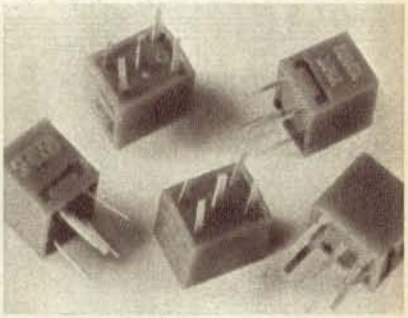
# CERAMIC RESONATORS as IF filters and oscillators . . . . 1

This discussion on the characteristics of ceramic filters on a nominal frequency of 455KHz, shows that they have a very wide potential for applications in receivers and transmitters, etc., and opens up a new field which has interesting and exciting possibilities.

By Ian Pogson



*Here is a group of the resonators about which we are writing. The case measures about 5/16in x 9/32in x 7/32in.*

Concurrently, with the rapid development of solid-state devices, there has been a parallel development of ceramic products. These include ceramic capacitors of various types, and exploitation of the piezoelectric properties of certain ceramics. It is the latter in which we are currently interested.

Although the piezoelectric properties of ceramic materials have been known for some time, the earlier ceramics were not a practical proposition, due to lack of stability in terms of time, and an unsatisfactory temperature characteristic. Recently, lead-zirconate-titanate ceramics have been brought to a state of development where aging and temperature characteristics have been stabilised satisfactorily.

This has resulted in a number of components being brought on the market, generally in the form of small units for use as filters in IF applications, particularly at 455KHz. The manufacture of ceramic filters is not as widespread as many other components, but we have seen samples from the United States, England and Japan. It is the latter source with which we are mainly concerned at present.

From Japan, two makers have come to our notice, Murata and National. Of the two, Murata appear to make the wider range and, from our experience, the Murata units seem to offer the greater scope for investigation. Another important point is the fact that the Australian distributors for Murata filters, I.R.H. Components Pty. Ltd., are active in the field and keep good stocks on hand.

The writer has already made use of ceramic filters, both Murata and National, in tuners for the broadcast band, described in May, August and October, 1968. Such filters are attractive in that they are small in size, they do not need to be aligned and the ones most likely to be used in simple applications, are cheaper than IF transformers. On the other hand, there are some multiple ladder types offered, which have excellent characteristics, particularly skirt selectivity, and which are quite expensive.

Regarding the more expensive devices, Murata and we understand, others, have produced units which rival and often can take the place of crystal lattice and mechanical filters, so often used for SSB applications. In fact, Murata catalogues two grades of such filters, differing in the skirt shape and thus the adjacent channel rejection. The higher grade lists no less than 10 items, ranging from a nominal bandwidth of ±17.5KHz to ±1.5KHz; the other grade lists eight items, ranging from ±17.5KHz to ±3KHz. It was one of the latter group that we used in the Wide Band Tuner, with a nominal pass band of ±9KHz at the 3dB points.

From the experience thus gained, limited though it was at this stage, the idea naturally followed of using such filters in solid-state communications receivers. In such a receiver, we would otherwise use conventional IF transformers, backed up by either a mechanical or a crystal lattice filter, for the reception of SSB signals.

But each time we considered using the ceramic filters, obstacles seemed to appear. In the case of the expensive ceramic filter to take the place of the mechanical or crystal lattice filter, the unfortunate fact emerged that the narrowest unit offering was ±1.5KHz minimum, at the 6dB points. In fact, one of these units which became available, turned out to be a little over ±2KHz or more than 4KHz wide between the 6dB points. As a figure of 2KHz to 2.5KHz is the widely preferred choice for SSB, it is obvious that the narrowest ceramic filter would not be adequate.

When we turned our attention to the low-cost versions of the ceramic filters, for applications where they would be cascaded in an IF strip, the problem arose of tolerances on the centre frequency. The quoted tolerance is ±2KHz on the nominal centre frequency of 455KHz. This means that, in the extreme case and where we wished to use say four units in an IF strip, the centre frequencies of the individual units could be separated by as much as 4KHz. Where we are likely

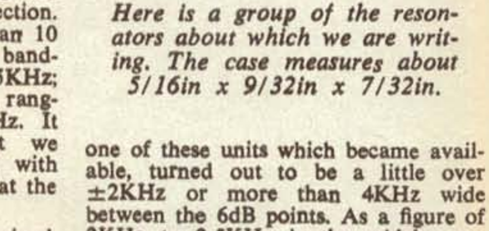


Figure 1

*The SFD-455B resonator consists of two "ring-dot" elements connected as shown right. The capacitor size determines the band-width.*

## TABLE 1

Results of tests on an SFD-455B ceramic filter unit. Top coupling, 47pF. Centre frequency initially, 454.75KHz.

| | | | |
|---|---|---|---|
| 10K, | pin 1 to E: | fc = 454.30KHz | Approximately 10dB loss |
| 10K, | pin 2 to E: | fc = 454.55KHz | Approximately 3dB loss |
| 4.7K, | pin 1 to E: | fc = 454.15KHz | Approximately 20dB loss |
| 4.7K, | pin 2 to E: | fc = 454.51KHz | Approximately 5dB loss |
| 27pF, | pin 1 to E: | fc = 453.76KHz | Practically no loss |
| 27pF, | pin 2 to E: | fc = 454.86KHz | Practically no loss |
| 82pF, | pin 1 to E: | fc = 452.63KHz | Practically no loss |
| 82pF, | pin 2 to E: | fc = 454.87KHz | Practically no loss |

to be looking for a band width of 4 or 5KHz, or even less, it is obvious that such tolerances would be unacceptable.

Still looking for an answer to the filter problem for SSB reception, we investigated the availability of mechanical filters and suitable crystals (FT-241, etc.). We found that mechanical filters were not as readily available as we had hoped. Also, while FT241 crystals are still available in the United States, they are not readily available here. So we turned our thoughts to the low-cost ceramic filters again. Would it be possible to make use of them, in spite of the spread in tolerances?

With nothing to lose, and the possibility of something to gain, we decided to concentrate our efforts on the Murata type SFD-455B, a 5-terminal device. Its bandwidth can be adjusted by different values of top capacitive coupling, between the two elements which go to make up the complete unit.

Figure 1 illustrates the "works" of an SFD-455B assembly. It consists of two elements, each a ceramic slab about 3/16in square and about .015in thick. The slab is silver-plated on opposite faces. On one side, the plating covers the full surface. On the other side, the plating is such that two separate areas are formed, as shown. When two of these matched elements are placed back-to-back, we have the five terminal device, type SFD-455B. In the actual package, the two elements are held in small clips, making the appropriate contacts and brought out as small flat flexible leads.

To study the behaviour of the ceramic resonators under various conditions, we set up a sweep generator on 455KHz, actually the one described in December, 1963. A standard signal generator was used as a marker, monitored by an Advance frequency meter.

The sweep generator was fed into the test circuit as shown in figure 2; the output of the test circuit fed into a detector probe which in turn, connected to the vertical input of the CRO.

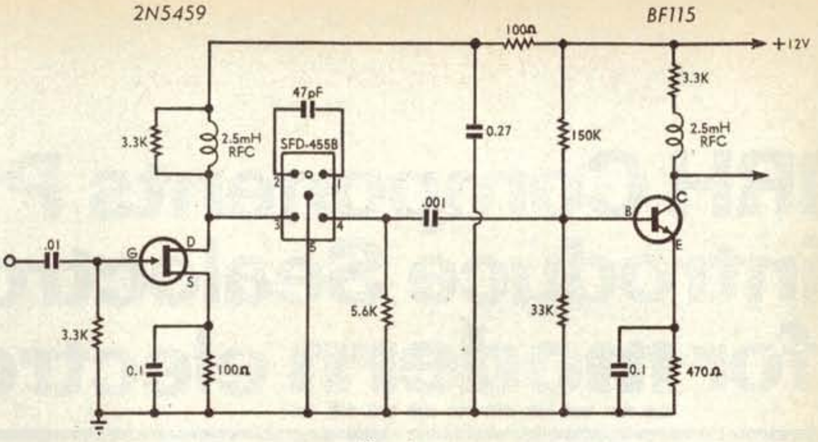


Figure 2

*This is the circuit which we used to make tests on individual resonators. The circuit is straightforward and representative of current practice.*

Our first test was to determine the centre frequency of each of a number of randomly selected SFD-455B units. Of five units checked, the centre frequencies turned out to be, 456.15KHz, 455.08KHz, 455.63KHz, 456.00KHz and 456.63KHz. The units all come well within the maker's tolerance of ±2KHz. The greatest separation is represented by one on 455.08KHz and another on 456.63KHz; this amounts to 1.55KHz and looks promising, but we must face the fact that other samples could be much wider apart than these tested.

Our next test was a check on the band width at the 3dB points, of the same units and with the coupling of 47pF as shown in figure 2. The band widths turned out to be, 1.95KHz, 2.17KHz, 2.23KHz, 2.37KHz and 2.34KHz. Although there are notable differences, they are well within the maker's tolerances.

At this point, the vital question arose. Could we do something to bring all units to the same centre frequency, or otherwise control them so that a number of them could be used in cascade? If we could do this, then the selectivity characteristics of each unit in the setup would be additive, possibly resulting in a good shape factor. Also, could the band width be controlled?

Our next test consisted of placing a random selection of SFD-455B units in the same test circuit, figure 1, as before. Arbitrary tests were carried out by connecting resistors and capacitors of various values across different terminals of the device. The results of this test are shown in Table 1.

A perusal of Table 1 can be very enlightening and indeed, very promising. It will be noted that a resistor or a capacitor across certain terminals changes the centre frequency quite appreciably. The frequency shift is to the low side in most cases, except where a capacitor is connected from pin 2 to earth, which results in a small shift in the high direction. It will also be noted that while resistors shift the frequency, they introduce a considerable insertion loss, whereas a capacitor introduces no significant loss.

It would seem from the above that resistors should be avoided and only capacitors used to modify characteristics, but this has turned out to be a premature assumption. In cases where elements in a complete system vary to a significant extent in Q, a suitable value of resistor can be used to advan-

*An extension of the one above, this circuit was set up to test a full set of resonators, as they may be expected to be used under IF conditions of a short-wave or communications receiver. The switching would be more elaborate on an actual strip, compared with the token switching shown.*

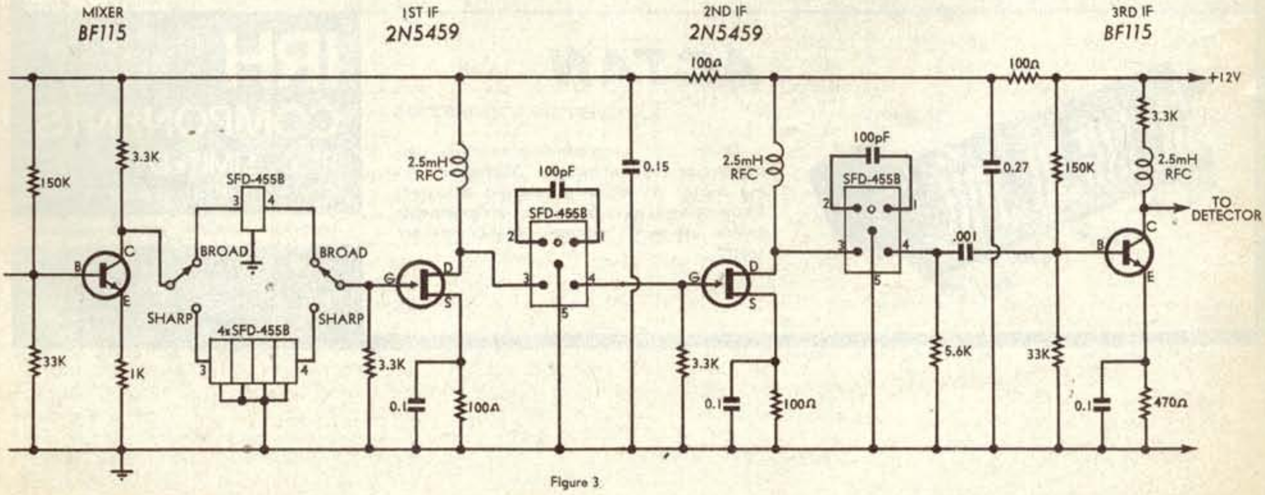


Figure 3

tage to correct this. More will be said about this later on.

Further study of Table 1 shows up other points of interest. The higher the value of capacitor used, the greater is the frequency change. Alternately, the lower the value of resistor used, the greater the frequency change. Also, the amount of frequency change, all other things being equal, is different when different terminal connections are used.

A further point worth mentioning, and which is not shown in Table 1, is the fact that frequency changes can be achieved by connecting external components between terminals 3 and 4, and earth but the changes are not so great. Also, it is possible to effect changes by connecting between terminals 2 and 3, or 1 and 4. Again, the changes are not so marked.

The next series of tests were more ambitious, having been prompted by the results given in Table 1. Another test circuit was set up, so that a series of tests could be made which simulated actual application in an IF strip. The circuit is shown in figure 3.

This circuit consists of a BF115 transistor in the first stage, which could be the mixer in an actual application of the full system. Following this stage is provision for checks to be made on one or more SFD-455B filters. Then follows an amplifier stage in which we are using a 2N5459 field effect transistor. Between this and the next and similar stage is an SFD-455B filter as the coupling medium. Another SFD-455B is used to couple from the second FET, to the third IF amplifier stage, using a BF115 transistor.

Field effect transistors were selected for the first two amplifiers, as thev could be controlled by an easilv generated AGC voltage. The final stage uses a BF115, because it will not be controlled and it gives somewhat more gain than the FETs.

It will be noticed that the two FETs have a 2.5mH RF choke as the drain load, instead of the more conventional 3.3K resistor, which is associated with ceramic filters. The reason for this is that FETs take a much higher current than bipolar transistors, something between 5 and 10 milliamps. This would mean excessive voltage drop through a 3.3K resistor and, with a supply voltage of 12, the proposition would not be practical. The use of an RF choke solves the voltage drop problem and at the same time presents about the right source impedance for the filter.

An important point which should be mentioned in this circuit is the top capacitive coupling used for the two SFD-455B filters, already installed. The coupling capacitor used is 100pF. This results in some overcoupling, with a slight double hump. The thinking behind this approach is that, if we make these circuits somewhat wider than the widest pass band required, most of the selectivity can be determined in the first stage, with the other two acting only in a supplementary capacity.

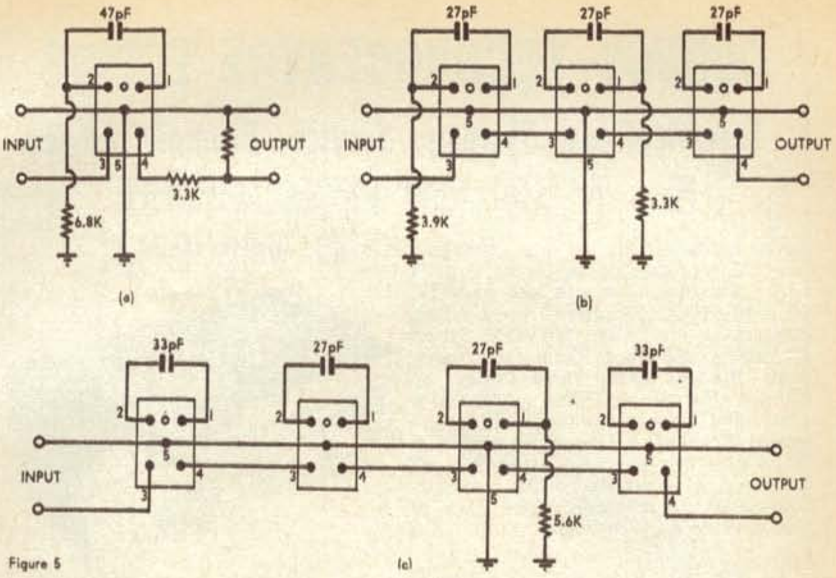
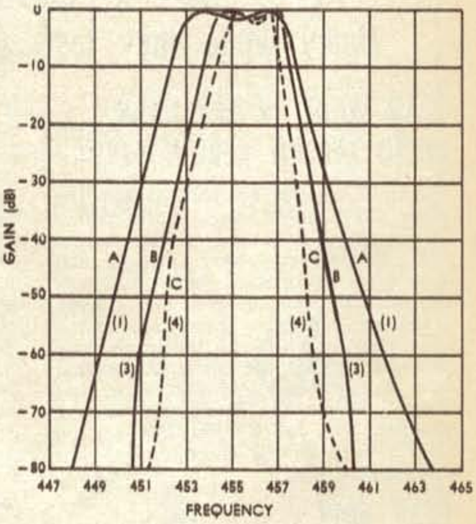


Figure 5

*Circuits (a), (b) and (c) are those which produced the wide, medium and sharp curves. The compensating resistors would be different for other cases.*



*The curves A, B and C at right, were derived from filters (a), (b) and (c) above, when used in figure 3.*

Figure 6

With figure 3 ready to go, we connected one SFD-455B unit between the first BF115 and the following FET. The top coupling capacitor used on this occasion was 47pF, the pattern on the CRO appearing substantially as shown in figure 4A. Although not by any means perfect, it could be more or less acceptable. By connecting a 6.8K resistor from terminal 2 to earth, the pass band shape as shown in figure 4B was obtained.

The single SFD-455B was then removed to make way for a more ambitious test. It was considered that we may be able to connect a number of these units in cascade, to improve the overall pass band. Normally, terminals 3 and 5 are the input, with terminals 4 and 5 for the output. As the units are symmetrical, i.e., the input and output impedances are equal, it should be possible simply to connect a number of units in series, pin 4 to 3, etc., and all pins 5 to earth.

On this assumption, we connected three units together in this way. The 27pF capacitors were chosen for the top coupling for each unit and the whole assembly was then connected into the same position as previously. A reasonable shape was obtained, but attempts were then made to improve it. In this case, by connecting a 3.9K resistor from the first pin 2 to earth and a 3.3K resistor from the second pin 1 to earth, we obtained a very satisfactory shape.

Pursuing this approach a little further, we connected together another group of four and put them into the test circuit. Once again, our experience was much the same. By connecting a 5.6K resistor from the third pin 1 to earth, an excellent shape was again obtained.

The connections for the three tests just given are summarised in figures 5A, 5B and 5C respectively. At this point, quite a number of important observations can be made. Firstly, it would appear that the investigations are reasonably successful so far. The next question is, just how successful? This can be answered at least in part by referring to the three photographs from the screen of the CRO and in somewhat more detail from the curves shown in figure 6.

The photographs look encouraging, but they only tell part of the story. Just how good is the skirt selectivity? The answer to this is given in curves of figure 6. Curve "A" is 5KHz wide at —6dB and 12.3KHz at —60dB. This gives a shape factor of 2.46. Curve "B" is 3.3KHz wide at —6dB and 9KHz wide at —60dB, a shape factor of 2.73. Curve "C" is 2.2 and 6.5 at the —6 and —60dB points, giving a shape factor of 2.96.

These figures for the shape factors could be considered as very satisfactory. It may be possible to improve upon these figures further by taking

a little more care in adjustment, or by adding an extra unit or two, to those already existing. At this stage, we have not tried to improve upon these figures.

It will be noticed that we have taken the curves down to the —80dB points. While we can vouch for the accuracy of the curves, within reasonably small limits, down to —60dB, there may be some greater errors at the higher attenuation. Suffice to say, that the overall adjacent channel attenuation is little short of excellent.

In cases where more than one degree of selectivity is required, blocks of filters with selected characteristics would be fitted between the mixer and the first IF amplifier, with facilities to switch from one position to the other. As the insertion loss of these filters increases with additional units added in cascade, it may be necessary to introduce some attenuation to the filter with the lower insertion loss, so that there will be no change in signal level, when switching from one position to the other. This is the reason for the voltage divider shown at the output of the filter in figure 5A.

By now, readers will be asking how the band-width of these assemblies can be controlled to give the wanted characteristics. Fortunately, the answer is simple. The overall band-width is controlled simply by changing the value of the top coupling capacitance for each unit. This, of course, has to be determined for the particular assembly, together with any corrective measures such as the use of shunt capacitors or resistors, as mentioned previously. It is doubtful if the band-width could be changed, of a particular assembly, after it has been finally adjusted, simply by altering the top coupling capacitors.

To sum up on the question of obtaining a certain band width, it is kept to a minimum by using a small coupling capacitance, such as 27pF. Progressively wider pass bands are achieved, within reasonable limits, by increasing the top coupling to something of the order of 100pF.

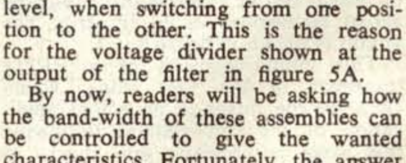
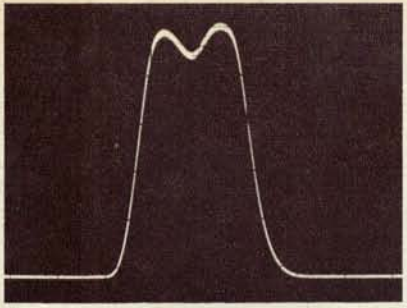


Figure 4

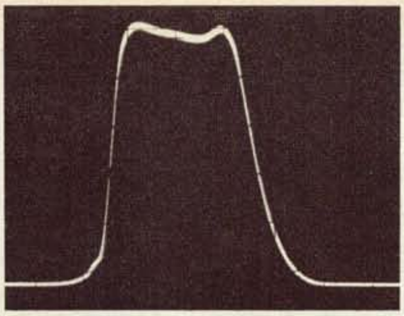
*These curves are typical of "before" and "after" corrective measures are taken.*

So far, the whole idea looks very promising. However, in spite of all the investigations up to this point, the question of maker's tolerances on centre frequency has not been fully resolved. As a further check, we picked at random another four new SFD-455B units and connected them up in a similar manner to those of figure 5C without any corrective measures.

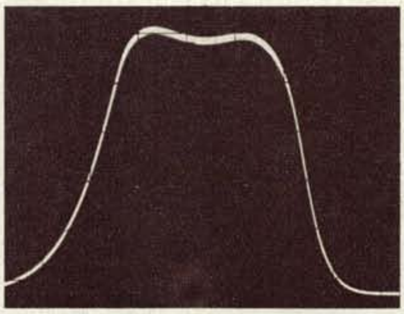
A check on the sweep equipment showed that although the pass band shape was anything but correct, it would be reasonably satisfactory if nothing more was done about it. However, as it did leave quite a bit to be desired, we set about taking corrective measures. It transpired, after a few minutes' investigation, that a 3.3K resistor from the first pin 1 to



*This photograph from the CRO, corresponds with the curve of figure 6C.*



*This photograph of the 3-unit filter corresponds to the curve of figure 6B.*



*A broad curve, with one unit and suitable for AM, corresponds to the curve of figure 6A.*

earth, was sufficient to give a good shape. In short, and considering the foregoing, it would seem that there is no reason why these results could not be closely and satisfactorily approximated.

Clearly, a case has been established for the application of type SFD-455B ceramic resonator units in IF circuits where a high performance filter is required. It now becomes of interest to compare this potential, with the more firmly established mechanical filter and crystal lattice filter.

Although it is not easy to be too specific in a short space, we can at least make some general observations. The ceramic filters just described, compare favourably with either the more commonly used mechanical or crystal lattice filters in available bandswidths and shape factor. In size, the ceramic units would normally be smaller than equivalent mechanical or crystal filters. Perhaps one of the greatest advantages offered by the ceramic filters is that of cost. For a given performance, we suggest that a ceramic filter could be installed for about 20 per cent of the cost of a mechanical filter. It would also be much less than a crystal filter, depending on the source of the crystals.

We have already referred to the apparent reduction in supplies of mechanical filters and suitable crystals in this country, whereas stocks of SFD-455B ceramic resonators are readily available at a modest price.

So much for the advantages which ceramic filters have to offer. The question may be asked as to whether there are any disadvantages or, what is the catch? There are indeed, a couple of minor disadvantages but these can be readily overcome in most cases. We refer to the problem of alignment, where a builder has only limited test equipment in one instance and the insertion loss where several units are used for high performance.

The problem of insertion loss can be immediately overcome simply by adding an extra stage to the IF strip. The answer to the alignment problem with limited equipment, is not quite so easy. It may be possible to use an ordinary signal generator and a vacuum tube voltmeter, with a detector probe. However, we have not looked too closely into this one but we hope to have more to say about it later on, in a subsequent article.

Although we have spent some time on this investigation and we have come up with enough information to answer a lot of questions and to give much food for further thought, we feel that there is so much to be learned about these devices and the surface has only been scratched. Suffice to say that the findings so far are most exciting and the application potential could be far-reaching. **(To be continued).**