The author (left) checking transmitter at Bramco plant while serving as Chief Engineer. Mr. Von Valtier is now on active duty with Air Force.

THE "WHYS" AND "HOWS" OF SIMULTANEOUS CONTROL FOR MULTI-CHANNEL R/C

By ERIC VON VALTIER

■ The ultimate goal of any R/C enthusiast is to build and fly a plane that can be made to perform exactly like the real thing. To most hobbyists, this remains only a dream. For me the real action started at Bramco in late 1956 and early 1957. At that time, it was decided that although the then recently perfected multi-channel equipment certainly did seem like perfection, an easy step forward could be taken: simultaneous control.

To those not familiar with this term, simultaneous control allows the operator to have multi-channel operation with two controls operated simultaneously, such as up elevator and rudder for tail spins and snap rolls; down elevator and rudder for tail spins; and elevator and ailerons for aileron rolls. Also possible is a maneuver performed by holding the rudder and beeping down elevator. This is an outside barrel roll and requires a great deal of co-ordination to perform it well.

Now we haven't reached our ultimate goal yet; there are still more elaborate and complete systems to be uncovered, but simultaneous control will offer a good challenge to the present modeler and serve as a stepping stone until something even more excellent comes along.

Since it is customary to begin the discussion of any communication system with the receiver, we will do just that. The multi-channel receiver in its present form consists of a superregenerative detector followed by several stages of audio amplification. The audio signal is then demodulated in some frequency selective device such as a reed bank or a set of tuned filters. We will limit discussion to reed type receivers.

The requirements for the "front end" of a simultaneous receiver are basically the same as for any multi-channel receiver. A good, stable, detector must be used. The pitfall of most detectors is their inherent sensitivity to the proximity of metal objects. This is usually caused by excessive antenna coupling. Another major problem is microphonism in the detector tube. When a microphonic tube is subject to vibration, it produces energy which may fall in the audio frequency range of the reeds. All of these factors are many times amplified in their importance when reliable simultaneous operation is anticipated.

The audio amplifier requirement is the next item. The output of the amplifier must be sufficient to drive two reeds to full amplitude with a slight reserve power. Translated into empirical units, this means that your receiver must be capable of putting out 250 milliwatts of audio frequency power. How can you determine just exactly how much your receiver's audio section puts out? Get out your voltmeter and measure the audio voltage received from the transmitter.

One note about this measurement: check your receiver schematic or if one is not available, trace the circuit out, and see if there is any capacity connected across the reed coil. If there is, fine. If there isn't, temporarily connect an .02 across it. This supresses voltage spikes which the coil develops as the current through it goes through cutoff—this voltage helps nobody and serves only to give an inaccurate voltage reading.

After measuring the audio voltage, measure the d.c. resistance of the reed coil itself. It should be in the vicinity of 5000 ohms. The power output delivered to the reed bank can then be calculated by the following formula (if you have no provision to have the inductance of your reed bank measured, omit the entire term since in most cases it is so small as to be considered almost negligible):

"P" (power output) equals "E"-squared (voltage measured across reed bank) divided by "R" (d.c. resistance of reed bank) and multiplied by 1,000.

If your receiver does not come near to this power requirement, something must be done to increase its output. There is not enough space here to mention all of the ways to increase a receiver's output. The only thing I would recommend is obtaining a receiver capable of such a requirement, or build (or modify) a receiver according to the design of such a suitable receiver. The circuit of the Bramco transistorized receiver is given for the benefit of those who prefer home construction. All Bramco receivers are capable of at least 250 milliwatts of audio output and even the single channel Cardinal fitted with a reed bank and relays can be used for simultaneous operation.

After ample audio output has been obtained, selection of reed frequencies must be carefully considered. For this purpose, a brief glimpse of heterodynes. In higher electronics, mention is often made of non-linear impedances. This term is somewhat "high classed" for our discussion here, and we will abbreviate it to a more common name—mixers. The original expression is more descriptive from a mathematical standpoint and the latter from an electrical standpoint. In either case, a mixer has an interesting property: it does not behave according to Ohm's Law.

If two alternating current signals are fed into a linear circuit, such as an ordinary resistor, they pass through it unchanged. However, if the same two signals are fed into a non-linear circuit, or a mixer as it is called, an interesting transformation takes place: the two signals unite to form two altogether different signals. Although the waveforms of the new signals are not the same as the original input waveforms, this fact does not affect the life of the average R/C modeler. It is the frequency of these new products that is of any value. Their frequencies are numerically equal to the sum and difference of the frequencies of the original input waves. These new products are called heterodynes, or more commonly—beats.

Take, for example, a mixer circuit into which is fed two a.c. waves of frequencies of 100 and 1000 cycles per second. The output waveforms have frequencies of 900 and 1100 cps respectively. Also present in the output are traces of the original input waves, e.g. 100 and 1000 cps, since no mixer is perfectly non-linear and obviously the linear portion of the circuit passes the original waves unchanged. This process of mixing is of no positive value to the R/C fan and is an undesirable effect which must be minimized. Unfortunately, it cannot be entirely eliminated. Therefore, it is necessary to design the reed bank so that the reed frequencies are such that the sum or difference of two reed frequencies is not equal to the frequency of a third reed.

An example of a violation of this rule would be a reed bank having reeds on 100, 200, 300, and 400 cps. If the transmitter generated tones on 100 and 200 cycles, the first two reeds will vibrate. Then, somewhere along the line between transmitter and receiver the two tones will combine to form the beats on 100 and 300 cps. The new 100 cycle tone will not do any harm. However, the 300 cycle beat will vibrate the third reed!

What is the answer to this? Minimize mixing in the transmitter and receiver and cut the reeds so that beats of two reeds do not coincide with a third reed. Unfortunately, the modeler usually hasn't the facilities to cut his own reeds and expect a satisfactory frequency curve and Q factor (to be described later). Obviously, the only solution is to work with someone who is experienced, or via a commercial reed bank.

Frequency is not the only important consideration in the design of reeds for a simultaneous multi-channel system. The Q of the reeds must also be considered. To the engineer, the Q of a circuit is the ratio of its reactance to its resistance. This definition is somewhat involved in its analysis in a mechancal circuit and to the layman radio fan, the Q may be roughly considered as its frequency divided by its bandwidth (bandwith is the frequency range over which a given reed will vibrate). Thus a reed 5 cycles broad has about one fifth the Q of a reed which is 1 cycle broad. This Q factor

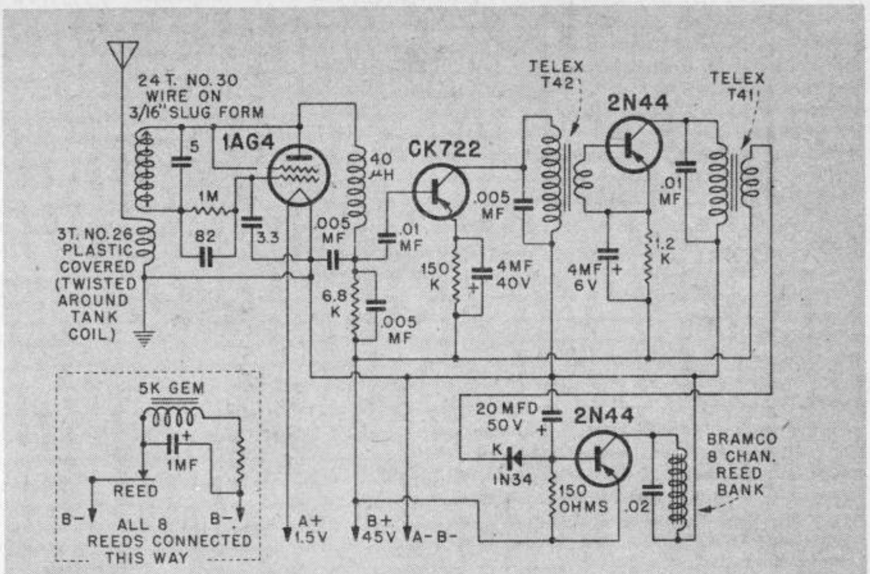


FIG. 1 BRAMCO 8 CHANNEL RECEIVER

is important in the performance of a reed bank and its value should be made as high as practical. Do not try to make reeds too sharp unless you have a transmitter stable enough that you can depend on it to hold its frequency so you don't have to retune it every flight. Separate the reeds as far as possible (in frequency, that is) and avoid mixing combinations. A reed bank designed in the described manner should give the home builder no trouble in its receiver operation.

The last departure from standard practice in a simultaneous receiver is the use of large filter condensers. In a simultaneous receiver the duty cycle (that is, the amount of contact time) decreases rapidly as the frequency of the transmitter drifts away from the center frequency of the reed. For this reason, larger filter condensers are

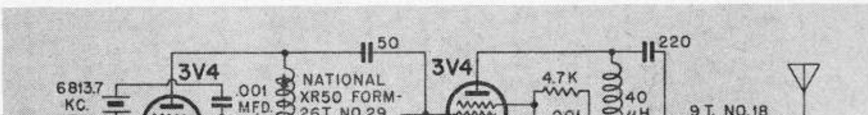


FIG. 2 BRAMCO 8 CHANNEL SIMULT. XMTR.

used to prevent relay chattering. About 2 mfds is sufficient if pulsed operation is contemplated. If pulsed operation is not used, condensors as large as 3.2 mfds can be used with satisfactory results. These values are suitable for use on a 5000 ohm Gem.

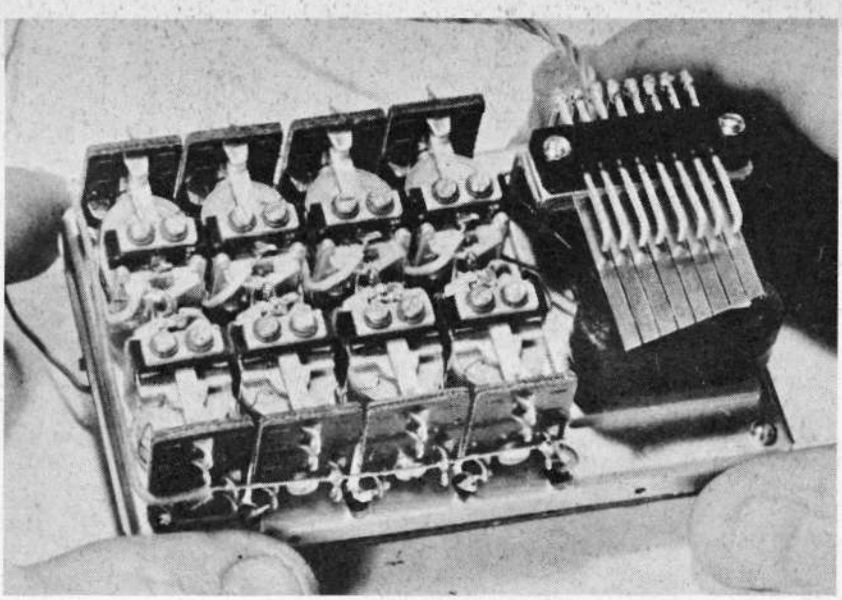
The diagram of the Bramco transistorized simpltaneous receiver is given in Fig. 1. If this circuit is followed closely in the construction of such a receiver, no difficulty should be encountered. One word of warning: do not attempt to operate the receiver with a B battery below 38 volts, nor an A battery below .9 volt. DO NOT attempt to get more battery life by using a 67½ volt battery and a dropping resistor instead of a 45 volt bottery. This is because unlike a tube, which slowly deteriorates if it is overloaded, a transistor can be burned out easily with one sudden surge of voltage.

The dropping resistor does drop the voltage after the circuit is operating, but when the receiver is first turned on, there is no voltage drop in the resistor and the full B voltage appears across the transistor. Several fellows have tried this and after blowing several transistors, went back to a 45 volt battery. This circuit has a very low idle current and adequate battery life should be obtained from a standard 45 volt hearing aid battery.

Just because I described simultaneous receiving equipment first, it is no sign that the receiver is the most important link in the entire setup. The transmitter can be deemed the most important by virtue of the fact that almost any receiver will work to some limited extent with a properly designed transmitter. By a properly designed transmitter is meant a transmitter capable of transmitting two stable audio tones, a fully modulated, strong carrier, and one free of interaction between the audio generators.

One transmitter capable of fulfilling all of these requiments is the Bramco simultaneous transmitter, whose constructional details appear in Fig. 2. Basically the transmitter consists of a crystal controlled fundamental oscillator and electron coupled frequency doubler stage. This is fed into a high efficiency radio frequency amplifier which is coupled to the antenna through a low loss "pi" type filter network. The audio lineup is the only significant difference in the new transmitter. The two audio oscillators utilize a special cross coupled multivibrator. The audio oscillators feed individual and well isolated modulator stages.

This multivibrator circuit was somewhat unorthodox in most electronic circles in that it used an inductively tuned frequency determining circuit, trimmed with capacity to tune to the right frequency, rather than resistance-capacity networks. The use of inductive circuits provides several advantages not obtainable with the standard circuit. For instance, the use of inductance increases the Q of the circuit and has the effect of greatly reducing the voltage vs. frequency sensitivity of the entire circuit. For example: the frequency of a standard multivibrator circuit changes approximately 25 cycles per second from 90 to 160 volts. The frequency of the modified circuit drifts about one cycle per second from the same voltage points.



The frequency drift is eliminated altogether by the use of regulators on the plates of the audio oscillators. The regulators are the neon bulbs marked in the circuit diagram. They hold the audio frequency within 1/10 of a cycle per second over the range from 100 to 160 volts. Although they could be made to regulate even lower, the crystal oscillator will not operate well below that voltage, besides the fact that if operation below 100 volts is desired, the limiting resistors on the voltage regulators must be decreased in value. This is accompanied by an increase of B drain when the batteries are still fresh.

Another advantage of the inductively tuned oscillator is its waveform. The standard circuit puts out a square wave which is by nature composed of infinite numbers of harmonics. Then all of these mix together and form millions of harmonics and sub-harmonics all over the entire audio frequency spectrum as they pass through the portion of the transmitter. Besides affecting the performance of the reed bank, they rob and waste valuable power from the batteries. The circuit eliminates this because it puts out a sine wave, which is the purest waveform known (not full of harmonics). Consequently, no extra power is wasted on amplifying harmonics and distortion product thus improving the overall battery life.

Using a multivibrator to modulate an amplifier or oscillator usually results in increased voltage sensitivity due to loading effects on the modulator plate. That is to say, if a multivibrator is used to drive an r.f. stage directly, changes in the input power to the r.f. stage cause the grid to draw more or less audio power from the mutivibrator. When this change in power being drawn from the oscillator is present, it increases or decreases the plate current of the tubes in the oscillator and consequently changes their frequency.

For this reason we have incorporated modulator stages in our transmitter. There are several advantages to this. First, it eliminates the previously mentioned loading effect. Second, it allows the audio oscillators to be operated at a much lower voltage. This greatly increases their stability and reduces harmonic content considerably. Third, and most important, the use of separate modulators eliminates interaction between the two oscillators.

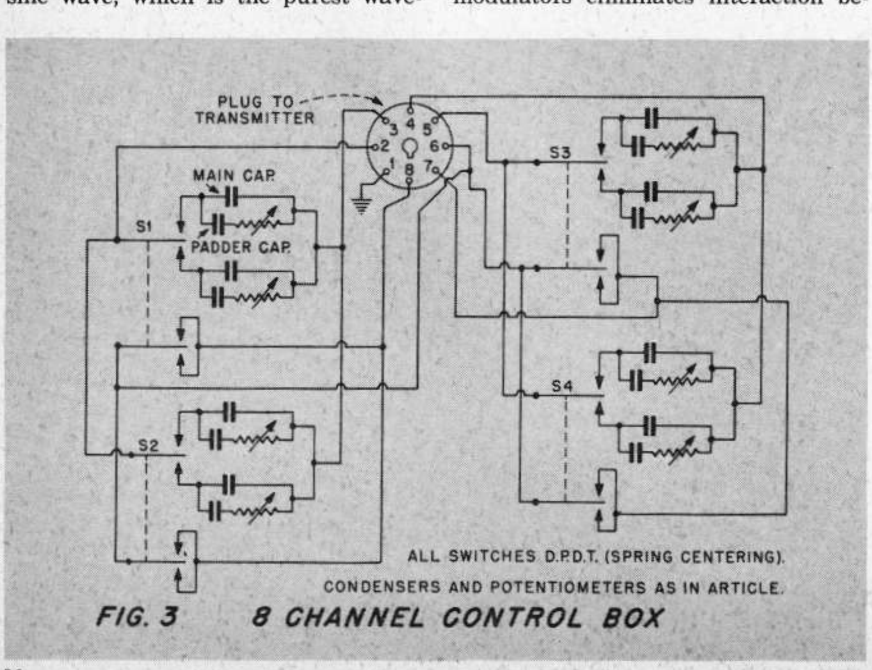


FIG. 3 *8 CHANNEL CONTROL BOX*

"Pulling" is a common effect usually found in superheteodyne radio receivers. It is the tendency of two oscillating circuits operating very near the same frequency to synchronize their operation. For instance, imagine an oscillator operating on 1000 cycles per second closely coupled to an oscillator operating on 1010 cycles per second. Depending on which is stronger, the other will tend to raise or lower its frequency until the frequencies of the two circuits are synchronized.

How does this affect a simultaneous transmitter for reed receivers? Imagine that one oscillator in the transmitter is tuned to 370 cycles per second which vibrates one reed. The other oscillator is tuned to a frequency of 390 cycles per second in order to hit another reed. Then both oscillators are fired simultaneously. Depending upon the circuit constants, one of the oscillators will change its frequency in its natural tendency to synchronize itself with the other. Chances are good that both oscillators will "pull" and end up at some median value that won't hit any reeds!

This indicates why the process of oscillator pulling must be eliminated. We learned this in our first experiments with this type transmitter. The rig used two standard multivibrators. The output of each was fed into the grid of the radio frequency amplifier stage in accordance with the standard grid modulation system employed in all our transmitters. Both oscillators were independently tuned and every thing seemed to be working satisfactorily. Then the two oscillators were fired simultaneously. Needless to say, they were both pulled so far out of tune that none of the reeds vibrated. They were retuned until two reeds could be operated simultaneously but when tuned to this combination, it was the only combination that worked.

It was then decided to scrap the idea of direct coupling. Modulator stages were installed. The first modulators utilized common plate load resistors for the two modulator stages in an attempt to create a stage resembling a mixer. As mentioned previously, this mixing process is detrimental to the operation of the receiver. Hence the mixer idea was dropped and the modulators were completely isolated, except for the minute amount of coupling that occurs in the common r.f. grid circuit. A glance at the schematic shows that this path has a resistance of 500,000 ohms between the two modulator plate circuits, a resistance high enough to reduce any mixing effects to a negligible value.

The pot marked "balance control" in the diagram of the transmitter is a refinement added when production was considered. This control compensates for variations in receiver output as the frequency of the audio oscillator in the transmitter is changed. Since the standard practice is to run four reeds on the four lowest channels, and the other four on four highest channels, the balance control adjusts the amount of output from the transmitter on each simultaneous group (this is a term used in simultaneous transmitters to signify these channels which are operated from one audio oscillator; for example, an eight channel setup uses 2 groups of 4 channels each). This adjustment is necessary since two reeds are vibrating but one is vibrating stronger than the other, it will tend to cancel the oscillation of the other. Hence, the amplitude of each reed must be carefully balanced with the others. The adjustment itself is described later.

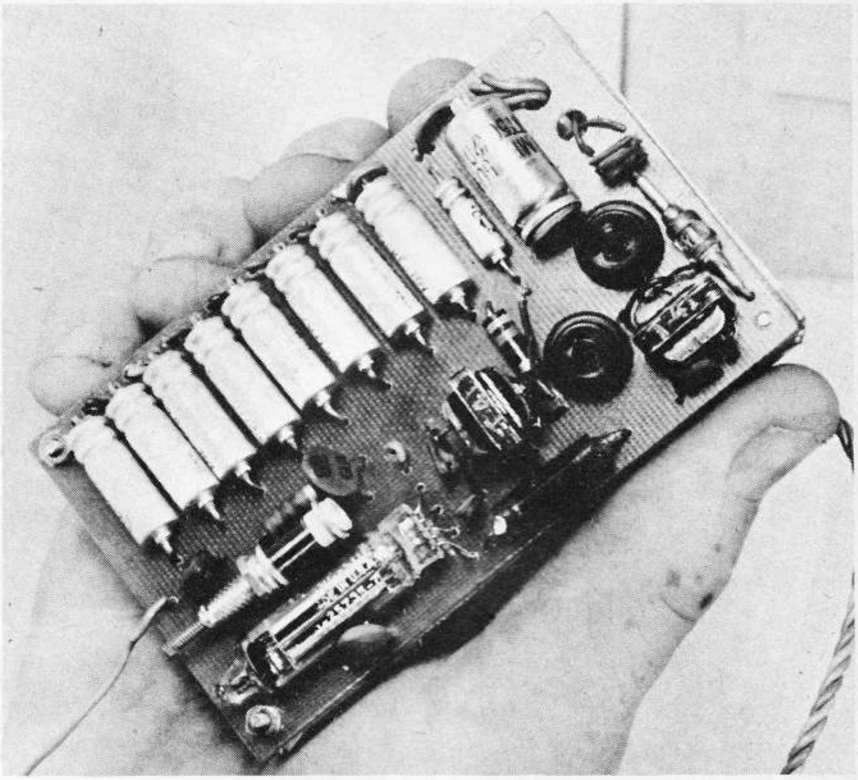
For the benefit of those who like to "roll their own" here's a brief rundown on how to fire up this type of transmitter. Adherence to these instructions will result in a rapid alignment of the whole transmitter with a minimum of trouble. When the transmitter is ready for the initial test, all sections must be ready to operate. The condensers in the control box (Fig. 3) should not be wired in as their value must be determined experimentally. The process of finding the right values for these condensers is the main operation in the original testing of the transmitter.

A brief word about the reason for this close adjustment is in order. In an attempt to build a very stable oscillator, we found this circuit to be the best. Its only disadvantage is that the tuned circuit it uses contains a very high capacity. A small amount of frequency vernier can be obtained by placing pots in series with the capacity. Unfortunately, the amount of vernier obtained in this manner is just about sufficient to tune on and off of one reed. Using more resistance in series with the capacity will result in more frequency but it also decreases the output of the oscillator. Therefore, we change the frequency of the oscillator by both methods. Small amounts of fixed capacity are added to bring the oscillator frequency within the range of each reed, and a pot is placed in series with part of the capacity to provide a fine tuning control with which to make the final reed peaking adjustment. Refer to the basic schematic of the oscillator before reading further.

Determining the amounts of capacity necessary for each channel by the trial and error method but if the frequencies of the reeds are known, the proper values can be calculated. In calculating the capacity of the padders, make your calculation for a frequency 5% lower than the actual frequency of the reed itself. The pot is then used to bring the frequency up the right point. The equation for calculating these capacitors is "F" equals 1 over 2 pi times the square root of "L" times "C"—where "L" is the inductance of oscillator inductors measured in henries, and "C" is the total capacity across inductor measured in farads (1 mfd equals .000001 farad).

The method for apply this formula is first, calculate the amount of capacity necessary to oscillate on a frequency 5% lower than the highest reed in each group. Subtract .05 mfd from this value (one value for each group) and the remainder is the amount of capacity to connect directly across the inductor. This capacitor in each group is called the main tuning capacitor.

Second, determine the amount of capacity necessary to oscillate 5% below the frequency of the second reed. From this value subtract .05 mfd and the value of the main condenser found in step one. This remainder is the amount of capacity necessary for padding the oscillator; these condensers are marked PADDERS in the drawing. Note that the capacity was calculated for a frequency 5% lower than the reed frequency. This is because the pots will provide just enough vernier to go up and slightly beyond the center frequency of the reed.



Third, continue the process for the remaining reeds in each group. After these values have been determined, 5% condensers can be soldered directly into the control box and it should work perfectly the first time. By perfectly is meant that each reed can be tuned in. Final tuning is described later.

If you are not fortunate enough to know the exact frequency of your reeds, or your math is weak, these condenser values can be found just as accurately by experimentation. Then the condensers can be soldered in once, permanently. The result is a control box that doesn't look like a Brillo pad from much soldering and unsoldering of condensers. The procedure is almost identical to the mathematical method. First, add enough capacity to the tuned circuit to oscillate at a frequency slightly below the highest reed in each group. To determine if you are near a reed or not, connect an .01 mfd condenser in series with a 5000 ohm pot across the inductor in the oscillator. This will provide a very slight amount of frequency vernier in the upward direction. Capacity is added to the tuned circuit and when you think that is is just below the reed in question, turn the pot to full resistance and see if the reed starts to vibrate (not necessarily maximum vibration, but enough to notice). If it does, there is sufficient capacity. If the reed doesn't vibrate, add more capacity directly across the inductor. In all cases, the reed should not start to vibrate until the pot is opened up. Using this procedure of adding capacity until the oscillator is slightly below each reed, follow the previous steps until all values have been determined on all except the highest reed. In each group, start with just the main tuning capacitor connected. This must be done because the main tuning capacitor is connected at all times and must be only slightly padded to lower the frequency enough for each reed.

Note that in all channels the oscillator is adjusted for a frequency slightly below the reed frequency. This is because the .05 condensers and 5000 ohm pots provide enough vernier to go high enough to tune on and off each reed. On each channel only a small amount of padding capacity is necessary to go down one reed. This is because the main tuning condensers (which were added in the first step) are in parallel with all of the channels in its group. In practice it is found that increases of approximately .05 mfd per channel will be sufficient.

Occassionally it will be found that one value of padding capacity will be sufficient to hit two or three reeds. In such a case, just use the same value

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of padding capacitor for both channels. If standard values of capacity will not work, do not be afraid to parallel condensers to get the right combination.

When wiring the control box, provide some sort of tie points to which the condensers can be fastened. Use only stranded wire on the switch leads to prevent breakage. If your control box mechanism utilizes movable switches, always use heavy stranded wire for the connections to it, and wrap them around the terminals several times. Don't depend on solder for strength. For those who thrive on miniaturization, there are readily available miniature pots which greatly reduce the size of the control box.

If your transmitter has been built as I have described, you can now completely assemble it and load it with batteries. Leave the back cover off to provide access to the balance control. The final tuneup is the only step remaining. For this tuneup, you will require your receiver, in operating condition, and a field strength meter. The first step is the peaking of the radio frequency section. Note that no special tuning wands are necessary. All adjustments have been grounded to the chassis so that an ordinary small metal screwdriver can be used.

Start out by peaking the oscillator coil for maximum output as indicated on the F.S. meter. This coil is located between the oscillator and amplifier tubes. It has a small ferrite core which is screwed in and out to resonate the circuit on the crystal frequency. This peak will seem quite broad but will also be distinct enough to notice.

After peaking the oscillator, proceed to the amplifier. You will notice that there are two compression type trimmer condensers located at the amplifier side of the chassis. The tank coil is soldered directly between them. The one closest to the front of the panel is the antenna loading control. The other is the plate tuning condenser. Tuning the amplifier requires careful adjustment of both. Begin by peaking the amplifier tuning control for maximum field strength. Then advance the antenna loading a quarter of a turn. After doing so, retune the plate tuning condenser for maximum. You will find that each time you change the antenna loading and retune the plate, the output will increase or decrease. Carry out this procedure until maximum field strength is obtained. This completes the tuning of the radio frequency section of the transmitter. The audio section must then be aligned.

Begin by setting the audio balancing control at the center of its rotation. The pots must now be tuned to their individual reeds. For the benefit of those who have never operated multichannel reed equipment, we repeat the procedure for tuning an audio oscillator to a reed. Start by tuning the pot to its lowest frequency (all of the way closed). Gradually increase the frequency until the reed just begins to vibrate. Then tune it VERY SLIGHTLY higher, just enough to notice a change in frequency. This is the optimum point of operation. DO NOT start at the low end and tune upward for maximum vibration. Tune the pots up for each channel and you are ready to balance the audio oscillators. To do this, actuate two simultaneous channels on the control box. Chances are the reeds may vibrate equally strong. If they don't, adjust the balance control until they vibrate approximately the same amplitude.

When doing this, beep your stick or buttons on and off several times to be certain that the two channels are equally balanced. This operation can became rather tricky since a reed requires much less power to operate once it has begun vibrating. The best way to adjust the balance control is to beep the two simultaneous channels, moving the balance control a bit at a time until best performance is obtained.

After balancing the oscillators, try several simultaneous combinations. If some don't work, or are erratic and sluggish, retune their pots a little until they all work in any combination. The main factor in determining the performance of reeds in simultaneous vibration is their Q, as pointed out earlier. It may happen that your reeds are too low in their Q factor and you may have to replace them with better ones in order to get any simultaneous operation at all. This only after spending several sleepless nights trying to make all the reeds vibrate with one another, you find it impossible.

If proportional operation is desired, the audio oscillators can be pulsed and the reeds will follow them. Note in the circuit that two leads must be broken to operate each channel. Therefore double pole relays will be required. One word of caution is in order before attempting to pulse reeds simultaneously. Only a well cut set of high Q reeds will operate satisfactorily under pulse conditions. In simpler words, a beginner should start out with a commercial reed bank that is designed for simultaneous operation. The manufacturers have spent considerable time and effort in the design and construction of such reed bank. The seemingly high price of these reed banks is actually small when the time required for the hobbyist to build one is taken into consideration.

One more word of caution before making your final installation and it pertains to the operation of servos. If you use ordinary flashlight cells for servo power, it is often wise to use two sets of them, one on each group of simultaneous channels. The reason is quite simple. As your servo batteries run down, they reach a point at which they have just enough capacity to operate on servo. When another servo is connected, such as during simultaneous operation of two channels, there won't be enough current to operate both, and since they are in parallel, neither will operate. A condition may even exist where the two will oscillate. The answer to this problem is to use two battery packs, or silver cells. Silver cells won't cause this kind of trouble because they reach the end of their charge and drop dead suddenly!