Varactor Diode Applications for DXers

Mark Connelly - WA1ION DX Labs - 28 FEB 1984

Introduction

The varactor is a diode which can be used as a voltage-controlled variable capacitor. This is done in a reverse-biased condition (cathode voltage more positive than anode voltage). Low-value varactor diodes have long enjoyed popularity in VHF/UHF TV tuner applications and also in functioning as externally-adjustable trimmers to peak the performance of various circuits within professional-grade commo RX's (communications receivers).

Several varactors introduced recently have relatively high maximum capacitance (over 300 pF) and high Cmax/Cmin ratios (12 to 1, or better). These include Motorola's MV1401, MVAM108, and MVAM109.

Instead of using the traditional 10 to 365 pF variable capacitor in antenna tuner, loop, VFO, phaser, and receiver circuits; one may sometimes find that the varactor is a useful alternative. The primary focus of this article will be the use of these larger capacitance varactors, as there already have been articles in the DX press (available as reprints) about using the smaller capacitance varactors as externally-tweakable trimmers in homebrew receiver designs.

There are both advantages & disadvantages associated with replacing a conventional variable capacitor with a varactor diode. Each circuit to be considered has its own particular characteristics which may weigh towards use of varactors or towards use of variable capacitors.

The advantages & disadvantages of using varactors in several MWDX-enhancing projects will both be addressed.

Varactor Advantages

SIZE: A varactor diode and its associated pot generally occupy less space than a full-sized 10-365 pF air variable capacitor. Miniature mica-dielectric variable capacitors may occupy less space, but these mini-caps. are notoriously prone to early failure.

IMPROVED CIRCUIT-BOARD LAYOUT: A varactor may be mounted directly on an active-front-end circuit board with other components, whereas a variable capacitor is control-panel-mounted (in other words, off of the circuit board). The cable connection between the variable cap. & the circuit card adds extra capacitance (decreasing the Cmax/Cmin ratio). If the variable cap. is 'floating' (= neither side grounded), undesired stray coupling leading to unplanned feedback may be another side effect. Floating variable capacitors present assorted other problems, such as hand-capacitance detuning effects and mechanical assembly / mounting difficulties far greater than those involved in the installations of one-side-grounded variable capacitors. The pot controlling a varactor, on the other hand, controls only DC, not RF, so it may be located at a considerable distance from the circuit card with no stray coupling problems, reduction of tuning range, or other ill effects. Cabling to this control pot can be simple twisted-pair or 2-conductor speaker wire rather than expensive, harder-to-prepare coaxial cable.

REMOTE TUNING CAPABILITY: This is, by far, the greatest advantage of varactors over variable capacitors. A tuner or tunable-amplifier may be located at a considerable distance from a control box. Remote tuning is very valuable when the antenna to be used must be in a noise-free, good-signal-pickup area (e. g. outdoors) while the receiver to be used is in an area of considerable RF noise (and also, perhaps, of considerable broadcast-signal attenuation).

A typical situation demanding a remote tuner is that of a DX shack located in the basement of a large steel-frame apartment or industrial building, a shack site far from windows or other outside exposures. Any antenna wire brought in from the outside picks up so much noise (from fluorescent lights, TV's, dimmers, computers, motorised machinery, etc.) that it would be worthless at the point that it reached the receiver.

The solution would be to locate a wire aerial either on the roof of the building or in a nearby open outdoor area; an outdoor remote tuner-amplifier fed by this aerial could then send desired-frequency signals back to the receiver site through low-impedance shielded coaxial cable to prevent any noise-pickup. A second coaxial line, consisting of 2 inner conductors & a ground shield, would transfer amplifier DC power, varactor control voltage, & power ground to the remote tuner from the control box. Good grounding and stiff RF-decoupling at each end of the DC lines, as well as proper impedance management on the RF coaxial line, would be required to keep noise pickup to an absolute minimum.

Varactor Disadvantages

INFERIOR STRONG-SIGNAL-HANDLING CAPABILITY: A varactor being 'hit' with a strong signal will tend to produce spurious signals on other frequencies. The more strong signals present, the worse the spur problem gets as the varactor starts behaving more like a mixer and less like a capacitor. The variable capacitor, on the other hand, is relatively 'bulletproof': not likely to introduce any distortion products. With varactors, steps have to be taken to ensure that, when desired stations are properly peaked, garbage from way-off-channel stations is kept to a minimum. Reducing overall system sensitivity by loosely-coupling the antenna is often the only solution. This is usually implemented by selecting a small-value coupling capacitor (less than 22 pF) between the aerial wire & the tank. Unfortunately, doing this severely reduces low-band sensitivity (already at a disadvantage if aerial length is less than 100 m.). The small input coupling capacitor solution is OK if the strong offending stations are MW broadcast only; it, however does not cure VHF-mixing-caused spurious 'hash' in areas of strong TV & FM signals. Indeed, the small coupling capacitor makes the VHF QRM situation worse: MW signals are attenuated considerably, whilst VHF signals sail through even an input capacitor as small as 5 pF with little difficulty. Inductive loose-coupling may be one way to lick the VHF-trash problem. This may be accomplished by connecting the aerial wire to the junction of two inductors that we'll call L1 & L2: L1's value would be about 90 % of the total required tank inductance, L2 the other 10 % or so. The opposite end of L2 is routed to ground whilst the opposite end of L1 goes to the tuning capacitance. Really difficult spur problems may required custom-designed bandpass & band-reject filters, optimised for the specific aerial, ahead of the remote tuner. It's useful to note that a longer aerial will present fewer VHF-related spurious problems than a very short one. Urban & suburban areas - the most likely locations requiring the use of remote tuners - also present the greatest problems in the realm of strong-signal management.

NEED FOR REGULATED CONTROL VOLTAGES: For a varactor to maintain a (somewhat) constant capacitance, the control voltage should be regulated. Regulators gobble up a good deal of current to transform an unregulated or sloppily-regulated (and perhaps noisy) input DC voltage to a lower, firmly-regulated, clean output DC voltage suitable for varactor control. Many varactors do not attain their minimum capacitance until the applied voltage is considerably greater than 9 volts. [Note: Maximum varactor capacitance is at minimum applied voltage; minimum capacitance at maximum applied voltage. Normal minimum voltage is about 1.5 V.]

These considerations make battery-operated varactor control circuits impractical, at best. Use of a mains-AC to regulated-DC power supply is mandated for good results. For the MVAM108 & MV1401 varactors, with required maximum voltages in the 9 V to 12 V ballpark, the Radio Shack # 22-124 regulated 12 VDC supply (designed for home operation of car stereos & CB's) is probably the cheapest, easiest way to go. Some mains-powered commo RX's may provide built-in user-accessible regulated supplies of +12 VDC or greater.

GREATER EXPENSE (in some circumstances): A high-capacitance varactor may alone cost close to the $7 to $11 pricetag that a good 10-365 pF air variable retails for today. Even a two-air-variable scheme (10-365 pF main tuner in parallel with a 3-30 pF fine tuner), costing about $15, may be cheaper than a one-varactor setup when you consider that, for really good varactor control, a regulated DC supply is necessary. Furthermore, a 10-turn type pot with a turns-counter dial (another sizeable chunk of cash) is the best way to control varactor voltage for fine-tuning capability rivalling that of a dual variable air capacitor configuration.

Other cost considerations include the need for additional fixed-value resistors, coupling/decoupling capacitors, & RF chokes in some varactor-implementation strategies.

Few DXers live within reasonable driving distance of electronics shops (catering to the general public) which stock the new high-C varactors. Therefore, the costs of shipping & handling get into the varactor cost-consideration equation, as well.

RANDOM CAPACITANCE DRIFT: A varactor, even when controlled by an absolutely pure & stable filtered DC voltage, may shift its capacitance (admittedly just slightly) more than an air-variable capacitor would. This could be detrimental in critical applications such as the production of phasing-nulls & regeneration (super-Q) peaks: situations demanding a set capacitance that remains rock-steady until intentional change is desired.

When to Use Varactors

Varactor technology is best applied (1) in remote tuners properly designed to prevent undesirable overloading/spurs, (2) in receiver local-oscillator circuitry and AGC-controlled circuitry in which the varactor will be acting upon a known-acceptable-level, essentially-single-frequency signal, and (3) in circuits where the length of cable between a panel-mounted capacitor and internal circuit-card components could contribute too much capacitance or other undesirable side effects.

When Not to Use Varactors

There is little or no justification for using varactors in non-remote tuners, especially in those not requiring 'floating' tuning capacitors and in those which will be used (1) in strong-signal areas, (2) for regeneration, (3) for phasing, and/or (4) with batteries or with no other required power sources (e. g. passive tuners).

Varactor Circuit Implementations

Now that we've covered the pro's & con's of varactor diodes, it may well be worthwhile to see how these devices are connected to replace the conventional variable capacitor.

The Motorola RF Data Manual is a goldmine of useful information in this regard; it also covers related areas of interest such as high-frequency amplifier design using both discrete transistors and the immensely-valuable MWA & MHW - ranges of hybrid amplifiers / 'gain boxes'.

The symbol for the varactor diode is like that of a conventional diode except that it has an added line at the cathode end. Some add a curved line instead of a straight line just as some represent a capacitor with a straight line & a curved line instead of with two straight lines.

Figure 1 shows the most common varactor symbol in use:

Figure 1

(anode)  (cathode)

Varactor Diode Applications for DXers [continued]

Circuits to follow include:
- Figure 2: C to ground from RF-high in parallel-LC tank
- Figure 3: 'Floating' C across balanced loophead (DC ground accessible via loop centre-tap)
- Figure 4: 'Floating' C, general case (DC ground not necessarily available to cap. in the original circuit design)
- Figure 5: A varactor-tuned non-remote MW aerial tuner
- Figure 6: A varactor-tuned remote MW aerial tuner (semi-block-diagram format, based upon Figure 5).
- Figure 7: A varactor VFO (variable-frequency oscillator) for broadcast-band applications [receiver LO, QRP-transmitter driver, frequency-spotter/digital-counter driver, etc.]
  (Fig. 7A = VFO Overall Schematic)
  (Fig. 7B = VFO Card Subassembly)

Appendix: Manufacturer-Supplied Plots of Capacitance versus applied Reverse Voltage

FIGURE 2
Parallel-LC-tank from RF-high to ground

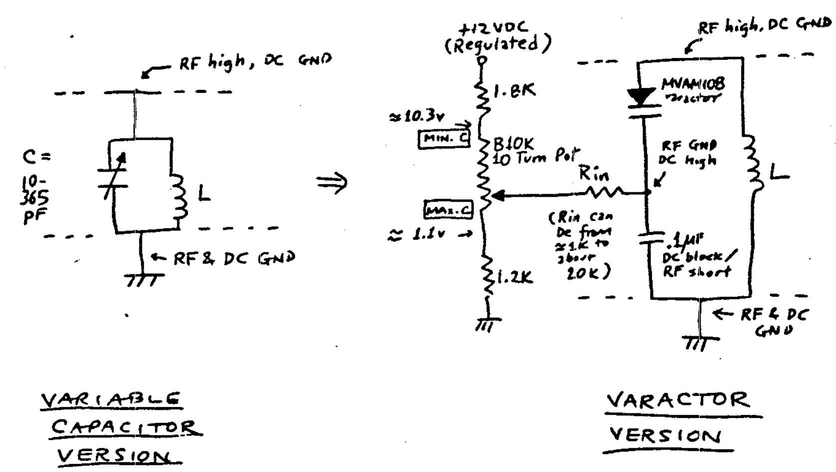

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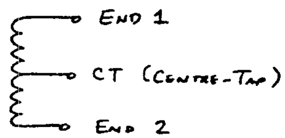
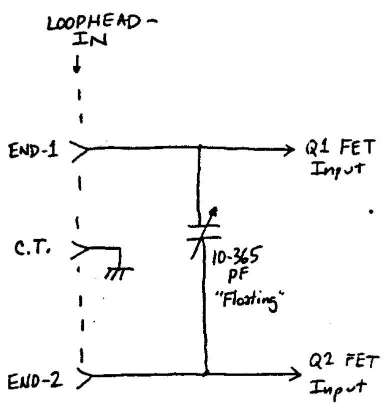
FIGURE 3 : Balanced Loop

Note : Loophead =

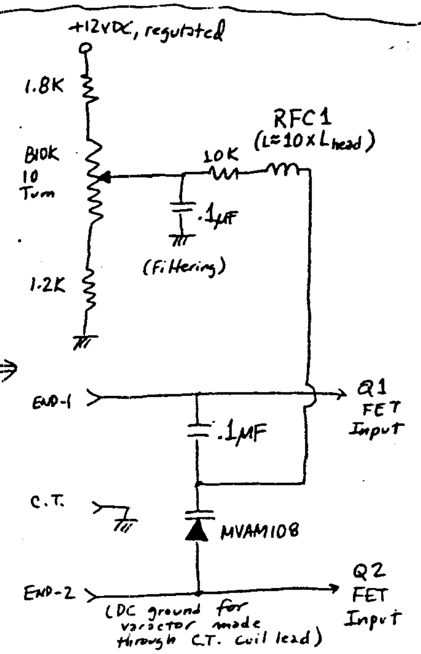


L_{HEAD} = Inductance measured from END 1 to END 2



VARIABLE CAPACITOR VERSION

⇒



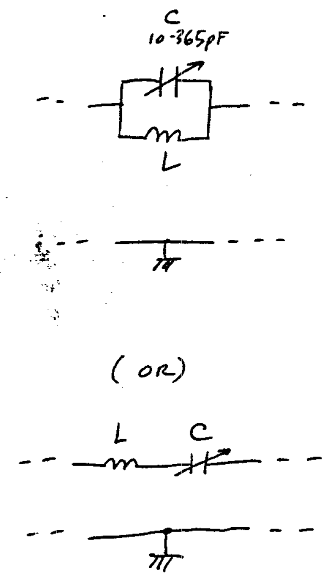
VARACTOR VERSION

(Note : when changing from variable - capacitor to varactor it may be necessary to decrease loophead inductance)

FIGURE 4

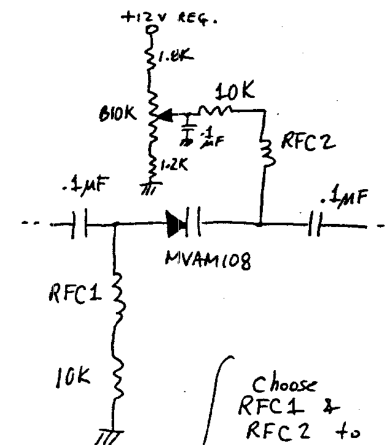
GENERAL - CASE 'FLOATING' (= NEITHER SIDE GROUNDED) VARIABLE CAPACITANCE.

DC - GROUND CONNECTION TO CAPACITOR PRESUMED TO BE ABSENT IN ORIGINAL CIRCUIT.



VARIABLE CAPACITOR VERSIONS

⇒

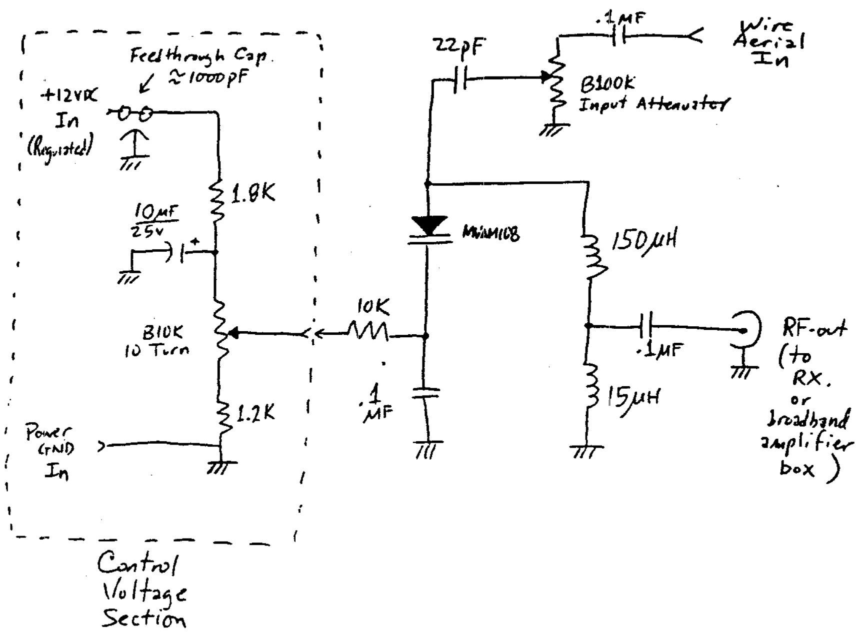


Choose RFC1 & RFC2 to be at least 6 times the value of the inductor connected to the varactor circuit

VARACTOR REPLACEMENT FOR VARIABLE CAP. SECTION OF DRAWINGS TO LEFT.

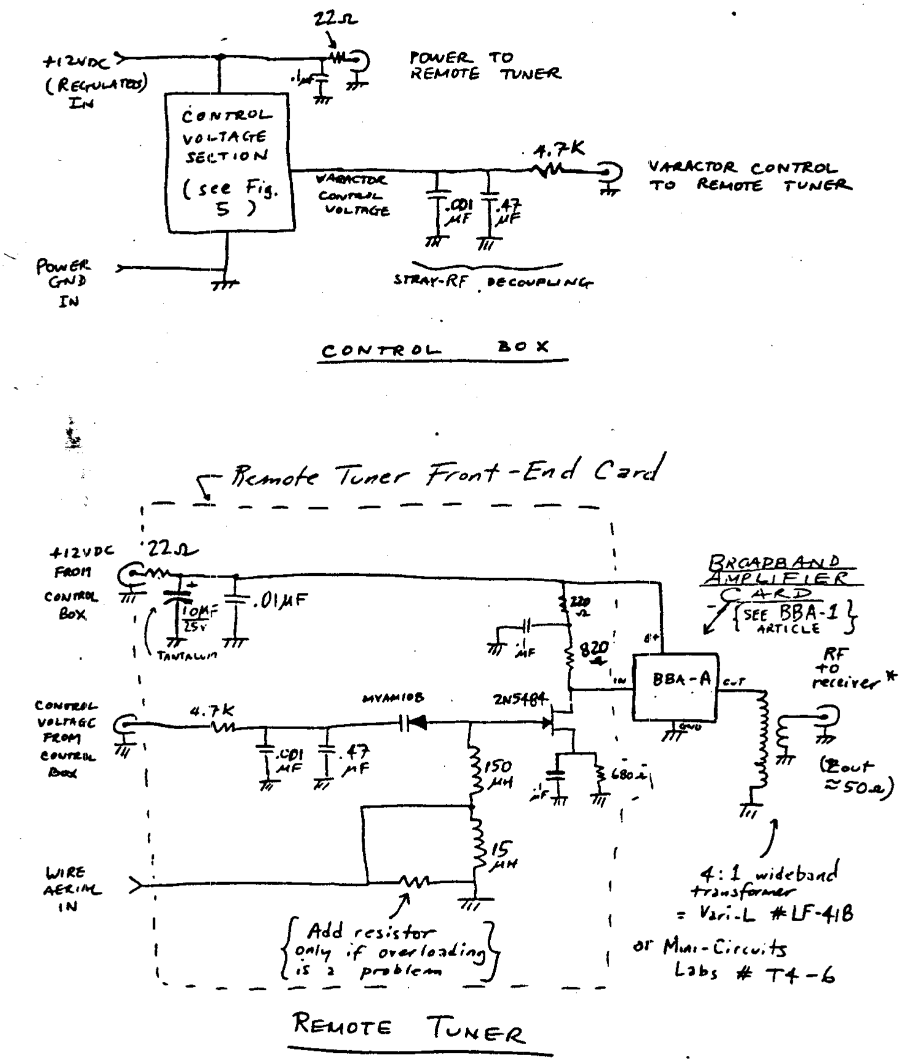
Figure 5

A non-remote varactor MW aerial tuner, using capacitive input coupling



Notes: There is little appreciable voltage drop across the 10K fixed resistor.
With the varactor cathode at approximately +1.2VDC, the frequency of peak reception should be approximately 530 KHz. with the above circuit. If a +10VDC cathode to ground voltage is set, resonance at (about) 1620 KHz. should occur.

Figure 6 : Remote Tuning System



* Impedance at receiver-end of RF cable should be approx. 50Ω.

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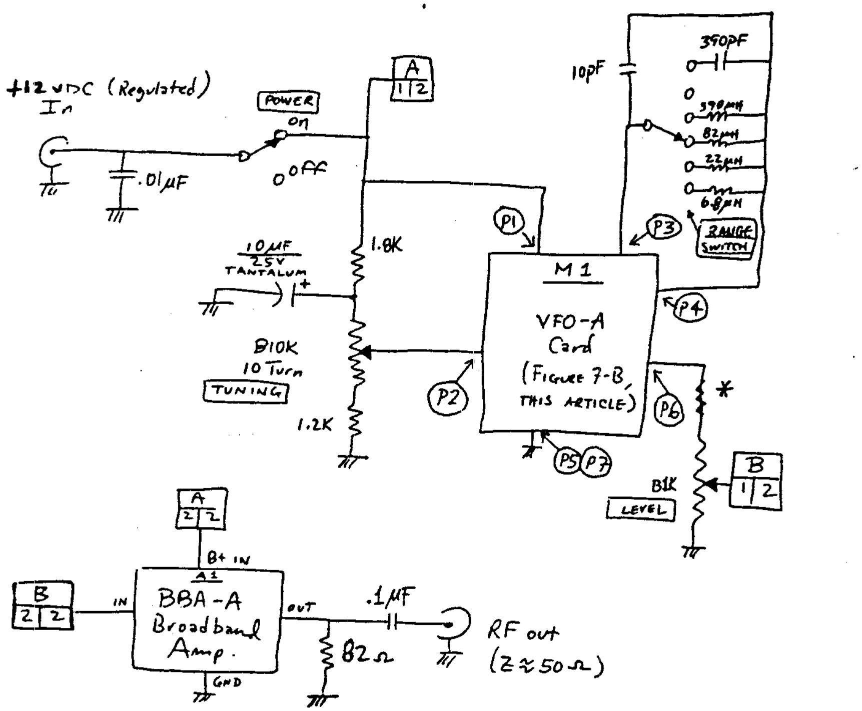
Figure 7-A

Varactor Longwave-Mediumwave VFO Overall Schematic



* = Add resistor between VFO-A Card and pot, if necessary, to keep maximum level output undistorted.

VFO USES

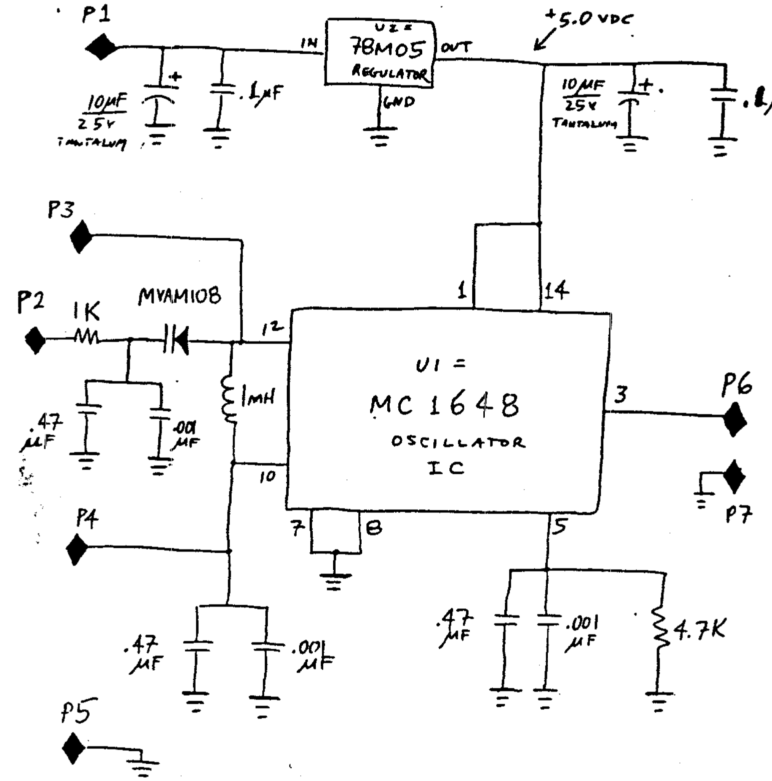
(1) ZERO-BEAT STATION, TAKE FREQUENCY MEASUREMENT ON A DIGITAL COUNTER (= "SPOTTING")

(2) DRIVE A LOW-POWERED TRANSMITTER (E.G. 1750-METRE BAND)

(3) LOCAL OSCILLATOR IN HOMEBREW RECEIVERS.

Figure 7-B : VFO-A Card

(M1 of Figure 7-A)



Appendix

Manufacturer-supplied varactor voltage-versus-capacitance plots.