Outstanding Results with More Selective fm Ceramic filters

by BILL NIENAJADLY

A few weeks back Bill Nollman informed me of even more selective FM ceramic filters. These are a 150 kHz bandwidth and they are HOT! Finding them wasn't easy at first, but as luck would have it we did find some sources; soon I had these babies and I was ready to re-modify. The day before I was given a poor-selectivity-but-real-sensitive Pioneer SX--828 receiver, so this was the one I would give the "double test" -- first with the 180's, then with the 150's.

With only 3 filters to replace, the 180s were put in.... the results were comparable to the modified digital SONY with the 180's. This was pretty much what I expected, though the Pioneer was a bit more selective due to being an analog .... now..... comes the REAL change. I re-modified the Pioneer with the 150's and low and behold .... I now have a receiver almost or maybe on par with the Mac-78! I can tune (all the time) now all Philly, Hartford and even real toughies like WBSS 97.3, WRCH 100.5, WWYZ-WXTU 92.5; before, these stations would come in only on tropscatter or tropo with the 180's.

The effect of now razor-sharp selectivity is something I'm still getting used to. When I tune to WRCH 100.5 it's like adjacent 100.3 WHTZ local and 100.7 WHUD strong semi local are not on the air! As I'm tuning around I actually notice BLANK SPOTS between the adjacents! What is even more incredible is the fact that I could look out my attic window and see the World Trade Center & Empire State Building 12 miles away with the home of NYC xmtrs of the FM's and I'm hearing WMMR 93.3 Philly under dead conditions and 62 miles on the adjacent, NO 93.1 WPAT 5 93.5 WRTN! I could tune to 97.3 and hear WBSS or scatter from WHP and yet no, I repeat NO WQHT 97.1!

Having been in shock of the incredible selectivity of the SX-828,I quickly rushed to re-modify the SONY ST-J60....... Ready for this? The darn thing is also super selectivity, a hair less than the Pioneer. On the signal meter (really it has lights) the NYC locals register to 5 lights (the max)...when you tune to the adjacent the light meter only registers one light or two. Wow!............. When I had the 180's in the SONY the adjacent had 3 or 4 lights.

Interesting to also note that the mod Pioneer sounds exactly the same as when a Mac-78 is in super-narrow. Well are you impressed'? Actually I had a lot more to report but I gave much info and had comparison tests given to Bruce Elving far his column and I believe he too is doing a special write up on this very interesting subject. Other info given to Tim McVey also for a special write up. I highly encourage all to write in and report your results!

Quite a stir has been going around lately about a simple, inexpensive modification to any FM tuner that can improve its Adjacent Channel Selectivity (ACS). There have been some very exciting times for a number of DX'ers in NJ and CT who have performed the surgery described in Mike Bugaj's article in the Feb. 90 VUD. For example, Bill Nollman modified his Carver TX-11 tuner and reclaimed virtually all of his previously unlistenable, un-DX-able channels.

BEFORE: 100.1 useless due to local 99.9 WEZN (27.5 kW, 45 miles away) in Bridgeport, CT
AFTER: 100.1 clear reception of WJRZ (1.6 kW, 150 miles away in same direction) in Manahawkin, NJ
DELTA: WJRZ at least 10 dB weaker due to longer path, and 12.4 dB weaker due to lower power; at least 22.4 dB ACS required

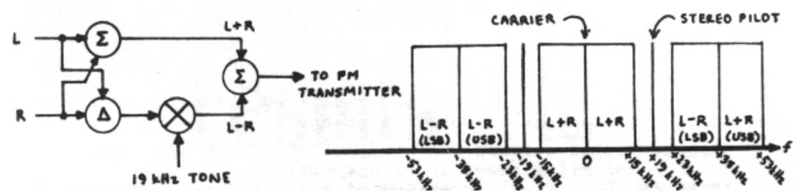
BEFORE: 106.7 useless due to local 106.9 WCCC (23 kW, less than 10 miles away) in Hartford, CT AFTER: 106.7 clear of interference with WLTW (7.8 kW, 98 miles distant) from NYC
DELTA: WLTJ at least 26 dB weaker due to longer path, and 4.7 dB weaker due to lower power; at least 31 dB ACS needed in this case.

Compare these figures with published ACS specs for a Mac MR-78 tuner. The upshot of all this is that by replacement of a simple $2 component, many otherwise mediocre tuners or receivers used for FM DX'ing can be brought up to levels of ACS performance associated with the DX super hitters like the '9090 and TX-11. And for those who already own an excellent tuner, the same procedure, together with the great RF stages they have already, may elevate FM DX potential higher than ever ***before.*** In this article we will cover in detail why this procedure works so well, why it's just now making the news, and answer a number of questions that have been sent to me.

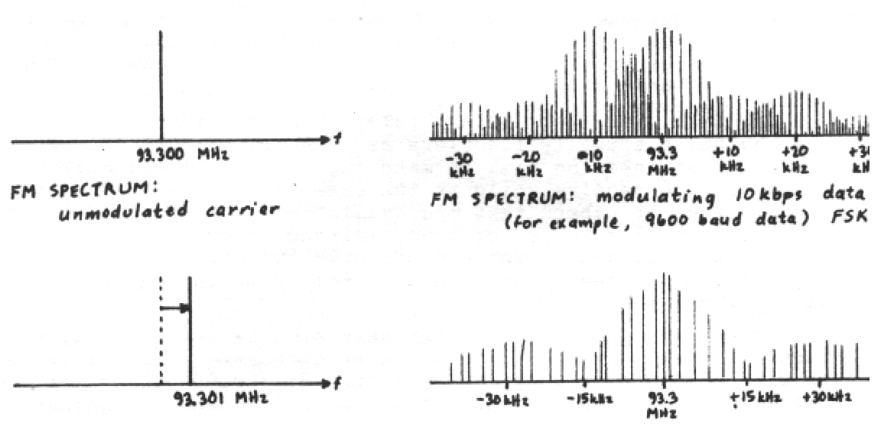
Every radio, receiver, tuner, television, or piece of communications equipment actually functions as a small, tunable window. It is a major engineering task to make that window let in only the signal we wish to receive while at the same time blocking the infinitely large number of others that are available. One approach is to design a tuner with a series of band-limiting stages, where each successive stage is a narrower and narrower "window." The IF stage filters are the narrowest, and are selected to match the type of signal we expect to receive.

In the case of FM, it turns out that signals have very wide bandwidths. Recall that to generate a frequency-modulated wave, one starts with a pure tone (say it's vibrating 93,300,000 times per sec at station WMMR) and then causes that tone's frequency to change according to the information to be transmitted. For example, a 1000 Hz note played into the microphone will cause the transmitter to broadcast at 93,301,000 Hz. It is widely accepted that in music, most of the sound exists at frequencies of 15 kHz or less. (Alright, the harmonics above 15 kHz are needed for some people to enjoy a complete experience...) Therefore, given that we transmit sidebands_ on both sides of the carrier, one might conclude that an FM channel need only be 30 kHz wide. But they are 200 kHz wide in the U.S. There are two main reasons for this.

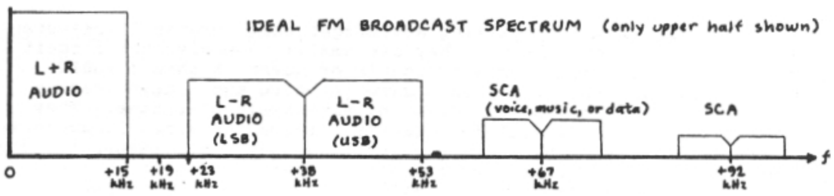
First, we wish to transmit in stereo; this alone doubles the bandwidth since there are left and right components to be sent out over the air. [In the 50's a number of schemes were proposed to transmit stereo audio on a single FM channel, not increase bandwidth, and maintain compatability with the millions of monaural FM receivers already in existence. The winner is still used today. In the multiplexed stereo transmission standard, the left and right components are summed and transmitted normally. At the same time, a circuit takes the difference between left and right, shifts that up in frequency by 38 kHz, and combines the result with the L+R signal at the transmitter. With this method, any old mono receiver can still pick up the L+R part clearly, and with no loss of frequency content: But a stereb receiver can use the "pilot tone" transmitted 19 kHz above the center of the channel to lock on to the L-R sideband and re-create separate left and right channel audio. Please refer to the figure below. We shall come back to this later.]



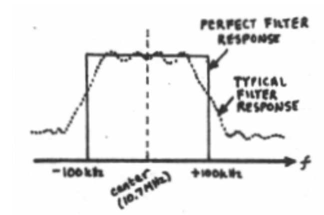
The second reason is because, with FM, actual signal bandwidth is theoretically infinite. Back to the WMMR example, we saw that a single note at 1 kHz caused the transmitter to produce 93.3 MHz plus a 1 kHz "deviation." If, instead, a Rolling Stones record was played, energy would be radiated from the transmitter at frequencies out to several hundreds of kHz at least, even if the record was band limited to 15 kHz. The reason for this involves some very complex mathematics, but it is important to note that the amount of energy contained in the (infinite) sidebands of the FM carrier varies with the volume level and frequency content of the music. This suggests that we may, to some extent, control exactly how wide a range of frequencies the FM sidebands will extend out to. This is precisely what the FCC requires FM stations to do ... because it turns out that much more than 15 kHz of bandwidth is required to accurately transmit all the information in a piece of music, and because it is impractical to place each station infinity MHz apart on the dial!



Specifically, each FM station must carefully set and monitor its modulation index (a measure of the way a program's frequency content and amplitude affects deviation), compression thresholds (often compression is used to ensure that loud and/or fast-attack passages in voice or music does not cause the transmitter to generate sidebands that splatter over into an adjacent channel), etc. Because it is impractical to totally compress music (it would not sound natural) and to predict the exact statistical nature of its spectral components, extra space ("guard bands") is inserted between broadcast channels.
By *adding* the guard bands and reducing the transmitted amplitude of the stereo subcarrier by an appropriate amount, it is possible to enjoy clear FM stereo programs without excessive bandlimiting or compression, and with an acceptable spacing between channels. In the US, there are 100 FM channels, each spaced 200 kHz apart, and each capable of carrying stereo audio to 15 kHz. (In areas where the FCC feels there is little chance of interference to an adjacent channel, often a station will be granted a Subsidiary Communications Authorization, or SCA, to transmit music or data on a subcarrier, usually at 67, 75, or 92 kHz from the carrier, and bandlimited to 7 kHz.)



Now the reader may ask, hat does all this have to do with selectivity? It has to do with the bandwidth of the filters one will need in the receiver! In order to obtain every little bit of information from the received signal and reproduce the best quality audio, the tuner should have at least the 200 khz bandwidth available in a standard FM channel. In fact, many use 230 or even 280 khz wide IF filters. However, in a crowded part of the country, most would prefer to use a bandwidth less than 200khz so that no interference is picked up from an adjacent or strong alternate channel. Thus, the choice of IF filtering is a tradeoff between selectivity and audio quality. The manufacturers of today's tuners are very aware of this tradeoff, and almost always opt for wider bandwidths so that the best audio specs can be achieved (and used in advertising). Further, it is fair to assume that most consumers have little desire to try to receive a station on an adjacent channel anyway. Of course, DX'ers hav very different requirements and since we do not exist in large enough numbers to make up a significant market segment. We must take this tradeoff into our own hands.

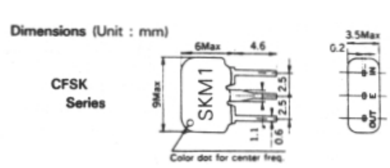


Since it is the IF filter(s) that ultimately determines the alternate channel selectivity (ACS) of a tuner, it is important to understand what filters might actually be needed. Ideally, FM tuners would use a filter having this kind of response (see figure). Nature will not allow the manufacture of such a filter, but we can come very close. Indeed, with carefully designed and built crystal or mechanical resonators, a filter very close to ideal can be built at great expense. (This is how a MacIntosh tuner can offer superb audio, incredible ACS, and a $2000 price tag.) Alternatively, a circuit of resistors, inductors, and capacitors can be built and painstakingly aligned. To approach the response curve above would require a complex design based on the mathemetical equations of Chebyshev, but at the cost of (1) dozens of components, and (2) poor audio quality due to the "group delay" of the filter. (Group delay means that some frequencies pass through the filter more slowly than others. This effect introduces a noticable form of audio distortion because the phase relationships within the music have been altered.) The group delay of the filter can be reduced to an acceptable level only by reducing the number of sections (or "Q"), which increases the slope of the curve and ruins ACS. Typically, a compromise design is used based on the equations of a fellow named Butterworth. With a five section circuit, reasonable selectivity is obtained while introducing negligable group delay.

Such a circuit would require about 12 separate components. The Japanese had a better idea, however, which brings us to ceramic filters. Because a de facto standard exists on the IF frequency used in FM tuners and radios for the consumer market (and for a lot of other applications, as well), it was possible to develop a standard, plug-in part which could be mass-produced and sold to various manufacturers.

So with some research and engineering effort, and the promise of sales of millions of units, the ceramic IF filter was designed. It operates at a center frequency of 10.7 MHz, matches into 330-ohm input and output impedances, comes in bandwidths of 150, 180, 230, and 280 kHz, and offersexcellent group delay and "Q" (a figure of merit which describes the slope of the filter response curve; the perfect filter shown above has infinite Q).

CFSK Series (CFSK 107M□)
(Ultra-compact, low temp. coefficient)

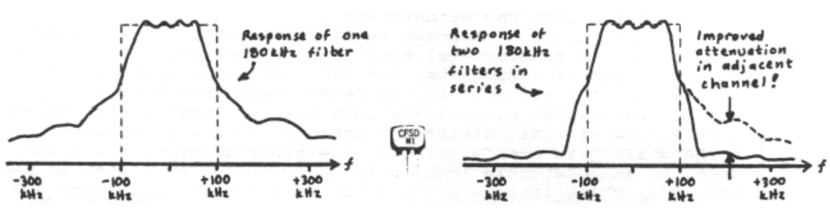


There are several compelling advantages that ceramic IF filters have over their alternatives. They are small; an equivalent circuit made up of discrete components (a couple of dozen of them!) would take up much, much more space on a circuit board and require costly labor to install. They do not drift significantly over time. They are standardized. And, most importantly perhaps, they are inexpensive (less than 25t apiece in the huge quantities that a manufacturer would purchase) Therefore, almost every receiver designed to receive FM broadcasts and built since the early 70's uses them. Two companies, both Japanese, seem to have the vast majority of the market: TOKO and MURATA-ERIE. The big, famous names like Sony, JVC, and Matsushita (the parent of Panasonic, National, and Technics) buy these little dudes by the millions, but they are available to experimenters from a few distributors in the US for less than $2 apiece.

Typically it seems that most tuners, portable radios, walkmans, and hi-fi gear comes with anywhere from one to four ceramic filters, each having 230 kHz bandwidth. This is the best choice from the maker's standpoint because this bandwidth passes all the information presumably available in a standard FM channel, and allows for drift in the IF which may occur in the equipment over time. For really top-quality audio the expensive tuners may even use 280 kHz filters! Those tuners having wide/narrow bandwidth switches generally just switch in a 180 kHz filter or two so that better ACS can be achieved in the "narrow" position.

Now DX'ers have a different perspective on this whole matter.

Of course, we would rather give up some audio quality in order to gain more ACS. Perhaps some of us would even accept a nearly unintelligable sound at the speaker if we could have 100 dB ACS in return! Now, with the availability of ceramic IF filters in small quantities to experimenters, we can finally take the tradeoff decision into our own hands. Indeed, replacing stock 230 kHz filters with 180 kHz units does not significantly alter the sound (those with good hearing will notice that the highest frequencies are lost ... a subtle effect) but it can add 14 dB of ACS. By going to 150 kHz filters, one adds over 18 dB of ACS, with some dulling of sound. If several 150 kHz filters are cascaded (that is, replacing all of the stock filters) much more ACS is achieved. The two figures below illustrate how, when two filters are cascaded in series, the stopband attenuation improves. (This is subtle ... notice that, while the IF response does not really get much sharper than with just one filter, each additional filter adds about 10 dB to the ultimate attenuation in the next channel over.) There's no reason why, a cascade of four (a number I selected because many $300 and up tuners use four) 150 kHz filters can't yield an ACS of 40-50 dB or more.



For the experimenter that wants to try replacing the stock filters in a receiver, there should be little difficulty involved. Substitution of one filter for another should have no significant effect on sensitivity (the narrower filters have a bit more insertion loss, but that will have little effect on sensitivity since there are several gain stages ahead of the filter. A cascade of 4 or more filters will add up to 12 dB or more extra loss which may tend to reduce sensitivity a noticable bit.) Also, because of reduced bandwidth, any SCA decoders you may be using will suffer. If you have an analog tuner it will be necessary to detune slightly in order to recover the subcarrier. If you have a digitally-tuned tuner, you will probably be out of luck. The filters are easy to locate: they are more or less square and have three leads. It doesn't matter which way they are soldered in.

You may buy TOKO filters from DIGI-KEY, POB 677, Thief River Falls, MN 56701-9988. (Phone orders are taken at 1-800-344-4539.) 180, 230, and 280 kHz models are available; the 180 kHz one is part number TK2307 for $1.67 each or $13.88 for ten. MURATA filters in 150 kHz style are available from HOSFELT ELECTRONICS, 2700 Sunset Blvd., Steubenville, OH 43952. (Phone orders are taken at 1-800-524-6464.) Ask for part number 27-109, at $1.00 each. The author has a large number of 150 kHz Murata filters available for $2.00 each postpaid, if you'd like to buy just a few from me.

QUESTIONS FROM READERS

1. How come the manufacturers are not using the "narrow band" filters? As suggested earlier, filters narrower than 230 kHz will degrade audio quality (first noticable as a loss of treble). Given a choice of pleasing DX'ers or pleasing audiophiles, the latter group wins every time.Onkyo, Carver, and other top notch tuners by DX standards are expensive because they have superb RF sections and because their designs have been painstakingly executed to deliver the best sound in a crowded signal environment. Good ACS was a design goal from the start in such tuners. DX'ers who already own these will benefit the most.

2. Are there even MORE selective filters out there? Say a 130? 110? This author isn't aware of them, and can't imagine who would buy them besides a handfull of DX'ers in the WTFDA. There are some options, though. A custom circuit could be designed, for instance, that would only pass the L+R component of the signal (a 30 kHz wide band), and which could be wired in in place of a ceramic filter. It would not be stereo, of course, but might turn out to offer tremendous selectivity, assuming the RF stages of the tuner are decent and the mixer doesn't produce a lot of spurs and intermods. (I am working on such a circuit, if anyone is interested.)

3. If 2 filters work well, will 4 work better?

To the extent that stopband attenuation is increased, yes.

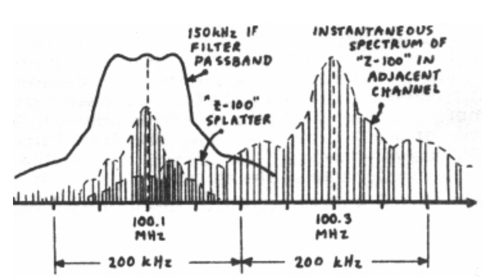
A cascade of several filters, in any case, can't do any better if an adjacent channel splatters into the tuned channel. It is not really worthwhile to string together more filters than the tuner possessed to begin with, unless you incorporate some sort of amp stage to compensate for the loss.

4. Why do some stations present such a bad ACS problem? There are a couple of stations in my area that splatter into the channels on both sides and no amount. of narrow filtering seems to help.

Music that is heavy in bass content, and has fast dynamics (rate of change of amplitude) will cause a transmitter to throw sidebands hundreds of kHz away from its center frequency. This effect is controlled using spectral limiters and compressors (the name Orban "Optimod" comes to mind...) to keep transmissions within their legal bandwidth. Though your narrower 150 kHz filters help, the best approach is to weaken the offending signal somehow (move the antenna, install a trap, or off-tune the other way). Unfortunately, there isn't much you can do about a station that may not have its equipment set right (how do you prove it? And besides, if they compressed all FM stations to avoid any remote chance of adjacent splatter, they would sound dull during those times you're driving around and want to use the FM band for normal entertainment!). See illustration below.

5. Why is the selectivity on my upper adjacent channels better than that for the lower adjacent channels?

This is caused by either or both of two reasons: (1) the tuner is a bit out of alignment, meaning that its IF passband has moved away from the RF passband, (2) the center frequency of the ceramic filter may be different from the IF of the tuner. (It wouldn't be unusual if the IF center of the tuner drifted by 50 kHz over time, or if the tolerance of the filter came to 30 kHz.)



THANX to Bill Nienajadly for supplying information used in this article. Also kudos to Bill Nollman for locating a source for 150 kHz filters. My distributors are much less reasonable!

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MORE TO COME next month!