Theory and Practice

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Norman H. Crowhurst, P.E. is a prolific writer on all things electronic. His byline has appeared in nearly every periodical on electronics and he has authored many textbooks on engineering and mathematics. His distinguished career as an engineer spans several decades. An authority on both sides of the theory and practice fence, Mr. Crowhurst has both the insight and the credentials to bridge the gap between these two poles.

● Much of what I have written over the years has concerned the relationship between theory and practice. A common viewpoint regards theory and practice as mutually irreconcilable: theory is one thing, practice another. The man of theory has his head in the clouds, the man of practice does what he knows from experience will work.

Of course, recent scientific development has served to prove otherwise, to an extent. The best known example is the atom bomb: theory developed this new weapon which, when made, "worked." The transistor and many electronic devices are examples less widely known. But in every-day electronics, including audio, we have countless examples where theory and practice still appear to be contradictory to many of us.

It is in these examples that this column will take an interest. Actually, *true* theory is never wrong. *Incomplete* theory is what practice often proves wrong. Disregarding details thought not to be important leads to an erroneous result; the thing thought negligible wasn't!

Articles and chapters I've written on matching have brought responses from theorists, telling me that my references to standard definitions are incorrect, particularly regarding the quantity called *insertion gain*. They infer that my practical slant is at variance with EIA and IEEE definitions.

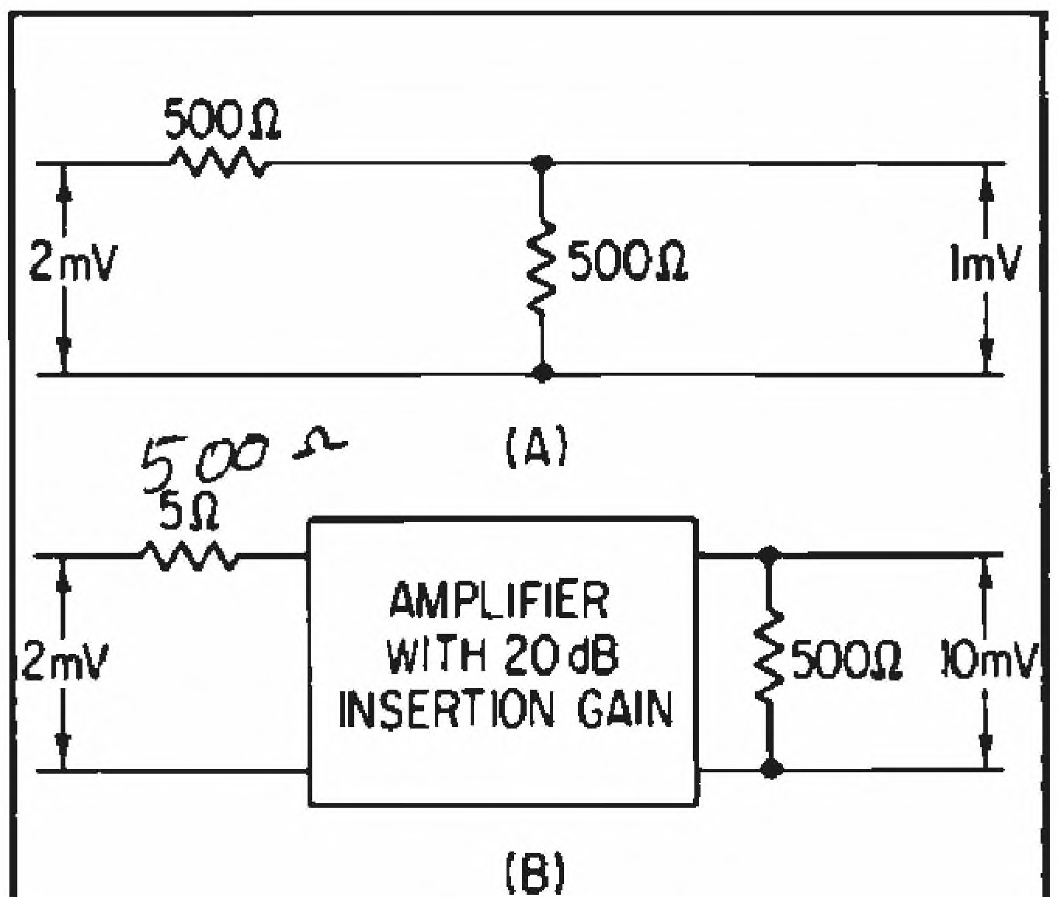

Figure 1. The definition of "insertion gain": (A) transfer between two impedances; (B) gain when amplifier is inserted between them.

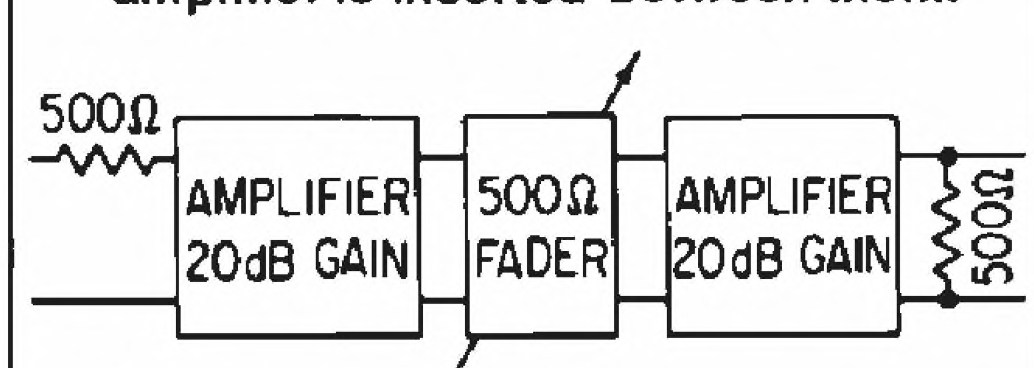

Figure 2. The situation explored in this column to show various deviations that can occur.

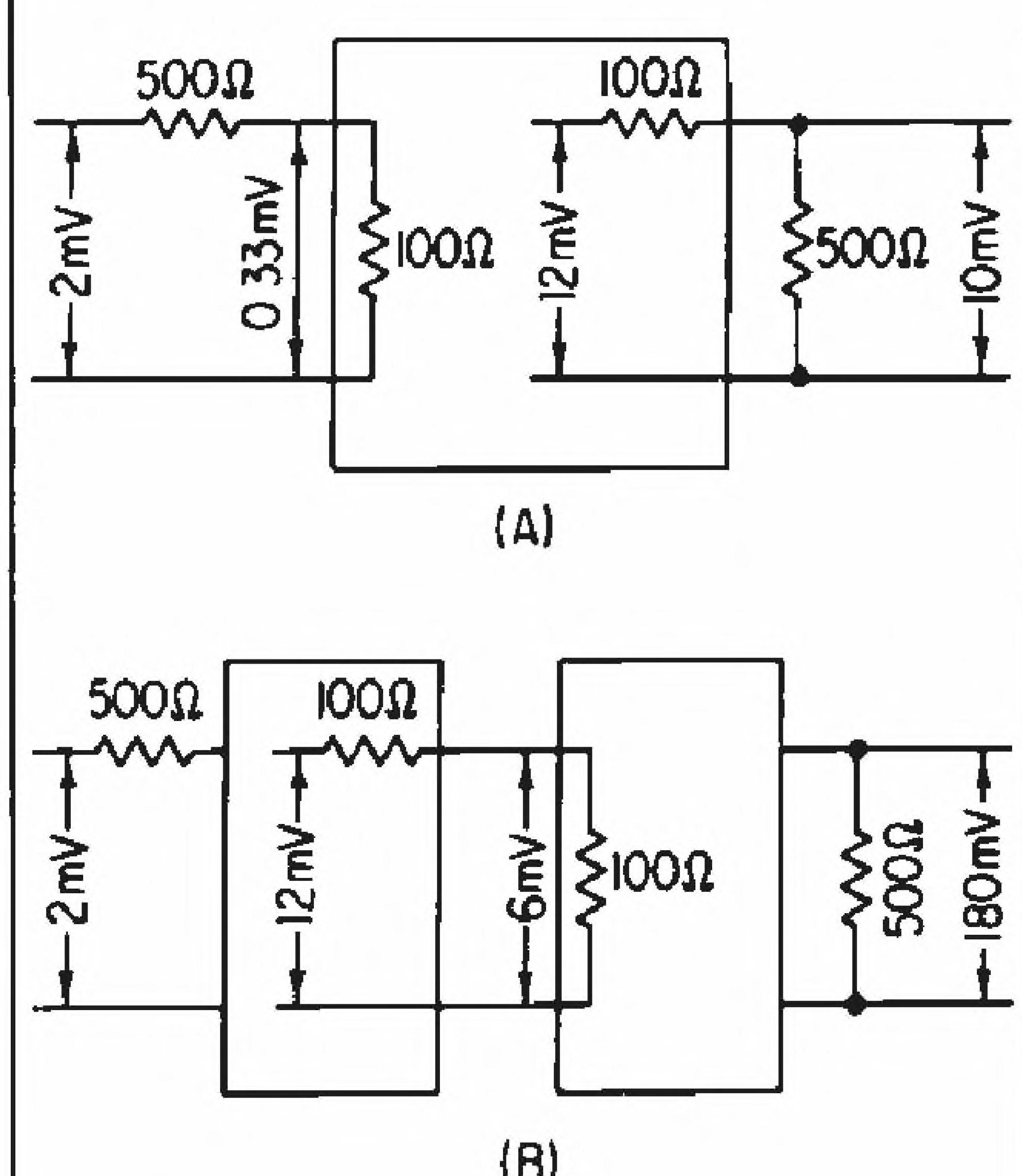

Figure 3. One deviation: both internal impedances are one fifth nominal. (A) what this means in terminal-input and open-circuit output volts; (B) the cascaded combination, showing how 5 dB extra gain appears.

For several years I was a member of the committees of these institutions that produced the now-accepted definitions of insertion gain. A lot of time was spent around the table, trying to make the wording more meaningful and "foolproof." We believe we did a good job.

This problem, like most theory and practice dilemmas, can best be understood by example. We'll assume that a unit we're going to use in a variety of circuit positions is a line amplifier with an insertion gain of 20 dB. Input and output impedance are both 500 ohms. By definition, this means that inserting this amplifier between the source and load impedance, each of 500 ohms, will raise the output level by 20 dB, or 10 times.

Without the amplifier in circuit (FIGURE 1A), a 2 mV input through the source impedance of 500 ohms will produce 1 mV across the output load of 500 ohms. Put the amplifier between them (FIGURE 1B) and the output at 500 ohms will now get 10 mV. By definition, and in fact, this is an insertion gain of 20 dB.

We naturally assume that the input is still 1 mV. But it may not be. The specified method of measurement requires that the voltage at the input end of the 500-ohm input resistor still be 2 mV. Whether the input to the amplifier is still 1 mV depends on whether, as well as working from a 500-ohm source, its own internal input impedance is 500 ohms.

But isn't this the same thing? No, it isn't! The rated input and output impedance of amplifiers refers to the impedances to which they should be connected, which may or may not be the same as the measured internal impedances of the amplifier itself.

In a tube amplifier, the input is a grid. To achieve a line-impedance input, a transformer is used that will give as much step-up as feasible from the 500-ohm source impedance, consistent with a specified frequency response requirement. The internal impedance, reflected back to the transformer primary, is unlikely to be precisely 500 ohms. It may be much higher, at most frequencies.

In a transistor amplifier, the impedance at the input is more readily controllable than in a tube amplifier, but this does not guarantee that the designer chose values to achieve precisely 500 ohms as input loading, as well as achieving satisfactory operation *from* 500 ohms.

The output is even more likely to possess this difference. Voltage feedback is generally used, operative at its nominal value when the nominal output load is connected. From this, the facts of life make the source impedance at the output much lower than the load impedance. On the other hand, if current feedback instead of the voltage variety is used, the source impedance will be higher than load impedance.

At the output end, the only way to achieve correct matching, in the academic sense, is to divide the feedback between voltage and current forms, so the resulting impedance agrees with the

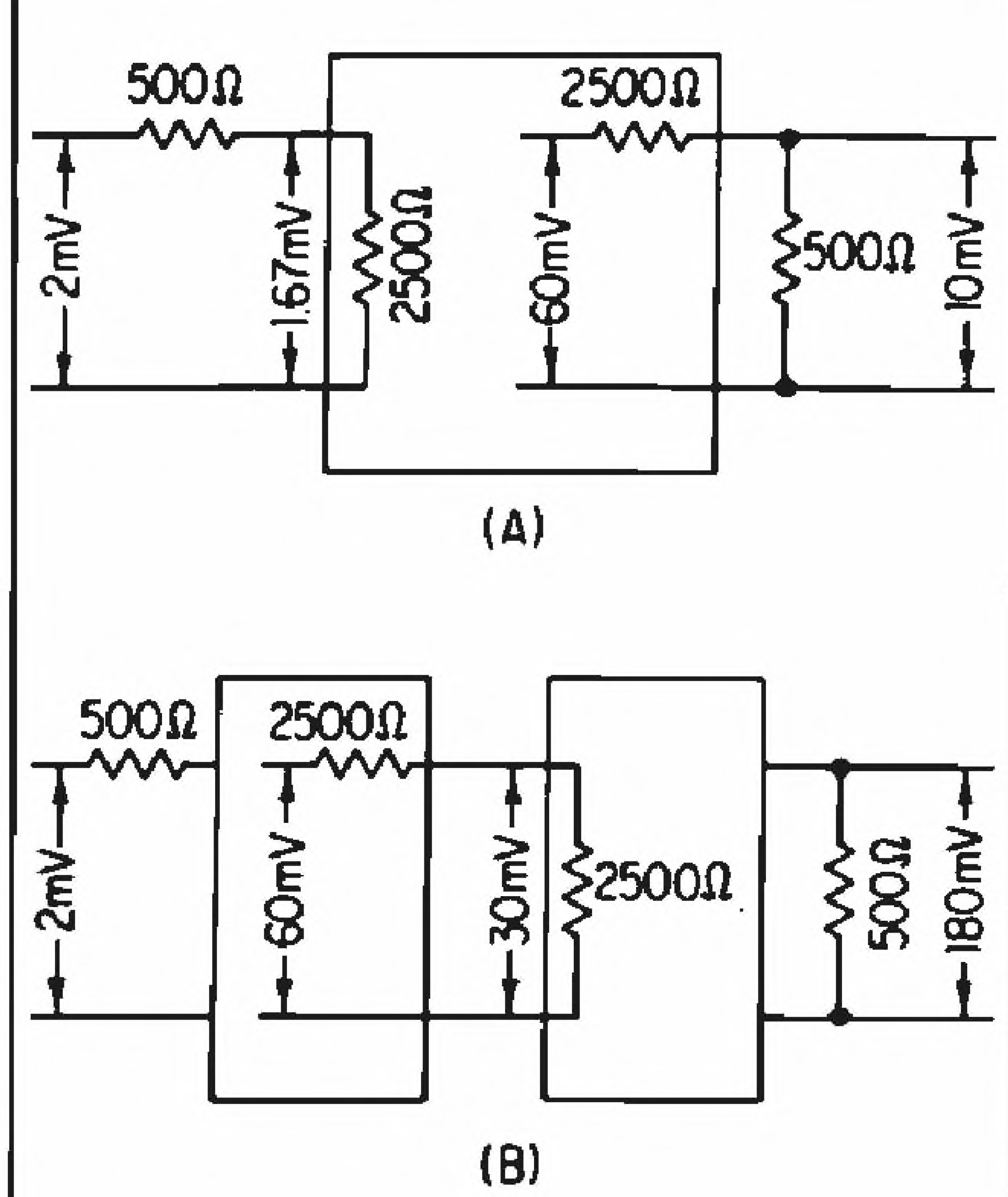

Figure 4. Another deviation: both internal impedances 5 times nominal. (A) effect on one amplifier; (B) over-all effect.

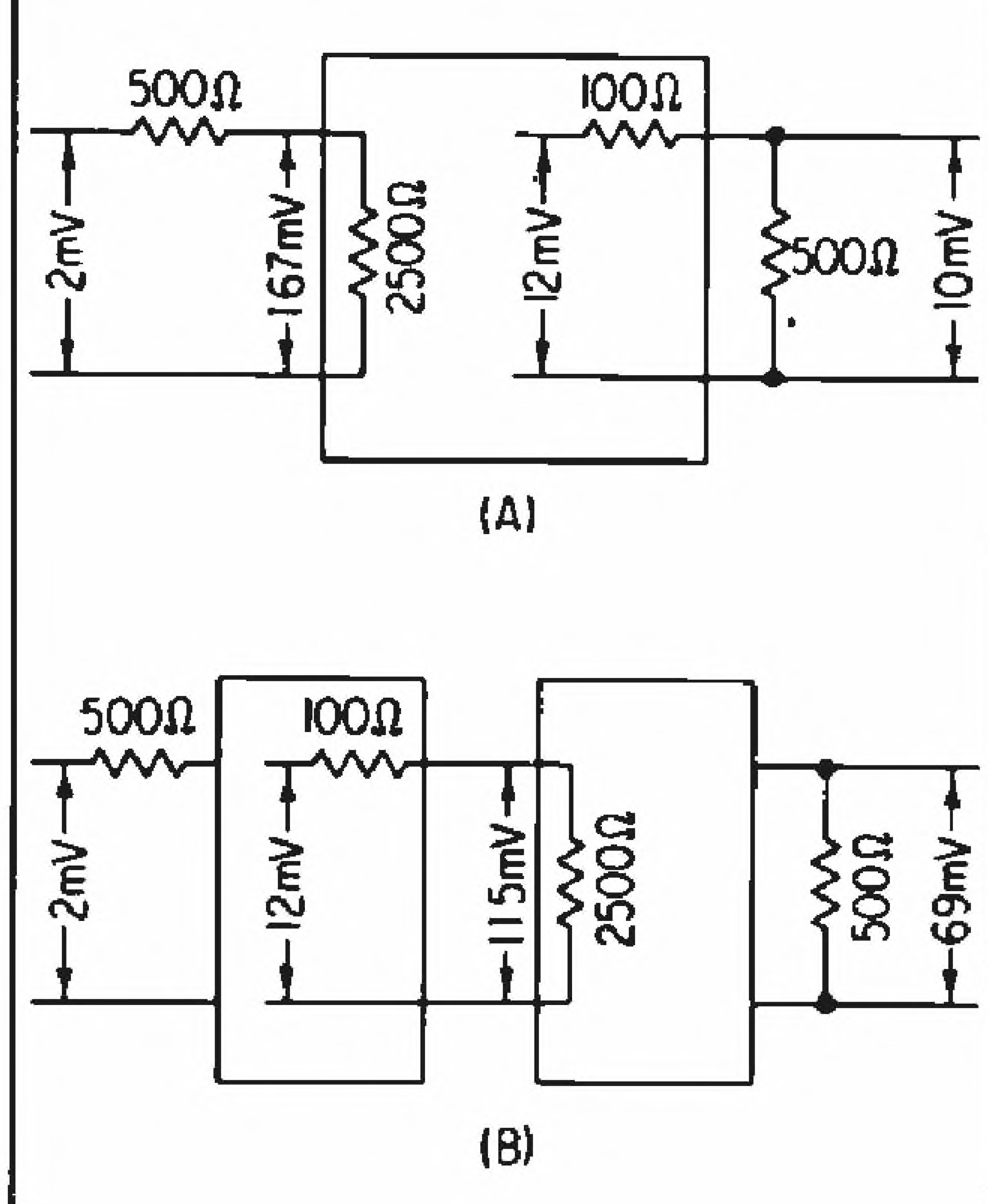

Figure 5. A third deviation: input 5 times, output one fifth nominal. (A) effect on one amplifier; (B) over-all effect.

nominal load. Many amplifiers in service were not designed that way!

Let's use some figures to see what this means. Assume we cascade two of these amplifiers, with a professional gain control (fader) between them (FIGURE 2.) The input and output impedance of each of these line amplifiers may differ from the nominal load of 500 ohms for which they are designed. Let's assume each internal impedance may be either 100 ohms or 2,500 ohms.

At input and output of the whole combination, where we have shown true 500-ohm termination, it doesn't matter what the internal impedances are, because any difference from nominal is taken into account in the way insertion gain is measured and specified. But the connection between the two amplifiers can be seriously invalidated, especially when all attenuation is removed by running the fader all the way up.

Let's continue the assumption that the input is 1 mV (or to be precise, 2 mV through the 500-ohm input resistor): if all impedances have their nominal value, the output of the first amplifier, connected to the input of the second, will be 10 mV, and the output of the second will be 100 mV.

Now suppose the internal impedances both at inputs and outputs are 100 ohms. The first amplifier, instead of being loaded with 500 ohms, is loaded with 100 ohms. Removing a true 500-ohm load would allow the output voltage to rise from 10 mV to 12 mV (FIGURE 3). Then connecting an actual load of 100 ohms, to match the internal value, will load its output down to 6 mV.

The 20 dB gain of the second amplifier (to give 100 mV output) assumed an input actually measuring 100 ohms was connected to a 500-ohm source, with an actual input voltage of 20 mV. So the voltage at the input terminals, to give 100 mV output, would be 3.33 mV. Now our actual input voltage is 6 mV. So the output voltage will be 100 mV multiplied by 6/3.33, or 180 mV. We have 5 dB more gain than we're supposed to have.

Next let's assume both input and output impedances are 2,500 ohms (FIGURE 4). The actual input voltage, instead of being 1 mV, will be 5/6 of 2 mV, or 1.67 mV. And the output voltage will be 60 mV open-circuit, to load down to 10 mV with 500 ohms. So 2,500 ohms will only load it down to 30 mV.

Had the source for the second amplifier been 500 ohms, the actual input voltage would have been 16.7 mV, to produce 100 mV output. So 30 mV input will produce (30/16.7 x 100=) 180-mV output; just as in the other case, this is 5 dB extra gain.

Finally, let's assume the output impedance is 100 ohms and the input impedance is 2,500 ohms (FIGURE 5). As in the second case, the actual input voltage will be 1.67 mV. The open-circuit output voltage will be 12 mV, as in the first case. The actual output voltage will be 25/26 times 12 mV, or 11.5 mV.

To get the nominal 100 mV output from the second amplifier, the input should be 16.7 mV. So 11.5 mV will give about 69 mV output. A loss of 3.2 dB from the nominal 100 mV.

Now let's think about what the fader will do. With about 20 dB attenuation, it will present close to its nominal impedance at both input and output, so the nominal condition is closely approached. Over-all gain will be close to 20+20—20=20 dB. But as attenuation is removed, the gain will change by the amounts calculated just now.

Where both input and output impedance err from nominal in the same direction (both high or both low) the last few studs of the fader will change gain by more than they're supposed to do. If the fader is designed to insert 1.5 dB per stud, it will more likely become 3 dB or more on the last stud or two.

On the other hand, where input and output impedance err in opposite direction (input high, output low, or *vice versa*) the last few studs will seem to be almost inactive. The 1.5 dB per step nominal may drop to less than 0.5 dB.

Does that explain some unpredicted gain problems you may have encountered at some time? That discrepancy is the simplest consequence of this effect. Next month, we will discuss other consequences, such as changes in frequency response or increase in distortion that can come about at the same time.

Meanwhile, please don't write to tell me that I'm misjudging the standard method of specifying insertion gain. Or that manufacturers' ratings are deceptive when their internal input and output impedances don't match their nominal values. The problem arises because we have so many variables that it's difficult to specify them all without causing confusion. The only solution is a little better understanding of the theory!

Beyond this, I have several ideas of my own to discuss in future columns. But many of the ideas are going to come from you, the readers. It takes a couple of months between the time I work the idea up and you read it in print. So start the questions coming if you want to see yours answered soon!

Letters

The Editor:

Your editorial in the January issue of **db** interested me and brought back memories. I realized that when we moved to this country (in 1953) one of the "translations" I had to make (like *tube* for *valve* and *wrench* for *spanner*, not to mention *sidewalk* for *pavement*), was *public address* for *sound reinforcement.*

Yes, as early as 1933 I was employed by a British company that specialized in two kinds of service: sound reinforcement and sound relay. Each had its own problems. Sound reinforcement intensified sound in the same room. Relay carried sound into other rooms and buildings.

Back in those days there were *lousy* installations, but the cause of the lousiness was usually failure to accommodate to the acoustic problems. The British would never have tolerated the raspy quality that Americans accepted in the name of public address.

At that time I could not have said that we British never used public address, only sound reinforcement. Americans wouldn't have known what I meant. Few had heard sound reinforcement. To try to explain (as you did in your editorials) would have sounded so dreadfully snobbish. But eventually the viewpoint has changed. Now, here too, the public will no longer accept high distortion.

I don't remember the date when St. Paul's Cathedral first installed line radiators with a time-delay system, to overcome the building's appalling reverberation problem, but it was before we emigrated. That was a problem triumphantly solved by sound reinforcement.

However, I suppose the main reason I could not have insisted on use of the term sound reinforcement then was the number of operators, scattered across this country, who knew nothing better than public address, as you so succinctly describe the distinction. And **db** would have been completely beyond them!

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