THE USE OF ARITHMETIC IN RADIO-TV

REFERENCE TEXT 27X

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THE USE OF ARITHMETIC IN RADIO-TV

YOU need not read this book unless you want to! You can complete your course and obtain A's all the way through, even if you never read it. However, if you do decide to go ahead, you will find not only that arithmetic is interesting and even fascinating at times, but also that you use it in your everyday life much more, perhaps, than you realize.

When you buy a twenty-five cent item in the ten-cent store, you may hand the clerk a one-dollar bill and receive seventy-five cents in change. Most of us like to check on our change to make certain that the sales person does not make a mistake. Therefore we usually perform the very simple mental arithmetic of subtracting twenty-five cents from one dollar and finding that it leaves seventy-five cents. Similarly, you perform simple addition when you look at the money in your hand and mentally add up the fifty-cent piece, the two dimes, and the nickel, which constitute your seventy-five cents change.

As a matter of fact, you are actually using that rather fearsome sounding tool known as decimals, in your everyday living! We're not going to discuss decimals here, but we shall later. You've probably forgotten the fact that when you see a price ticket marked $2.50 you do not think of it as "two and fifty-hundredths dollars," you unconsciously interpret it, and know it means two and a half dollars.

Every time you add up your income for your income tax or do anything at all with money, you're working with a *decimal* system. Later on we will give you some rules for handling decimals and working with them. When we come to that point, you may be surprised to realize that you knew it "all the time," but just didn't realize how simply your daily experiences of living with decimals can be applied to calculations.

In your work as a serviceman or a communications technician you will find you hardly ever need to make a calculation. If you're repairing a receiver and have to replace a part, you will find the correct value from the service instructions, or from the value of the defective part. About the only times you will need to make any sort of calculation are if you are designing some new equipment or working out some new ideas for apparatus to be used around your shop, or in replacing a part that has completely disintegrated beyond recognization. However, it is always useful to be able to make these calculations if necessary. As you will see as you go through this book—that is, of course, if you decide to read it—many of the calculations for radio and television can be made mentally. At least, quickly calculating mentally, in the way we will show you later, can usually give you a sufficiently close idea of the value required, and avoid the need for any very precise figuring.

Even the operator-technician in the communications field has very little use for even simple arithmetic, once he has obtained his license. Anyone looking through the study guide to the FCC licenses could not be blamed for thinking there are a tremendous number of questions involving arithmetic, but actually, this is not so. As a matter of fact, out of the scores of questions in any particular element in the examination, you are asked only fifty questions, and out of this number only a few of them involve any calculation! Even then, you don't have to answer every single question. If you can get a grade of 70%, you can pass the examination.

With all these things in mind, we at NRI prepared this book for you purely as a *reference text*—to be referred to if you want to review the fundamentals of arithmetic. You can use this book not only in connection with your course, but also, in connection with your everyday living and it may even help you figure out your income tax—or any of the other deductions, such as social security, which are made from everybody's pay checks.

As we said at the beginning of this introduction, you do not need to read this book to get all A's on your course, and you need not study it except as a source of information that goes beyond that contained in the lessons. You can understand how radio and television receivers and equipment work without being able to perform even simple subtraction and addition. But if you read on into the book, you may be surprised at how much you have missed by letting long words scare you!

Simple Arithmetic

ADDITION

Usually we do not have any difficulty in adding up a few numbers. Of course, sometimes, such as when we go for the weekly grocery supplies we have quite a long column of figures to check. But generally our addition involves only a few things such as a lunch check consisting of three items —coffee, hamburger, and ice cream. We are so used to adding up these figures and checking them mentally to make certain that we get the right change, that we do it without thinking—that's mental arithmetic.

However, we may be working with a voltage-divider network in a television set that has as many as nine sections. This could involve a long column of large numbers such as is shown below. Let us assume that we have measured each section, in turn, on a very accurate resistance bridge and now we want to know the total resistance. We might, of course, measure the resistance of the entire unit, but there may be practical reasons why we cannot do this. So we find it necessary to total, or add up all the figures. To do this, we set the figures in a column and proceed to add them like this:

```
      5 3 5
      4826
      2958
      8277
a)    3936
      5729
      9127
      6344
      7413
      1662
     -----
     50272
```

```
        52
b)      32   check
        49
        45
     -----
     50272
```

To start adding this column of figures we commence with the right hand column—this is often known as the "units column." As a way of saving time and mental effort as we add up figures we don't say "two plus three are five, plus four are nine," and so on. We mentally add the two and three and say "five."

We add this to the next figure and mentally say "nine," and so on up the column. As a matter of fact if you are alone or in a place where your adding is not likely to confuse anyone there is no reason why you shouldn't (while adding by inspection, as this process is often called), say aloud the sum of the numbers you add. But you should remember, that, as with reading, you do not acquire speed and proficiency by working aloud.

In the last paragraph we referred to the extreme right-hand column as the "units column." As we move toward the left, the next column is the "tens," the next the "hundreds," and then the "thousands," and so on. It is not necessary to think of the columns of figures in these terms, but sometimes giving the columns these labels helps in handling figures.

Commencing our addition, we find that the right-hand column adds up to 52. As children we probably learned to write down the 2 and carry the 5 to the next column. If you like you can put the 5 at the head of the next column as shown. Or, you can write down the 52 under the tens and units columns as shown in (b). If you do this, a very small, simple addition at the end of the main addition will give you the grand total as well as a simple method of double checking the addition of the individual columns.

Next we add the tens column, and we find that the total of that column is 32. We write down the 32 beneath our first total but move it one place to the left as shown in (b). You can of course put down the 3 at the top of the next column as in (a). We continue in this way as we move to the left putting down the individual total of each column as shown in section (b), marked "check," or we continue with method (a), putting down the last digit and carrying the rest over and adding it in with the next column.

No matter which way we performed our addition, by method (a) or (b) we should have the answer 50272.

By writing down the sub totals of each column the way we have shown in (b) we have only very small figures to work with. This makes it much easier to check for errors in individual columns and to perform the final addition.

Some people like to start at the top of the column when adding, and work their way down, others like to start at the bottom and work their way up. Which method you choose is immaterial, provided you add every figure.

If you have to do a large amount of addition involving long columns of figures you can often save time by adding three or four figures at a time. For example, in this problem, starting at the top, 6 plus 8 plus 7 plus 6, etc., we can add as 14 (6 plus 8) plus 13 (7 plus 6) plus 9 plus 11 (7 plus 4), etc. Also by looking for figures that add up to 10 as you go down the column you can save time. Thus, if there are a 7 and a 3, a 6 and a 4, or an 8 and a 2, even though they are separated by one or two numbers we can immediately add 10 to the total and then add the intermediate numbers. The important thing here is to *remember* which figures you have added, and to be sure that you do not leave any out —or add any twice!

Sometimes there are several repetitions of the same number. If this happens, it is often easier to count the number of times this figure occurs and multiply it by this number. The rest of the figures in the column can then be added and the two totals added together will give the total for the entire column.

Probably the most important thing to remember in handling figures in radio and television is that we can combine only figures dealing with the *same* units. Thus we cannot add ohms and microfarads, or henries, any more than you can add dollars and gallons of gasoline.

Similarly, we cannot add quantities which are not expressed in the same unit. By this we mean that we cannot add amperes and milliamperes, we first have to convert both quantities to similar terms. Thus, in adding 100 milliamperes to 1 ampere, we would convert the ampere to milliamperes—1000—and add 100 milliamperes. Our total then would be 1100 milliamperes.

Below are three columns of figures. If you wish, practice adding them up using both systems. Try to be as fast as you can, consistent, of course, with accuracy.

53296	4257	4139
19387	9316	3146
23845	8297	9357
72971	5489	2879
68346	2568	5764
71291	4697	3192
36572	3963	8653

The correct answers are on page 37.

SUBTRACTION

Most of us find little difficulty in subtracting even complicated numbers. But just in case you have forgotten any of the very simple rules, let us work out the following problem, and go through the various steps involved.

$$\begin{array}{r} 7{,}849{,}630 \\ -4{,}291{,}375 \\ \hline 3{,}558{,}255 \end{array}$$

Starting at the right (the units column), we see at once that we cannot subtract 5 from zero—we all know from our income tax problems that you can't take something away from nothing! Therefore we have to borrow 10 from the next number to the left. Taking away 5 from the 10 we borrowed, we have 5 left. We then move one place to the left, since this is the "tens" column, and we have borrowed one ten from it, we have 2 instead of 3, from which we must take away 7. Again we must borrow from the next column over, and the 2 now becomes 12. Because 7 from 12 leaves 5, we write down 5 in the answer.

We again move one place to the left and subtract 3 from 5—not 6 because we borrowed one from that six in the last operation. 5 minus 3 equals 2 so we write this down. In the next column, 1 taken away from 9 leaves 8. In the fifth column, to subtract 9 from 4 we have to borrow 1 from the next column, making it 9 from 14, leaving 5.

The next subtraction is simple, 7, (because we borrowed one) minus 2 equals 5, and in the last column, to the extreme left, 7 minus 4 equals 3.

To check the answer to this type of problem, all we have to do is add the answer which we obtained below the horizontal line to the smaller number (this is normally the lower one). If we have subtracted properly, the total of these two numbers is the same as the larger (upper) number of the problem, thus:

$$\begin{array}{r} 4{,}291{,}375 \\ +3{,}558{,}255 \\ \hline 7{,}849{,}630 \end{array}$$

Here are some subtraction problems for you to try:

3572	2904	9007
—1831	—1692	—6321

The correct answers are on page 37.

MULTIPLICATION

Don't let the long word "Multiplication" frighten you. Multiplication is nothing more than a form of addition. If you see seven multiplied by nine (written 7×9), you know that this means the sum of nine 7's. On the other hand, it could also mean the sum of seven 9's. However, if we wrote 9 down 7 times and then added them it would take quite a long time. Of course, we would get 63 whether we did it by addition or multiplication.

An interesting point arises here—if we write 7 down 9 times and add it up, we get the sum of the column. On the other hand, when we write 7×9 and *multiply* we get the same answer, 63, this is known as the product.

In the problem 7×9, since we are multiplying 9 by 7 we say that 7 is the *multiplier* and 9 (the number that is being multiplied), we call the *multiplicand.*

The whole subject of mathematics was developed through a search for shortcuts and easier and quicker ways of doing things. Multiplication tables take the place of a lot of very awkward

	1	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	6	7	8	9	10
2	2	4	6	8	10	12	14	16	18	20
3	3	6	9	12	15	18	21	24	27	30
4	4	8	12	16	20	24	28	32	36	40
5	5	10	15	20	25	30	35	40	45	50
6	6	12	18	24	30	36	42	48	54	60
7	7	14	21	28	35	42	49	56	63	70
8	8	16	24	32	40	48	56	64	72	80
9	9	18	27	36	45	54	63	72	81	90
10	10	20	30	40	50	60	70	80	90	100

Table 1

and cumbersome additions. Table 1 is a multiplication table. To use this table, find one of the numbers to be multiplied in the left column, then find the other one along the top row. Go down the vertical column under this latter number and across on the horizontal row until the two lines intersect. At this point is the product. Let us take 9 × 7 as an example. Find 9 at the left side, and find 7 along the top row. Move your finger down the 7 column until it is level with 9 on the left. The number in the square is 63.

Let us see what we do if our multiplication involves large numbers, rather than single ones. Suppose we want to multiply 9437 by 7. The proper method of doing this is shown below:

```
  9437
×    7
66,059
```

Note that we multiply the large number by the small number. It is important to remember that it is nearly always much easier and quicker to multiply the larger number by the smaller because then we have fewer operations to perform and shorter columns of figures to add.

Let us consider this problem in multiplication as we do it. The operation is performed like this:

```
  3 2 4
  9437
     7
66,059
```

Multiply the lower number (7), and the digit farthest to the right in the upper number. This is 7 times 7, which is 49.

Put down the 9 directly under the right-hand column, carry the 4 to the next column, and write that above the 3 so that you can remember it. Now say 7 × 3 = 21, add in the 4 you carried over, and you have 25. Put down the 5, and carry the 2 to the next column. Then say 7 × 4 = 28, plus the 2 carried forward, equals 30. So you set down 0 in that column and carry 3, which you write above the 9. 7 × 9 = 63, plus the 3 carried forward, makes 66. Write 66 down under the 9, and you have the complete product, which is 66,059.

Another way of performing this operation would have been to break the number down into thousands, hundreds, tens, and units. For example: The number 9437 is the same as 9000, plus 400, plus 30, plus 7. If we multiply each of these by 7 and add the products, we get 66,059. This is proved in the following operation:

```
7 × 9000 = 63,000
7 × 400  =  2,800
7 × 30   =    210
7 × 7    =     49
7 × 9437   66,059
```

This shows us that if we multiply the sum of several numbers by any given number, the product is equal to the sum of the products of each of the multiplicands and the multiplier.

Sometimes in radio and television mathematics the number to be multiplied is the difference between two numbers. Suppose we have the problem 6 × (30 — 7). This is equivalent to 6 × 23, since 30 — 7 = 23. The product is 138.

Another way of doing this is to say 6 × (30 — 7) = (6 × 30) — (6 × 7) = 180 — 42 = 138.

Parentheses: In the preceding example we showed some numbers inside parentheses (). We use these in mathematics to separate groups of numbers that are to be handled separately. We simplify mathematical expressions by working out the contents of the parentheses first, for example:

$$2(6\times13) - 12 + 3(10+4) - 7(5-1)$$
$$= 2(78) - 12 + 3(14) - 7(4)$$
$$= 156 - 12 + 42 - 28$$
$$= 144 + 14$$
$$= 158$$

Note that a number immediately in front of parentheses merely means to multiply what is inside the parentheses by that number.

Many operations in multiplication can be performed very simply, such as the one shown earlier, in which we multiplied 9437 by 7. However, most problems involve numbers with several places (figures) in both the multiplier and the multiplicand. For example, to multiply 8468 by 241, we would set up the problem as follows:

```
   8468
 ×  241
   8468
  33872
 16936
2040788
```

In working a problem of this type, multiply the upper number first by the number farthest to the right (1 in this case), then by the next number to the left (4), and so on, moving to the left each time. Each time we multiply by one of these figures we write the product below and one place to the left, because when we multiply by the 1, we are multiplying by the units column. When we multiply by the 4, although we call it 4, we really multiply by 40, since in the number 241, the 4 is in the tens column and thus represents 40. In the same way when we multiply by the 2 we are really multiplying by 200 since the number 241 breaks down into 200, 40, and 1:

```
200
 40
  1
241
```

When we add the products from the three multiplying operations, we have the solution to the complete problem.

It doesn't matter how many figures there are in the multiplier or the multiplicand; it is usually easier to choose the smaller number to be the *multiplier*. Then, setting the multiplier below the multiplicand, we multiply by each figure in turn, starting with the one on the right, and offsetting the product one place to the left each time we multiply by a new figure.

Shown below is another example—in this case the multiplier and the multiplicand each has four places. Because each has the same number of places, we multiplied by the *easier* number. (The lower number has a 1, a 2, and a 5 in it, all of which are easy to multiply by.)

```
    3947
    5126
   -----
   23682
   7894
  3947
 19735
--------
20232322
```

The following problems will give you some practice in four-figure multiplication.

4157	9208	7564
2631	6452	3158

The correct answers are on page 37.

Squaring Numbers. Many times in radio and television work, and in many other simple calculations, you will come across a term similar to the following: 4^2.

The little 2 is known as an *index* figure, and it means that the figure 4 is multiplied by itself. In the example shown we read the expression as "four squared." This equals 4 multiplied by 4, which equals 16.

For example 10^2 means 10 squared, or 10 multiplied by 10, which equals 100. The little figure 2 showing that a number is squared is known as an index or power. Another way of saying four squared is to say 4 raised to the power of 2, or to the second power. However, this is a rather technical expression and you need not bother to remember it.

Sometimes you will see $(4)^2$. This is the same thing as 4^2 and is another way of writing it. Sometimes you will see an expression in parentheses, for instance, $(12—5)^2$. In this case, by looking at the brackets and the squaring sign we know that the difference between 12 and 5 has to be squared. So we say 12 minus 5 equals 7, and 7^2 is 7×7, which equals 49.

Squaring is an important part of mathematics, but as long as you remember that the little figure 2 to the upper right hand side of a number means multiply by itself you should have no trouble.

One of the most important things to remember about squaring a number, and one which sometimes confuses the beginner is that squaring a number is *not* the same thing as multiplying that number by 2. For example, 4^2 equals 4 times 4, equals 16. But, 4 multiplied by 2, equals 8.

Cubing Numbers. Sometimes you may find a problem in which you have a number and a little 3 written beside and above it, such as 4^3. This is read as "4 cubed." It means 4 times 4 times 4, which equals 64. In other words we have raised 4 to the power of 3.

It is interesting to note that although a number that is squared, does not necessarily become a very large number, as soon as it is cubed the difference really becomes noticeable.

For example: 4^2 equals 4 times 4, equals 16.

4^3 equals 4 times 4 times 4, equals 64.

We have discussed squaring and cubing, since, as you will find later in this book, we are often very much concerned with squares and cubes of figures, as well as square roots. We shall not discuss square roots until we have covered division in the next section. Then we shall discuss what is meant by "a square root" and see how it ties in with "squared numbers."

Before we leave the subject of multiplication, let us go over two very important points that can help you work out these problems much more quickly. The first is quite obvious, but it is amazing how many people are fooled by it every day. Whenever any number is multiplied by 0, the product is always 0. Thus, 1000 multiplied by 0, or 0 multiplied by 1000 equals 0. If you remember that nothing times something must be nothing, you will be able to follow this reasoning quite easily.

The second very important rule is that when anything is multiplied by 1, the product is always the same as the other term. For example 200 multiplied by 1 equals 200 or, putting it another way, 1 multiplied by 200 equals 200.

You may say, "surely these points are obvious," but we are emphasizing them, because, in spite of their apparent obviousness, even the most expert mathematicians can sometimes become confused when using them in practical work in a long multiplication.

Occasionally we get a long multiplication operation to perform, such as the following: $394f^2L$. This expression can be re-written as $394 \times f^2 \times L$.

We need not worry at this point about what the formula stands for. In this case f equals frequency in cycles per second, and L equals inductance in henries. If the frequency is 120 cycles, and the inductance is 30 henries, we can rewrite the expression as follows: $394 \times (120)^2 \times 30$ which equals $394 \times 14400 \times 30$.

Since most of us like to do the easiest things first, it is usual to do the squaring operation first. In this case we set the problem out as follows:

```
         120
       × 120
     -------
       2 400
      12 0
     -------
      14 400
        × 30
     -------
     432 000
       × 394
   ---------
   1 728 000
  38 880 00
 129 600 0
 -----------
 170,208,000
```

Notice that when the multiplier contains a zero, instead of writing a whole row of zeros, we put down one zero in the proper column below, and then put the product of the next figure and the multiplicand directly beside it. When we do this, we must remember to put the next row over *two* places to the left. For example, instead of writing:

```
  120                    120
 ×120                   ×120
 ----                   ----
  000                   2400
 240       we write:   120
120                    -----
-----                  14400
14400
```

DIVISION

Division is to multiplication what subtraction is to addition. In other words when we add numbers we get a larger number, and when we multiply we also normally get a larger number. When we subtract one number from another the result is also usually a smaller number.

We use division when we want to find out how many times a certain number is contained in another number. This is another way of saying how many times we have to multiply a number to obtain a given number. Instead of using the rather cumbersome expression "is contained in a given number" we usually say "a number goes into another number" a certain number of times.

For example, 3×9 equals 27, or 3 "goes into" 27 nine times, and 9 "goes into" 27 three times. In other words we can subtract 9 from 27 three times.

The sign for division is $\div$. The problem can also be set down as a fraction, $27 \div 3$ is the same as $\frac{27}{3}$. Both expressions mean exactly the same thing. The number above the line is called the *dividend* because it is being divided, the number below the line is called the *divisor*, that is, the number that is doing the division, and the answer is called the *quotient*. Thus, in the example just given, 27 is the dividend, 3 is the divisor, and 9 is the quotient.

A brief reference to Table 1 at this point will do two things—it will refresh your mind on the division of single numbers, and it will show you why division may be considered as being the opposite of multiplication. Instead of locating our multiplier and multiplicand on the top and the left-side of the table respectively, and reading the product at the point where the two columns intersect, locate the divisor in the left-hand column, and the dividend in the body of the table, then read the quotient at the top.

There are two methods of working division, the "short" method and the "long" method. When the divisor is a number smaller than 10, we use "short division" as shown below.

```
    4 1 5 6 3
9 ) 3 7 4 0 6 7
```

Our mental process in performing this operation is something like this: 3 is not divisible by 9, so we combine it with the next number (7) to make 37. 9 goes into 37 four times; 4×9 is 36, so there is a remainder of 1. 4 is written above the 7 of the 37 and the 1 is carried over as a 10 and added to the next number (4). This gives 14. 9 goes into 14 once, so 1 is written above the 4. 9 from 14 leaves 5 and this is carried forward as 50. Combined with the next number (0) it thus becomes 50. 9 goes into 50 five times ($9 \times 5 = 45$) so we write 5 above the zero and subtract 45 from 50 leaving 5. This 5 is carried forward as 50 and added to the 6, making 56. 9 goes into 56 six times ($6 \times 9 = 54$) and we write 6 above the 6 and carry the 2 remaining to the next figure calling it 20. Carrying this to the next figure, we get 27. 9 goes into 27 three times so we write the 3 above the 27. Since $9 \times 3 = 27$, there is nothing left over.

Therefore our answer is 41563. We can check this by multiplying 41563 by 9. If we have performed the operation properly, we obtain the result, 374067. So we say the quotient is 41,563.

Long Division. If the divisor is larger than 10, we use long division. The following example, in which 31 is the divisor and 969,424 the dividend, illustrates the method.

```
      3 1 2 7 1
31 )  9 6 9 4 2 4
      9 3
        3 9
        3 1
          8 4
          6 2
          2 2 2
          2 1 7
              5 4
              3 1
              2 3
```


In actuality we perform the same process as in short division, but because of the size of the numbers used, we set down the individual processes. The operation is performed as follows: 31 goes into 96 three times. We put 3 above the line and 93 (31 multiplied by 3) under the 96. Now subtracting 93 from 96 leaves 3. We "bring down" the next figure in the dividend, which is 9. This makes our next sub-dividend 39. 31 goes into 39 once, so we write down 1 above the 9. Subtracting 31 from 39 leaves 8. We bring down the next figure, 4, making a sub-dividend of 84. Now 31 goes into 84 twice, so we put 2 above the 4 and subtract twice 31, or 62, from 84, which leaves 22. We bring down the 2 making a sub-dividend of 222, and find that 31 goes into 222 seven times. Therefore we write 7 above the 2, and subtract 217 (7 times 31) from 222 which leaves 5. We bring down the 4 making 54. 31 goes into 54 once, we write one above the 4 and our quotient is 31271.

In the short division example, the answer came out exactly even. However, if the last sub-dividend is not capable of being divided exactly by the divisor, we have a number left over. There are no more figures to bring down from the main dividend, so we have a fraction or a decimal figure left over.

In the long division example above, our quotient came to 31271, and 23 was left over. If we had reached the stage of being able to handle decimals, we could have continued division and obtained a decimal figure in our answer. However we have not yet tackled decimals in this reference text although we are going to very shortly. Therefore, we write the quotient thus: $31271 \frac{23}{31}$, in other words 23 of the original dividend is left over.

When we get to decimals we will finish this example and give the answer as a decimal.

The quotient of any number divided by 1 is always the same as that number. We can check this by applying the rule—divisor multiplied by quotient equals dividend.

Another way of reducing the size of large numbers before division is possible if the divisor and the dividend each end in 0. If this is the case, we can cross off the zeros in the ending of these two numbers and divide by what is left. This often saves time.

```
          1 0 7 4 5
81øø )  8 7 0 4 0 5 ø ø
        8 1
          6 0 4
          5 6 7
            3 7 0
            3 2 4
              4 6 5
              4 0 5
                6 0
```

Here are some problems in division for you to try, if you like:

```
36 ) 1 9 4 4        23 ) 1 7 0 4 3
```

You can check your answers on page 37.

Finding Square Roots. A few pages back we discussed squaring numbers and we mentioned square roots.

At that time we learned that the process of "squaring" really means multiplying one number by itself. Therefore, if we write down 12^2 we know that it means 12 multiplied by 12, which equals 144.

The converse, or opposite, of squaring a number is finding its square root. The square root of a quantity is that number which when multiplied by itself produces the given number. For example, the square root of 144 is 12, since 12 multiplied by 12 equals 144. Similarly the square root of 9 equals 3, because $3 \times 3 = 9$.

The square roots of simple terms such as these can be found by inspection, or very rapidly by mental arithmetic, by squaring numbers on a trial and error basis to see if they produce the required number. However, it is obvious that on many occasions we need to know the square roots of numbers running into more than two digits. In cases like this we have to use a definite system for finding, or "extracting" as it is sometimes called, the square root.

We have a symbol for indicating that a number is to be squared—as we showed a few paragraphs back. We also have a special sign to show that a square root is to be found. It is known as the "radical sign" and is a quick way of writing "the square root of." In the expression below, the sign means "find the square root of 25."

$$\sqrt{25}$$

This is, of course, 5 (because $5 \times 5 = 25$).

Whenever you see this symbol $\sqrt{\ }$ it means that you are to find the square root of a number.

Here is an example of finding the square root of a number.

$$\sqrt{2304}$$

The first thing to do in finding the square root of a number is to separate the number into groups of two figures (each of these groups is called a "period"), starting at the right, thus:

23 | 04

We now find the largest square (number multiplied by itself) contained in the first, or left-hand group. In this case, it is 16 (4×4). Place this figure under the first group and put its square root (4) as the first figure of the answer above the 3 of the number 23 as shown below.

```
       4  8
    √ 23 04
      16
 80 |  7 04
 88 |  7 04
```

As in long division, we subtract the 16 from the 23, which leaves 7. We then bring down the next *pair* of digits instead of the next one as we would in long division.

Now we come to the part which is sometimes confusing in trying to find a root. We must find a "trial divisor" to use with a new dividend (704 in this case). We find this trial divisor by multiplying the number we have already obtained in the answer by 2 and then by 10. (We could have multiplied it by 20 and obtained the same results.) Thus, since 4 is the number in the answer, we double it, giving us 8, which when multiplied by 10, gives us 80 which we write to the left of the 704. We now try to determine how many times 80 will go into 704. By inspection, it appears to go 8 times. Therefore we put the number 8 in the answer position to the right of the 4 and add this number to the 80, giving us 88, which we write below the "trial divisor." We multiply 88 by 8 (which we have in the answer) and find that it comes out to exactly 704. Therefore, the square root of 2304 is 48, so in other words, 48 multiplied by 48 equals 2304.

This probably seems a little confusing, so we will work another example. Find the square root of 14641, which would be written $\sqrt{14641}$. Now we break the number into groups of two, starting from the extreme right hand-side; so we get 1 | 46 | 41.

The largest square in the extreme left-hand number is of course 1, since 1×1 equals 1. Therefore we write 1 in the quotient, and place 1 underneath the 1 in the dividend. Subtracting leaves 0, so we bring down the 46. Remember that 1 is the first figure in our quotient (answer). Doubling this figure we get 2 (twice one) and multiplying by 10 we obtain 20 for a trial divisor. Dividing 20 into 46 we find that it goes twice, so we write the figure 2 in the quotient, or answer. We now add 2 to 20 and obtain 22. When we multiply 22 by 2 this gives us 44 which we subtract from 46. Since 44 from 46 leaves 2, we write down the 2 and bring down the next pair of figures, which is 41, and thus obtain 241.

```
        1  2  1
      √ 1 46 41
        1
  20 |  0 46
  22 |    44
 240 |     2 41
 241 |     2 41
```

Now we go through the second step again. This time we double 12, since that is the answer thus far obtained. Twice 12 equals 24, multiplying by 10 gives us 240. We write this down to the left of the number 241. We divide 240 into 241 and find that it goes once. Therefore we write 1 in the answer, then add 1 to 240 and obtain 241. We write this down on the left-hand side and also on the right-hand side under the first 241 and by subtraction we find there is no remainder. Thus we have found, because there is no remainder, that the square root of 14,641 is 121. We can check this by squaring 121.

```
    121
  × 121
    121
   242
  121
  14641
```

Here is a simple example for you to try. Find the square root of 4096.

$$\sqrt{4096}$$

You can check your answer on page 37.

Fractions

A fraction is a part of a whole. When we divide, we get a fraction. For example when we divide 1 by 2 we can write 1 ÷ 2 or $\frac{1}{2}$. In a fraction, the number above the line, the *numerator*, is divided by the number below the line, the *denominator*. If the numerator and the denominator are the *same*, the fraction is equal to 1. For example writing 4/4 is the same as writing 4 ÷ 4, which equals 1. Therefore you see that 2/2, 3/3, 4/4, 5/5, etc. are equal to 1.

The same value can be expressed in many different ways. Let us suppose you had something which you divided into 4 parts. If you took two of these parts you would have half the original quantity. So you see 2/4 is also equal to a half. Similarly, if you divided the original quantity into 6 parts and took 3 of them, you would have half the original quantity. Therefore, you see that 2/4, 3/6, 4/8, 5/10, etc. are all equal to 1/2. This illustrates the rule that if the numerator of a fraction and the denominator are each multiplied by the same number, the *form* but not the value of the fraction will be changed.

If we start with the fraction 1/2, we can multiply the numerator by 2 and get 2, and the denominator by 2 and get 4, so we have 2/4. Similarly if we multiply each by 3, we get 3/6, if we multiply each by 4, we get 4/8, etc. and each of these is still equal to the original fraction, 1/2.

Conversely if we divide the numerator and the denominator each by the same number, the form but not the *value* of the fraction will be changed. For example, if we have 4/8 and we divide the numerator and the denominator each by 4, we get 1/2. If we have 3/6 and divide each by 3, we get 1/2, if we have 2/4 and divide each part by 2, we get 1/2. We say that 1/2 has been reduced to its lowest possible form, because the only number that will go evenly (without a remainder) into the numerator and into the denominator is 1.

To reduce a fraction to its lowest possible form, divide the numerator and the denominator each by the largest number that will go into each a whole number of times. For example, if you have the fraction $\frac{36}{48}$, you can divide both 36 and 48 by 3, by 4, by 6, or by 12. You choose the largest, 12, and dividing 36 by 12 gives you 3, and dividing 48 by 12 gives you 4, so when $\frac{36}{48}$ is reduced to its lowest possible form it is 3/4.

A fraction in which the numerator is greater than the denominator is called an "improper fraction," and is greater than 1. To reduce an improper fraction to its lowest form, divide the numerator by the denominator, and express the remainder in its lowest possible form. For example, if you have the fraction $\frac{12}{9}$, to express it in its lowest possible form, divide 12 by 9, and this will give 1 with 3 left over; 3/9 can be expressed as 1/3, so you have 1 1/3. Here are some examples.

$$\frac{7}{5} = 1\ 2/5$$

$$\frac{6}{4} = 1\ 1/2$$

$$\frac{12}{3} = 4$$

ADDING FRACTIONS

We can add, subtract, multiply, or divide fractions. Before we can add fractions, all terms must be expressed with the same denominator. Suppose we want to add 5/6 and 1/2. We must have a common denominator, so we change 1/2 to 3/6 and *add the numerators*. We get 8/6, which when reduced equals 1 2/6 or 1 1/3.

To find a common denominator, we must find a number into which *all* the denominators in the problem will go an even number of times. If we wanted to add 5/6, 3/4, and 2/3 we could use 12 as the common denominator, because 6, 4, and 3 will all go into 12 an even number of times. Now we must change the form of each fraction so that each one is expressed in twelfths. To change the form of a fraction, we multiply the numerator and the denominator each by the same number. This is the same as multiplying by 1, because you would be multiplying by 2/2, 3/3, 4/4, etc., which are each equal to 1.

To change 5/6 to twelfths, we must multiply each part by 2, so we have $\frac{10}{12}$. To change 3/4 to twelfths we must multiply each part by 3, so we have $\frac{9}{12}$. To change 2/3 to twelfths, we must multiply each part by 4, so we have $\frac{8}{12}$.

Now we add the numerators, and we have 10 + 9 + 8 = 27. This is the numerator of the answer. *The denominator of the answer is the same as the common denominator used in the problem.* So we have $\frac{27}{12}$. Reducing this we have $2\frac{3}{12}$, or 2 1/4.

Here are some more examples:

1. Add 1/2, 3/4, and 7/8

   1/2 = 4/8
   3/4 = 6/8
   7/8 = 7/8

   $\frac{17}{8} = 2\ 1/8$

2. Add 2/5, 2/3, and 1/2

   2/5 = 12/30
   2/3 = 20/30
   1/2 = 15/30

   $\frac{47}{30} = 1\ 17/30$

To add mixed numbers, that is, numbers in which there is a whole number plus a fraction, add the fractions and the whole numbers separately.

```
 5 3/4
 7 2/4
 8 1/4
 -----
20 6/4
```

6/4 = 1 1/2 so you have 20 + 1 1/2 or 21 1/2 for the answer.

SUBTRACTING FRACTIONS

In subtracting fractions just as in adding them, we must have a common denominator. To subtract fractions, find a common denominator, change each fraction to the form using this denominator, and subtract the *numerators*. Again the answer will have the common denominator. Here are some examples.

1. Subtract 1/3 from 5/9

   5/9 = 5/9
   1/3 = 3/9

   2/9

2. Subtract 5/13 from 7/15

   7/15 = $\frac{91}{195}$

   5/13 = $\frac{75}{195}$

   $\frac{16}{195}$

Just as in addition, when mixed numbers are subtracted, subtract the fractions and the whole numbers separately.

33 7/8
11 5/8
22 2/8 = 22 1/4

MULTIPLYING FRACTIONS

To multiply fractions, multiply the numerators and the denominators (you do not need a common denominator as in addition and subtraction). For example:

3/4 × 2/3 = 6/12 = 1/2

Here is a short cut that can be used. If one of the numerators and one of the denominators are divisible by the same number, you can divide them by the number thus giving smaller figures to multiply. For example:

5/12 × 3/10

We can see that the first numerator 5, and the second denominator, 10, are both divisible by 5 so we divide both by 5 which gives us 1/12 × 3/2. We can also see that 3 and 12 are both divisible by 3. Dividing each by 3 gives us 1/4 × 1/2, which gives us 1/8. If we had multiplied the problem as it originally stands, we would have had 15/120, dividing the numerator and the denominator each by 15 would give 1/8, so you see we would get the same answer either way.

Here are some examples of multiplication:

$$3/5 \times 7/8 \times 2/3 = \frac{42}{120} = 7/20$$

3/7 × 4/5 = 12/35

When you want to multiply mixed numbers, you must first convert them to improper fractions. To do this, multiply the denominator by the whole number and add the numerator. This figure will be the new numerator of your fraction, and the denominator will be the same. For example:

7 3/4 × 1 2/3

First convert both numbers to improper fractions:

31/4 × 5/3 = 155/12 = 12 11/12

DIVIDING FRACTIONS

Once you have learned to multiply fractions, dividing them is very easy There is only one rule to remember:

To divide by a fraction, *invert it and multiply*. In other words put the denominator where the numerator was, and the numerator where the denominator was. For example:

1. 3/4 ÷ 2/3
   = 3/4 × 3/2 = 9/8 = 1 1/8
2. 5/8 ÷ 4/9
   = 5/8 × 9/4 = 45/32 = 1 13/32

To divide mixed numbers, first change them to improper fractions, invert the divisor, and proceed as in multiplication.

7 1/3 ÷ 2 1/2
22/3 ÷ 5/2
22/3 × 2/5 = 44/15 = 2 14/15

Decimals

In the introduction, we mentioned decimals. At that time we mentioned decimals very briefly in connection with everyday living, and promised to return to the topic later in the book. We are now ready to kill that dragon and show that decimals are really very simple and we are much more familiar with them than we often realize.

We will start off by defining the decimal system. It is merely a means of expressing numbers smaller than 1, in terms of tenths. If you want to write the number one-tenth, you would write it like this: $\frac{1}{10}$. If you want to write one-half, you write $\frac{1}{2}$.

When dealing with capacity of condensers, we very frequently work with values such as $\frac{5}{10{,}000}$. This is a rather awkward figure. As a matter of fact, 5 over 10,000 is actually the same thing as writing .0005. In your radio and television work you will use many condensers with a capacity of .0005 mfd; what you are actually using is five ten-thousandths of a microfarad.

We know that ½-megohm resistance is the same as 500,000 ohms. This is usually written as .5 megohm, since .5 is another way of writing half.

Now let's see why this is so. We all know that there are 100 cents in a dollar. We also know that if we multiply one dollar by 10 we have 10 dollars, or 1000 cents. If we have 950 cents, it is much easier for us to write down the dollar sign, and then 9.50 because the term is much smaller and more convenient. We know that fifty cents equals a half dollar, so when we say fifty cents we are really saying 50/100ths of a dollar. Reducing 50/100, gives us 5/10 which reduces still further to 1/2.

In the same way twenty-five cents equals 25/100, or in other words a quarter of a dollar. We could also write seventy-five cents as 75¢, or 75/100, or 3/4.

If we wanted to write fifty cents we would put .50 which of course is also 1/2. In a number, the decimal point means that whatever is on the *right hand side* of it is less than 1.

Here is an example in adding money. I am sure you have plenty of practice in doing this, but we will just go over it as a starting point for what is to come.

$2.50
5.93
1.17
0.03
$9.63

You see that the total of our addition is $9.63.

Now let's go back and see how we arrive at this figure. Starting from the right-hand side, we add 3,7,3,0, which gives us 13. Writing down 3 under the column, we carry 1 forward to the next column. We added 1,5,9,1, which gave us 16 so we write down the 6 and carry the 1 over to the dollars column. Adding this column we get 9. We put a decimal point directly below the decimal points in the problem, and our answer is 9.63. You can see that this is right, because if you add the amount as 250 cents, 593 cents, etc., you would get 963 cents, which you know is the same as $9.63. Another way of writing this would be $9 63/100. As you can see it is much more simple to write $9.63 than $9 63/100.

Here is an example adding small numbers:

$$\begin{array}{r} \$0.05 \\ 0.17 \\ 0.71 \\ \hline \$0.93 \end{array}$$

Adding these small amounts, gives us 93 cents. We could of course write this $93/100, but that is clumsy, so we write $0.93.

Engineers almost invariably put a 0 in front of the decimal point when they are writing a number less than 1. This is to prevent any confusion arising because of the blank space to the left of the decimal point. In the example just given, as soon as we see 0.93 we know that there cannot possibly be any figure on the left of the decimal point. However if we just saw .93, that is, decimal point 93, it is quite possible for a mark to get on the left of the decimal point and thus accidentally change the value of that number completely. So, instead of reading 93 it might be interpreted as 1.93 or some other value. Also another important reason for putting a 0 in front is to show that whoever wrote down the number had not carelessly omitted a number.

However, in radio and television, by common usage, it has become the exception rather than the rule to write down a 0 to the left of the decimal point when discussing condensers. The main reason for this is the fact that we are accustomed to thinking of condensers in terms of fractions of microfarads. As soon as we see a .0005-mfd condenser we know that it would not be a 1.0005-mfd condenser because the difference is too great. If we indicated a .5 condenser we know that we are not very likely to get a 1.5 condenser. Even so, it is not unusual to see a .5 condenser described as a 0.5 mfd.

In radio and television we deal with decimals to many places, such as .0008, .0025, etc. Table II below shows you how these are read and includes the fractional equivalents.

As a short cut, when reading decimals with a large number of places, such as .0008, instead of reading eight ten-thousandths, we often read "point 0-0-0 eight," "three zeros eight," or even "triple-0-eight." Sometimes decimals of one place are read in this way. Thus .5 may be read "point five," or "one-half" instead of "five-tenths."

TABLE II

.1	=	1/10	=	one-tenth
.01	=	1/100	=	one-hundredth
.001	=	1/1000	=	one-thousandth
.0001	=	1/10,000	=	one-ten-thousandth
.00001	=	1/100,000	=	one-hundred-thousandth
.000001	=	1/1,000,000	=	one-millionth

If you should hear someone say that a certain quantity is "5 zeros three," you will know that he means "three-millionths," or .000003. If you hear "double 0 two five," you will immediately see in your mind .0025 which you know to be 25 ten-thousandths.

Here is a simple sum, adding decimals and following the same principles that we learned in adding dollars and cents. You will remember that when we add dollars and cents together we keep the decimal points one under the other in a vertical line. We do exactly

the same thing when we are adding other numbers, even though some of these numbers may have four or five digits on the right-hand side of the decimal point. For example:

$$\begin{array}{r@{}l} 1&.008 \\ &.0005 \\ 121&.0 \\ 31&.1 \\ 14&.05 \\ \hline 167&.1585 \end{array}$$

Naturally the decimal point in the answer will be directly below the decimal points in the numbers added. You will see this time however that we have four places on the right hand side of the decimal point. Another way of showing this answer would be like this:

$$167\frac{1585}{10{,}000}$$

We would say this as 165 and 1585 ten-thousandths. You can see how clumsy this is, and how much simpler it is to say 167 point 1585. As a matter of fact some people call it "167 decimal 1585."

When we subtract decimals, we handle them in exactly the same way as we do subtraction of money.

The only difference between handling decimals and handling plain numbers is that we have to be sure to put the decimal points one under the other in the columns. Once the decimal points have been lined up, one under the other, we forget about them, and proceed just as though they were not there. For example:

$$\begin{array}{r} 1405.03972 \\ -\ 907.10007 \\ \hline 497.93965 \end{array}$$

We needn't go through the *mechanics* of subtraction here but we will just take a look at how we performed subtraction of the decimal part. We started at the extreme right, just as for whole numbers and subtracted in the same way. When we came to the decimal point, we "borrowed 1" from the number on the left-hand side of the decimal point. Because we added it to the place immediately to the right of the decimal point it becomes 10/10th. So now subtracting 1 from 10/10ths, leaves 9/10ths which we can write as .9 then we continue across on the other side of the decimal point as in ordinary subtraction. Our answer becomes 497.93965. Actually, we don't need to worry about the decimal point until we have subtracted all the way across; then, we simply put it in the answer directly under the ones in the problem.

Here is another example in which we are dealing with two very small numbers:

$$\begin{array}{r} 2.000083 \\ -\ 0.001094 \\ \hline 1.998989 \end{array}$$

You can, of course, check the accuracy of your subtraction by adding the answer to the number you are subtracting.

$$\begin{array}{r} 0.001094 \\ +\ 1.998989 \\ \hline 2.000083 \end{array}$$

We *could* have handled these numbers as fractions, but think what a horribly unwieldy problem you would have to do, and how much chance of error there would be if you converted these two numbers to fractions!

One very important point to remember when handling decimals is that the zeros in the last place to the right in a decimal number have no significance of any kind (a decimal number is the portion of a number to the right of the decimal point). Any number of zeros can be added to the right without changing the value in the slightest.

Thus .05 is exactly the same as .0500 or .05000000; and 27.903 is exactly the same as 27.9030000.

However, every time you add a zero *between* the decimal point and the number on its right you decrease its value ten times. For example: .3 equals 3/10ths, but .03 equals 3/100ths and .003 equals 3/1000ths. From this you can see that it is extremely important that the decimal point be handled with great care.

Students who are taking communications course work and intend to obtain a radio operator's license will find that some FCC license questions require mathematical answers.

In the following examples on multiplication and division we are going to give you some special rules regarding the handling of decimal points. Because the FCC questions are multiple-choice types, these mathematical answer questions are usually designed to test an applicant's knowledge of arithmetic as well as his technical knowledge, and they consist of four or five numbers, which are identical except for the position of the decimal point. You, the student, have to decide which of the various answers has the decimal point in the right place. We shall return to this after we have discussed multiplication and division of decimals.

MULTIPLYING DECIMALS

To multiply two numbers containing decimals, we follow exactly the same procedure as for ordinary numbers. That is, we multiply one number by the other, completely ignoring the position of the decimal point during the time that we are performing the multiplication.

Suppose we wanted to multiply 8.468 by 24.1. Multiplying this, we get the following figures:

```
    8.468
 ×   24.1
 --------
     8468
   33872
  16936
 --------
  2040788
```

Now the question is: where do we put the decimal point in the answer? *All we do* is count the number of decimal places in *both* the multiplier and the multiplicand. Decimal places are the places occupied by figures to the right of the decimal point. The number 8.468 has *three* decimal places because there are 3 figures to the right of the decimal point. Similarly 24.1 has *one* decimal place—one figure on the right of the decimal point. We have a total of four decimal places (3 + 1). This means that we put the decimal point four places from the right in the answer. The final result is not 2040788, but 204.0788.

Remember the simple rule: Add the number of decimal places in the multiplier and the multiplicand. Count from the extreme right hand figure in the answer and position the decimal point the required number of places to the left.

Multiplication Rules. To multiply by 10, move the decimal point ONE place to the RIGHT. Remember that zeros to the right of the decimal number should be dropped because they have no significance.

10 × .7 = 7.0 = 7
10 × .01 = .10 = .1
10 × .0035 = .0350 = .035

To multiply by 100, move the decimal point TWO places to the RIGHT.

100 × .01 = 1.00 = 1
100 × 15.798 = 1579.8

To multiply by 1000, move the decimal point THREE places to the RIGHT.

1000 × .01 = 10.00 = 10
1000 × 1.75 = 1750

To multiply by 1,000,000, move the decimal point SIX places to the RIGHT.

1,000,000 × .000250 = 250

Here are the two rules for decimal multiplication, and two examples.

Decimal numbers are multiplied in the same way that ordinary numbers are multiplied in simple arithmetic. The number of decimal places in the answer is the SUM of the decimal places in the two numbers being multiplied together.

EXAMPLE: Multiply .0025 by 43

```
 .0025   4 decimal places
    43   0 decimal places
 -----
    75   Total is 4 decimal places,
  100      therefore the answer is
 -----
  1075     .1075
```

EXAMPLE: Multiply .025 by .0043

```
  .025   3 decimal places
 .0043   4 decimal places
 -----
    75   Total is 7 decimal places,
  100      therefore the answer is
 -----
  1075     .0001075
```

If you are moving a decimal point more places over than there are digits in the answer, fill in the places with zeros.

DIVIDING DECIMALS

Let's go back for a moment and consider the problem we did in the section on long division.

Remember that when we performed this without going into decimals, we got an answer of 31, 271 $\frac{23}{31}$. At that time we didn't know what to do with the 23/31 to avoid having a fraction in the answer. Now we can carry out the division beyond the decimal point and automatically convert the answer to decimals.

```
      3 1 2 7 1. 7 4
 31 ) 9 6 9 4 2 4. 0 0
      9 3
      ---
        3 9
        3 1
        ---
          8 4
          6 2
          ---
          2 2 2
          2 1 7
          -----
              5 4
              3 1
              ---
              2 3 0
 - - - - - - - - -A
              2 1 7
              -----
                1 3 0
                1 2 4
                -----
                    6
                       etc.
```

Look at the division operation shown above the dotted line A. Here we have the problem of dividing 23 by 31, which we cannot do. We have no more numbers to bring down, therefore we know that we shall have to use decimals to obtain an answer that does not contain fractions. To do this we place a decimal point in the dividend to the right of the last number, and one directly above it in the quotient. Now we can add zeros beyond the decimal point and continue to divide, until we are satisfied with the number of decimal places we have obtained or until the problem comes out even. In this case we placed a decimal point immediately after the one in the quotient and brought down a zero, making 230 instead of 23.

Continuing in long division, we see that 31 goes into 230 seven times. Seven times 31 is 217, so we subtract 217 from 230, leaving 13. Since we have a remainder and we want to continue our division, we add another zero, making the 13 into 130. 31 goes into

130 four times, so we subtract 124 from 130, leaving 6.

At this point we will stop, although we could go on indefinitely until we had either completely solved the problem or decided (as we have here) that we had enough decimal places in the answer.

Where the dividend but not the divisor contains a decimal, the procedure is the same as that just illustrated. When dividing, place the decimal in the quotient above the decimal in the dividend. If the quotient is set down carefully, there will be no difficulty in placing the decimal point correctly.

If the divisor contains a decimal, the simplest procedure is to move the decimal point enough places to the right to make a whole number of it. Then move the decimal point in the dividend the same number of places to the right. For example, suppose we have the problem 974.63 ÷ 1.3. We can write this:

```
              .
13. ) 9 7 4 6. 3     (9746.3 ÷ 13)
```

A slightly more difficult problem would be 1.41 ÷ .0025. To make the divisor a whole number, we have to move the decimal four places to the right—our problem becomes 14100 ÷ 25, or $\frac{14100}{25}$. Here we have put zeros in the empty spaces:

```
                  .
0025. ) 1 4 1 0 0.
```

Note: The decimal point in the quotient is placed above the *new* position in the dividend.

On the other hand, suppose we have to divide a whole number into a decimal number, as for example:

.0007 ÷ 45 or $\frac{.0007}{45}$

We would work this out as follows:

```
      .0000155
45 ) .0007000
         45
         250
         225
          250
          225
```

Notice that we set down in the quotient the three zeros in the dividend. Then, because 45 won't go into 7, we set down another zero. 45 goes into 70 once, so we write down 1 in the quotient. 45 from 70 leaves 25. Bring down a zero from the dividend, and divide 45 into 250. It goes 5 times, with 25 left over. Bring down another zero and divide 45 into 250. It goes 5 times, so we set the 5 down in the quotient. We could continue adding zeros to the dividend, but for most purposes we are satisfied with three "significant figures." Shortly we will explain what is meant by "significant figures."

In radio and television work we often have to divide a whole number into 1 to obtain the reciprocal. In this case the procedure is exactly the same as we showed you above. Suppose you want to find the conductance $\frac{1}{R}$, where R is 2500 ohms. You do this as follows:

```
        0.0004
2500 ) 1.0000
        1 0000
```

Notice that the quotient has as many decimal places as the dividend. The conductance in this case is 4 ten-thousandths of a mho. To simplify our division we could have gotten rid of the 2 zeros in the division by moving the decimal point two places to the left, *provided* we also moved it two places to the left in the dividend.


```
      .0004
25 ) .0100
       100
```

As you can see, we would get the same answer.

Division Rules. Here are some rules to remember when dividing decimal numbers:

To divide by 10, move the decimal point ONE place to the LEFT.
.0035 ÷ 10 = .00035

To divide by 100, move the decimal point TWO places to the LEFT.
.5 ÷ 100 = .005

To divide by 1000, move the decimal point THREE places to the LEFT.
5.7 ÷ 1000 = .0057

To divide by 1,000,000, move the decimal point SIX places to the LEFT.
750,000 ÷ 1,000,000 = .75

SHORT CUTS

Multiplication. Multiplying large numbers can become a very tedious operation. If one or both of the numbers contains several zeros, we can apply a very simple short cut.

For example, 24,000 × 4,000 = 96,000,000. Multiply the numbers together, without the zeros, and add to the answer as many zeros as there are in both the multiplicand and the multiplier. In this problem we multiplied 24 × 4 = 96. There are three zeros in each term of our example; therefore, there will be six zeros in the product.

In multiplication it doesn't make any difference which term we use as the multiplier. However, it is nearly always easier to use the smaller term. For example, suppose we are to multiply 5134 and 2100. With 5134 as the multiplier, our problem would be set up thus:

```
     2100
     5134
     8400
    6300
   2100
 10500
 10781400
```

Using 2100 as the multiplier would be much simpler, as shown below:

```
     513 4
     210 0
     513 4
  10 268
  10,781,400
```

Here we followed our rule about numbers containing zeros, adding two zeros to the product of 5134 × 21

Short cuts can be used where a number is multiplied by ½ (.5), ¼ (.25) or ¾ (.75).

To multiply by .5, divide by 2. This is self-evident, since .5 is the same as 5/10, which is equal to 1/2. If the number to be multiplied is 15, we see that 15 × .5 is the same as 15 × 1/2, which becomes 7.5.

To multiply a number by .05, move the decimal point of the number one place to the left, and divide by 2. Suppose 5 per cent of a number is required. Now 5 per cent is 5/100, which becomes in decimals .05. If the number is 15, move the decimal point one place to the left, which gives 1.5, and divide by 2, obtaining .75.

To multiply by .25, divide by 4. If 264 is to be multiplied by .25, considerable calculation would be necessary to multiply it out. But by dividing by 4, we quickly obtain the answer, 66.

We can use this method whether our multiplier is 2.5, 25, 250, or 25 million, simply by adding to the multiplicand as many zeros as there are whole numbers in the multiplier. Multiplying by

2.5 we add one zero and divide by 4. Multiplying by 25 we add 2 zeros and divide by 4, etc.

To multiply by .75, divide by 4 and multiply the result by 3. For example, multiply the number 264 by .75. Applying the rule, we have 264 divided by 4, equals 66, and multiplying by 3, we get 198.

To multiply by 7.5, 75, 750, etc. add zeros to the multiplicand exactly as when multiplying by variations of .25.

Division. There are also many short cuts that can be used to make division easier. To divide by 25, move the decimal point two places to the left, and multiply by 4. Taking the number 2640, we move the decimal two places to the left and obtain 26.40 × 4 = 105.6.

To divide by 250, move the decimal 3 places to the left and multiply by 4. To divide by 2500, move the decimal 4 places, etc.

In the same way, to divide by 50, 500, 5000, etc., move the decimal point in the dividend to the left as many places as there are whole numbers in the divisor, then multiply by 2.

If you have to divide by decimal numbers such as .5, multiply by 2 but do not move the decimal point. Thus 33.7 divided by .5 can be performed very quickly and simply by multiplying 33.7 by 2. This equals 67.4.

If you have to divide by .05 you can multiply by 20 and obtain your answer very quickly. In the example given in the last paragraph, 33.7 divided by .05 is the same as 33.7 multiplied by 20. This equals 674.

Here is a typical question based on Ohm's Law: E = 100 volts, R = 1000 ohms, what is the current?

$I = \frac{E}{R}$; substituting, $I = \frac{100}{1000}$

Answer (a) 1 ampere? (b) 1000 ma? (c) 10 ma? (d) 100 ma? (e) 1 ma?

1.000 amp = 1000 ma
.1 amp = 100 ma
.01 amp = 10 ma
.001 amp = 1 ma

Which of these five answers is correct?

By very rapid inspection, you can see that $\frac{100}{1000}$ is the same as $\frac{.1}{10}$ so the correct answer is .1 amp or 100 ma.

What would the current be if the voltage were 10 volts, 1000 volts, 1 volt?

CONVERSION UNITS

In radio and television, numbers such as .0005 are very commonly used. Many of the calculations that we make involve the multiplication and division of numbers of this order. At this point if you said, "my goodness, how difficult it is to handle long numbers with so many zeros" you'd be quite right.

Therefore, radio and television engineers have developed special small units to use when working with very small capacities so as to avoid the need to multiply and divide by figures such as .0005.

In this section we shall show how some of these special small units simplify arithmetic in dealing with such numbers.

As you are no doubt aware, the basic units used in electrical measurements are volts, amperes, ohms, farads, henries, and cycles. When considering radio and television operation, these units are often either too large for the small values that we use, or, as in the case of cycles and ohms, the numbers used would be too large (for instance a radio station which comes in at 880 on your dial actually has a frequency of 880,000 cycles per second, but because this is such a large number we divide by 1000 and call it 880 kilocycles). In this section we are going to tell you the very simple relationship between the basic units and the fractional ones that we use in our radio and television calculations.

In a typical radio and television problem we might have to divide 10 by 170,208,000. This is a pretty formidable looking problem isn't it?

```
               00.000000058
170,208,000 ) 10.000000000
               8 51040000
               1 489600000
               1 361664000
                 127936000
```

You will notice that we had to add 9 zeros to the dividend. Therefore, there will be nine places in the quotient, and the answer reads 58 thousand-millionths.

The particular problem given above might represent the capacity worked out in farads. As you know, the farad is so large a unit of capacity that only small fractions of it are ever used in radio and television. Therefore, we convert it to microfarads by multiplying by one million and our answer becomes .058, a much easier number to handle.

Technical men have developed a code of their own to indicate *thousands* and *millions*, and *thousandths* and *millionths*. Actually this code has been taken from ancient Roman and Greek so that many of the terms we use are a combination of modern English and an old language. Here is a table showing what these prefixes mean and how they affect the major units.

Kilo = 1000, therefore multiply by 1000 or 10^3 (ten cubed, or 10 raised to the third power)

Mega = 1,000,000, therefore multiply by 1,000,000 or 10^6 (ten multiplied by itself 6 times, or the 6th power)

Milli = $\frac{1}{1000}$, therefore divide by 1000

Micro = $\frac{1}{1,000,000}$, therefore divide by 1,000,000

Micro - Micro = $\frac{1}{1,000,000,000,000}$ therefore divide by 1,000,000,000,000

It is very important that you realize the difference between the prefix kilo and the prefix milli. The former means one thousand *times* and the latter means one-thousandth of. In the same way mega means one million times, and micro means one millionth of.

Remembering these points, let us look at our unit of capacity, the farad. This is such a large value that we never use it in radio and television work, in fact it is not even used in normal engineering work. To make it easier to handle, we have divided the farad into a million smaller units and call them millionths of a farad.

Since we have divided the farad into millionths, we can write each unit representing one millionth as a whole number without having to worry about decimal points, for example: 10 microfarads instead of .000010 farad. However, as you already know, even the microfarad is often too large for general radio and television use, and we often have to write a condenser value as .0005 microfarad. For such cases we use micro-microfarads; a millionth part of a millionth of a farad. This means that one microfarad (mfd) equals one million micro-micro-farads, (mmf).

Sometimes we need to convert microfarads into micro-microfarads or vice-versa. Doing this is really very simple. To convert microfarads to micro-microfarads we multiply by one million; therefore .0005 microfarad equals .0005 × 1,000,000 or 500 micro-micro-farads. To convert micro-microfarads to microfarads, divide by a million.

The same thing applies to the units of inductance. The henry is used as a unit in radio and television work, but we sometimes need to use smaller units. It simplifies our calculation if we use whole numbers instead of fractions of a henry, such as .5 henry. Therefore we use the *millihenry*. This is one thousandth of a henry. In other words .5 henry would equal 500 millihenries. In order to convert henries to millihenries we multiply by one thousand, and to convert millihenries to henries we divide by one thousand. However, even the millihenry is not always a small enough unit now that we are concerned with ultra-high frequency television and radar. Therefore we use the microhenry. This is one thousandth of a millihenry, or one millionth of a henry. Conversion from millihenries to micro-henries is exactly the same as conversion from henries to millihenries. We multiply millihenries by one thousand to obtain microhenries and divide microhenries by one thousand to obtain millihenries. Thus .5 henry equals 500 millihenries, or 500,000 microhenries.

The ampere is the basic unit of current. We meet it in many of our radio and television measurements, but we are more generally concerned with smaller values of current such as occur in grid and plate circuits. Here we use thousandths (milliamperes) and millionths (microamperes) of an ampere. The milliampere is one thousandth of an ampere. The microampere is one thousandth of a milliampere, or one millionth of an ampere. Thus .25 ampere = 250 milliamps or 250,000 microamps.

We apply exactly the same prefixes to voltages; thus, a millivolt is a thousandth of a volt, and a microvolt is a millionth of a volt.

In the case of resistance, we do not normally use units smaller than the ohm, but often in radio and television work, we have to use large quantities of ohms so that the numbers become very unwieldy. Thus a much more convenient unit than an ohm is the kilohm which equals 1000 ohms and is written with the letter K. For example, a 5000-ohm resistance is often written as 5K ohms. However, even using the kilo prefix does not always make the number too easy to use since we find that values of millions of ohms are common. Therefore we use the megohm for one million ohms. We can write 1,000,000 ohms as 1 megohm, or 1000 kilohms. However, as you can see, if we write 1000 kilohms we are getting into large numbers again, and if we have a large number there is more risk of errors creeping in. Therefore, it is much more convenient to write one million ohms as 1 megohm, or as more commonly done, 1 M.

We use a similar system with cycles, the unit of frequency. A television station operating on Channel 13 has a frequency of approximately 216,000,000 cycles. This is a very large number. So we convert it to megacycles (millions of cycles) and to do this we divide by one million. Therefore 216,000,000 divided by 1,000,000 equals 216, so we say that the frequency of a Channel 13 television station is 216 megacycles. This is usually written as 216 mc.

The kilocycle (one thousand cycles) is used in the broadcast bands to indicate the frequency of radio stations. For example, WABC in New York has a frequency of 770 kilocycles. This means that the frequency is 770,000 cycles. We could, of course, express this in megacycles, but to do this we would have to go into fractions, since 770 kc is actually .77 megacycle. In other words, it is not as great as one million cycles, so in this case kilocycle is the most convenient unit to use.

PERCENTAGES

The use of percentages is a very convenient method of conveying information concerning relationships between numbers. By using percentages, we can compare gains or losses more easily without having to state the specific amounts. Of course, we could use fractions to do the same thing, but this uses much more unwieldy numbers and in order to obtain the same reference (denominator) it would sometimes be necessary to use fantastically large numbers. By using percentages, we have a standard of reference (100) and all the advantages of the decimal system.

Suppose you wanted to find 29% of 193. This means 29 hundredths of 193, so we divide the 29 by 100 and multiply it by 193. We can divide 29 by 100 and multiply the resulting .29 by 193 and obtain 55.97 or we can write the whole problem down as follows:

$$193 \times 29\% = 193 \times \frac{29}{100} = \frac{5597}{100} = 55.97$$

Because when we write x% we are really writing "x over 100," it is a very simple mental process to calculate percentages in most cases. Most people do it by multiplying the percentage and the number together and then dividing by 100 by pointing off the two right-hand figures in the answer. Thus 57% of 83 equals 47.31

$$\frac{57 \times 83}{100} = \frac{4731}{100} = 47.31$$

To find a certain percentage of a given quantity, you can express the percentage as a decimal by moving the decimal point two places to the left, and multiply the quantity by the resulting decimal, as follows:

$$30\% \text{ of } 70 = .30 \times 70 = 21$$
$$3\% \text{ of } 70 = .03 \times 70 = 2.1$$

Similarly, we can express a decimal fraction as a percentage by moving the decimal point two places to the right, as follows:

$$.75 = 75\%$$
$$.75 \times 60 = 45, \text{ or } 75\% \text{ of } 60 = 45$$

The term "per cent" is derived from the Latin "centum" for hundred. Thus, per cent actually means so much per hundred. One per cent is the same as one per hundred, or one one-hundredth; 10 per cent means ten one-hundredths.

Percentage is an easy way of expressing a proportion. For example, you might see a survey stating that 50% of the homes in a given area had TV sets. This would mean that for every one hundred homes, there were 50 TV sets, so if there were 1000 homes, there would be 10 × 50, or 500 TV sets. In other words, 500 is 50% of 1000, or .5 × 1000.

On the other hand, if a survey showed that 25% of the families in a given area had more than one TV set, you would have no way of knowing the total number of homes with more than one set, unless you knew the number covered in the survey. If only 100 families were covered, 25 would own more than one TV set, if there were 1000 covered, 250 would have TV sets.

All these operations we are performing with decimals and percentages are really very simple, provided you remember to count the number of decimal places in the various numbers with which you are working. Then follow the rules regarding the position of the decimal point.

There are several ways of expressing the same value, for instance:

$$\tfrac{1}{4} \text{ of a quantity} = \frac{25}{100} = .25 = 25\%,$$

$\frac{1}{2}$ of a quantity $= \frac{50}{100} = .5 = 50\%$, etc.

In radio and television work, you are most likely to come across *percentage* in connection with resistor and condenser tolerances, and frequency drift. We are not going into tolerances very deeply at this point although we shall in a later section of this book. Most of the resistors and condensers that you use are described as being "20% condensers or resistors." This simply means that the resistance or capacity of the component in question can vary by as much as 20% more or 20% less than its rated value.

You may also see 5% and 10% resistors and condensers, and in some cases even 1% resistors are used. Shown below are the various limits for resistors ranging from 1% to 20%.

Nominal resistance = 51,000 ohms

51,000-ohm, 20% = 51,000 + or — 10,200 ohms

51,000-ohm, 10% = 51,000 + or — 5100 ohms

51,000-ohm, 5% = 51,000 + or — 2550 ohms

51,000-ohm, 1% = 51,000 + or — 510 ohms

Percentage of Frequency Drift. Technicians who work in radio or television stations or with communications equipment will often see a statement such as the following: "Frequency stability: plus or minus .002%." All this means is that the equipment is designed to operate at a maximum frequency variation of plus or minus .002% of its operating frequency.

Let us consider a radio station operating on 770 kc. If we want to find out what the maximum frequency variation may be when the equipment has a frequency stability of ± .002%, we merely calculate .002% of 770 kc. We do this as follows:

$$.002\% \text{ of } 770 \text{ kc} = \frac{.002 \times 770}{100} = .0154 \text{ kc}$$

This answer is given as a decimal part of a kilocycle and is extremely difficult to handle. Therefore we will convert .0154 to cycles. To do this we multiply .0154 by 1000, and the answer is 15.4 cycles. Therefore the maximum frequency deviation permitted for this radio station is + 15.4 cps. or — 15.4 cps. This is a total deviation of 30.8 cycles.

You may sometimes see a frequency stability described as one part in 100,000.

$$1 \text{ in } 100{,}000 = \frac{1}{100{,}000}$$

This can be expressed as a percentage—

$$\% = \frac{1}{100{,}000} \times 100 = \frac{1}{1000} = .001\%$$

In actual fact, a frequency stability of at least 1 in 100,000, or .001% is very common today and most radio and television equipment is required by the FCC to have much better stability than this.

SIGNIFICANT FIGURES

Sooner or later in your radio and television mathematics you are bound to come across the phrase "significant figures." This concerns the accuracy of calculation needed in any particular problem.

In most of our work a result that is accurate to two or three places is sufficient. However, by this we do not mean that radio and television engineers are careless, or willing to sacrifice accuracy just to be lazy. The real reason is that beyond a certain point numbers represent such small values that they may become insignificant—depending on their function.

Occasionally we have to carry out a division to many decimal places, but generally this is not necessary.

Suppose we have $10 and divide it among three people. If you divide 3 into $10 you get $3.33 for each person. If you add together these three quotients to check your arithmetic, you find that the answer is $9.99. You have one cent left over! You could, of course, continue to divide and get a third decimal place. You would have $3.333. No matter how many times you continued to divide you would still get the figure 3 as your answer. So we say that the answer is $3.33. There is no point in going any further because no matter how many threes you add to the answer, it will not change the fact that the amount of money each person gets is $3.33.

In the answer above we have three significant figures. We could say if we were dividing 10 by 3 for example, that the answer was 3.33 recurring. The word "recurring" informs any reader that the number 3 will continue to occur in the answer an infinite number of times.

Mathematicians and engineers use a special method to show that an answer has been calculated to the maximum number of significant figures and that the last figure recurs. To do this, a dot is placed over the extreme right-hand number. For example if we wanted to show that 3.33 was the answer, and that after this operation the 3 would recur, we would write the number as follows:

$$3.3\dot{3}$$

In the case above, the significant numbers were limited to those which have their counterparts in dollars and cents; in other words, they were limited by the practical consideration of our monetary system.

In radio and television, the limitations are imposed by the accuracy of electrical instruments, and these are seldom more accurate than 5%. Most meter scales are marked so that no more than 2 or 3 significant figures can be obtained. Generally one or more of these will have to be estimated.

Consider the following example: If an accurately known current of 3.16 amperes is flowing through a resistance of 45.7 ohms, by simple Ohm's Law, (E = I × R), 3.16 × 45.7 = 144.412 volts.

However, there are no voltmeters that will indicate differences of thousandths of a volt when reading values over 100 volts. In fact it takes a very good voltmeter to read 144.4 volts. Therefore we say that the last three figures are insignificant, and for practical purposes we would take 144 volts as correct.

However, if our calculated answer had been 144.567 we would have regarded it as 145 volts. From this, we find a system for reducing to the number of significant figures required.

Consider the figure on the extreme right hand—in other words the last decimal place. If this is less than 5 drop it, and use the figure on its left. On the other hand if it is more than 5, increase the figure on its left by 1, thus making it one number larger.

Suppose that in the first case we had the number 103.4572, and wanted to make it significant to 3 decimal places. We would drop the 2 and make the answer 103.457. It would have *six* significant figures. Now suppose that we have the number 103.4577. This time, reducing to six significant figures we would write the number as 103.458. The number of significant figures is determined by practical considerations. If a meter cannot give more than three significant figures, and our results have 4 or 5, we can reduce to the required number as we have shown.

In calculations involving meter readings, three significant figures are all that are ever required, but in this case, the three are those to the *left* of the decimal point. Actually, with most meters it is possible to read two significant figures and to estimate the third with reasonable accuracy. If great care is used, a fourth significant figure might be estimated, but since this is purely an estimation (and since such accuracy is not required for practical purposes) there is no point in going beyond 3 at the most.

A general rule to follow is that if two or more numbers are multiplied, divided, or added, the answer should contain as many significant figures as the least accurate number. For example, suppose we measure a resistance on an extremely accurate Wheatstone Bridge and find it is 45.7285 ohms. Then we read the current flowing through the resistance on a less accurate ammeter and find that it reads 3.22 amperes. If we wish to calculate the voltage, our accuracy can be no better than that of the ammeter which reads to two significant figures. To calculate the voltage, we multiply 45.7285 by 3.22. The answer comes to 147.2458 volts. However, we take as our answer 147 volts, because the ammeter could be read to only two decimal places and we thus obtained three significant figures from it. Also, a voltmeter used to measure the voltage and thus check our calculations could not give a reading containing 7 significant figures.

In most radio and television calculations we consider only three figures as being significant. For example, applying the rule, the number 39607 would become 39600. On the other hand, .39657 would become .397, and .51749 would become .517; however, .51751 would become .518, etc.

Meter Scales

If you look at Fig. 1 you will see a voltmeter scale with a 150-volt range on it. A voltage—86 volts—is indicated by the pointer. You will notice that each major division is sub-divided into 5 sub divisions, each of which is equal to 2 volts. You can also see that it is not too difficult to read 85 volts, or 87 volts. These values are half-way between the marked sub divisions. We could even estimate 87.5 volts reasonably accurately. Beyond that it would be difficult, in fact foolish, to try to estimate on this particular meter.

Now look at the second scale, in Fig. 2. This time the scale, which has the same number of divisions, is calibrated to read up to 75 volts, or exactly half the previous readings.

The angular deflection of the needle is the same, but this time it reads 43 volts. Each major scale division is worth 5 volts and each sub division is only 1 volt.

Now look at Fig. 3. This time the meter scale has a full-scale value of only 7.5 volts. With the same needle deflection, the meter reads 4.3 volts. Each major division is equal to 0.5 volt and each sub division is 0.1 volt.

Let us look at the relationship between the three scales. Fig. 3 is one tenth of Fig. 2, and one twentieth of Fig. 1 and a similar relationship exists of course, between the three readings.

If we consider scale 1, we see that it is difficult to read to half a volt. We might be able to read 75.5 volts but it would be merely a good guess. In any case the meter accuracy would not make it worth our while to read as close as half a volt on the 150-volt scale, since this would work out to an error of 1 in 150 or .7%. Accuracies of this order are usually impossible to accomplish with the average meter.

This discussion of meter readings brings us now to:

PRACTICAL METER READINGS

If you have occasion to buy a meter or specify a meter for a piece of equip-

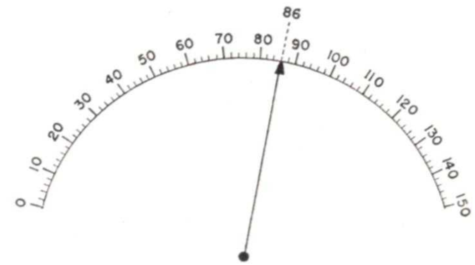

FIG. 1. A 150-volt meter scale. Each scale sub-division indicates 2 volts.

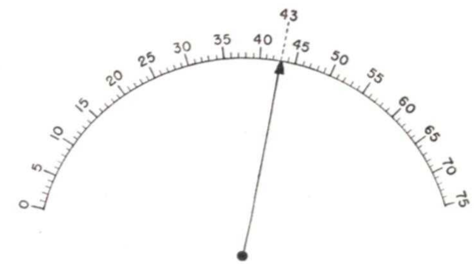

FIG. 2. A 75-volt meter scale. The scale is the same size as the one shown in Fig. 1, but in this figure, each sub-division shows one volt.

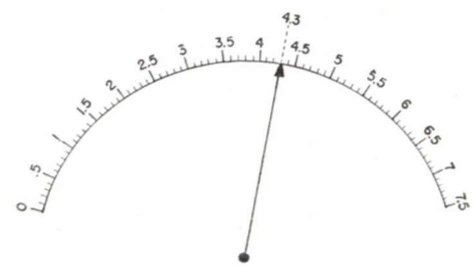

FIG. 3. On this scale, each sub-division is equal to a tenth of a volt (.1 volt).

ment, you should choose one that will indicate the expected values at about two-thirds of full scale. Put another way, the meter range should be selected so that all readings are made between half scale and full scale. This means that if you want to measure a voltage of about 135 volts, you should choose a 150-volt meter. This would give more accurate readings than a 300-volt meter.

There are two reasons for this. First it is easier to read on the lower range meter because the divisions are larger and each scale division represents a smaller voltage. Secondly, the meter accuracy, or scale accuracy, is greater between half scale and full scale.

Meters are rated for accuracy in terms of percentage of full-scale reading. The average inexpensive meter has an accuracy of 5% or 10% depending upon the way it is constructed. Precision meters in high-quality measuring instruments generally have an accuracy of 2%. Whenever we discuss meter accuracy in terms of percentage we mean plus or minus this figure. Therefore on a meter with a full-scale deflection of 10 volts and a 10 per cent accuracy, the reading may vary by as much as plus 1 volt or minus 1 volt from the true voltage. In other words, if the meter indicates 10 volts, the true voltage may be anywhere between 9 volts and 11 volts (10, plus or minus 1 volt).

In the case of a 2% meter, the maximum variation with 10 volts applied to it would be 2% of 10 = .2 volt. Therefore at full scale, the voltage could be between 9.8 volts and 10.2 volts.

A variation of even 10%, that is 1 volt in 10, does not seem too bad. In many cases, certainly, a variation of .2 volt in 10 is almost negligible. However, consider what happens towards the low end of the scale. For example, the 4-volt point. Remember the meter accuracy can vary between — .2 and + .2 volt (2% of 10 volts). But at 4 volts, a variation of plus or minus .2 volt can give a reading of 3.8 volts or 4.2 volts. Expressed in another way a variation of .2-volt becomes 5%!

Reading 2 volts on the same meter might give us an error of 10%. Fortunately great accuracy in meter reading is not generally essential because of variations in components themselves. It is usually only in the laboratory that extreme precision is required in reading meters and in the results they give. As far as radio and television servicing is concerned, in almost every case, an accuracy of 5% or 10% is perfectly adequate.

TOLERANCE

One of the main reasons for the tremendous popularity of radio and television in the United States is mass production. By mass production we mean production on a tremendous scale, using all the assistance that can be provided by mechanical means. When we manufacture things using mass production methods we have to sacrifice something, and this is a certain amount of fine quality.

Suppose we want to wind a coil with an inductance of 10 millihenries. In the laboratory, a man will sit down with a coil-winding machine, and having calculated how many turns should be put on the coil, proceed to wind it. Then he measures the inductance of the coil on an inductance bridge. The value is almost certain to be wrong. If it is too high, he will remove a few turns, put the coil back on the bridge, and measure again. If it is too low, he will have to wind another coil, because he can't add any turns once he has cut the wire. The technician will continue to adjust the coil and reconnect it to the inductance bridge until he has obtained exactly the 10-millihenry inductance desired.

This process may take an hour. So you can see how time-consuming it is when you want to get *exact* values. As a matter of fact, this is one of the reasons why the early radio and television receivers were so expensive—many parts were made by hand. A machine cannot think—in spite of all of the improvements that have been made in automatic calculators, no machine has yet been made that can think the same way that a man does. On the other hand, we *can* set certain limits between which a machine can operate, and know that unless something fails, the machine will continue to run between these two limits.

By doing this, we sacrifice the preciseness obtained by manual operations. In the case of the 10-millihenry coil, we could design a machine that would wind a coil to within about 1 per cent of the required value as far as mechanical considerations are concerned. But the machine could not account for variations in thickness of the wire, thickness of the insulation on the wire, tiny changes in size of the form on which the coil was wound—changes which are sometimes caused by temperature or weather conditions. However, we could set the machine so that it made the required number of turns, say fifty, and give us approximately 10 millihenries. We can then set up a special type of inductance bridge with a jig (a jig is a device that makes possible very rapid connections for testing purposes). This inductance bridge would have a large meter scale with upper and lower limits on the dial. The limits might be marked "low" and "high" and would correspond to an inductance of 10 millihenries ± 5%.

The operator would take the coils as the coil-winding machine wound them, and drop them in the jig. If the meter read anywhere between high and low, he would accept the coil, although it might vary as much as 5% from the required value. However, similar types of variation occur in every mechanical manufacturing process, and by a fortunate coincidence, very frequently a minus variation in one component is offset by a plus variation in another so that the net result is approximately what we want.

You have heard of 20%, 10%, 5%, and 1% resistors. Let's see what this means when applied to a 20-megohm (20,000,000-ohm) resistance, and to a 100-ohm resistance. In the 20-megohm resistance, the tolerance, as we call this allowable manufacturing variation, of 20% will be 20 megohms ± 4 megohms. Thus its value can be anything between 16 megohms and 24 megohms, or a 4,000,000-ohm variation in either direction.

On the other hand, a 1% resistance variation (20 megohms ± 1%) equals 20 megohms ± 200,000 ohms. You are not very likely to encounter 20-megohm 1% resistors since a variation of 200,000 here is so slight as to be just about negligible.

If a 100-ohm resistor has a 20% variation, it can vary between 80 and 120 ohms. On the other hand, in a 100-ohm 1% resistor, such as might be used in a multitester or a vacuum-tube voltmeter, the permissible variation is only 1 ohm. In other words it might vary between 99 ohms and 101 ohms.

When interpreting meter readings, you must always take into consideration the type of circuit you are measuring. For instance if the voltage in a high B+ circuit is supposed to be 250 volts, any value between 225 and 275 is nearly always acceptable. In an extreme case the voltage might even read as low as 200 and still be correct.

On the other hand, you know that the heater voltage in an ac receiver is normally 6.3 volts. If you got a reading of 5 volts you could reasonably suspect that something was wrong with the circuit. But if the meter read 6 volts or 6.6 volts, you would not need to worry unduly. A 5% error in the meter you were using would account for .5 volt if you were using a 10-volt meter.

As you go through your experiments, you will realize more and more how wide the variations between individual tubes of the same type may be. When we take these tube variations into account and consider them in connection with resistance, inductance, and capacity tolerances, we begin to see why meter readings should be regarded as guides or indicators rather than absolute values.

In general, radio and television transmitters are much more critical in their reaction to voltage variations than receivers are. As a result the meters mounted in transmitter cabinets, which form an integral part of the transmitter, usually have a 2% accuracy. In fact the FCC normally requires meters of this accuracy to be used for transmitters.

When using very accurate meters, the reader should also be as accurate as possible. If an accurate meter is supplied, the readings are usually important and should be made very carefully. Remember that in an oscillator, a very small change in voltage can quite frequently produce a comparatively large change in frequency. By the time this frequency change has been multiplied perhaps fifty times or more, the resulting carrier frequency may be a long way away from the transmitter's assigned frequency. On the other hand, in the power-amplifying stages of the transmitter, even a large change in plate or screen voltage will not affect the transmitter's frequency, and may make only a very small change in the power output.

In the receiver, voltage and current changes are usually not too important provided the readings obtained are *approximately* correct. For instance, in the output stage, the power can drop to one half of its original value, or can double, before our ears are able to detect the change.

Because of this very useful characteristic of the human ear, we do not have to worry too much if our output stage voltages are not *exactly* the same as those specified in the manufacturer's instructions. In the case of radio and television receivers, if the receiver is completely inoperative, a small variation from the manufacturer's figures generally has no significance whatever. The only exceptions to this may be found in the oscillator and mixer stages of a superheterodyne receiver where the oscillator voltage is frequently critical. On the other hand, if the set works, but distortion is present, a smaller voltage or current change may have significance. In the case of distortion in an audio stage, the presence of a small positive dc voltage on the grid of one of the audio tubes can indicate that the tube is gassy, or that the coupling condenser between that stage and the previous one is leaky and is allowing B+ to reach the grid of the tube. This naturally results in distortion.

Summing up, *tolerance* is important in your consideration of meter readings. Before dismantling a radio or television receiver because B+ varies by 50 volts from the manufacturer's

figure, consider whether the meter on which you are reading this voltage has a high or a low accuracy and whether a 50-volt variation is important in connection with the receiver's symptoms.

Algebra

Don't let this word algebra frighten you! As a matter of fact, algebra is very often easier to do than ordinary arithmetic!

Algebra is only the use of letters as symbols instead of figures. When we use algebra, all we do is use letters to represent numbers and figures. There are many reasons for doing this, but chief among them is the fact that using letters instead of figures is very convenient. Sometimes we have to handle very large numbers, or numbers containing many decimal places. It is sometimes necessary to re-write expressions containing these numbers many times during the course of a calculation. This often introduces errors and in any case it is very time-consuming. So, provided that we realize that the letters should be treated in exactly the same way as the numbers, and do in fact stand for numbers, we shall have no difficulty in following simple algebra.

We can also combine numbers with letters and use these combination expressions in exactly the same way as we use numbers in arithmetic—we can add, subtract, multiply, and divide with, and by, letters.

Ohm's Law is probably the most well known radio and television formula. It certainly enters into almost every problem in connection with electronics. We know that Ohm's Law states that current equals voltage divided by resistance. Instead of writing current we use the symbol I. Similarly instead of writing voltage we use the symbol E, and we denote resistance by the symbol R. Already we have developed a form of algebra when we write this expression.

$$I = \frac{E}{R}$$

Now let us suppose that we want to calculate the value I (current) and that we know that the resistance in the circuit is 100 ohms and the voltage is 20 volts. We write down R (resistance) equals 100 ohms, and we write down E = 20 volts. Now we write down the expression $I = \frac{E}{R} = \frac{20}{100} = .2$ amp. You see, all we did was substitute. We replaced the letters in the formula with the numbers they represented.

Many of us find difficulty in determining which way we need to write Ohm's Law to find a given circuit value. Or sometimes we become confused in translating letters into numbers. Although we write $I = \frac{E}{R}$ or $E = I \times R$, this does not mean that there is any direct relationship or connection between ohms, volts, and amperes, except the manner in which variations in one or two of these quantities affect the third.

Ohm's Law is merely a statement of an operation which can be performed only when the values represented by the letters are known. In other words, when we say $I = \frac{E}{R}$, we are stating that the *amount* of voltage when divided by the *amount* of resistance gives the *amount* of current. So that all we have to do is substitute the *amounts* for the letters and then perform the arithmetic operations indicated.

As soon as we determine which of the three forms of Ohm's Law we need to use depending upon which two values we know, and have substituted the two known amounts in figures for the letters which represent them, we can perform the multiplication or division required and thus find the third, unknown amount.

Let us take an example, using very simple numbers:

Suppose that E = 6 and R = 2. Substituting the figures in the formula $I = \frac{E}{R}$, we have:

$$I = \frac{6}{2}$$
$$= 3$$

Now, by substituting the figures, we can find the other forms of Ohm's Law. Since E = 6, R = 2, and I = 3, we can see that to find E, we must multiply I × R, and to find R, we must divide E by I. This gives us the three forms of Ohm's Law:

$$I = \frac{E}{R}$$
$$E = I \times R$$
$$R = \frac{E}{I}$$

Every time you work out a problem in Ohm's Law, you are actually using algebra. It is not so hard, is it? Here is an example:

Suppose a tube is drawing a total current of 25 ma. What value of cathode bias resistor should be used to produce a bias voltage of 10 volts?

We know the current and the voltage, so to find the resistance, we use the formula:

$$R = \frac{E}{I}$$

You must remember when using any of the forms of Ohm's Law, that the voltage must be expressed in *volts*, the current in *amperes*, and the resistance in *ohms*. So before we can go ahead we must convert the 25 milliamperes to amperes. To do this, we divide by a thousand, which gives us .025 ampere. Then, substituting figures in our formula, we have:

$$R = \frac{10}{.025} \text{ or } \frac{10{,}000}{25}$$
$$= 400 \text{ ohms.}$$

In a later reference text we will tell you more about algebra, and show you how algebra can help the radio-TV serviceman. Remember that you can complete your course and go into service work without even reading these books on mathematics, but if you do study them, you will find them interesting and useful not only in your servicing work, but in your everyday life.

PROBLEMS

Given here, are the correct answers to the sample problems given throughout this reference text, so that if you want to try your hand at them, you can check your work. Remember, you do not have to solve these problems. They are merely included to give you practice if you want it. Do not send your answers in to NRI, the answers are here so that you can check them yourself.

Addition, page 4:
345,708 38,587 37,130

Subtraction, page 5:
1741 1212 2686

Multiplication, page 8:
10,937,067 59,410,016 23,887,112

Division, page 11:
54 741

Square root, page 13:
64

IF—

If you can dream—and not make dreams your
master;
If you can think—and not make thoughts your
aim;
If you can meet with Triumph and Disaster
And treat these two impostors just the same; . . .
If you can fill the unforgiving minute
With sixty seconds' worth of distance run,
Yours is the Earth and everything that's in it,
And—which is more—you'll be a Man, my son!

* * * *

This poem by Rudyard Kipling has long been an inspiration to me, so I am passing it along to you.

J. E. Smith