes 30 MHz. A 100-kHz swath might only cover 10 or 20 units on a 0-to-100 scale making interpolation less accurate.



Horizontal Axis: Frequency – 10000 to 9300 kHz; Vertical Axis: Log Scale 0 to 70

Figure 14. Example of a Bandspread Frequency Plot for the 31-Meter Band

Crystal Calibrators

The example of 31 meters described above is, unfortunately an exception. Not many of the shortwave broadcast and amateur bands have a convenient, steady signal on which to spot the main tuning dial and therefore align the bandspread. Enter the crystal calibrator, Figure 15. This became a staple accessory for all serious SWLs during the glory years. In essence it is a tiny radio transmitter. It has a crystal oscillator, rich in harmonics. When connected to the antenna input of the receiver and turned on, it produces stable continuous wave signals which can be tuned throughout the shortwave spectrum.

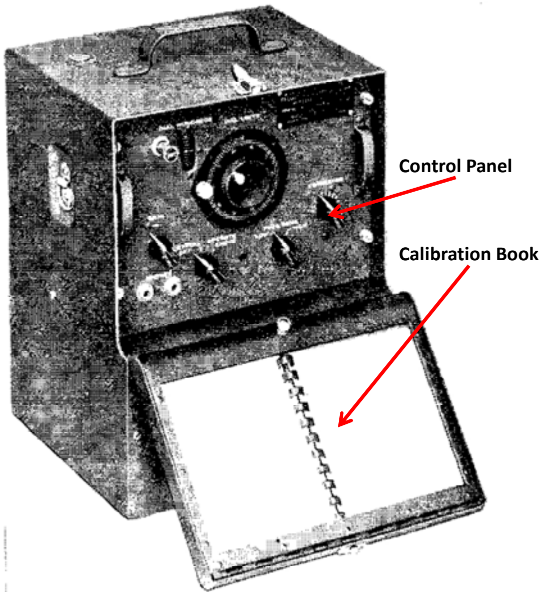
Most commonly, the crystals were cut to 100 kHz, although other frequencies could be obtained. Most popular models were produced by Allied Radio and Heathkit, and presented the budding enthusiast with an opportunity to do some assembly and soldering. In operation you set the bandspread to minimum capacitance, turn on the calibrator, set the main tuning dial to the high end of the band you want to monitor, and tweak it for the nearest 100 kHz marker. The bandspread will tune any lower marker that falls within its range. For precision, you can turn on the BFO and note the points on the bandspread where zero beat occurs.

Figure 15 shows a Heathkit Model HD-20 Crystal Calibrator. This is a one-transistor, 100-kHz crystal oscillator, powered by a 9-volt battery. The red-capped terminal on the top is connected to the receiver antenna terminal. The calibrators have an adjustment capacitor in the circuit. By tuning a standard time signal, such as WWV and adjusting the calibrator for zero beat, the calibrator will produce accurate markers at 100 kHz up to 30 MHz.

Figure 15. Heathkit HD-20 Crystal Calibrator

Frequency Meters

The concept of the crystal calibrator was employed in high-precision frequency meters such as the BC-221 (Figure 16) of which thousands were used by military communications troops during WWII. These are battery-operated field units, which can produce very precise calibration signals for tuning up transmitters and receivers. The example here covered a frequency range of 125 kHz to 20 MHz.



Source: War Department TM 11-300, *Frequency Meter Sets SCR-211-A,B,C,D,E,F,J,K,L,M,N,O,P,Q,R,T AA,AC,AE,AF,AG,AH,AJ,AK,AL*; 20 July 1944

Figure 16. BC-221 Frequency Meter

The frequency meter takes the crystal calibrator one step further by producing continuously variable signals between its crystal-controlled marker points. It did this using a highly-stable, finely-calibrated variable frequency oscillator operated by a worm gear train and terminating in a Vernier dial. The worm gear and Vernier dial are described later.

Since the circular dial is calibrated on a linear scale, the readings have to be translated into a frequency. This is done in a tabular calibration book. The procedure is to align the dial with a nearby signal from the crystal-controlled oscillator, and then consult the book to determine the frequency corresponding on the dial. The wonder of these frequency meters is that each one had a unique calibration book painstakingly compiled frequency-by-frequency throughout its tuning range. In other words, the calibrations take into account all of the component variations from unit to unit. Again, as with so much fine military communications equipment, the frequency meters were eventually surplused and found their way into amateur use. Being battery operated as originally built, this required design and construction of some power supplies to operate the units off ac mains.

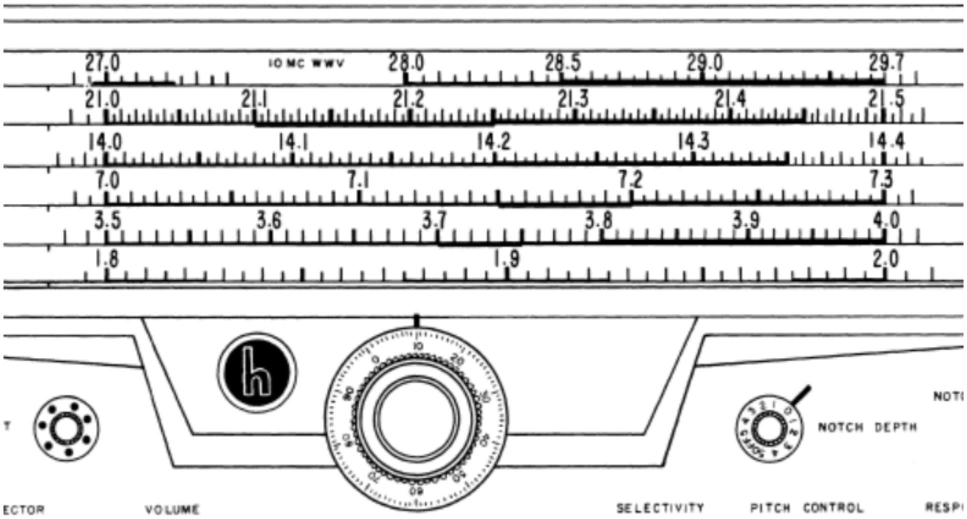
Crystal Control

The ultimate frequency control in the classic era was the use of a crystal-controlled oscillator. These substituted for the variable-frequency oscillator, which would otherwise be tuned by the listener. Crystals can be cut to very precise frequencies. Care must be taken that the specified frequency compensates for the intermediate frequency of the radio. The tuning knob still must be turned to peak the converter and any RF amplifier circuits, but the oscillator will be spot on. A good example of this method is the Hammarlund SP-600, which, as an option to its variable-frequency oscillator, contains a crystal oscillator capable of switching up to six crystals at different frequencies. The downside of a crystal-controlled receiver is, of course that reception is limited to the frequencies of your crystals – good for the military, but not for the knob twisters.

Limited Coverage Receivers

The discussion so far has mostly applied to what are known as general coverage receivers, that is receivers which continuously cover a large portion of the radio spectrum – no gaps between covered low and high frequencies. If the desired tuning ranges of a radio can be limited to a few short portions of the spectrum, the frequency resolution and ease of use can be improved. In the 1950s and 1960s, this concept worked to the benefit of a large amateur community by making design and production of such radios economically feasible.

The Hallicrafters SX-101 is a good example of a “ham band only” receiver which covers the 160- through 10-meter amateur bands. Figure 17 shows the dial and tuning knob portion of the SX-101 front panel. The frequency markings for each of the amateur bands extend 10.5 inches across the front panel permitting the inclusion of several incremental marks. Compare this dial with that of the bandspread on the general coverage National NC-109, Figure 13, which is effectively 4.5 inches wide. Tuning the SX-101 is accomplished with a single knob, which is also marked off in 100 increments for linear logging. The receiver features a 100 kHz crystal calibrator as described above. With the calibrator turned on, the tuning knob is set to zero beat its signal, then the pointer reset knob (lower left) is adjusted to place the pointer directly over the corresponding 100 kHz dial mark.



Source: *Operating and Service Instructions for Selectable Sideband Receiver Model SX-101 Mark III*, The Hallicrafters Co., 1958.

Figure 17. Portion of a Hallicrafters SX-101 Mark III Selectable Sideband Receiver

For the SWLs, the concept of limited band range was employed on some high-quality portable radios, which featured multiple international shortwave broadcast bands. Notable among these were the Zenith Transoceanics. With the coming of digital radios, this concept has been rendered virtually obsolete.

The Collins 75A-4 Receiver is also a classic ham band receiver. However, dial interpretation is somewhat like the general coverage National HRO-500 described earlier, where a gross frequency in a window must be added to the frequency on a circular dial to indicate the exact frequency.

Although not related to our focus on frequency determination, note that short tuning ranges of amateur band receivers are conducive to better overall sensitivity. All other things being equal, the best sensitivity for analog radios, which depend on resonant tuned circuits occurs at high L/C ratios, that is the end of the band where there is less capacitance and more inductance. In other words, sensitivity falls off at the low-frequency end of the band, and this is more noticeable over the span of a large tuning range. A relatively high L/C radio could be applied to a short ham band with little loss in sensitivity at the low end of the band. Where possible, manufacturers of general coverage receivers tried to arrange bands so that the amateur bands were near the high frequency end of the range.

Mechanical Considerations

If the dial is mounted on the end of the capacitor shaft, as in the case of the one shown in Figure 9, there are no other mechanical pieces to come into play and the capacitor increases or decreases almost as soon as the dial is rotated. Further, it stops almost as soon as the rotation of the dial stops. As more pieces are added to the mechanical drive, including cords, pulleys, and additional shafts, the potential for some significant lag in capacitor rotation exists. In addition, when rotation of the tuning knob stops, tension on the cord relaxes, and the capacitor may tend to reverse direction. This effectively produces some *hysteresis* in the tuning mechanism. This may be apparent when a station is approached from a lower or higher frequency; that is, the position of the pointer may stop in slightly different positions when the station is perfectly tuned in.

Dial Cord

Some consideration must be given to the quality of the cord or “string” used to connect the drum and shaft. Special dial cord resistant to stretching and abrasion is used. This is often a two-part composite having a very unelastic inner core to resist stretching and an outer fabric which resists abrasion. Further, the cord must be pliable and somewhat adhesive to properly wrap around and grip the small diameter of the tuning shaft. Thick cord has the tendency to “walk” along the shaft as turns are laid down and taken up with the rotation of the shaft. Unlike that shown in Figure 10, many cords ride in grooved “U-shaped” depressions in the shaft. In that case, thick cord can climb the groove and become tangled. In short, thinner cord works better, provided it does not stretch or abrade.

All cord windings around the tuning shaft slip. This should only occur when the capacitor has reached its mechanical stop, fully open or closed. That slippage will prevent excessive stress on the tuning components when the knob is turned against either end of the band. In addition, some axial slippage of these turns will occur in U-shaped grooves in the shaft, but this should not affect lag or backlash.

Even with normal use and care, cords get out of adjustment or wear out, and their replacement has become something of an art in radio repair. It goes without saying that dial cord is not a growth industry in today’s economy. Consequently, when you find some, it comes in small quantities at considerable expense and is probably new-old-stock at best. Hobbyists and restorers have resourcefully started using substitute material for original dial cords. One of the best is simply fishing line. This writer has had excellent results using microfilament, braided, 50-lb test, 0.36-mm-diameter fishing line. It fills all the qualifications listed above and will outperform any cord manufactured specifically for radio dials.

Looking back on the bandspread example shown in Figure 13, you will notice that the dial markings form straight lines (linear) rather than conforming to a circular surface. In the case of the circular dial, the dial moves, and the pointer remains fixed; just the opposite for the linear dials. Linear dials almost always have cord drives, which require some additional pulleys or bollards to guide the cord along a vertical or horizontal path near the dial, plus a sliding rail for the dial pointer. Pulleys will generally provide less resistance to the movement of the cord than bollards. Again, each item added to the system increases the potential for lag or backlash in the tuning.

Like the CEI RS-111-1B described in the beginning, more expensive radios use precision gear trains instead of cord, which can greatly reduce the lag and backlash. Gear trains can be designed to produce more precision operation between the knob and the capacitor. Planetary Gears and Worm Gears (covered later) are mechanical techniques to lower the tuning ratio between the capacitor and the listener’s hand.

Flywheels

Many shortwave radios in the medium and upper price ranges have flywheels attached to the tuning shaft. Once set in motion, the momentum of the flywheel provides smoother operation. The heavy flywheel overcomes the resistance of the cord and capacitor, and lets the operator quickly spin the dial over large portions of its range.

Vernier Dials

A Vernier dial is a very clever but simple way of increasing the accuracy of a linear 0-to-100 circular dial by an order of magnitude. Vernier dials were not used directly on radios very often. Instead, you could find them on separate variable frequency oscillators (VFOs) and frequency meters, which could be used in conjunction with the radio to determine the tuned frequency more accurately. Vernier dials are still used extensively today on measuring devices such as micrometers and calipers.

Figure 18 and Figure 19 show a typical Vernier dial in use. This example shows the dial on the BC-221 Frequency Meter described above. The lower or main scale is on a circular dial, the knob being just below the pictures. The scale runs from 0 to 100 in a counterclockwise direction. Thus, when the dial is rotated clockwise, the numbers advance. It is important to note that the main scale must be linear. In other words, a Vernier scale cannot be used on a typical dial marked off in a logarithmic frequency scale.

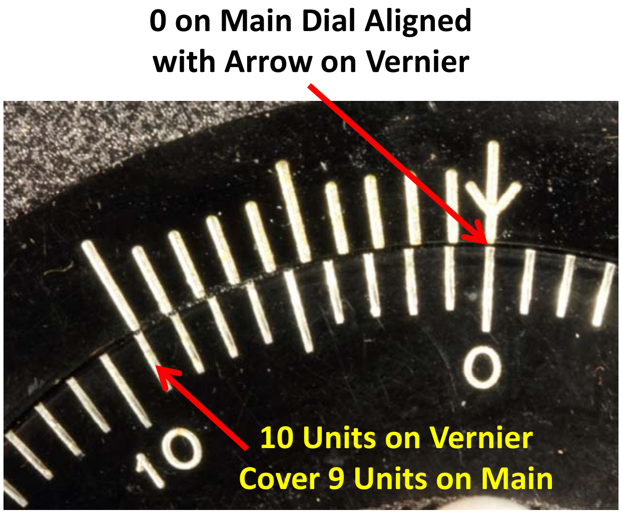


Figure 18. Vernier Set to 0.0

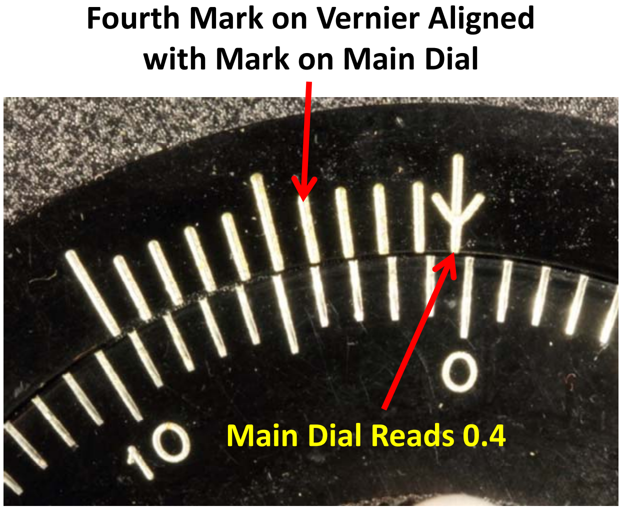


Figure 19. Vernier Set to 0.4

The top stationary scale is the Vernier scale. The right-hand marking with the arrow is equivalent to the dial pointer indicating the current setting. In Figure 18, the dial has been rotated exactly to 0. Notice that there are 10 marks on the Vernier scale to the left of the arrow mark. Notice also that the length of the Vernier scale is equivalent to only nine units on the main dial scale. As the dial is rotated clockwise, one and only one mark on the Vernier scale will align with a mark on the main scale. As you rotate the main dial from 0 to 1, each mark on the Vernier scale will in turn align with the next mark on the main scale.

In Figure 19, for example, the dial has been rotated clockwise slightly and the fourth mark to the left of the arrow on the Vernier scale is aligned with a mark on the main dial. All the remaining Vernier marks are more or less out of alignment. Interpreting this reading, the main tuning dial has been rotated 0.4 of the way between 0 and 1. Checking the alignment of the arrow mark against the main dial, this appears to be correct. In short, the addition of the Vernier scale provides a better way to estimate the position of the dial pointer between to marks on the main scale.

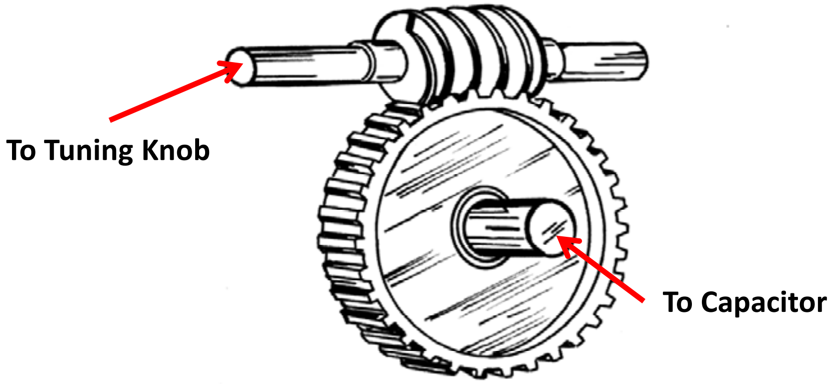
Planetary Gears

Planetary gears (also known as an epicyclic train) are a good way to lower the tuning ratio between the tuning knob and the capacitor. Think of a solar system in which the center or sun is represented by the tuning shaft to which a knob is attached. Typically, three planet gears mesh with the sun and rotate around an outer ring gear. The planet gears are mechanically linked and turn an output shaft to the capacitor. A good example of a planetary gear system is a hand-cranked pencil sharpener. In that case however, the sharpener works just the opposite of a radio, whereby the crank is the high gear end and produces faster rotation of the pencil grinders. A typical planetary gear set has a ratio of 8:1.

Planetary gear sets are still available for a reasonable price and can be adapted to many old radios with relative ease. Some gear sets are intended for direct attachment to a tuning capacitor and have a mechanical stop preventing rotation of the output shaft more than 180 degrees. Unfortunately, planetary gear sets are often mistakenly referred to as Vernier dials. This probably stems from the fact that better planetary gear sets come with Vernier scales incorporated on them. Vernier refers only to the dial marking, not the mechanical gearing.

Worm Gears

Worm gears are helically-threaded cylinders (not to be confused with helical gears); think of a machine screw. They are mounted on the tuning shaft and provide the “teeth” which mesh with a conventional spur gear. As can be seen from Figure 20, one complete rotation of the tuning knob will advance the spur gear by only one tooth. For example, if the spur gear is attached directly to a variable capacitor, which rotates 180 degrees, and it has 60 teeth, the tuning knob will require 60/2 = 30 complete turns to rotate the capacitor through its entire 180-degree range. Many times, the spur gear is actually a split gear, two gears side by side and held together with springs to provide some angular tension against the worm gear. This provides very good motion transmission with negligible lag. In other cases, the spur gear is actually a helical gear with the teeth angled to more accurately match the worm.



Source of Drawing: Wikimedia Commons, https://commons.wikimedia.org/wiki/File:Worm_Gear_(PSF).png

Figure 20. Typical Worm Gear Train

A New Trick for an Old Dog

I will describe a procedure, which could not be done when these old analog radios were new. It takes a second multiband digital radio to assist with the trick. No physical connections are needed, and no radios are harmed in the process.

The trick relies on the fact that the analog radio contains a local oscillator which is effectively a small continuous-wave transmitter, and can be received 30 or more feet away, even coming from inside a metal cabinet. The local oscillator is humming along at a frequency either above or below the incoming signal. This difference is 455 kHz on most single-conversion radios. The oscillator and incoming signals are *mixed* or converted to form the intermediate frequency, or IF. By knowing this IF frequency, e.g., 455 kHz, and assuming the radio is in good alignment, you can then add or subtract 455 kHz from the tuned frequency to determine the oscillator frequency. The digital radio is simply used to *read* the oscillator frequency of the analog radio.

In the example shown in Figure 21, a 2012 Tecsun PL-660 is used to tune a 1953 Hallicrafters S-40B to a frequency of 4423 kHz. The Hallicrafters has a 455 kHz IF amplifier. 4423 kHz is on the second lowest band, where the local oscillator runs 455 kHz above the incoming signal, in this case 4878 kHz.

Figure 21. A Tecsun PL-660 Used to Tune a Hallicrafters S-40B to Specified Frequency

1. Set the PL-660 to LSB or USB and tune it to 4878 kHz.
2. Turn up the volume on the PL-660.
3. Tune the S-40B to 4423 kHz, which will be detected by a loud CW tone from the PL-660.
4. Tune the S-40B to zero-beat on the PL-660.
5. Now turn off the PL-660 and monitor 4423 kHz on the S-40B.

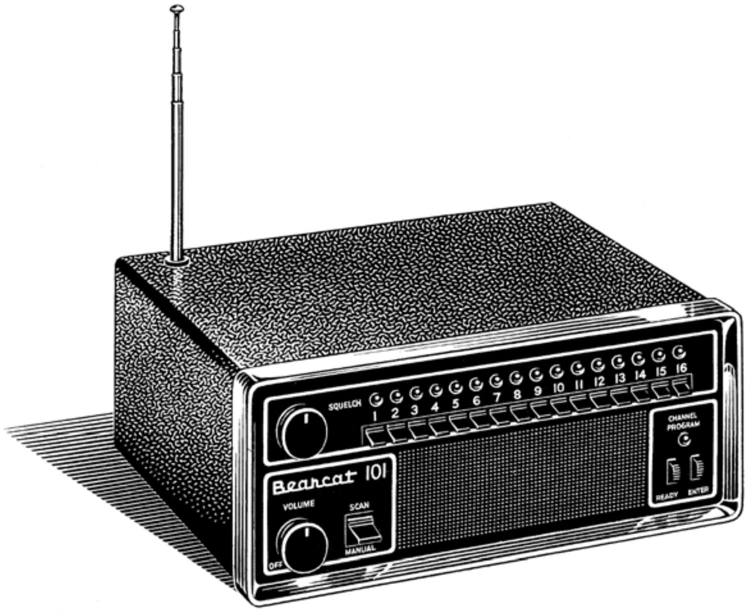
Or instead, suppose we don't know the frequency tuned on the S-40B.

1. Estimate the frequency from the S-40B dial setting.
2. Turn on the PL-660 and search for the oscillator signal 455 kHz higher or lower than the estimate.

For most 4-band analog radios, the IF frequency is higher than the tuned frequency on the lower three bands, and lower than the tuned frequency of the top band. This trick may not work if your analog radio is double conversion, as the first IF stage will be considerably higher than 455 kHz, and may be out of range of the digital receiver.

A Transitional Radio

Some of the examples cited above indicate that the transition from analog to digital radio took place over several years, beginning with attempts to provide direct frequency readout on traditional superheterodynes using mechanical means (the R-390A and the HRO-500) and electronically with Nixie tubes. Conversely, some of the first radios to use synthesized tuners and processing control did not have direct frequency displays. A good example is the Electra Company's Bearcat 101, a revolutionary VHF/UHF scanner from 1975, Figure 22.



Source: *Bearcat 101 Operating Instructions and Frequency Programming Directory*, 1975.

Figure 22. Electra Company's Bearcat 101

Early VHF/UHF radios had listener variable tuning, which conformed to all the analog dial characteristics described up to this point. Because of the intermittent nature of most VHF/UHF transmissions and the desire of the listener to monitor more than one station (think first responders, 2-meter hams, etc.), the technique of crystal control came into being. That made it possible to monitor two or more stations, quickly transitioning from one to another. However, that limited the radio to only a few channels, not to mention the expense of purchasing crystals for each desired frequency.

The classic Bearcat 101 was revolutionary for its time in that it substituted digital synthesis for crystals and opened the capability of a single radio to receive all the frequencies in its designed range. When I say all the frequencies, I don't mean it had continuous tuning. Instead, it could be programmed for any standardized channel throughout each band it covered.

The listener programmed the frequency in 16-bit binary code through a bank of 16 switches and associated LEDs on the front panel. After one or more stations were programmed, the radio was switched to the listening mode. At that point, the switches and LEDs provided a method to select which programmed channels one wanted to scan. The difficulty remained that there was no indication of the tuned frequency, hence station. Not long after the Bearcat 101, digital readouts were married with the digital tuning and the rest is history.

Final Thoughts

I have tried to describe some of the problems and handicaps faced by older generations of radio listeners and those of us still trying to identify stations on analog radios. Sometime in the early digital age I recall one old sage opining that identifying stations was now, "like shooting fish in a barrel." Knowing the frequency was just one of the challenges. There was also a language barrier. This has largely been overcome by the plethora of reasonably accurate, downloadable logs which indicate the language. But formerly, if you did not know the frequency and couldn't understand the language, you were lost.

Then there was the matter of selectivity. The fight for band space by various services was intense and defies description. Today for the most part, you can set your selectivity at a comfortable audible range and leave it there. Adjacent channel interference is not the problem it once was. If we only had then what we have now.

Something you do not hear much about these days is *stability*. You can take even a low-cost portable receiver today, set it to a station, and it will be there the next hour or the next day. On the other hand, high-voltage thermionic devices, i.e., vacuum tubes, tend to drift. Oscillator circuits on more expensive receivers include voltage regulators which help somewhat. Warm-up periods and power line fluctuations further exacerbate the problem.

There was no High Frequency Coordinating Committee (HFCC) to keep things more or less in order by adjudicating agreed frequency and time allocations. Frequency space was at a premium. There were a lot more players, and, consequently a lot more stations that did not play by the rules.

There were no Internet user groups to share information and help. There were clubs, several good ones, but information was spotty and communication slow. The bible was the *World Radio Handbook* (later WRTH), which only came out once a year and generally had to be obtained by mail order. Useful information also appeared in publications such as *Popular Electronics*. Later, Lawrence Magne's *Passport to World Band Radio* provided marvelously detailed PERT-style, time-frequency listings. Intrepid DXers regularly monitored shortwave broadcasts for schedules.

I have tried to provide some sense of what SWLs went through 50 or 60 years ago to engage in this hobby. As I indicated back in the beginning, it was a challenge, but it was eagerly accepted by the "gamers" of that era. There was an indescribable thrill hearing a weak signal from a long way off. The results came slowly. This writer remembers logging about 30 countries and then hitting a stone wall. All the low-hanging fruit had been picked, and I had to hone some skills before I could bag any more trophies.

You may have noticed I have frequently used the present tense to describe analog radios. That is not without purpose. A thriving aspect of the hobby today is the restoration, preservation, and use of these devices; so the enjoyment and marvel continues. Today we take for granted flawless streaming over the Internet, endless podcasts, and high-fidelity music from most any radio station around the world. Try to remember it was not always this way. Contending with the handicaps I have described was the only option. At the same time, it had its own indescribable rewards.

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