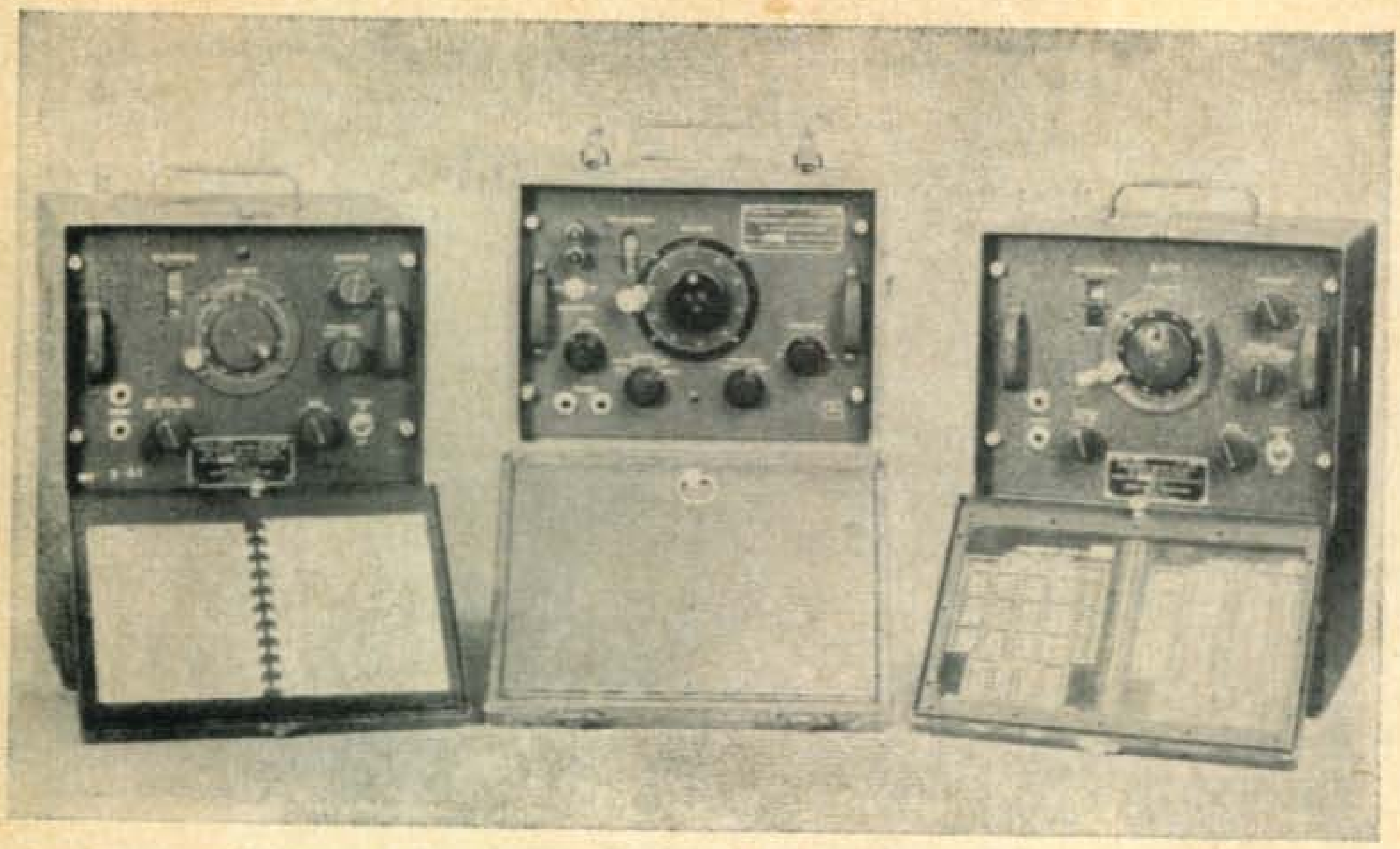

Shown here are three different versions of the BC-221. From l to r, BC-221M made by Bendix, the BC-221AN made by Cardwell, the very latest model and the BC-221F made by Zenith.

Notes on the BC-221

BY HERBERT W. GORDON*, W1KWB/W1IBY

The BC-221 (or LM version), a desirable instrument in the shack, can be made more versatile and dependable with the suggested techniques and modifications. A comprehensive summary of all past articles covering this frequency meter is also given.

IN THE practical sense, it isn't my wish to explain the operation of the BC-221 or LM frequency meter since this subject is covered adequately in the calibration book accompanying each instrument and is fully covered in the technical manual TM11-300 issued by the government printing office. Rather, it is my wish to convey information not ordinarily found or otherwise available which will help the user obtain the maximum benefit from the LM series or BC-221 type of instrument.

Before detailing what these specifics are, I would like to stress the need for thorough and complete understanding of the basic operating functions of the instrument. As a matter of fact, the operator should be so conversant and so familiar with these functions that he should be able, almost subconsciously, to understand the limitations and order of processes required in using the instrument.

Assuming such a degree of experience and utilizing the best possible techniques, it is possible to achieve an order of accuracy with the BC-221 amounting to .002% or even better. In contrast, the inexperienced, taking a BC-221 as he gets it and merely getting it to function, will probably realize errors as great as .015%.

Determining Instrument Condition

Before going any deeper into the subject, it is recommended that each BC-221 be examined or analyzed to determine its degree of condition, and I don't mean mechanical condition as much as I do electro-mechanical condition. Actually, this is one instrument where every screw and bolt has to be tight, where every soldered wire has to be right, and where any significant changes in some portions of the circuit simply cannot be tolerated.

To determine whether your BC-221 is in good condition, two simple tests are available. However, the first thing to do in checking your BC-221 is to remove the nameplate, carefully putting aside the screws and lock washers. Behind the nameplate there should be chalked or crayoned a number. This was put on by the original manufacturer and this number subsequently became the serial number on the nameplate and on the frontispiece of the calibration book. If your BC-221 calibration book number does not match the plate or the number behind the plate, you are in serious difficulty. Many plate changes were employed by disreputable dealers in an effort to sell BC-221's. I have noted in examining some thousands of instruments that, at various times, the manufacturer omitted marking his serial number behind the nameplate, so this omission by itself shouldn't be considered too serious. If the book does not match your instrument it is still possible to use the frequency meter and calibrate it with its own harmonic markers and sub-har-

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monic markers and with the aid of a slide rule, provided that the instrument is otherwise in excellent condition and complete. Such a process of calibration involves a great deal of work and careful concentration to avoid errors and was thoroughly covered in a previous magazine article.[1]

Checking For Accuracy

To check the frequency meter for accuracy the following procedure may be used. Set the function switch to the HETERODYNE OSCILLATOR or OPERATE position. Set the RANGE switch to HIGH. Set the MAIN TUNING dial somewhere in the 2000-2500 kc region. A suitable spot would be 2333.333 or 2250 kc. Now switch back to the CRYSTAL CHECK position and observe the resulting beat note heard in the earphones. The note should not exceed 150 cycles.

Another and somewhat more suitable test is to set the frequency meter to any crystal check point in the HIGH range. Zero in with the corrector in the prescribed manner. Set the function switch to the HETERODYNE or OPERATE position. Do not disturb the corrector setting. Now, move the MAIN TUNING dial to the next check point listed in the calibration book. Set the function switch back to the CRYSTAL CHECK position; a tone will be heard in the phones. Note the MAIN TUNING dial reading and tune the dial for an exact zero beat. If the difference in the two dial readings exceeds 1.2 divisions, the calibration is not good.

On the low band this same test should indicate a maximum error not greater than 1.8 dial divisions. If the error is greater than this, your instrument is bad. The smaller the error the better the condition of your instrument.

At this point I would like to inject a third test utilized by the government to determine the quality of a BC-221. This test involves a second instrument, preferably a lab instrument of better quality, but it can be a second BC-221, the quality of which is beyond question. The easiest method involves the use of frequency meter type receivers such as the 51J, the R338, R389 or R390 series. To check a BC-221 with these auxiliary devices, there are five specific test points on the low bands. These are: 130 kc, 160 kc, 190 kc, 210 kc, and 240 kc. On the high band there are four reference points tested. These are: 2100 kc, 2400 kc, 2900 kc, and 3800 kc. The deviations in dial divisions, when checked at any of these specification points against an external standard, should not exceed ½ dial division as measured with the vernier scale in order to be considered an excellent instrument. In effect, an instrument to be certified for FCC purposes must meet this particular test. Those whose deviations reach one dial division are considered good and those greater than 1½ dial divisions are considered poor.

[1]Dudley, B., "Calibrating a BC-221 Frequency Meter," *QST*, March 1950, page 40.

Maximum Frequency Error

Since the principal application of the BC-221 is to measure radio frequencies so as to determine edge of band positions in compliance with tolerances imposed by the FCC, it follows that the ordinary error found in the BC-221 should be both understood and rectified.

The technical manual TM11-300 is the source of the following statistics on possible frequency errors.

Cause	*Error in Cycles*
Small shocks (caused by handling and thrust on the dial and panel)	100
Action of locking the dial	30
Warming up	100
Change of load on antenna post	50
A drop of 10% in voltage or of 5° C. in temperature	325
Error in calibration	500
Error in crystal frequency	250
Total Error	1,355 c.p.s.

This represents 0.034% error at 4000 kc and is the theoretical maximum. Many of the errors may actually cancel each other rather than be additive. Also, the error is less at lower frequencies. For example at 2000 kc it is only 985 cycles and 125 kc only 180 cycles. The average error that can be expected would be closer to 0.015% than 0.034%.

With these error percentages in mind consider the problems of checking band edges or setting a v.f.o. on the Army MARS frequency of 3289 kc. A maximum error of 329 cycles is allowed by MARS. If the error is the maximum, 0.034%, the deviation can be as great as 1120.3 cycles. However, as pointed out before, the error is more likely to be in the order of 0.015% presenting the possibility of a deviation 494.25 cycles, still in excess of the maximum permissible error.

Improving Accuracy

How then may we employ the BC-221 as a reliable tool for measuring our frequency? The answer lies in a system known as the additive or subtractive system which recognizes that the very accurate 1000 kc crystal oscillator bears the main responsibility for measurement accuracy and that the low frequency range of 125-250 kc is more uniformly frequency stable than the high frequency range of 2000-4000 kc.[2]

By the simple expedient of a small, easily effected alteration in the plate circuit of the multi-grid mixer, it is possible to utilize this additive or subtractive method to produce errors not greater than .0025% and very frequently much less than this.

[2]Grammer, G., "The Additive Frequency Meter," *QST*, May 1949, page 32. Riley, C. L., "Interpolation Frequency Measurements With the BC-221," *QST*, January 1956, page 41.

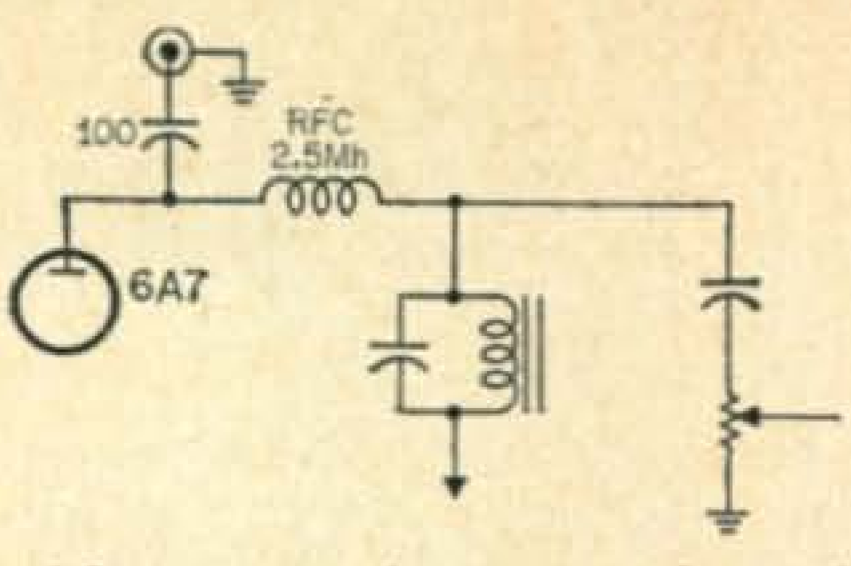

Fig. 1—Modification made in the plate of the mixer tube that will enable the additive-substract system of frequency measurement to be used. This can provide a great increase in frequency meter accuracy. The mixer tube type will vary from model to model and may be a 6A7, 6K8 or a 7B8.

The first mechanical alteration made in your BC-221 involves cutting into the plate circuit of the multi-grid mixer and inserting a conventional 2.5 mh r.f. choke as shown in fig. 1. The plate itself should couple through a small 100 mmf capacitor to a new output connector. If you wish to alter the panel you may insert a suitable r.f. connector jack such as a BNC fitting. Insertion of the r.f. choke and capacitor modifies the original circuitry so that the multi-grid mixer can produce sums and differences of both the crystal fundamental or its harmonics as well as the v.f.o. fundamental and its harmonics. Thus you can use the low frequency side of the BC-221 where the calibration book shows each 1/10 of a kc, and by doing so, with proper recognition of the beat notes, the accuracy can be improved by a factor of 10 or more.

The function switch still determines the mode of operation. It is normal in the HETERODYNE OSCILLATE position and you may now heterodyne in the CRYSTAL CHECK position as well.

To illustrate the additive or subtractive method, suppose that you wanted to measure 2360 kc. The second harmonic of the crystal (2000 kc) is beat with the second harmonic of 180 kc to give the frequency 2360 kc, *i.e.*, (2 × 1000) plus (2 × 180) equals 2360 kc. This also gives rise to other signal combinations but they will be 180 kc removed from 2360.

The accuracy of measurement is even better if you subtract, as an illustration, the 360 from the next one mc and set your low frequency range to the difference, or 640 kc. By this so-called subtractive system the error is halved.

There are slight complications in this method which are helpful rather than troublesome if they are used to advantage. The full procedure is to turn the BC-221 on and let it warm up for one hour with the band switch on LOW. To measure 2360 kc, set the dial to check point 181.82 kc and zero beat the CORRECTOR knob. This can be done, at least once, as soon as the frequency meter is turned on in order to determine the frequency drift during the warm-up period. This rate of warm-up is handy information in case it is desired, subsequently, to make a measurement with a cold frequency meter. (The direction of magnitude and drift should be noted.) Each vernier division will be approximately 2.7 cycles on the fundamental or 5.4 cycles for 2360 kc measurements.

Now set the dials to the settings given for 180 kc, the sub-harmonic of 360 kc. While listening on the frequency meter head phones, slowly rotate the main dial one complete revolution to the right and then to the left. You will hear lots of "birdies". Each of those little "birdies" is actually a check point accurate to .0001%. If you use a 12" piece of wire for a small antenna and set your frequency meter to 180 kc dial setting, then you could turn on the oscillator in your transmitter which is being set for 2360 kc, and slowly move the BC-221 dial a one-half turn to the right or left. You will note that while the "birdies" are still present, the beat note between your transmitter and the frequency meter can be heard over one complete revolution. (1000 vernier units) In fact, it will be difficult to find exact zero beat since it covers 4 to 5 vernier divisions.

The system described above is at first confusing due to the many beat notes heard, however, with practice, measurement of various frequencies can be made with little difficulty if you will remember that the beat notes in which you are interested change very slowly in comparison with the spurious beats.

Locating the Zero Beat

Three methods for finding the exact zero beat can be employed. One is the use of an external "magic eye" tube to be discussed later, a second is to take the center of the dial readings for the lowest audio beats and the third way is to plug an output meter into the phone jack.

The zero beat point can be recognized more easily if the low frequency response of the audio amplifier is improved. The low frequency response of the audio portion of the BC-221 can be greatly improved by the use of a high quality 8000 to 250 ohm output transformer in those models that use output transformers and by connecting a 10 or 20 mf, 20 volt electrolytic capacitor from the cathode of the audio stage to ground. In some models it is necessary to disconnect the audio stage cathode from the heater connection (ground) and to insert a ½ watt cathode bias resistor of 350-500 ohms. The original bias connection presupposed the use of batteries which provided the bias and most amateurs use these meters with a.c. supplies.

Time Saving Graphs

Interpolation between the frequencies listed in the calibration book is awkward and time consuming. You will save a great deal of time and obtain better accuracy if you make up a special graph or in reality two graphs for each major frequency in which you are interested. In the illustrated case of 2360 kc, one graph should cover the high band position using one square per vernier division on one axis and

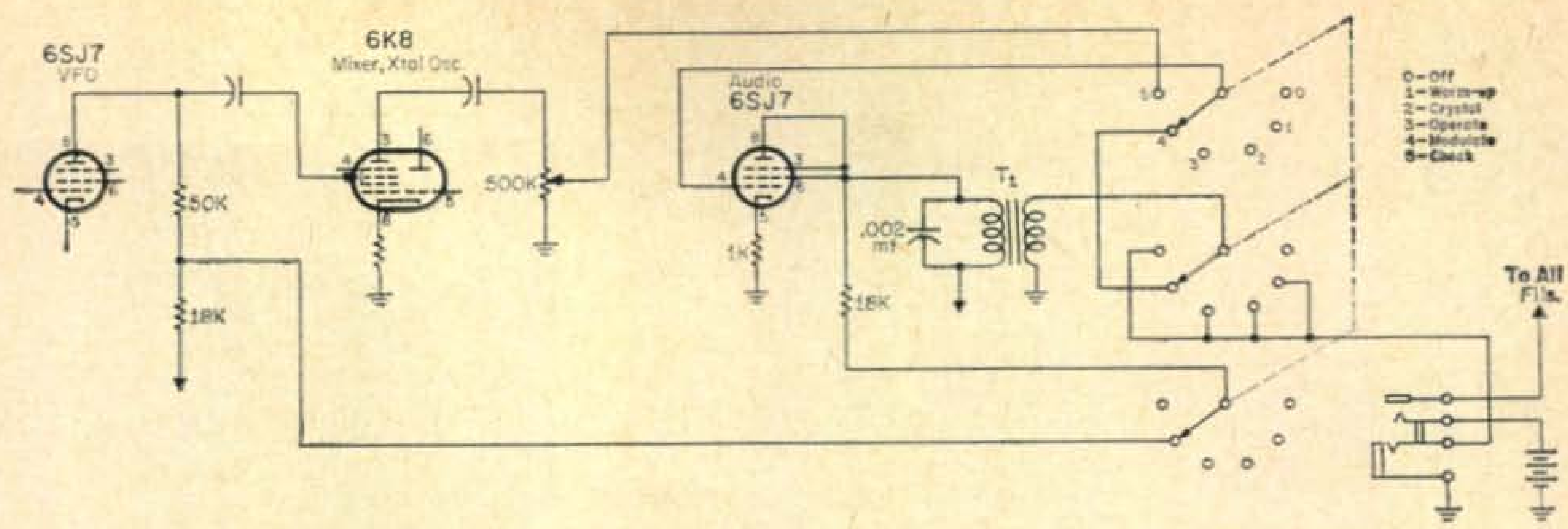

Fig. 2—Skeletal diagram showing the modulation set up in the BC-221 AK series. The output transformer, T_1, is used as the oscillator transformer in position 4. Audio taken from the plate of the 6SJ7 is fed to the junction of the two plate resistors in the 6SJ7 v.f.o. There are two more switch sections used to handle voltage distribution but these are not shown.

one square for 10 cycles of frequency (2357.5-2362.5 kc) on the other axis. Label this graph "rough measurement." For the additive method the second graph is employed and this should use 2/10 dial divisions per square on one axis and 10 cycles per square for frequency on the other axis. The graph line will cover the same 2357.5-2362.5 kc. Place red marks on the curve at plus .01 and minus .01%. The portions of the curve between .0075 and .01 may be drawn with red ink, the rest of the band with black ink. The red curve then suggests the accuracy limits.

Accuracy of the Modified BC-221

Summarizing the maximum possible accuracy of the BC-221, the best possible conditions would be to have a constant room temperature, a constant B voltage, a constant A voltage or filament supply, a quartz crystal which has been checked at plus or minus one cycle of WWV at 5 mc, a frequency meter that has been warmed up to reach thermal equilibrium and finally graphs which have been substantiated by spurious harmonic points.

Assuming these ideal conditions then the maximum errors that you could get would be: (1) the accuracy of the crystal 1/5 of a cycle per mc, (2) a calibration curve error not greater than 8 cycles in the low range, (3) a mechanical dial back-lash error of 4 cycles and, (4) a zero beat error of 5 cycles or less. Adding these together could come out to at least .0002% theoretical error.

Practical Improvements to the BC-221

Several modifications enhancing the value of the BC-221 have appeared in magazines[3] over the past decade.

[3]Pitts, J. E., "Tone Modulating the BC-221," *CQ*, August 1949, page 14. "Compact Power Supply for the BC-221," *CQ*, April 1947, page 30. Grayson, K. B., SURPLUS, *CQ*, April 1959, page 79. Wood, W., "Null Indicator for the BC-221," *QST*, May 1950, page 66. Carlson, H., "Adding Tone Modulation to the BC-221," *QST*, May 1948, page 68. Cross, H. "Using the BC-221 Frequency Meter at VHF," *QST*, January 1950, page 46.

Modulation—the most important improvement is perhaps the easiest one to accomplish and has to do with using the BC-221 as a signal generator. This change is accomplished by merely adding tone modulation to the local variable frequency oscillator and either of two ways can be employed to gain this end.

First, we can add a small audio oscillator transformer wired in as is shown fig. 2, the circuit of the BC-221 AK. This involves a change in the function switch which permits the output of the variable frequency oscillator to be modulated approximately 375 cycles. The function switch in the BC-221AK reads OFF - WARM-UP - CRYSTAL - OPERATE - MODULATE - CHECK. In the OFF position, both the A and B battery circuits or power supply are disconnected. In the WARM-UP position 6 volts is connected, through the switch built into the phone jack, to energize the filaments in the three tubes.[4] The B battery circuit is closed, subsequently, in the CRYSTAL position, energizing all tubes with the exception of the variable frequency oscillator. In the OPERATE position, the B voltage is applied to all tubes with the exception of the crystal oscillator portion of the multi-grid mixer.

In the MODULATE position, in addition to converting the audio amplifier circuit to an audio oscillator, the operation switch closes the B voltage circuit for all tubes with the exception of the crystal oscillator, and the plate circuit of the variable frequency oscillator is now connected to the modulator. In the CHECK position, the audio amplifier circuit is restored to normal and the B voltage is fed to all tubes. This modification involves the acquisition of a small audio transformer and two resistors in addition to changing the FUNCTION switch as shown in fig. 2.

A similar modulating device, but without the complexity of the AK circuit, is one which makes use of a simple NE-2 neon lamp and several other components. This cir-

[4]This is a safety precaution. The front panel lid cannot be closed if the phone plug is inserted. When the phone plug is removed the A batteries are automatically disconnected thus preventing accidental discharge.

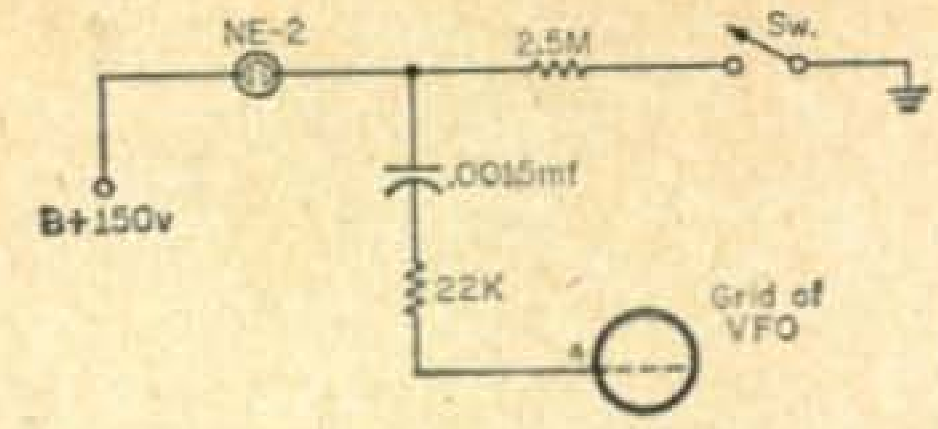

Fig. 3—A simple relaxation type oscillator developed by DL4VG (W9YUE). Care must be taken to keep the leads short.

cuit is shown in fig. 3. In operation, the switch is closed to provide a 400 cycle tone on the carrier of the local variable frequency oscillator.

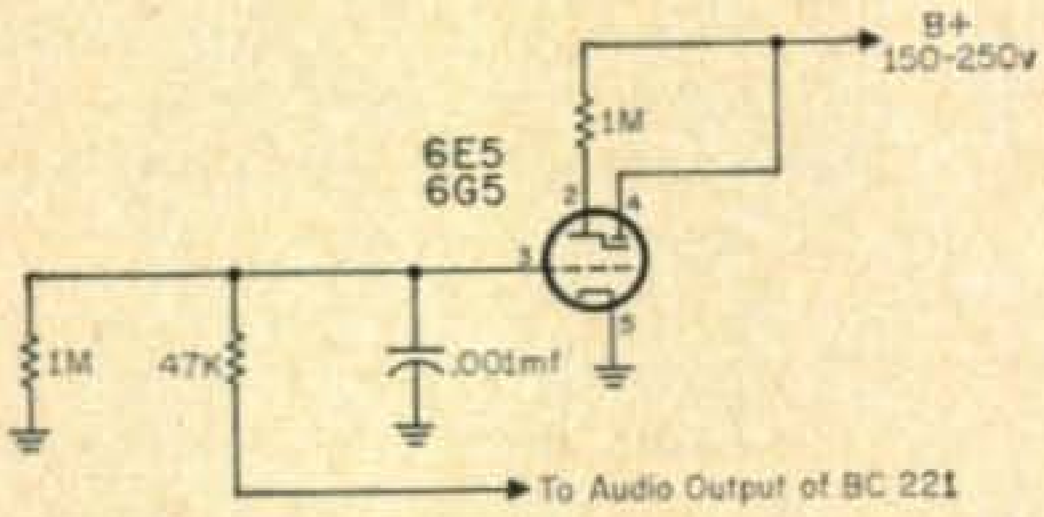

Fig. 4—An excellent null indicator makes use of a 6E5 or 6G5 "tuning eye" type tube. The circuit, suggested by VE4MW, permits the operator to observe low level signals that are inaudible.

Null Indicator—For those readers requiring a simple null indicator or zero beat detector, a 6E5 or 6G5 tuning eye tube, connected as shown in fig. 4 will provide a positive means for indicating the low frequency beat notes. This device may be constructed externally to the BC-221 and connection made through the phone jack if you don't wish to alter the BC-221.

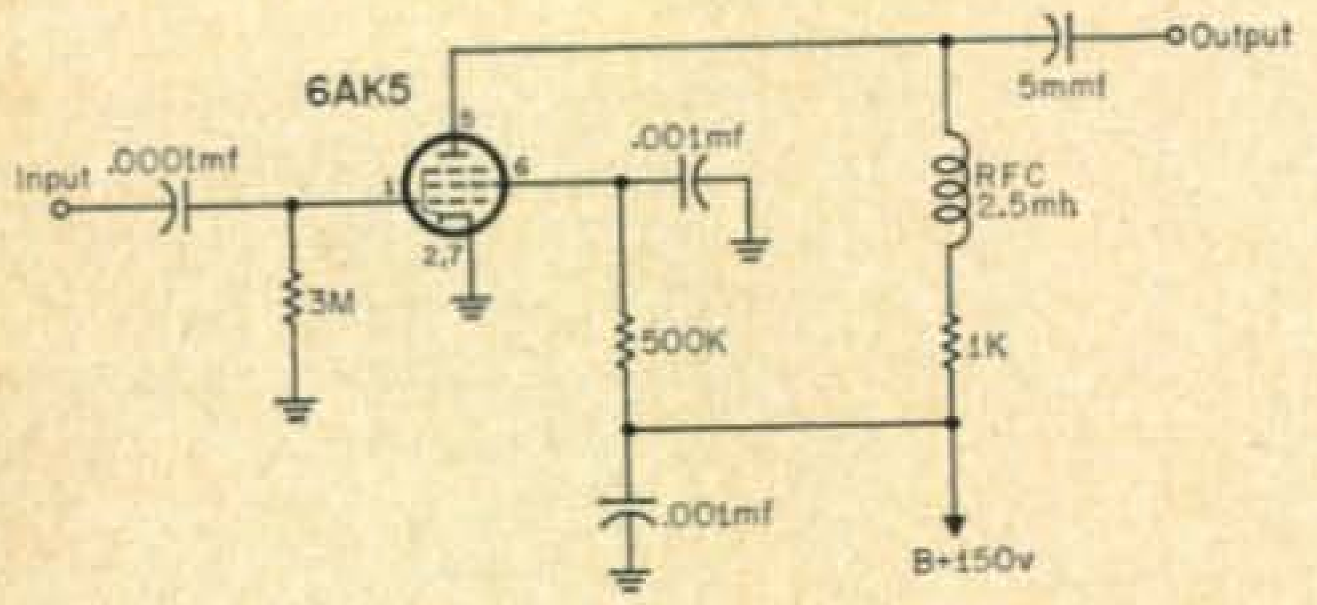

Fig. 5—A harmonic generator to improve performance in the v.h.f. range may be added to the BC-221.

Harmonic Generator—A most useful addition to the BC-221 is the harmonic generator using a 6AK5 miniature tube as shown in fig. 5. This can be assembled on a small bracket and fastened to the chassis of the original BC-221 and should not interfere with the function of the original controls in the slightest. Harmonics, useful through 300 mc will be generated by this device, and for those working with frequencies in the order of 2 and 1¼ meters this is a very desirable addition to the original BC-221.

BC-221 As an Audio Source

The BC-221 can be used as a source of reasonably good audio frequency sine waves by turning on the low frequency portion of the BC-221 and looking for the 10,000 cycle spread between 990 and 1000 kc. You will find that this takes up over 800 readable divisions with approximately 12 cycles per division. Therefore, with the meter in CHECK position, the resulting beat note will be a reasonably, accurately known audio frequency. To check this, tune in WWV on your receiver and feed the receiver output to the horizontal amplifier of an oscilloscope. With the frequency meter set to 996 kc, the 4 kc beat note which results should form a perfect circle or an ellipse when fed to the vertical deflection plates of the oscilloscope.

BC-221 As a V.F.O.

The BC-221, with the aid of suitable isolation amplifiers and then untuned voltage amplifiers, makes an excellent adjunct to either your sideband transmitter or it may serve directly as a v.f.o. A typical application would involve taking the output of the BC-221 with its precisely known control of frequency and feeding it into a cathode follower and thence into two or more stages of broadly tuned 6CL6 multipliers or voltage amplifiers from which point the output will in all probability be sufficient to directly feed a 2E26 or 5763 or 6146. Thus the BC-221 is capable of being a tremendous v.f.o. for a sideband exciter. More details on this type of application may be found by referring to the *Radio Handbook* published by Editors and Engineers at Sunnyvale, California.[5]

To reduce the confusion about the proper operation of the BC-221 and to make this valuable instrument even more popular to the people owning them, the author would be pleased to hear about other applications involving the BC-221 or its Navy counterpart.

Some further information may be gleaned from the previous articles listed below. ■

Bibliography

Chamberlain, N. K., "Identifying Frequency Meter Harmonics," *QST*, September 1952, page 24.

Dudley, B., "Adding a Bandspread Range to the BC-221," *QST*, August 1953, page 38.

Nebel, R., "De-Mothballing the BC-221," *CQ*, December 1950, page 28.

Dorsey, M., "Measuring Frequency with the BC-221," *CQ*, December 1950, page 29.

[5] *Radio Handbook*, Editors and Engineers, 11th ed., page 445.