Defogging Microstrips

An intro to microstripline filters.

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This article describes microstipline filters. They perform the same functions as LC circuits but don't look anything like typical ones. I'll show you how to design and make your own. I retraced my steps as I was trying to develop one, so you wouldn't waste time and make the same mistakes I did. Let's try to remove some of the fog surrounding this topic.

I needed an input filter for a microwave downconverter that I built. It translates microwave frequencies to VHF. Without a filter at the RF input, the signal was noisy because the converter combined both the desired signal and the image noise in the output. I had seen microstripline filters in commercial equipment, but had no idea how to design them or how they worked. The filter I designed provides noise-free signals, whereas before the signal was covered with so much noise that it was useless.

These filters can be used in equipment for the 440, 902, and 1296 MHz ham bands and the 1691 MHz weather satellite band (my application). They are useful at higher frequencies if test equipment is available that can go higher.

Theory

Microstripline filters can consist of several grounded 1/4-wavelength-long sections of printed circuit track on double-sided PC board. See **Photos A** and **B**. The energy in one element is coupled into the next element due to their close proximity. They resonate at one frequency, just like a 1/4-wave antenna. The loss through the filter is determined by the spacing between the elements and the number of elements. The bandwidth decreases (gets sharper or narrower) as the spacing between elements is increased, and the loss
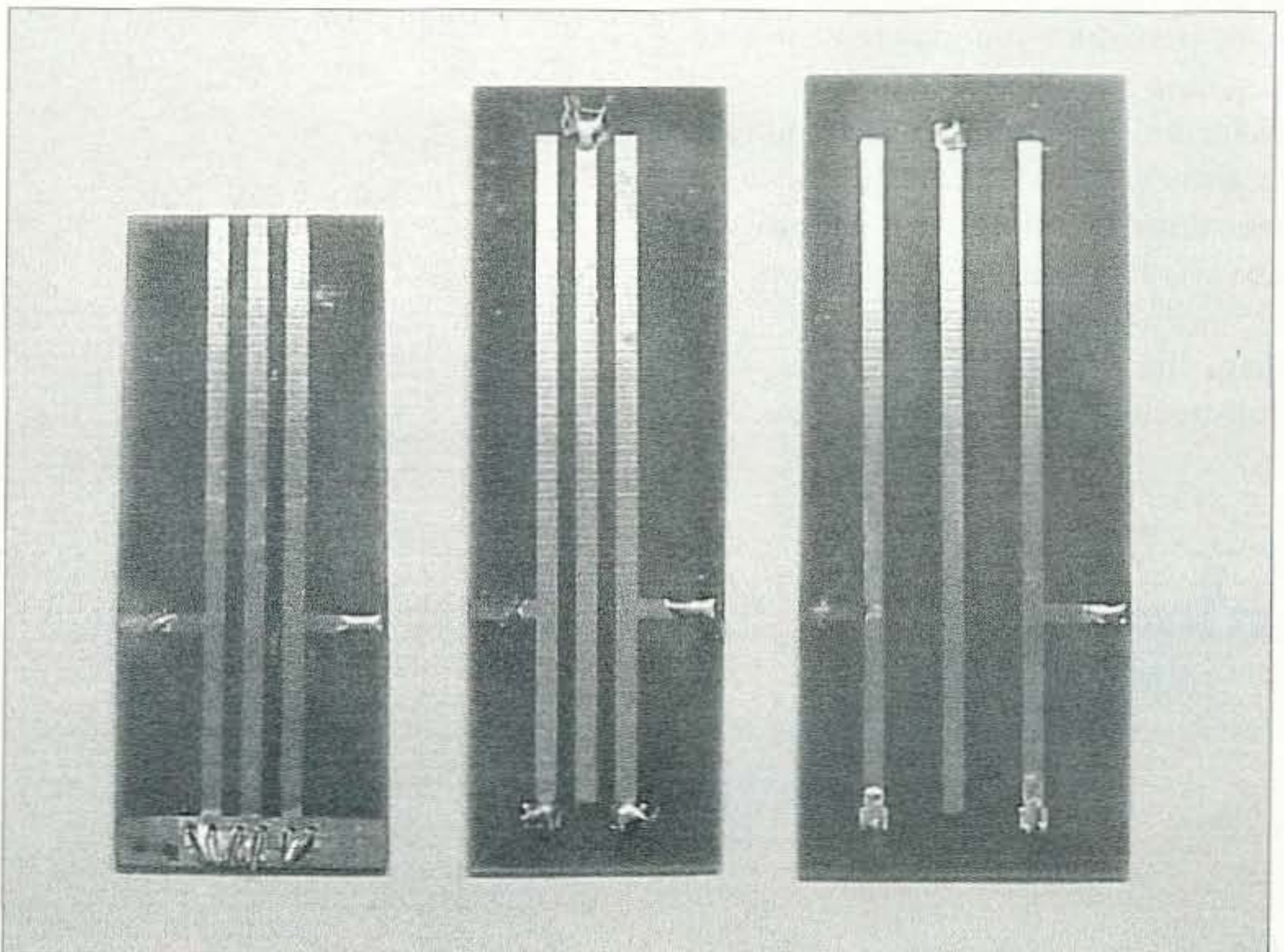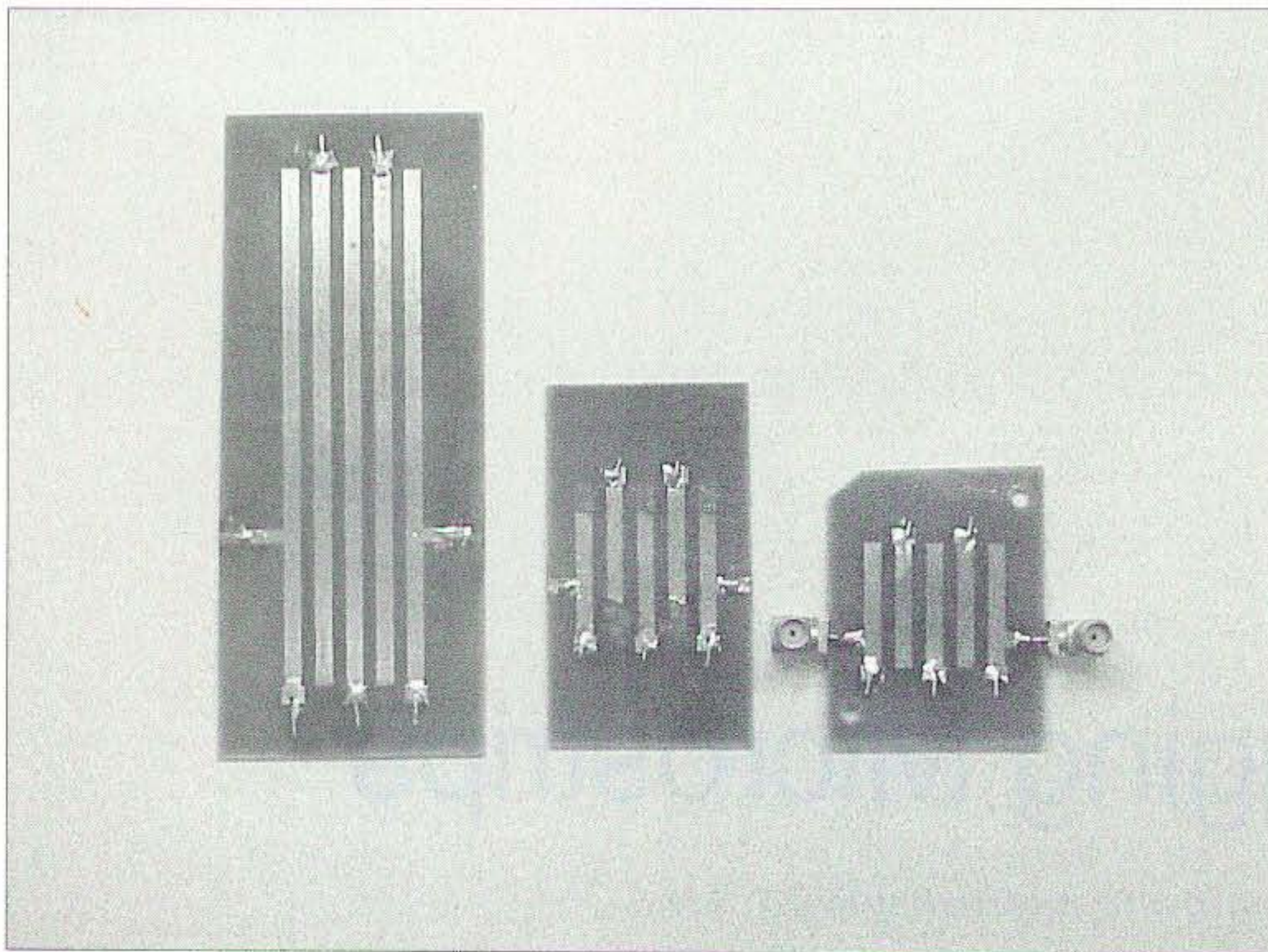
Photo A. From left, filters 1, 2, and 3.

Photo B. From left, filters 4, 6 (filter 5 after trim), and 7.

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increases as the spacing is increased. (Compare **Figs. 3** and **4**.)

The amount of loss you can tolerate and the bandwidth you require determines the spacing. You can add more elements and get a sharper filter curve (steeper sides on the filter response; compare **Figs. 3** and **5**), but more board space is required. If you want lots of rejection far from the passband *and* a wide passband, you may have to stagger tune the elements, making each element resonate at a slightly different frequency. There is no one filter configuration (number of elements and spacing) that is correct for every application.

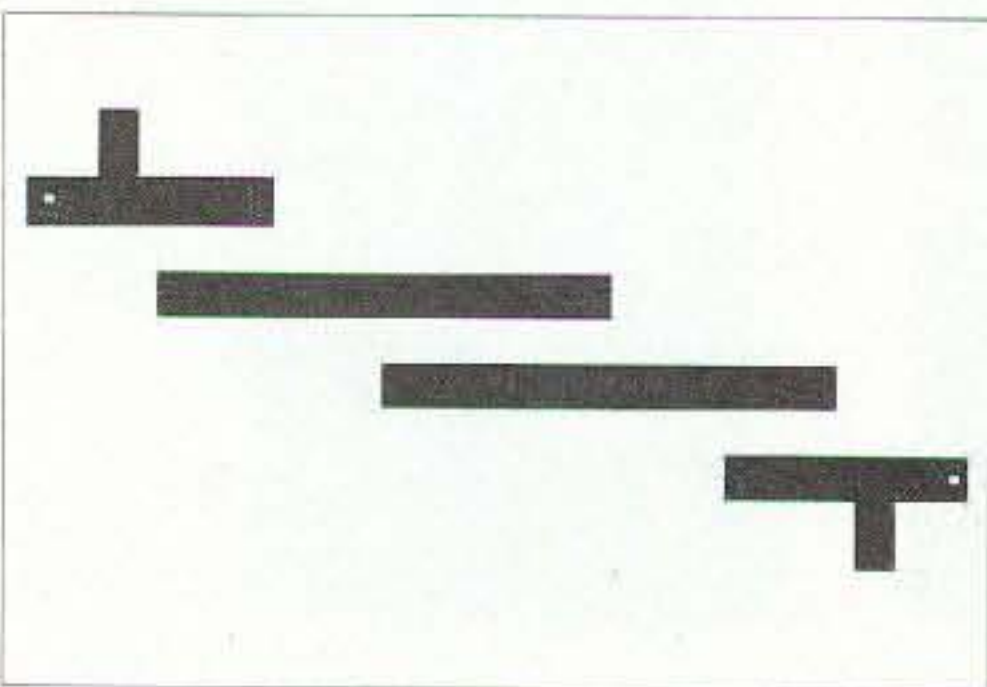Since the 1/4-wave lines (we'll call them lines instead of PC tracks) are constructed above a ground plane, the board insulating material affects the velocity factor because it has a dielectric constant different from that of air. This makes the lines shorter than they would be if the dielectric was air.

In this article, I'll discuss two configurations of microstripline filters: comb and interdigital. In a comb configuration, all the lines are grounded at the same end. In an interdigital configuration, the grounded ends alternate. I obtained greater loss with a comb configuration. The graphs discussed later will demonstrate this higher loss.

There is a third type of configuration that I did not try. It uses 1/4-wave lines grounded at the input/output and 1/2-wave floating lines for the intermediate lines. See **Fig. 1**. I don't know whether this type has other desirable characteristics. See Ref. 3 for further details.

The actual lines should be 50 ohms impedance, because that provides a good match to other devices (the LNA, mixer, etc.). The input and output track should also be 50 ohms impedance. For 0.062-inch glass epoxy board, a 50 ohm line is 0.100-inch wide. The 50 ohms is determined by the line width and the type and thickness of substrate. A good article on determining the impedance of various thicknesses, substrates, and line widths was referenced by many other articles. See Ref. 1. To obtain the desired 50 ohm impedance, the input and output taps should be about 1/3 of the way up from the ground end.

Development and design

The first thing I always do when starting a new concept is to go over all my old issues of *73 Magazine, Ham Radio, QST,* and the *ARRL Handbooks.* I also get *RF Design* at work and keep a file of articles that I think I might need in the future. After spending many hours searching for information on microstripline filters, I found one brief article in *Ham Radio* (Ref. 1), one page in the *ARRL UHF and Micro-*
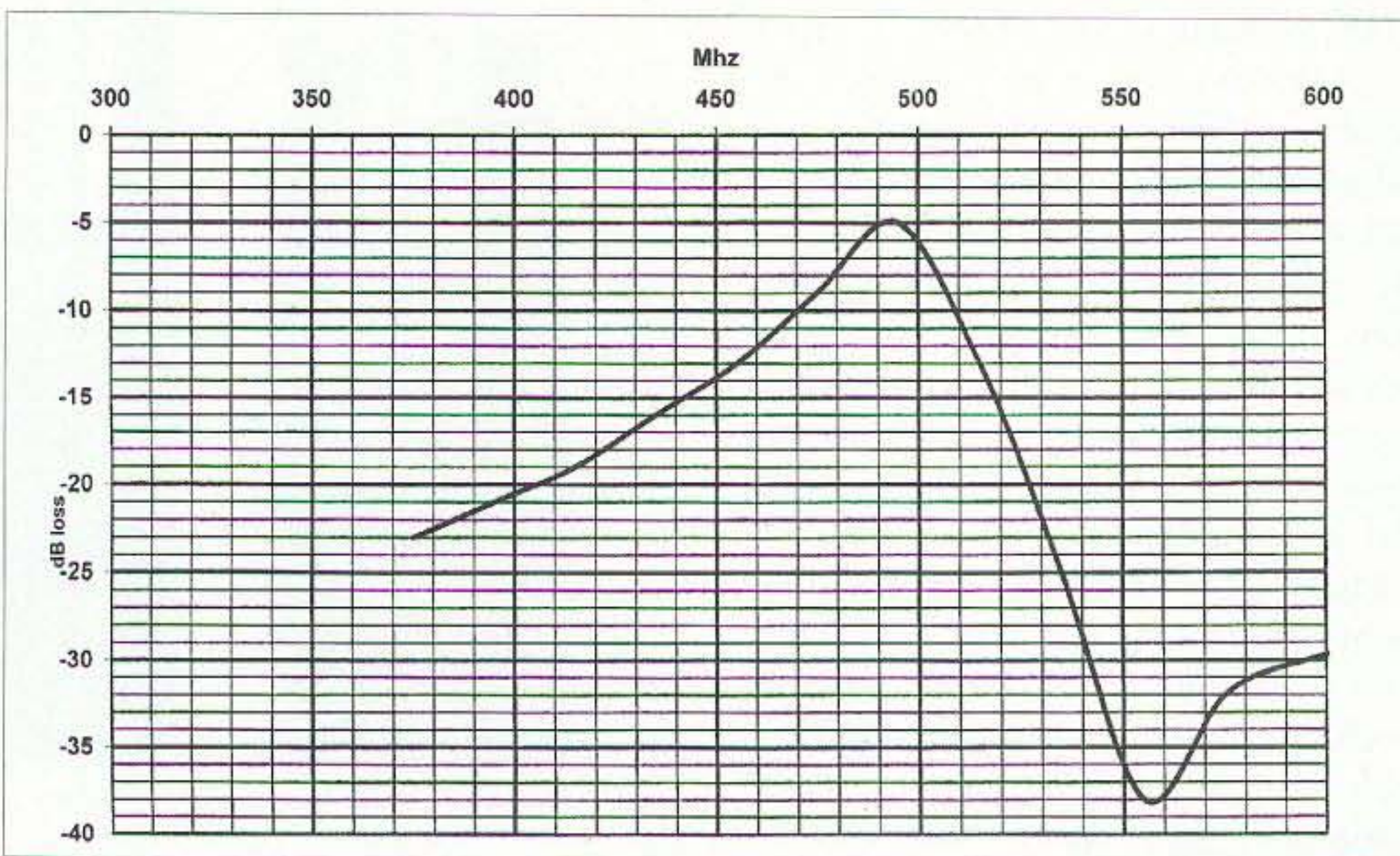

Fig. 1. Typical PC board artwork for "floating 1/2-wave" design.

Fig. 2. Frequency response curve of filter 1, 3-pole, .100" spacing, comb configuration.
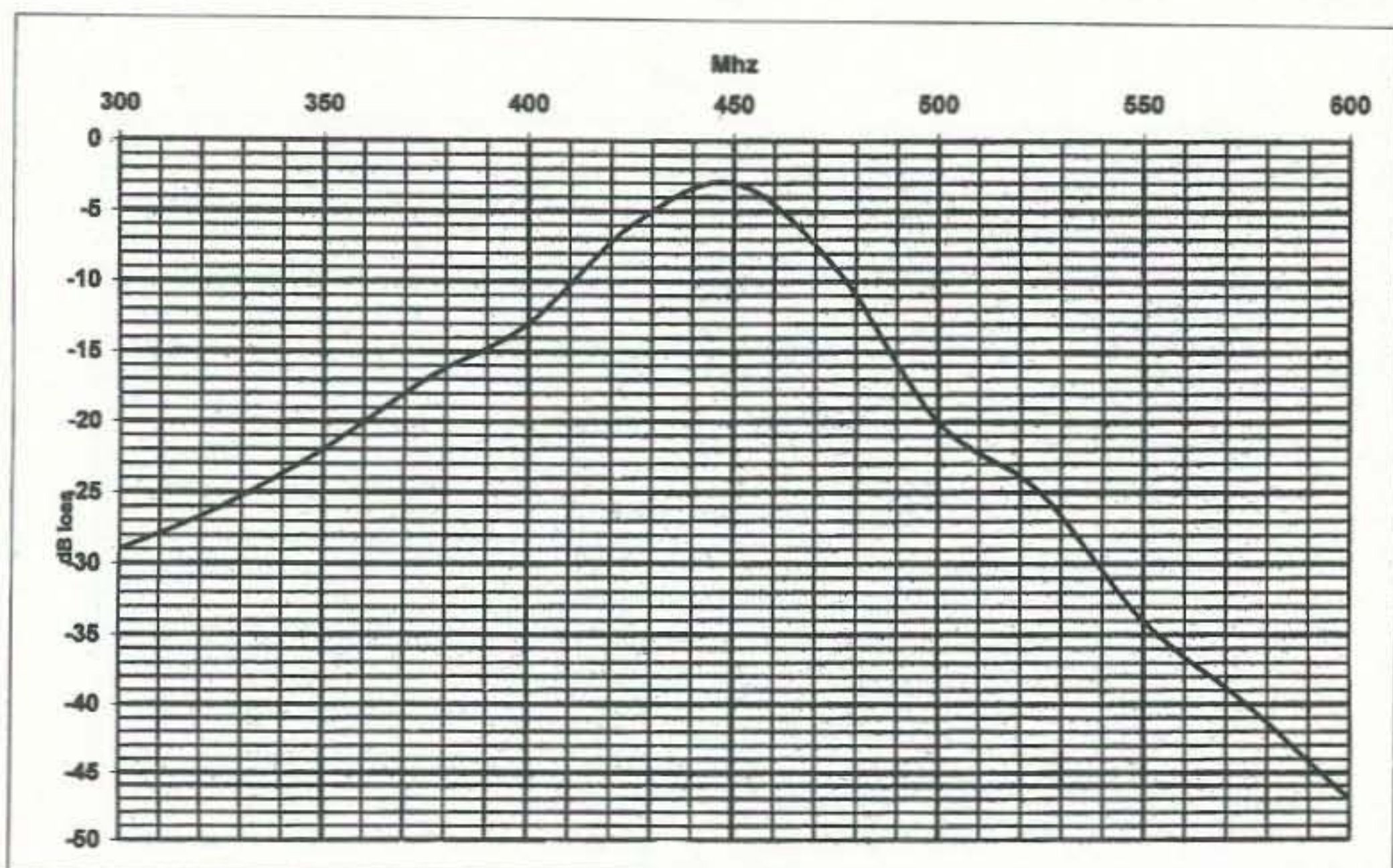
Fig. 3. Frequency response curve of filter 2, 3-pole, .100" spacing, interdigital configuration.

wave Experimenters Handbook (Ref. 2), two *very* technical articles in *RF Design* (Refs. 3 and 4), and some technical correspondence I had with Chuck Houghton WB6IGP about 7 years ago (he does the excellent Above and Beyond column in *73 Magazine*). One *RF Design* article didn't really explain how the filters function but was just a computer program you could purchase or enter yourself. The other *RF Design* article discussed a lot of theory I didn't understand. The *Ham Radio* magazine article showed a little of what I was looking for; it described 2- and 3-element filters and demonstrated that 3 elements produce a sharper filter than one with 2 elements. *The ARRL UHF*

and Microwave Experimenters Handbook listed an example of a filter but didn't provide much design information. The best guidelines I was able to obtain came from Chuck Houghton. He sketched out some notes in answer to questions I posed and said I would have to experiment with the design. The handwriting was on the wall! It was time to stop reading and start making some filters!

Where I work, we use DOX (Design of Experiment) and Taguchi methods wherein we vary one (or more) parameter(s) at a time to see the effects of each change on a given design. Using these techniques to develop the required filter, I would have to vary the
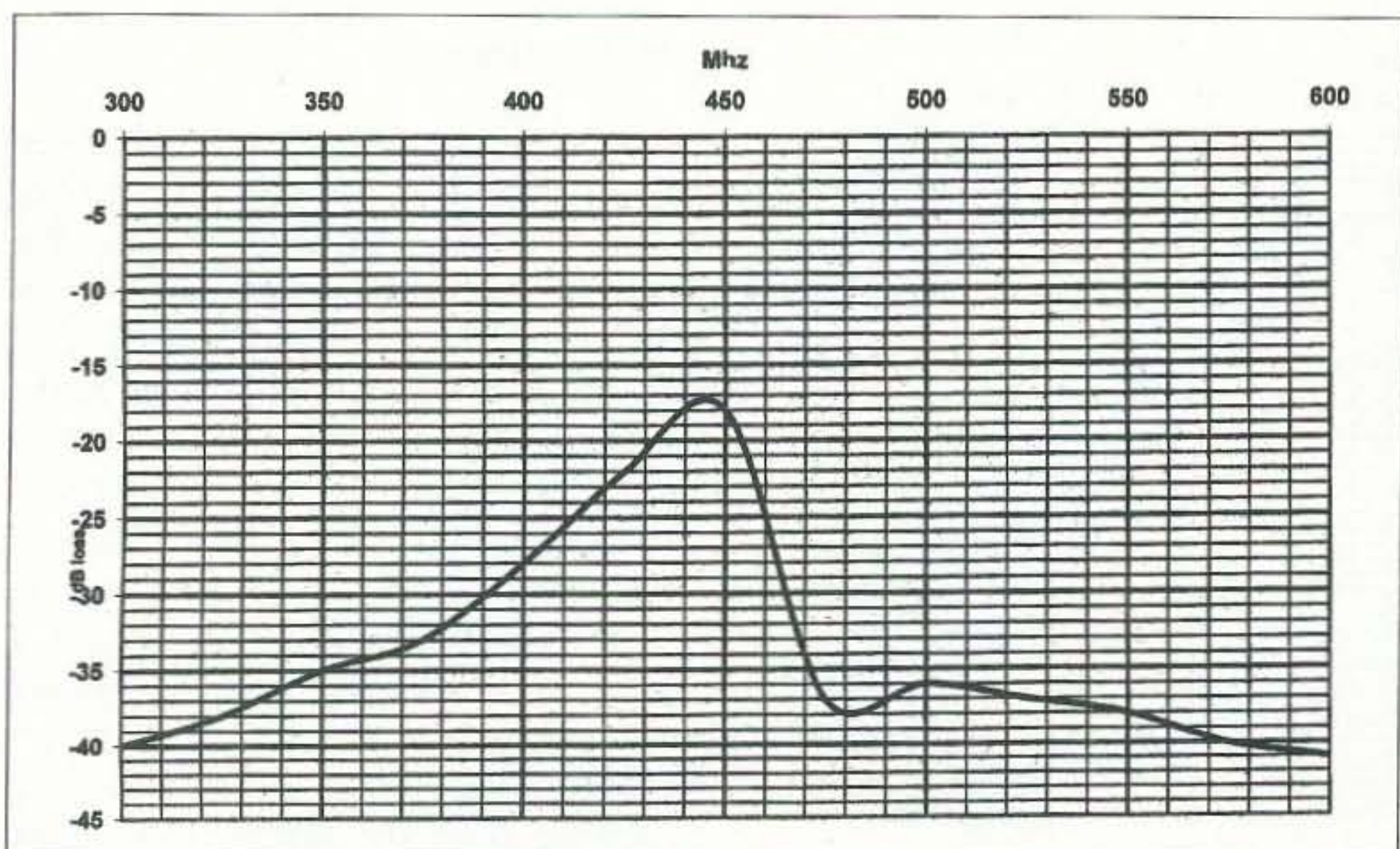

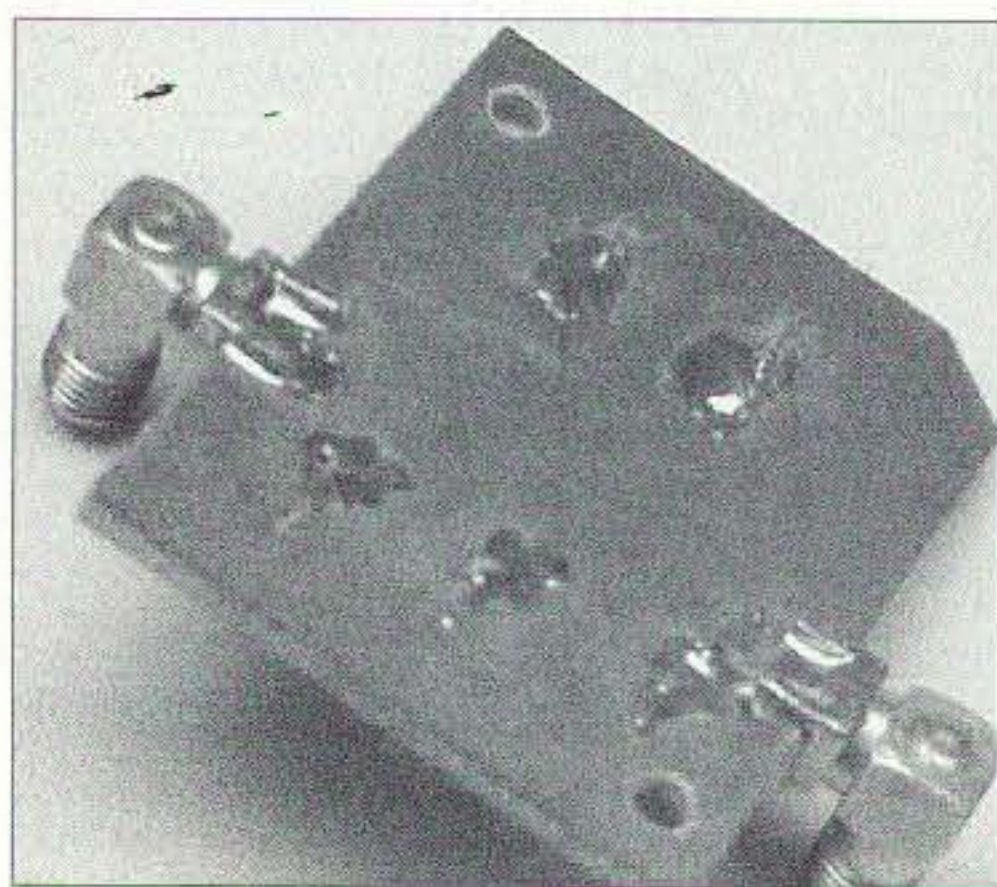*Fig. 4. Frequency response curve of filter 3, 3-pole, 5/16" spacing, interdigital configuration.*

Photo C. Bottom view of SMA connectors.

Fig. 6. Frequency response curve of filter 5, 5-pole, .100" spacing, interdigital configuration.

spacing, try both interdigital and comb configurations, and vary the number of elements until I obtained the desired bandwidth and loss.

I began by building a filter that I could easily test and analyze with our commercial generator. Both the frequency and level can be set accurately. The first filter I built resonated at around 450 MHz, well within the range of both the spectrum analyzer and the commercial signal generator. I plotted the data showing the performance of each filter after it was built. I made more filters that had different spacing, a different configuration, and a different number of elements. Plots of filter performance vs. filter type are shown in **Figs. 2** through **8**. See also **Photos A, B,** and **C**.

Figs. 2 and **3** show the difference between comb and interdigital configurations. Comb filters have about 3 dB more loss than interdigital filters for a
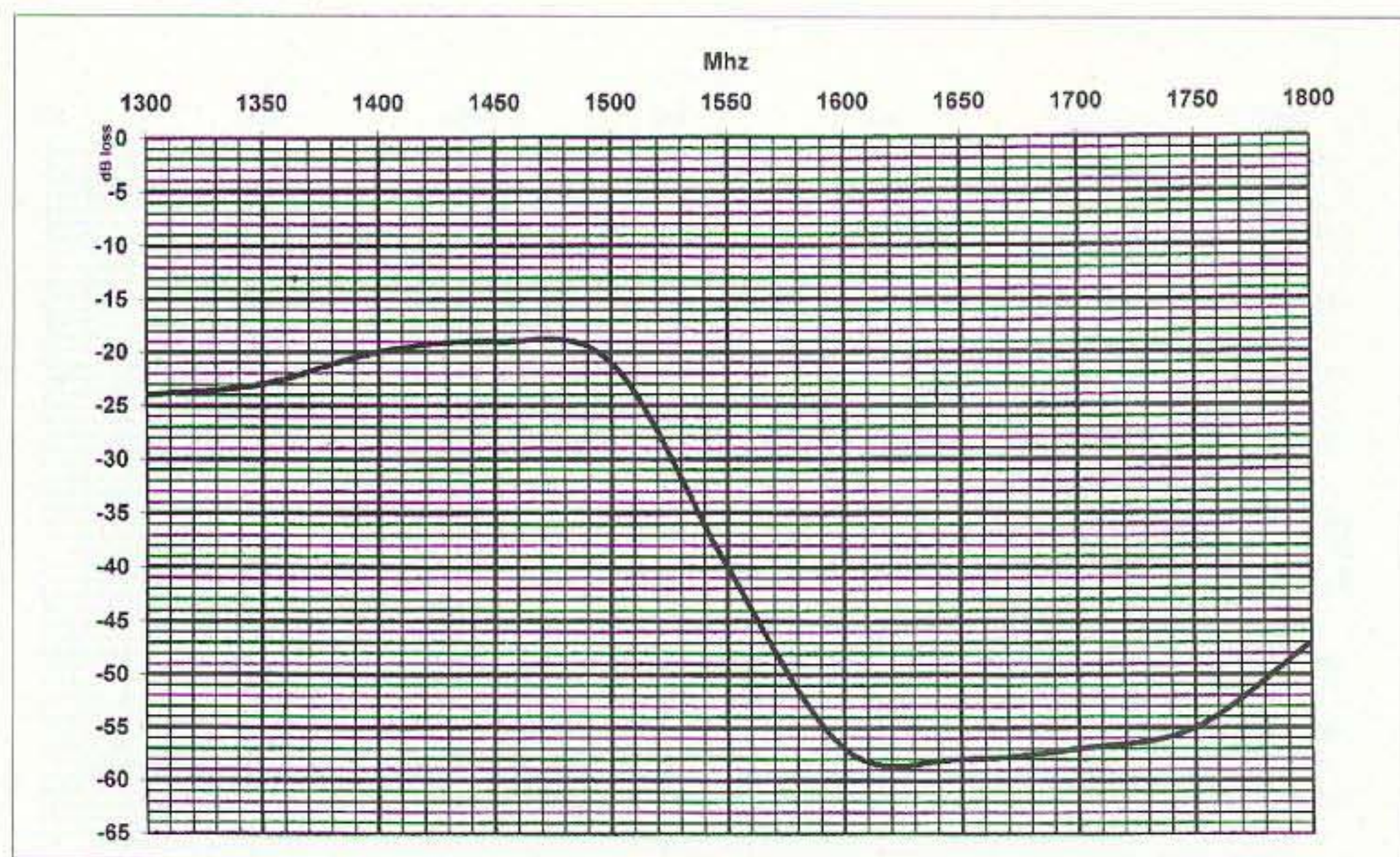
given spacing and number of elements. In **Fig. 4** the lines were placed farther apart. Note that the loss at the pass frequency is very high (-17 dB). In **Fig. 5** the number of elements was increased from 3 to 5. This change provided steeper sides, indicating more attenuation of undesired frequencies.

Fig. 6 shows a filter that has the proper spacing. It's an interdigital configuration and was purposely made too long so that it could be trimmed to resonate at the desired frequency (1691 MHz). After trimming, notice in **Photo B(b)** that the elements are no longer fully engaged. This showed up as more attenuation than I thought should be present (-10 dB), although the curve had the correct shape.

The only change to be made at this point was to change **Fig. 7** so that the elements were more fully engaged with the correct length. The finished filter performance is shown in **Fig. 8**. While the final design does have more loss than I thought my receiver could tolerate, it actually worked fine as-is for my application. Later I'll discuss how to reduce the loss of the filter. If you must change the length of a filter element a significant amount to get it exactly on frequency, don't forget to move the input and output lines to 1/3 the distance from the ground end. This will retain the 50 ohm input/output impedances.

Filter line lengths for the frequencies I tested are as follows: 450 MHz— 3.625 inches; 1400 MHz—1.00 inch; and 1691 MHz—0.85 inches.

Making the filters

To compose the filter artwork I used the Paintbrush software that comes with Windows 3.1, Win95, and Win NT. You will have to turn on the coordinates (X,Y) to provide information on the position and dimensions of the filter elements. Use zoom so you can see each grid square. You should also have the gridlines turned on. This software will give you 0.01-inch resolution, which is adequate for this type of filter work and most other PC artwork you may need.

Select black for the color, then begin clicking along the outline of the track you need. After this use "fill" (the icon
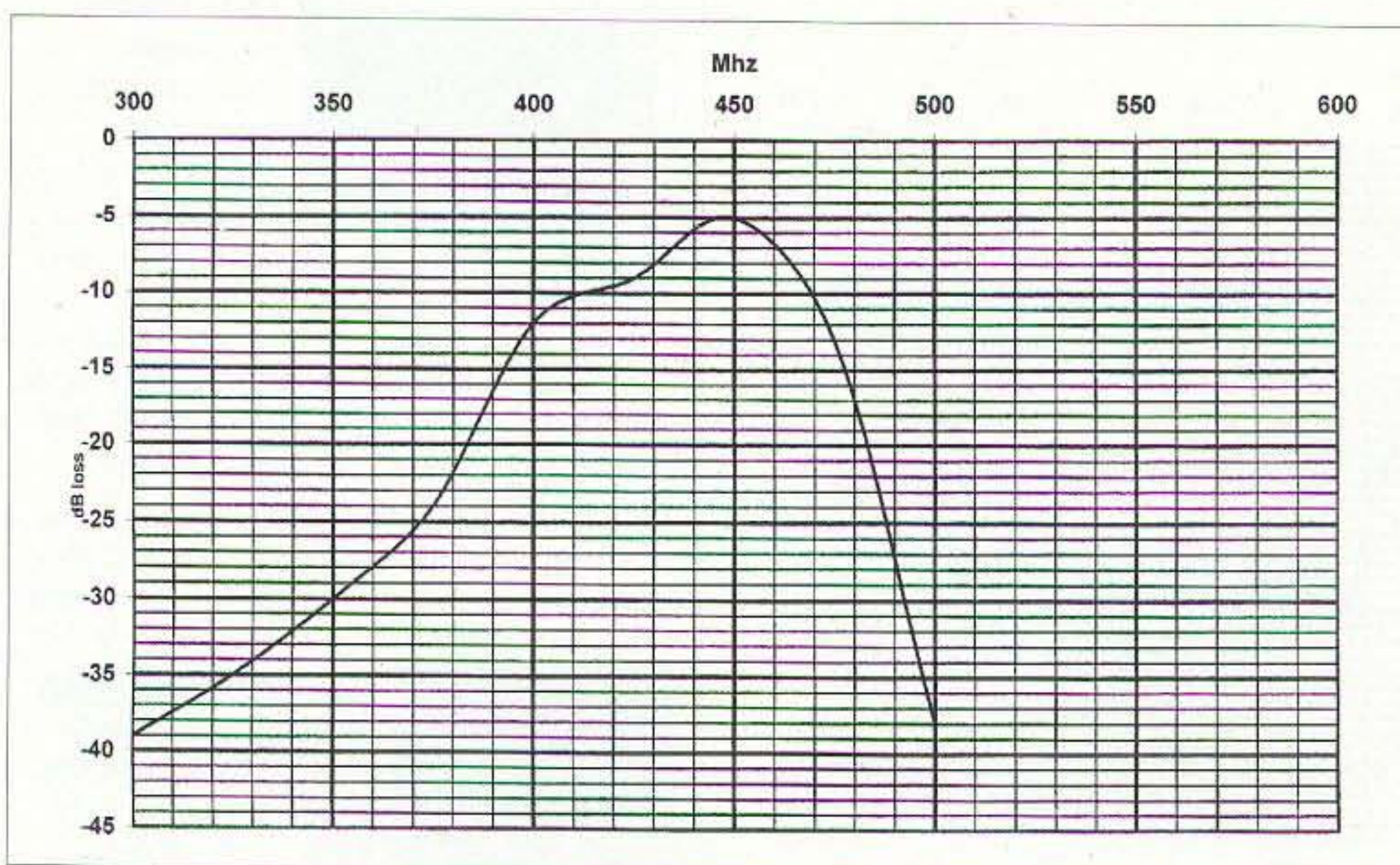

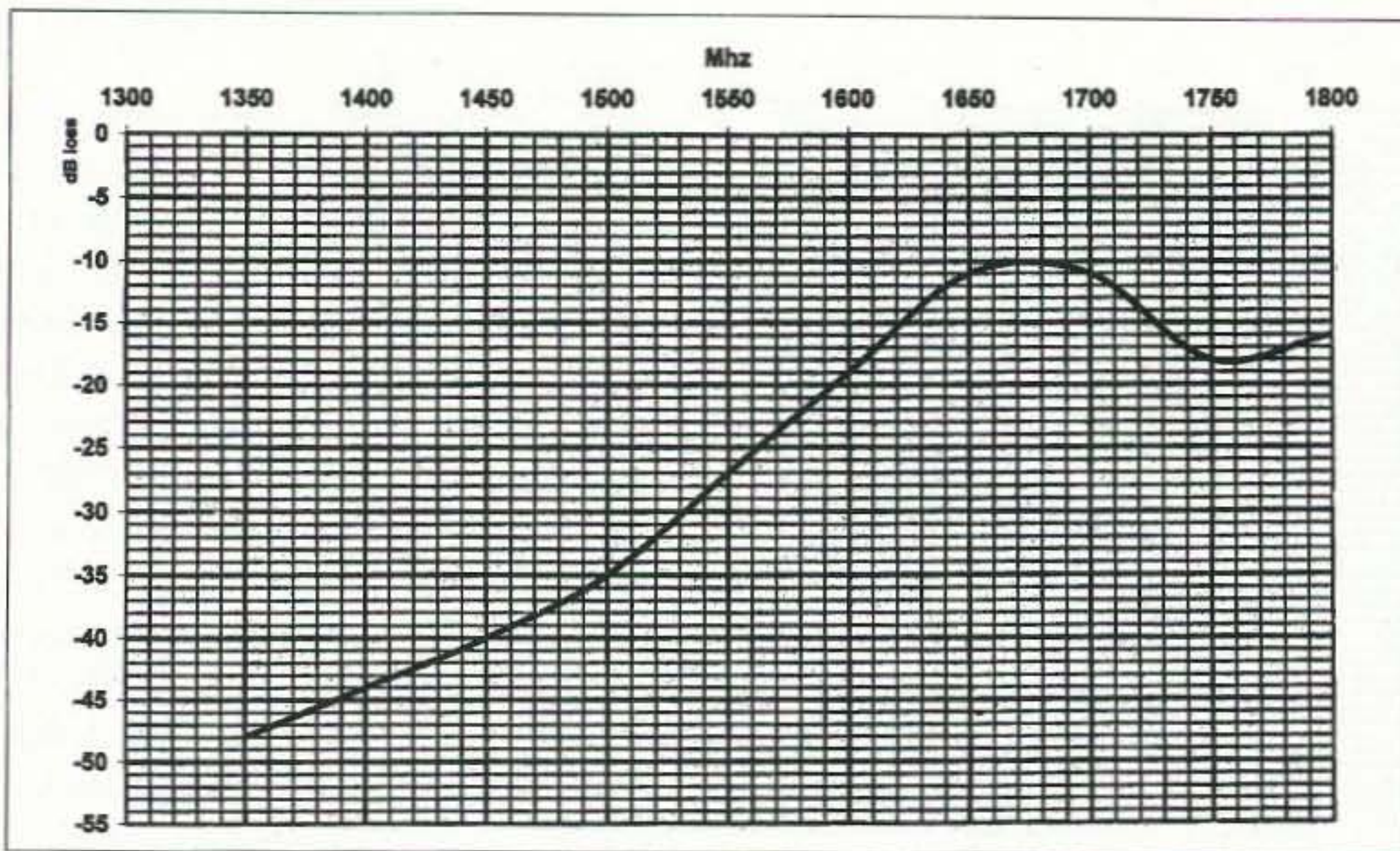Fig. 5. Frequency response curve of filter 4, 5-pole, .100" spacing, interdigital configuration.

Fig. 7. Frequency response curve of filter 6; this is filter 5 trimmed to peak at 1691 MHz.

looks like paint being poured from a can) to complete that section of track. Make sure the outline is solid, or else the entire image will be filled in. (Use "undo" if you missed a grid square.) You should start near one corner, working out from that corner toward the center of the work area. The software provides a 6.4" x 4.8" working area. I recommend starting at an even-numbered grid square, say 100,100. That way you can make the track width the required 0.100 inches.

The spacing will be what you determine to be best for your application, and the length will be what you need. Note the difference between the coordinates of the upper left and lower right of a given track, and that will give you track width and length. For example, assume the upper left is 100,100 and the lower right is 300,110. Subtracting the first point from the second, you can determine that the track is 2 inches long and 0.100 inches wide. I recommend putting a single line "test pattern" near the edge of your board (away from the filter elements) that is exactly 1 inch long and has a short perpendicular line at each end. This test pattern is shown in **Fig. 9**. If this line is exactly 1 inch long on your printed artwork then the rest of the artwork is accurate. If not, then the rest of your artwork is wrong. Verify that you have the scaling set to 100%.

I used Press-n-Peel to transfer the artwork to double-sided board. This

product is very easy to use. It requires that you have a laser printer to print the track image on their special media. See Ref. 5. (I've used Press-n-Peel to make these filters and several other boards and only had problems the first time.)

After printing the track onto the special media, use a common clothing iron to transfer it to double-sided copperclad board. I've used both the paper-based and the blue plastic film
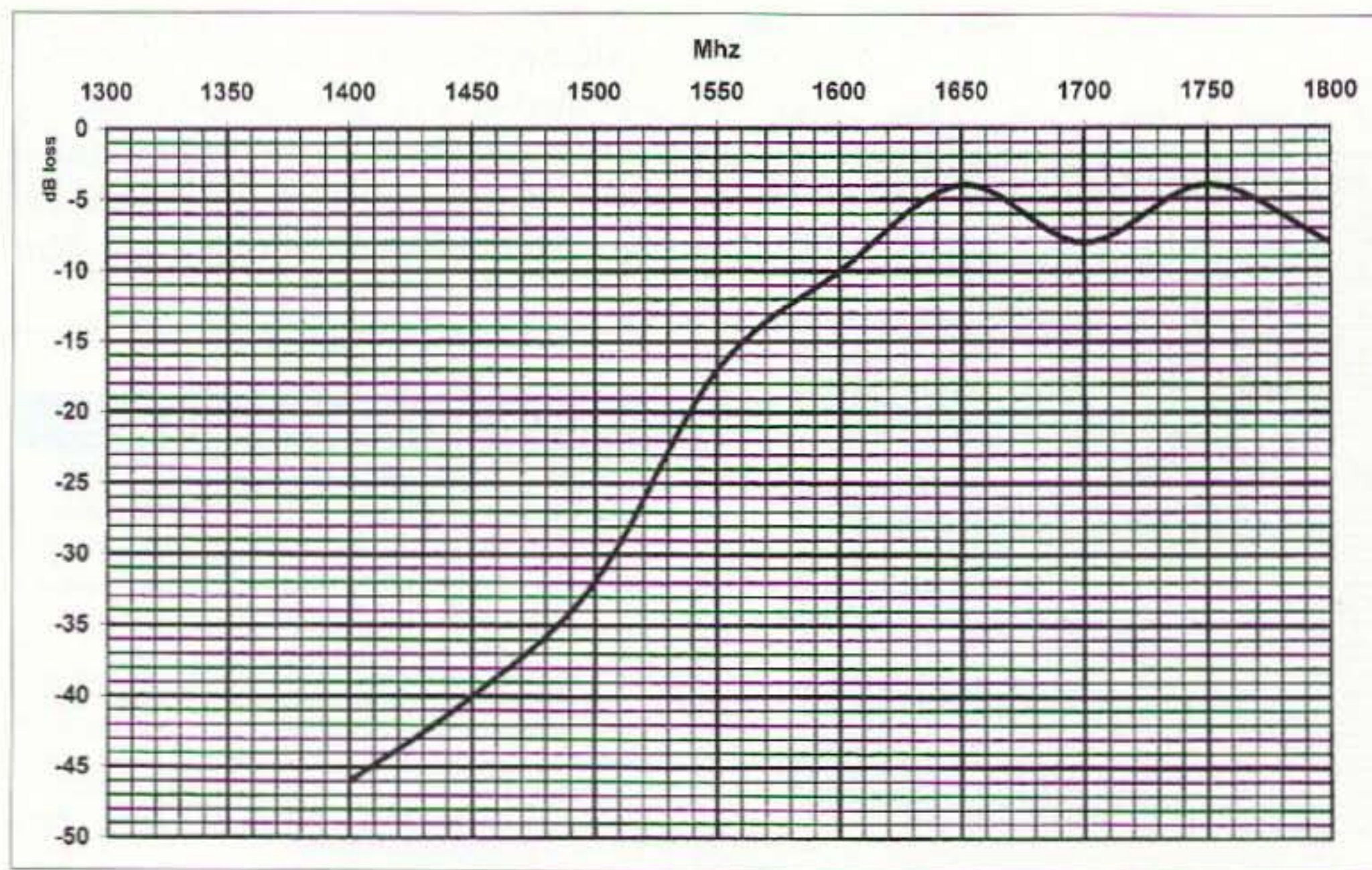
Fig. 8. *Frequency response curve of filter 7, 5-pole, .100" spacing, interdigital configuration.*

types, and prefer the latter. I use Scotch/3M Super 33+ electrical tape as a resist for the ground plane. Handle the board very carefully when attaching the tape. The track resist on the filter side can come off if you scratch it too hard. I used etchant from Radio Shack that I heated with a 100 watt spotlight held about 6 inches above a small plastic tray. Please *don't* pour the used etchant down the drain! It will eat metal (it ate the copper from your board, right?), so must be discarded properly at a hazardous material handling station.

To ground the one end of each filter element, I drilled a small hole (0.044-inch-diameter), pushed a small wire through, bent the wire over on both sides, and soldered it on both sides. Make sure that you are drilling all holes the same distance from the ungrounded end, or else the lines will be a different physical and electrical length, thus spoiling the shape and performance of the filter.

I don't know how close the end of each element can get to the edge of the board before filter performance starts to suffer. I used a minimum 1/2 inch spacing all around the board.
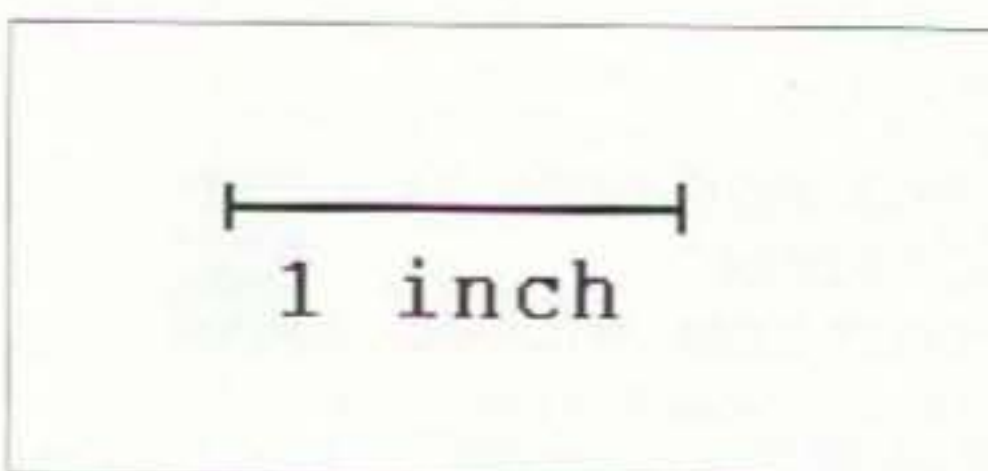

Fig. 9. *Printer scaling test pattern.*

Testing the filters

Connect your signal generator to the spectrum analyzer and adjust the level of the generator (if yours is adjustable) until the display reads nearly full scale so you can use the full range of the analyzer. Then insert the filter to be tested in line between the analyzer and generator. Vary the frequency from the lowest to the highest frequency of interest. The lowest should be well below the "image" frequency of your converter if you are building a lowside injection converter.

The range over which you test the filter should include all frequencies you want to reject and pass. In my case, I wanted to pass 1691 MHz and reject 1416 MHz, since 1416 MHz is the "image" of 1691 MHz. The image frequency is two times the IF lower than the frequency you want to receive. [My IF is 137.5 MHz; 1691 - (2 x 137.5) = 1416.] Plot the frequency vs. level output every 25 MHz (more or less, depending upon what kind of resolution you need on your filter's performance).

Note that the level without the filter in line is the starting level. All the data points with the filter in line are below the starting level (negative dB). The filter ideally would have no loss (0 dB) at the center frequency and lots of loss (-40 dB or more) away from the center frequency. Plot the data points you took using axis scales as shown in **Figs. 2–8.** The plots shown here were

made using Excel software and data I recorded manually.

The HP generator I used only goes up to 1100 MHz. I needed a filter that operates at 1691 MHz, and I needed to test it well above 1691 MHz. To test above 1100 MHz, I used a POS-2000 VCO from Mini-Circuits (Ref. 6). The VCO costs $20 (plus handling/shipping) and covers 1300 MHz to 2000 MHz with about 15 milliwatts output power. They make very good, rugged VCOs. They are all 50 ohm output impedance and cover frequencies from 10 MHz to 2000 MHz. Obtain the data sheet that covers the unit you use. They are tuned over the range with a pot as shown in **Fig. 10**.

You'll also need to design a simple circuit board for this "generator." The VCO's pins are all on 0.100" centers, so the layout is very simple. I recommend getting a copy of their *RF/IF Designers Handbook* and *VCO Designers Handbook.* See Ref. 6. They have extensive and very useful theory and practical design and construction information on various types of microwave components.

I used SMA-type connectors to couple signals in and out of the filters. I bought used ones at a hamfest for $1 each. New ones cost $10. They mount on the edge of the board as shown in **Photos C** and **D.**

Summary and other changes

As you can see, I built a lot of filters. By keeping characteristics that helped performance (0.100-inch instead of 5/16" spacing, using an interdigital instead of comb configuration) and discarding ones that hurt performance, I was able to get close to the desired bandwidth and loss.

You will need access to a spectrum analyzer and a VCO at a minimum. If you don't own an analyzer, perhaps a broadcast engineer at a local TV/FM station (hopefully a ham) can let you use theirs. The VCO is adequate for the home experimenter. Of course, a generator is easier to use.

These filters are not made for transmitting applications. I don't know how much power they can handle, since my application was for receiving. I didn't have any equipment to measure SWR,
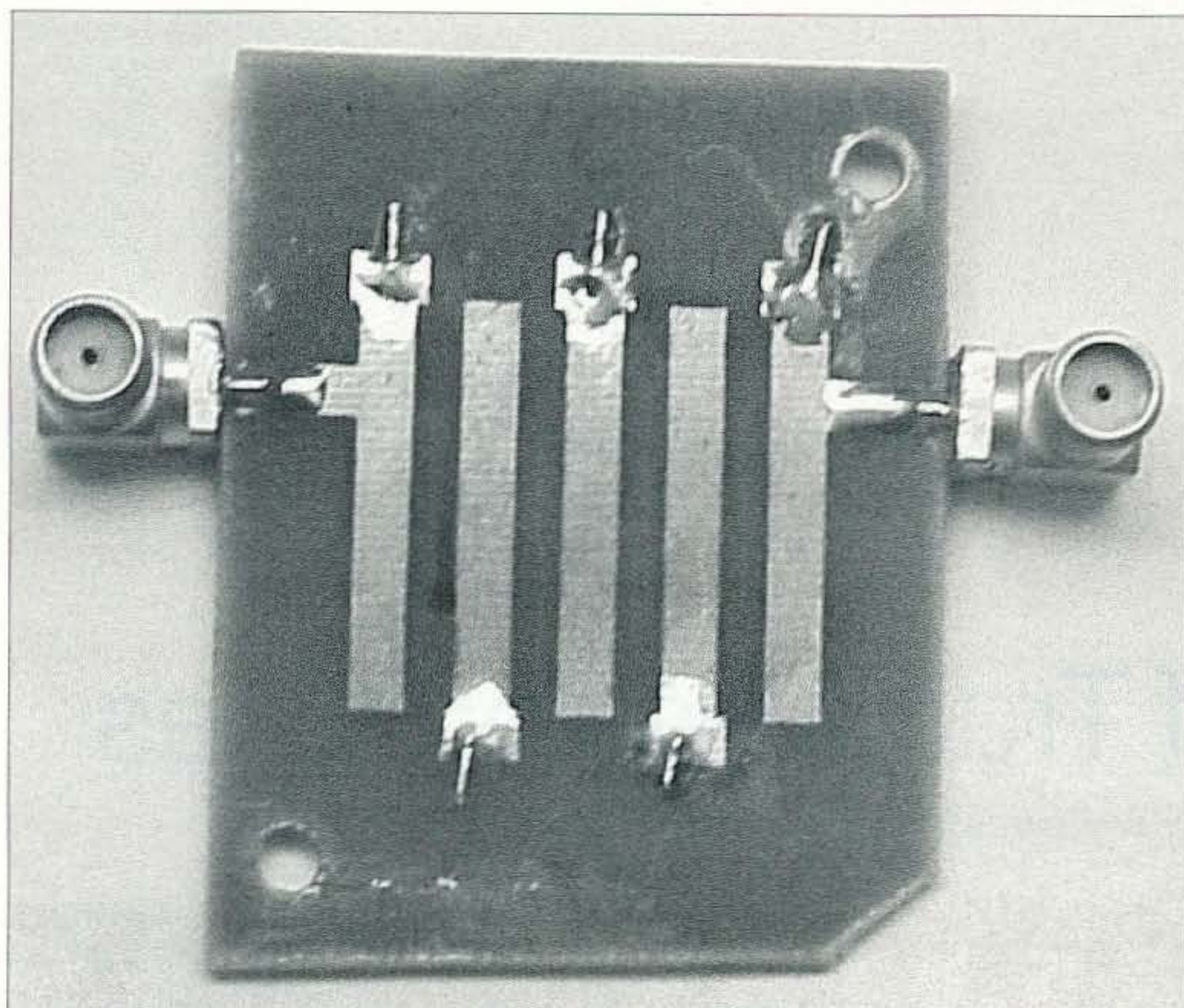
Photo D. *Top view of SMA connectors.*

so I couldn't determine the input and output impedances. They may be slightly different from 50 ohms and may be reactive (capacitive or inductive).

Tuning capacitors can be added at the ungrounded end of each line in the filter to allow the center frequency and passband to be varied or if you want to tune the filter exactly on the desired frequency. If you want to experiment with this feature, make sure you use high quality piston-type capacitors. Be aware that they are not cheap! I bought some at a hamfest just in case I needed them. They were $5 each. That's $25 for a five-element filter! I prefer to make the passband a little wider than I

really need—This ensures that the frequency you want to pass unattenuated will be in the passband. At the higher frequencies (over 1000 MHz), only a few picofarads of capacitance is needed to move the frequency of each line many megahertz. To increase the bandwidth by a large amount, the lines should be stagger tuned (each line is tuned to a different frequency so the overall response is a summation of the individual responses). This requires a tracking sweep generator that allows you to get an instant picture of the filter's response curve. I understand that tracking sweep generators are quite rare, so if you have access to one,

consider yourself very lucky! The alternative is to use your existing setup and plot the results of each tuning adjustment you make. Obviously, this requires infinite patience and good data taking/analysis skills.

The cost of materials is very low. Double-sided 0.062" glass epoxy circuit board is available at larger hamfests. The Press-n-Peel is the most expensive item you'll have to buy. It runs around $1 for an 8-1/2 x 11 sheet. If you want to be real cheap (okay, conservative!), you can use part of a sheet of the Press-n-Peel taped to a full-sized sheet of regular printer paper. Run a test on regular paper to see where to tape the Press-n-Peel. Put this "carrier" paper in the printer paper bin and print your artwork.

I enjoyed making the filters, analyzing the data, and learning how each variable affected filter performance. If you decide to try the techniques described here, please write me and let me know how you did. I would enjoy hearing from you and am willing to provide help and share all my notes. Please send an SASE (thanks!)—I'll cover all the copying costs.

Many thanks to my wife Yvonne for proofreading the text of this article.

References

1. *Ham Radio Magazine,* Dec. 1975, pages 46–49.

2. *ARRL Microwave & UHF Experimenters Handbook,* pages 8-31 and 8-32.

3. *RF Design,* Aug. 1995, pages 95–102, "Filter Synthesis & Analysis Program," software listing in article.

4. *RF Design,* Mar. 1989, pages 56–57, "A Parallel-Coupled Resonator Filter Program," software is $25.

5. Press-n-Peel is available from Techniks, Inc., P.O. Box 463, Ringoes NJ 08851; (908) 788-8249.

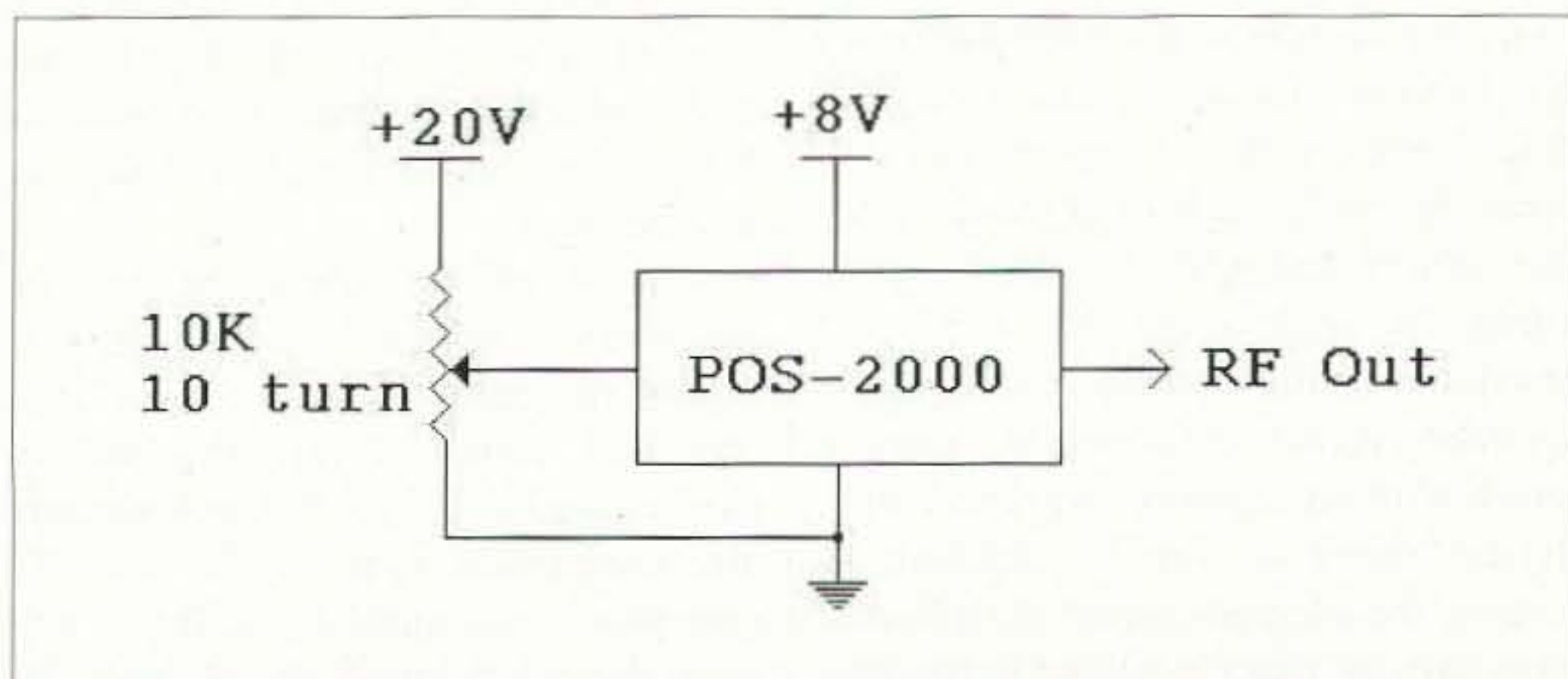6. Mini-Circuits, P.O. Box 350166, Brooklyn NY 11235-0003; (718) 934-4500; [www.minicircuits.com]. 🔳

Fig. 10. *VCO schematic.*