A Practical 2m Synthesizer

-- who said it can't be built?

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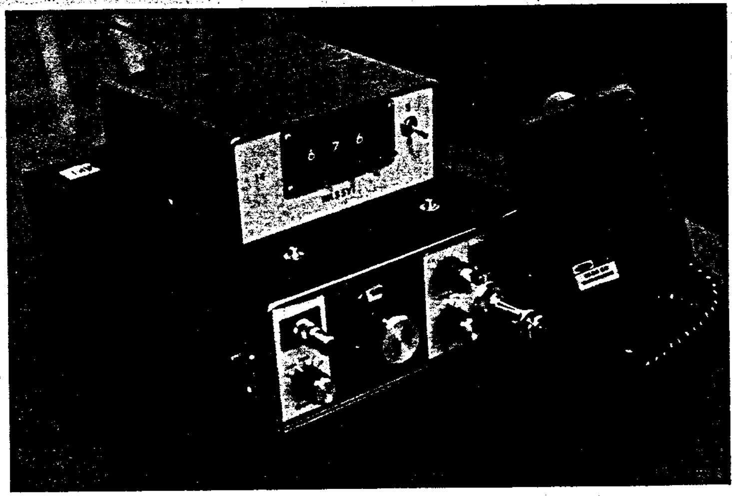
A simple frequency synthesizer for use with amateur 2m radios is described below. It features portability, using state of the art CMOS construction, and it draws only 18 mA. A phase-locked loop (PLL) is employed to achieve precise high purity output. The entire PLL circuitry includes only five transistors and four integrated circuits for low cost and small size. Most of the required parts are readily available from Radio Shack, including much of the CMOS logic and the circuit board. Coverage of the synthesizer is 140-150 MHz in 5 kHz steps. Frequency input may be obtained directly by thumbwheel or lever switches or indirectly by miniature keyboard encoder; may be built from CMOS chips and includes an LCD readout and scanner. This circuit operates on only 0.4 mA total current draw. The synthesizer described here was built on a single board with favorable results. It draws a total of 20 mA and measures 4.5" x 5.0" x 2.4" overall. This synthesizer will interface directly to the Drake TR33C and to the Heathkit HT with minor modification.

The one I built fits right on the top of my TR33C with Velcro holding it in place. It is connected to the rig by a single length of RG-174/U cable, using the auxiliary jack on the back of the radio. The unit goes on and off with the TR33C, so there is no need for a separate ON/OFF switch on the synthesizer.

Photos by Michael A. Gray



The completed synthesizer with Drake TR33C transceiver.

Schematics

Fig. 1 shows a block diagram of the PLL synthesizer. This diagram shows the frequencies for 144-148 MHz, although these are not the limits of coverage. The diagram in Fig. 1 illustrates that the input frequency to the system is the reference signal. It is one input to the phase comparator. The other input to the phase comparator is the i-f ÷N, which varies directly with the VCO since the LO and N are constant. The phase comparator outputs a correction signal that is applied to the VCO through a low pass filter. The digital edge triggered-phase comparator used here will maintain inputs of both frequency and phase coherence at lock. Thus, the lock range is the capture range, and locking on harmonics is not possible.

Fig. 2 is a complete schematic of the PLL frequency synthesizer. Also shown are TR33C and Heathkit HT interface modifications. Synthesizer power must be regulated. The power supply is a 723 precision regulator. The 723 is wired with no external components. Consequently, the chip reference voltage of about 7.15 volts becomes the output voltage for the synthesizer. The 723 offers high ripple and noise rejection. Three terminal regulator substitutes are not recommended if any mobile operation is planned where alternator whine may become a problem.

The VCO is a grounded base Colpitts oscillator. It offers high stability and separate outputs for the rig and mixer buffers. L1, C1, and the varactor diode comprise the tuned circuit. C1 may be made variable to adjust the VCO center frequency and L1 fixed. Both L1 and C1 can be made variable so that both the spread (L1) and center frequency (C1) of the VCO are adjustable. However, such control is not necessary. The rig buffer is a broadband amplifier. The load inductance is taped to match the cable going to the radio.

The VCO-to-mixer buffer is a single CMOS quad NAND gate chip. Each gate is wired as an inverter and is biased up for linear operation. This buffer configuration offers the following advantages: excellent reverse isolation from the mixer, four stages, low current draw, high input impedance, and few parts count. The mixer is a dual gate MOSFET with a resistive load. The dual gate MOSFET offers good isolation between the VCO and LO signals. However, drive to this stage should be the minimum required at each input to reduce crosstalk as much as possible. Following the mixer is an i-f amplifier. A grounded emitter circuit is used to achieve the high gain required to produce a CMOS compatible square wave i-f output. The reference oscillator and divider are obtained using a single CD4060 RCA CMOS chip. This reduces component count and simplifies wiring, although it may increase the cost a little.

The local oscillator employs a JFET for high stability and low current operation. As can be seen, the LO has a switchable capacitor to shift its frequency slightly. This is how the 5 kHz steps are implemented.

The divide-by-N and phase comparator are combined on one Hughes CMOS chip. The phase comparator is of the digital edge triggered type, so the duty cycles of the incoming signals are not important. The divide-by-N portion accepts three BCD and one 7 bit binary number, which are added together to form the final division integer. The binary inputs may be used to generate offset splits between transmit and receive, but only the BCD

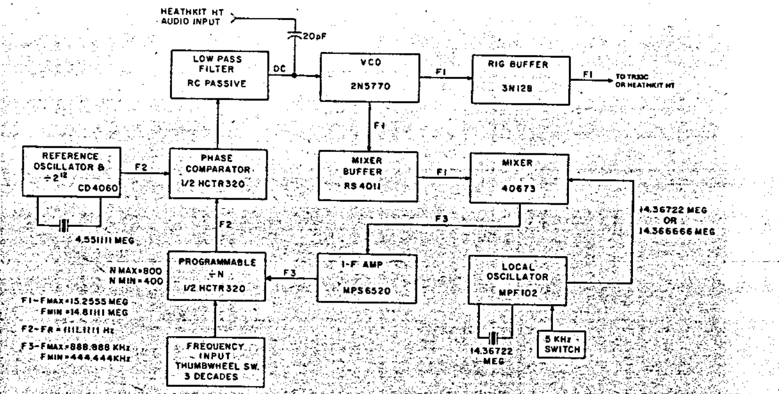


Fig. 1. Block diagram of the PLL 2m synthesizer showing the frequencies for 144-148 MHz coverage with TR33C.

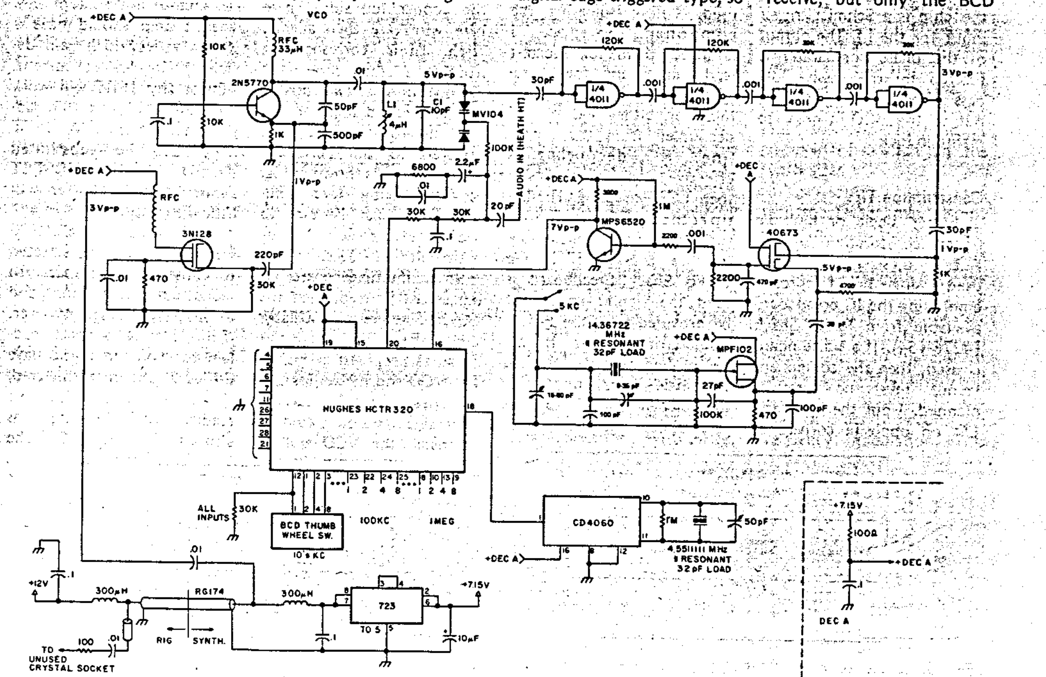
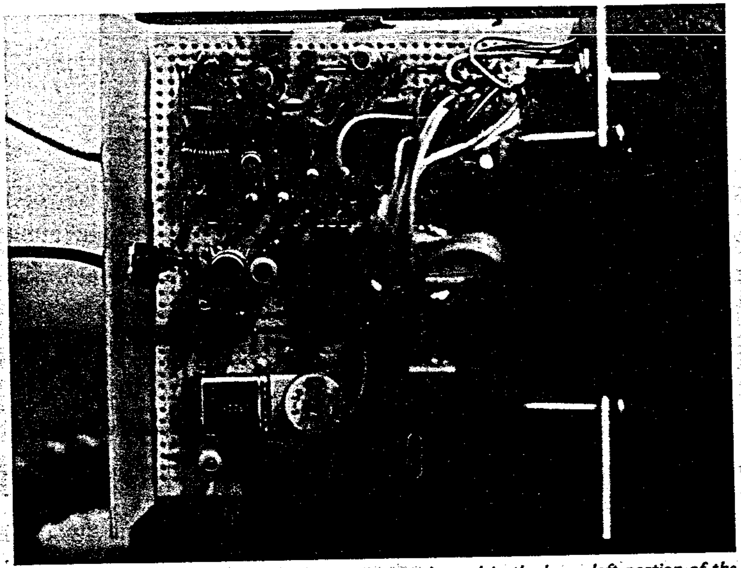


Fig. 2. PLL 2m synthesizer.



Top view of the synthesizer. Reference oscillator is located in the lower left portion of the perfboard.

inputs are used here and the binary inputs are all tied to ground. Also employed on the chip is a Schmitt trigger input for the i-f. The output of the phase comparator is filtered by the passive low pass filter and applied as input to the VCO in order to maintain lock.

Construction Tips

Either single or multiple board construction of the PLL synthesizer is possible. I used a single board approach employing the IC breadboard available from Radio Shack (#276-154). If a single board is used, then the component layout must be carefully planned. I put the VCO and LO on opposite corners of the board to help isolate them from one another. Fig. 3 illustrates the stage layout used. Before soldering the components in place, I arranged them for shortest lead length and fewest required jumpers. All stages must be either RC or LC decoupled from the supply line. RC decoupling is effective and less expensive then LC decoupling. The importance of having a sufficient ground plane cannot be overstated. If the Radio Shack breadboard is used, the ground plane must be provided after the PLL is operational. This is accomplished by cutting a piece of single-sided, copperclad, prepunched board to the same dimensions as the breadboard. Then ground leads are soldered at every stage on the breadboard to protrude from the copper foil side. These bare wires are then aligned with their corresponding holes on the copperclad perfboard. The two boards are sandwiched together and the numerous ground leads soldered to the perfboard ground plane as shown in Fig. 4. Also, hobby store "solderable tin" may be used to make stand-up shields between the rf stages.

If a multiple board arrangement is used, then the LO and reference oscillator should share their own circuit board as proposed in Fig. 6. The VCO and its buffers also comprise a sensible board. A preferable method would be to install the VCO and its buffers in a shielded box if space permits. In any configuration, the VCO components should be glued in place and its circuit board acoustically decoupled to minimize microphonics. Double-sided foam tape works well for this purpose. Braided strap should be used to make interboard ground connections. This strap is called slot car pickup cable in hobby stores.

Toroids are preferable to tubular inductors, and their use is encouraged if possible. This will help make the circuit less susceptible to nearby rf fields.

Alternative Stages

Every stage has a suitable alternative. The rf section works quite well, so I won't recommend any changes there. However, you may wish to substitute different transistors for the VCO, i-f amp, LO, or rig buffer. For the VCO you want a transistor with a low output capacitance and medium gain. The i-f amp should have a garden variety, high gain device with low leakage current. Almost any JFET will work for the LO with the appropriate biasing. A JFET may also be substituted directly for the MOSFET shown as the rig buffer with little difficulty.

The Hughes HCTR320 synthesizer chip was selected to conserve board space, to reduce component count, and to simplify wiring. However, if board space is not a problem for you, or if you have difficulty obtaining this chip, it may be replaced by two readily available chips as shown in Fig. 5. The divide-by-N function is now handled by the RCA CD4059 programmable divider, and the phase comparator is obtained using two type D CMOS flip-flops. Alternatively, the phase comparator number two on the CD4046 phase locked loop chip may also be substituted for the digital edge triggered type called for above. It should be noted that, if the Hughes chip is eliminated, an additional stage of i-f amp may be required to properly condition the i-f signal for the CD4059 counter.

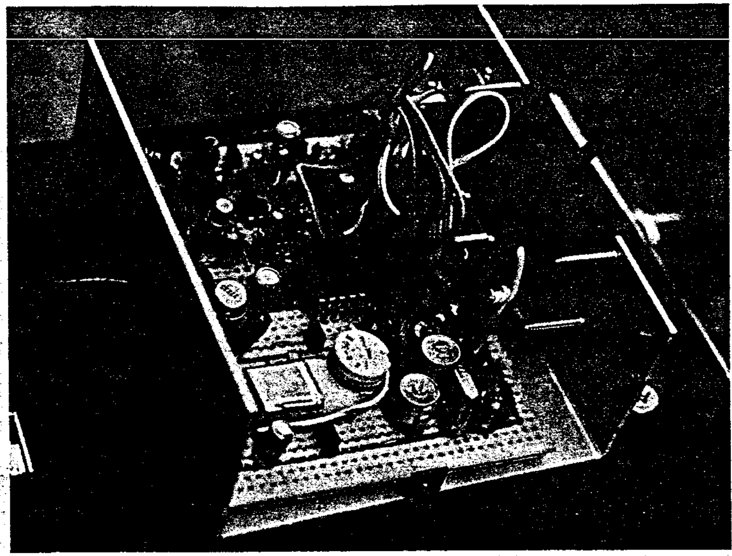
Troubleshooting

Not much difficulty is anticipated in getting the PLL operational. If something is amiss, start with the VCO. Verify the output amplitude and frequency as well as range of the VCO. Make sure that you have not forgotten the 100k Ohm resistor between the loop filter and the VCO. Check the signal levels at the mixer inputs. Verify that the local oscillator is working properly. Once the mixer is operational, check the i-f amp for a high amplitude clean output. Check the output of the divide-by-N chip to see if the chip is responding to the i-f signal. If it is not, then adjust the i-f amp components until an acceptable signal is presented to the divide-by-N chip. On the Hughes chip, pin 14 is the divide-by-N output. Once the appropriate signal is appearing at the output of the divide-by-N logic, check to make sure the reference oscillator is working and the divider is generating the required reference frequency. Verify the inputs to the divide-by-N chip and make sure none of the CMOS inputs are floating. Look at the output of the phase comparator with a dc coupled oscilloscope. If the output is saturated, go back to the rf section and start with the VCO to look for the problem. If the output is oscillatory, then you probably just need an adjustment of the low pass filter. Try changing the damping resistor and/or integrating capacitor in an effort to stop the loop from oscillating. If this fails, seek references on phase locked loop low pass filters in the library. The Signetics analog manual has a thorough discussion of the loop filter used here.

Interfacing

The synthesizer will work without modification for the TR33C. This ham uses the Drake Mike Encoder to achieve touchtone capability, which frees the mini jack on the rear panel for synthesizer application. As shown in Fig. 2, the dc supply to the synthesizer goes through the center conductor of a length of RG-174/U coax. In return, the synthesizer sends its rf output back down the same wire and connectors. Thus, there is no inconvenience associated with this synthesizer. The dc supply and rf are isolated by rf chokes at each end, and the rf is coupled by capacitors at both ends. The rf goes to an unused crystal socket in the rig. The dc supply comes from the 12 volt switched line in the radio, so there is no need for an ON/OFF switch on the synthesizer.

The same system used with the TR33C may also be used for the Heathkit HT. However, the TR33C applies the audio modulation to the 10.7 MHz transmit mix-up oscillator so the synthesizer need not be interfaced with audio signals. In the case of the Heathkit HT, audio will have to be applied to the VCO in order to accomplish frequency modulation. This



Another view of the 2m synthesizer. The complete circuit is assembled using point-to-point breadboard techniques.

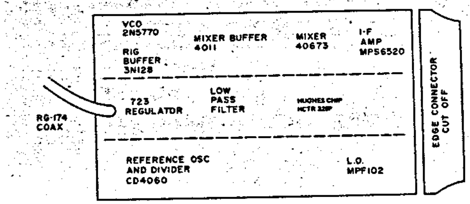


Fig. 3. Single board synthesizer layout using Radio Shack breadboard and Hughes synthesizer chip.

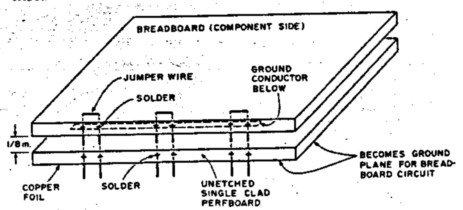


Fig. 4. Method for supplying a ground to breadboard circuits.

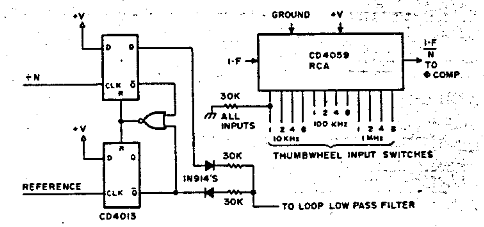


Fig. 5. Alternative digital logic for the PLL synthesizer. a) Phase comparator (CMOS); b) ÷N (CMOS).

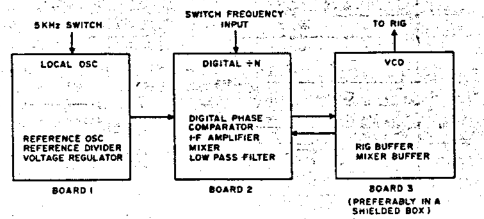
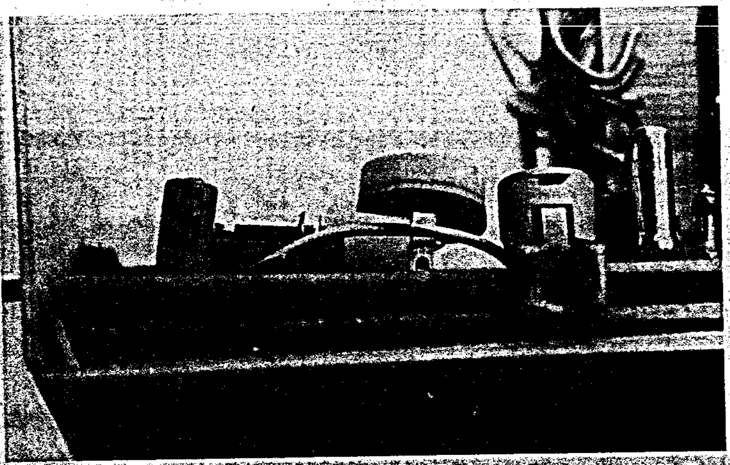


Fig. 6. Suggested multiple board synthesizer.



Close-up of the mounting bracket employed to secure the two perfboards. Oscillator components are visible above the bracket.

connection is shown in Fig. 2.

Of course, the basic synthesizer will work with any radio if the appropriate changes are made. Primarily, these changes involve the mathematics of the phase locked loop relative to the desired application. Tutorial information regarding the design of phase locked loops is available from RCA and Motorola upon request. Some sources are listed as references below. It should be pointed out that spurious responses in the synthesizer may result due to undesired interstage coupling or ground loops. The synthesizer described above offers inherent immunity to this problem. However, extreme layout or ground plane deficiencies can promote spurious interactions in any multifrequency system. It is your responsibility, as a ham, to check for and eliminate any spurious responses in your home brew synthesizer. Therefore, multiple board construction is recommended but is not necessary for the experienced rf home brewer.

A Keyboard Entry System For Your PLL Synthesizer

Here is a CMOS circuit that enables you to have keyboard frequency entry for your 2m synthesizer. It draws only 0.4 mA, has 4.5 digit LCD readout, and a built-in scanner capability. This is a viable alternative to thumbwheel or lever switch frequency input.

The circuit is shown in Fig. 7. It uses a Hamlin 3909 reflective LCD readout available through most Resco stores on order. RCA CD4056 LCD drivers are also employed. The drivers and display may be replaced by a conventional LED arrangement in the interest of reduced overall cost if current draw and portability are not important to you. The LCD readout is quite attractive, though, and is of the latest — black on white — FET LCD variety. The numerals are large and clearly visible in bright sunlight.

When a key is depressed, the one shot fires, causing the CD4022 counter to increment. Meanwhile the keyswitch places the appropriate BCD data on the input lines of the 74C192 presettable decade counters. By now, the falling edge of the previous output of the CD4022 causes the load line of one of the 74C192s to become active, thus loading the data into that counter. The load line is restored to an inactive high state before the data is removed from the input lines. The data is then removed after releasing the keyboard switch. The one shot cycles for the next entry. Inadvertent double entries are almost impossible due to the one shot. The cheapest noisiest keyboard switches may be used due to the adjustable duration of the flash picture the 74C192s take of the data lines.

Output from the presettable counters goes to the synthesizer input and to the display decoder-driver. Note that pull down resistors at the inputs of the programmable divide-by-N chip are not required if this encoder is employed, but are required if thumbwheel or lever switches are used. A keyboard lockout switch may be included if the keyboard is located where it is susceptible to accidental entries. ■

References

1. RCA ICAN 6101, ICAN 6267, ICAN 6498, ICAN 6716.
2. Motorola AN 564, AN 535, AN 553.
3. *Signetics Analog Manual*, 1976.

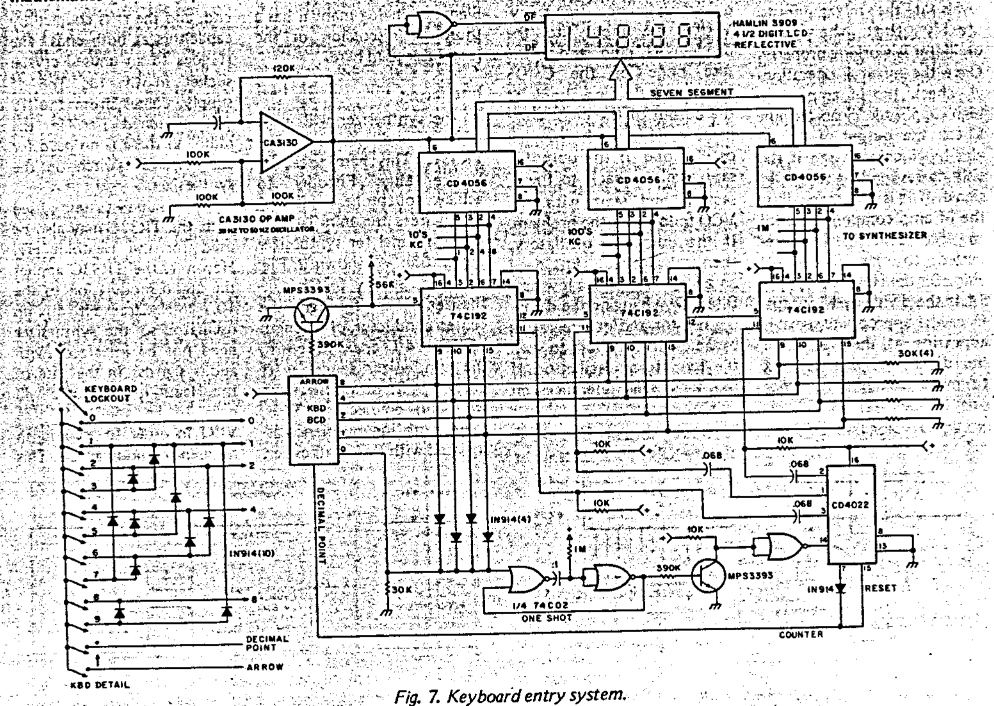


Fig. 7. Keyboard entry system.

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Buying Surplus

— how to remain sane

Is inflation getting you down? Tired of fighting the high cost of living? Prices are rising everywhere — in the metropolitan area, the inflation factor hovers between 10 and 15 percent. Maybe you are thinking of taking up stamp collecting or some less expensive hobby? Don't give up. Help is on the way!

If you are a builder of ham gear, or even if you do a little experimenting, you may be pleasantly surprised to learn that many of your supplies and electronic components can be purchased at discount prices. How? Simply by buying at surplus. Some of these prices taken from a recent catalog may seem high to you: type 1625 tube, $11.25; dc meters, from $15 to $20; relays, $5 to $6. But did you know that these same components can be purchased as new merchandise from surplus sources at prices of $1.25, $3 to $4, and $1 to $2, respectively?

Let me point out that the situation is not all peaches and cream. There are certain factors in the surplus market which should be understood in order to reap the greatest benefit. The most prominent difference in the surplus market lies in the fact that it is not a substitute for the regular electronics dealer who generally offers for sale whatever you may wish to purchase. The surplus dealer is a seller of what he has to offer. Once you have grasped this fundamental difference, you've bridged the gap. If you can utilize some of the merchandise offered by the surplus dealer, tremendous savings are possible.

This proposition suggests a certain flexibility of mind. If a certain component is needed, the chances are good that it can be bought at surplus, but if you insist upon a part made to certain specification, perhaps made only by one manufacturer, then the odds are that you will not see it offered for sale in the surplus market. Also, one should try to put himself in the surplus dealer's shoes, so to speak. To my way of thinking, the surplus shops are roughly akin to the thrift stores presently being patronized by knowledgeable women . . . if you can use what's available, substantial economies are possible.

How do you pick a good surplus dealer? If you are located near a large city, why not drop in and see for yourself? If this is not convenient, you can ask for the various catalogs that are available. I have noticed that many of the better surplus houses generally have a supply of such catalogs. In some cases, you may be asked to pay for the cost of mailing the catalog.

With the catalog in hand, you are in a much better position to see for yourself the size, shape and style of what is being offered for sale. Often this helps to clear up any doubtful points that might exist. If you can't find what you need in catalog A, there are others that may carry the wanted item. Sometimes a catalog may offer merchandise in groups of several pieces, all at bargain prices. This economy allows you to buy at the lowest possible cost and still have something left over for the spare parts box. Over the years, I have amassed a fair sized collection of catalogs from various surplus dealers. While I do not believe in favorites, a few outfits have served me without headache or heartache for more years than I care to recall, among them Meshna and Fair Radio. Naturally, there are many other respectable firms dealing in surplus.

Finally, if you should experience any trouble, real or otherwise, in your business dealing with any surplus firm, my advice is quite simple: Holler — loud and clear. Amazingly simple and effective, that formula!

When you order from any mail-order house, it is always wise to state in big, bold letters: No substitutes/no back orders/no credit slips/refund any overage in check or stamps.

Good surplusing! ■