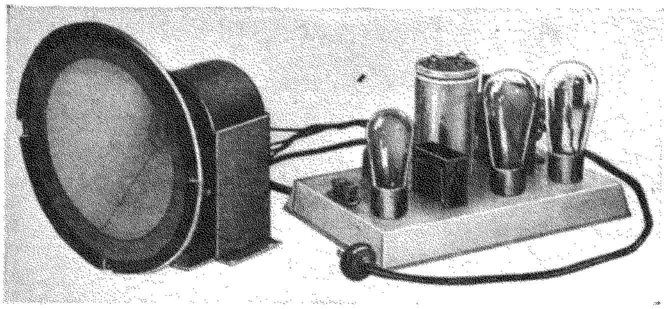


Photograph of an A.F. direct-coupled amplifier built by the author which uses the circuit of Fig. I.

DESIGNING AND CONSTRUCTING DIRECT-COUPLED A. F. AMPLIFIERS

The first of a series of two articles designed to give the reader a number of practical direct-coupled circuits with sufficient design data to explain "what's what."

L. B. BARCUS

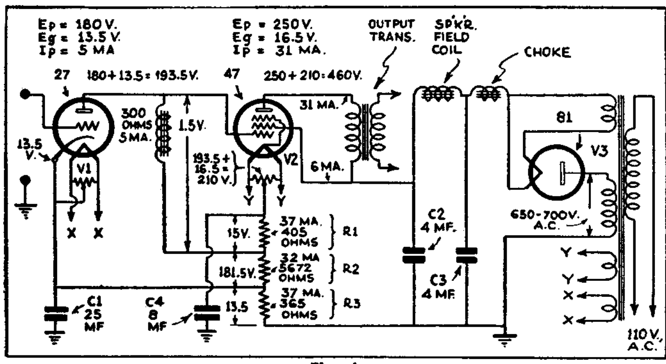


Fig. 1
Circuit of a direct-coupled amplifier using a 27 (or 56) feeding a 47.

OF LATE the attention of the radio fraternity has been turned more and more to the audio characteristics of radio apparatus. Urged on by the better class of radio receivers, the public has become critical of tone quality wherever audio amplification is employed. In an attempt to stimulate the sale of radio sets, engineers have made tremendous strides in the perfection and development of existing circuits. The past year has seen a number of elaborations in audio circuits, giving, in the aggregate, more power, better control and greater fidelity.

Unfortunately, however, practically every application of audio amplification in use today makes use of circuits almost impossible of complete perfection. Even the best amplifiers, in use today, show considerable distortion, regardless of the care and expense involved in their construction. For this reason, the amplifiers to be discussed in these articles were developed to give every constructor the opportunity to build an amplifier which will fulfill his every expectation and to give results noticeably superior to the most expensive conventional circuits.

The direct-coupled amplifiers, to be described, are all alike in that they are uniformly free of drummy, muffled, or blaring output. Their frequency response is uniform from the lowest bass to the highest note broadcasted. The limitations of these circuits are not in themselves, but in the speakers and the input systems in use today.

Each of these amplifiers is constructed upon one basic system, and a clear understanding of the principles will enable anyone to devise an instrument to exactly fit his own needs. A close study of Fig. 1 will reveal the underlying facts encountered in the system. Since the plate of one tube is directly connected to the grid of the next, the first problem, naturally, is that of arranging the voltages to give each of the tubes its normal operating potentials.

Theory of Direct-Coupled Circuits

If V1 and V2 have the same plate-current drain, and the plate of V1 is connected to the filament circuit of V2 by the choke, it follows that the two tubes will form an electrical circuit similar to two resistors in series, and any plate voltage applied to V2 will be divided between the two tubes. Thus, by giving the plate of V2 a potential equal to the sum needed by both tubes, we have a method of giving both stages the proper differences of voltages while gaining, at the same time, the highly desirable direct-coupling. Let us consider the facts in greater detail.

It is seldom that the first stage, V1, draws as much current as the succeeding tube. Therefore, we must rely on resistors R1, R2, and R3 (Fig. 1) to apportion the currents properly. The determination of the values of these resistors is the chief calculation encountered in designing an amplifier.

If any value of "B" voltage is available, the voltage requirements of each tube are noted. Then, beginning with the grid of V1 which is effectively at ground potential, the required tube voltages are jotted down on the diagram and added, progressively, throughout the circuit as shown. In Fig. 1 there are four voltage levels in the circuit, the cathode of V1 being the first. With the operating potentials given, the voltage applied to the plate of V2 amounts to 460 volts. This high voltage can be best obtained by using a type 81 rectifier tube, as shown. The usual power transformer with a 650- or 700-volt center-tapped secondary winding may be used. When used with a choke input to the filter, the well regulated output of the filter is approximately the correct voltage needed. In case only a *limited* "B" voltage is obtainable, it must be apportioned to the tubes in a manner best calculated for their satisfactory operation.

The first step is to determine the voltage drop across the coupling choke by the formula, E equals IR, where I is the plate current of V1 and R is the resistance of this choke. This voltage drop is seldom enough to furnish the bias for V2, it being only 1.5 volts with the choke shown in Fig. 1, so that the balance of the bias must be obtained otherwise. It is feasible to place a resistor in series with the choke, but the author prefers to use R1 to maintain a more stable bias. The entire plate current of V2 flows through R1. Thus, the rest of the needed bias is calculated in the usual manner. Tube V2 normally has a bias of 16.5 volts, 1.5 volts of which results from the voltage drop across the choke, leaving 15 volts as the potential across R1. Therefore, by Ohm's law, R1 equals E/I or 15 divided by .037 ampere, which gives R1 as 405 ohms. It should be observed that the screen of the 47 tube draws 6 ma. which must be added to the plate current in the calculations.

The bias of V1 is derived from R3, which is seldom over 500 ohms due to the large current flowing through it. While the plate of V1 draws 5 ma. from the resistance strip, this entire amount is returned to it through the cathode of the tube resulting in the same current flowing through R3 as through R1. The 13.5 volt bias divided by 37 ma. thus gives us a value of 365 ohms for R3.

It falls upon R2 to bear the greatest load in maintaining the filament of V2 at the proper potential. The voltage drop across R2 is always equal to the desired plate voltage of V1 plus the voltage drop across the choke, or 181.5 volts in Fig. 1. Since the 5 ma. consumed by V1 does not flow through R2, that amount is subtracted from the total current flow through R1 in calculating the correct value of R2. In Fig. 1, therefore, R2 equals 181.5 volts divided by .032 amp which results in 5,672 ohms.

Regardless of the complexity of the circuit to be used, it is necessary to rely on no more than arithmetic in calculating the values of the components. No difficulty will be encountered if, first of all, the required voltages at all points are noted and the various divisions of currents traced, as was done above. In each of the diagrams illustrating this article, each step is shown. A study of them should give enough pointers to enable the average technician to design any type of amplifier, desirable, from two stages to a multi-stage P.A. system with 500 watts output.

Volume Controls

In order not to disturb the voltages and currents flowing in an amplifier, a different type of volume control is necessary. A potentiometer shunted across the choke would remove the grid bias of the following tube in some cases and alter it in others when the arm of the potentiometer, to which the grid of the tube is connected, is turned to the low potential side. In Fig. 3, where the voltage drop of the choke is only 1.5 volts and the total bias 50 volts, the use of the potentiometer shunt could scarcely be called objectionable since the bias would not be thrown off over 3%. In Fig. 2, however, the bias would be altered over 10%. It is wise, therefore, to insert a large bypass condenser on the lower side of the potentiometer or to run the lead to a tap on R2 at the same voltage level as that of the plate of V1.

Considering that these systems were designed solely for their superior tonal characteristics, care should be taken in choosing the components with which an amplifier of this type is to be built. For example, C1 and C4 shown in Fig. 1 should have a high capacity, with C1 one of the low-voltage, high capacity bias type. The audio chokes are most important, too; although the action of this type of amplifier tends somewhat, it seems, to improve the frequency characteristics of audio chokes so that one having only a fairly straight line choking effect will be found to give good account of itself when used in this connection. Naturally, however, a choke of the very best sort should be selected.

DIRECT-COUPLED AMPLIFIERS

Most men are afraid to build direct-coupled amplifiers because they don't know what makes the wheels go 'round. The author, in this series of articles, gives a number of modern arrangements using the direct-coupling principle; and, at the same time, explains each and every step. Nothing is left to the vivid imagination of the builder.

Direct-coupled amplifiers have long been known for their simplicity, low cost, and, most important of all, for their excellent fidelity characteristics.

Here is your chance to understand and build direct-coupled amplifiers.

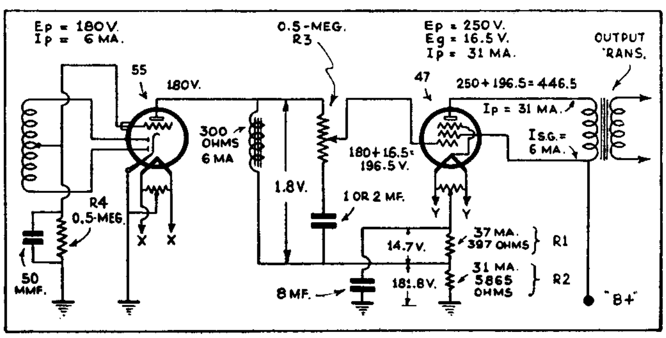


Fig. 2
Another direct-coupled amplifier featuring the 55, duo-diode triode.

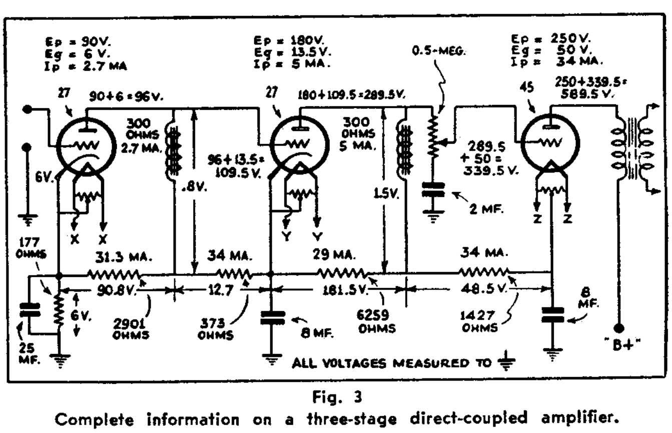


Fig. 3
Complete information on a three-stage direct-coupled amplifier.

Uses of the Amplifiers

When using a tuning system of extremely high gain, we may fall back on a recently popular layout; that is, the use of a power detector with one audio stage. V1 of Fig. 1 would thus be converted into the detector with V2 as the power output tube. The tone quality would be good, to be sure, and much better than if any other type of interstage coupling were used. If at all possible, a type 45 tube should be substituted for the 47 because of the inherent weaknesses of the pentode tubes in operation and performance. Likewise, a screen-grid tube is not at all satisfactory in place of V1. The high resistance necessary in its plate circuit precludes the use of this system without the use of automatic bias and other desirable factors which are to be found in the well-known Loftin-White circuits. Screen-grid tubes are subject to many of the weak points of the pentode in tone, and are never recommended by the author in audio amplifiers.

Another possible use of two stages is with diode detectors, as shown in Fig. 2. If the R.F. end of the receiver gives sufficient gain, there is a good possibility of excellent performance insofar as the 47 pentode may be dispensed with and a triode power tube used in its place. Since the amplifying half of the 55 is diode-biased, there is no need for an audio bypass condenser which means better tone. It should be noted here, that in many cases the voltage drop across R4, due to the rectified signal, may be insufficient to properly bias the triode half of the 55, except on strong local stations. For this reason the plate voltage on the 55 should be as low as possible without too much sacrifice.

In the quest for greater gain, the most logical development of the two stage layout is, naturally, the use of three or more stages using practically the same system as the two-stage amplifier. Figure 3 shows a three stage amplifier designed along these lines. It is actually very simple to construct and requires only one tapped resistor, a point which promises long, trouble-free life. Every technican knows how often the numerous resistor units fail, especially in resistance coupled systems, and the promise of substantial wire wound components and unchanging voltages should be appealing.

We may extend the idea to four or even five stages should it be necessary. There is no technical difficulty other than the necessity for a high potential. Regardless of the number of stages, only one tapped resistance is used, and the tone quality is superior to resistance-capacity coupling. It should be noted that a separate filament winding is used for each stage to avoid high poten-

(Continued on page 111)

DIRECT-COUPLED A.F. AMPLIFIERS

(Continued from page 81)

tials between the elements of the tubes.

Since the very high potential necessary calls for more expensive parts, which are sometimes hard to obtain, we will, next month, go into more elaborate types of direct-coupled circuits which give high gain and even better tone without demanding other than the standard components in universal use today.

DESIGNING AND CONSTRUCTING DIRECT-COUPLED A. F. AMPLIFIERS

PART II

This article is the second, and final, of the series giving complete theoretical and constructional details of direct-coupled amplifiers.

L. M. BARCUS

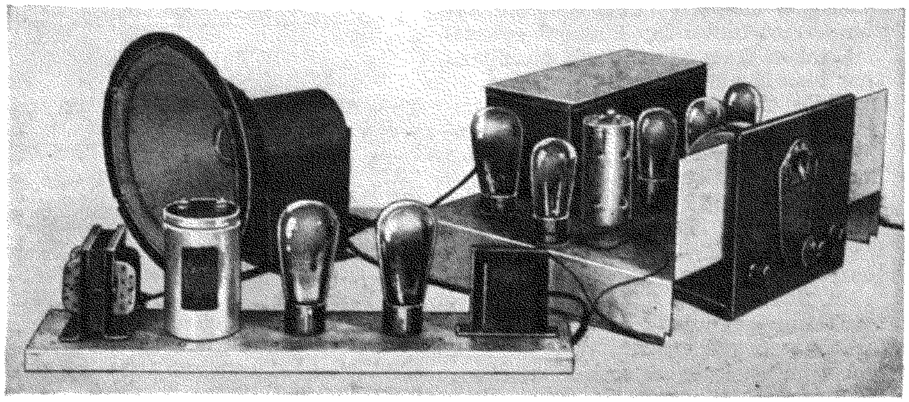
IN last month's issue of RADIO-CRAFT we touched briefly upon the construction of a two stage amplifier and gave enough details of the calculations to enable anyone to design his own particular amplifier. It was remarked, at that time, that the two stage amplifier had too small a voltage gain to have extensive uses, and that the plain, three or more stage circuit had drawbacks which limited its applications with ordinary materials. Therefore, this article will touch upon more elaborate types which give high gain and output without demanding other than standard components in universal use today.

In order to derive the benefits of multi-stages without resorting to special apparatus in the voltage supply—which would mean high cost and possibly trouble—a double powered amplifier was developed, as shown in Fig. 4. By using this method, the number of stages may be extended indefinitely without relying upon excessively high potentials; in addition, it does away with some of the bias bypass condensers, which naturally results in an additional advantage—better tone quality.

The layout of Fig. 4 is the one preferred for all receivers, including television. Outside of the power units, there is only one audio bypass condenser employed. This gives the lower frequencies a chance to show themselves, and their strength and clarity are amazing. Yet, there is absolutely no trace of the hollow barrel effect usually associated with receivers that produce the lower notes by artificial tone control methods.

For Service Men or others who desire to remodel old receivers whose tuning units are satisfactory, the layout of Fig. 4 is especially convenient. It permits the use of practically all the parts in the receiver, and only requires the addition of a power transformer, a filter choke, and two filter condensers. Because the power stage requires but 250 volts, the 50-volt bias being obtained from the first power unit, and because the current drain is small, the power transformer may be of any of the now obsolete types. They all have a 2½-volt filament winding which is suitable for the 45.

The second audio stage (a 27 or 56) requires a separate filament winding since the filament is at a much higher potential than ground. If the filament of the first-audio socket in the receiver is not individually wired, the power tube winding is usually adaptable, provided that a 45 tube is used. In case 5-volt filaments are used, the voltage may be dropped to 2½ volts by suitable resistors or, if the winding is center tapped, one-half of it may be used.



Typical converted receiver using the circuit of Fig. 4 constructed by the author.

As a general rule, any audio transformers in the receiver may be used as audio chokes in the revamped set. The primaries and secondaries should be wired in series to obtain the best results. It is preferable, however, to use good audio chokes if the added expense is not objectionable.

The removal of the heavy drain of the power tubes from the tuner power pack will necessitate readjustments of the voltages. In some cases, particularly those where the power section and speaker are separate from the tuner, it may be advisable to use the new power supply for the tuning section and to retain the power section of the set as it stands. A few changes are necessary to adapt such a unit for its new purpose.

Whatever voltage supply is used for the tuner, it must be capable of giving a fairly high potential, since V1 and V2 derive their operating voltages, in addition to the bias for V3. 300 volts is usually sufficient for this purpose. As 50 volts are required for V3, this leaves 250 volts to be divided between V1 and V2. Inasmuch as the triode half of the 55 is diode biased, 90 volts on its plate will tend to accommodate the inequalities of bias and give better results than if the maximum potential were used. This will leave some 160 volts for V2 of which about ten will be required for its bias.

For those desiring a straight amplifier of the type in Fig. 4, for P. A. systems, phonographs, and the like, the only changes are in the first stage where the proper tube is substituted for the 55 and means for its bias taken care of as explained previously. If four stages are wanted, the second power section can be designed to accommodate another tube between V2 and V3. The effect is, in general, that of two, two stage amplifiers placed in series.

It must always be remembered that the second power unit is at a very high potential above ground and its parts must be insulated from the tuner chassis, or first section. For this reason, it is always preferable to build it as an individual unit in conjunction with the power tube and speaker.

The fact that a bleeder current flows through the series of resistances in Fig. 4 does not complicate the calculations to any extent. The only requirement is to add the desired bleeder current to the normal tube currents in each case. In Fig. 4, a bleeder current of 10 ma. was used in the calculations. The 5 ma. of V2 and the 10 ma. bleeder current thus flow through R1, while only 10 ma. passes through R2. V3, of course, has no bearing on any of the current flows, being an entirely separate unit.

Choke 2 of Fig. 4 may be mounted on either unit, depending entirely on mechanical convenience. However, three lead wires are necessary when it is mounted on the power tube unit, the leads running from the points marked

DIRECT-COUPLED AMPLIFIERS

Look through your files of diagrams of commercial radio receivers and notice how many of them use transformer coupling in the audio stages—practically none. Resistance coupling is at the wheel, and it certainly is doing its stuff. Direct coupling is an improved form of resistance coupling; it has all of its advantages and few of its disadvantages. In fact, it's the only "perfect" coupling to use.

with an x. R1 should preferably be placed in the second unit with choke.

One for the Experimenter

For those of an experimental turn of mind, the circuit in Fig. 5 may provide an interesting and instructing amplifier. The cost of construction is practically the same as that of a two stage system, yet it has the added advantages of much greater gain and output.

Unfortunately, the auxiliary power tube is not directly coupled to the source of its signal input, but must make use of the usual stopping condenser. However, this condenser is preferably of a large size and the usual bypass condenser from the power tube filaments to ground is eliminated, so any impairment of tone is more than counteracted.

The use of such an amplifier with power tubes of high gain is somewhat doubtful, although it has been operated with great success with standard low mu tubes, such as the 45. When used with a radio tuner, such an amplifier is sometimes obstructed in its operation by residual R.F. currents which go into a regenerative cycle in the power stages. Such an action is easily overcome by the use of a small bypass condenser from the plate of the first power tube to ground.

While only a few circuits have been presented in these articles the system of direct-coupling must not be construed to be limited to them. This coupling method can be adapted to practically any situation where superb tone is the chief factor. While the author has not actually constructed push-pull arrangements, there is little reason to doubt the success of complete systems. The absence of bias condensers and the removal of other restricting elements of the straight systems should result in beautiful reproduction with tremendous power. The cost, too, is very little more, since the same number of resistors would be used and only additional chokes and sockets needed. In a push-pull circuit based on Fig. 4, the full-wave rectification of the signals would be achieved by the use of twin 55 tubes, each feeding one side of the amplifier, or one 2B7 tube could be used with each diode plate operating into one half of the audio section.

In closing, it is appropriate to stress the fact that any amplifier based on this system should be considered more in the light of a delicate and precise musical instrument than as a soulless bit of apparatus. It is not exacting in its requirements and will perform miraculously over a wide range of values, but every additional care taken in its construction is reflected in increased beauty and mellowness of tone. It will make any speaker sound like a new thing; yet that vital part should be chosen with the greatest of care, and one should be sought which is capable of performing over the extended range of frequencies. The input transformer should be carefully examined. Usually they are small and totally unfit to step down the lower frequencies. If necessary, it may be wise to purchase a separate transformer of the best quality and of generous size. Further, the cone should be so mounted that it has a wide range of unrestricted movement and is not stiff. Finally, a baffle-board of generous size should be used, one that will properly bring out the lowest notes.

(Unquestionably, direct-coupled A.F. amplifiers will become *la mode* in a short time. The technician is referred to the following articles in past issues of RADIO-CRAFT, for interesting data on amplifiers of this type. "Bureau of Standards Audio Amplifiers," by S. R. Winters, September, 1929, pg. 112. "Constructing the Loftin-White Amplifier," by M. W. Sterns, September, 1930, pg. 156. "A Direct-Coupled Pentode Amplifier," August, 1930, pg. 100. "Servicing Direct-Coupled Amplifiers," by Sidney Fishberg, January, 1932, pg. 403. "How to Build a Direct-Coupled Type 45 Amplifier," by S. H. Burns, December, 1930, pg. 354.

Additional information concerning direct-coupled amplifiers, has appeared in the Information Bureau of past issues. *Technical Editor.*)

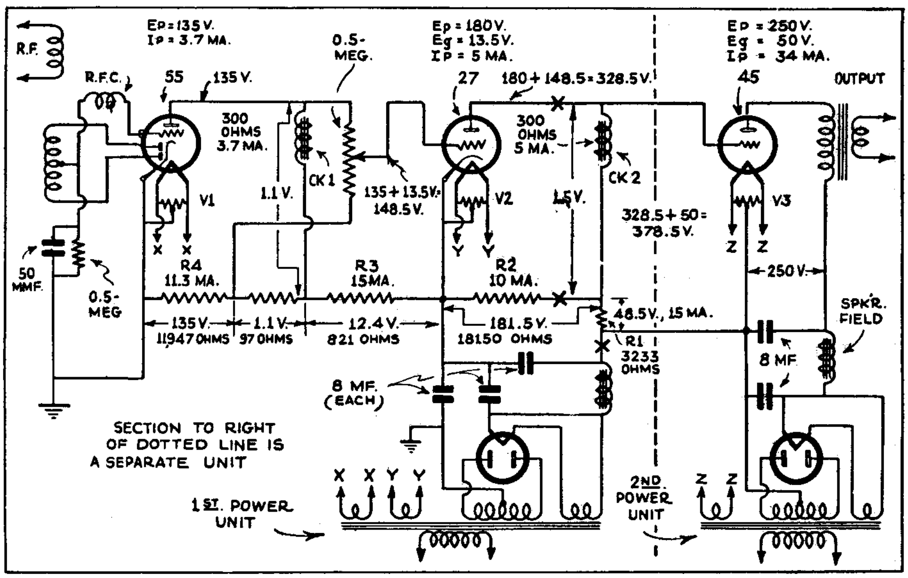


Fig. 4
A double-powered amplifier circuit. See the photograph.

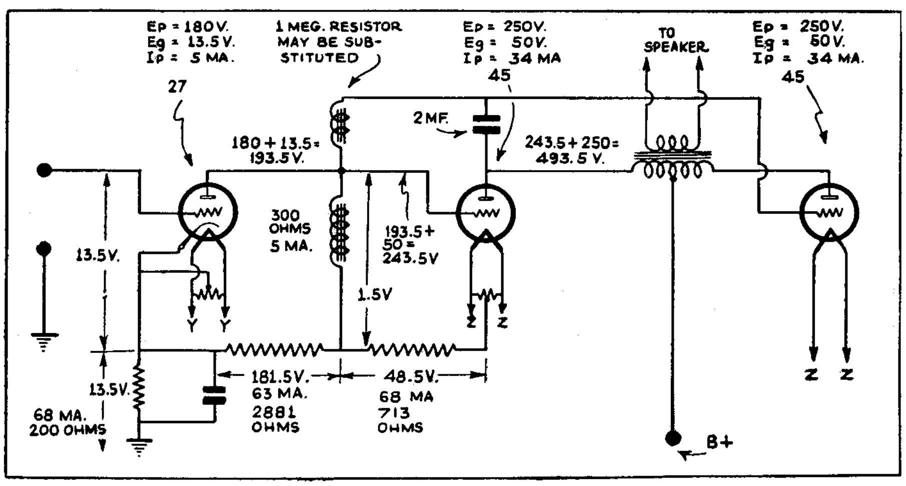


Fig. 5
Here is a good circuit for the experimenter, as suggested by the author.