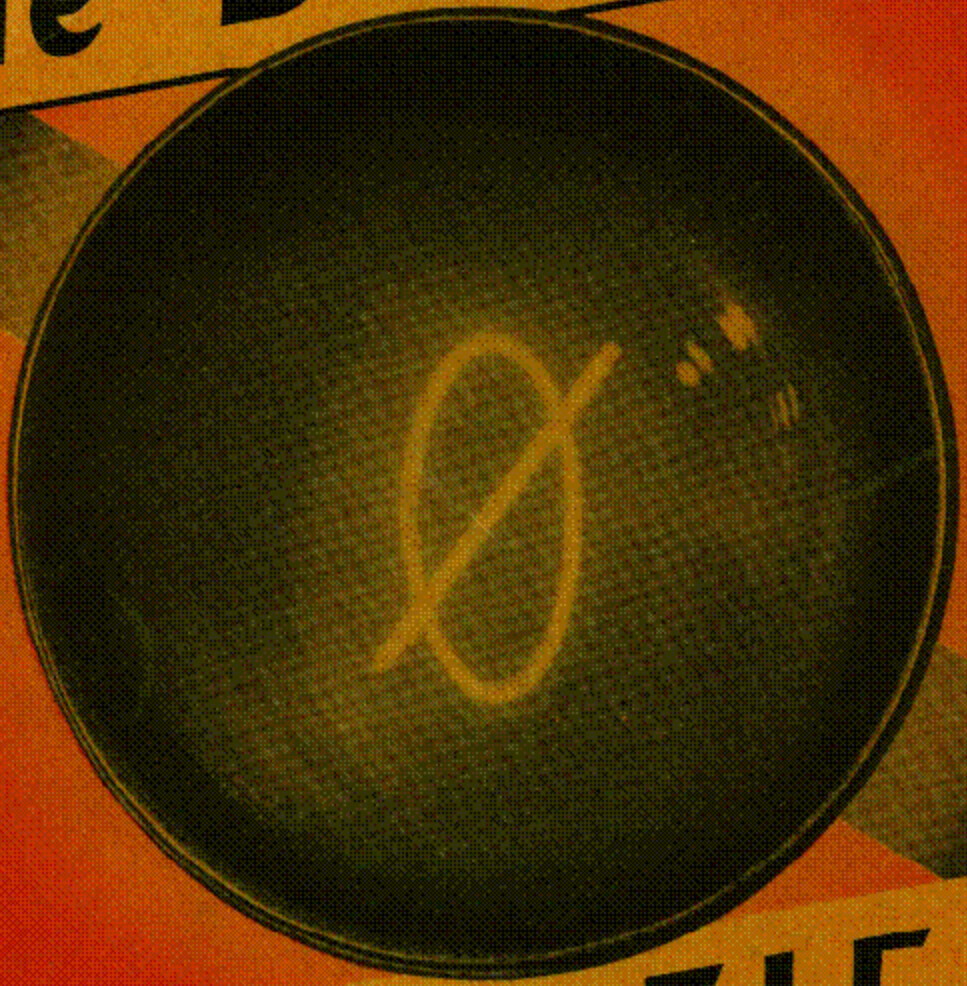
The DOHERTY AMPLIFIER



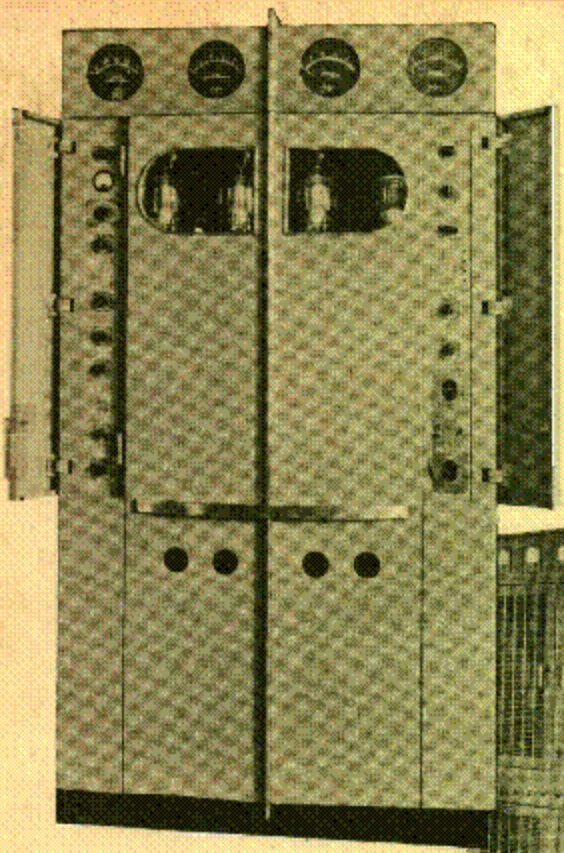
A Development of

BELL TELEPHONE LABORATORIES

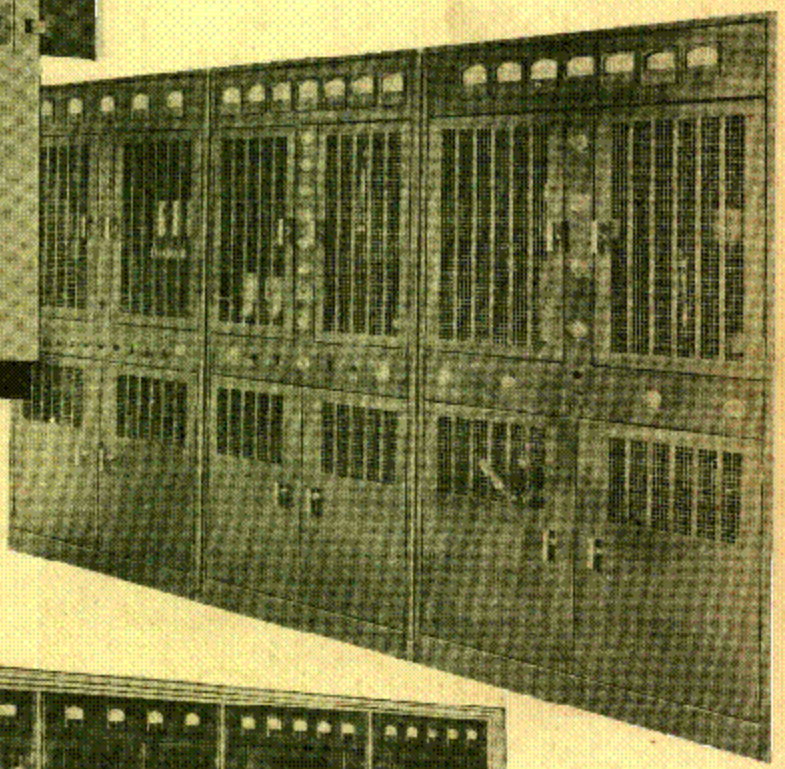
Western Electric

TRANSMITTERS

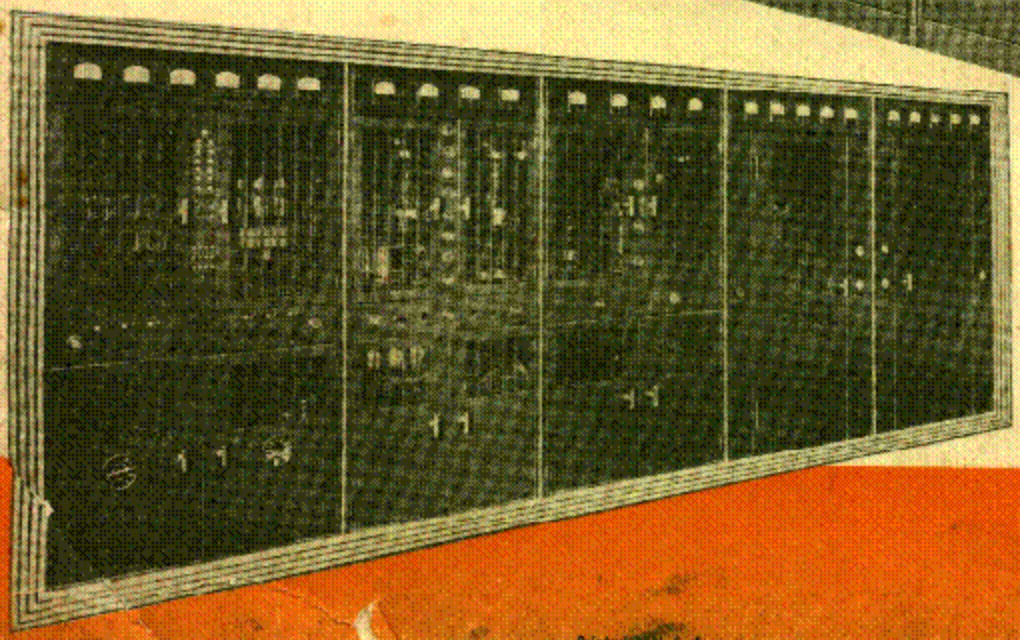
Western Electric
DOHERTY AMPLIFIER TRANSMITTERS



The 1 KW



The 5 KW



The 50 KW

Printed in U. S. A.

WECO—T-1701

The DOHERTY

AMPLIFIER

An Appraisal...

William H. Doherty

RECIPIENT, MORRIS LIEBMANN MEMORIAL PRIZE, 1937

William H. Doherty was born in Cambridge, Massachusetts, on August 21, 1907. He received a B.S. degree in electrical communication engineering from Harvard in 1927 and a M.S. degree in engineering in 1928. After a few months in 1928 in the Long Lines Department of the American Telephone and Telegraph Company in Boston, he became a research associate of the radio section of the National Bureau of Standards and was assigned to the study of radio wave phenomena. In June, 1929, he joined the radio development department of the Bell Telephone Laboratories where he has since been engaged in the development of high power transmitters in transoceanic radiotelephony and broadcasting. He joined the Institute as an Associate in 1929 and transferred to the Member grade in 1936.

The Morris Liebmann Memorial Prize was voted to him for his improvement in the efficiency of radio-frequency power amplifiers. It was presented to him during the Silver Anniversary banquet of the Institute which was held in the Hotel Pennsylvania on May 12, 1937.

Institute of Radio Engineers

votes

WILLIAM H. DOHERTY

The MORRIS LIEBMANN *Award*

1937

Facts about . . .

THE DOHERTY CIRCUIT

The Doherty Circuit was the conception of W. H. Doherty, a Bell Telephone Laboratories engineer engaged in the development of commercial products for the Western Electric Company. His idea for a new high efficiency amplifier circuit had such tremendous possibilities that all of the facilities of the commercial broadcast development group were devoted to perfecting its application.

The Doherty Circuit was first announced in May, 1936, at the annual convention of the Institute of Radio Engineers. It was demonstrated for the first time at the 1937 convention of the NAB in Chicago, where a complete working model of the circuit was operated by Doherty himself.

The first commercial transmitter to employ the new circuit was the 50 kilowatt equipment installed in 1938 at WHAS in Louisville, Kentucky. Since that time the Doherty Circuit has been incorporated in every 50, 5 and 1 KW transmitter manufactured by Western Electric.

Four years have now passed and the Western Electric Company feels that the results obtained by the use of this circuit, so revolutionary in design and operation, should be made known to the broadcasting industry as a whole. Such is the purpose of this booklet.

INSTALLATIONS OF DOHERTY AMPLIFIER TRANSMITTERS

To date, 35 stations in the United States and abroad have installed or ordered transmitters using the Doherty Circuit. Among these are:

WHAS—Louisville, Ky.
WRVA—Richmond, Va.
WJSV—Washington, D. C.
KSL—Salt Lake City, Utah
KRLD—Dallas, Texas
WBIG—Greensboro, N. C.
KQW—San Jose, Calif.

LS-1—Buenos Aires, Argentina
KZRM—Manila, P. I.
CJOR—Vancouver, British Columbia
CHSJ—St. John, New Brunswick
CBK—Montreal, Quebec
CBL—Toronto, Ontario

WKAR—East Lansing, Mich.
KTUL—Tulsa, Oklahoma
WIP—Philadelphia, Pa.
KOAC—Corvallis, Oregon
WICA—Ashtabula, Ohio
KRRV—Sherman, Texas
WHOM—Jersey City, N. J.

THE DOHERTY AMPLIFIER

How it works . . . What it does . . .

It is a fundamental characteristic of vacuum tube power amplifiers that the maximum efficiency is obtained only when the tube is delivering the maximum possible radio-frequency voltage to its load. Since the maximum possible voltage is delivered only on occasional momentary modulation peaks, the normal or carrier voltage being only half of the maximum value, the average or all-day efficiency of such amplifiers is only about 33 per cent.

The Doherty High-Efficiency Circuit has provided the solution to this difficulty through the use of a new principle, whereby the normal or carrier power is delivered at high radio-frequency voltage, and hence high efficiency, by one tube alone, and the additional voltage required for modulation peaks is supplied by a second tube when needed.

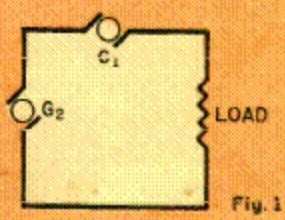


Fig. 1

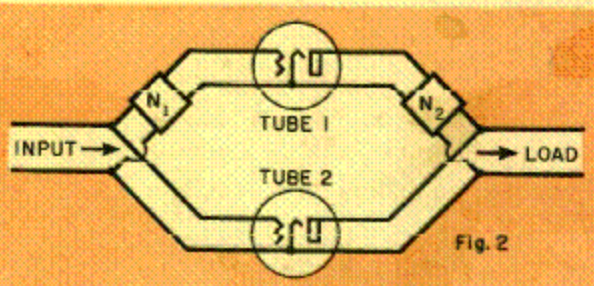
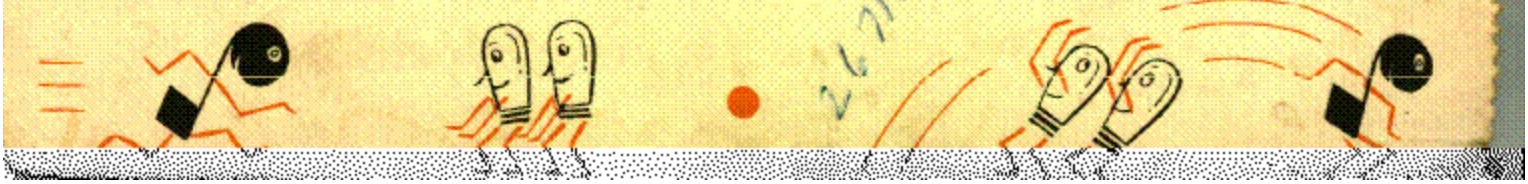


Fig. 2

If we consider an electric power system in which a generator G_1 is delivering power to a load at its maximum voltage, and more voltage is found to be required, the additional voltage would be obtained by connecting an additional generator G_2 in series with the first, as shown in Figure 1. Vacuum tubes cannot be operated directly in series in this manner. The basis of the Doherty circuit, however, is the discovery that by the use of simple coupling networks (N_1 and N_2, Figure 2), the tubes may be made to give the effect of a series connection even though they are operating in parallel into their common load. Tube 1 can then operate alone at high efficiency for the carrier output, while Tube 2 contributes the necessary additional power for the positive swings of modulation.

As with any amplifier regardless of type, the load impedance for the Doherty amplifier is adjusted to the proper value with a radio-frequency bridge. The amplifier is then tuned, with power applied, by adjusting three variable condensers from the front panel as shown in the photographs. The three are independent, and the entire adjustment can be made and checked in less than a minute. Although the cathode ray tube as a tuning indicator first came into vogue with the Doherty circuit, it is the best possible means of checking the tuning of any type of amplifier, because it is the only positive indicator of phase relations.

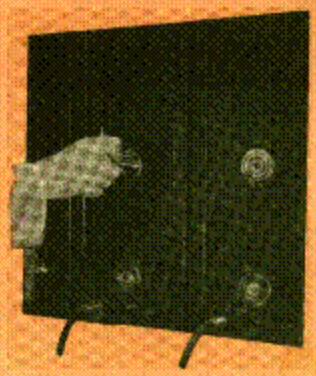
The Doherty circuit reduces the power consumption of linear power amplifiers by a factor of two, and reduces the plate dissipation by a factor of three. Unlike high-level plate modulation, it does not require additional tubes as high-power modulators, nor does it subject the radio-frequency amplifier tubes to excessive plate potentials, since the plate voltage is held constant. It permits operation with zero carrier shift, giving maximum signal coverage. In three years of use in commercial broadcasting it has been successful at all power levels from 500 watts to 50 kilowatts.



Is the DOHERTY AMPLIFIER *Easy to tune?*

HERE'S HOW:

1 ADJUST PLATE PHASING



TO CATHODE RAY OSCILLOSCOPE

TO GET THIS PATTERN

2 ADJUST PLATE TUNING

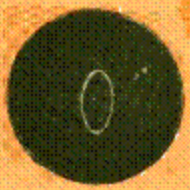
TO CATHODE RAY OSCILLOSCOPE

TO GET THIS PATTERN

3 ADJUST GRID PHASING

TO CATHODE RAY OSCILLOSCOPE

TO GET THIS PATTERN



4 A FINAL CHECK

TO CATHODE RAY OSCILLOSCOPE

TO GET THIS PATTERN

Four SIMPLE STEPS—EACH INDEPENDENT OF THE OTHERS—AND THE AMPLIFIER IS TUNED IN LESS THAN A MINUTE . . .

WHAS

DOHERTY AMPLIFIER EXPERIENCES
by ORRIN W. TOWNER.

All set? Fire it up! As we put the first commercial Doherty Amplifier in the United States on the air a little over two years ago at Station WHAS, questions were raised which time alone could answer. Now, since we have had the opportunity due to the passage of time and increased experience, let us check back on some the these questions and see what the answer has been.

How would my technical staff at the Transmitter take to a new tuning method using Cathode Ray Oscillograph ovals and straight lines instead of conventional plate and tank meters? Would the ninety degree phase shifting networks scare them into thinking it was more complicated than the old Class B amplifier used before? It was a challenge to their imaginations, and as they dug into the circuit they were amazed at its simplicity. It wasn't as bad as the theory made it sound, and certainly it took less apparatus and space than our old equipment. Then, during the installation tune-up period they discovered the ease with which the tuning oval could be made horizontal and the one hundred-eighty degree oval a straight line, either with or without modulation. This was such a departure from the use of tuning meters which varied with modulation, that it made a hit immediately.

Some questioned the stability of the Amplifier, especially as we put it on the air with only the carrier tube neutralized. It is still that way, although we have another neutralizing coil which fits in the peak tube compartment. This Amplifier refuses to misbehave, so why should we show distrust by installing additional neutralization? The average number of times we have tuned the transmitter is once per year--something we were never able to do before. At first we made frequent checks of the ovals, which, of course, indicated all was well; then the checks were made more seldom as this condition continued. We have seen no tendency developing that would cause us to change, except the two times when we ourselves made adjustments necessitating a minor front of the panel tuning change. No fixed clip or behind the panel adjustment has ever been changed since our original installation tune-up, and we do not expect it will be necessary until we come face to face with our August 1st frequency shift.

There have been arcs inside these units--three or four in all--which were in each case caused by secondary induction from some of the thirteen or

Early in 1938 WHAS, Louisville, went on the air with the first transmitter incorporating the Doherty circuit, a Western Electric 50 KW. Orrin W. Towner, WHAS Chief Engineer, here tells of his station's experience with this revolutionary circuit, now a standard feature of Western Electric broadcast transmitters.

so direct lightning bolts which have hit our shunt excited antenna during summer electrical storms. The total damage to date amounts to one small bypass condenser. Then, too, there was the time when a severe wind storm, coupled with a cold wave, snapped one of our two feed line taps on the tower. With half of our series capacity suddenly disabled by this break, the Doherty protective circuit immediately kicked the transmitter off the air due to the de-tuning effect of the feed line circuit. Quickly the protective circuit was disabled as the cause was discovered, and the transmitter put back on the air with full voltage on the tubes. Anyone inside the transmitter building would not have guessed the transmitter was operating other than normally, unless he looked at the "would be" ninety degree plate to plate oval of the Doherty Amplifier, which showed the extent of the de-tuning, as the oval axis was standing nearly forty-five degrees from horizontal. Operation under this condition was continued throughout the day and evening without event, indicating to us in some measure what excellent stability really is inherent in this Doherty Amplifier.

Tube life makes interesting speculation, especially if the tube is worth the price of a high-grade automobile. Well, we still don't know what our 100 KW tubes will do. Our veteran has accumulated some 14,000 hours and still does not need to be operated at rated filament voltage in order to get sufficient emission. Its companion has had about 6,000 hours and is still going strong. At this rate it will take up six or eight years to answer another question--which tube of the Doherty Amplifier will inherently last the longer? Our veteran, incidentally, is in the carrier tube position.

The final criterion of commercial success is the power savings. It sounded good on paper, and then the bills started coming in. The figures were correct. As compared with our old equipment, we are saving something over $5,000 per year on power, in spite of an expanded schedule. This without mention of the $500 savings obtained by the use of the waste heat in our cooling system to take care of our transmitter building's winter heat requirements.

Nothing interesting (?) ever seems to happen in the transmitter any more, so before we forget how to look for trouble, we have decided to hold an occasional fire drill during those wee small hours when anything goes--that is except frequency deviation. The fact is, as you may have guessed, we at Station WHAS are proud of our Doherty Amplifier.

ANNOTATIONS BY W. H. DOHERTY

[1] Oscillograph tuning, as explained in the Doherty-Towner I.R.E. paper of September, 1939, is the ideal method of adjusting amplifiers of any type. It is particularly useful with the Doherty circuit because of the 90-degree phase relations, which give an oval pattern.

[2] This is a balanced device which instantly detects any accidental de-tuning of the output or antenna circuits, such as might result from a flashover or a mechanical failure.

[3] The No. 1 [illegible] tube in this circuit supplies all of the output except when modulation occurs. In neither tube, however, are the [illegible]

KTUL

DOHERTY AMPLIFIER EXPERIENCES
by NATHAN WILCOX

At a first glance that appears to be rather a blunt title. I'll admit that it's wholly inadequate, however, experiences with the Doherty are neither blunt nor inadequate. Those that I have had have been a decided pleasure.

The operating procedure is disgustingly simple. You turn the transmitter on in the morning. Log the meter readings every half hour. And these might well be rubber stamped because they are always the same unless you purposely change them. At the end of the broadcast day you shut the transmitter down and go to bed with a peaceful mind because you know that tomorrow is going to be the same as today. In fact, after sixteen months operation, we are still waiting for something to happen.

Maintenance night-----Ah! Now we'll find out something because this is done after one o'clock when you can do things with the carrier---modulation--- things that are not permissible during the broadcast day. Well I'm afraid that you are due for a great disappointment because maintenance night on a Doherty transmitter consists of going over the transmitter with a vacuum cleaner--blower and dust rag. When this is finished you can check the distortion and noise. We do this because we think that perhaps it will indicate when a tube is getting old. But after 9500 hours operation with the filament voltage still considerably below normal we are beginning to have our doubts. The same results are obtained---week after week---month in and month out. Noise a minus 64db below 100% modulation and distortion 1.2% at 400 cycles. Occasionally we make an overall frequency run---reading the results on the db scale of our modulation monitor. Our oscillator has a range from 20 to 16000 cycles. The transmitter is within one db over that range. Possibly this is one of those so-called straight curves we hear so much about. I have had to demonstrate this a few times----and if any one is doubtful I'll be glad to accommodate anyone that desires to stay up after one o'clock. Most any night will be perfectly satisfactory---and you won't have to notify me in advance because this is one transmitter that stays put-----and it doesn't need to be prettied up either mechanically or electrically before a demonstration.

When the transmitter was first installed we checked the oscilloscope patterns about a dozen times a day. After a few weeks operation this became somewhat of a chore. Especially since we always obtained the same patterns. If you want to change the patterns---go ahead and change them. It will still operate with them all cockeyed. In fact you can change nearly everything on the front panel without disturbing the operation to any great extent. Of course, it will make a difference in the distortion and noise measurements. But the difference is hardly noticeable on the air. If the patterns are a little off---we don't worry much about it any more.

There is one important feature about this transmitter that fifteen years operating experience has taught me to respect. That is the fact that it has a Western Electric name plate on the front. That name plate is more than just a symbol or a trade mark. To me it means that there is an organization behind it. An organization of trained men who have thought things out ----designed them---played with them---built and rebuilt them. When I get a piece of equipment with that name plate, I know that it will perform as stated. Not just today or tomorrow under ideal conditions, but day in and day out under ordinary service conditions.

If I had it to do over again I would make the same choice I made two years ago when I decided that our new transmitter would be a W. E. Doherty.

KQW

DOHERTY AMPLIFIER EXPERIENCES
by CEDRIC V. DAVEY

Installation of our new transmitter went ahead with enthusiasm and discussions centered mainly on the Doherty Amplifier. Questions were raised. Many of them. How did it work? Was it hard to tune? Would it be critical in adjustment? Would it maintain that adjustment or require constant attention? What about the tube life?

Installation completed. Equipment and connections checked and rechecked and tuning began. Finally the high point of the job--the first test--was at hand. Fire it up, check the tuning, check the oscillograph pattern on the Doherty, check the plate current on the peak tube, the carrier tube; re-check everything. Modulate with tone, 10, 20, 50, 90, 100%--CRACK--Kill the power. What happened? A cracked insulator, voltage too high. The condition corrected, further adjustments made, tone applied, pattern checked, feedback adjusted, plate currents and antenna currents re-checked and all was well. Now can it take it? Let's see. Hit it hard, it can! Anything show any signs of breaking down? No, not a thing. Let's have music--perfect. Shut it down, start it up, check those relays, try it again. Man, it works, and how.

Start program tests? Why not? It's stable, signal clean, quality excellent, hum-way down. Manual and mechanical operation precise. Thus, on October 24, 1939, KQW came on the air with a new signal to serve its listeners with the most modern facilities that radio engineering provides.

Time and experience have proved this transmitter dependable. Stability excellent. Adjustment? Definitely not critical and certainly tuning the final by oscillograph proved easy and accurate. Maintenance from the standpoint of periodical readjustment and general servicing required, extremely low. Retuning, a rare necessity, usually only as a check on operation after cleaning. Frequency drift, negligible, within one cycle of assignment. Protection, the Doherty circuit definitely proved itself for us when a heavy wind storm caused a momentary short circuit at the tower end of a transmission line--result, no damage, trouble cleared and the tower end of a transmission line--result, no damage, trouble cleared and the business of broadcasting resumed immediately.

Equipment failures? Minor in nature and did not involve time off air. For example:

1. An arc over on the jacks provided for oscillograph tuning made necessary the replacement of two jacks. Further trouble from this source prevented by increasing the number of turns on the associated RF chokes.

2. An arc over on the RF pick-up coil provided for the modulation monitor. Cure, change position of pick-up coil and add more turns.

Tube maintenance costs? 4000 hours of operation and tests show that it is still quite practical to run filaments of the final 343A's considerably under rated voltage and yet obtain the necessary emission for 100% modulation. When will they have to be replaced? Maybe in another year or so we'll know.

Economy of operation with respect to the power bill? Results to date have fulfilled all expectations and have more than justified the claims for the efficiency of the Doherty amplifier.

AND SO ... Are we STILL SOLD ON WESTERN ELECTRIC? WE ARE.

KRLD

DOHERTY AMPLIFIER EXPERIENCES
by ROY M. FLYNN

Our transmitter has been in operation about ten months, and, as you know, we have had quite an experience here in Dallas. Besides having an entirely new type of transmitter, directional antenna and shunt feed system all of which were new to us, we had the misfortune to lose the top section of one our antennas. During this experience, it was, naturally, necessary for us to get well acquainted with the high efficiency amplifier by being compelled to retune this unit under conditions which were far from the best. Up to the time of our antenna trouble, we had, naturally, made checks on the tuning of this unit and were well pleased with the ease of handling and the stability of the amplifier. We did not fully appreciate the flexibility of the Doherty circuit until we were forced to make an emergency change from the directed antenna to a single tower in the shortest possible time. At the time our tower fell, the branching circuit was changed and the transmitter ready to go in approximately three hours time. This time could have been cut in half had there not been the usual confusion coupled with trouble of the type. As you know, at the present time, it is necessary for us to run 10 KW from local sunset until midnight. This change is made by simply lowering the plate voltage and driving until the proper antenna current is reached. This is possibly not the best way to do the job, but it is the simplest and, as our distortion is well within the limits, it allows us to make this change without any break whatsoever.

I believe that you can see from the above that we are well pleased with the unit, and we would not hesitate to recommend the Doherty Amplifier to anyone.

As to the life of our tubes, it is still too early to form any opinion as to their normal life, due to the fact that the original tubes are still operating satisfactorily.

I trust that the above will give you some ideas as to our experience here in Dallas, and you have our permission to use any or all of the above that you wish.

KSL

DOHERTY AMPLIFIER EXPERIENCES
by WILLICE E. GROVES

Although for seven years the veteran 7A had been doing a first-class job of delivering KSL's programs to Western America's homes and, through its broad secondary coverage, to far flung reaches of the world, it could no longer justify its existence in the light of the revolutionary Doherty Circuit.

Power saving through use of the Doherty Circuit is averaging close to $600. On the basis of the 407A transmitter's record elsewhere, tube savings will be appreciable. Quality of transmission is practically perfect. It certainly looks as though Station KSL is due for another long period of economical, trouble-free, A-1 broadcasting.