Authors Hankinson and Fallgren tune up the tiny transistorized transmitter with a grid-dip meter prior to going on the air.

Transistorized Amateur Transmitter

45,000 Miles-per-Watt

By

GUS FALLGREN, W1OGU & AL HANKINSON, W1OSF

Research Technicians, Missile Systems Div., Raytheon Manufacturing Company

Bored with your big rig? Want a new and exciting experience? Build this tiny .08 watt transmitter for your DX-ing. It is transistorized and compact!

YES, that's what we said! On .08 watt (6 volts at 13 ma.) to a *Raytheon* 2N113/CK761 transistor doubler stage, we worked OZ7BO in Denmark, about 3600 miles away. And, as simple math will show, 3600 miles ÷ .08 watt = 45,000 miles per watt!

It all started one lunch hour last September when the three of us—Gus (W1OGU), Hank (W1OSF), and Dick Wright (W1UBC), a senior at Worcester Polytechnic who had a summer job with us at *Raytheon*—were kidding about low power. Dick said, "Let's go on 20 c.w. with transistors and work all continents." We laughed at this, all of us being medium-power DX hounds. But we talked it over through lunch as a joke project, and brought it up again that evening when the three of us met again at Gus's home.

None of us was a transistor expert so we called up a fellow ham who is a transistor applications engineer. He thought that *Raytheon* 2N113/CK761's, readily available at parts suppliers, should do the trick. We obtained them a few days later, and that evening a breadboard rig crudely haywired together was ready for preliminary tests.

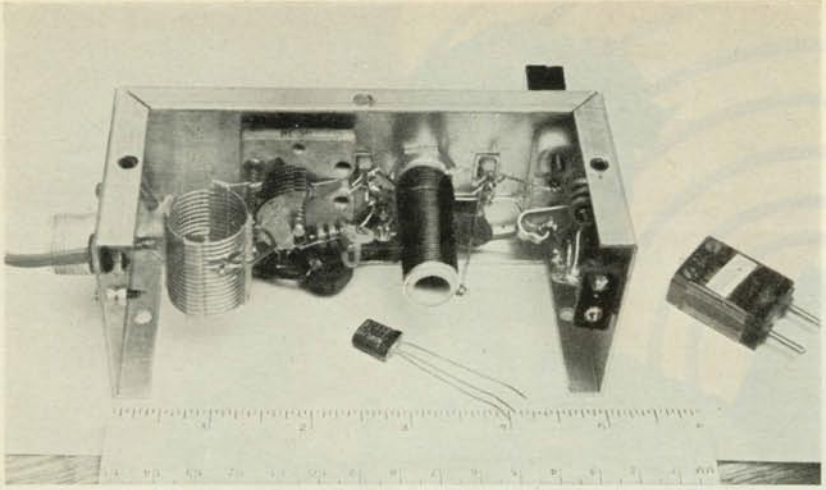
Since Gus has the only three-element wide-spaced beam on 20, there was no argument about where the rig would be fired up. With a "by guess and by gosh" measurement, we tapped the coax lead from Gus's beam directly onto the final tank and plugged the key into the jack.

The first note, clear and steady, blasted forth from the receiver—not one of those chirpy notes that infest the 20-meter band but a note of pure d.c.

Feeling like characters in a science fiction thriller, we carefully scanned the band for a 599 plus 40-db-over signal. After a couple of false starts we decided to use Gus's big rig for the initial contact and then switch over to the small rig.

First call went out to WØVZB in Kansas City, Missouri. He came back to the big rig and then agreed to listen for the small rig. Out went the call—all 80 milliwatts flooding the airwaves. "Break" went W1OGU and a 559 re-

Gus Fallgren keys the transmitter whose power source is the battery shown.



Under-chassis view of transistorized transmitter. Note the simplicity of the construction. Output tank circuit is at left, oscillator tank just right of center.

port came back. This was too much! Like horse players, we decided to try "just one more." Again it worked, the QSO this time being with a K4 in Virginia. That did it—we were ready for the big venture. As far as we knew, no one had ever worked outside the continental U.S.A., but we were going to try.

Our call went out to a KV4 in the Virgin Islands but QRM was hashing up the band. Suddenly, KP4ZW in Puerto Rico broke in to tell us he was copying the small rig. He was the first DX contact. In the days that followed, Gus manned the rig morning and evening before and after work, and the following QSO's resulted: T12PZ, Costa Rica, report 439; OZ7BO, Denmark, 339; and G3AAM, England, 349.

At this point the big rig was out of a job—QSO's were coming in fast and easy with the transistor rig alone. All it took was plenty of listening and making sure the frequency was clear except for the intended victim, who had to be someone calling CQ DX with a 599-plus-plus-plus signal.

Of course, plenty of credit goes to the beam which selected those nice fat signals. However, some contacts were made using an 80-meter doublet with tuned feeders, so the city cave-dweller need not despair.

Comments of operators worked cover the whole band from surprise to outright disbelief—from "wow!" to "ridiculous!" No one has failed to mention the sweet-sounding note. Signal strength reports have ranged from 239 to 579 at W8OCT. The score sheet for the first two weeks shows nine states, five countries (including the first transatlantic jump on record at the ARRL), and many duplicate contacts. Requests for schematics and construction data come in every day.

Meanwhile, with the able assistance of our friend the transistor applications engineer, we have been catching up on transistor theory and can now explain why the 2N113/CK761 transistors perform so well in our rig. These transistors are of the fusion-alloy germanium type. They were introduced by *Raytheon* over a year ago and have been widely used in portable receivers and medium-speed computers.

Three important factors in the design of high-frequency transistors are low collector capacitance, a high *alpha* cut-off frequency, and a low value for a parameter called "extrinsic base resistance."

Collector capacitance is simply the capacitance of the collector junction; it is ordinarily kept low by keeping the area of the collector junction as small as possible. In the 2N113/CK761, this value is about 12 $\mu\mu$fd. at 6 volts.

Alpha cut-off frequency is defined as the frequency at which the current gain of the transistor has fallen to .7 of its very-low-frequency value. However, this is not necessarily the maximum usable frequency. The 2N113/CK761 has an average *alpha* cut-off frequency of about 10 mc., yet it operates successfully as a doubler final in our transmitter at 14 mc.

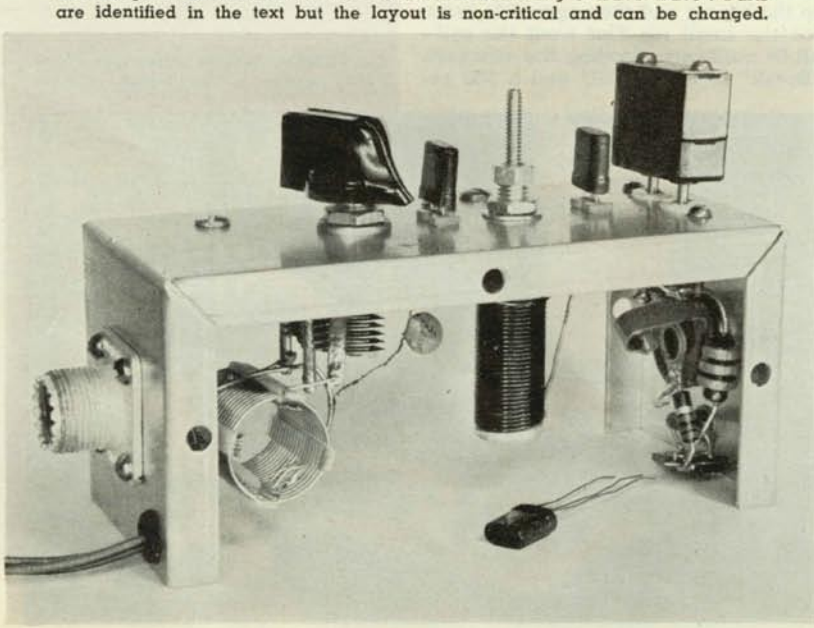
It is true that *alpha* cut-off frequency does affect efficiency, and that an *alpha* cut-off value four or five times our operating frequency of 14 mc. would theoretically give our rig increased efficiency. However, transistors with very high *alpha* cut-off frequencies are so much more expensive than the 2N113/CK761 that the improvement in efficiency is not worth the greater cost. Furthermore, an increase in *alpha* cut-off frequency in abrupt junction types like the 2N113/CK761 results in a reduction in the maximum voltage that can be applied. It may well be that more useful power can be obtained at 14 mc. from a unit like the 2N113/CK761 than from one having a higher *alpha* cut-off but a lower permissible power input.

Extrinsic base resistance, the third factor, is the series resistance of the semiconductor body between the point where the external connection is made to the transistor and the point inside the body where transistor action really occurs. It is called "extrinsic" because in a sense it is not a true (intrinsic) transistor characteristic. This series resistance causes a reduction in the input signal. It is only about 75 ohms in a 2N113/CK761 but may run as high as several hundred ohms in an audio-type transistor.

Although the output power has not been measured, the efficiency is probably not greater than 25%; hence 60 mw. is being dissipated within the transistor and 20 mw. is delivered as useful power.

The amount of power that a junction transistor can handle is mainly determined by the temperature rise of the junction and the maximum safe temperature. In the 2N113/CK761, the temperature rise in free air is specified as about .6° C per milliwatt and

The complete transmitter is built into a case measuring 5" x 2¼" x 2¼". Parts are identified in the text but the layout is non-critical and can be changed.



the maximum temperature as 85° C. Applying these specifications to our rig, we get a temperature rise of 36° C for our 80 mw. input. Adding this to a room temperature of 28° C we get a maximum temperature of 64° C, which is well within the 85° C maximum specified.

There is additional latitude because of the intermittent nature of a c.w. transmission. Also, it is possible to strap down the transistors to a heat sink so as to lower the temperature rise to about .4° C per milliwatt, thus increasing the permissible dissipation by 50% for a given ambient temperature. However, there is another reason for approaching maximum temperature limits with caution. Although the 2N113/CK761's will stand junction temperatures of 85° C without damage, they will not necessarily operate in a circuit at this temperature.

Now for construction details. We'll skip the breadboard stage, for our original rig has been refined into a neater and more efficient transmitter using the same transistors and circuitry.

The entire unit is built in a standard 5" x 2¼" x 2¼" *ICA* "Flexi-mount" case. Bottom photo on facing page shows, right to left, the key jack, the crystal socket, a transistor socket for the oscillator section, the slug adjustment for the oscillator coil, another transistor socket for the doubler-final stage, the tuning knob for the output tank capacitor, and the antenna coax connector. The battery leads are brought out below the coax fitting in the lower left-hand corner. No further comments on component placement are needed, as nothing seems to be critical; you can adapt the layout to fit the components available.

For matching the antenna to the transmitter, we use 52-ohm coax—mainly because we had some on hand. However, you will do well to wind the oscillator coil as indicated on the schematic. Don't attempt to build the oscillator separately and then check it out, as you may run into trouble from individual transistor variations. Build the entire transmitter, plug in the transistors, and you are ready to tune.

Tuning is a little different than with a regular tube transmitter, but if you follow directions you should find it simple. You will need a grid-dip meter or your receiver's "S" meter, a 0-25 milliammeter, and the simple r.f. indicator shown on the schematic. The r.f. indicator is easily constructed and is very handy for working with transistor transmitters. R_x is a carbon resistor which matches the line impedance—51 ohms for a 52-ohm coax, etc.

Here is the tuning procedure to be employed:

1. Using either the grid-dip meter or the "S" meter, adjust the slug-tuned coil L_1 for maximum 7-mc. output. This step should give you no trouble, as transistor oscillators seem to oscillate easily.

2. With the milliammeter inserted in the final stage collector lead, adjust link L_2 for maximum current (12 to 15 ma.).

3. Again using either the grid-dip meter or the "S" meter, adjust the final tuning capacitor for maximum 14-mc. output.

4. You are now ready to select the tap for the collector. Using the grid-dip meter as an absorption wavemeter tuned to 14 mc. record the meter reading, then change the tap and hunt for a point where the output is maximum. Simple but effective! The best tap will be quite far down on the tank coil because of the low collector impedance.

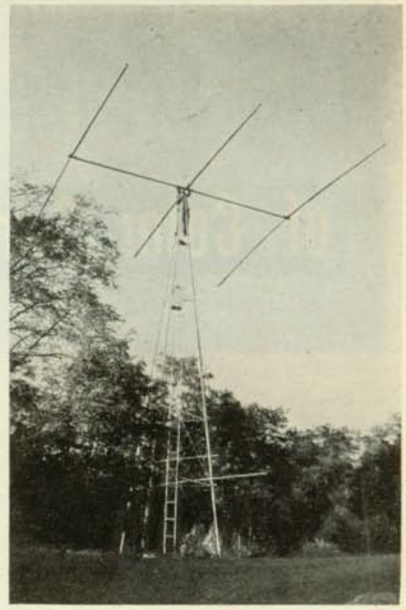
5. Using the r.f. indicator, move up and down the final coil until the point of maximum output is found, and connect the antenna tap at this point.

Now that you have a working rig, any variations are up to you. One that we tried and discarded only for the sake of simplicity was the use of a 1-megohm potentiometer in place of R_1 and R_2. With a pot in this location, you will have control over your drive and also your keying characteristics. We had no keying trouble whatsoever so we eliminated the pot.

Another possible refinement is to include a closed-circuit jack in the "high voltage" lead to the final. Then all you have to do to go on 20-meter phone is plug in a carbon mike of the F1 variety. We haven't given this any serious study but have worked locally on phone with excellent modulation reports.

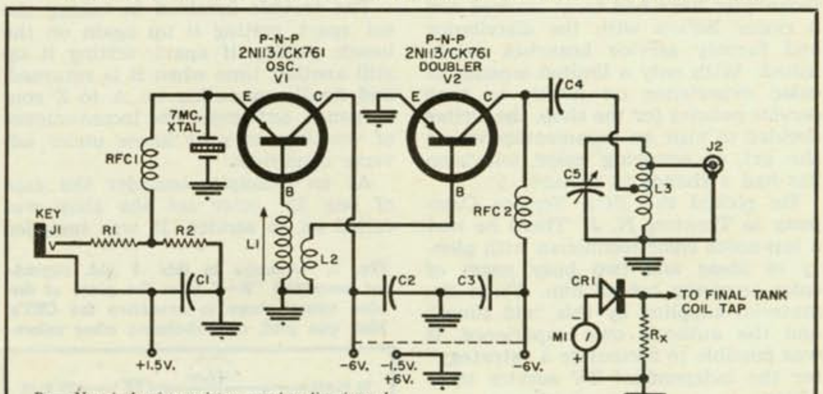
As a final note, we are the cautious type so we limited our "high voltage" supply to 6 volts instead of operating the transistors at the maximum collector voltage permitted by the specifications.

Take it from us, if you're tired of traffic handling and rag chewing at length, if you would like to work on the new frontiers of the radio art, build your own transistorized rig and get a load of thrills. We know, because we have worked all sorts of DX on regular rigs in our time. Gus has 140 countries confirmed, Dick has 101, and Hank has years of maritime mobile QSO's, yet the first DX on transistors topped all the thrills of the past. All except one—the day we received our ham tickets and made our first solid QSO's! —30—



The 20-meter, 3-element, wide-spaced rotary beam that was connected to the little rig for its record-breaking DX.

Complete schematic diagram of the transistorized transmitter. Note that the oscillator and doubler transistor collector voltages can be tied together, as shown by the dotted line, after the initial tune up with the milliammeter has been completed. The circuit for determining the correct output tap and for tuning up the little transmitter is shown in the lower right-hand corner.



R_x—Non-inductive resistor equal to line impedance (see text)
R_1—160 ohm, ½ w. res.
R_2—1 megohm, ½ w. res.
C_1, C_3—.01 µfd. disc ceramic capacitor
C_2—.005 µfd. disc ceramic capacitor
C_4—.001 µfd. disc ceramic capacitor
C_5—50 µµfd. variable capacitor (National HF50)
L_1—38 t. #22 en. closewound, ½" dia. (CTC slug-tuned form)
L_2—8 t. #22 en. wound over ground end of L_1
L_3—17 t. B & W "Miniductor" #3011, tapped 5¼ t. from ground
J_1—Miniature open-circuit jack
J_2—Coaxial cable connector
M_1—1 ma. d.c. meter
CR_1—CK705 or equiv.
RFC_1, RFC_2—2.5 mhy. r.f. choke (Grayburne M25)
Xtal.—7 mc. crystal
V_1, V_2—"p-n-p" transistor (Raytheon 2N113/CK761)